A Study of Aging Effects in Gas-Monitoring Proportional Counters at the BAC Calorimeter of the ZEUS Experiment

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Abstract

The multi-cell proportional chambers at the backing calorimeter of the ZEUS experiment at the storage ring HERA are supplied with an Ar/CO_2 gas mixture by an open gas system. Flow proportional counters with built-in ^{55}Fe sources are used as gas system monitoring detectors. The results of measurements of aging effects for the gas-monitoring counters will be presented.

1 Introduction

The problem of wire aging is as old as the use of gas detectors for particle registration [1]. The formation of insulating layers on anode wire is still a major limitation to their use in long-term experiments [2]. The presence of the insulating deposit modifies the space-time distribution of the electric field near the wire surface where the avalanche formation takes place. It is known that these processes depend both on gas mixture, cathode and anode materials as well as on the materials of gas system feeding detectors [3].

It has been shown in laboratory tests with very pure gases and under otherwise clean conditions, very low aging rates are obtained using the same primary gas mixtures, which have not given very good results when gas purity was not controlled. These observations show that very small amounts of certain constituents of the gas mixture can have important effects on aging processes. In big high-energy physics experiments in which the volume of gaseous detector is a few cubic metres, made in different technology with the use of different outgassing materials, the control of the level of impurities is very difficult or mostly impossible. In this case at least the explanation for the experimental data, if not quantitative, at least qualitative recommendations for the design of proportional chambers operating should be proposed / suggested. In this report, we present the results of aging effect in monitoring proportional counters of the gas system at the BAC Calorimeter of the ZEUS Experiment.

2 BAC – gas system

The backing calorimeter (BAC) of the ZEUS experiment at the storage-ring HERA consists of over 5100 multi-cell proportional chambers (MCPC) with the total volume of about 50 m^3 placed in an iron yoke. A system of pipes feeds these chambers with the non-flammable gas mixtures of Ar/CO_2 for safety reason. The concentration of CO_2 chosen is at a level of 10% to 15%. The gas system is open with the exhaust to the atmosphere. It provides up to a few exchanges per day of the gas mixture in BAC chambers [4].

Due to the structure of the ZEUS detector the whole gas system has been divided into 79 branches. Each branch consists of more or less 65 proportional chambers paralelly connected. There are monitoring proportional counters both at the input of each branch and at the output of "the last chamber" of the branch. "The last chamber" means the chamber placed in the longest distance from the gas inlet. For these chambers the worst condition of the gas exchange occurs. So in total we have 158 proportional monitoring counters (PC).

The control proportional counters [5] have the same geometry in cross-section as one cell of the BAC MCPC (10x15 mm^2). The counter windows are made of kapton foil, 0.1 mm in thickness, whereas the ^{55}Fe source radioactivity is about 10 MBq. Gold plated tungsten wires of 50 μm in diameter are used as the anodes. The operating voltage of the PC is the same as the HV applied to the MCPC of that branch to which these counters are gaseously connected. Spectra of ^{55}Fe – line (MnK_α – 5.9keV) from all PC are collected four times per day.

The topology of all the gas system and of the one branch is presented in Fig. 1 and 2, respectively.

The materials used in the construction of the detector itself and of its active gas system are among the most critical items that may affect the lifetime both of MCPC and of PC. This is because many plastic materials outgas, which transported within active gas flow, may be deposited directly on the surface of electrodes or leads to the growth of deposits in the vicinity of the irradiated regions. For obvious reason, the use of glues, plastics and other organic materials is unavoidable in most particle detectors.

2.1 Materials used in BAC – gas system

The working gas Ar/CO_2, from the tanks to mixing machine is transported / flowing threw stainless steal pipes, 25 mm length. In mixing machine one can find stainless steal and brass made valves, mass and ball flow meters with rubber o-rings and pressure gauges.

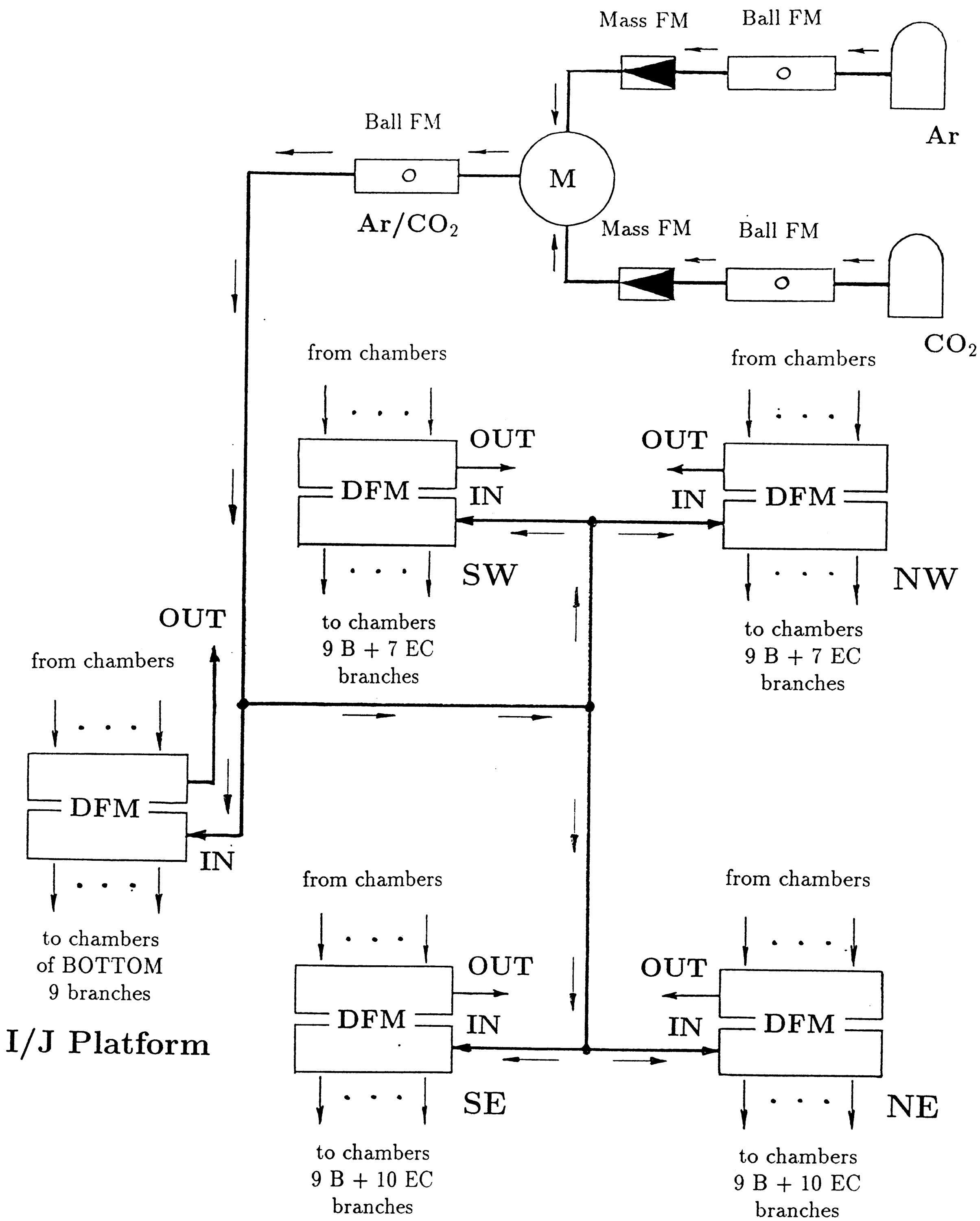

Fig. 1. Schematic presentation of the BAC gas system. Its topology follows the structure of the ZEUS detector. FM – flow meter; M – mixer; DFM – differential flow meter; B – barrel of ZEUS detector; EC – end-cap of ZEUS detector; SW, NW, SE, NE – ZEUS quarters of South – West, North – West, South – East, North – East.

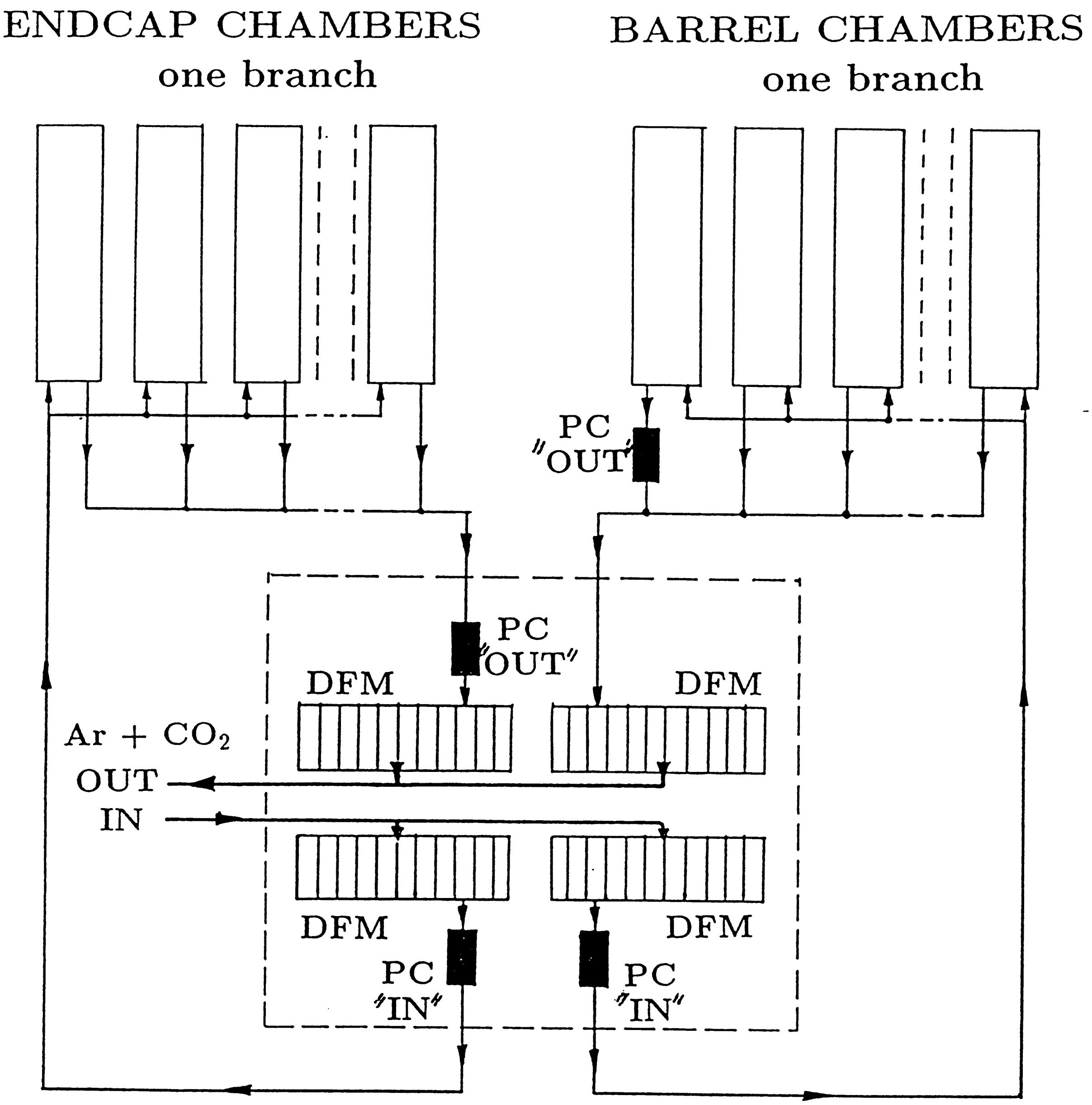

Fig. 2. Block scheme of the allocation of monitoring proportional counters (PC).

PC “IN” – monitoring proportional counter at the input of the branch.

PC “OUT” – the same but at the output of the branch or at the output of “the last chamber”.

Many of them may contain silicon or another type of lubricant or seal. For example, GYROLOK connections commonly used at the gas system contain plenty of Si vacuum oil, and in practice, it is not possible to clean them to the required level. The MCPC are fed with the gas by both Cu (25 m in length) and plastic Rilsan pipes (5 m in length). For detector construction the Araldite AW 106 and Hardener HV 953 glue have been used. Plastic parts have been used to provide the anode wires and pad location and fixation as well as the electrical contacts (G10 board) [6].

3 Aging effect

The aging effect manifests generally in:

- loss of gas gain/pulse height,
- degradation in energy resolution,
- reduction of efficiency plateau,
- increase in leakage current and
- decrease in sparkproofness.

The mixtures of noble gases and hydrocarbons are commonly used in wire chambers. In above chambers these undesirable effects are the result of an anode wire surface degradation. The hydrocarbons, cross-linked polymers and radicals created in the process of gas discharge are deposited on the anode, thus degrading the detector parameters. In certain gases, which are known, as an unpolymerising gas the deposit of elemental carbon is observed, e.g. $C0_2$ [1].

The deterioration of counter parameters is observed after exceeding either the certain number of counted pulses or the integrated charge per unit length of an anode wire. The aging effects are dangerous because they are not yet well understood and the sources of some of the deposited elements are still unknown. The laboratory results are generally in disagreement with those obtained from currently running experiments because of different counter operating conditions. In order to shortening the aging time the laboratory measurements are usually carried out at much higher anode current density than normally encountered in long lasting experiments. The radiation sources mostly used in laboratory tests are radioactive isotopes of ^{55}Fe and ^{90}Sr as well as the X-ray generators.

3.1 Aging of monitoring counters

In BAC calorimeter, there are 79 input and 79 output counters. For all these counters the pulse height distributions of ^{55}Fe line were measured during the counters operation. Typical spectra representative for all the output and input counters used, registered after the counting of the same number of pulses, are presented in the Figs. 3 and 4 [7].

As it can be seen, the characteristic behaviour of degradation for the output counters is dramatically exhibited by deterioration of the ^{55}Fe X-ray spectrum on the lower energy side of the main peak, Fig. 4. The left peak side becomes nearly exponential, the escape peak disappears and even the extra second peak is created. These observations are in a good agreement with those presented in Refs. [1, 8, 9].

However, it should be strongly pointed out that for the input counters the degradation behaviour is in contradiction to that for the output counters. The unexpected peak degradation is visible (Fig. 3). The undesirable changes in height pulse distribution appear on the higher energy side of the main peak.

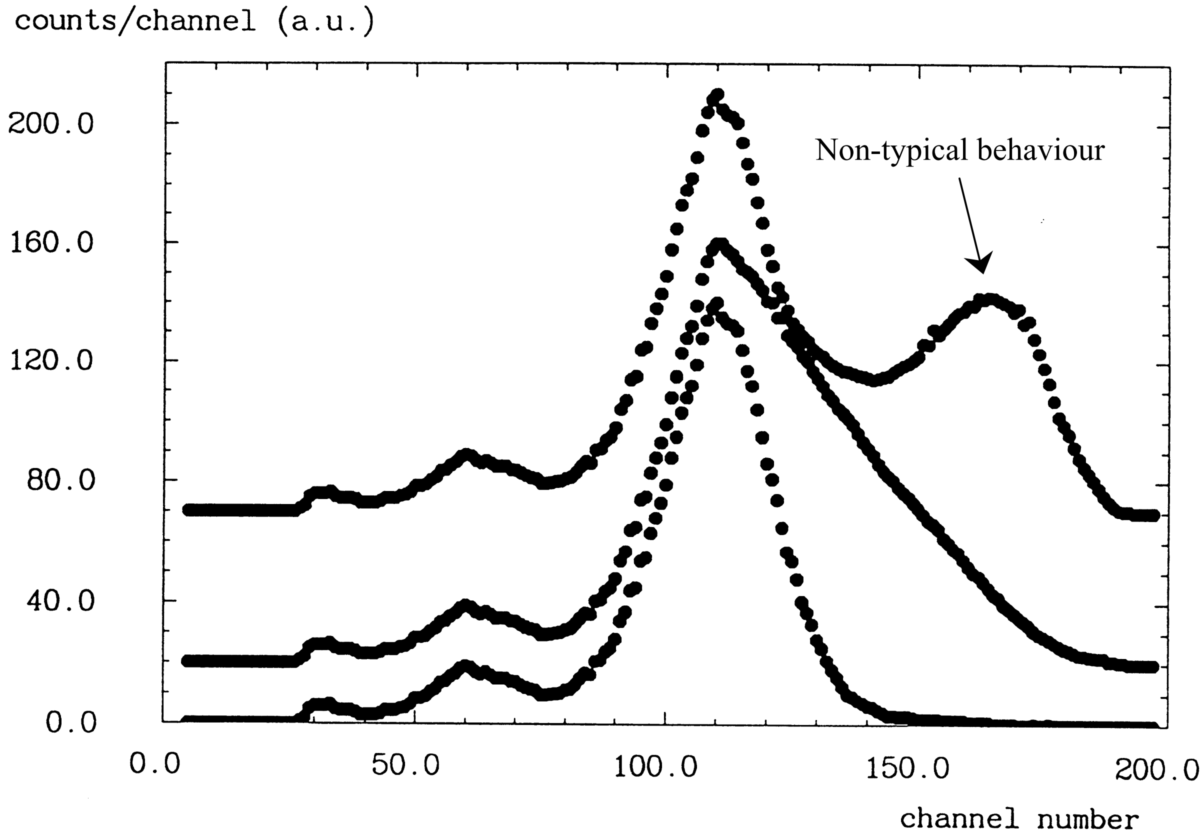

Fig. 3. Averaged spectra of the ^{55}Fe – line for the "IN" counters. For comparison the pulse height distribution in the branch new counter is given (the lowest curve). Degradation in the spectra shapes in time is also shown (two upper curves).

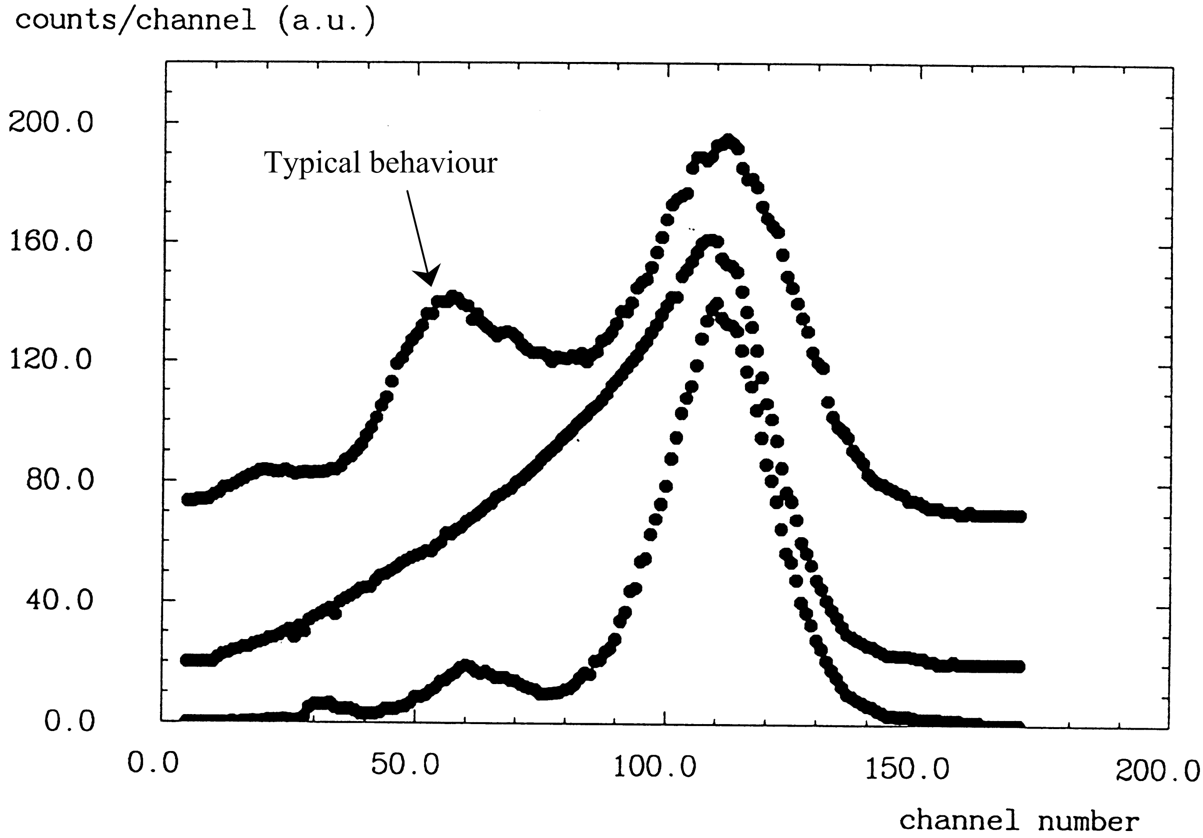

Fig. 4. The same as Fig. 3, but for "OUT" counters.

Change in energy resolution as a function of collected charge per unit length of anode wire is shown in Fig. 5. Degradation in energy resolution ensures in very different pace. For some counters, small degradation was observed after 200 days of counters performance, while for others after few days, energy resolution overcame 30% [10, 11].

For:

- gas gain $A \approx 5\text{x}10^4$
- mean count rate, $\bar{\nu} \approx 600$ cps,
- energy per ion-electron production $W = 26$ eV,

collected charge per time unit, Q, can be calculated from the equation

$Q = A \cdot N_0 \cdot \bar{\nu} \cdot e$, where: e – electron charge,

N_0 – number of primary ion-electron pairs

$N_0 = \dfrac{\Delta E}{W}$, where: ΔE – energy deposited by the particle in the gas

In our case $\Delta E = 5.9$ keV.

The collected charge per ONE DAY, per 1 cm of anode wire is equal:

$$Q = 0.1 \text{ mC/cm/day}.$$

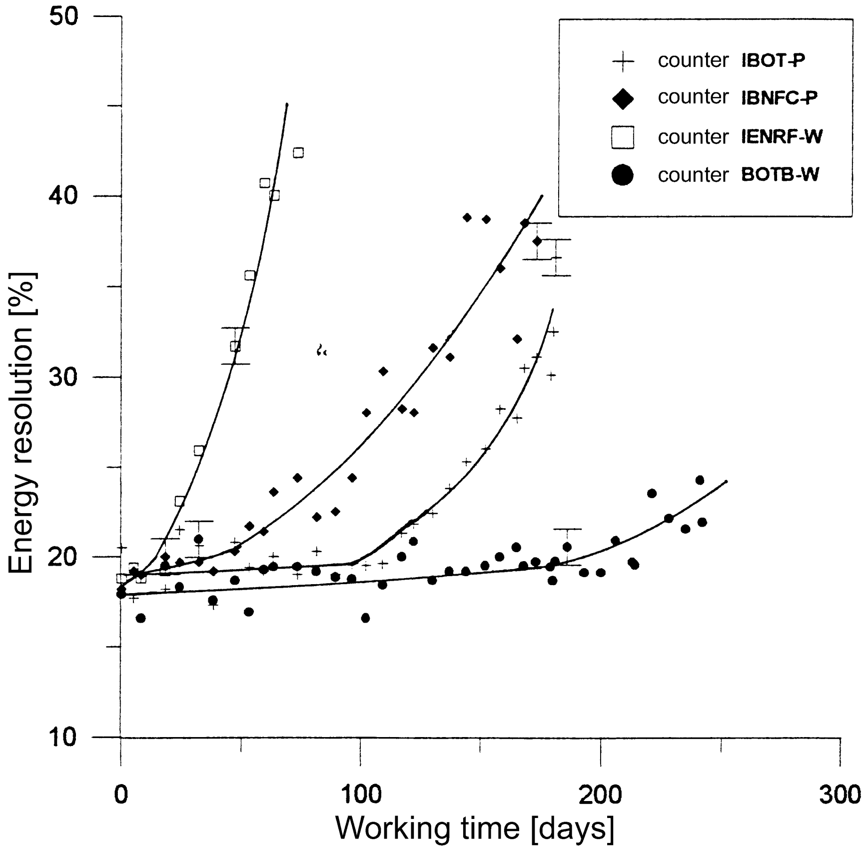

Fig. 5. Energy resolution as the function of the time of counter performance. Detailed information on counters location in gas system is also given.

Some counters were left for a period of time without HV, in the air environment (up to 6 months) and in most cases an improvement in the pulse height spectra was seen. Above effect strongly depends on air moisture. However, this quickly returned to previous levels after flushing the counter with dry working gas (Fig. 6). To speed the elimination of water vapour from the counter the flushing working gas was heated. As one can expect, the recovery of aging manifestation was much faster. Similar improvement of analog response can be achieved by passing part of the counter gas through a bypass bubbler, which allowed us to add the water vapour to the working gas.

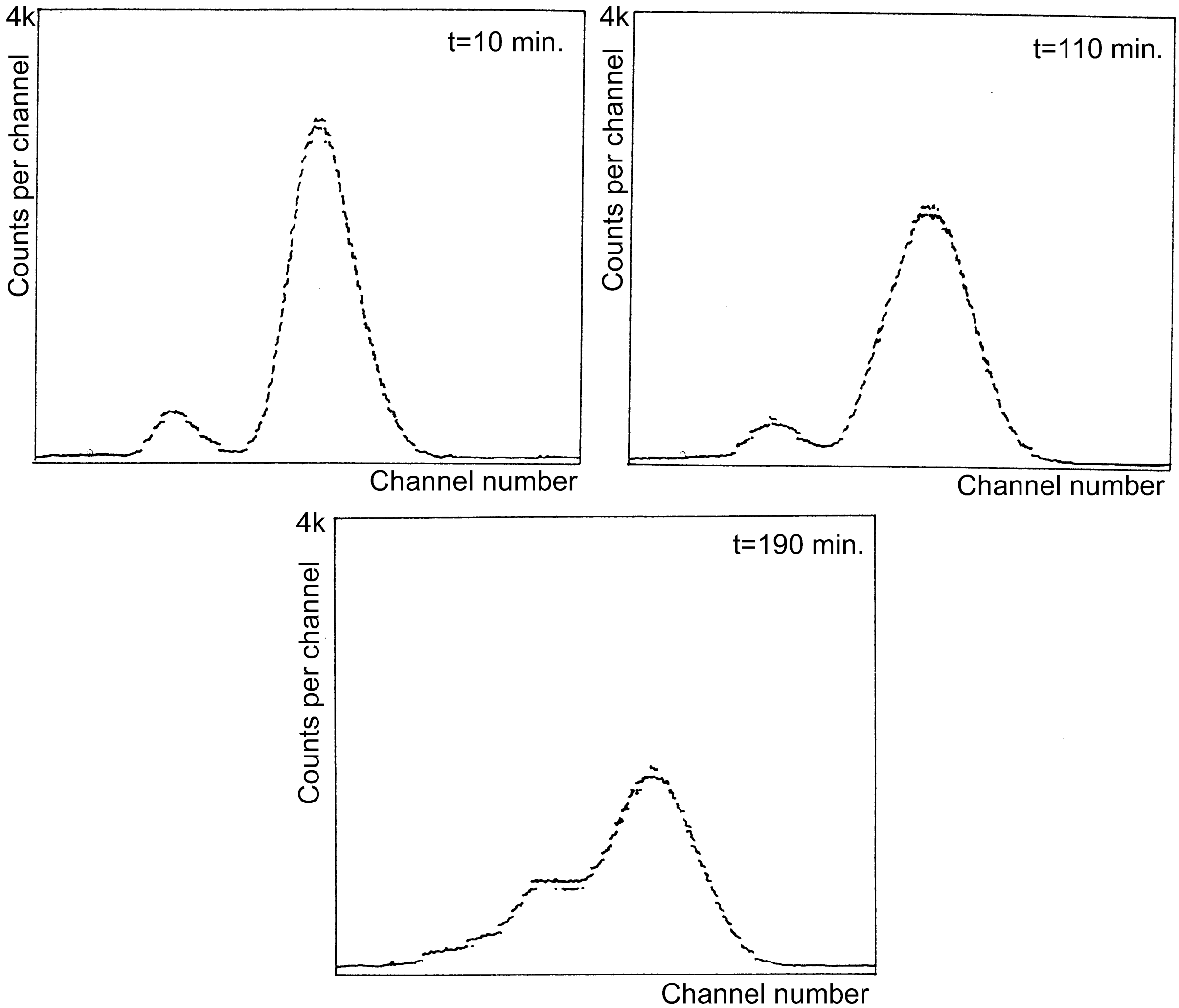

Fig. 6. Change of pulse – height distribution measured in aged, "self-regenerated" counter for different time of flushing with working gas. It should be noticed, that after only 2-hours of flushing the aging effect is reappear.

4 Discussion

For all "OUT" counters there was a reduction in pulse height. The ^{55}Fe peak became degraded as show in Fig 4. Initially the main peak dropped until the appearance of a second peak. It is a typical behaviour of aged counters and is caused by the formation of polymer isolating layers on the anode wire. The gas passing these counters contains the vapours released by the construction element of the chambers. The influence of water admixtures on aging phenomena has also been discussed in the literature [2]. Whereas there is come controversy on the eventual reduction of aging speed by water, in general there is agreement on the improvement of alnalog response. The water tends to increase surface conductivity.

On the other side, for all "IN" counters there was an increase in pulse height. The ^{55}Fe peak became degraded as show in Fig 3. Initially the main peak heightened up to appearance of a second peak. It is non-typical behaviour. The detailed analyses of anode surface for both „IN" and „OUT" counters were made using X-ray fluorescence method. Results of the element analysis of anode surface show the presence of Cu on "aged anode" of "IN" monitoring counters only (Fig. 7). No Cu was found on the surface of the anode of "OUT" counters. One can expect to find the Cu in the form of CuO. The following process leading to increase in gas gain can be proposed (is possible):

$$CuO + h\nu \text{ (from the electron avalanche)} \rightarrow (CuO)^{+} + e$$

The liberated electron contributes to the growth of electron avalanche. Ionised $(CuO)^{+}$ leads to local increase in anode potential. Thus, one has increase in gas gain and deterioration in energy resolution. The CuO itself is hygroscopic, so can explain the "self-regeneration" of aged counters kept in moisture environment.

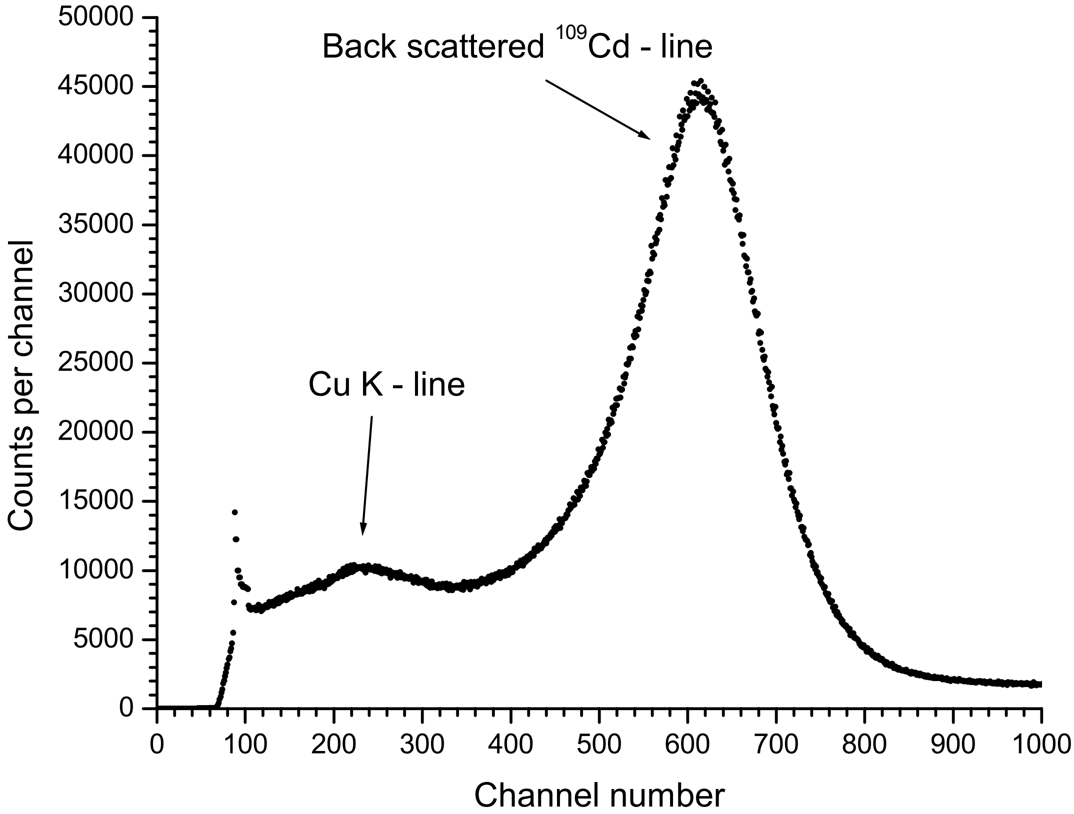

Fig. 7. X-ray fluorescence spectrum of anode surface of aged "IN" counters.

5 Conclusions

Conclusions are based on the analysis of aging phenomena of 158 monitoring proportional counters.

- In laboratory tests it was found that up to a collected charge of 1.8 C/cm no changes in counter operation was observed; while for some counters in the “real system” degradation in energy resolution was observed after collection of the charge 2 mC/cm . After nine months of performance, charge collecting of ~ 30 mC/cm, one hundred of counters were aged and were exchanged.
- For all 79 “IN” monitoring counters strong left-side peak deformation occurs.
- For all 79 “OUT” monitoring counters strong right-side peak deformation occurs.
- Keeping counters in moisture air or admixture of water vapour to working gas leads to temporal improvement of their analog response.
- The closed-loop and open gas-detector system should be flushed with clean working gas as long as possible (minimum 3 months) before applying high voltage on detector.

6 References

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