POLLUTION OF LIQUID ARGON AFTER IRRADIATION OF VARIOUS CALORIMETER PARTS WITH FAST NEUTRONS

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Irradiation tests have been carried out for two years at the SARA facility with fast neutron fluences of a few 10^{14} ncm^{-2}. Many parts of the ATLAS calorimeters have been irradiated, immersed in a liquid argon cryostat: various polymers, cables, connectors... The purity of the liquid was monitored in measuring the response of an α-cell. Some pollution has been observed but the impurity causing it is not oxygen. Extrapolation to the ATLAS detector shows that the effect of this pollution should be negligible in the electromagnetic calorimeter.

1 Introduction

Liquid argon calorimetry plays a very important role in the ATLAS[1] detector, and the question has to be raised about the behaviour of this part of the detector when irradiated with neutrons at the highest luminosity expected in LHC. Simulations[2] have shown that in the electromagnetic barrel, in the electromagnetic and hadronic endcaps and in the forward hadronic calorimeter, 1 MeV n_{eq} fluences up to 10^{14}, 5×10^{15} and even 5×10^{16} n.cm^{-2}, respectively, will be attained in about 10 years. Passive materials are very unlikely to suffer very serious radiation damages, but under such fast neutron fluxes, some parts of the calorimeters may undergo radiolysis to a point where undesirable elements, compounds or radicals will be released in the liquid. A well known example is oxygen, which is highly electronegative and captures electrons drifting in the argon gaps with a high probality: a concentration of about 10 ppm oxygen in the liquid may result in a 10% loss in the calorimeter signal[3].

2 Facilities used by ATLAS

In order to find out whether such or such a material should be considered or rather more safely discarded in the final design, samples have to be put into a liquid argon cryostat and submitted to a high neutron flux such that the desired fluence, i.e., equivalent to a 10 year irradiation at LHC, can be reached within a few days. The amount of impurities released in the liquid are usually monitored with the help of an α-cell also immersed in the liquid. It is a small ionisation chamber with an ^{241}Am α-source on its cathode.

2.1 DUBNA

A pulsed reactor [2] is being used for the purpose. Proper screens or shieldings can be used to favor a desired type of irradiation and the maximum gamma dose rate is 300 $Gy.h^{-1}$ whereas the neutron flux can reach 10^{10} $n.cm^{-2}s^{-1}$ with a mean energy around 1.5 MeV. These figures make this reactor suitable for testing parts relevant to the endcaps and the forward calorimeter. A cryostat has been installed in the irradiation room and is due to be used for its first runs before end 1997. Meanwhile, warm tests have been performed: samples of electrodes, honeycomb spacers and sintered tungsten slugs have been irradiated in a very high vacuum container and residual gases were analysed before and after irradiation. For fluences up to 10^{16} $n.cm^{-2}$, no significant increase of those gases was measured, and one can therefore expect that the oxygen pollution in the ATLAS calorimeters should not exceed 0.1 ppm after running for 10 years.
However, oxygen is not the only possible source of pollution. For example, it is suspected that halogens could be a nuisance at a level of a few ppb. As another example, the attachment coefficient of N_2O for electrons has been measured to be one thousand times as large as oxygen's and SF_6 is even a more powerful electron scavenger [4]. Consequently, warm tests lead to results which may be encouraging but are definitely not fully conclusive.

2.2 SARA

SARA is the Systéme Acclérateur Rhônes-Alpes at Grenoble, formerly used for heavy ion nuclear physics. The facility, fully described in an earlier paper [5], uses a 20 MeV deuteron beam accelerated in the first cyclotron, with a mean intensity of 5 to 7 μA. Neutrons are produced on a Beryllium target with a mean energy of 6 MeV. Samples are placed in a cryostat containing 5 litres of liquid argon, very close to the target. Averaged over a volume of $8 \times 8 \times 4$ cm^3, a fluence of 10^{14} $n.cm^{-2}$ can be obtained in about 1 day, with a very low contamination in gammas. The fluence being a factor 10 as low as at DUBNA, SARA is more suited for testing parts of the electromagnetic barrel calorimeter. The pollution tests described hereafter have been made at SARA exclusively.

3 Purity monitoring at SARA

The level of pollution one can anticipate from the nature of the samples should not be very high and the easiest way to emphasize the effect is to increase the amount of material in the irradiation cryostat. If we assume that the pollution rate is a surface more than a volume effect, one should enhance the sample area per liquid unit as compared to the actual situation in the calorimeter. It would also be desirable to monitor the pollution with a large gap ionisation chamber and a full integration of the charges to be most sensitive to the variation of the absorption length. However, a compromise has to be found because of the activation of the argon via the reaction: $^{40}Ar + n \rightarrow \ ^{41}Ar \rightarrow \ ^{41}K + \beta$. The counting rate becomes very quickly overwhelmed with the beta activity, the alpha peak is hardly visible and measurements are rather inaccurate because of pileup as well. The gap thickness of the monitor was chosen to be 0.7mm, i.e., the typical drift time is 160 ns, and the shaping time was set at 145 ns.

3.1 Procedure

The α-cell output is connected to a warm preamplifier via a 1.4 metre low capacitance cable. The preamp output is fed into a shaper of the CR-RC type with CR=145 ns. A calibrated pulse is fed onto the anode. It carries the amount of charge one expects to collect from the alphas at a particular value of the electric field when there is no pollution. Before, during and after irradiation, pedestal, alpha and pulser signals are measured at various field values. To get rid of electronic fluctuations, the relevant quantity is

$$\mathrm{Q(E)} = \frac{alpha-pedestal}{pulser-pedestal},$$

where E is the electric field.

As illustrated on figure 1, this factor is checked to be stable before starting irradiating. Then a fast fall off can be observed, which seems to go towards some saturation. When irradiation is stopped, the purity seems to recover partly, but this phenomenon was not observed with all samples. When the liquid is evaporated, the attenuation increases again, which indicates that the contaminants are not evaporated but are still fully present in the remaining liquid. The results presented on figure 1 correspond to the worst pollution observed so far.

It is assumed that the recombination rate is not altered by the presence of impurities as long as their concentration is very low (ppm). Measurements before and after the irradiation lead to the attenuation factor:

$$\frac{Q_{after}(E)}{Q_{before}(E)} = \frac{\lambda(E)}{d} \times (1 - exp(-d/\lambda(E))),$$

where d is the detector gap and λ is the absorption length. The variation of λ with E depends on the nature of the liquid and of the impurity. It is inversely proportional to the attachment coefficient [7]. In the particular case of oxygen in liquid argon, Hofmann et al. [6] have shown that this variation was best fitted with the formula:

$$\lambda(E) = \alpha E/\rho, \text{ where } \alpha\text{=14}\pm\text{3 ppm.mm}^2\text{/kV}.$$

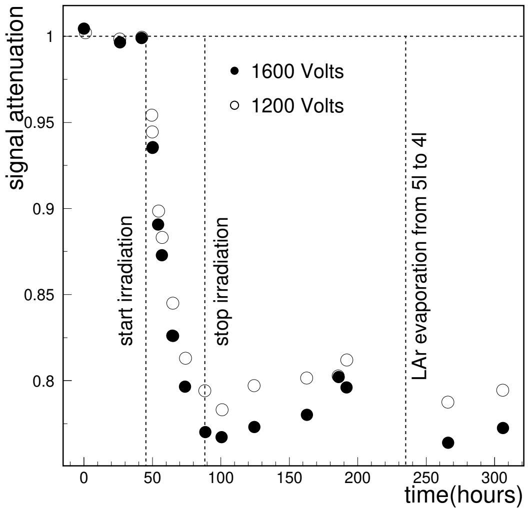

Figure 1: Evolution of the attenuation factor before, during and after irradiation.

3.2 results

The behaviour of the attenuation factor when oxygen is admixed to liquid argon was observed in this setup to be exactly as just described, but it is not the rule whatever the contaminant might be. We have checked that it is not true for nitrogen, and all the irradiation tests performed so far at SARA have also led to the opposite, i.e., the absorption length decreases slightly at higher fields or may remain about constant, as shown on figure 2.

The very first conclusion is that the impurity released after irradiation is not oxygen. Its nature has not been determined, since it seems to remain in the cryostat after evaporating the argon. Chemical analyses of the final vapors were not conclusive. Quantitative results have been summarized in table 1.

3.3 From SARA to ATLAS

In order to obtain a prediction on the possible signal loss in ATLAS from the tests performed at SARA, one has to consider first that the detector gap will be 2mm instead of 0.7 mm, ionisation will take place throughout the gap whereas α-tracks are about 50 μm long and that the shaping time will be 13 ns long

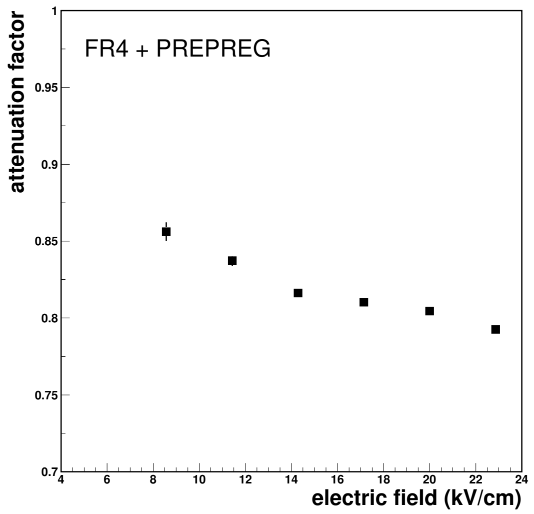

Figure 2: Signal loss after irradiating prepreg plates.

versus 145 ns. It ends up with a loss on the calorimeter signal 3 times as small as in the tests. The enhancement (last column in the table) has also to be taken into account. Adding up all contributions from the parts tested so far, one gets 1.5% loss at a field value of 10 kV/cm and for a fluence of 2. 10^{14} n.cm^{-2} at $< E_n >$=6MeV.

A few comments have to be made:

• In the case of the epoxy bars to be used in the em endcaps, the signal loss was found to be zero. On the other hand, when the cryostat was irradiated full of liquid argon and containing no samples at all, the charge signal was degraded by 2 % very quickly at the beginning and remained at this level thereafter. This means that, when signal losses are seen to be of the order of 1 or 2 % in the above table, they may very well be attributed to some sort of background.

• There are two lines in the table labeled "prepreg". They show that pollution does indeed scale with the amount of samples irradiated.

• Absorbers have not been and will not be tested, but they are not expected to give trouble, owing to their steel surface.

• Samples were not always of the final material and electrodes are still

Table 1: Results of the irradiation tests performed so far at SARA. The second column shows the fluence attained at the end of each run. The fourth column shows the signal loss extrapolated at a field value of 10 kV/cm and for a fluence of 2. 10^{14} n.cm^{-2}. The last column shows the excess of material in the tests compared to the calorimeter conditions. Extrapolation to the calorimeter requires dividing the 4th column by 3 (see text) and by the corresponding enhancement factor.

material	fluence	signal loss ($\pm$20%)		enhancement factor
		E=10kV/cm	E(10) & 2. 10^{14}	
FR4 (PS)	1.6 10^{14}	0.04	0.04	11
prepreg (PS)	2. 10^{14}	0.16	0.16	22
prepreg ($\approx$1/2)	1.4 10^{14}	0.06	0.07	11.5
G10	2.5 10^{14}	0.11	0.10	9.5
epoxy (endcap)	2.5 10^{14}	0	0	
cables	2.4 10^{14}	0.015	0.015	1.4
honeycomb	1.4 10^{14}	0.01	0.01	1.7
μD connector	3. 10^{14}	0.03	0.02	5
mother boards	1.8 10^{14}	0.02	0.02	21

missing. This again is not expected to add very much to the above loss.

• The exact nature of the contaminants is not known, and in some cases it looks as if they were disappearing after some time, or getting nested in some unknown place where they are no longer a nuisance.

• The extrapolation from SARA to ATLAS relies on the assumption that the liquid in the cryostat is always homogeneous, which is conceivable when one talks on a year scale.

4 conclusion

The very first point to emphasize is that no clear emission of oxygen has been observed so far in cold tests. In the em barrel, tests are almost complete and the signal loss after 10 years should certainly be below 1.5%, especially if one considers that the evaluation was made at a fluence twice the expected value and at a mean neutron energy of 6 MeV instead of 1 MeV (see TDR[2]). It is more difficult to anticipate the effect of the pollution in the endcaps, but the present results are a fair indication and lead us to be optimistic. About the forward calorimeter, the warm tests are very encouraging but cold tests have definitely to be performed. Whereas the SARA facility will close down mid 98 after a last series of tests, the DUBNA facility is now about to start the cold tests, in particular on hadronic endcap and forward calorimeter parts.

References

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