Further advances in aging studies for RPCs

G. Aielli [a,*], P. Camarri [a], R. Cardarelli [a], A. Di Ciaccio [a],
L. Di Stante [a], B. Liberti [a], A. Paoloni [a], E. Pastori [a],
R. Santonico [a]

[a] *INFN and Dipartimento di Fisica dell'Università di Roma "Tor Vergata", Italy*

presented by: Giulio Aielli

Abstract

Aging phenomena in RPCs have been studied since 1996 in the framework of the ATLAS experiment with small-size detectors, irradiated with a ^{60}Co source. The results evidenced a decrease of the detector rate capability at fixed electric field, due to an increase of the total resistance of electrodes. This was confirmed by an extensive aging test performed on the ATLAS RPC "module-0" at GIF-X5, the CERN irradiation facility. A primary cause for this effect was previously shown to be the degradation of the anodic graphite coating, which distributes the electric field on the bakelite electrode. We present here a systematic study of the graphite aging which fully confirms this interpretation. Moreover, we show that detectors with improved graphite coating allow to gain a factor of at least two in lifetime. In the framework of these tests, we also show that the aging behavior of a detector working at high current induced by heavy irradiation can be reproduced by operating the detector, filled with pure Argon, in "self-sustaining" streamer mode.

Key words: RPC; aging; high rate; front-end electronics; ATLAS

---

1 The aging problem in the RPC

Dedicated aging tests carried out on large-size [1] and small-size [2,3] RPCs showed a decrease of the rate capability at fixed applied voltage as the main aging effect. In particular, it has been demonstrated that this effect is due to an increase of the total resistance of the electrodes and can be therefore

---

[*] Corresponding author. Fax: + 39 06 2023507
Email address: `aielli@roma2.infn.it (G. Aielli).` (R. Santonico).

compensated, within certain limits, by increasing the applied voltage. Nevertheless, in the test of the large-size RPC the rate capability was observed to decrease from 1.6 kHz cm^{-2} to 300 Hz cm^{-2} after integrating 360 mC cm^{-2} of charge delivered in the gas at the selected working point. All the other detector performances were found to be unchanged.

An explanation of this behavior relies on the concept that, in case of uniform irradiation, the detector working point is not determined by the applied voltage V, but by the effective potential $V_{gas}(x,y,t)$ present in the gas . This is in general a complicate function of time and position accounting for the effects of charge depletion on the resistive electrodes due to previous avalanches. In a stationary situation, however, these effects can be taken into account by assuming a uniform value for the voltage applied to the gas $\overline{V}_{gas}$ which is defined as the space and time average of $V_{gas}(x,y,t)$. This parameter is particularly meaningful when the fluctuation of $V_{gas}(x,y,t)$ is small with respect to the average voltage drop V-$\overline{V}_{gas}$, and in this case it gives the effective working point of the detector.

This hypothesis looks to be satisfied for RPCs working in avalanche mode above some tens of Hz cm^{-2} [4,5]; the explanation of this fact involves the horizontal conductivity of the bakelite and the reduced gain of a discharge point with respect to the neighbors.

This "thermodynamic" approach is depicted in Fig. 1 which demonstrates that the average value of $V_{gas}(x,y,t)$ is simply obtained by accounting for the voltage drop across the resistive plates with Ohm's law, while the detector capacitance does not play any role:

$$V_{gas} = V - IR, \tag{1}$$

where I is the average working current and R is the total electrode resistance. The switch frequency represents the event rate while R_{gas} accounts for the power dissipated in the gas. In this picture it is clear that for a given current (i.e. rate) V_{gas} (i.e. the working point) is displaced proportionally to R. The increase in the resistance of the electrodes due to aging can be attributed to two main components: a moderate increase of the bakelite resistivity and a more relevant increase of the anodic graphite coating resistivity. The cathodic graphite layer remains almost unaffected [1].

The graphite resistivity increases exponentially as a function of the integrated charge and reaches a breakdown point characterized by a faster than exponential behavior, which could be explained as a loss of connectivity of the graphite grains. This appears to be the dominant long-term aging phenomenon.

2 Direct measurement of the increase in plate resistance

A direct measurement of the electrode resistivity was performed on 10×10 cm^2 bakelite samples, 2 mm thick, and coated on both sides with graphite layers that were kept under a fixed potential difference to produce a current flowing across the plate, as in the real case. The samples are (Fig.2) protected by PET films, which are glued on the graphite by means of a standard hot melt currently used in the RPC construction and sealed on the edges by a ring of the same glue. The graphite surface resistivity is 100 k$\Omega/\square$, and the electric contact is made with enhanced heavy graphite strings of low resistivity, supporting the power supply connections [6]. We performed the test on several samples, with bakelite resistivity ranging from 10^9 to 10^{11} Ωcm and with 400 and 800 V applied, to obtain different testing speeds. The current was monitored along with the stabilized temperature (around 24 ^{o}C). The graphite resistivity was periodically measured via two copper labels glued with silver epoxy at opposite corners of the graphite electrode.

Two types of graphite coating were tested: the "standard" (SG) and an enhanced type (EG). Both types had the same surface resistivity but the enhanced one contained approximately twice the number of graphite grains per unit surface.

Fig. 3 shows the evolution of the "apparent" electrode resistivity at 20 ^oC, which is defined as the total plate resistance normalized by geometrical factors, as a function of the integrated charge. The two curves refer to low resistivity (3×10^9 Ωcm) bakelite plates coated with the SG and the EG, respectively, and kept under a constant voltage of 400 V. The apparent resistivity coincides with the plate bulk resistivity only when the graphite resistivity effects are negligible. The increase of the graphite resistivity normalized to its initial value is shown in Fig. 4 vs. the integrated charge for the standard and enhanced graphite. Both curves are characterized by a "breakdown knee" after which the graphite abruptly loses its conducting properties. Moreover, the comparison of the curves shows that the EG survives an integrated charge a factor of two larger. Comparison of Figs. 3 and 4 shows that the limits of integrated charge for both samples are dominated by the graphite degradation, not by the increase of the bulk resistivity of the plates.

A further question to be investigated is how the increase of the graphite resistivity depends on the aging time for fixed integrated charge. This is particularly relevant because the aging tests are usually much shorter than the real case.

With the purpose of answering this question several SG and EG samples were tested at different rates, i.e. under different aging currents. The results are summarized in Fig. 5, which shows a scatter plot of the integrated charge at the "breakdown" limit vs. the time needed to reach it. Here only the "active" time, i.e. with voltage continuously applied, is accounted for, because we observed that the graphite properties do not evolve in case of long test pauses. The plot clearly demonstrates that the shorter the time, the larger the integrated charge at the breakdown. However, in the limit of infinite aging time, which represents to a good extent the real case, both SG and EG plots appear to reach asymptotic limits. The corresponding values are $\sim$ 35 mC cm^{-2}, corresponding to 10 ATLAS years (AY), and $\sim$ 70 mC cm^{-2} (20 AY) for SG and EG, respectively, thus confirming an improvement of a factor of two for the EG.

3 Test of RPCs filled with pure Argon

With the purpose of studying aging effects induced in the electrode plates by the detector working current under conditions as close as possible to the real case, we introduce here a new aging method. It entails running the RPCs filled with pure Argon in a self-sustaining streamer regime. Indeed, if the gas quenching components such as the isobutane are removed, the UV photons are no longer absorbed and can ionize the gas far away from the point where the primary ionization occurred, thus propagating the streamers all over the detector area. It has to be stressed that this regime does not develop any spark because the electrode resistivity limits the current that can be locally maintained in the gas to values much below what is required by the spark development, i.e. the streamer development time is orders of magnitude shorter than the relaxation time of the electrodes. In this case the only energy available for a single discharge process is obtained from the static electric field present across the gas volume induced by the streamer itself [7].

The advantage of this method is the possibility to keep a real detector under a high current without the help of a radioactive source, without a complex gas system, and with relatively low voltage.

In Fig. 6 we report the V-A characteristic of two 10×10 cm^2 RPCs operated in pure Argon. The vertical log scale is evidence of the sudden transition of the detector to the self-sustaining streamer regime. The operating current, once this regime is reached, depends on the ohmic drop on the resistive electrodes, which had an initial resistivity of $1.6 \times 10^{10}\,\Omega$cm.

The two chambers were identical except for the graphite coating (SG and EG). They were operated for 70 days integrating 645 mC cm^{-2}, and 4.5 months integrating 1100 mCcm^2, respectively, before the breakdown knee as shown in Fig.7. The test was ended when the EG chamber reached the apparent resistivity of $4 \times 10^{11}\,\Omega$cm, measured in avalanche mode with the effective voltage (V_{gas}) method[4,5], using the ^{60}Co source.

At the end of the test performed in pure Argon, we tested the EG chamber again under standard ATLAS conditions, i.e. in avalanche mode with the gas mixture TFE/i-C_4H_10/SF_6 96.7:3:0.3, to verify that this aging method was not destructive for the detector. The ohmic current of this chamber (from the linear V-A characteristics below the gas multiplication voltage [1]) was $\sim$ 20 nA kV^{-1}, compatible with the initial one. The efficiency was measured with cosmic rays triggered by a small size telescope, also in presence of a ^{60}Co photon background producing a counting rate of $\sim$ 100 Hz cm^{-2} on the detector under test. The results are shown in Fig. 8, where the displacement of the efficiency plateau at higher rate due to the increased electrode resistance is visible. The good efficiency indicates that the chamber survived an aging test carried out under extreme conditions, as indicated by an initial current density of more than 1 μA cm^{-2}.

4 Test of real detectors at GIF

To confirm the results of the tests described above, we conducted a further aging test with four small-size 50×50 cm^2 RPCs built according to the ATLAS standards with respect to plate material, construction procedure, and front end electronics[9][1], at the GIF facility of CERN [8]. In particular, the plate resistivity was $\rho = 2.5 \times 10^{10}$ Ωcm and the chambers worked in avalanche mode with the gas mixture quoted above. In this test the EG was used for the first time in a realistic setup. The results are reported relative to one of the installed detectors which had already integrated 0.3 C cm^{-2}, equivalent to 10 AY. The detector plate resistance, measured at the end of the test through the V-A characteristics for different source intensities, was $\rho = 10^{11}$ Ωcm, a factor 4 above the initial value, compatible with the expected [1] resistivity drift of the present electrode material. In Fig. 10 we report the final (10 AY) V-A characteristics for closed and full source, demonstrating that the bias current is negligible (1 μA at 8 kV) and that the operating current is completely due to the avalanches induced by the source. The efficiencies as reported in Fig. 9 show that after 10 AY the rate capability is still $\sim$ 560 Hz m^{-2} and that the plateau displacement is consistent with the voltage drop due to the measured electrode resistance. However, a longer testing time would be required before observing aging effects due to the degradation of the enhanced graphite coating.

5 Conclusions

In this work the electrical degradation of the anodic graphite coating of RPCs is systematically investigated as the main long-term aging effect. An enhanced graphite coating could increase the detector's lifetime by a factor of two. A new testing method based on RCPs filled with pure Argon and working in self-sustaining streamer mode has proven to be very effective for simple and fast tests of the aging phenomena induced by the current flowing across the electrode plates. Several tests carried out at the GIF facility are still under way after passing the limit of 10 AY.

References

[1] G. Aielli, et al., RPCs aging studies, Proc. of VCI 2001, to be published in Nucl. Instr. and Meth. A.

[2] ATLAS Muon Spectrometer Technical Design Report (Chapter 8), CERN/LHCC/97-22.

[3] G. Aielli, Master's thesis, (Oct. 1997).

[4] G. Aielli, et al., An RPC γ irradiation test, Nucl. Instr. and Meth. A 456 (2000) 82.

[5] G. Aielli, Ph.D. thesis, Univ. of Rome Tor Vergata (Feb. 2001).

[6] PRR of ATLAS RPC Muon Chambers (January 1999).

[7] R. Cardarelli, et al., Progress in Resistive Plate Counters, Nucl. Instr. and Meth. A 263 (1988) 20.

[8] S. Agosteo, et al., A facility for the test of large area muon chambers at high rate, CERN-EP-2000-031 (February 16, 2000).

[9] G. Aielli, et al., Performances of a large size RPC, equipped with the final ATLAS frontend electronics, at X5 GIF facility, Nucl. Instr. and Meth. A 414 (1998) 77.

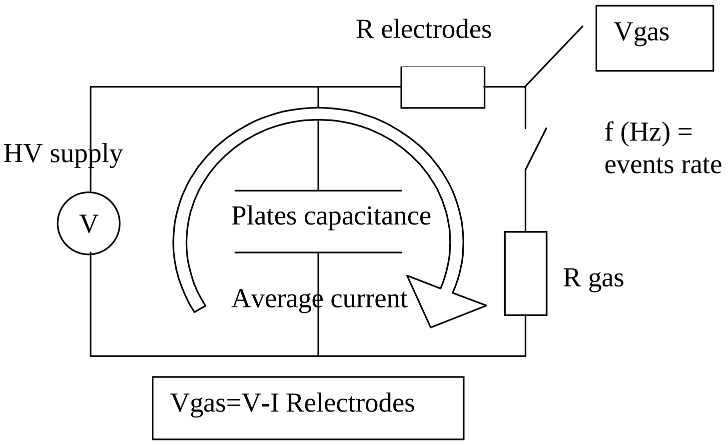

Fig. 1. Equivalent circuit for average values of an RPC uniformly irradiated, working in avalanche mode.

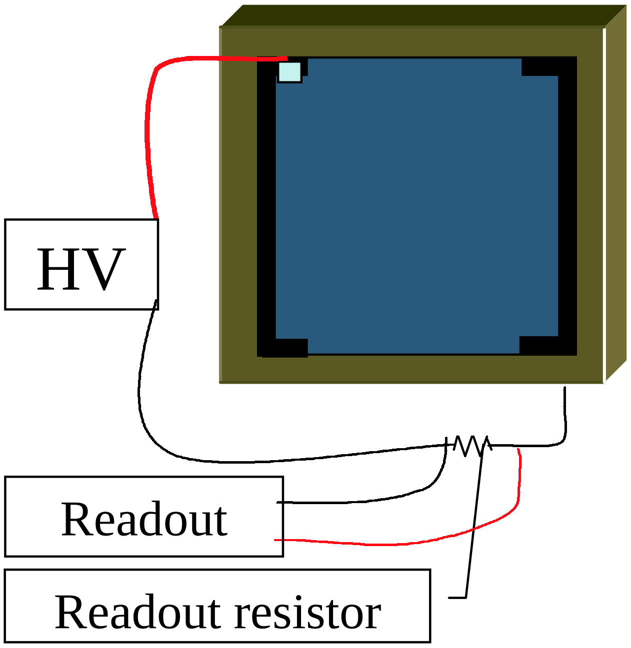

Fig. 2. Schematic of the setup for the electrical aging of a resistive plate.

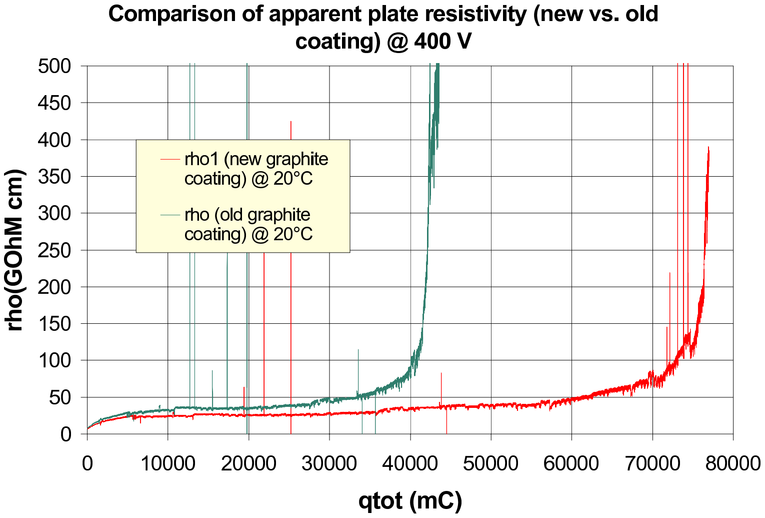

Fig. 3. Comparison of apparent plate resistivity (EG vs. SG) at 400 V vs. the total integrated charge.

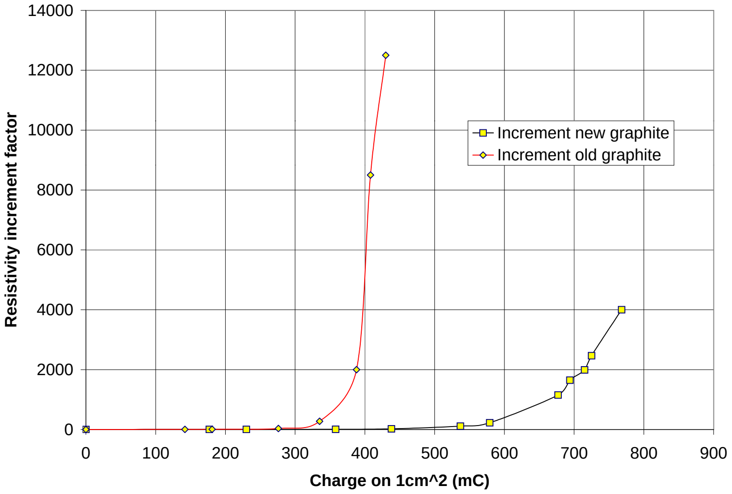

Fig. 4. EG and SG surface resistivity normalized to the initial value vs. the integrated charge per unit surface.

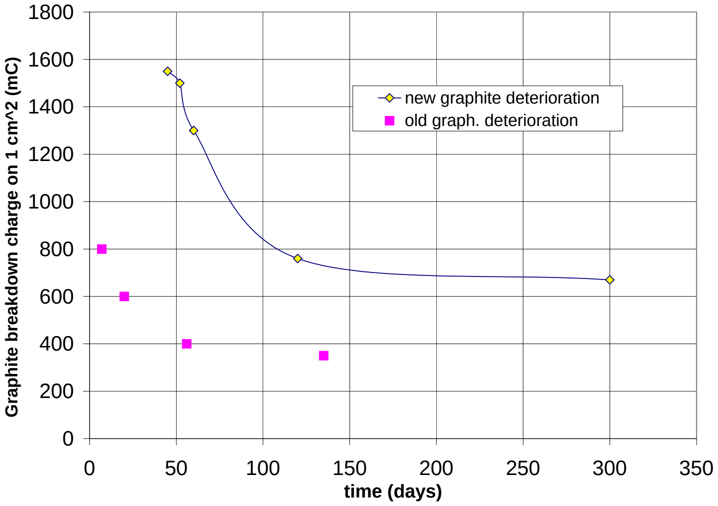

Fig. 5. Scatter plot of graphite breakdown charge limit vs. the breakdown time for SG and EG.

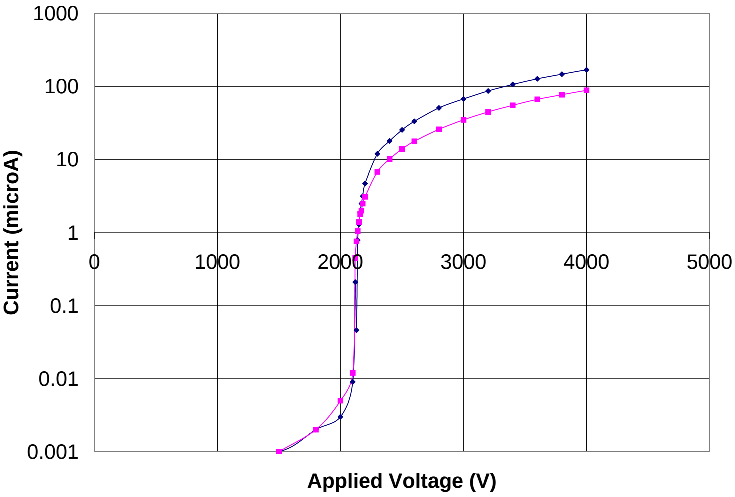

Fig. 6. Log plot of the V-A characteristic for two 10×10 cm^2 low-resistivity RPCs, operated in pure Argon.

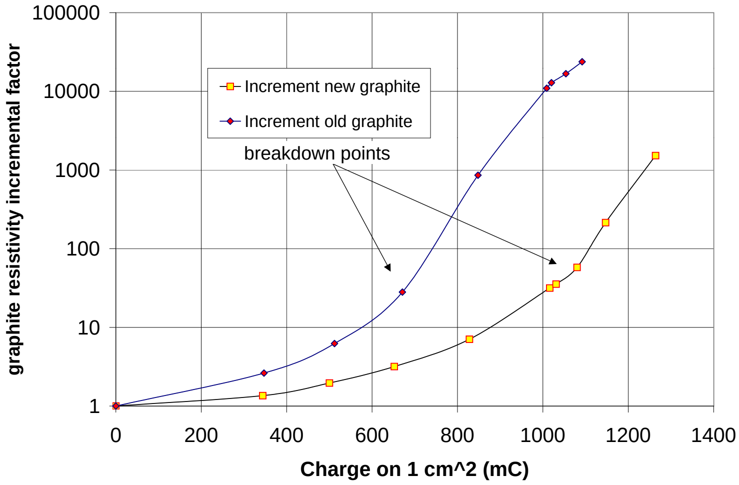

Fig. 7. Incremental factor for the SG and EG coating resistivity of two RPCs aged in self-sustained streamer regime.

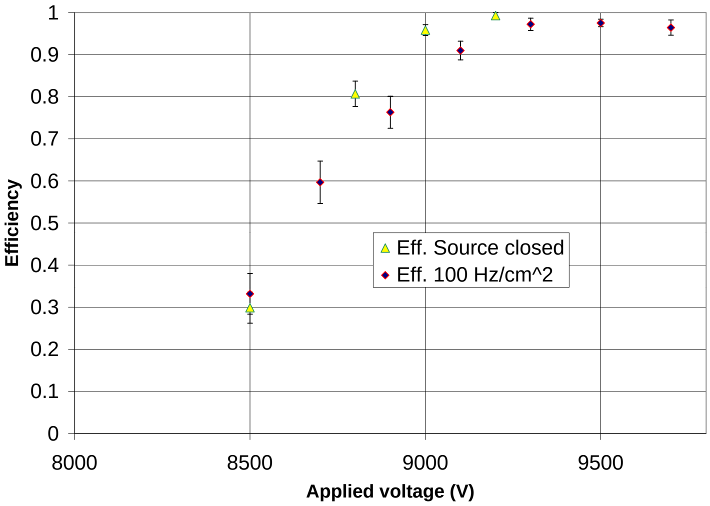

Fig. 8. Efficiency plot of the EG-coated RPC after the aging, with and without the 100 Hz cm^{-2} background.

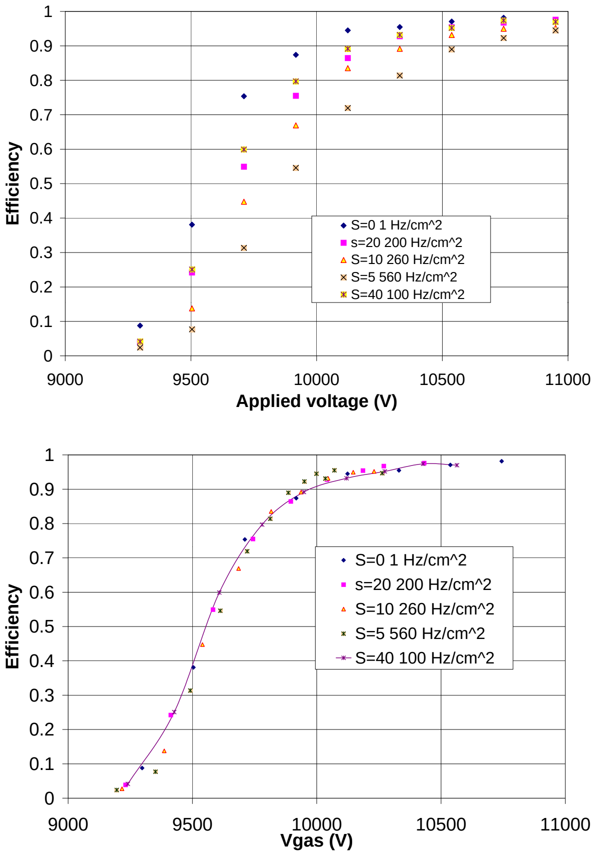

Fig. 9. Efficiency vs. applied voltage (upper) and vs. V_{gas} (lower) for a 50×50 cm^2 EG-coated RPC, after 10 AY of aging at GIF.

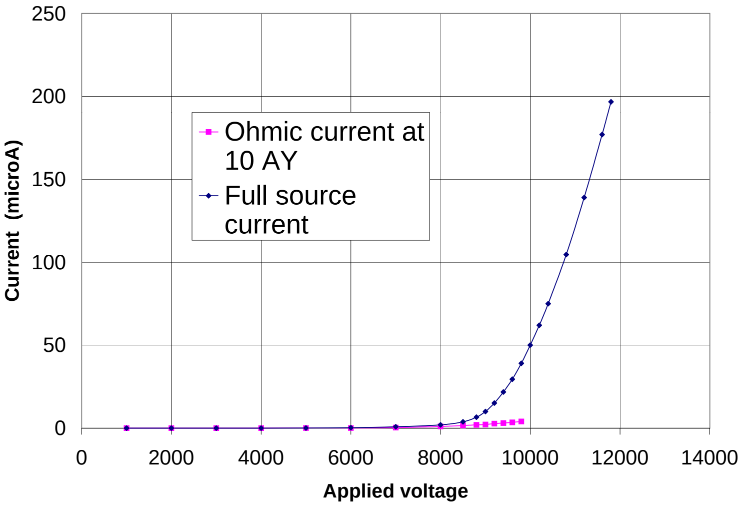

Fig. 10. V-A characteristics of the aged RPC for full and closed source.