INFLUENCE OF CHEMICAL TRACE ADDITIVES ON THE FUTURE AGEING OF THE UA1 CENTRAL DETECTOR

Sean P. Beingessner¹⁾, Thomas C. Meyer²⁾ and Michel Yvert³⁾

Abstract: A number of systematic tests investigating the effect of various chemical additives on the ageing of prototypes of the UA1 Central Detector have been performed. In addition to the classical substances of water, ethanol and isopropanol emphasis is also put upon more uncommon chemicals, usually required as doping seeds for UV laser calibration. Chamber lifetime can be strongly influenced by them, depending on their concentration. Evidence is presented, that proper choice and dosage can lead to a significant extension of normal wire chamber lifetime.

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1) University of Victoria, Victoria, Canada

2) CERN, Geneva, Switzerland

3) LAPP, Annecy, France

1. INTRODUCTION

In spite of the numerous tests and reproducible evidence that exist about the ageing phenomenon a complete understanding of the governing mechanisms of the process remains elusive. The fact is that ageing depends on a multitude of influential parameters, such that all the evidence so far is still insufficient to give either a systematic picture of the phenomenon or a reliable prescription for avoiding it. In his comprehensive summary of detector ageing Juroslav Va'Vra [1] could only produce a list of things to do and things to avoid amidst the otherwise confusing puzzle of ageing. This leads to the unfortunate situation that individual ageing tests, including the present ones, do not seem to give a conclusive answer to the ageing issue for all cases. However, although the present tests are focused on the needs of the UA1 Central Detector, it is believed that the results apply to more general situations. Even though these tests could not be exhaustive, a fairly consistent picture seems to be emerging.

The UA1 Central Detector (CD) is a large drift chamber with long drift paths (18cm), high gain (10^5), and cathode fields of the order of 33 kV/cm. In view of the tenfold increase in proton-anti-proton luminosity expected from ACOI the detector will face serious new problems [2], such as large space charge distortions and radiation damage, or ageing. It is hoped that the problem of distortions can be controlled by the addition of a laser calibration scheme. Such a scheme requires the addition of a laser seed [3]. Such seeds can cause increased ageing. The ageing problem is further aggravated by the high electric fields on the cathode. These wires have the potential to develop Malter currents, leading to the premature breakdown of the detector.

Under present conditions with a chamber gas mixture of argon/ethane (40:60) and a cathode electric field of the order of 33 kV/cm, there is no evidence of any ageing effects at present. This has been studied by comparing the characteristics of the CD near the beginning of operation to those near the end of the last physics run [4].

Two tests with a small prototype version of the CD without additives were performed as a form of standard measurement. Both of these tests resulted in the formation of Malter currents, beginning with the high field cathode wire.

Tests with the addition of either DMA or TMPD, our two candidates as a laser seed [3], did not develop problems with the cathode, Malter currents. However, in relatively large concentrations they caused rapid deterioration of the anode resulting in wire gain loss. On the other hand, at the 1 ppb level TMPD seemed to inhibit the formation of Malter currents, gave reasonable laser ionization, and did not cause extensive damage to the anode wire.

Examining the case, where the Malter currents had already developed, it was found that they could be stopped with additives such as, Ethanol, Isopropanol, water, and DMA. The amount of additive needed to stop the currents depends on the extent, to which they have progressed. This implies that the cure is best applied before the problem develops. Determining the minimum concentration necessary to inhibit the start of the Malter currents could not be within the scope of these tests.

Evidence shows that given the proper choice and dosage, these chemical additives may lead to a significant extension of the normal Central Detector lifetime.

2. AGEING STATUS OF THE UA1 CENTRAL DETECTOR

2.1 The Image Chamber

Fig. 1 and 2 show the basic geometry of the UA1 Central Detector. The 25 m³, 6 meter long cylinder is divided into 6 half cylinders, the 0.7 Tesla magnetic field is horizontal and parallel to the wires, perpendicular to the beam line. The planes of wires are specially arranged in order to optimize the momentum measurement accuracy, the sagitta being measured by the drift time. The general characteristics of the detector are shown in Table 1. The electronics record the total charge collected and the 3 space coordinates (wire number, drift time, and position along the wire using the charge division technique) for each hit. Fig. 3 gives a Megatek display of all the hits of a typical UA1 event.

2.2 Charge Collected in the Hot Region

Since 1981 a large amount of data has been collected, which, excluding the 1987 technical run, amounted to 770 events/nb. At large luminosities currents up to $30 \mu\text{A}$ have been drawn in the "hot-test" drift gaps, near the beam pipe. The currents are almost linear with the luminosity, as shown in fig. 4. This proves that the beam gas interactions are not the dominant source of gap current. In these drift gaps, which are in the forward chambers, the current is approximately given by:

$$I [\mu\text{A}] = 7 \times 10^{-29} \times L [\text{cm}^{-2}\text{s}^{-1}].$$

Using the hits from minimum bias tracks the probability of a hit reaching a given wire in the first drift gap of the forward chamber was derived (see fig. 5). This ranges between 0.6% to 0.7%. The charge division coordinate distribution, in fig. 6, is almost Gaussian with a fitted standard deviation $\sigma = 20 \text{ cm}$ for all forward drift gaps. This width does not change significantly along the beam direction.

From these observations it was concluded that the total charge collected on the hottest wires, corresponds to a maximum density of $10 \text{ mC/cm} \times \text{pb}$. Taking the total integrated luminosity and assuming a 20% data taking inefficiency, this corresponds to a collected charge of about 10 mC/cm as of 1987.

2.3 Search for an Ageing Effect

Two approaches were taken in searching for an ageing effect in the Central Detector. The first was to compare the performance of the detector in September 1983, almost at the beginning of the large integrated luminosity runs, with that of December 1985, the end of the last physics run. Using the hits from minimum bias data, we select those situated in the hottest region of the detector, namely wires 61 to 110 and $||z|| < 20 \text{ cm}$ (see figs 5 and 6) and plot the charge collected per hit correcting for the track angle. In order to compare the two periods, fig. 7 shows the September 1983 and December 1985 distributions normalized to the same gain and to one event. In case of serious illness one would expect a deformation of this distribution, meaning a change in the width and not the mean value. No noticeable change was observed.

The second approach was to assume that a possible deterioration of the performances, if any, can be due to local defects on the sense wires; a deposit in the immediate vicinity of the avalanche. With the magnetic field being directed along the wires, the drift direction is tilted 23° with respect to the electric field orientation (fig. 8). Keeping in mind the fact that UA1 has run with the same field polarity since 1981, one would expect the eventual deposit to be non-uniformly distributed around the sense wires. Since 80% of the positive ions from the avalanche return to the drift volume, one can deduce that the avalanche does not spread around the wire, but covers an area with a sigma of about 60° . Thus the non-uniformity of the deposits should be preserved at some level. We therefore inverted the magnetic field, such that the drift angle becomes -23° and hence the "young" part of the sense wire is exposed. Fig. 9 gives the same distribution as fig. 7 for hard trigger tracks, and normal and inverted magnetic fields from December 1985 data. Once again, no observable change in the width of these distributions is found.

The conclusion is that there is no observable change in the performance of the UA1 Central Detector.

3. TEST CHAMBER CONDITIONS

The laboratory tests were made with small test chambers, which served as models for the UA1 Central Detector. These chambers were identical to those described earlier [3,4]; their basic features and relevant parameters are given in Table 2.

Two configurations were used for the tests. In the first (fig. 10), the ^{90}Sr source faced the quartz window used for the laser. This attenuated the source somewhat, and led to a slower ageing of the chamber. The source profile inside the chamber had to be measured, and is shown in fig. 11. This format was used for the first standard run without additives.

For subsequent tests the ^{90}Sr source irradiated the chamber through a thin Mylar window facing the wires opposite to the drift direction as shown in fig. 12. This increased the radiation inside the chamber and thus accelerated the tests. It was found necessary for practical reasons, as the first test ran

continuously for three months. This configuration also permitted the determination of the source intensity profile through measurement of the lateral spread of current on each of the 24 anode wires. Assuming a uniform azimuthal collimation of the source, we used this information for the calculation of the longitudinal spread or the induced charge along the wire. The source intensity distribution for this configuration is given in fig. 13.

Unlike the large chamber, the small test apparatus allows easy diagnoses of the progressing ageing symptoms. During the tests it was possible to:

- (a) measure the anode current on individual sense wires with and without a ^{90}Sr source,
- (b) measure the gain and stability with a weak ^{55}Fe source,
- (c) monitor the resolution σ/E of the 5.9 keV X-ray line of the ^{55}Fe source.

To correctly determine the absorbed charge density [mC/cm] on the sense wires, the current measurements on the wires were repeated regularly in the course of the experiment. The shape of this distribution, as shown in fig. 13, remained unchanged. However, the absolute value of the current readings would vary, if not by ageing itself, then due to systematic effects influencing the wire gain, such as small changes in temperature and/or gas mixture. The short-term fluctuations, at the level of a few per cent, were averaged out by updating the sense current measurements roughly every 12 h.

Two goals determined the conditions of the tests:

First to study ageing under conditions similar to those in effect for the main UA1 Central Detector; (i.e. pure gas without additives) in order to anticipate the ageing symptoms that could be expected. If possible to estimate some kind of maximum charge [mC/cm] the detector could sustain without serious harm. Serious harm being either gain changes or the evolution of the Malter effect. Having identified the problems, possible cures for the degraded chamber performance were then investigated. Secondly to study the influence of low ionization potential (IP) chemical additives on chamber lifetime as compared to the behavior of an un-seeded chamber. DMA and TMPD were the two additives studied here due to their promising behavior as doping seeds for UV laser calibration, as shown in earlier work [3].

4. AGEING TESTS WITHOUT ADDITIVES

4.1 *The Slow Test*

A "slow" test was thought to be desirable, as it was believed that it would more closely approximate the actual conditions in the CD as compared to the very highly accelerated ageing tests usually performed for practical considerations. Thus the chamber was irradiated with a ^{90}Sr source over a period of a few months.

The test cell seemed to exhibit two clearly distinguishable phenomena. The first was a presence of some after pulsing mechanisms, which would turn on and then disappear after a few minutes as if the cause was destroyed by the effect. The second, and by far most serious phenomenon was the appearance of large DC currents with the characteristics of a Malter or thin film current from the cathode wires. This current led in a short time to sparking.

The after pulsing, if truly a separate phenomenon, seems to be only a nuisance. Whether or not it exists in the UA1 CD, is not known. It was first observed after about 270 h of radiation in the test chamber, but may have been present at an earlier time. It is associated with no particular wire and never lasts long. An example of this is shown in figs 14(a,b). These figures show two ^{55}Fe spectra from the same wire taken in a very short time sequence. In fig. 14(a) one can see the excess counts below the escape peak caused by the after pulsing. A short time later it returned to normal (fig. 14(b)). This might be related to the possibility reported by Va'Vra [1] that deposits may form on the cathode wire, which cause them to become photo sensitive. Later the deposits are destroyed by the positive ions from the pulses they cause. Whether or not this phenomenon is a precursor to the Malter effect, is not clear. If it could be shown to be an early indication of the Malter effect, it could be quite useful as a warning of the approach of further problems. It must be emphasized, however, that in the present tests there was no observed correlation between wires, where the after pulsing was observed, and those, which later developed Malter currents.

The Malter currents are by far the most serious problem, as they did not follow a completely regular pattern, such that the probability of a problem increased with collected charge on a wire, but was not solely dependent on it. The problem does seem to be connected to the large electric field on

the cathode wire surface, as observed by others [5, 6]. The problem occurred in three separate cells before the test was terminated. In each case it seemed to originate on the cathode wire closest to the anode wire. The cathode would emit a current in a DC fashion, as opposed to any kind of pulse structure. This current would be amplified at the anode wire, and the resulting positive ions would return to all three cathode and two field wires. This would greatly accelerate their ageing as well as the degradation of the original cathode wire. However, by the time this happened, the wires shared by other cells would also begin to have secondary currents, spreading the problem to the next cell. This is clearly fatal to chamber operation.

The fact that the field wire current does not grow at the same rate as the cathode, may be a sign that the trouble has spread from the center cathode wire to the outer cathode wire first. It could be explained by the bulk of the positive ions generated by the first bad wire returning to that wire and some to its nearest neighbors. The neighboring wires then undergo accelerated ageing and become current sources as well. This cycle then repeats itself. Thus the field wires only draw current when positive ions from the wires next to a damaged one move there. The currents then distort the local fields, and the field wires themselves age.

The first cell to develop a problem, the ninth from the source was allowed to proceed to sparking. This occurred after about 300 hours of irradiation. After the sparking, the three cathode and two field wires flanking the anode wire had visible deposits. It was decided to clean the wires with acetone. The deposits on the center cathode wire were much harder to clean. After all visible deposits were removed and the chamber gas restored, voltage was applied. Immediately a very uniform blue discharge was observed on the center cathode extending in the direction of both anodes. This wire was then removed and viewed with an electron microscope, which showed the presence of a thin film [4]. Again voltage was applied. However the two cathode wires on either side of the original problem cathode wire were found to be emitting electrons to neighboring cells. Thus left alone the currents quickly spread from cell to neighboring cell. These neighboring cells were then shut off by applying a negative voltage to the anode wires, and the test was continued.

After 1200 h of irradiation currents appeared in the seventh cell from the source. In this advanced state of wire ageing, we investigated more closely the behavior of the Malter current.

It is well-known that these currents are totally "extinguished", when the gain of the chamber is reduced to zero and then restored.

Since the Malter effect seems to be primarily associated with high cathode fields, we measured this current as a function of cathode voltage. This is shown in fig. 15(a) for cathode voltages between 2.0 and 2.7 kV. For this curve the field voltage remained at 2.0 kV and the drift voltage at 27.0 kV. If the measured current values are corrected for the proper gain; (i.e. the wire amplification in the absence of these currents), the Malter currents tend to fall behind the expected gain curve (fig. 15(b)). This effect can be partially explained by an unusual concentration of positive space charges in the vicinity of the sense wires, which effectively reduces the original wire gain. The apparent increase in the field wire current at the expense of the cathode current is caused by the change in the electric field lines followed by the positive ions.

Assuming the currents are attenuated by space charge, as the gain increases, this figure demonstrates that the source of the current stays approximately unchanged, while the voltage is lowered. While the cathode voltage had only been lowered 700 V, the cathode electric field went from 33 kV/cm to 16 kV/cm, (i.e. it falls to half its value). At the same time the field wire electric field goes up to 11kV/cm as a consequence of now having the same voltage as the cathode wires. Thus, once the Malter effect has been initiated, it is not influenced by the electric field even down to values usually considered safe in wire chamber construction. At this point the currents were monitored at the lowered gain for 3 h and found to initially drop slightly and then began to grow again.

The cell was then turned off and the test continued. The currents next appeared at the cell farthest from the source. The chamber was then used to examine the effects of cures described below.

4.2 The Fast Test

After a reconfiguration of the apparatus as described above, which included a purifier, a second test with no additive was conducted to look for discrepancies due to the increased radiation. The results of the ageing with the purified and unseeded gas are shown in figs 16(a - c). The results are shown for wire No. 12, the most irradiated one in our test.

In both this test and the slower test above, the chamber lifetime was limited by the development of severe Malter currents, which ultimately reached values of a few μA per wire. As we have seen before, this rapidly increases the rate of ageing. The plots of figs 16(a-c) clearly indicate that the history of ageing, under these circumstances, exhibits essentially no indication of progressing degradation in chamber performance. Furthermore, the quality of the ^{55}Fe spectra remains almost perfectly intact, even up to the sudden onset of Malter currents, as shown in fig. 16(b). Only then does the ^{55}Fe X-ray spectrum become abruptly masked by gain modifying currents caused by electrons emitted from the ageing defects on the cathodes (see fig. 21(c)). It seems that the anode wires are relatively unaffected by the large amount of charge provoked in the avalanche region. After quenching the Malter current by turning the wire gain off and on, the recovered ^{55}Fe sense wire spectrum in fig. 21(b) remains indistinguishable from the reference spectrum of fig. 21(a). Microscopic analysis revealed that indeed anode deposits, though visible, are clearly outnumbered by cathode defects, as has been reported previously [4].

These currents were always found to originate with the cathode wires with the highest electric field, (i.e. 33 kV/cm). This tends to corroborate the general view that these large fields should be avoided.

5. AGEING WITH LOW IONIZATION POTENTIAL ADDITIVES (DMA AND TMPD)

In many of the present and future wire chambers, like the UA1 Central Detector or the large volume TPC's, electrons must drift over relatively large distances before they reach the detection region of the counter. A typical problem associated with such drift distances is electron attachment due to electronegative impurities such as oxygen, present in the counting gas. Therefore, to maintain a reasonable lifetime for the track generated primary electrons, gas purification devices are usually employed in a recirculating closed loop gas system. For the UA1 track chambers (Central Detector and Muon detector) a system consisting of a catalytic purifier and a molecular sieve was chosen to remove prima-

rily oxygen from the counting gas. However, the catalytic conversion of oxygen in the presence of hydrocarbons effectively removes other impurities, such as the organic residues of solvents, (e.g. Phenol), used by the gas supply industry [7]. On the other hand, double photon ionization with lasers, also of prime interest for these large detectors, relies on these trace impurities for their low ionization potential. In this situation it then becomes necessary to add the chemicals to the gas. However, tests by J. Kadyk [8], show that ageing can be influenced by different grades of gas quality. Therefore it was necessary to worry about what these additives would do to the detector.

It should be emphasized that by investigating the influence of two chemicals on wire ageing we had not made an arbitrary choice. Both compounds, Di-Methyl-Anilin (DMA) and N-N'-N'-Tetra-Methyl-p-Phenylene-Diamine (TMPD, also known as Wurster's Blue) had been carefully selected in earlier tests [3] as low ionization potential (IP) (DMA: 7.10 ± 0.05 eV [9], TMPD: 6.75 ± 0.02 eV [10]) doping seeds in counting gases for UV laser induced ionization. Also, in terms of chemical structure (as Benzene derivatives) they are typical representatives of seeding agents used for UV laser calibration of gaseous detectors [11].

DMA, a liquid at NTP, is easy to handle and can be introduced into the chamber as a saturated vapor (0.1 Torr at 4 °C) with the counting gas.

TMPD, on the other hand, is a solid with very low vapor pressure at NTP (approximately 10^{-3} Torr), and due to its sublimation and adsorption behavior is quite difficult to control as a gas seed. However, its excellent efficiency and electron yield under UV irradiation also made it a choice candidate for the ageing test series.

5.1 Ageing with DMA

The test chamber was re-equipped with a new wire plane, made from the same spools of wire as the original chamber, while the gas system was slightly revised to allow for the addition of DMA vapor. Since the chamber gas is bubbling through a sample of liquid DMA, the amount of vapor is easily controlled via the temperature of the sample, typically between -2 and 0 °C. Hence the concentration of DMA in the chamber gas was kept at approximately 100 parts per million (ppm). At this value the

laser induced ionization of a $10\ \mu\text{J}\ \text{N}_2$ laser yielded $1300\ \text{e}^-/\text{cm}$ or nearly 10 times the minimum ionizing equivalent. The testing procedure and monitoring for ageing were otherwise the same as before. The results are shown in figs 17(a–c).

In the present tests, essentially every industrial chemical residue had been removed by the purifying system. For even at the highest possible wire gain no N_2 laser induced ionization was detectable. We can therefore be reasonably sure that, whatever had caused an abnormal ageing in our tests, must be attributed to the deliberate seeding of the counting gas with the chosen chemicals. Figs 17(a–c) show that, in the case of 100 ppm of DMA, ageing is strongly influenced by this chemical, resulting in a rapid loss of wire gain. The almost instantaneous deterioration in the X-ray resolution, σ/E , shown in fig. 21(d), suggests a prompt build up of anode deposits in the avalanche region spreading quickly along the entire length of the sense wire. Within a short time, (i.e. $5\ \text{mC}/\text{cm}$ absorbed charge), the wire gain has dropped by a factor of two. The effects on the anode currents also become visible at approximately $5\ \text{mC}/\text{cm}$. They are less drastic due to the non-uniform ageing of the wire. After termination of the test, (fig. 21(e)), the wires were inspected visually and microscopically. To the naked eye the sense wires appeared to be coated with a greasy blue tinted substance. The scanning electron microscope showed a $2\ \mu\text{m}$ thick insulating layer of a carbon and oxygen containing compound, possibly a polymer, covering the sense wire. The cathode wires, in contrast, showed only negligible deposits of carbon and oxygen rich material.

5.2 Ageing with TMPD at NTP

Discouraged by the negative results obtained with DMA, it was hoped that a significant reduction in additive concentration would slow down the ageing rate accordingly. However, DMA vapors diluted to the ppm level, release practically no ionization when tested with our UV laser. Therefore, DMA had to be ruled out in favor of TMPD, known to have a vapor pressure of a few mTorr at NTP. It then enters the test chamber at a volume level of no more than a few ppm. In spite of this 100-fold reduction in trace admixture, TMPD still has the highest electron yield under UV laser irradiation; i.e. $> 10^4\ \text{e}^-/\text{cm}$.

As for liquid DMA, the gas would pass through a vessel holding only 2 small crystals of TMPD (circa 2 mm³ large), before entering the test chamber, with a new wire plane. The presence and concentration of TMPD were regularly checked with the N₂ laser.

The results obtained with our standard test method are shown in figs 18(a-c).

Unfortunately similar results and observations hold true for TMPD, when used at a level of approximately 1 ppm as for 100 ppm of DMA. This includes X-ray and microscopic analysis. The characteristics of ageing are the same. However, in spite of the fact that the TMPD concentration was much less than that of DMA, ageing in terms of anode wire deposition proceeded more rapidly for TMPD, as seen in figs 21(f) and 21(g).

5.3 Ageing with TMPD at the PPB Level

After the last test it was clear that, whatever the ageing mechanism in the presence of these low IP organic molecules, a further ageing test would be sensible only, if these organic traces could be reduced by a few orders of magnitude, without sacrificing the goal of laser induced ionization. Fortunately, TMPD is very efficient in this respect, but handled in proportions of a few ppb posed severe problems for controlling and maintaining such minute concentrations. It was found that TMPD is partially sticky, i.e. its adsorption rate on surfaces is larger than the evaporation or sublimation rate into the gas volume.

Cooling TMPD crystals for the purpose of lowering the vapor pressure proved unfeasible, since over a wide temperature range, ($-100 < T [^{\circ}\text{C}] < -30$), no detectable vapor would enter the chamber. Above -30°C , however, the concentration of TMPD could not be controlled any more, probably due the adsorption effects, and consequently saturated the preamplifiers. The method finally adopted was to have the chamber gas pass over the TMPD grains (at NTP) for only a short period of time, while otherwise bypassing the TMPD container. One can define in this way a duty cycle in time equivalent to a certain concentration of TMPD. In practice, two electrical three way valves (see fig. 19), operated by a simple timing mechanism, would open the TMPD volume to the gas flow for a fixed time (minimum 13 sec). Thereafter, the counting gas is directly admitted to the chamber for a long period, of the order

of 2×10^4 sec. This defines an average dilution factor of 6×10^{-4} . Due to the small chamber volume of 15 l, this method created fluctuations in the actual TMPD concentration monitored via the UV laser. Owing to the slow sublimation effect, this resulted in an average integrated trace level of < 1 ppb.

This is still adequate for laser induced ionization being equivalent to approximately 1 minimum ionizing particle, or $100 \text{ e}^-/\text{cm}$. The above method can be improved with shorter on/off periods of the electrical valves, still keeping the original duty cycle of 6×10^{-4} . Although the timing circuitry worked reliably throughout the experiment, the TMPD concentration was periodically monitored with the UV laser. The laser was by far the most accurate and sensitive method of trace analysis.

As in all previous measurements, the standard test cycle was followed by monitoring at regular intervals, the anode currents, the gain and the resolution on the most irradiated wire. The results are shown in figs 20(a - c).

When the TMPD concentration is reduced to the ppb level, the ageing pattern remains essentially the same. As one would expect, however, the degradation in chamber performance follows a much slower pace. With respect to the former ageing test (1 ppm), one may consider the ageing at this level a controlled "slow motion" ageing process. Since the formation of anode deposits is still the dominant process during the ageing history, the ^{55}Fe energy resolution σ/E reacts most sensitively to the doping seed in the course of the test. Due to the very strong dilution of TMPD the anode deposits are built up only sporadically, i.e. non-uniformly on the anode wire. This could explain, for example, the rise in the σ/E plot of fig. 20 between 30 and 90 mC/cm absorbed charge. Afterwards, once the anode coating is more uniformly spread on the wire surface, the ^{55}Fe X-ray resolution improves, as the gain becomes more uniform as well. This phenomenon is probably totally masked in the two previous tests, since the wire gain had dropped to nearly zero by the time an improvement in σ/E could be detected. Notice that the speed of ageing is reduced approximately 100 times, although the TMPD concentration has changed by more than a factor of 1000. This discrepancy could be explained by saturation effects in the 1 ppm test and other possible systematic errors typical for a single test. For comparison the ^{55}Fe spectrum taken at the end of this test is given in fig. 21(h).

Another interesting outcome of the 1 ppb test is the total absence of Malter currents even after 300 mC/cm. In the two tests without additives, these currents appeared by the time approximately

40mC/cm absorbed charge had been accumulated. Therefore, cathode deposition seems to be suppressed by the presence of only 1 TMPD molecule out of 10^9 gas molecules. Whatever the cause of the Malter currents, 1 ppb of TMPD seems to be sufficient to totally inhibit it.

6. GAS ADDITIVES AGAINST MALTER CURRENTS

This part of the test series concerned the interesting question of possible cures, once ageing had advanced beyond the stability region of the wire chamber. Clearly, any progress made on this issue will also forecast specific preventive action, before a wire chamber becomes unstable or inoperable due to electrode deposits. As will be discussed below, the test results show two distinct features, namely where and under what test circumstances, the dominant deposit growth on wires occurs. It was soon found that the test apparatus, where smooth uniform anode coatings had degraded the gas gain, was virtually incurable by standard gas additives such as H_2O , ethanol or isopropanol. Only mechanical cleaning with strong solvents like acetone proved to be successful.

Cathode deposits are different and manifest themselves frequently as a spontaneous emission of electrons from the cathode. This process supports itself by a feedback of positive ions emerging from the anode multiplication region towards the cathode, where they enhance the build-up of dielectric deposits. It is believed that the phenomenon seen here is the Malter effect.

This effect was studied with the chamber used in the first, "slow", no additive test. After the end of the first test this chamber was used to investigate problems caused by discharges. The discharges ultimately caused anode deposits to form, so that the anode wires no longer had uniform gain. However, there were no deposits in the chamber that could be associated with additives. Following the experience of many other groups, Ethanol was tested as a means of stopping these currents.

With 0.8% Ethanol the currents ceased. If the Ethanol was turned off and the chamber flushed with fresh gas, the currents returned within 10 minutes, corresponding to about 0.5% Ethanol in the gas volume. Fig. 24 (discussed below) gives a similar behavior. With 0.6% Ethanol in the test chamber, it lasted approximately 2 hours before the currents returned. The Ethanol was replenished to 0.8%, and

the chamber operated for an additional 500 hours of ageing as in the first test (i.e. the source electrons entered through the quartz window). If at any time the Ethanol was turned off, the currents would return as before. At the end of the 500 hours, the wire gain was checked along the wires and found to be the same as before. Thus, the Ethanol did not cause any further harm to the chamber, nor did it do any permanent good to it. No evidence of the Ethanol cleaning the wires was seen. However, as it will be shown later, the need for 0.8% Ethanol was probably due to the level of ageing in the chamber at the time of the test.

This test chamber was then used to examine the other common additives for limiting currents. During the course of these tests the chamber was allowed to draw currents for extended periods of time. These currents caused the state of the chamber to deteriorate very rapidly. This in turn caused the magnitude of the currents to increase. Thus the results are only qualitative and not quantitative, because, when each additive was tried, the conditions of the test changed.

The next substance to be tested was isopropanol. 0.5% isopropanol was added to the gas and found to control the currents (fig. 22). The isopropanol was then removed from the gas system and pure $\text{Ar}/\text{C}_2\text{H}_6$ flushed through the chamber. The chamber was then exposed to the ^{90}Sr source. It was periodically removed and the current without source checked. As a function of concentration the currents then returned (as shown in the square symbols of fig. 22) to a value fluctuating between 1.1 and 1.2 μA . When the isopropanol was re-introduced, the currents returned to background level as shown in the round symbols of fig. 22.

In the next test we investigated Di-Methyl-Aniline (DMA). This was done in the opposite order to isopropanol. With clean gas the source was used to initiate the Malter currents and then removed. DMA was introduced to the chamber at 1.3 μA initial current. This current then diminished, as shown by the round symbols in fig. 23. However, in this case only 0.02% (200 ppm) of DMA was needed to stop the currents. The DMA was disconnected, and the concentration needed to fall below 0.01%, for the Malter current to return (square symbols in fig. 23). Note that as in previous tests the return of the Malter current had to be triggered by a short exposure of the chamber to the ^{90}Sr source!

This test could not be performed with TMPD due to the much longer period of time needed to introduce and remove the chemical.

In order to examine the advanced ageing state of the chamber, the same test was then done with Ethanol. The currents were restored with pure gas, now to the level of $1.5 \mu\text{A}$. The ethanol was then introduced and the currents monitored. The currents diminished as in the first two cases. However, this time there seemed to be steps in the process (round symbols of fig. 24). This could have been due to current sources in different regions of the chamber being quenched by different concentrations of ethanol. In the end it took 20 minutes and about 1% ethanol to stop the current. The reverse process was then tried and the currents turned on sharply at about 0.5% (square symbols in fig. 24). This was similar to the behavior before the long-term ethanol test.

The chamber now went through very rapid deterioration, and we wanted to test, whether the addition of water might also remove the Malter current. The chamber with pure $\text{Ar}/\text{C}_2\text{H}_6$ now drew $4.5 \mu\text{A}$ with the source removed. The water was then introduced and at a concentration of 0.7% had reduced the currents to $0.4 \mu\text{A}$ (fig. 25), but still above background. When the voltage was turned off and on to stop the residual current, and the source used to re-trigger the current, it now returned to $0.2 \mu\text{A}$ and then began to grow. The water was then flushed from the chamber.

At this point isopropanol was again introduced to the chamber, and it was found that 0.5% no longer reduced the currents to background levels, but to $0.2 \mu\text{A}$ as in the case of water. It was then decided that, given the highly advanced state of chamber deterioration, even qualitative comparisons were becoming difficult, and so the test chamber was retired. However, it seemed clear that the absolute amount of additive needed to control the current depended on the level of damage to the chamber. The further advanced the state of ageing, the greater the concentration of a given additive had to be to control the currents.

Notice that our measurements with water were included in this series of tests as a matter of completeness, for due to electron attachment water is not practical in this sense for large drift gaps.

These Malter currents were known to be easily extinguished by the polar and oxygen containing molecules, such as water, ethanol and isopropanol at about the per cent level. It is interesting to note that an intrinsically different chemical, DMA, in spite of its nearly non-polar molecular moment and lack of oxygen, exhibits identical behavior in quenching the Malter currents, even at a significantly lower concentration, (i.e. 0.01% or 100 ppm, as seen in fig. 23).

7. DISCUSSION

The impact of low Ionization Potential additives on ageing can be summarized as beneficial for the cathode but detrimental to the anode. So while their presence accelerates the growth of polymers on the anode, they inhibit the polymerization on the cathode. This suggests that the two problems are separate. The mechanisms that lead to radiation damage to the cathode are not exactly the same as those causing radiation damage to the anode wires in wire chambers.

In his review, VaVra [1] presented a simple model of the polymerization process. His model suggested that polymers form in the avalanche near the anode wire and then migrate toward the cathode. The present tests indicate that both DMA and TMPD enhance the formation of polymers at the anode wire. The above simple model should then indicate that this will lead to a rapid polymerization on the cathode wire as well. However, this does not seem to be the case.

Kotthaus [6] presented an example, where Malter currents formed with cathode fields of 40 kV/cm, but were absent, when the cathode field was kept below 15 kV/cm. In his test the conditions at the anode wire were the same, only the cathode field was altered by changing the cathode wire diameter. His tests used a 50/50 Ar/C₂H₆ gas mixture, which support the view that the cathode field is critical to the formation of the film responsible for the Malter current. The tests made here on the Malter current show that, once the cathode wire starts acting as a current source, the source will remain approximately constant, even as the field is reduced to about 16 kV/cm. Thus, while a large cathode field appears to be important to the growth of damage to the cathode wire, it is not needed to maintain the Malter effect.

Here it was found that 1 ppb of TMPD was sufficient to inhibit the formation of Malter currents, even in the presence of 33 kV/cm cathode fields. 100 ppm of DMA proved efficient at controlling the Malter currents, after they had formed. That such small amounts are so effective would seem to imply that there is some mechanism, which must increase their concentration near the cathode wire. A natural possibility is that the charge exchange between neutral DMA or TMPD molecules and positive ethane ions must be very efficient. Thus, the argon and ethane ions, produced in the gas amplification process, are replaced by ions of the low IP additives, which are then brought by the electric field to the cathode.

7.1 The Importance of Charge Exchange

The charge exchange cross section for these molecules and ethane or argon ions is, as far as we know, completely unknown. The low ionization potential of TMPD and DMA, combined with the large number of accessible molecular quantum states, could enhance the charge exchange cross section for these molecules. In this way, despite their small concentration, DMA and TMPD would replace ethane ions, so that by the time the positive ions have reached the cathode they would be primarily DMA^+ or TMPD^+ . The ionization potentials of ethanol (10.5 eV) and isopropanol (10.2 eV) are closer to the ionization potential of ethane (11.5) [1]. Thus, the charge exchange cross sections may be smaller, requiring a much higher concentration of alcohol. However, the effectiveness of water (IP = 12.6 eV) [1] at reducing the currents with an IP greater than ethane seems to contradict this argument.

It is possible that water is much more efficient at charge exchange with argon (IP = 15.8 eV) [1], than ethane with argon. Hence, even in small amounts the argon is neutralized more favorably by water than by ethane, even though there is more ethane in the gas mixture. The water is then not so easily neutralized by the lower ionization potential ethane. On the other hand, the effectiveness of water is often attributed to its ability to increase the conductivity of the cathode film, thereby destroying the Malter effect.

If the mechanism for charging the insulating film was itself a form of charge exchange, it might explain, why the lower ionization potential ions are not effective at charging the film. The film is not charged by ions that come and "stick" to it, but by the arrival of ions that are neutralized at the film, leaving it with a positive charge and the molecule neutral. Thus, the low ionization potential of DMA and TMPD could exclude this. But again one is left with the observation that the higher ionization energy alcohols and water molecules are also ineffective at charging the surface. It may be that there are two different processes for neutralizing the film. One, the inability to charge it, and the other, the ability to make it conductive.

This does not seem to answer the question of why the ethane ions are so effective at growing the insulating film, while the others are not, nor does it explain the importance of the field itself. Two pos-

sible models present themselves; reality may in fact be a mix of the two. Alone, neither is found to be totally satisfactory.

7.2 The Feedback Mechanism for the Growth of Malter Currents

This mechanism is based on the observation that, once the Malter currents form, they grow at a very accelerated rate. Once a thin film has been built up and is now acting as a localized current source, the emitted current is amplified at the anode and accelerates the ageing process. On this very small scale one can think of this as the inception of the problem. It is compatible with Va'Vra's simple model of the polymerization process.

A small amount of polymer, which is formed near the anode, as described by Va'Vra, migrates to the cathode and is fixed there. It generates a very small insulating region, which eventually charges up and, on a very small scale, becomes a Malter source. This sends electrons to the anode and accelerates the formation of polymers in that region, which then drift to the cathode. This continues, until a current develops large enough to be noticed. The additives kill this effect (e.g. 1 ppb of TMPD) by stopping the production chain at the root; (i.e. the TMPD ions generated via charge exchange, do not charge up the initial bit of cathode film), thus stopping the entire process.

The problem here is that we ignore the fact that the field is very important. It has been shown by us that the film on a wire with only 16 kV/cm acts as a current source approximately equal to that at 33 kV/cm, once charged. Thus, the above picture should work equally well in the case of a 33 kV/cm cathode field as for a 16 kV/cm field. This seems to be in contradiction with the tests of Kotthaus and the general experience of the wire chamber field. At this point, we should preferably come up with a model that provides cathode polymerization independent of anode polymerization. If there is polymerization near the cathode, it must be fed by the only source of energy around, the cathode electric field.

7.3 Polymer Formation in the Cathode Field

In the high field region near the cathode wire typically only positive ions are found. Thus, if there is polymer formation in this region, it cannot be fed by electron collisions. It would have to be fed by positive ion impact. Since the positive ions, which are copiously produced in the gas avalanche, drift through this region, they are present in large numbers. However, for the positive ions to cause polymerization, they must have a reasonable probability of gaining a few eV in kinetic energy. In general however, it is normal to think of positive ions as having a constant mobility, which follows from assuming that they remain at thermal temperatures. To have polymer formation in the cathode field this can no longer be true.

Loeb [12] discusses the value of fields, where the mobility is no longer constant. This depends on the type of ions involved and seems to vary from E/P of a few tens of volts/cm/torr to above a hundred volts/cm/torr. For N_2^+ in N_2 there is a strong break point around 40 volts/cm/torr. In our case, 33 kV/cm at 760 torr and 300 °K correspond to about 48 volts/cm/torr (reduced to 273 °K). Thus, it is conceivable that the ethane ions are no longer in thermal equilibrium with the surrounding gas at these fields. But no further information seems to be available. Without much comment Von Engel [13] suggests that an ion can pick up perhaps 0.1 to 1 eV along a mean free path at these energies. Therefore, if the mean free path for a collision was 0.1 μm and a positive ion was moving in the direction of a 3.3 V/ μm electric field, it would have to travel 3 mean free paths to gain 1 eV. The collision cross sections for ethane ions on ethane or argon in the range of 0.1 to 10 eV are not known.

Because the positive ions, unlike electrons, can lose a large fraction of their energy in an elastic collision with the gas, it is difficult for them to keep the energy they gained from the electric field. We may therefore intuitively estimate the energy distribution in these circumstances as:

$$f(\epsilon) = \exp(-\epsilon/\epsilon'),$$

where ϵ' is the product of the electric field and the average mean free path between collisions. Loeb [12] gives a similar expression based on classical assumptions. If such an energy distribution was valid, it would permit some empirical observations.

The first is that, if a process depended on the probability P of the positive ions exceeding some threshold energy, halving the electric field would reduce that probability to P^2 . Thus, if there was a 1% probability of a positive ion exceeding the energy needed to start polymerization at an electric field of 33 kV/cm, this probability would fall to 10^{-4} at 16 kV/cm. In other words, where 40 mC/cm accumulated charge was needed to cause the Malter current at 33 kV/cm, 4000 mC/cm would be needed at 16 kV/cm. Hence, there would be an exponential rise in the probability of Malter currents developing with an increase in the electric field.

This would then explain the strong dependence of the appearance of the Malter currents on the electric field. The probability of their appearance should depend linearly on accumulated charge and exponentially on the cathode electric field. As a consequence, once the currents have developed at 33 kV/cm, they can still grow, even when the field is reduced to 16 kV/cm due to the large increase in positive ions that result. However, if a chamber is always operated at a low cathode field, the danger is reduced to close to negligible.

Where the larger DMA or TMPD ions replace the ethane ions, the mean free path between collisions could be greatly reduced. This would have an affect similar to reducing the electric field. Thus reducing the mean free path between collisions by changing the ion type or increasing the gas pressure, would increase chamber safety.

It should be noted that the positive ions also move through much larger fields near the anode and so would have to contribute to some form of polymerization there as well. This however, could be masked by the effects of the electrons in the avalanche.

The above described feedback mechanism could then accelerate the cathode ageing, once initiated by the field.

It should be further emphasized that, lacking more quantitative evidence, this explanation seems to be only qualitatively plausible, and therefore still speculative. If such a process were present, it would have implications with respect to wire chamber breakdown.

7.4 Ionization by Positive Ion Impact

Ionization by positive ion impact is generally accepted as a negligible process in wire chambers. However, if the positive ions have a reasonable chance of reaching the few eV in energy needed to polymerize, there must be a finite probability of reaching the few tens of eV required to cause ionization by positive ion impact. If the above discussion is valid, this probability would increase exponentially with the electric field. Furthermore, if the probability of ionization by positive ion impact was of the order of 10^{-10} for fields of 33 kV/cm (a negligible probability), then at fields of 66 kV/cm the probability would rise to the order of 10^{-5} . This would no longer be negligible.

The criteria required to cause breakdown due to secondary mechanisms near the cathode (the release of electrons, while the positive ions are neutralized at the cathode for example), are when the product of wire gain and probability of an electron being released reaches 1. Therefore, if the probability of ionization by positive ion impact was 10^{-5} , and the gas amplification was 10^5 , for each electron produced, 10^5 positive ions would be generated leading on average to one more electron, etc. This is the point where the chamber is no longer stable, the breakdown point.

Thus, for the above argument on polymerization in the cathode field to be valid, there must be a value for a cathode field not far above where, depending on anode wire gain, the chamber breaks down. There is some evidence that this is the case.

Giubellino et. al. [14] have published results, which they have interpreted as implying that the chamber breakdown is caused, when the product of the anode gain (for electrons) and cathode gain (for electrons [!]) is of the order of 10^7 . However, it is difficult to see, what the effect of electron gain at the cathode would be. If there were 10^5 electrons and positive ions produced in the avalanche, none of those electrons would return to the cathode and therefore, it should be of no importance, how many are actually produced. On the other hand, the 10^5 positive ions can drift to the cathode. The electron gain increases exponentially with the field, as would the probability of ionization by positive ion impact. Thus, their estimate of the electron gain at the cathode may have the same form as the ionization probability by positive ions, only 7 orders of magnitude different in scale. Hence, the point where they estimate the electron gain to be 100, may be the regime, where the positive ion ionization probability is 10^{-5} .

Their evidence would seem to support the hypothesis that polymerization by the positive ions in the high cathode field is possible. To clearly identify the different processes would require additional specialized tests.

8. CONCLUSION

This work originated with the critical requirement that the UA1 Central Detector continue to operate in a reasonable fashion during the high luminosity (ACOL) runs of the collider. This represents a problem from increased space charge distortion of the track measurements and the increased danger of ageing, especially from Malter currents.

The first approach to reducing both the danger of Malter currents and the space charge distortions was taken in the Fall 1987 technical run. The gain of the preamplifiers was increased by a factor of three, and the operating voltage of the chamber was lowered accordingly. This reduced the wire gain by about a factor of three, and hence the number of positive ions. It also reduced the cathode electric field to 27 kV/cm. It is hoped that these measures will lessen the risk of Malter currents forming.

To map the residual space charge distortions necessitates a laser calibration system with the addition of a low IP gas seed. Such a system was tested in the last collider run and will be reported separately. At present there seems to be no visible ageing problem with the UA1 CD. However, there was enough concern to understand future problems, and how laser seeds would influence them to warrant this study.

We believe that the results quoted here are not specific to this detector alone and may therefore be of general interest for any device, under similar circumstances, where laser double photon induced ionization is based on low IP chemicals, deliberately added to or residually present in pure counting gases. In high radiation environments these trace additives, even at the ppm level, can cause severe degradation in chamber performance and should be used with extreme caution.

TMPD, if employed in minute ppb concentrations, has been shown to give tolerable chamber ageing ($Q_{\max}$ of the order of 300 mC/cm) with acceptable laser induced track ionization, using a low power 10 μ J Nitrogen laser over a two meter track length.

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TABLE CAPTIONS

TABLE 1 General characteristics of the UA1 Central Detector.

TABLE 2 General characteristics of the test chamber.

TABLE 1

Type	Drift chamber with charge division readout of the second coordinate
Gas mixture	Argon (40%) + ethane (60%)
Drift field and gap length	1.5 kV/cm, 18cm
Drift velocity	5.3 cm/microsec
Drift angle	23^0 at $B = 0.7$ T
Anode plan arrangement	
a) Distance between sense wires	10 mm
b) Wire length	80 cm min., 220 cm max.
c) Sense wire charac.	35 microns Ni-Cr stretched at 80 g
d) Field wire charac.	100 microns gold-plated Cu-Be stretched at 200 g
Cathode plane structure	
a) Distance between wires	5 mm
b) Wire characteristics	150 microns gold-plated Cu-Be stretched at 200 g
Total number of wires	22800
Total number of sense wires	6110

TABLE 2**1.) Mechanical Parameters:**

Chamber material outside: copper plated G10

inside: STESALITE covered with G10; Kapton foil with etched copper strips serving as potential degrader; drift gap: 18 cm; MYLAR window for sources; Quartz windows for laser.

Chamber volume: ~ 15 liters

Wires: 24 anode wires, 35 μm f , Ni-Cr, 10 mm apart and interspaced with field wires.

25 field wires, 100 μm f , gold plated Cu-Be, 10 mm apart.

49 cathode wires, 150 μm f , gold plated Cu-Be, 5 mm spacing.

2.) Gas Parameters:

Gas mixture: ARGON-ETHANE (40-60); Argon taken as Ar-vapor from LAr; Ethane - commercial grade - supplied in bottles.

Purity: < 5 ppm O_2 , purified via catalytic conversion and molecular sieve (system LEYBOLD-HAEREUS).

Tubing: stainless steel and RILSAN.

Flow: 60 liters/hour

3.) Electrical Parameters:

Drift voltage: $V_D = - 27.0 \text{ kV}$ $\Rightarrow E = 1.5 \text{ kV/cm}$

Field voltage: $V_F = - 2.0 \text{ kV}$ drift velocity: 53 mm/ μsec

Cathode voltage: $V_C = - 2.7 \text{ kV}$

Anode field: $E_A = 210 \text{ kV/cm}$

Cathode field: $E_C = 33 \text{ kV/cm}$

FIGURE CAPTIONS

- Fig. 1 Open, schematic view of the UA1 Central Detector.
- Fig. 2 Basic arrangement of the drift cells of the Central Detector.
- Fig. 3 MEGATEK display of a typical UA1 event.
- Fig. 4 Current in the first drift gap of a forward chamber versus the luminosity.
- Fig. 5 Probability of a hit reaching a given wire in the first drift gap of a forward chamber.
- Fig. 6 Charge division coordinate (along the wires) in the hottest region.
- Fig. 7 Minimum bias trigger; Landau distribution obtained in September 1983 and December 1985 for the hot region.
- Fig. 8 Sketch of the drift lines in the presence of a magnetic field.
- Fig. 9 "Hard" trigger; Landau distribution with normal and inverted magnetic field for the most aged region of the Central Detector.
- Fig. 10 Sketch of the experimental test setup. The position of the source for the first test without chemical additives is shown. The wire configuration is identical to the UA1 Central Detector.
- Fig. 11 Three dimensional "Lego" plot of the measured source intensity inside the test chamber for the first test.
- Fig. 12 Source and laser position for all but the first ageing test. Sketch of the experimental test setup (not drawn to scale).
- Fig. 13 ^{90}Sr source intensity profile. The profile was fitted to a Gaussian plus a constant background to determine the charge distribution along the wires.

FIGURE CAPTIONS (Cont'd)

Fig. 14 An example of the ^{55}Fe - spectrum taken while afterpulsing was present on the wire (fig. (a)). After typically a few minutes the afterpulsing would vanish, and the wire would return to normal. See fig. (b) taken on the same wire shortly after that of fig. (a).

Fig. 15 Absolute value of the Malter current drawn by the anode wires (round symbols), the cathode wires, (square symbols) and field wires (triangles), as the cathode voltage was reduced to 2.0 kV (fig. (a)). At the same time the electric field on the surface of the cathode wire drops from 33 kV/cm to 16 kV/cm. After correcting for the change in gain with voltage, (fig. (b)), the current appears to increase as the cathode field is decreased. This is assumed to be a space charge effect.

Fig. 16 (a)-(c) Ageing history with no additives.

Fig. 17 (a)-(c) Ageing history for 100 ppm of DMA.

Fig. 18 (a)-(c) Ageing history for 1 ppm of TMPD.

Fig. 19 Schematic of gas flow with and without TMPD.

Fig. 20 (a)-(c) Ageing history for 1 ppb of TMPD.

Fig. 21 Examples of the ^{55}Fe spectra taken during different stages of the various tests. In all cases the energy scale is in arbitrary units.

(a) ^{55}Fe reference spectrum with pure gas and no ageing. At the beginning of all tests the spectra taken were essentially equivalent to this one.

(b) Recovered ^{55}Fe spectrum after the Malter discharge has been quenched. At this point the anode has collected a maximum charge of 50 mC/cm running in clean gas without any additives.

FIGURE CAPTIONS (Cont'd)

Fig. 21 (c) ^{55}Fe spectrum masked due to Malter discharges.

(d) Degraded ^{55}Fe spectrum after 4.6 mC/cm accumulated charge with 100 ppm of DMA in the gas mixture.

(e) ^{55}Fe spectrum at the end of DMA ageing test; the spectrum was then dominated by noise. Total accumulated charge 12.2 mC/cm

(f) Ageing in the early stages of the 1 ppm of TMPD test. Total collected charge was 0.63mC/cm.

(g) ^{55}Fe spectrum at the end of 1 ppm TMPD test. Total collected charge on the anode wire was 3.2 mC/cm.

(h) ^{55}Fe spectrum at the end of 1 ppb TMPD test. This corresponded to a maximum charge of 312 mC/cm on the surface of the anode wire.

Fig. 22 Malter current as a function of Isopropanol concentration. The open square symbols represent the increase in current, as the isopropanol is removed from the chamber by gas flow. The solid round symbols represent the drop in current, as the isopropanol is introduced to the chamber.

Fig. 23 Malter current as a function of DMA concentration. As in fig. 22 the solid symbols represent the fall in current, as the DMA enters the test chamber. Open squares demonstrate the return of the current, as the DMA is flushed from the chamber.

Fig. 24 Malter Current as a function of Ethanol concentration. Symbols as in figs 22 and 23. Note the step-like decrease in current, as ethanol enters, but abrupt increase in current, as the ethanol is flushed from the chamber.

FIGURE CAPTIONS (Cont'd)

Fig. 25 Drop in malter current versus the concentration of water, as water is introduced to the chamber. The current never reached background levels even, as the water reached maximum concentration for the apparatus configuration.

Fig. 1

FORWARD CHAMBER

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

The sense wires
have not the same
"age" all around

Enlarged view

Fig. 8

Fig. 9

"Anode " plane
same as
UA1 Central Detector

- x 100 μ Φ
gold plated
Cu Be
- Ni-c_r
35 μ m Φ

Fig. 10

Source intensity for ^{90}Sr

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

AGING WITH PURE GAS

Fig. 16

Fig. 17

AGING WITH 1 PPM TMPD

Fig. 18

Fig. 19

AGING WITH 1 PPB TMPD

Fig. 20

Fig. 21(a)

AGING WITH PURE GAS - Q = 50 mCoul/cm

Fig. 21(b)

AGING WITH PURE GAS - Q = 50 mCoul/cm

Fig. 21(c)

Fig. 21(d)

AGING WITH 100 PPM DMA - Q = 12.2 mCoul/cm

Fig. 21(e)

AGING WITH 1 PPM TMPD - Q = .63 mCoul/cm

Fig. 21(f)

AGING WITH 1 PPM TMPD - Q = 3.2 mCoul/cm

Fig. 21(g)

AGING WITH 1 PPB TMPD - Q = 312 mCoul/cm

Fig. 21(h)

Fig. 22

Fig. 23

Fig. 24

Fig. 25

INFLUENCE OF CHEMICAL TRACE ADDITIVES ON THE FUTURE AGEING OF THE UA1 CENTRAL DETECTOR

Sean P. Beingessner¹⁾, Thomas C. Meyer²⁾ and Michel Yvert³⁾

Abstract: A number of systematic tests investigating the effect of various chemical additives on the ageing of prototypes of the UA1 Central Detector have been performed. In addition to the classical substances of water, ethanol and isopropanol emphasis is also put upon more uncommon chemicals, usually required as doping seeds for UV laser calibration. Chamber lifetime can be strongly influenced by them, depending on their concentration. Evidence is presented, that proper choice and dosage can lead to a significant extension of normal wire chamber lifetime.

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¹⁾ University of Victoria, Victoria, Canada

²⁾ CERN, Geneva, Switzerland

³⁾ LAPP, Annecy, France

1. INTRODUCTION

In spite of the numerous tests and reproducible evidence that exist about the ageing phenomenon a complete understanding of the governing mechanisms of the process remains elusive. The fact is that ageing depends on a multitude of influential parameters, such that all the evidence so far is still insufficient to give either a systematic picture of the phenomenon or a reliable prescription for avoiding it. In his comprehensive summary of detector ageing Juroslav Va'Vra [1] could only produce a list of things to do and things to avoid amidst the otherwise confusing puzzle of ageing. This leads to the unfortunate situation that individual ageing tests, including the present ones, do not seem to give a conclusive answer to the ageing issue for all cases. However, although the present tests are focused on the needs of the UA1 Central Detector, it is believed that the results apply to more general situations. Even though these tests could not be exhaustive, a fairly consistent picture seems to be emerging.

The UA1 Central Detector (CD) is a large drift chamber with long drift paths (18cm), high gain (10^5), and cathode fields of the order of 33 kV/cm. In view of the tenfold increase in proton – anti-proton luminosity expected from ACOL the detector will face serious new problems [2], such as large space charge distortions and radiation damage, or ageing. It is hoped that the problem of distortions can be controlled by the addition of a laser calibration scheme. Such a scheme requires the addition of a laser seed [3]. Such seeds can cause increased ageing. The ageing problem is further aggravated by the high electric fields on the cathode. These wires have the potential to develop Malter currents, leading to the premature breakdown of the detector.

Under present conditions with a chamber gas mixture of argon/ethane (40:60) and a cathode electric field of the order of 33 kV/cm, there is no evidence of any ageing effects at present. This has been studied by comparing the characteristics of the CD near the beginning of operation to those near the end of the last physics run [4].

Two tests with a small prototype version of the CD without additives were performed as a form of standard measurement. Both of these tests resulted in the formation of Malter currents, beginning with the high field cathode wire.

Tests with the addition of either DMA or TMPD, our two candidates as a laser seed [3], did not develop problems with the cathode, Malter currents. However, in relatively large concentrations they caused rapid deterioration of the anode resulting in wire gain loss. On the other hand, at the 1 ppb level TMPD seemed to inhibit the formation of Malter currents, gave reasonable laser ionization, and did not cause extensive damage to the anode wire.

Examining the case, where the Malter currents had already developed, it was found that they could be stopped with additives such as, Ethanol, Isopropanol, water, and DMA. The amount of additive needed to stop the currents depends on the extent, to which they have progressed. This implies that the cure is best applied before the problem develops. Determining the minimum concentration necessary to inhibit the start of the Malter currents could not be within the scope of these tests.

Evidence shows that given the proper choice and dosage, these chemical additives may lead to a significant extension of the normal Central Detector lifetime.

2. AGEING STATUS OF THE UA1 CENTRAL DETECTOR

2.1 *The Image Chamber*

Fig. 1 and 2 show the basic geometry of the UA1 Central Detector. The 25 m³, 6 meter long cylinder is divided into 6 half cylinders, the 0.7 Tesla magnetic field is horizontal and parallel to the wires, perpendicular to the beam line. The planes of wires are specially arranged in order to optimize the momentum measurement accuracy, the sagitta being measured by the drift time. The general characteristics of the detector are shown in Table 1. The electronics record the total charge collected and the 3 space coordinates (wire number, drift time, and position along the wire using the charge division technique) for each hit. Fig. 3 gives a Megatek display of all the hits of a typical UA1 event.

2.2 Charge Collected in the Hot Region

Since 1981 a large amount of data has been collected, which, excluding the 1987 technical run, amounted to 770 events/nb. At large luminosities currents up to $30 \mu\text{A}$ have been drawn in the "hot-test" drift gaps, near the beam pipe. The currents are almost linear with the luminosity, as shown in fig. 4. This proves that the beam gas interactions are not the dominant source of gap current. In these drift gaps, which are in the forward chambers, the current is approximately given by:

$$I [\mu\text{A}] = 7 \times 10^{-29} \times L [\text{cm}^{-2}\text{s}^{-1}].$$

Using the hits from minimum bias tracks the probability of a hit reaching a given wire in the first drift gap of the forward chamber was derived (see fig. 5). This ranges between 0.6% to 0.7%. The charge division coordinate distribution, in fig. 6, is almost Gaussian with a fitted standard deviation $\sigma = 20 \text{ cm}$ for all forward drift gaps. This width does not change significantly along the beam direction.

From these observations it was concluded that the total charge collected on the hottest wires, corresponds to a maximum density of $10 \text{ mC/cm} \times \text{pb}$. Taking the total integrated luminosity and assuming a 20% data taking inefficiency, this corresponds to a collected charge of about 10 mC/cm as of 1987.

2.3 Search for an Ageing Effect

Two approaches were taken in searching for an ageing effect in the Central Detector. The first was to compare the performance of the detector in September 1983, almost at the beginning of the large integrated luminosity runs, with that of December 1985, the end of the last physics run. Using the hits from minimum bias data, we select those situated in the hottest region of the detector, namely wires 61 to 110 and $\|z\| < 20 \text{ cm}$ (see figs 5 and 6) and plot the charge collected per hit correcting for the track angle. In order to compare the two periods, fig. 7 shows the September 1983 and December 1985 distributions normalized to the same gain and to one event. In case of serious illness one would expect a deformation of this distribution, meaning a change in the width and not the mean value. No noticeable change was observed.

The second approach was to assume that a possible deterioration of the performances, if any, can be due to **local** defects on the sense wires; a deposit in the immediate vicinity of the avalanche. With the magnetic field being directed along the wires, the drift direction is tilted 23° with respect to the electric field orientation (fig. 8). Keeping in mind the fact that UA1 has run with the same field polarity since 1981, one would expect the eventual deposit to be non-uniformly distributed around the sense wires. Since 80% of the positive ions from the avalanche return to the drift volume, one can deduce that the avalanche does not spread around the wire, but covers an area with a sigma of about 60° . Thus the non-uniformity of the deposits should be preserved at some level. We therefore inverted the magnetic field, such that the drift angle becomes -23° and hence the "young" part of the sense wire is exposed. Fig. 9 gives the same distribution as fig. 7 for hard trigger tracks, and normal and inverted magnetic fields from December 1985 data. Once again, no observable change in the width of these distributions is found.

The conclusion is that there is no observable change in the performance of the UA1 Central Detector.

3. TEST CHAMBER CONDITIONS

The laboratory tests were made with small test chambers, which served as models for the UA1 Central Detector. These chambers were identical to those described earlier [3,4]; their basic features and relevant parameters are given in Table 2.

Two configurations were used for the tests. In the first (fig. 10), the ^{90}Sr source faced the quartz window used for the laser. This attenuated the source somewhat, and led to a slower ageing of the chamber. The source profile inside the chamber had to be measured, and is shown in fig. 11. This format was used for the first standard run without additives.

For subsequent tests the ^{90}Sr source irradiated the chamber through a thin Mylar window facing the wires opposite to the drift direction as shown in fig. 12. This increased the radiation inside the chamber and thus accelerated the tests. It was found necessary for practical reasons, as the first test ran

continuously for three months. This configuration also permitted the determination of the source intensity profile through measurement of the lateral spread of current on each of the 24 anode wires. Assuming a uniform azimuthal collimation of the source, we used this information for the calculation of the longitudinal spread or the induced charge along the wire. The source intensity distribution for this configuration is given in fig. 13.

Unlike the large chamber, the small test apparatus allows easy diagnoses of the progressing ageing symptoms. During the tests it was possible to:

- (a) measure the anode current on individual sense wires with and without a ^{90}Sr source,
- (b) measure the gain and stability with a weak ^{55}Fe source,
- (c) monitor the resolution σ/E of the 5.9 keV X-ray line of the ^{55}Fe source.

To correctly determine the absorbed charge density [mC/cm] on the sense wires, the current measurements on the wires were repeated regularly in the course of the experiment. The shape of this distribution, as shown in fig. 13, remained unchanged. However, the absolute value of the current readings would vary, if not by ageing itself, then due to systematic effects influencing the wire gain, such as small changes in temperature and/or gas mixture. The short-term fluctuations, at the level of a few per cent, were averaged out by updating the sense current measurements roughly every 12 h.

Two goals determined the conditions of the tests:

First to study ageing under conditions similar to those in effect for the main UA1 Central Detector; (i.e. pure gas without additives) in order to anticipate the ageing symptoms that could be expected. If possible to estimate some kind of maximum charge [mC/cm] the detector could sustain without serious harm. Serious harm being either gain changes or the evolution of the Malter effect. Having identified the problems, possible cures for the degraded chamber performance were then investigated. Secondly to study the influence of low ionization potential (IP) chemical additives on chamber lifetime as compared to the behavior of an un-seeded chamber. DMA and TMPD were the two additives studied here due to their promising behavior as doping seeds for UV laser calibration, as shown in earlier work [3].

4. AGEING TESTS WITHOUT ADDITIVES

4.1 *The Slow Test*

A "slow" test was thought to be desirable, as it was believed that it would more closely approximate the actual conditions in the CD as compared to the very highly accelerated ageing tests usually performed for practical considerations. Thus the chamber was irradiated with a ^{90}Sr source over a period of a few months.

The test cell seemed to exhibit two clearly distinguishable phenomena. The first was a presence of some after pulsing mechanisms, which would turn on and then disappear after a few minutes as if the cause was destroyed by the effect. The second, and by far most serious phenomenon was the appearance of large DC currents with the characteristics of a Malter or thin film current from the cathode wires. This current led in a short time to sparking.

The after pulsing, if truly a separate phenomenon, seems to be only a nuisance. Whether or not it exists in the UA1 CD, is not known. It was first observed after about 270 h of radiation in the test chamber, but may have been present at an earlier time. It is associated with no particular wire and never lasts long. An example of this is shown in figs 14(a,b). These figures show two ^{55}Fe spectra from the same wire taken in a very short time sequence. In fig. 14(a) one can see the excess counts below the escape peak caused by the after pulsing. A short time later it returned to normal (fig. 14(b)). This might be related to the possibility reported by Va'Vra [1] that deposits may form on the cathode wire, which cause them to become photo sensitive. Later the deposits are destroyed by the positive ions from the pulses they cause. Whether or not this phenomenon is a precursor to the Malter effect, is not clear. If it could be shown to be an early indication of the Malter effect, it could be quite useful as a warning of the approach of further problems. It must be emphasized, however, that in the present tests there was no observed correlation between wires, where the after pulsing was observed, and those, which later developed Malter currents.

The Malter currents are by far the most serious problem, as they did not follow a completely regular pattern, such that the probability of a problem increased with collected charge on a wire, but was not solely dependent on it. The problem does seem to be connected to the large electric field on

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the cathode wire surface, as observed by others [5, 6]. The problem occurred in three separate cells before the test was terminated. In each case it seemed to originate on the cathode wire closest to the anode wire. The cathode would emit a current in a DC fashion, as opposed to any kind of pulse structure. This current would be amplified at the anode wire, and the resulting positive ions would return to all three cathode and two field wires. This would greatly accelerate their ageing as well as the degradation of the original cathode wire. However, by the time this happened, the wires shared by other cells would also begin to have secondary currents, spreading the problem to the next cell. This is clearly fatal to chamber operation.

The fact that the field wire current does not grow at the same rate as the cathode, may be a sign that the trouble has spread from the center cathode wire to the outer cathode wire first. It could be explained by the bulk of the positive ions generated by the first bad wire returning to that wire and some to its nearest neighbors. The neighboring wires then undergo accelerated ageing and become current sources as well. This cycle then repeats itself. Thus the field wires only draw current when positive ions from the wires next to a damaged one move there. The currents then distort the local fields, and the field wires themselves age.

The first cell to develop a problem, the ninth from the source was allowed to proceed to sparking. This occurred after about 300 hours of irradiation. After the sparking, the three cathode and two field wires flanking the anode wire had visible deposits. It was decided to clean the wires with acetone. The deposits on the center cathode wire were much harder to clean. After all visible deposits were removed and the chamber gas restored, voltage was applied. Immediately a very uniform blue discharge was observed on the center cathode extending in the direction of both anodes. This wire was then removed and viewed with an electron microscope, which showed the presence of a thin film [4]. Again voltage was applied. However the two cathode wires on either side of the original problem cathode wire were found to be emitting electrons to neighboring cells. Thus left alone the currents quickly spread from cell to neighboring cell. These neighboring cells were then shut off by applying a negative voltage to the anode wires, and the test was continued.

After 1200 h of irradiation currents appeared in the seventh cell from the source. In this advanced state of wire ageing, we investigated more closely the behavior of the Malter current.

It is well-known that these currents are totally "extinguished", when the gain of the chamber is reduced to zero and then restored.

Since the Malter effect seems to be primarily associated with high cathode fields, we measured this current as a function of cathode voltage. This is shown in fig. 15(a) for cathode voltages between 2.0 and 2.7 kV. For this curve the field voltage remained at 2.0 kV and the drift voltage at 27.0 kV. If the measured current values are corrected for the proper gain; (i.e. the wire amplification in the absence of these currents), the Malter currents tend to fall behind the expected gain curve (fig. 15(b)). This effect can be partially explained by an unusual concentration of positive space charges in the vicinity of the sense wires, which effectively reduces the original wire gain. The apparent increase in the field wire current at the expense of the cathode current is caused by the change in the electric field lines followed by the positive ions.

Assuming the currents are attenuated by space charge, as the gain increases, this figure demonstrates that the source of the current stays approximately unchanged, while the voltage is lowered. While the cathode voltage had only been lowered 700 V, the cathode electric field went from 33 kV/cm to 16 kV/cm, (i.e. it falls to half its value). At the same time the field wire electric field goes up to 11kV/cm as a consequence of now having the same voltage as the cathode wires. Thus, once the Malter effect has been initiated, it is not influenced by the electric field even down to values usually considered safe in wire chamber construction. At this point the currents were monitored at the lowered gain for 3 h and found to initially drop slightly and then began to grow again.

The cell was then turned off and the test continued. The currents next appeared at the cell farthest from the source. The chamber was then used to examine the effects of cures described below.

4.2 The Fast Test

After a reconfiguration of the apparatus as described above, which included a purifier, a second test with no additive was conducted to look for discrepancies due to the increased radiation. The results of the ageing with the purified and unseeded gas are shown in figs 16(a-c). The results are shown for wire No. 12, the most irradiated one in our test.

In both this test and the slower test above, the chamber lifetime was limited by the development of severe Malter currents, which ultimately reached values of a few μA per wire. As we have seen before, this rapidly increases the rate of ageing. The plots of figs 16(a–c) clearly indicate that the history of ageing, under these circumstances, exhibits essentially no indication of progressing degradation in chamber performance. Furthermore, the quality of the ^{55}Fe spectra remains almost perfectly intact, even up to the sudden onset of Malter currents, as shown in fig. 16(b). Only then does the ^{55}Fe X-ray spectrum become abruptly masked by gain modifying currents caused by electrons emitted from the ageing defects on the cathodes (see fig. 21(c)). It seems that the anode wires are relatively unaffected by the large amount of charge provoked in the avalanche region. After quenching the Malter current by turning the wire gain off and on, the recovered ^{55}Fe sense wire spectrum in fig. 21(b) remains indistinguishable from the reference spectrum of fig. 21(a). Microscopic analysis revealed that indeed anode deposits, though visible, are clearly outnumbered by cathode defects, as has been reported previously [4].

These currents were always found to originate with the cathode wires with the highest electric field, (i.e. 33 kV/cm). This tends to corroborate the general view that these large fields should be avoided.

5. AGEING WITH LOW IONIZATION POTENTIAL ADDITIVES (DMA AND TMPD)

In many of the present and future wire chambers, like the UA1 Central Detector or the large volume TPC's, electrons must drift over relatively large distances before they reach the detection region of the counter. A typical problem associated with such drift distances is electron attachment due to electronegative impurities such as oxygen, present in the counting gas. Therefore, to maintain a reasonable lifetime for the track generated primary electrons, gas purification devices are usually employed in a recirculating closed loop gas system. For the UA1 track chambers (Central Detector and Muon detector) a system consisting of a catalytic purifier and a molecular sieve was chosen to remove prima-

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rily oxygen from the counting gas. However, the catalytic conversion of oxygen in the presence of hydrocarbons effectively removes other impurities, such as the organic residues of solvents, (e.g. Phenol), used by the gas supply industry [7]. On the other hand, double photon ionization with lasers, also of prime interest for these large detectors, relies on these trace impurities for their low ionization potential. In this situation it then becomes necessary to add the chemicals to the gas. However, tests by J. Kadyk [8], show that ageing can be influenced by different grades of gas quality. Therefore it was necessary to worry about what these additives would do to the detector.

It should be emphasized that by investigating the influence of two chemicals on wire ageing we had not made an arbitrary choice. Both compounds, Di-Methyl-Anilin (DMA) and N-N'-N'-Tetra-Methyl-p-Phenylene-Diamine (TMPD, also known as Wurster's Blue) had been carefully selected in earlier tests [3] as low ionization potential (IP) (DMA: 7.10 ± 0.05 eV [9], TMPD: 6.75 ± 0.02 eV [10]) doping seeds in counting gases for UV laser induced ionization. Also, in terms of chemical structure (as Benzene derivatives) they are typical representatives of seeding agents used for UV laser calibration of gaseous detectors [11].

DMA, a liquid at NTP, is easy to handle and can be introduced into the chamber as a saturated vapor (0.1 Torr at 4 °C) with the counting gas.

TMPD, on the other hand, is a solid with very low vapor pressure at NTP (approximately 10^{-3} Torr), and due to its sublimation and adsorption behavior is quite difficult to control as a gas seed. However, its excellent efficiency and electron yield under UV irradiation also made it a choice candidate for the ageing test series.

5.1 Ageing with DMA

The test chamber was re-equipped with a new wire plane, made from the same spools of wire as the original chamber, while the gas system was slightly revised to allow for the addition of DMA vapor. Since the chamber gas is bubbling through a sample of liquid DMA, the amount of vapor is easily controlled via the temperature of the sample, typically between -2 and 0 °C. Hence the concentration of DMA in the chamber gas was kept at approximately 100 parts per million (ppm). At this value the

laser induced ionization of a $10\ \mu\text{J}$ N_2 laser yielded $1300\ \text{e}^-/\text{cm}$ or nearly 10 times the minimum ionizing equivalent. The testing procedure and monitoring for ageing were otherwise the same as before. The results are shown in figs 17(a–c).

In the present tests, essentially every industrial chemical residue had been removed by the purifying system. For even at the highest possible wire gain no N_2 laser induced ionization was detectable. We can therefore be reasonably sure that, whatever had caused an abnormal ageing in our tests, must be attributed to the deliberate seeding of the counting gas with the chosen chemicals. Figs 17(a–c) show that, in the case of 100 ppm of DMA, ageing is strongly influenced by this chemical, resulting in a rapid loss of wire gain. The almost instantaneous deterioration in the X-ray resolution, σ/E , shown in fig. 21(d), suggests a prompt build up of anode deposits in the avalanche region spreading quickly along the entire length of the sense wire. Within a short time, (i.e. $5\ \text{mC}/\text{cm}$ absorbed charge), the wire gain has dropped by a factor of two. The effects on the anode currents also become visible at approximately $5\ \text{mC}/\text{cm}$. They are less drastic due to the non-uniform ageing of the wire. After termination of the test, (fig. 21(e)), the wires were inspected visually and microscopically. To the naked eye the sense wires appeared to be coated with a greasy blue tinted substance. The scanning electron microscope showed a $2\ \mu\text{m}$ thick insulating layer of a carbon and oxygen containing compound, possibly a polymer, covering the sense wire. The cathode wires, in contrast, showed only negligible deposits of carbon and oxygen rich material.

5.2 Ageing with TMPD at NTP

Discouraged by the negative results obtained with DMA, it was hoped that a significant reduction in additive concentration would slow down the ageing rate accordingly. However, DMA vapors diluted to the ppm level, release practically no ionization when tested with our UV laser. Therefore, DMA had to be ruled out in favor of TMPD, known to have a vapor pressure of a few mTorr at NTP. It then enters the test chamber at a volume level of no more than a few ppm. In spite of this 100-fold reduction in trace admixture, TMPD still has the highest electron yield under UV laser irradiation; i.e. $> 10^4\ \text{e}^-/\text{cm}$.

As for liquid DMA, the gas would pass through a vessel holding only 2 small crystals of TMPD (circa 2 mm³ large), before entering the test chamber, with a new wire plane. The presence and concentration of TMPD were regularly checked with the N₂ laser.

The results obtained with our standard test method are shown in figs 18(a-c).

Unfortunately similar results and observations hold true for TMPD, when used at a level of approximately 1 ppm as for 100 ppm of DMA. This includes X-ray and microscopic analysis. The characteristics of ageing are the same. However, in spite of the fact that the TMPD concentration was much less than that of DMA, ageing in terms of anode wire deposition proceeded more rapidly for TMPD, as seen in figs 21(f) and 21(g).

5.3 Ageing with TMPD at the PPB Level

After the last test it was clear that, whatever the ageing mechanism in the presence of these low IP organic molecules, a further ageing test would be sensible only, if these organic traces could be reduced by a few orders of magnitude, without sacrificing the goal of laser induced ionization. Fortunately, TMPD is very efficient in this respect, but handled in proportions of a few ppb posed severe problems for controlling and maintaining such minute concentrations. It was found that TMPD is partially sticky, i.e. its adsorption rate on surfaces is larger than the evaporation or sublimation rate into the gas volume.

Cooling TMPD crystals for the purpose of lowering the vapor pressure proved unfeasible, since over a wide temperature range, ($-100 < T [^{\circ}\text{C}] < -30$), no detectable vapor would enter the chamber. Above -30°C , however, the concentration of TMPD could not be controlled any more, probably due to the adsorption effects, and consequently saturated the preamplifiers. The method finally adopted was to have the chamber gas pass over the TMPD grains (at NTP) for only a short period of time, while otherwise bypassing the TMPD container. One can define in this way a duty cycle in time equivalent to a certain concentration of TMPD. In practice, two electrical three way valves (see fig. 19), operated by a simple timing mechanism, would open the TMPD volume to the gas flow for a fixed time (minimum 13 sec). Thereafter, the counting gas is directly admitted to the chamber for a long period, of the order

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of 2×10^4 sec. This defines an average dilution factor of 6×10^{-4} . Due to the small chamber volume of 15 l, this method created fluctuations in the actual TMPD concentration monitored via the UV laser. Owing to the slow sublimation effect, this resulted in an average integrated trace level of < 1 ppb.

This is still adequate for laser induced ionization being equivalent to approximately 1 minimum ionizing particle, or $100 \text{ e}^-/\text{cm}$. The above method can be improved with shorter on/off periods of the electrical valves, still keeping the original duty cycle of 6×10^{-4} . Although the timing circuitry worked reliably throughout the experiment, the TMPD concentration was periodically monitored with the UV laser. The laser was by far the most accurate and sensitive method of trace analysis.

As in all previous measurements, the standard test cycle was followed by monitoring at regular intervals, the anode currents, the gain and the resolution on the most irradiated wire. The results are shown in figs 20(a–c).

When the TMPD concentration is reduced to the ppb level, the ageing pattern remains essentially the same. As one would expect, however, the degradation in chamber performance follows a much slower pace. With respect to the former ageing test (1 ppm), one may consider the ageing at this level a controlled "slow motion" ageing process. Since the formation of anode deposits is still the dominant process during the ageing history, the ^{55}Fe energy resolution σ/E reacts most sensitively to the doping seed in the course of the test. Due to the very strong dilution of TMPD the anode deposits are built up only sporadically, i.e. non – uniformly on the anode wire. This could explain, for example, the rise in the σ/E plot of fig. 20 between 30 and 90 mC/cm absorbed charge. Afterwards, once the anode coating is more uniformly spread on the wire surface, the ^{55}Fe X – ray resolution improves, as the gain becomes more uniform as well. This phenomenon is probably totally masked in the two previous tests, since the wire gain had dropped to nearly zero by the time an improvement in σ/E could be detected. Notice that the speed of ageing is reduced approximately 100 times, although the TMPD concentration has changed by more than a factor of 1000. This discrepancy could be explained by saturation effects in the 1 ppm test and other possible systematic errors typical for a single test. For comparison the ^{55}Fe spectrum taken at the end of this test is given in fig. 21(h).

Another interesting outcome of the 1 ppb test is the total absence of Malter currents even after 300 mC/cm. In the two tests without additives, these currents appeared by the time approximately

40mC/cm absorbed charge had been accumulated. Therefore, cathode deposition seems to be suppressed by the presence of only 1 TMPD molecule out of 10^9 gas molecules. Whatever the cause of the Malter currents, 1 ppb of TMPD seems to be sufficient to totally inhibit it.

6. GAS ADDITIVES AGAINST MALTER CURRENTS

This part of the test series concerned the interesting question of possible cures, once ageing had advanced beyond the stability region of the wire chamber. Clearly, any progress made on this issue will also forecast specific preventive action, before a wire chamber becomes unstable or inoperable due to electrode deposits. As will be discussed below, the test results show two distinct features, namely where and under what test circumstances, the dominant deposit growth on wires occurs. It was soon found that the test apparatus, where smooth uniform anode coatings had degraded the gas gain, was virtually incurable by standard gas additives such as H_2O , ethanol or isopropanol. Only mechanical cleaning with strong solvents like acetone proved to be successful.

Cathode deposits are different and manifest themselves frequently as a spontaneous emission of electrons from the cathode. This process supports itself by a feedback of positive ions emerging from the anode multiplication region towards the cathode, where they enhance the build-up of dielectric deposits. It is believed that the phenomenon seen here is the Malter effect.

This effect was studied with the chamber used in the first, "slow", no additive test. After the end of the first test this chamber was used to investigate problems caused by discharges. The discharges ultimately caused anode deposits to form, so that the anode wires no longer had uniform gain. However, there were no deposits in the chamber that could be associated with additives. Following the experience of many other groups, Ethanol was tested as a means of stopping these currents.

With 0.8% Ethanol the currents ceased. If the Ethanol was turned off and the chamber flushed with fresh gas, the currents returned within 10 minutes, corresponding to about 0.5% Ethanol in the gas volume. Fig. 24 (discussed below) gives a similar behavior. With 0.6% Ethanol in the test chamber, it lasted approximately 2 hours before the currents returned. The Ethanol was replenished to 0.8%, and

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the chamber operated for an additional 500 hours of ageing as in the first test (i.e. the source electrons entered through the quartz window). If at any time the Ethanol was turned off, the currents would return as before. At the end of the 500 hours, the wire gain was checked along the wires and found to be the same as before. Thus, the Ethanol did not cause any further harm to the chamber, nor did it do any permanent good to it. No evidence of the Ethanol cleaning the wires was seen. However, as it will be shown later, the need for 0.8% Ethanol was probably due to the level of ageing in the chamber at the time of the test.

This test chamber was then used to examine the other common additives for limiting currents. During the course of these tests the chamber was allowed to draw currents for extended periods of time. These currents caused the state of the chamber to deteriorate very rapidly. This in turn caused the magnitude of the currents to increase. Thus the results are only qualitative and not quantitative, because, when each additive was tried, the conditions of the test changed.

The next substance to be tested was isopropanol. 0.5% isopropanol was added to the gas and found to control the currents (fig. 22). The isopropanol was then removed from the gas system and pure $\text{Ar}/\text{C}_2\text{H}_6$ flushed through the chamber. The chamber was then exposed to the ^{90}Sr source. It was periodically removed and the current without source checked. As a function of concentration the currents then returned (as shown in the square symbols of fig. 22) to a value fluctuating between 1.1 and 1.2 μA . When the isopropanol was re-introduced, the currents returned to background level as shown in the round symbols of fig. 22.

In the next test we investigated Di-Methyl-Aniline (DMA). This was done in the opposite order to isopropanol. With clean gas the source was used to initiate the Malter currents and then removed. DMA was introduced to the chamber at 1.3 μA initial current. This current then diminished, as shown by the round symbols in fig. 23. However, in this case only 0.02% (200 ppm) of DMA was needed to stop the currents. The DMA was disconnected, and the concentration needed to fall below 0.01%, for the Malter current to return (square symbols in fig. 23). Note that as in previous tests the return of the Malter current had to be triggered by a short exposure of the chamber to the ^{90}Sr source!

This test could not be performed with TMPD due to the much longer period of time needed to introduce and remove the chemical.

In order to examine the advanced ageing state of the chamber, the same test was then done with Ethanol. The currents were restored with pure gas, now to the level of $1.5\ \mu\text{A}$. The ethanol was then introduced and the currents monitored. The currents diminished as in the first two cases. However, this time there seemed to be steps in the process (round symbols of fig. 24). This could have been due to current sources in different regions of the chamber being quenched by different concentrations of ethanol. In the end it took 20 minutes and about 1% ethanol to stop the current. The reverse process was then tried and the currents turned on sharply at about 0.5% (square symbols in fig. 24). This was similar to the behavior before the long-term ethanol test.

The chamber now went through very rapid deterioration, and we wanted to test, whether the addition of water might also remove the Malter current. The chamber with pure $\text{Ar/C}_2\text{H}_6$ now drew $4.5\ \mu\text{A}$ with the source removed. The water was then introduced and at a concentration of 0.7% had reduced the currents to $0.4\ \mu\text{A}$ (fig. 25), but still above background. When the voltage was turned off and on to stop the residual current, and the source used to re-trigger the current, it now returned to $0.2\ \mu\text{A}$ and then began to grow. The water was then flushed from the chamber.

At this point isopropanol was again introduced to the chamber, and it was found that 0.5% no longer reduced the currents to background levels, but to $0.2\ \mu\text{A}$ as in the case of water. It was then decided that, given the highly advanced state of chamber deterioration, even qualitative comparisons were becoming difficult, and so the test chamber was retired. However, it seemed clear that the absolute amount of additive needed to control the current depended on the level of damage to the chamber. The further advanced the state of ageing, the greater the concentration of a given additive had to be to control the currents.

Notice that our measurements with water were included in this series of tests as a matter of completeness, for due to electron attachment water is not practical in this sense for large drift gaps.

These Malter currents were known to be easily extinguished by the polar and oxygen containing molecules, such as water, ethanol and isopropanol at about the per cent level. It is interesting to note that an intrinsically different chemical, DMA, in spite of its nearly non-polar molecular moment and lack of oxygen, exhibits identical behavior in quenching the Malter currents, even at a significantly lower concentration, (i.e. 0.01% or 100 ppm, as seen in fig. 23).

7. DISCUSSION

The impact of low Ionization Potential additives on ageing can be summarized as beneficial for the cathode but detrimental to the anode. So while their presence accelerates the growth of polymers on the anode, they inhibit the polymerization on the cathode. This suggests that the two problems are separate. The mechanisms that lead to radiation damage to the cathode are not exactly the same as those causing radiation damage to the anode wires in wire chambers.

In his review, Va/Vra [1] presented a simple model of the polymerization process. His model suggested that polymers form in the avalanche near the anode wire and then migrate toward the cathode. The present tests indicate that both DMA and TMPD enhance the formation of polymers at the anode wire. The above simple model should then indicate that this will lead to a rapid polymerization on the cathode wire as well. However, this does not seem to be the case.

Kotthaus [6] presented an example, where Malter currents formed with cathode fields of 40 kV/cm, but were absent, when the cathode field was kept below 15 kV/cm. In his test the conditions at the anode wire were the same, only the cathode field was altered by changing the cathode wire diameter. His tests used a 50/50 Ar/C₂H₆ gas mixture, which support the view that the cathode field is critical to the formation of the film responsible for the Malter current. The tests made here on the Malter current show that, once the cathode wire starts acting as a current source, the source will remain approximately constant, even as the field is reduced to about 16 kV/cm. Thus, while a large cathode field appears to be important to the growth of damage to the cathode wire, it is not needed to maintain the Malter effect.

Here it was found that 1 ppb of TMPD was sufficient to inhibit the formation of Malter currents, even in the presence of 33 kV/cm cathode fields. 100 ppm of DMA proved efficient at controlling the Malter currents, after they had formed. That such small amounts are so effective would seem to imply that there is some mechanism, which must increase their concentration near the cathode wire. A natural possibility is that the charge exchange between neutral DMA or TMPD molecules and positive ethane ions must be very efficient. Thus, the argon and ethane ions, produced in the gas amplification process, are replaced by ions of the low IP additives, which are then brought by the electric field to the cathode.

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7.1 *The Importance of Charge Exchange*

The charge exchange cross section for these molecules and ethane or argon ions is, as far as we know, completely unknown. The low ionization potential of TMPD and DMA, combined with the large number of accessible molecular quantum states, could enhance the charge exchange cross section for these molecules. In this way, despite their small concentration, DMA and TMPD would replace ethane ions, so that by the time the positive ions have reached the cathode they would be primarily DMA^+ or TMPD^+ . The ionization potentials of ethanol (10.5 eV) and isopropanol (10.2 eV) are closer to the ionization potential of ethane (11.5) [1]. Thus, the charge exchange cross sections may be smaller, requiring a much higher concentration of alcohol. However, the effectiveness of water (IP = 12.6 eV) [1] at reducing the currents with an IP greater than ethane seems to contradict this argument.

It is possible that water is much more efficient at charge exchange with argon (IP = 15.8 eV) [1], than ethane with argon. Hence, even in small amounts the argon is neutralized more favorably by water than by ethane, even though there is more ethane in the gas mixture. The water is then not so easily neutralized by the lower ionization potential ethane. On the other hand, the effectiveness of water is often attributed to its ability to increase the conductivity of the cathode film, thereby destroying the Malter effect.

If the mechanism for charging the insulating film was itself a form of charge exchange, it might explain, why the lower ionization potential ions are not effective at charging the film. The film is not charged by ions that come and "stick" to it, but by the arrival of ions that are neutralized at the film, leaving it with a positive charge and the molecule neutral. Thus, the low ionization potential of DMA and TMPD could exclude this. But again one is left with the observation that the higher ionization energy alcohols and water molecules are also ineffective at charging the surface. It may be that there are two different processes for neutralizing the film. One, the inability to charge it, and the other, the ability to make it conductive.

This does not seem to answer the question of why the ethane ions are so effective at growing the insulating film, while the others are not, nor does it explain the importance of the field itself. Two pos-

sible models present themselves; reality may in fact be a mix of the two. Alone, neither is found to be totally satisfactory.

7.2 The Feedback Mechanism for the Growth of Malter Currents

This mechanism is based on the observation that, once the Malter currents form, they grow at a very accelerated rate. Once a thin film has been built up and is now acting as a localized current source, the emitted current is amplified at the anode and accelerates the ageing process. On this very small scale one can think of this as the inception of the problem. It is compatible with Va'Vra's simple model of the polymerization process.

A small amount of polymer, which is formed near the anode, as described by Va'Vra, migrates to the cathode and is fixed there. It generates a very small insulating region, which eventually charges up and, on a very small scale, becomes a Malter source. This sends electrons to the anode and accelerates the formation of polymers in that region, which then drift to the cathode. This continues, until a current develops large enough to be noticed. The additives kill this effect (e.g. 1 ppb of TMPD) by stopping the production chain at the root; (i.e. the TMPD ions generated via charge exchange, do not charge up the initial bit of cathode film), thus stopping the entire process.

The problem here is that we ignore the fact that the field is very important. It has been shown by us that the film on a wire with only 16 kV/cm acts as a current source approximately equal to that at 33 kV/cm, once charged. Thus, the above picture should work equally well in the case of a 33 kV/cm cathode field as for a 16 kV/cm field. This seems to be in contradiction with the tests of Kotthaus and the general experience of the wire chamber field. At this point, we should preferably come up with a model that provides cathode polymerization independent of anode polymerization. If there is polymerization near the cathode, it must be fed by the only source of energy around, the cathode electric field.

7.3 Polymer Formation in the Cathode Field

In the high field region near the cathode wire typically only positive ions are found. Thus, if there is polymer formation in this region, it cannot be fed by electron collisions. It would have to be fed by positive ion impact. Since the positive ions, which are copiously produced in the gas avalanche, drift through this region, they are present in large numbers. However, for the positive ions to cause polymerization, they must have a reasonable probability of gaining a few eV in kinetic energy. In general however, it is normal to think of positive ions as having a constant mobility, which follows from assuming that they remain at thermal temperatures. To have polymer formation in the cathode field this can no longer be true.

Loeb [12] discusses the value of fields, where the mobility is no longer constant. This depends on the type of ions involved and seems to vary from E/P of a few tens of volts/cm/torr to above a hundred volts/cm/torr. For N_2^+ in N_2 there is a strong break point around 40 volts/cm/torr. In our case, 33 kV/cm at 760 torr and 300 °K correspond to about 48 volts/cm/torr (reduced to 273 °K). Thus, it is conceivable that the ethane ions are no longer in thermal equilibrium with the surrounding gas at these fields. But no further information seems to be available. Without much comment Von Engel [13] suggests that an ion can pick up perhaps 0.1 to 1 eV along a mean free path at these energies. Therefore, if the mean free path for a collision was 0.1 μm and a positive ion was moving in the direction of a 3.3 V/ μm electric field, it would have to travel 3 mean free paths to gain 1 eV. The collision cross sections for ethane ions on ethane or argon in the range of 0.1 to 10 eV are not known.

Because the positive ions, unlike electrons, can lose a large fraction of their energy in an elastic collision with the gas, it is difficult for them to keep the energy they gained from the electric field. We may therefore intuitively estimate the energy distribution in these circumstances as:

$$f(\epsilon) = \exp(-\epsilon/\epsilon'),$$

where ϵ' is the product of the electric field and the average mean free path between collisions. Loeb [12] gives a similar expression based on classical assumptions. If such an energy distribution was valid, it would permit some empirical observations.

The first is that, if a process depended on the probability P of the positive ions exceeding some threshold energy, halving the electric field would reduce that probability to P^2 . Thus, if there was a 1% probability of a positive ion exceeding the energy needed to start polymerization at an electric field of 33 kV/cm, this probability would fall to 10^{-4} at 16 kV/cm. In other words, where 40 mC/cm accumulated charge was needed to cause the Malter current at 33 kV/cm, 4000 mC/cm would be needed at 16 kV/cm. Hence, there would be an exponential rise in the probability of Malter currents developing with an increase in the electric field.

This would then explain the strong dependence of the appearance of the Malter currents on the electric field. The probability of their appearance should depend linearly on accumulated charge and exponentially on the cathode electric field. As a consequence, once the currents have developed at 33 kV/cm, they can still grow, even when the field is reduced to 16 kV/cm due to the large increase in positive ions that result. However, if a chamber is always operated at a low cathode field, the danger is reduced to close to negligible.

Where the larger DMA or TMPD ions replace the ethane ions, the mean free path between collisions could be greatly reduced. This would have an affect similar to reducing the electric field. Thus reducing the mean free path between collisions by changing the ion type or increasing the gas pressure, would increase chamber safety.

It should be noted that the positive ions also move through much larger fields near the anode and so would have to contribute to some form of polymerization there as well. This however, could be masked by the effects of the electrons in the avalanche.

The above described feedback mechanism could then accelerate the cathode ageing, once initiated by the field.

It should be further emphasized that, lacking more quantitative evidence, this explanation seems to be only qualitatively plausible, and therefore still speculative. If such a process were present, it would have implications with respect to wire chamber breakdown.

7.4 Ionization by Positive Ion Impact

Ionization by positive ion impact is generally accepted as a negligible process in wire chambers. However, if the positive ions have a reasonable chance of reaching the few eV in energy needed to polymerize, there must be a finite probability of reaching the few tens of eV required to cause ionization by positive ion impact. If the above discussion is valid, this probability would increase exponentially with the electric field. Furthermore, if the probability of ionization by positive ion impact was of the order of 10^{-10} for fields of 33 kV/cm (a negligible probability), then at fields of 66 kV/cm the probability would rise to the order of 10^{-5} . This would no longer be negligible.

The criteria required to cause breakdown due to secondary mechanisms near the cathode (the release of electrons, while the positive ions are neutralized at the cathode for example), are when the product of wire gain and probability of an electron being released reaches 1. Therefore, if the probability of ionization by positive ion impact was 10^{-5} , and the gas amplification was 10^5 , for each electron produced, 10^5 positive ions would be generated leading on average to one more electron, etc. This is the point where the chamber is no longer stable, the breakdown point.

Thus, for the above argument on polymerization in the cathode field to be valid, there must be a value for a cathode field not far above where, depending on anode wire gain, the chamber breaks down. There is some evidence that this is the case.

Giubellino et. al. [14] have published results, which they have interpreted as implying that the chamber breakdown is caused, when the product of the anode gain (for electrons) and cathode gain (for electrons [!]) is of the order of 10^7 . However, it is difficult to see, what the effect of electron gain at the cathode would be. If there were 10^5 electrons and positive ions produced in the avalanche, none of those electrons would return to the cathode and therefore, it should be of no importance, how many are actually produced. On the other hand, the 10^5 positive ions can drift to the cathode. The electron gain increases exponentially with the field, as would the probability of ionization by positive ion impact. Thus, their estimate of the electron gain at the cathode may have the same form as the ionization probability by positive ions, only 7 orders of magnitude different in scale. Hence, the point where they estimate the electron gain to be 100, may be the regime, where the positive ion ionization probability is 10^{-5} .

Their evidence would seem to support the hypothesis that polymerization by the positive ions in the high cathode field is possible. To clearly identify the different processes would require additional specialized tests.

8. CONCLUSION

This work originated with the critical requirement that the UA1 Central Detector continue to operate in a reasonable fashion during the high luminosity (ACOL) runs of the collider. This represents a problem from increased space charge distortion of the track measurements and the increased danger of ageing, especially from Malter currents.

The first approach to reducing both the danger of Malter currents and the space charge distortions was taken in the Fall 1987 technical run. The gain of the preamplifiers was increased by a factor of three, and the operating voltage of the chamber was lowered accordingly. This reduced the wire gain by about a factor of three, and hence the number of positive ions. It also reduced the cathode electric field to 27 kV/cm. It is hoped that these measures will lessen the risk of Malter currents forming.

To map the residual space charge distortions necessitates a laser calibration system with the addition of a low IP gas seed. Such a system was tested in the last collider run and will be reported separately. At present there seems to be no visible ageing problem with the UA1 CD. However, there was enough concern to understand future problems, and how laser seeds would influence them to warrant this study.

We believe that the results quoted here are not specific to this detector alone and may therefore be of general interest for any device, under similar circumstances, where laser double photon induced ionization is based on low IP chemicals, deliberately added to or residually present in pure counting gases. In high radiation environments these trace additives, even at the ppm level, can cause severe degradation in chamber performance and should be used with extreme caution.

TMPD, if employed in minute ppb concentrations, has been shown to give tolerable chamber ageing ($Q_{\max}$ of the order of 300 mC/cm) with acceptable laser induced track ionization, using a low power 10 μ J Nitrogen laser over a two meter track length.

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TABLE CAPTIONS

TABLE 1 General characteristics of the UA1 Central Detector.

TABLE 2 General characteristics of the test chamber.

TABLE 1

Type	Drift chamber with charge division readout of the second coordinate
Gas mixture	Argon (40%) + ethane (60%)
Drift field and gap length	1.5 kV/cm, 18cm
Drift velocity	5.3 cm/microsec
Drift angle	23^0 at $B = 0.7 \text{ T}$
Anode plan arrangement	
a) Distance between sense wires	10 mm
b) Wire length	80 cm min., 220 cm max.
c) Sense wire charac.	35 microns Ni-Cr stretched at 80 g
d) Field wire charac.	100 microns gold-plated Cu-Be stretched at 200 g
Cathode plane structure	
a) Distance between wires	5 mm
b) Wire characteristics	150 microns gold-plated Cu-Be stretched at 200 g
Total number of wires	22800
Total number of sense wires	6110

TABLE 2

1.) Mechanical Parameters:

Chamber material outside: copper plated G10

inside: STESALITE covered with G10; Kapton foil with etched copper strips serving as potential degrader; drift gap: 18 cm; MYLAR window for sources; Quartz windows for laser.

Chamber volume: ~ 15 liters

Wires: 24 anode wires, 35 μm f , Ni-Cr, 10 mm apart and interspaced with field wires.

25 field wires, 100 μm f , gold plated Cu-Be, 10 mm apart.

49 cathode wires, 150 μm f , gold plated Cu-Be, 5 mm spacing.

2.) Gas Parameters:

Gas mixture: ARGON-ETHANE (40-60); Argon taken as Ar-vapor from LAr; Ethane - commercial grade - supplied in bottles.

Purity: < 5 ppm O_2 , purified via catalytic conversion and molecular sieve (system LEYBOLD-HAEREUS).

Tubing: stainless steel and RILSAN.

Flow: 60 liters/hour

3.) Electrical Parameters:

Drift voltage: $\text{VD} = - 27.0 \text{ kV}$ $\Rightarrow E = 1.5 \text{ kV/cm}$

Field voltage: $\text{VF} = - 2.0 \text{ kV}$ drift velocity: 53 mm/ μsec

Cathode voltage: $\text{VC} = - 2.7 \text{ kV}$

Anode field: $E_A = 210 \text{ kV/cm}$

Cathode field: $E_C = 33 \text{ kV/cm}$

FIGURE CAPTIONS

- Fig. 1 Open, schematic view of the UA1 Central Detector.
- Fig. 2 Basic arrangement of the drift cells of the Central Detector.
- Fig. 3 MEGATEK display of a typical UA1 event.
- Fig. 4 Current in the first drift gap of a forward chamber versus the luminosity.
- Fig. 5 Probability of a hit reaching a given wire in the first drift gap of a forward chamber.
- Fig. 6 Charge division coordinate (along the wires) in the hottest region.
- Fig. 7 Minimum bias trigger; Landau distribution obtained in September 1983 and December 1985 for the hot region.
- Fig. 8 Sketch of the drift lines in the presence of a magnetic field.
- Fig. 9 "Hard" trigger; Landau distribution with normal and inverted magnetic field for the most aged region of the Central Detector.
- Fig. 10 Sketch of the experimental test setup. The position of the source for the first test without chemical additives is shown. The wire configuration is identical to the UA1 Central Detector.
- Fig. 11 Three dimensional "Lego" plot of the measured source intensity inside the test chamber for the first test.
- Fig. 12 Source and laser position for all but the first ageing test. Sketch of the experimental test setup (not drawn to scale).
- Fig. 13 ^{90}Sr source intensity profile. The profile was fitted to a Gaussian plus a constant background to determine the charge distribution along the wires.

FIGURE CAPTIONS (Cont'd)

- Fig. 14 An example of the ^{55}Fe —spectrum taken while afterpulsing was present on the wire (fig. (a)). After typically a few minutes the afterpulsing would vanish, and the wire would return to normal. See fig. (b) taken on the same wire shortly after that of fig. (a).
- Fig. 15 Absolute value of the Malter current drawn by the anode wires (round symbols), the cathode wires, (square symbols) and field wires (triangles), as the cathode voltage was reduced to 2.0 kV (fig. (a)). At the same time the electric field on the surface of the cathode wire drops from 33 kV/cm to 16 kV/cm. After correcting for the change in gain with voltage, (fig. (b)), the current appears to increase as the cathode field is decreased. This is assumed to be a space charge effect.
- Fig. 16 (a)-(c) Ageing history with no additives.
- Fig. 17 (a)-(c) Ageing history for 100 ppm of DMA.
- Fig. 18 (a)-(c) Ageing history for 1 ppm of TMPD.
- Fig. 19 Schematic of gas flow with and without TMPD.
- Fig. 20 (a)-(c) Ageing history for 1 ppb of TMPD.
- Fig. 21 Examples of the ^{55}Fe spectra taken during different stages of the various tests. In all cases the energy scale is in arbitrary units.
- (a) ^{55}Fe reference spectrum with pure gas and no ageing. At the beginning of all tests the spectra taken were essentially equivalent to this one.
- (b) Recovered ^{55}Fe spectrum after the Malter discharge has been quenched. At this point the anode has collected a maximum charge of 50 mC/cm running in clean gas without any additives.

FIGURE CAPTIONS (Cont'd)

Fig. 21 (c) ^{55}Fe spectrum masked due to Malter discharges.

(d) Degraded ^{55}Fe spectrum after 4.6 mC/cm accumulated charge with 100 ppm of DMA in the gas mixture.

(e) ^{55}Fe spectrum at the end of DMA ageing test; the spectrum was then dominated by noise. Total accumulated charge 12.2 mC/cm

(f) Ageing in the early stages of the 1 ppm of TMPD test. Total collected charge was 0.63mC/cm.

(g) ^{55}Fe spectrum at the end of 1 ppm TMPD test. Total collected charge on the anode wire was 3.2 mC/cm.

(h) ^{55}Fe spectrum at the end of 1 ppb TMPD test. This corresponded to a maximum charge of 312 mC/cm on the surface of the anode wire.

Fig. 22 Malter current as a function of Isopropanol concentration. The open square symbols represent the increase in current, as the isopropanol is removed from the chamber by gas flow. The solid round symbols represent the drop in current, as the isopropanol is introduced to the chamber.

Fig. 23 Malter current as a function of DMA concentration. As in fig. 22 the solid symbols represent the fall in current, as the DMA enters the test chamber. Open squares demonstrate the return of the current, as the DMA is flushed from the chamber.

Fig. 24 Malter Current as a function of Ethanol concentration. Symbols as in figs 22 and 23. Note the step-like decrease in current, as ethanol enters, but abrupt increase in current, as the ethanol is flushed from the chamber.

FIGURE CAPTIONS (Cont'd)

Fig. 25 Drop in malter current versus the concentration of water, as water is introduced to the chamber. The current never reached background levels even, as the water reached maximum concentration for the apparatus configuration.

Fig. 1

FORWARD CHAMBER

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

The sense wires
have not the same
"age" all around

Enlarged view

Fig. 8

Fig. 9

Fig. 10

Source intensity for ^{90}Sr

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

AGING WITH PURE GAS

Fig. 16

Fig. 17

AGING WITH 1 PPM TMPD

Fig. 18

Fig. 19

Fig. 20

Fig. 21(a)

AGING WITH PURE GAS - Q = 50 mCoul/cm

Fig. 21(b)

AGING WITH PURE GAS - Q = 50 mCoul/cm

Fig. 21(c)

AGING WITH 100 PPM DMA - Q = 4.6 mCoul/cm

Fig. 21(d)

AGING WITH 100 PPM DMA - Q = 12.2 mCoul/cm

Fig. 21(e)

AGING WITH 1 PPM TMPD - Q = .63 mCoul/cm

Fig. 21(f)

AGING WITH 1 PPM TMPD - Q = 3.2 mCoul/cm

Fig. 21(g)

AGING WITH 1 PPB TMPD - Q = 312 mCoul/cm

Fig. 21(h)

Fig. 22

Fig. 23

Fig. 24

Fig. 25