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Fundamental understanding of aging processes: review of the workshop results

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Abstract

A short summary of major observations reported at the workshop is given, together with a critical discussion of points still obscure or controversial, with suggestions on possible lines of research towards finding solutions to the problem of aging detectors.

Keywords: gas detector aging; polymerization; anode wire deposits; electron avalanches
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1. Introduction

A slow deterioration of performances under irradiation has been observed since the early development of Geiger and proportional counters and attributed to the formation of polymeric deposits in the avalanche processes [1,2]. In the seventies, with the introduction of multiwire chambers (MWPC) and their wide use in experiments operating at high rates, radiation-induced degradation (nicknamed "aging") became an unfortunate common observation [3]. The effects of gain, materials, and gas composition on aging rates have been extensively studied; a summary of the status of knowledge in the mid-eighties can be found in the proceedings of the first dedicated workshop [4]. Despite often contradictory results, from these works emerged a set of general guidelines on how to build and operate gaseous detectors capable of withstanding the radiation fluxes of the time. The "golden rules" included warnings against the use of heavy organic quenchers, care to avoid sources of silicon oil pollution, and indications on good and bad materials for the construction of detectors [5]. Use of additives in the gas flow appeared also, if not capable of totally preventing the aging processes, at least to slow them down to an acceptable pace.

The advent of new generations of detectors, very

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performing but more vulnerable, coupled to the commissioning of higher luminosity accelerators has opened the aging issue again in all its dramatic relevance. Additives often turned out to have undesirable effects, and the recipes for choices of gas and materials became more and more difficult to enforce, particularly for large-area systems where cost is a major issue.

The numerous works presented at the present second workshop dedicated to the subject, whilst very rich in information, demonstrate that the aging problem is far from having received a general solution. Some progresses in the understanding of the basic underlying chemical and physical processes are counterbalanced by reports on the dramatic loss of detector systems due to unforeseen events. Many properties of plasma chemistry, reported at this workshop by Yasuda [6] are reminiscent of similar observations made in proportional counters, such as the larger polymerization rate of silicon as compared to carbon compounds, and the effects of the electrode material and surface quality. Usually obtained, however, in rather specific pressure and charge environments, they remain qualitative when extrapolated to the quite different conditions met in gas detectors.

Possible connections between plasma chemistry and gas counter aging have been discussed by Va´vra [7]. Preliminary results of systematic investigations on polymer formation in conditions close to those of gas counters have been reported by Kurvinen [8], and confirm for example the strong reduction of polymer formation with increasing current density, an effect observed in detectors. A larger effort in this direction seems very desirable in order to improve our understanding of the aging chemistry in the operating conditions of gas counters.

In this note, I will try to summarize the major findings reported at the workshop, pointing out areas in which further assessment of the data seems necessary, and to indicate promising directions of research. Subjects are, somewhat arbitrarily, itemized in separate sections, but are actually overlapping and interactive.

2. Units of measurements and goals

Certifying in a reasonable time the survival of a detector for several years of operation needs an accelerated test procedure. Intuitively, if aging is a consequence of the formation and accumulation of polymers or other chemical processes occurring in the avalanches, the scale invariant should be the total accumulated charge, independently from other factors such as voltage, type and flux of radiation, and gas flow.

In the times of wire chambers, it became customary to express the accumulated charge in Coulomb per unit length of wire, a detector being qualified good if it could withstand up to several C/cm without gain drops. With the introduction of micro-strip chambers, the corresponding unit was charge per unit strip length, and “good” MSGCs could survive up to 100 mC/mm. In the new generations of detectors without wire or strip structures responsible for multiplication, such as micromegas, gas electron multiplier (GEM), parallel plate and resistive plate chamber (PPC, RPC) the appropriate scale factor is the collected charge per unit area, with good devices being able to properly operate after 100 mC/mm^2 or so. The corresponding radiation fluxes can be calculated from the known geometry, gain, and primary ionization release.

3. Dependence of aging on dose rate and other parameters

Long ago, Kadyk introduced a parameter, the aging rate R, defined as percentage gain variation normalized to the total collected charge [9]. Ideally, this should be a constant for a given detector; as it turned out, the value of R depends, sometimes critically, on various test conditions, the main one being the dose rate, or acceleration factor. As found in many experiments, data collected at high current densities tend to be optimistic, often by a large factor, compared to those obtained at lower rates [10]. Also, space charge gain saturation can set in at high current densities, possibly decreasing the polymerization efficiency; the appearance of diffused micro-discharges, producing irreversible local damages or filament growth (“hairs”), can seriously affect performances. Binkley [11] showed an impressive collection of pictures taken in an aged detector, and Blinov discussed possible mechanisms for the formation of silicon filaments as a result of micro-discharges [12].

A strong voltage dependence of aging rate was reported by Kollefrath [13]. In some detectors, the presence of heavily ionizing tracks in the radiation field was found to largely enhance the discharge probability and hence the degradation of detectors [14,15]. Extreme sensitivity to some pollution sources, particularly if containing traces of silicon compounds, was confirmed and reported by Capeans [16]. The interpretation of irradiation results can be seriously biased if these sources, often external to the chamber, are undetected, making comparisons with other observations doubtful.

Given the dose rate, a larger irradiated area can also increase the aging rate, as reported by the HERA-B MSGC group [14,17]. The gas flow itself affects, although mildly, the aging rate that is larger for lower flow. Moreover, the gain degradation appears to move along the detectors with the gas flow [18], with the damaged area often exceeding the irradiated region [19]. A possible explanation of these effects lies in a dependence of polymerization rate on the time, which reactive radicals produced in the avalanches spend in the region of ionization, a point that can and should be enlightened by a dedicated set of experiments.

4. Microstrip gas chambers: a good pollution detector?

Microstrip gas chambers raised great interest because of very promising high-rate, high-accuracy performances. For reasons that are not yet fully understood, but possibly connected to the small area of the anode strips, MSGCs turned out to be far more sensitive to aging than conventional wire counters, therefore requiring more stringent requirements on the purity of gases and materials used [20]. A perhaps extreme example is the fast aging rate observed in a detector with an oil bubbler added at the output of the gas flow, probably due to back-diffusion of residual oil vapors [21]. It is tempting to suggest the use of MSGCs to certify the quality of gas systems, upstream of larger detectors. With their efficient polymer deposition rates, MSGCs (or perhaps similar but simpler devices) may even be considered as a way to clean the gas before entering other detectors.

5. Planar detectors: more tolerant to aging?

In wire chambers, a clear correlation between the wire diameter and the rate of aging has been found, with thinner wires aging much faster (see for example Ref. [22]). It is not clear if this is simply due to the smaller area available for the deposits, or to an increased polymerization efficiency induced by the higher field close to the anode.

Planar wireless devices where multiplication is obtained over extended regions in relatively moderate field appear indeed to age at a much slower pace. Kappler [23] described recent measurements with a large-size triple GEM chamber, showing no gain variations after about ten mC/mm^2 of collected charge, and Miyamoto reported similar results obtained with a combined MICROMEGAS and GEM detector [24]. Several reports described the relative insensitivity of resistive plate chambers (RPC) in long-term exposures to charged particles, photons, and neutrons [25-28]. Mostly used for relatively low-rate particle detection, RPCs are of course less demanding in terms of collected charge; the very large area covered, requiring simplified manufacturing methods and reduced criteria of quality control for material, however, make them rather susceptible to damages due to local defects or external environmental changes, as painfully discovered in the BaBar detector [29].

6. The water case

The beneficial effects of adding water to detectors have been known for a long time (see for example various contributions in Ref. [4]). Aside from reducing the polymerization rates in plasma discharges, water has also the property to make all surfaces in the detectors slightly more conductive, thus preventing, if not the formation of polymers, at least the accumulation of ions on thin layers responsible for the gain degradation and the increase of dark current through Malter effect. Some improvements in operation have been reported after adding water to the BaBar drift chambers [30] and the ZEUS central drift chambers [31], but the inevitable increase in conductivity on frames and spacers and the modification of the electron drift parameters are not always acceptable. Relying on the dielectric rigidity of the small insulating gap between anode and cathode strips, MSGCs do not tolerate water additions in any quantity that would be useful to prevent aging [17, 20]. A recent detailed study of discharge probability of GEM detectors under exposure to heavily ionizing tracks has revealed a somewhat unexpectedly large increase with water content: at a given gain, an increase of moisture from 35 to 100 ppm enhanced the discharge probability by several orders of magnitude [23]. Given the rare but possibly devastating occurrence of such discharges, this point should be carefully considered in other types of detectors.

7. CF_4: medicine or poison?

Use of carbon tetra-fluoride as additive in gas mixtures is attractive because of its properties: swift electron drift velocity already at moderate fields, non-flammability, and low neutron cross-section. Not a hydrocarbon, it does not form polymers, and actually it has been demonstrated that, thanks to the reactivity of the species produced in the avalanches, CF_4 can prevent polymer formation and even remove them from electrodes if already present [32]. The delicate balance between etching and deposition has been argued by Capeans [16]. Schreiner [33] discussed the reactivity and lifetime of species produced by CF_4 in the avalanches, particularly in presence of organic pollutants, water, and oxygen.

It was found long ago that, when irradiating detectors with CF_4 in the gas mixture, long-lived electro-negative molecules form and propagate with the gas flow [34]; this propagation has been confirmed by other studies presented at this workshop [15,18], and can obviously affect the efficiency of a large system with many detectors in series, imposing strict limits to the number of devices in cascade and to the value of the gas flow. The design of a re-circulating gas system, required in large experiments particularly if making use of xenon, seems singularly difficult in presence of species that can react with delicate components such as purifiers and filters. Damages to the detector materials during operation, and in particular to the anode wires have been reported [19,35,36]. Under irradiation, the gold-plated tungsten anodes swell, presumably because of the penetration of fluorinated compounds into the tungsten, that can then shed off gold flakes; the ill effect of such occurences need not be discussed.

The swelling under irradiation has been correlated to the quality and provider of the anode wire and to the amount of residual water in the gas, although on the second point the tolerance limits are not clear: Romaniouk [36] demonstrated good behaviour below ~ 500 ppm of water, while Schreiner [33] reported cases of complete wire erosion and breaking in dry gas. Whilst the instrumental advantages of the use of CF_4 are clear, the study of alternatives seems very desirable; for example, the use of slower and somewhat gain-limited mixtures with CO_2, or of different metals for the wires such as stainless steel, demonstrated to be impervious to aging [10] but having the drawback of a larger resistivity.

8. Emergency care for aged chambers

Over the years, experience has shown that even an a priori robust detector can suffer from severe aging problems due to unexpected presence of pollutants. A therapy permitting to cure the disease, even exceptionally, would be very welcome. Some time ago, Va'vra succeeded in evaporating oily deposits on anodes by heating the wires with an externally supplied current; the procedure was helped by the high resistivity of the anodes (thin carbon fibres) [22]. The sublimation products, however, affected the efficiency of the detector, a RICH photon detector, probably by condensation on the windows. In most cases, detectors are not designed to heat up the wires by DC current, either for lack of connections on both sides of the wires or because of their low resistivity. Marshall [37] described a rather extreme method of removing the crud deposited on the anodes by the out-gassing and polymerization of a resin used for construction. A high voltage pulse, provided by a large capacitor, was used to "zap" the wires with energy of a few tens of joules, effectively removing the crud. Aged chambers cured using this method recovered and operated successfully. This rather extreme treatment can presumably only be used after removal of the electronics, and it is not clear what the fate of the zapped fragments is.

A gentler method for burning deposits in a reactive atmosphere was presented by Boyarski [30]. In an aged detector with a large noise current due to Malter effect, addition of small amounts of oxygen (~500 ppm), permitted to gradually reduce the current, presumably by "burning" away the organic deposits. This gentler curing procedure, if demonstrated applicable in other devices, has the advantage of not requiring special connections to the wires, and represents perhaps the most promising contribution to this conference.

9. Conclusions

Three decades of research on the aging processes in gas detectors have permitted to gradually improve the radiation tolerance of the devices; this progress is, however, continuously overcome by the commissioning of new machines with harsher radiation levels. The development of more performing but delicate detectors, the use of faster but aggressive gases, the need to cover very large areas brought many unexpected problems with it, amply discussed in this workshop. Systematic investigations have permitted to identify many unsuspected sources of pollution leading to aging, setting constraints on the materials, gases, and components that can be used for the manufacturing and operation of gas detectors. Non-polymerizing gases, such as CF_4, have been successfully used, but appear to be extremely critical with the choice of components and the presence of residual moisture. Promising methods for curing aged detectors have been tried, and could offer an essential additional safety factor if widely applicable. The many contributions discussed at this workshop and collected in the proceedings, whilst not representing the final word on the subject will certainly be an invaluable source of information for future developments on this crucial subject.

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