INFN - Laboratori Nazionali di Frascati
Servizio Documentazione

LNF-91/004 (P)
21 Gennaio 1991

EFFECTS OF GAS MIXTURE ON LIMITED STREAMER CHAMBER PERFORMANCE

G. Bari, G. Bruni, G. Cara Romeo, A. Contin, C. Del Papa, G. Iacobucci, G. Maccarone, D. Mencarini, R. Nania and G. Sartorelli
University of Bologna and INFN, Bologna, Italy

G. Anzivino, S. Bianco, R. Casaccia, F. Cindolo, L. Daniello, M. De Felici, M. Enorini, D. Fabbri, F. L. Fabbri, M. Giardoni, I. Laakso, M. Lindozzi, E. Pallante, L. Passamonti, V. Russo, M. Ventura, L. Votano, and A. Zallo
Laboratori Nazionalei di Frascati dell' INFN, C.P13, 00044 Frascati (Rome) Italy

Y. Dong, G. Q. Ji, N.I. Qazi, and S. Sarwar
ICSC World Laboratory, Lausanne, Switzerland

G. D'Ali
University of Palermo, Italy

The large volume detector at Gran Sasso employs roughly 15,000 limited streamer chambers for its tracking system. Streamer chamber performance strongly depends upon the nature of gas mixture used to fill it. We describe a comparison between the use of the standard binary (30% argon + 70% isobutane) and a low-hydrocarbon ternary (2% argon + 10% isobutane + 88% carbon dioxide) gas mixture. The ternary mixture results in a 400 volts shorter single count rate plateau, a 20% smaller primary streamer pulse-height and a much higher streamer multiplicity. The single count rate plateau was also studied for a wide composition range for isobutane, argon and carbon dioxide mixtures. Finally the source and effect of gas impurities, on performance of chambers operated with the standard binary mixture, was also investigated.

1. INTRODUCTION

The Large Volume Detector[1] (LVD) being installed at the Gran Sasso laboratory can be defined as an underground observatory to study neutrino astronomy and the penetrating components of cosmic rays. It consists of 2280 m^3 of liquid scintillator inter-layered with 15,000 tracking chambers operating in the limited streamer mode. These chambers will divide the LVD volume in eight horizontal and five vertical planes. Each of these planes consists of two layers of streamer chambers, external pickup strips, and appropriate readout electronics.

The operating principles and constructional details of limited streamer chambers are well known[2]. The LVD chambers (Fig.1), are Frascati-standard, coverless devices with a length of 6.3 m. A PVC profile containing eight rectangular cells with a 1-cm^2 cross section is internally coated with graphite paint. Surface resistivity of the painted profile varies within a range of 0.05-2 MΩ/sqr. Silver-plated, 100 μm, Cu-Be wires are extended through the center of each cell and connected to a printed circuit board at two ends. Plastic bridges support the wires at 50-cm intervals. The profiles are enclosed by a PVC jacket, and plastic caps welded at the two ends provide electrical and gas connections.

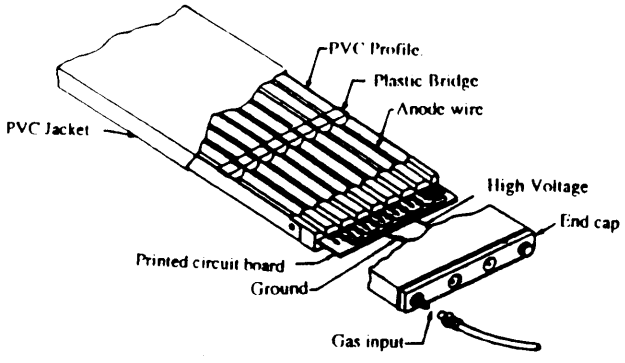


FIG. 1 - LVD streamer chamber.

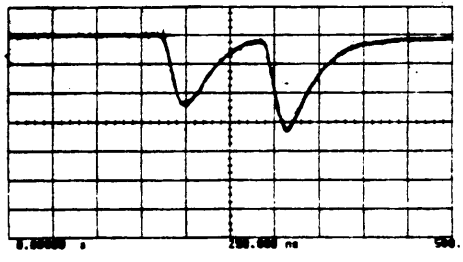


FIG. 2 - Photon generated afterpulse in a 1.1-m-long chamber. (50ns/div, 50mV/div).

The LVD will require 75 m^3 of the gas filling its streamer chambers. The gases usually employed for this purpose are mixtures of a noble gas (argon or neon) and some hydrocarbon (ethane, isobutane, or n-pentane). The binary (30% argon + 70% isobutane) and the ternary mixture (15% argon + 25% n-pentane + 60% carbon dioxide) are generally considered to be the standard mixtures as they are well studied and have satisfactory quenching properties. Both of the standard mixtures are flammable because of their high percentage of hydrocarbon component. Operating with large volumes of flammable mixtures, as in LVD, requires careful safety considerations to be made. Many low-hydrocarbon mixtures have been proposed and investigated by different groups[3-8]. We performed a detailed study of an already suggested[9] low hydrocarbon "ternary" mixture (2% argon + 10% isobutane+ 88% carbon dioxide). We compared the ternary mixture with the standard "binary" mixture (30% argon + 70% isobutane) by observing their relative influence on single count rate plateau, streamer pulse height, electron drift time, chamber efficiency, and multi-streamer formation. In addition we explored a wide range of relative percentages for the isobutane, argon and carbon dioxide mixtures and studied the respective single count rate plateaux. We also investigated the source and effects of gas impurities for chambers operated with the standard binary mixture.

2. STREAMER MULTIPLICITY AND AFTERPULSES

An important merit of a gas mixture is its ability to restrict streamer regeneration over a wide range of the chamber voltage. The phenomena of streamer formation and the operation of streamer chambers have been intensively studied[10-12]. For convenience, we give a brief review of how the streamers are formed and regenerate themselves. A primary charge is formed when the gas is ionized by a crossing particle. The electrons from the primary charge are accelerated towards the anode because of the electric field generated by the applied voltage. An avalanche charge multiplication takes place near the anode wire with a gain of the order of 10^7. As positive ions have a mobility[13] roughly 10^3 times less than that of electrons, the ions remain essentially stationary during few tens of nanoseconds in which the electrons are collected by the anode wire. The resultant space charge effect reduces the local electric field and limits further charge multiplication. The streamers, when photographed[12,14] appeared as ~100 μm wide and a few mm long charge filaments. They extend from the anode wire along the direction of electric field. During streamer formation de-exciting atoms emit UV photons. A hydrocarbon with high UV photon absorption cross section is used in the gas mixture as a quenching component.

Different phenomena may cause a pulse-multiplicity in a streamer chamber. In such cases an incident particle can originate multiple streamers and the wire-pulse is seen with a degenerated shape or followed by trailing pulses. Double or lobed pulses of a trivial nature can be originated by rear-end reflections. Each cell of the chambers has a capacitance[15] of 12 pF/m, and an inductance of 1 μH/m, which give it a characteristic impedance of 290 Ω and a pulse propagation velocity of 2.88 x 10^8 m/s. The cells have an open circuit termination on the rear end. When the time for the reflected pulse to travel along the wire is comparable to the pulse width, the reflected pulse on the readout side gets separated. Multiple-streamers in a chamber are formed by electrons emitted from its cathode. The cathode may emit electrons when UV photons, not absorbed by the quenching gas, or the positive ions from the streamers impinge upon its surface. As the emitted electrons drift to the anode, they can originate secondary streamers, termed "afterpulses". The characteristic time interval between the parent pulse and its afterpulse identifies whether the cathode electrons were emitted by a photon or by a positive ion. This delay, 100 ns for photon-generated afterpulses in the binary mixture (Fig.2), roughly corresponds to the maximum half cell drift time for the electrons. Multiple streamers can also be originated by crossing particles, which make a small angle with the anode wire. Such geometrical multi-streamers can give rise to events which appear as super imposed, lobed, or as separated pulses within an interval of 0-100 ns.

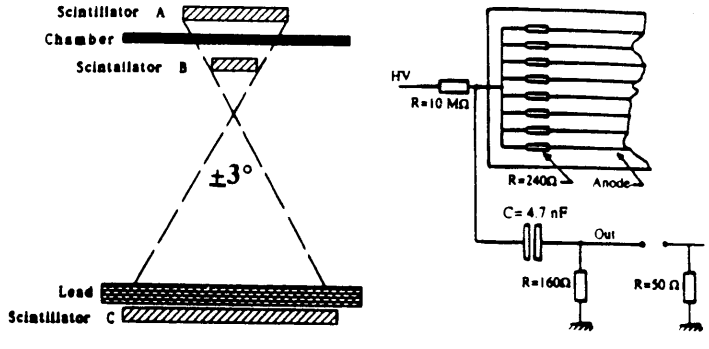


FIG. 3 - Scintillator telescope, and the circuit used for reading out the chamber wire signal.

3. EXPERIMENTAL SETUP

A scintillator counter telescope was used to select cosmic rays within an angle of ±3° with respect to the normal to the chamber wires. Fig.3 and 4 show the experimental setup of the test facility and the electronics used. Four chambers with their length between 85 and 105 cm, were used. For such short lengths the maximum possible delay for the arrival of a reflected pulse is negligible compared with the average pulse width. The studied chambers were carefully selected out of a batch of 100 devices for their excellent and stable performance with the standard mixture. The plateau length varied from 500 to 900 volts from device to device, but the four selected chambers had a length greater than 800 volts. The operational conditions, selected by the small angular acceptance and small length chambers, reduced geometrical multi-streamer formation. The probability of a geometrical multi-streamer for a triggering cosmic ray is roughly estimated to be less than 2%. The reduction of geometrical multi-streamers is a basic condition to allow an effective study of the quenching ability of the two gas mixtures and their afterpulse generation probability. The chambers were filled with the two mixtures, formed by using Hi-Tech electronic mass flow meters/regulators. All mixture compositions reported in this article are the percentages by volume with an accuracy better than 1 percent.

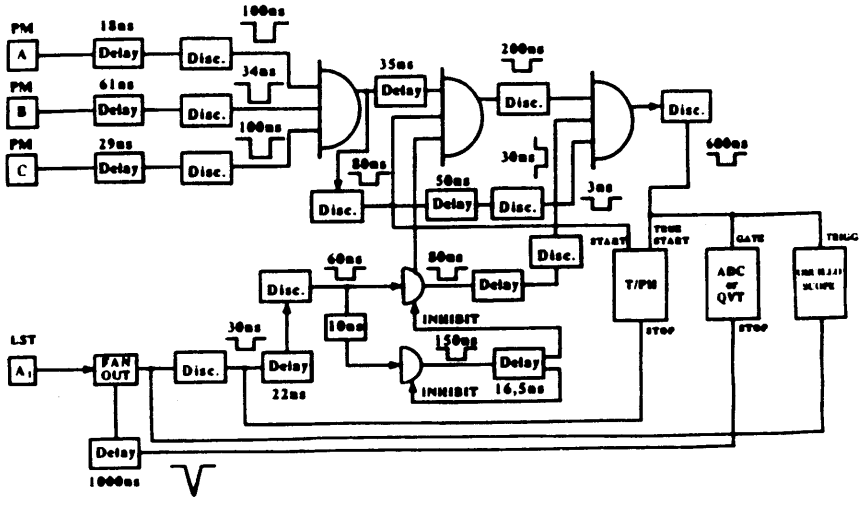
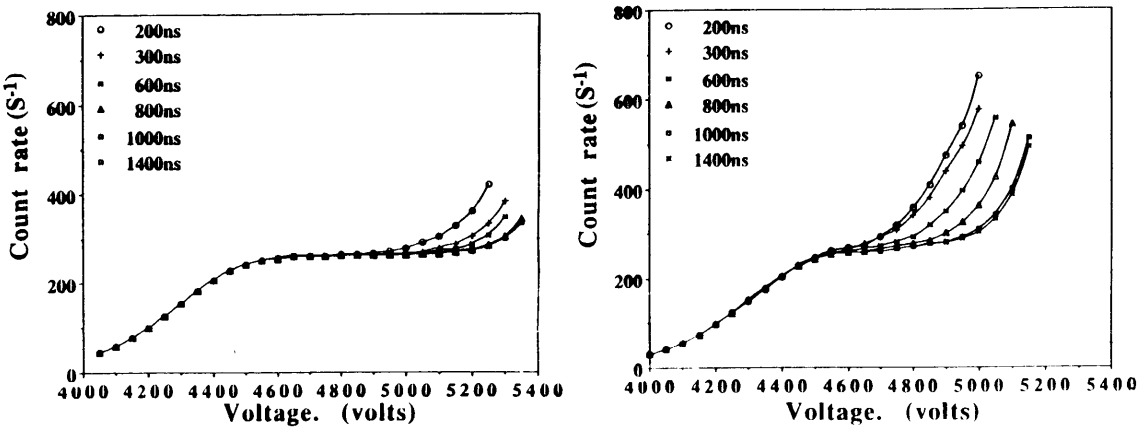


FIG. 4 - Electronics used with the test facility.

4. COUNT RATE, EFFICIENCY, AND ELECTRON DRIFT TIME

For all single count rate measurements, a low discriminator threshold of -8 mV/50Ω was used to make the knee voltage a true representation of transition between the proportional and the limited streamer regime[2]. The mixture overpressure was kept at 5~6 mbars with controlled ambient temperature (22~24°C) and humidity (< 60%). In Fig.5 we show the count rate measurements with different counter dead times. Both of the mixtures had the plateau knee roughly at 4500 volts, while the ternary mixture had a much shorter plateau length even with a dead time of 1μs, which showed its poorer quenching ability.

The chamber efficiency was calculated as the ratio of the count of a 300-ns coincidence between the wire and the telescope trigger to the trigger count only. Both the mixtures have almost the same efficiency in the plateau region as shown in Fig. 6.



(a) 30% argon + 70% isobutane (b) 2% argon + 10% isobutane + 88% carbon dioxide

FIG. 5 - Single count rate plateau of 1.1-m-long streamer chambers with different dead times.

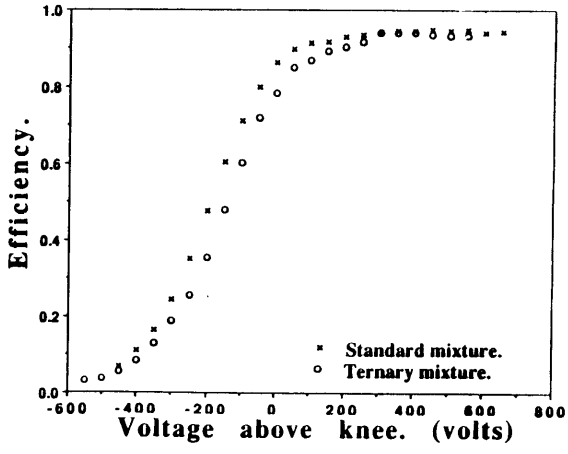
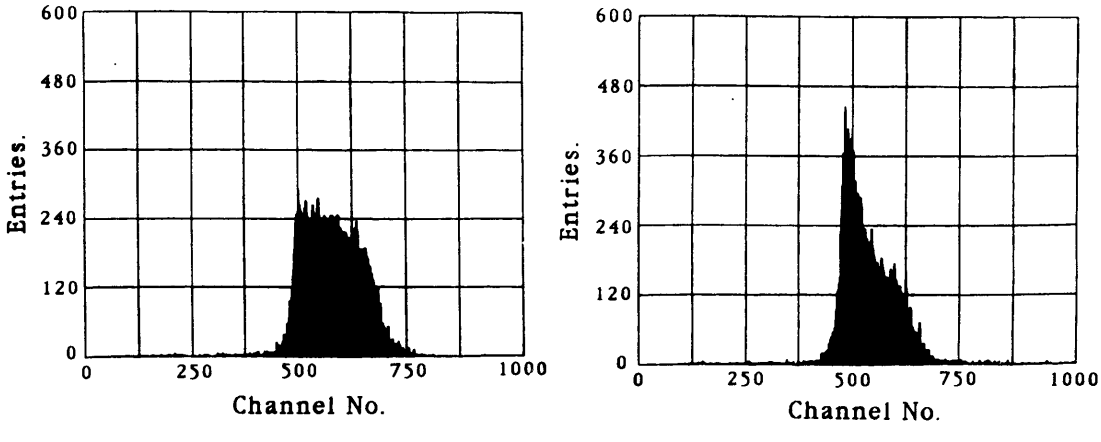


FIG. 6 - Chamber efficiency as a function of the voltage above the plateau knee.

For drift time measurement, we used an ORTEC time-to-pulse converter with a full scale of 400 ns. The start and stop signals to the time-to-pulse converter were the telescopic coincidence and the 20-ns-shaped OR signal respectively. The module was analyzed by a Lecroy QVT with a calibration of 0.42 ns per channel. The drift time spectra with the two mixtures were measured at 100 volts above the respective plateau knee (Fig. 7). The spectra reflect an unsaturated drift velocity of the electrons in the ternary mixture and a nearly constant drift velocity in the binary one. We found that the maximum drift time for electrons, corresponding to the half cell dimensions, is about 100 ns for the binary mixture and 92 ns for the ternary composition.



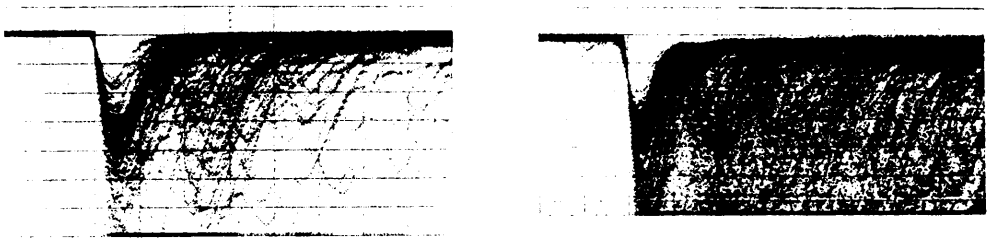
(a) 30% argon + 70% isobutane (b) 2% argon + 10% isobutane + 88% carbon dioxide

FIG. 7 - Electron drift time spectra at 100 volts above the plateau knee.

5. SIGNAL DIGITIZING AND EVENT SCANNING

A comparison of after pulse generation is usually based on single count rate plateau measurements performed with different dead times or on pulse charge spectra. However, these methods are unable to yield precise results. The two mixtures were indicated[16-17] to differ largely for after pulse generation (Fig. 8). For a more resolved comparison, we printed a total of 15000 individual streamer events with the two mixtures using hp54111D digital oscilloscope. The scope was triggered by a coincidence of the wire and the scintillator telescope signal and the chamber voltage was varied over 3000-5200 volts.

The off-line analysis of the recorded pulses allowed us to study the average primary streamer pulse-height and afterpulse probability. The ternary mixture exhibited a ~20% smaller average primary streamer pulse-height, compared with the binary mixture (Fig.9). The analysis showed that the secondary streamers in the ternary mixture had an average pulse-height equal to or greater than the average pulse-height for the parent streamer. However, in case of the binary mixture, the secondary streamer pulse-height is peaked at approximately 2/3 of the pulse-height for the parent streamers. The poorer quenching ability of the ternary mixture was indicated by an earlier exponential growth in the average streamer multiplicity as a function of the anode voltage (Fig. 10). Fig. 11 shows further distribution of overall streamer multiplicity for the two mixtures. In case of the ternary mixture it can be noticed that at voltages towards the end of the count rate plateau, the probability of more than one afterpulse events increases rapidly, and that of one afterpulse starts decreasing (Fig. 11b).



(a) 30% argon + 70% isobutane (b) 2% argon + 10% isobutane + 88% carbon dioxide

FIG. 8 - Hundred superimposed wire signals at 4800 volts.

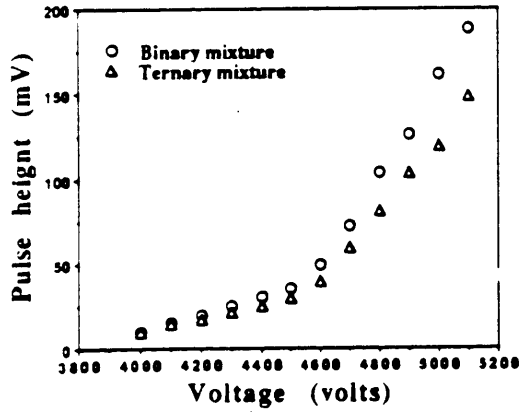


FIG. 9 - Primary streamer pulse height as a function of applied voltage.)

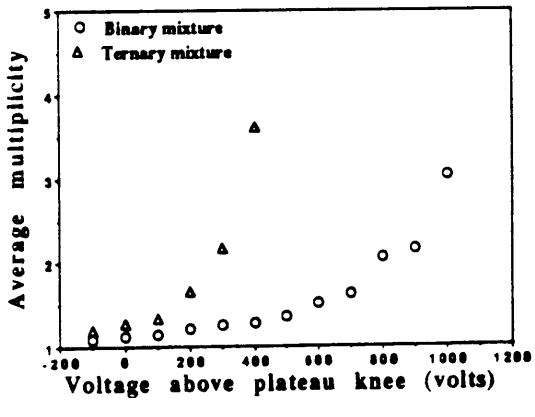
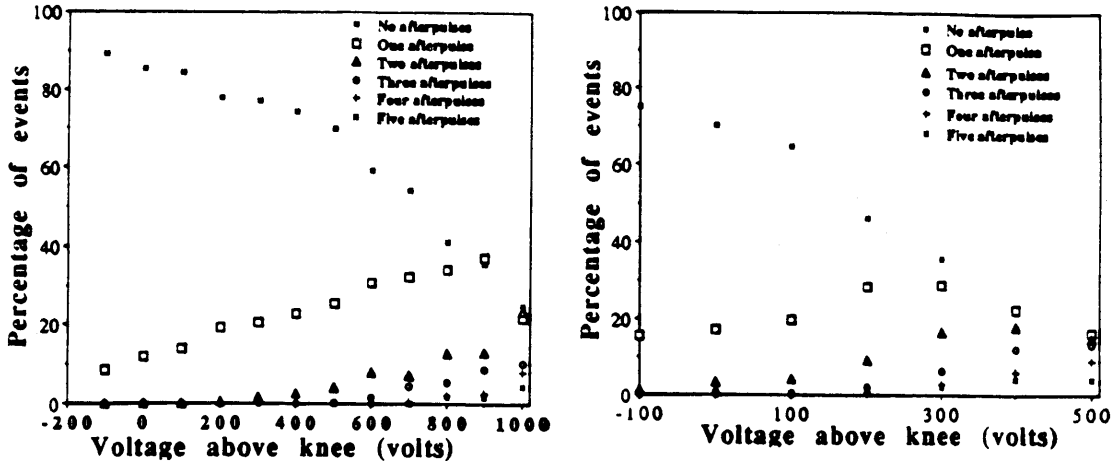


FIG. 10 - Average streamer multiplicity as a function of applied voltage.

In general, afterpulses can be ignored when a dead time of the order of μs is acceptable for chamber operation, and the readout is originated by wire signal. However, when pickup strip readout is used, the multi-strip hitting is determined by streamer multiplicity. In such readout systems afterpulse regeneration becomes an important factor to be considered. For strips lying perpendicular to chamber wires, strip-hit multiplicity reaches a value 1.75 at 200 volts above the plateau knee with the well quenched binary mixture (Fig.12). Whereas, at the same voltage for the ternary mixture, the percentage of afterpulses is already three times higher than that for the binary mixture (Fig. 10).



(a) 30% argon + 70% isobutane (b) 2% argon + 10% isobutane + 88% carbon dioxide

FIG. 11 - Distribution of average streamer multiplicity. The figure shows the percentage of events with the given number of afterpulses.

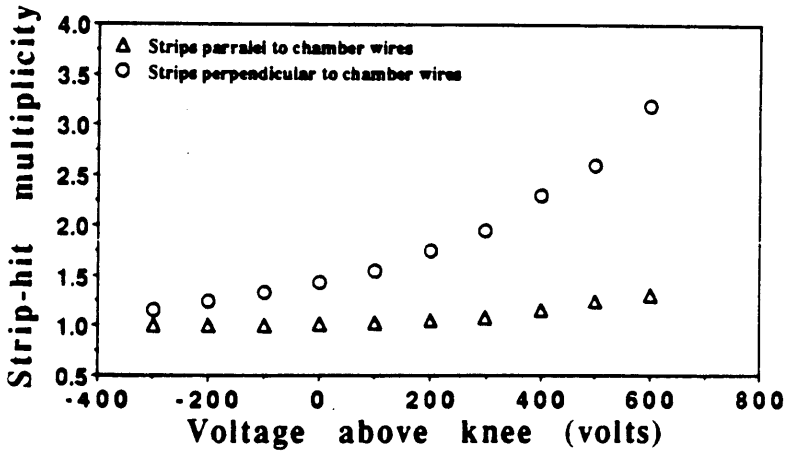


FIG. 12 - Average number of strips hit by one crossing particle.

6. ALTERNATIVE TERNARY MIXTURES

The low hydrocarbon ternary mixture (2% argon + 10% isobutane + 88% carbon dioxide) is at the limit of flammability region[18]. There are other combinations of the three gases, that can be tested with the intent to find a useful mixture with significantly smaller isobutane percentage, compared with 70% of the standard binary mixture. We explored a wide domain of various

ternary compositions by measuring the corresponding single count rate plateau of the chambers in the standard conditions (1 μs dead time, -8mV/50Ω discriminator threshold)

The values obtained for the knee voltage and the length of the single count rate plateaux are reported in Fig.13. As expected, the knee position moves to higher voltages, and the length of the plateau increases when the quenching gas percentage (isobutane or carbon dioxide) is increased. The relatively smaller quenching efficiency of carbon dioxide is demonstrated by the increase in knee voltage and reduction in plateau length when carbon dioxide to isobutane ratio increases for a given argon percentage. For a better understanding of the potential of these mixtures, as possible alternatives for the standard binary composition, a detailed investigation is needed concerning afterpulse formation, electron drift time and streamer charge. The results on plateau knee and its length suggest that possible alternative mixtures to be considered for a detailed study are (13% argon + 29% isobutane + 58% carbon dioxide) and (8% argon + 20.4% isobutane + 71.6% carbon dioxide). These two have a reduced isobutane percentage compared with the standard binary mixture (by a factor of 2.4 and 3.4 respectively) and at the same time exhibit a sufficiently long plateau with a lower knee voltage.

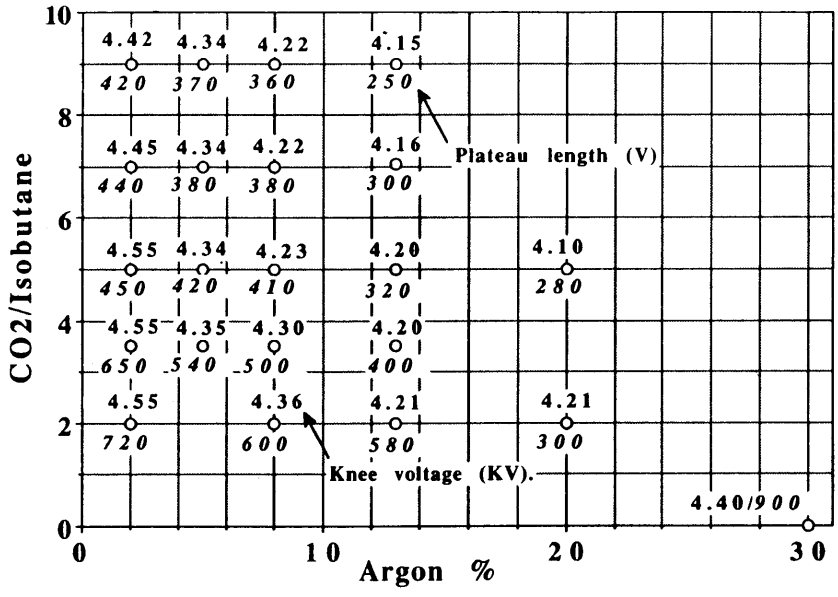


FIG. 13 - Variations in single count rate plateau knee/length with the relative percentage of argon, isobutane and carbon dioxide mixture.

7. SOURCE AND EFFECT OF GAS IMPURITIES

As chamber performance depends upon the composition of its mixture, it becomes important to investigate the source and effects of gas impurities. These impurities can possibly come from three origins: the inherent impurity of the source gases used to form the mixture, the intrusion of external atmospheric gases due to the non-hermetic plastic jackets (or distribution system) and the impurities generated within the chamber itself as polymerization or combustion products from sparks.

In this section we report a group of studies related to gas impurities. During these measurements, the mixture composition was determined using Carlo Erba's Vega series Gas Chromatograph, G.C.600. Its packed columns, Porapak-Q and molecular sieve, were

calibrated for retention time using samples of pure gases. The hot wire detector was calibrated for its sensitivity by injecting known quantities of the pure gases. The resultant measurement system was accurate to a level of a few parts per thousand. However, as the argon and oxygen peaks cannot be separated by the two columns, the system was unable to distinguish the two gases from each other (Fig.14).

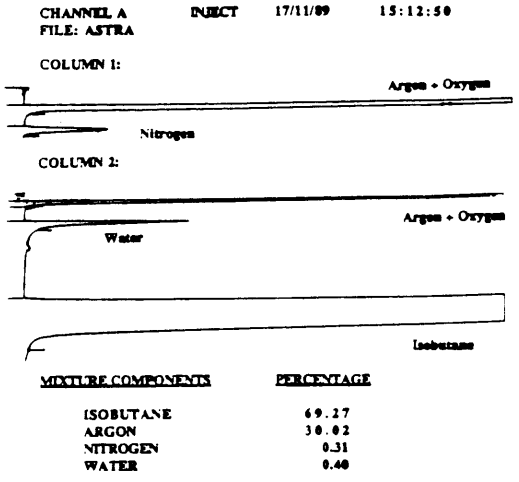


FIG. 14 - Typical chromatogram for chamber gas (One volume change in 48 hours)

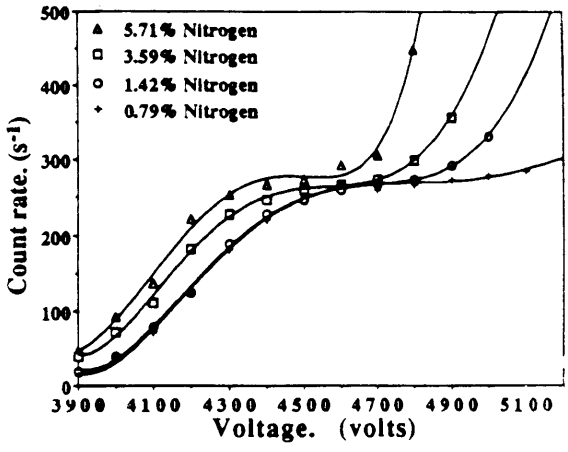


FIG. 15 - Variations in the count rate plateau as top of a contaminated isobutane cylinder was being consumed.

The standard binary mixture (30% argon + 70% isobutane) was formed using the Hi-Tech mass flow meter/regulator system. The gases used to prepare the mixture have a stated purity of 99.999% for argon and 99.5% for isobutane. Samples of the two gases were tested for impurity content and the gas quality found was generally better than the stated level. However, occasionally a pocket of trapped air was found at the top of the isobutane cylinders, which can give rise to ~ 5% of air. The impure gas was washed out of the cylinder as we used an initial 2-3 kg of isobutane. When the cylinder was inadvertently used to provide gas for well working chambers, it deformed the chamber plateau. The chambers retuned to their previous performance as the cylinder top was finished (Fig. 15). A small content of propane was usually found in isobutane cylinders, which was below our calibration limit of parts per thousand. Isobutane and argon cylinders were found to have water vapors below parts per thousand level.

Washing of air filled chambers required 5~6 volume changes of the mixture to reach a nitrogen concentration of < 1% by volume. Fig. 16 shows the percentage of nitrogen as a 6.3-m-long chamber, with all air in it, was washed by fresh mixture. After this initial washing, a flux of one volume change in 48 hours was maintained. With this flux we observed a dynamic total impurity level of ~1% (0.4%-0.7% water + 0.3-0.5% nitrogen), which however did not show an appreciable effect on chamber performance.

For plastic streamer chambers there exists an exchange of gases across the PVC jacket due to its non-hermetic nature. To observe the effect of gas intrusion on chamber performance, we washed a few 6.3-m-long chambers with the standard binary mixture. The chambers were

sealed at an internal overpressure of ~5 mbar and we observed them for the changes in count rate plateau during the following two months. The voltage was applied to the chambers only during the count rate measurements and this eliminated the possible polymer or combustion product accumulation from within the devices. Chambers with good gas tightness were observed to operate correctly for months (Fig.17a). Water and nitrogen were identified as major impurities. Carbon dioxide was also found with a concentration less than parts per thousand. Fig.17b shows a chamber with an average nitrogen accumulation rate of 0.230% per day. The impurity accumulation rate varied from chamber to chamber but at a given nitrogen percentage the changes in count rate plateau were roughly the same. Although the percentage of oxygen could not be measured, which probably existed in the impure mixture, the nitrogen percentage provided us with an index for the total accumulated impurity. The contamination of the mixture by air gases reduced the quenching ability of the pure mixture, the plateau knee moved to a lower voltage, and the plateau length was decreased. Upon completion of measurement, the chambers were again washed with the fresh mixture. As the mixture purity improved, the devices returned to their previous count rate plateau.

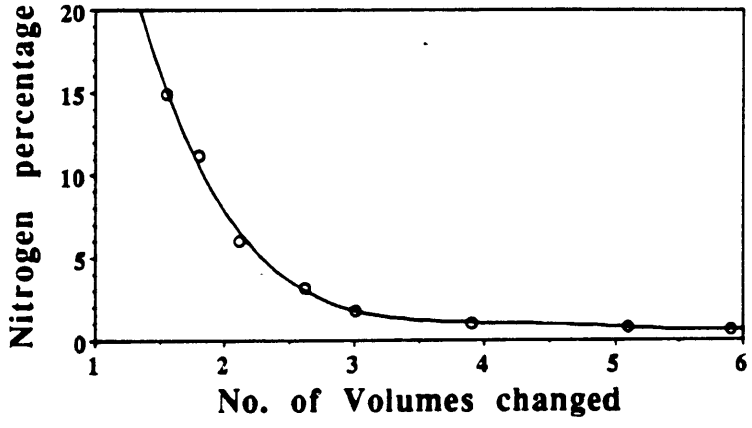
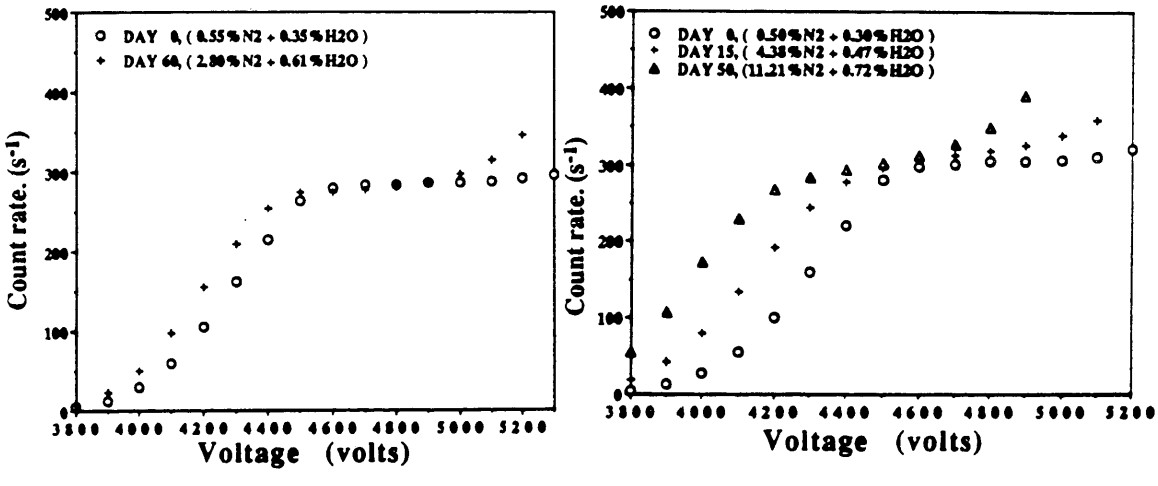


FIG. 16 - Nitrogen percentage during washing of an air filled chamber as a function of number of chamber volumes changed.



a: Average nitrogen accumulation rate of 0.036% per day.

b: Average nitrogen accumulation rate of 0.230% per day.

FIG. 17 - Changes in count rate plateau for sealed chambers.

8. CONCLUSIONS

The comparison between the low hydrocarbon ternary mixture (2% argon + 10% isobutane + 88% carbon dioxide) and the standard binary one (30% argon + 70% isobutane) shows a definite superiority of the later, both in the saturated electron drift velocity and in a smaller probability of afterpulses generation. The streamer multiplicity gives origin to many problems in the use of the chambers. Even when a long dead time is tolerable, multi-strip hitting is expected to be determined by the chamber streamer multiplicity. Also, the expected life-time of chambers operated with a low quenching mixture has never been demonstrated and it is questionable that it could be comparable with the score reached by the standard binary mixture[19]. However, we believe that a more resolved study has to be performed for other carbon dioxide based low hydrocarbon ternary mixtures, as suggested by our exploratory research on plateau knee and its length. The mixtures (13% argon + 29% isobutane + 58% carbon dioxide) and (8% argon + 20.4% isobutane + 71.6% carbon dioxide) are more suitable candidates for further investigations.

We have studied the influence of the mixture contamination by air gases on chamber performance. Closed chambers with good tightness properties can work correctly for several months. The intrusion of air gases worsen the device performance, resulting in decrease of knee voltage, reduction of plateau length, rise of afterpulses and instability of the chambers. A maximum of air gas intrusion corresponding to ~5% nitrogen can be tolerated. At this contamination level the knee voltage and plateau length are reduced roughly by 100 volts. A moderate gas flow rate of one volume change in 48 hours was demonstrated to be able to maintain the dynamic impurity level within ~1% (0.4%-0.7% water + 0.3-0.5% nitrogen). A recirculating gas system with purification ability could also be considered[20] that allows to maintain the air impurities within the tolerable limits, while providing an autonomy of several months.

REFERENCES

1. C. Bari et al., *Nucl. Instr. and Meth.* **A264** (1988) 5.
2. E. Iarocci, *Nucl. Instr. and Meth.* **217** (1983) 30.
3. T. Uebayashi et al., *Nucl. Instr. and Meth.* **A 265** (1988) 457.
4. G. Bagliesi et al., *Nucl. Instr. and Meth.* **A 268** (1988) 144.
5. G. Battistoni et al., *Nucl. Instr. and Meth.* **A276** (1989) 140.
6. B. Alpat et al., *Nucl. Instr. and Meth.* **A 277** (1989) 260.
7. S. Cartwright et al., *Nucl. Instr. and Meth.* **A 277** (1989) 269.
8. A. Antonelli et al., *Nucl. Instr. and Meth.* **A 281** (1989) 589.
9. J.H. Moromisato, et al., *Nucl. Instr. and Meth.* **A 274** (1989) 177.
10. S. Brehin et al., *Nucl. Instr. and Meth.* **123** (1975) 225.
11. G. Battistoni et al., *Nucl. Instr. and Meth.* **164** (1979) 57.
12. M. Atac et al., *Nucl. Instr. and Meth.* **200** (1982) 345.
13. F. Sauli., **CERN 77-09** (1977).
14. G.D. Alekseev et al., *Lett. Nuovo Cim.* **25** (1979) 157.
15. A.C. Benvenuti et al., *Nucl. Instr. and Meth.* **A290** (1990) 353.
16. S. Bianco et al., **LVD Memo 008** (May 1988).
17 R. Casaccia et al., **LVD Memo 009** (June 1988).
18. M.G. Zebatakis., *National bureau of mines.* **Bull 627** (1965)
19. G. Bari et al., "Limited streamer chamber testing and quality evaluation in Astra" Frascati Report LNF-91/005(P) (1991).
20. F.L. Fabbri et al., **LVD Memo 033** (Feb 1989).