Summary and Outlook of the International Workshop on Aging Phenomena in Gaseous Detectors (DESY, Hamburg, October 2001)

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***Abstract*—High-energy physics experiments are currently entering a new era that requires the operation of gaseous particle detectors at unprecedented high rates and integrated particle fluxes. Full functionality of such detectors over the lifetime of an experiment in a harsh radiation environment is of prime concern to the involved experimenters. New classes of gaseous detectors such as large-scale straw-type detectors, micropattern gas detectors, and related detector types with their own specific aging effects have evolved since the first workshop on wire chamber aging was held at LBL, Berkeley, in 1986. In light of these developments and as detector aging is a notoriously complex field, the goal of the International Workshop on Aging Phenomena in Gaseous Detectors was to provide a forum for interested experimentalists to review the progress in understanding of aging effects and to exchange recent experiences.**

A brief summary of the main results and experiences reported at the 2001 workshop is presented, with the goal of providing a systematic review of aging effects in state-of-the-art and future gaseous detectors.

***Index Terms*—Electrode etching, materials, matter discharge, plasma chemistry, polymerization.**

I. Introduction

AGING effects in proportional wire chambers, a permanent degradation of operating characteristics under sustained irradiation, has been and remains the main limitation to their use in high-rate experiments [1]. Although the basic phenomenology of the aging process has been described in an impressive variety of experimental data, it is nevertheless difficult to understand any present aging measurement at a microscopic level and/or to extrapolate it to other operating conditions. Many chemical processes are expected to occur simultaneously in the gaseous discharges surrounding the wire. Consequently, a quantitative description of aging effects, which would require as a minimum a detailed analysis of all gas-phase and gas-surface reaction products, is currently not available. There is much experimental information, well summarized in [2]–[4], that suggests that wire chamber lifetime may be extremely sensitive to the nature and purity of the gas mixture, different additives and trace contaminants, materials used in contact with the gas, geometry of electrodes, and configuration of electric field. The "classical aging effects," well known since the advent of wire chambers, lead to the formation of deposits, conductive or insulating, on the electrode surfaces and manifest themselves as a decrease of the gas gain due to the modification of electric field, excessive currents, self-sustained discharges, or sparking. Traditionally, the aging rate has been parameterized as a normalized gas gain loss: $R = -(1/G)(dG/dQ)$(% per C/cm), where G is the initial gas gain and dG is the loss of gas gain after collected charge dQ per unit length [3]. However, the assumption that the aging rate is only a function of the total accumulated charge has not been confirmed for gaseous detectors operated in high-rate environments. In reality, the rate of polymer formation depends upon many microscopic variables such as cross-sections of electron and photon processes and their energy distributions in gas avalanches and molecular dissociation energies, as well as densities of electrons, ions, and free radicals. Consequently, one may expect that the aging rate could also be affected by macroscopic parameters, such as gas gain, ionization density, and radiation intensity, which are directly related to the basic microscopic variables. Several results presented at the 2001 workshop clearly indicate that such dependencies do exist.

Some of the conclusions from the 1986 workshop are still valid in 2001. However, the dramatic increase in charge (up to 1.0 C/cm wire per year), which is expected to be accumulated on sensing electrodes in the new high-rate experiments, poses much more stringent constraints on the radiation hardness of materials and gas mixtures, assembly procedures, and basic rules for construction and operation of gaseous detectors than previously encountered. Only a limited choice of gases have been demonstrated to tolerate such doses. Moreover, recent experience with straws and honeycomb drift tubes revealed that chemical etching processes leading to a dramatic damage of gold-plating on wires could occur in nonpolymerizing CF_4 mixtures at exceedingly high current densities. These new developments since the 1986 workshop raise a question about the adequacy of using CF_4-based mixtures for long-term high-rate applications.

The scientific program of the 2001 workshop addressed specific questions that, as reported by many authors, are of a primary interest: classical aging effects, models and insights from plasma chemistry, materials for detectors and gas systems, lessons learned from detector operation at high radiation intensities, new aging effects, experiences with large systems, and recommendations for future detectors. About 100 detector experts attended the four-day workshop, and ten invited talks, 31 contributed talks, and nine posters were presented in seven sessions [5].

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II. General Characteristics of Aging Processes

A. Classical Aging Effects

The "classical" aging effects are the result of chemical reactions occurring in avalanche plasmas near anodes in wire chambers, leading to formation of deposits on electrode surfaces. During gas avalanches, many molecules break up in collisions with electrons, deexcitation of atoms, and ultraviolet (UV)-photon absorption processes. Whereas most ionization processes require electron energies greater than 10 eV, the breaking of covalent molecular bonds and formation of free radicals requires only 3–4 eV and can lead to a higher concentration of free radicals than that of ions in the gaseous discharges. Consequently, free-radical polymerization is regarded as the dominating mechanism of wire chamber aging. Since free radicals are chemically very active, they either will recombine to form the original molecules or other volatile species or may start to form new cross-linked molecular structures of increasing molecular weight. When the polymerized chain becomes large enough for condensation to occur, it will diffuse to an electrode surface.

It is worthwhile to mention that one has to distinguish between formation of polymers in the gas avalanche near the anode wire and their deposition on electrode (anode or cathode) surfaces. The polymer deposition mechanism can be viewed as a phenomenon that occurs whenever the gaseous species fails to bounce back after a collision with an electrode surface, including a surface layer of molecules previously formed in the gas discharges. Initially, the polymer could be attached to the surface very weakly, unless some additional chemical reactions take place between the polymer atoms and atoms of the wire material. Moreover, many free radicals are expected to have permanent or induced dipole moments, so that electrostatic attraction to a wire can also play a significant role in the polymer deposition process. For the inert gold-plated anode wires, the probability for polymers to stick to the surface is rather small until the creation of the first monolayer of deposits, which may significantly increase further deposition. The influence of surface wire quality on anode aging and a model of polymer film growth is proposed in [6]. The importance of reactions between the electrode material and polymers produced in avalanches for the deposition mechanism can be illustrated by the following examples.

1) Nongold anode wires react with fluorine radicals produced in an avalanche to form resistive metal fluorides. Many studies have demonstrated excellent aging properties, up to 10 C/cm·wire, of CF_4/iC_4H_{10} (80:20) gas avalanches [7]–[9], which also have the ability to etch silicon-based and hydrocarbon deposits on previously aged gold-plated wires [10], [11]. However, extensive deposition was observed on unplated wires irradiated in CF_4/iC_4H_{10} (80:20) [11], [12].
2) Exceedingly large aging rates were observed in pure CF_4 and in $Ar/CF_4/O_2$ (50:40:10) [11]–[13], which are typical etching gases and reluctant to polymerize. This effect was related to the chemical processes at the cathode, where trace fluorocarbon deposits were found, resulting in a loss of gas gain and not in a self-sustained Malter discharge.

Self-sustained discharge (Malter effect) [14], which is due to a thin insulating layer deposited on a conducting cathode by a polymerization mechanism, is one of the most devastating phenomena of all aging effects. The resistivity of the insulating layer defines the maximum rate capability of the detector before the onset of field-emission of electrons from the cathode, which starts if the rate of ionic charge neutralization across the dielectric film is smaller than the rate of ion charge buildup [15], [16]. There exists evidence that certain metal oxide coatings on the cathode and/or simply the cathode material itself (e.g., carbon-loaded polycarbonate foil) may not be conducting enough and could cause Malter-like breakdowns in the presence of large localized ionization densities [3], [16], [17]. Several other factors may facilitate its ignition, such as highly ionizing particles, sparks, sharp points on electrodes causing corona discharges, or thin anode wires [15]. It is easy to ignite Malter currents in a detector operating with hydrocarbon gases at elevated high voltages [18] or forcing chambers to breakdown [19]–[21], and in a detector, that has been previously exposed to TMAE gas [22]. The CRID RICH detector [23] with an excellent three-dimensional single electron reconstruction capability allowed the first imaging of the onset of the Malter effect, which starts from sporadic bursts of single electrons from a localized cathode spot [22]. Such a positive feedback between electron emission at the cathode and anode amplification will lead to high ionization densities at distinct chamber locations. This, in turn, can initiate the production of new reactive species at much larger rates, thus promoting more deposits to form at the same cathode spot to an extent sufficient to establish a classical self-sustained Malter discharge. The most dangerous consequence of this phenomena is that the Malter effect could easily spread over a large area if it goes undetected for a long period of operation, thus causing irreparable damage to the chamber.

Many experiments have demonstrated that the addition of H_2O or alcohols—after the insulating layer at the cathode is already formed—tends to stabilize the detector operation but not to cure the Malter effect [2], [3]. When these additives are removed, usually the chamber suffers from Malter effect again. Recently, it was discovered that the addition of oxygen (0.02–0.05%) or CO_2 (5%) to the damaged chamber, which showed a self-sustained dark current with He/iC_4H_{10} (80:20), could revert or cure a Malter breakdown in the presence of high current density [18]. When the oxygen is removed, the chamber can still operate at a high ionization level (although it will start to age again without additive). It is also worthwhile to mention that the possibility of reanimation of anode wires aged in hydrocarbon gases by means of sputtering was demonstrated in Ar/O_2 (99:1) and Ar/CO_2 (93:7) [24], [25]. These effects support results from plasma chemistry, where it is known that oxygen reacts with hydrocarbon molecules and the end products are volatile CO, CO_2, H_2O, and H_2.

B. Wire Chambers Versus Plasma Chemistry

While the specific reactions responsible for wire chamber aging are extremely complex, some qualitative approach to the aging phenomena in different gases could be obtained from similarities between chemical processes in plasmas of gas avalanches [2], [3], [11], [12] and those that occur in the

better understood low-pressure (<1 Torr) radio-frequency (13.6 MHz) plasmas [26], [27]. Although many parameters (electric field, gas pressure, electron density, power density) are vastly different between the two regimes, the electron energies are not so different. Also, in both cases, the free radicals are most likely the active species involved in polymer formation.

In plasma polymerization, the overall mechanism of "competitive ablation and polymerization" proves to be a basic principle that describes reactions occurring in a plasma polymerization system. Considerable fragmentation of the gas molecules or rearrangement of atoms occurs in the plasma. The extent of the process and the dominating mechanism vary with the types of gases and the discharge conditions. The most important concept here is that both polymer-forming species and species that cause ablation (physical or chemical etching) of materials are created in the plasma of the original gas. The significance of this concept is fully established in perfluorocarbon plasmas, which represent the most extreme case of ablation competing with polymer formation. Actually, CF_4-based gases are used for both etching and deposition processes, the distinction being made by the gas and its concentration with which CF_4 is mixed. In general, the addition of oxygenated species shifts the chemistry of CF_4 plasmas toward etching, while the addition of hydrogenated species shifts the chemistry toward polymerization [26], [28]. In the former case, the dissociative products of CF_4 and O_2 are the most desirable active species for the etching processes in plasmas [29]–[32]. For the latter case, in the absence of hydrogen, products of the CF_4 discharge could act as an effective etching gas especially for Si-based deposits, which react with fluorine to form volatile SiF_4. The addition of hydrogen atoms or molecules to CF_4 scavenges F atoms by the formation of more stable HF and produces a mixture with carbon-enriched (CF_3, CF_2, CF) residues. As the ratio of F/C decreases, perfluorocarbons polymerizes readily, i.e., the balance shifts from ablation to polymerization [28], [33]–[35]. For instance, very fast polymer formation was observed in C_6F_6 and $C_2H_2F_4$ plasmas [28]. On the other hand, hydrofluoric acid can chemically attack HF-soluble materials existing in the system. Under certain conditions, Si-etching can be accompanied by the polymerization of the etching gas CF_4 on the Si-substrate [29], [36], [37].

Correspondingly, recent results from wire chamber operation also show that both polymerization and etching phenomena can occur in CF_4-based gases (see Section V). Particularly, using the same experimental setup, a lack of apparant aging has been observed in CF_4/iC_4H_{10} (80:20) and CF_4/iC_4H_{10} (50:50) mixtures, whereas heavy carbonaceous deposits were observed on the gold-plated wires in CF_4/iC_4H_{10} (95:5), CF_4/iC_4H_{10} (20:80) and CF_4/C_2H_4 (95:5) gases [11].

Two other examples, where conclusions from plasma chemistry are qualitatively applicable to wire chambers, are as follows.

1) In plasma chemistry, most organic compounds with oxygen-containing groups are generally reluctant to form polymers. For example, water in plasmas could act as an efficient modifier of the polymer chain-growth mechanism by reacting with polymer precursors and forming volatile species (up to 50% H_2O was added to the plasma feed gas) [26]. In wire chambers, the addition of water (a few hundred to a few thousand ppm of H_2O) has been found to effectively suppress polymerization effects [38], [39], to prevent Malter breakdown [18], [40], [41], or even to restore the original operation in aged counters [42], [43]. There is more than one mechanism by which H_2O/alcohols can help in wire chambers [15], [44]. Because of the large dipole moment, these molecules will tend to concentrate near the electrode surfaces, where polymerization takes place. Water has an additional advantage in wire chambers since it increases the conductivity of the partially damaged electrodes—a property that can have adverse effects in a microstrip gas counter (MSGC) [4].
2) In plasmas, the characteristic polymerization rate of Si is higher than for C [28]. From the viewpoint of wire aging, even minor traces of Si-pollutants in the gas have a much higher tendency to create deposits than similar amounts of hydrocarbon molecules.

It has to be stated, though, that the absence of corresponding systematic studies in plasma chemistry with parameters similar to wire chambers (atmospheric pressure, power densities, gas mixtures) do not allow any quantitative comparisons between the plasma chemistry and wire chamber processes.

III. Experience From Laboratory R & D Experiments

Over the last few decades an impressive variety of experimental data has been accumulated from laboratory tests and detectors installed at high-energy-physics facilities. However, there are many contradictory experiences obtained in seemingly identical conditions, which means that we do not always control all parameters that influence aging effects. It is now well established that—even if a low aging rate can be obtained in the laboratory with very pure gas and otherwise clean conditions—large-area detectors using the same mixture can fail due to severe aging after a relatively small beam exposure. However, experience from the laboratory, where operating conditions are much better controlled, can be used to understand some general principles and might help to implement these results successfully in large chambers.

There are many experiments that clearly indicate premature aging in Ar/CH_4 mixtures exposed to intense radiation [38], [45]–[49]. Moreover, the aging rate in Ar/CH_4 (90:10) was found to be mainly a function of current density, i.e., the product of irradiation rate and gas gain, independently from electrode material and purity of methane [50], [51]. This observation indicates that CH_4 itself polymerizes in the avalanche plasma due to the hydrogen deficiency of radicals and their ability to make bonds with hydrocarbon molecules [3], [26], and similarly for all hydrocarbon gases. Under certain conditions the aging rate in Ar/C_2H_6 with alcohol can be strongly reduced [52], [53]. However, noble gas/hydrocarbon mixtures are not trustworthy for long-term high-rate experiments. To suppress polymerization of hydrocarbons, oxygen-containing molecules can be added to the mixture. For $Ar/CH_4/CO_2$, measurements have shown that sensitivity to aging decreases with decreasing CH_4 and increasing CO_2 content [24].

Dimethylether (DME) appeared in the 1986 workshop as a good quencher and a reasonably good radiation-hard gas for wire chambers operated at high intensities. The aging rate in

DME tends to be lower than the polymerization rate of ordinary hydrocarbons [2], and several groups reported the absence of aging effects in wire chambers up to large values of accumulated charge [6], [50], [51], [54]. However, the aging effects in DME appear to be highly sensitive to traces of pollutants at the ppb level, which are difficult to keep under control in large detectors. There is also evidence of high chemical reactivity of DME, which requires a careful material selection for detector assembly and gas system components [55].

Attempts were made to replace organic quenchers with aging resistant ones, like CO_2. The Ar(Xe)/CO_2 gases could be in principle absolutely radiation resistant under clean conditions; up to now, there is no well-established mechanism that could lead to the formation of anode deposits in these mixtures. Stable operation up to $\sim$1 (C/cm wire) was reported for Ar/CO_2 [2], [3], [56], [57] and up to $\sim$5 (C/cm wire) for Xe/CO_2 mixtures [58]. However, a gradual decomposition of CO_2 can also occur, and the resulting pure carbon can be deposited specifically at the cathode [24], [59]. Sometimes this carbon layer does not affect the performance of drift tubes [24]. Recent systematical aging tests were performed for the ATLAS muon aluminum drift tubes. To guarantee reproducibility of the results and to study aging behavior under different operating conditions, 26 tubes with Ar/CO_2 (93 : 7)+600 ppm H_2O mixture have been irradiated with an Am^{241} source up to an accumulated charge of ~ 1.3 (C/cm wire), and 47 tubes with Ar/CO_2 (90:10) gas were exposed to a Cs^{137} source up to $\sim$0.6 (C/cm wire) [25], [60], [61]. All tubes were 100% efficient at the end of these aging runs. However, these measurements represented an average performance of the wire over a length of 3 m and were not sensitive to local inefficiencies. It should be mentioned that the aging performance of Ar/CO_2 is sensitive to traces of impurities. Si-based pollutants are one of the sources of aging in Ar/CO_2, probably due to the production of nonvolatile SiO_2 [57], [60], [62], [63]. Several other experiments also observed aging effects in Ar/CO_2; however, the reasons for the gain reduction were not identified [6], [25], [64], [65].

The identification of radicals and fragments formed in the electron avalanches is a means to understand and eventually overcome the problems related to the aging of gaseous detectors [3], [66]–[68]. A recent investigation of avalanche products has shown that 17 new compounds were identified in the effluent gas stream from an irradiated proportional counter with Ar/C_2H_4 (50 : 50) mixture [69]. Some of the observed species (aliphatic hydrocarbons) contained double or triple bonds, which, similar to plasma polymerization, can be easily "opened" in the discharges and polymerize very aggressively. The systematic analysis of light emission spectra in proportional counters may also provide useful information about basic physics processes in electron avalanches [70], [71].

IV. Experience With "Standard Radiation Level" Detectors

A. Classical Wire Chambers

For a long time, classical wire chambers of various designs with many thousands of wires have been used for large-area tracking detectors in the "standard radiation levels" experiments, i.e., with total collected charges $<$50 mC/cm for the whole period or running. Basic rules for the construction and operation of these detectors are known. Moreover, many of the large wire chambers were built and demonstrated to work [2], [3], [72]. Nevertheless, recent experience with large systems still shows the appearance of aging effects associated mainly with hydrocarbon polymerization and with presence of pollutants in the gas system.

A time expansion chamber filled with $CO_2/i C_4H_{10}$ (80:20) mixture successfully operated as a vertex detector of the L3 experiment at the LEP collider at CERN. After an accumulated charge of 10^{-4} (C/cm wire) collected during 11 years of running, there was no sign of aging [73]. Classical aging effects (Malter effect or/and sense wire deposits) have been observed in the H1 Central Jet Chamber operated with Ar/C_2H_6 $(50{:}50) + 0.1\%$ H_2O and in the ZEUS Central Tracking Detector filled with Ar/CO_2/C_2H_6 $(83{:}12{:}5) + 0.5\%$ C_2H_5OH at the HERA *ep*-collider. In the former case, the replacement of 0.1% H_2O with 0.8% of ethanol cured the Malter effect and stabilized the detector operation [74], while for the latter case, the aging problem was alleviated by the addition of H_2O [75]. In both systems, there was no clear indication that polymerization is "fed" by the presence of impurities in the gas system, indicating that hydrocarbons are the likely source of chamber aging.

An abundance of literature exists describing the dramatic effect of certain gaseous constituents, which may be either due to the contaminants initially present in the gas system or result from outgassing of construction materials upon the aging rate of wire chambers. Several examples of large systems, where the presence of pollutants increased the aging rate many times, have been reported in [76] and [77]. While laboratory tests with a prototype chamber indicated negligible aging rates ($R < 10$ %/C/cm), a much larger aging rate (1000%/C/cm) was observed in the large central tracking chamber of the Collider Detector at Fermilab (CDF) experiment operated with Ar/C_2H_6 (50 : 50) + 0.1% alcohol. The analysis of the aged sense wires showed the presence of C, O, and Si elements. After cleaning the gas system components and making changes to reduce aerosols emanating from an alcohol bubbler, the aging rate was greatly reduced, allowing the detector to operate without dramatic loss in performance. The presence of Si is to be pointed out here since silicon has been systematically detected in analysis of many wire deposits, although in many cases the source of Si-pollutant has not been clearly identified. The Si-compounds are found in many lubricants, adhesives and rubber, encapsulation compounds, silicon-based grease, various oils, G-10, RTV, O-rings, fine dust, gas impurities, polluted gas cylinders, diffusion pumps, standard flow regulators, and molecular sieves, and their presence may not necessarily be noted in the manufacturer's documentation [2], [3], [51]. Because of a high specific polymerization rate, Si molecules should be avoided in the detector system at all cost. Consequently, if there is a question of whether or not some device may incorporate silicon compounds, the device should be subjected to additional aging test. Another example is the D0 WAMUS muon drift chambers, which suffered fast anode aging when operated with an Ar/CF_4/CO_2 (90:6:4) mixture. Here, the source of the contaminant was outgassing of glass-steel polyester epoxy resin used in the construction. A cold-trap

added to the gas recirculating system reduced the aging rate by a factor of ten, while the extreme method of quickly heating the wires just below their melting point ("zapping") succeeded in blowing hardened sheaths of outgassing products off of the wires, thus completely cleaning the aged gold wires in-situ [77].

The chosen examples underline the importance of having control over all detector parameters, but often it is quite difficult to draw final conclusions since nominally identical detectors connected to the same gas circuit may perform very differently [74], [77]. In some cases, it might be possible to eliminate harmful impurities by installing appropriate filters or cold traps in the gas system [76], [77]. Many helpful guidelines for construction and operation of classical wire chambers at "low" rates, which have been compiled over the past 40 years, are summarized in [78] as follows.

1) Create a moderately clean environment during detector construction and clean the gas system components prior to start of operation.
2) Avoid the presence of "bad" molecules in contact with active gas (Si, halogens, sulphur, plasticizers, outgassing) [2], [3].
3) A huge variety of gases can be successfully used (noble gases, hydrocarbons, CF_4, $C_2H_2F_4$, CO_2, DME, H_2O, alcohols, "magic gas," etc.
4) Hydrocarbons are the most likely source of aging (effect is more pronounced in presence of contamination or under discharges, sparks, or Malter effect). Even with the addition of water/alcohol, the improvements are limited and it is problematic to consider them for high-rate applications.
5) If aging effects are observed despite taking all of the above precautions, add suitable additives and/or identify the source of pollution and clean the gas system.

B. Resistive Plate Chambers

In the 1990s, resistive plate chambers (RPCs) were proposed as an economical and proven technology ideally suited for large-area detection systems. For example, both the Belle and BaBar experiments have instrumented their flux returns with RPCs operated in streamer mode. However, high chamber currents started to show up in Belle's RPCs almost immediately upon installation. This problem was related to the presence of high levels of water ($\sim$2000 ppm) in the gas, which permeated through the walls of the polyethylene tubing. Operating the RPCs with $Ar/C_4H_{10}/C_2H_2F_4$ (30:8:62) plus water in streamer mode led to the formation of hydrofluoric acid that etched the electrodes made from ordinary glass. This resulted in the creation of emission points, triggering chamber currents. The problem was finally solved by replacing the plastic tubes with copper ones ($H_2O < 10$ ppm) [79].

In the BaBar RPCs, the electrodes are made of Bakelite coated with linseed oil. After an initial period of successful operation with an $Ar/C_4H_{10}/C_2H_2F_4$ mixture, the RPCs started to show a permanent reduction in efficiency and an increase in dark current. The main conclusion of the subsequent extensive R&D studies related the BaBar RPC problem to the lack of polymerization of the linseed oil and formation of oil droplets under the influence of high temperature and high currents [80]. Further efficiency deterioration mechanisms that may play an important role in BaBar's RPCs have been proposed by Va'vra [15]. He suggested that this problem could be due to an electrochemical change of resistivity of fresh linseed oil, modulated by the presence of water in the RPCs. A positive example is the L3 RPC at LEP, which operated at a very low particle flux over eight years without significant loss of efficiency [81]. In contrary to RPCs used in streamer mode at the Belle, BaBar, and L3 experiments, the future Large Hadron Collider (LHC) experiments will operate RPCs in proportional mode, which is desirable in terms of total accumulated charge per particle. However, much higher particle fluxes at the LHC require more systematic R&D studies of the RPC technology, since many processes could degrade their performance under high-rate conditions. Recent results of aging tests for ATLAS, CMS, and LHC-B RPCs indicate that under the right circumstances, an RPC can withstand large integrated doses [82]–[84].

It should be stressed, though, that the problems with Belle and BaBar RPCs are not "classical aging effects" but rather unpredictable surface effects, related to the specific choices of materials and operating conditions.

C. Gaseous Photodetectors

Gaseous photon detectors used in high-energy-physics experiments must ensure an efficient way of converting UV photons to electrons with a subsequent detection of single photoelectrons [85], [86]. For gaseous converters, systematical aging studies have been carried out with TMAE and TEA vapors [87]–[89], which are added to the carrier gas to provide photoionization capability [90]. TMAE is the best material in terms of quantum efficiency; however, the main obstacle of using TMAE at high rates is an exceedingly rapid gas gain loss due to deposits on the anode wires [86], [91]–[94]. Several studies have indicated that anode wire deposits can be removed by heating the wires with elevated currents [89], [95]; unfortunately, this recovery is followed by a quick drop in gain [96], [97]. In addition, all photosensitive materials, and, most probably, their various aging products, are good insulators and may excite Malter self-sustained currents when deposited on the cathode [86]. Systematic studies with TMAE and TEA also allowed establishment of basic dependencies between the aging behavior and dissociation energy or wire diameter [91]:

1) aging rate for TMAE is larger than for TEA (TMAE molecule is more fragile than TEA);
2) aging rate for TMAE and TEA is inversely proportional to the anode wire diameter;

At low rates, the possibility to use gaseous photon detectors on a very large scale over the long term with hydrocarbon/TMAE gases has been demonstrated for large 4π devices (e.g., SLD CRID and DELPHI RICH) [86]. It is worthwhile to mention that the high reactivity of TMAE with oxygen and other substances necessitates a very high degree of cleanliness and leak-tightness for gas systems in these detectors.

In recent years, there has been considerable work in the field of photon imaging detectors by combining solid photocathodes (CsI) and wire chambers or gaseous electron multipliers. However, several aging tests also revealed degradation of CsI photocathode quantum efficiency for very high-rate environments. A collection of existing aging data for these can be found in [86], [91], [92], and [98]–[101].

V. Aging Experience With High-Rate Detectors of the LHC Era

The most recent developments in high-energy physics require a dramatic increase of the radiation intensity encountered by gaseous detectors: from mC/cm/wire for the "standard radiation level" detectors up to C/cm/wire for the new high-rate experiments of the LHC era (HERA-B, LHC). Among the most critical items that affect the lifetime of gaseous detectors (apart from the gas mixtures) are the materials in contact with gas, assembly procedures, gas mixing and distribution systems, and tubing. In Section V-A we discuss the outgassing properties of several materials and general rules for assembly of high-rate gaseous detectors and gas systems, while Section V-B to D summarize the recent experience with aging problems in gaseous detectors operated at extremely large particle fluxes.

A. Choice of Materials for Detectors and Gas Systems

The increasingly challenging requirements for building and testing the next generation of large-area gaseous detectors have demanded a concerted effort toward finding adequate materials for detectors and associated gas systems. Many nonmetallic "good materials" successfully used in the standard radiation-level detectors might nevertheless outgas at a small level, thus causing fast aging under high-rate conditions. The lifetime studies of MSGC in high-intensity environments, which also had the greatest impact on the understanding of aging phenomena in all types of gaseous detectors, demonstrate that the amount of pollutants in the gas system plays a major role in determining the aging properties of the detector [4]. Consequently, the outgassing from materials, epoxies, joints, tubing, etc., has to be carefully controlled. For obvious reasons, the use of glues, plastics, and many organic materials is unavoidable in particle detectors. It is therefore very important to choose materials suitable for the practical mechanical and electrical assembly of a gaseous detectors, in terms of their possible outgassing effects and radiation robustness.

It is suggested to start by searching for low-outgassing materials in a NASA database, which was originally developed for selecting spacecraft materials [51].[1] It contains more than 1600 entries for adhesives, 500 entries for rubbers and elastomers, and 800 entries for potting materials. This list can help to preselect assembly materials before doing tests matching the specific requirements of each detector.

A large amount of outgassing data for epoxy compounds, adhesive tapes, leak sealers, rigid materials, O-rings, and plastic pipes have been accumulated in the framework of the RD-10 project at CERN, which afterwards was merged with the more specific research on MSGC within the RD-28 project. In the RD-10 tests, an outgassing box, placed upstream of the strongly irradiated wire counter, was used to introduce samples of materials into the gas stream, thus allowing a systematic study of outgassing effects on the chamber lifetime. Furthermore, the gas flowing from the chamber was analyzed with a gas chromatograph (GC) and mass spectrometer (MS) or electron capture device. While for some materials only outgassing properties were verified and materials releasing detectable pollutants were rejected, for other radiation-hard materials, full evidence of suitability was obtained in long-term aging tests of a validated clean detector. The long list of candidates recommended for use in the construction of gaseous detectors can be found in [2]–[4], and [102]–[105] and was summarized at the 2001 workshop [51]. The effect of outgassing from materials on the lifetime of gaseous detector can be illustrated by several examples: Araldit AW103 epoxy mixed with HY991 hardener did not induce any detectable gas pollutants in the GC/MS and was also validated by irradiating the wire chamber. It is presently used as a glue for the construction of ATLAS straws [105] and triple gas electron multiplier (GEM) stations of the COMPASS experiment [106]. The GC/MS analysis of another popular epoxy, Araldit106 and HV953 U, extensively used in the assembly of older multiwire proportional chambers, revealed traces of heavy hydrocarbon molecules in the effluent gas stream, which could be partially responsible for the observation of aging reported in [17] and [60]. In fact, this glue has shown the largest outgassing rate among all tested glues in [105]. Interestingly, outgassing can also be due to an incorrect ratio of hardener to resin or even insufficient curing time; both factors may largely increase the gas contamination [51], [107].

Gas tubes used for the supply of the active gas have always been the object of primary attention when analyzing aging effects in wire chambers. Electropolished stainless steel and hydrogen-fired copper gas pipes are the best choices for gaseous detectors operated in high-rate environments, since they are free of outgassing and ensure zero gas permeability. However, due to their high price and concerns for the material budget in the active area of the detector, many experiments often use cheaper plastic tubes, although these are susceptible to outgassing, have high gas permeability, and can consequently cause severe aging. Particularly, polyvinyl chloride (PVC), Teflon, and neoprene rubber tubes contain halogen atoms in molecular chains, which are known to increase drastically the aging rate [2], [3]. Polyethylene tube outgasses water, large alcanes, and substituted aromatics [67]. One of the classical examples, cited by many authors, shows that the introduction of PVC pipe can initiate a gain reduction, which continues with the same rate even after the PVC tube is replaced with the original stainless-steel tubes [20]. This indicates a potentially very serious problem: one can cause permanent damage to a detector by the wrong choice of material even for a limited period of time. Therefore, one should use as much steel as possible for gas supply lines, especially in parts exposed to high radiation doses.

Up to now, there has been no strong objection to the use of nylon (polyamide, RILSAN) tubes if they are not too long. However, plastic pipes usually introduce water to the gas due to the natural outgassing and/or due to the diffusion of air humidity through the walls: as much as $\sim$1700 ppm of water can be added

[1]http://epims.gsfc.nasa.gov/og/index.cgi.

to the gas by placing 20 m of nylon pipe at the chamber inlet [51]. Particularly, nylon tubes were used to introduce water indirectly to the chamber for curing Malter breakdown [40]. However, the presence of water can cause bad surface chemistry, as described above, and is therefore extremely dangerous for certain RPC and MSGC detectors.

The general recommendations concerning the choice of assembly materials and rules for the mechanical construction of high-rate detectors, which include adequate assembly procedures, personnel training, quality checks, and final testing as part of fighting against the aging, have been reported at the workshop in [51] and [78]. There are clearly many bad and many usable materials. However, a specific material is either adequate or not for a particular detector type and operating conditions—one has to do tests matching the specific requirements of the experiment. Finally, no spontaneously chosen materials should be installed in the detector or gas system in the last minute before the start of real operation.

B. Micropattern Gas Detectors

Future high-luminosity experiments have prompted a series of inventions of new high-rate gaseous detectors: MSGC, MICROMEGAS, GEM, and many others [108], [109]. The systematic research of the physical parameters used to manufacture and operate MSGCs, such as substrate and assembly materials, metal for the strips, and type and purity of the gas mixtures, play a dominant role in determining their long-term stability [4], [110], [111]. Despite the promising performance of MSGCs (high rate capability, good space accuracy, and excellent multitrack resolution), there are several major processes, particularly at high rates, leading to operating instabilities: chargeup of substrates, destructive microdischarges, and surface deposition of polymers [4].

The influence of glass conductivity has been verified for MSGCs: the use of borosilicate glass as a substrate results in rate-dependent modification of gain due to the radiation-induced variation of surface resistivity. Use of electron-conducting or diamond-coated glass solves the problems of short- and long-term instabilities for detectors made on insulating support [4]. The problem of microdischarges, induced by heavily ionizing particles and destroying the electrode structure, turned out to be a major limitation to all single-stage micropattern detectors in hadronic beams [112], [113]. The nature and resistivity of the strip material affect the development of sparks [114]. Aluminum electrodes are more robust against gas discharges than gold. However, the use of Al electrodes led to the appearance of bubbles or craters on the cathode strips even at modest collected charges, while no aging effects were observed with strips made from gold [115].

Microstrip chambers have been operated with a large variety of gases; to prevent fast aging at high rates, convincing evidence suggests again to avoid hydrocarbons in the gas [116], [117]. Under optimal laboratory conditions, the absence of any degradation of MSGC performance with Ar/DME has been demonstrated by many groups up to large accumulated charges [4], [111], [117]–[120]. However, MSGC-GEM detectors operated with Ar/DME show fast aging under X-rays, if the size of the irradiated area is large enough, while identical chambers with Ar/CO_2 showed no aging [115], [121]. Long-term survival without degradation has been also observed for triple-GEM and MICROMEGAS-GEM detectors operated with Ar/CO_2 [122], [123]. Unfortunately, Ar/CO_2 mixtures have worse quenching properties and are more prone to discharges than Ar/DME. Protection against sparking can be significantly improved by adding a small amount ($\sim$0.3% of H_2O to the MSGC. However, contrary to wire chambers, such an addition of water led in one case to massive coating on the anode strips in both Ar/DME and Ar/CO_2 mixtures [4], [115]. These observations underline the importance of careful selection of materials and gas mixtures for high-rate applications and of treating micropattern detectors as delicate devices during production and running phases.

C. Choice of Gas Mixtures

Future high-energy and high luminosity experiments pose a new challenge for gas mixtures, raising the requirement for their radiation hardness up to $\sim$1 (C/cm wire) per year. Under these constraints, only a limited choice of gases is available, and from the conventional mixtures, only $Ar(Xe)/CO_2$ is demonstrated to tolerate such doses. Unfortunately, these mixtures are quite transparent for photons and have a low electron drift velocity, which limits their possible application for high-rate detectors and large drift distances.

About 20 years ago, CF_4 was proposed as the most attractive candidate for high-rate environments [124]–[126]. This is primarily due to the high-drift velocity, high primary ionization, low electron diffusion, and resistance to aging [13], [127], [128]. Within the broad spectrum of gas mixtures, there is no gas mixture without CF_4 that is able to tolerate doses $\sim$10 (C/cm wire). It is believed that when CF_4 dissociates in the gaseous discharges into highly reactive CF_x and F radicals, the atomic fluorine is very effective in suppressing polymerization effects. However, $Ar(Xe)/CF_4$ mixtures have rather poor energy and spatial resolution due to the dissociative electron attachment processes in CF_4 [129]–[131]. Moreover, the CF_4 molecule has small quenching cross-sections of metastable Ar-states [132], and excited CF_4 molecules emit photons from the far UV to the visible [134]. This results in an intolerable level of afterpulsing in Ar/CF_4 gases even at moderate gas gains. The advantage of the enhanced drift velocity of CF_4 for high-rate applications has been realized by the addition of one of the common quenchers (e.g., CO_2, CH_4) to CF_4 or to Ar/CF_4. This can also "cool" electrons to the extent that attachment does not occur.

D. Lessons Learned From Detector Operation at High Ionization Densities

Accelerated aging tests, often carried out with radioactive sources or X-rays to emulate the long-term lifetime properties of the detector, can be extrapolated to the real experimental conditions directly only if the aging rate depends on the total collected charge and not upon the current density, particle rate, or gas gain at which the dose was accumulated. In reality, many laboratory studies have demonstrated severe gain losses at lower charge accumulation rates, other conditions being held constant [4], [7], [20], [42], [48], [50]. The lower polymerization rate for higher current densities is attributed to the onset of space-charge effects, which reduce the electron energies in the avalanche, thus decreasing the density of ions and radicals in the avalanche plasma.

The new generation of high-rate detectors of the LHC era has not only to cope with high dose rates but also to survive in a hostile presence of heavily ionizing particles with an average energy deposition 10–1000 times larger than for minimal ionizing particles. An exposure of large-scale gaseous detectors over the full area in such a harsh radiation environment at high ionization densities (>100 nA/cm) can result in greatly enhanced polymer formation: an abundance of aggresive radicals will diffuse for rather long times ($\sim$ hours) within the irradiated chamber and will react with other avalanche-produced polymer fragments. According to this naive picture, this mechanism could significantly accelerate polymerization in large systems, whereas in small-scale laboratory tests, the aging rate typically decreases with increasing gas flow [3], [7], [8], [25]. Furthermore, polymer deposition in wire chambers likely starts from localized spots and then can spread over the entire irradiated region. Since in large, mass-produced systems an extremely high quality for electrode surfaces and cleanliness of the gas systems is hard to reach, any imperfections—in the presence of high currents—could easily trigger sparks, discharges, or Malter currents, which will in turn dramatically increase the polymerization rate.

Recent systematic research clearly demonstrates that the initial stage of radiation tests usually performed in the laboratory may not offer the full information needed to estimate the lifetime of the real detector. Strong dependence of aging performance upon the size of the irradiated area, current density, high voltage (gas gain), irradiation rate, particle type, and energy have been observed in high-rate environments.

Severe anode and cathode aging effects were found in prototype honeycomb drift tubes operated with CF_4/CH_4 (80:20) and $Ar/CF_4/CH_4$ (74:20:6) mixtures in the high-rate HERA-B environment (secondaries from interactions of 920-GeV proton with target nucleus) after a few mC/cm of accumulated charge [16], [17], [134]–[136]. This effect was surprising, since chambers had previously been proven to be immune to very large X-ray doses up to 5 C/cm. An extensive R&D program, carried out at ten different radiation facilities to resemble HERA-B conditions, revealed that X-rays or electrons were not able to trigger Malter currents, while in the large-area modules, irradiated with hadrons above a certain energy, the Malter effect appeared very rapidly. The aging effects in these honeycomb drift tubes were traced to a combination of several problems. A solution that uses gold-coated cathode foils and a $Ar/CF_4/CO_2$ (65:30:5) mixture was found to survive in a high-rate hadronic environment up to $\sim$1 (C/cm wire) [17].

The aging performance of the HERA-B muon proportional chambers has been studied with $Ar/CF_4/CH_4$, CF_4/CH_4, and $Ar/CF_4/CO_2$ mixtures in a variety of conditions [137]–[140]. The aging rate in $Ar/CF_4/CH_4$ was found to be more than two orders of magnitude higher in hadronic beams than in the laboratory studies with radioactive sources. In addition, strong dependences of the aging properties on high voltage and progressive deterioration of the gas gain in the direction of the serial gas flow have been observed for large-scale prototypes irradiated with $Ar/CF_4/CH_4$ (67 : 30 : 3) in the harsh HERA-B environment. Aging effects increasing in the direction of the serial gas flow (even outside the irradiation zone) also have been reported for a $Ar/CO_2/C_2H_2F_4$ mixture [141]. A strong dependence of the aging properties on high voltage, irradiation rate, length of irradiation, and gas flow rate also has been observed in the ATLAS muon drift tubes operated with $Ar/CH_4/N_2/CO_2$ (94 : 3 : 2 : 1) [24], [25], [60], [61]. Here, the systematic R&D studies have shown a nearly exponential dependence of chamber lifetime on high voltage and on the counting rate within the experimentally investigated parameter range. Unfortunately, the high voltage is not the physical quantity directly responsible for aging in wire chambers. Therefore, these aging effects could be classified as depending on the gas gain and/or current density, which are related to the density of ions and radicals in the avalanche plasma.

Dependence of polymer formation on the energy input is well established in plasma polymerization. Nearly all organic compounds, regardless of their chemical nature, can be polymerized under certain conditions. The structure of plasma polymers formed from the same monomer is highly dependent on the actual conditions of polymerization: the energy input level, the size (cross-sectional area) of a tube, and even the position within the reactor [26]. The experimental dependence of wire chamber lifetime on ionization density, gas gain, and irradiation rate, which are also related to the total dissipated energy in the detector from ionizing particles, indicates that the aging behavior cannot be solely explained on the basis of the molecule ratios in the mixture (gas composition) without taking into account the actual operating conditions. These results illustrate the need for studying the aging performance of a detector under conditions as close as possible to the real environment.

The dependence of the detector lifetime on the size of the irradiated area, in particular, and the increase of the aging rate in the direction of the serial gas flow means that aging should be viewed as a nonlocal and intensity-dependent phenomenon. These observations seem to be the most critical when trying to extrapolate the aging behavior from laboratory tests to large-scale detectors. Some of the long-lived aggressive radicals may diffuse in the direction of the gas flow and react with other avalanche-generated contaminants, thus enhancing aging effects with increasing usage of the gas. Here it is important to note that due to the increased aging in the direction of the gas flow, it is worthwhile to avoid gas distribution systems that supply many chambers by a serial flow.

As reported above, polymer deposition can occur in CF_4/CH_4 mixtures, as suggested by plasma chemistry. Similarly, the aging properties of $Ar(Xe)/CF_4/CO_2$ gases, which by analogy with plasma experiments should have excellent etching properties, have been widely investigated over the last few years. Using $Ar/CF_4/CO_2$ mixtures under optimal operating conditions, no observable drop in gain due to polymerization has been found for the HERA-B honeycomb drift tubes up to 1.5 C/cm [17], HERA-B aluminum proportional chambers up to 0.7 C/cm [137], CMS cathode strip chambers up to 0.4 C/cm [142], 13 C/cm [63], LHCb multiwire proportional chambers up to 0.25 C/cm [143], COMPASS straw tubes up to 1.1 C/cm [144], and HERMES drift tubes up to 9 C/cm [145]. Moreover, honeycomb drift tubes initially aged with $Ar/CF_4/CH_4$ were afterwards successfully recovered in $Ar/CF_4/CO_2$ [17]. However, an analysis of the cathode surfaces at the end of operation with $Ar/CF_4/CO_2$ revealed in some cases the presence of fluorine-based deposits on the cathodes, which fortunately did not result in self-sustained currents [63], [137], [142].

Since dissociative products of CF_4 react violently with many materials and the resultant polymer films at cathodes could provoke aging effects, one should seriously consider using materials in high-rate detectors that are very robust to CF_4. Gold-plated electrodes [17] or straw cathode materials [146] fulfill this requirement.

A further advantage of CF_4-based mixtures is additional resistance against Si-polymerization. This suggestion is based on experiences from plasma polymerization, where discharges of CF_4/H_2 are successfully used for SiO_2 etching, while CF_4/O_2 plasmas selectively etches Si [29]. Extensive studies performed for the ATLAS straws partially confirm this hypothesis: Si-deposits have not been observed in irradiation area for large current densities (>1 μA/cm). On the other hand, SiO/SiO_2 deposits were found at the edges and even outside of the irradiated area. The resulting balance between Si polymerization and CF_4 etching processes was found to be very sensitive to the Si-source intensity and ionization density [146].

In the most recent investigations at extremely high current densities ($\sim$1–5 μA/cm) in $Ar(Xe)/CF_4/CO_2$ mixtures, a new aging phenomenon has appeared—the damage of the gold-plating of wires in straws and honeycomb drift tubes. Several years of intensive research at CERN with straw tubes under different conditions and for different types of wires indicate that the main components responsible for gold wire damage in $Xe/CF_4/CO_2$ (70:20:10) are harmful radicals, products of CF_4 disintegration in connection with H_2O. (It was suggested that HF acid could be responsible for destruction of gold-plating and formation of WO deposits.) No wire damage effects have been observed for water concentrations below 0.1% up to 20 C/cm [146]. Dedicated studies with straw tubes performed at PNPI with $Xe/CF_4/CO_2$ (70:20:10) and $Ar/CF_4/CO_2$ (60:30:10) mixtures demonstrated that under high dose rates, the gold-plating of the wire was cracked, the wire diameter increased and a large amount of oxygen was observed on the tungsten in gold cracks [147]–[149]. Similar effects have been observed for wires irradiated in a $Ar/CO_2/C_2H_2F_4$ mixture [141]. The authors propose a model to explain the results—an anode wire "swelling" mechanism, where the forces causing the damage to the wire surface develop under the gold layer of the wire [148]. Fig. 1 shows examples of a variety of wires with damaged gold-plating from [146], [147]. Contrary to the experience with straws, in one test with honeycomb drift tubes irradiated with $Ar/CF_4/CO_2$ (65 : 30 : 5), the destruction of gold coating and even the rupture of anode wires have been observed only for water concentrations below 50 ppm, while for $H_2O > 400$ ppm, gold wire damage effects were avoided [150], [151]. Further study remains to fully understand the exact mechanism of gold wire damage during operation at high ionization densities. Although no F-based deposits were observed on the anode wires in any of the tests, the chemically reactive dissociative products of CF_4 most probably initiate the destruction processes of gold-plating.

Studies of straw proportional tubes with $Xe/CF_4/CO_2$ mixture revealed another phenomenon that might degrade detector performance in high-rate experiments. The gas composition was found to be modified in the avalanche plasma of a strongly irradiated straw, presumably due to the production of some long-lived and highly electronegative species [152].

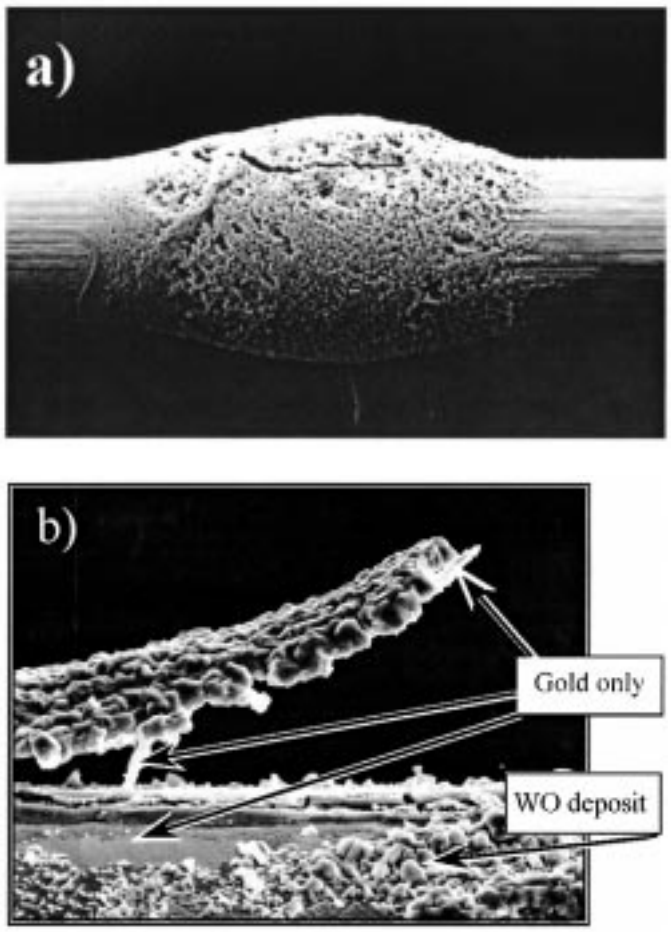

Fig. 1. Various manifestations of damage to the gold-plating of wires: (a) amorphous WO deposits [146]; (b) long piece of gold peeled away from the wire surface [147].

These electronegative radicals could be also responsible for the so-called transient aging effect observed at high rates in $Xe/CF_4/CO_2$ [153], $Ar/CF_4/CO_2$ [150] and $Ar/CF_4/CH_4$ [137]. A transient aging effect is a temporary gain reduction, which can be restored by an appropriate increase of the gas flow. The very high aggressiveness of dissociative products of CF_4 and the dynamic modification of the gas composition requires more detailed studies to evaluate the possible consequence of these effects on the long-term performance and stability of large-area gaseous detectors. In view of the aging results described here, one can see that the presence of large amounts of CF_4 in the mixture does not necessarily ensure good aging properties automatically.

The challenge to avoid aging in the new generation of high-rate experiments not only requires a very careful choice of all detector materials but also forces the gas systems to be of previously unnecessary quality and cleanliness. However, a real system will always contain some degree of imperfection and pollution—despite all precautions. It has to be stressed here that in closed-loop recirculation systems, which are required for detectors operated with expensive gases (Xe, CF_4), all impurities and reactive radical fragments will remain in the gas until they are removed by a purification system or deposited elsewhere. Therefore, for the construction of large-area gaseous detectors,

the maximal cleanliness for all processes and quality checks for all system parts are of primary importance. Examples of "clean" gas systems currently used for high-rate detectors are presented in [154] and [155]. Certainly, the definition of the word "clean" has changed considerably since the 1986 workshop.

VI. Summary

Aging phenomena obviously constitute one of the most complex and serious problems that could limit the use of gaseous detectors in unprecedently severe radiation environments. Operation in high-intensity experiments of the LHC era demands not only an extraordinary radiation hardness of construction materials and gas mixtures but also appropriate assembly procedures and quality checks during detector construction and testing. Since the 1986 workshop, considerable progress has been made on the understanding of general principles that might help to prevent or at least to suppress the aging rate to an acceptable level. However, a quantitative description of the aging processes, which would require a detailed knowledge of the reaction cross-sections of all chemical species in the avalanche plasma, is still not available.

After many years of intensive research and development of radiation-hard gaseous detectors, an impressive variety of experimental data has been accumulated. The radiation hardness and outgassing properties of the various materials used for the construction of detectors and gas systems are among the most crucial items affecting the lifetime of gaseous detector. However, the observed dependences of aging performance on the nature and purity of the gas mixture, different additives and trace contaminants, construction materials, gas flow, size of the irradiated area, irradiation intensity, ionization density, high voltage, and particle type and energy make quantitative comparisons of aging properties under very different conditions very difficult. Consequently, these data can serve only as a guideline before the start of long-term studies under conditions as close as possible to the real environment of the experiment. Such radiation tests should include an extended study of large-scale final prototype chambers, exposed over the full area to a realistic radiation profile (particle type and energy, ionization density, irradiation rate). It is of primary importance to vary the operating parameters systematically in order to investigate their possible influence on the aging performance. To exclude statistical fluctuations of unknown nature and to provide a reliable estimate for the detector lifetime, the radiation tests should be carried out with several detectors irradiated under identical conditions.[2]

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[2]This paper is based on the results reported at the DESY workshop and also briefly discusses other experience with gaseous detectors relevant to the present aging problems. Transparencies and videos of presentations from the International Workshop on Aging Phenomena in Gaseous Detectors (DESY, Hamburg) are available at the workshop's Web site (http://www.desy.de/agingworkshop). The proceedings of the workshop will be published in a special volume of *Nuclear Instruments and Methods: Section A.*

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