POLYMERCONCRETE FOR RADIATION BACKGROUND SHIELDING OF DETECTORS AT HADRON COLLIDERS

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Abstract

New shielding material, polymerconcrete, is developed. Its density is 1.2…3.6 $g{\cdot}cm^{-3}$ and the partial content of hydrogen and lithium (or boron) is $4.9…6.6{\cdot}10^{22}$ cm^{-3} and $1.3{\cdot}10^{22}$ cm^{-3} (or $3.3{\cdot}10^{21}$ cm^{-3}) , respectively. This material is suggested for use instead of CH_2 and Pb for the shieldings of D0 and CDF at Tevatron and CMS, ATLAS, ALICE at LHC.

1 INTRODUCTION

Due to the high neutron flux ~10^{10} $n{\cdot}cm^{-2}{\cdot}s^{-1}$, one has to employ the heavy materials, Fe and Pb, and the light ones, CH_2, to develop the compact shielding of detectors and accelerating structures at the future colliders. Preliminary designs of installations D0 and CDF at Tevatron, USA [1] and CMS, ATLAS, ALICE at LHC, CERN [2, 3] suppose the usage of Pb and CH_2 materials “in straight form”. This is objectionable because of CH_2 is flammable and not durable and Pb is toxic and extremely harmful for health.

If one enclose Pb and CH_2 into a capsule of a special binding material then the manufacturing of the compact shielding simplifies, the danger of aerosol gets lower and, moreover, the shielding cost reduces [4].

2 POLYMERCONCRETE

One can use the polymer-cement glue [5] for production of concrete bricks or for casting in a complex-shaped form *in-situ* at the installation. The Table 1 lists the density, ρ, and the content of chemical elements in the concretes of different compositions. As the components, the following materials are used: belitoaluminat cement [6] which contains three times as more of H and is two times as cheaper than the common portland-type cement; special liquid polymer; waste products of granulated polyethylene; ftoric lithium and lithium hydrit; lead powder or steel shot.

For comparison, in Table 1 is also presented the content of the most cheap boron-containing concrete made with the common portland-cement [7]. As the aggregates are used: colemanit $2CaO{\cdot}3B_2O_3{\cdot}5H_2O$ and gematit ore containing (in $g{\cdot}cm^{-3}$): Fe (2.32), O (1.3), Si (0.25), other elements (0.1). Nevertheless, the mechanical properties and quality are rather low and so this material is employed for the stationary shieldings only.

3 RADIATION STABILITY

The most sensitive to the irreversible radiation-induced modifications of a polymercement is the ‘linear-elastic destroy with a crack’. The cracks do not form if the critical deformation Δl after irradiation does not exceed 25% of the value l_0 of plastic deformation without irradiation typical to the self-supporting structures of the background shieldings.

As the Figure 1 shows, the limiting dose D_{lim} depends strongly on the dose rate because of the concrete porosity and deep penetration of oxygen into the samples. Radiation oxidizing reduces the level of radiation stability what is typical for every organic materials and polymers [8]. Nevertheless, at dose rate $D^{\bullet}$<<10^{-3} $Gy{\cdot}s^{-1}$ taking place in the shieldings at colliders, the limiting dose D_{lim}≈10^4 Gy is higher than the radiation loads even under the luminosity value of $2{\cdot}10^{34}$ $cm^{-2}s^{-1}$ during 10 years.

Table 1: Content of chemical elements (×10^{22} cm^{-3}).

Type ; (density, g·cm-3) ; notation used at Fig. 2	**H**	**B**	**Li**	**F**	**C**	**Na**	**Mg**	**Al**	**Si**	**Ca**	**Fe**	**Pb**	**O**
Polymerconcrete PPLC (1.12) 1, 1′, ○	6.6	-	1.3	-	2.0	-	-	0.13	0.01	0.07	-	-	1.3
Polymerconcrete PP(Pb)LC (3.53) 6, 6′, Δ	4.9	-	1.2	1.3	1.1	-	-	0.15	0.02	0.06	-	0.7	1.1
Common gematit-type concrete (3.48) 6, 6′, ●	0.8	0.08	-	-	0.1	0.2	0.08	0.05	0.02	0.2	2.0	-	4.5

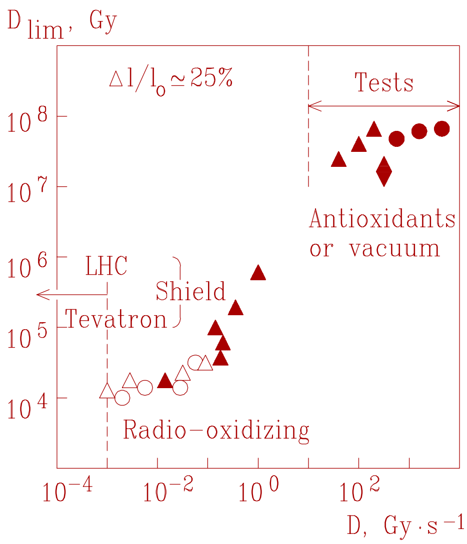

Figure 1: Radiation stability of polymerconcrete (see Table 2 for the legend).

Plastic deformation after irradiation is $\Delta l = u \cdot w$, where $u = dl/dt$ is the speed of radiation creep; w - radiation durability. In 1985, several samples of polymerconcrete were irradiated, see Table 2 for details. Ten years after, the following characteristics were measured: compression strength 42...46 MPa; tensile strength 6...8 MPa; dynamic coefficient of elasticity 103...104. There were no any crack formed in every of 32 samples.

4 INDUCED RADIOACTIVITY

Usually the estimations of the γ-dose of induced radioactivity are made on the basis of experimental results [4]. We managed to irradiate a sample of the PPLC polymerconcrete with a proton beam of 3.7 GeV energy at the JINR's synchrophasotron during 16 minutes. Fluence, $6\cdot10^{11}$ cm^{-2}, was monitored with the calibrated aluminum foils according to the reaction ^{27}Al(p, x)^{24}Na. The sample dimensions were 4.2×3.5×2.7 cm^3. Measurements were made with the Ge(Li) - spectrometer.

After 24 hours after the completion of irradiation, the major contribution to the induced radioactivity is given by the ^{7}Be nuclei produced in the fission of polymer nuclei. Additional minor contribution is given by the radionuclides ^{24}Na on Al and ^{52}Mn, ^{48}V, ^{48}Cr on the nuclei of cement contamination, which is below 1% in total. The levels of induced radioactivity are substantially lower than those ones for the common (2.3 g·cm^{-3}) and gematit (3.48 g·cm^{-3}) types of concrete.

5 SHIELDING OF STEEL AND CONCRETE

Considerable storage of moderated neutrons in the first layer (see Fig.2) leads to the necessity of making the second layer from the hydrogen-containing material (concrete). Production of γ-quanta resulting from capture of the resonant thermal neutrons requires to add B or Li into the concrete. And, as it is known [9], there exists some optimum in the content of H and B in the concrete of the layered shielding which does not depend strongly on the specific problem conditions.

At Figure 2, are shown the results of analysis made along the diffusive-aging method and the 'extraction sections' of the layered shielding for the N_n(E) spectrum of neutrons formed while the interactions of protons (from hundreds MeV to tens GeV) with the Be ion beam line. The following conditions were assumed of low background behind the shielding: fast neutrons F_n^{sf}=1 cm^{-2}s^{-1}; intermediate and thermal neutrons ($F_n^{f}+F_n^{th}$)≤0.1 cm^{-2}s^{-1}; captured γ-quanta and other charged particles formed in steel and concrete ($F_\gamma^{iron}+F_\gamma^{conc.}$)≤0.01 cm^{-2}s^{-1}, what is quite acceptable for the muon detectors.

For one and the same type of concrete, these conditions can be met at different X_1 and X_2, and at X^{min} also. All the curves at Fig.2 are the sets of X^{min} points. With the increase of H and B up to 0.04 g·cm^{-3} the X^{min} decreases rapidly because of the decrease of background from $F_n^{f}+F_n^{th}$ and $F_\gamma^{conc.}$. Then, the contribution from F_γ^{iron} begins to dominate which is not affected (as well as the F_n^{sf}) by the quantity of H, B or Li but is influenced by ρ only. Thus, at small ρ there is no use to add H and B more than

Table 2: Irradiation sources for polymerconcrete samples [5].

Source of radiation	Particles (i - primary, j - secondary)	Dose rate $D^\bullet$, Gy·s^{-1}	Max. Time of irradiation, s	LTE *), keV·μm^{-1}
● - Channels of IBR-2 reactor, JINR	$\gamma_i, n_i \to \gamma_j$, E_n> 1 MeV, $4.2\cdot10^{12}$ n·cm^{-2}·s^{-1}	$5.8\cdot10^3$	10^5	60
Δ - Copper target, 70 GeV synchrotron, IHEP	Different spectra $p_i \to (p, n, e^\pm, \pi_o^\pm, \mu \ldots)_j$	$2.5\cdot10^{-1}$	10^7	15
▲ - Outlet window, 650 MeV phasotron, JINR	Proton beam E_p=650 MeV, 10^{12} p·cm^{-2}·s^{-1}	$2.9\cdot10^2$	10^6	8
O - Copper target, 7 GeV synchrotron, ITEP	Different spectra $p_i \to (p, n, e^\pm, \pi_o^\pm, \ldots)_j$	$7\cdot10^{-2}$	10^7	9
◆ - Gamma-installation	E_γ=1.25 MeV	30	10^7	0.2

*) Here LTE is the mean weighted (over the spectra) linear transfer of energy.

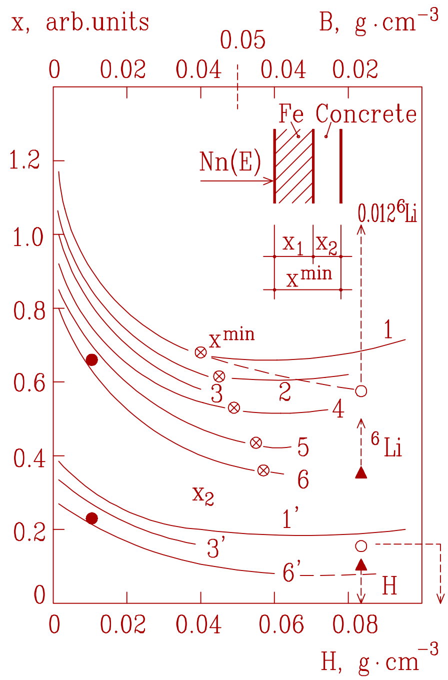

Figure 2: Shielding optimum. Density, g·cm^{-3}:
1.2 (1, 1'); 1.8 (2); 2.3 (3, 3' -common); 2.6 (4); 3.2 (5); 3.6 (6, 6'); ● - 3.48 Gematit concrete, experimental data [9]; ▲ - 3.53 Polymerconcrete ^{6}Li 0.012 g·cm^{-3}; ○ - 1.12 Polymerconcrete ^{6}Li 0.012 g·cm^{-3}; ⊗ - Optimum X^{min}.

0.04 g·cm^{-3} into the concrete.

In the case of large ρ, i.e. high density concrete, the background-dominating factors are F_n^f and $F_\gamma^{conc.}$, which depend strongly on H, B or Li. It is found that the contribution from F_n^f becomes fixed after the H=0.06 g·cm^{-3}. The presence of natural Li=0.15 g·cm^{-3} (^{6}Li=0.012 g·cm^{-3}) in the polymerconcrete with ρ=3.53 g·cm^{-3} does not favor to reduction of the γ-background and the decrease of X^{min} due to the fact that the background here is determined by F_γ^{iron}.

6 COST OF SHIELDING

There are common tendencies in the costs for shielding materials, despite of the differences in prices: if the figure is 1 for Russia, then for USA it is about 0.65, and for Europe - 0.76. The cost of polymerconcrete without the B or Li adds is proportional to ρ at 1.2≤ρ≤3.6 g·cm^{-3} and to ρ^2 at ρ>3.6 g·cm^{-3}. So, it is obvious *a-priori* that it is advantageous to built the space-saving shielding of Fe layers and heave concrete ρ=3.5 g·cm^{-3} instead of the extremely heave concrete blocks with the aggregates from lead to uranium and density 5…14 g·cm^{-3} [10]. From the other side, employing of light concrete (even with the highest content of H, see Tab.1) behind the steel layer, has always a disadvantage of the thickness (see Fig.2) and higher price for 1 m^2 of the shielding.

For example, the three-layer shielding of the ion beam line analogous to the D0 source, has the following characteristics: X_a^{min}=0.70 m, X_1^{Fe}=0.50 m (sheet steel - 5000 \$·m^{-3}), X_2^{CH2}=0.15 m (thick polyethylene - 6000 \$·m^{-3}), X_3^{Pb}=0.05m (lead - 8800 \$·m^{-3}). The results of estimations for the two-layer are:

Type of concrete	X^{min}	X_1^{Fe}	X_2	\$·m^{-3}
b, light polymer with Li	0.68	0.50	0.18	1300
c, gematit with B	0.66	0.43	0.23	500
d, heavy polymer with Li (B)	0.35	0.25	0.1	2000

Costs $C(X^{min})$ \$·m^{-3} for the shieldings of equivalent efficiency with respect to γ-background being expressed in percents of the cost for the 3-three layer shielding are as follows: C_a=100%, C_b=71%, C_c=59%, C_d=38%. These costs do not include the labor cost and the overhead expenses. It is obvious, that to build a shielding from a concrete is much easier than from steel, polyethylene and lead. With the different prices for materials, naturally, the percent relationships can vary somehow. Nevertheless, the heavy boron-containing concrete, due to its high shielding efficiency, gives the economy effect even in comparison with the most cheap gematit concrete of the same density.

7 CONCLUSION

Polymerconcrete poses sufficient strength and radiation stability, has low induced radioactivity, is not toxic and dusty, does not produce aerosols, can be easily cleaned. It does not need the paintwork (paint is adverse because it can be of low radiation stability and short life-time and so produce the dust inside a detector).

The shielding properties of polymerconcrete can be varied over wide ranges and so it can be employed favorably for the compact shieldings of accelerators and other advanced technologies.

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