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RADIOACTIVELY INDUCED NOISE IN GAS-SAMPLING URANIUM CALORIMETERS

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ABSTRACT

The signal induced by radioactivity of a U^{238} absorber in a cell of a gas-sampling uranium calorimeter was studied. By means of Campbell's theorem, the levels of the radioactively induced noise in uranium gas-sampling calorimeters was calculated. It was shown that in order to obtain similar radioactive noise performance as U-liquid argon or U-scintillator combinations, the α-particles from the uranium must be stopped before entering the sensing volume of gas-uranium calorimeters.

I. Introduction

The energy resolution of a hadron calorimeter constructed from a non-uranium absorber is limited by fluctuations in the nuclear interactions. If there is an event which gives its energy mainly to neutral pions in an early interaction, the hadronic shower appears mostly as an electromagnetic shower. On the other hand, if there are many charged pions and nuclear fragments, there is much energy lost in breaking down nuclei of the absorber. The fluctuations in this amount of the invisible energy (≈30%) is the fundamental limit of the hadronic resolution obtainable with an ordinary (non uranium) absorber in hadron calorimeters.

It was shown(1) that use of U^{238} as an absorber in a hadron calorimeter improves the energy resolution. The amplifying effect of nuclear fission in uranium is larger for hadronic showers where more original energy is absorbed by the nucleus. The part of the energy released by the nuclear fission process compensates for the loss of the original energy, event by event, resulting in the observed improvement in the energy resolution.

Up to now uranium calorimeters were constructed with liquid argon and scintillators(1,2) as sampling media. The natural radioactivity of U^{238} and its products are seen in these calorimeters as a radioactively induced noise which does not degrade the energy resolution, and is used for calibration and monitoring purposes.

The study of the compatibility of the combination of the gas sampling read-out and the uranium absorber is the purpose of this contribution. In a gas sampling calorimeter the amount of the sampled energy is extremely small (10^{-4} of the total). Two questions arise: i) does the compensation mechanism also work for the gas sampling calorimeter; and ii) what is the effect of the uranium radioactivity in a proportional wire chamber and how large is the radioactively induced noise.

The first question can be fully answered only by testing a real uranium-gas sampling calorimeter. However, we know that only a small fraction of the additional energy released by the nuclear fission (basically γ-rays) is seen in uranium-liquid argon or uranium-scintillator calorimeters. The sampling ratio for these γ-rays in gas-uranium and scintillator uranium combinations is the same as for hadronic showers, thus we can reasonably assume that the compensation will remain unchanged in the gas sampling calorimeter.

The second question was investigated experimentally. Instead of constructing a large gas-uranium calorimeter, we have built a small proportional chamber surrounded with uranium and from the measurement upon the chamber using the knowledge of the statistics, we have calculated the noise for real calorimeters.

II. Idea of the Test

The idea of the test is based on Campbell's theorem(3), which we will use in its generalized form.

Let us consider a signal composed of randomly arriving impulses at a mean rate ν and of a random amplitude a. If we detect the pulses by a linear instrument responding to a unit impulse excitation by a deflection $u=F(t-t_0)$ where t_0 is the time occurence of the unit impulse (Fig. 1), then:

i) the mean deflection (response) of the instrument is

$$\bar{s} = \bar{a}\nu \int_{-\infty}^{\infty} F(t)dt$$

ii) the deflection fluctuates with a variance

$$\mathrm{var}(s) = \overline{(s - \bar{s})^2} = \nu\, \overline{a^2} \int_{-\infty}^{\infty} F^2(t)dt$$

where ν was defined above, $\bar{a}$ is the mean amplitude of the random impulses and $\overline{a^2}$ is the mean of the squares of these amplitudes.

Campbell's theorem is directly applicable to the calculation of the radioactively induced noise in gas sampling uranium calorimeters. The radioactive decay is a truely random process giving pulses with a negligible duration. If the calorimeter read-out is linear, then it can be described by an overall (ionization in; voltage out) impulse response function F(t). The first part of Campbell's theorem thus gives the mean shift of the output level due to the radioactive signal and the second part gives the output fluctuations which is the contribution of the radioactivity to the total noise.

It is desirable to express the radioactively induced noise in energy units, that is as the shower energy deposited in a calorimeter which is equivalent to the noise. A muon traversing a calorimeter looses the energy dE/dx × W per plate, where dE/dx is specific energy loss in the plate and W is the plate thickness. Assuming that the hadron shower energy is sampled in a similar way, we can write the relation between the energy deposition in a calorimeter and the output signal as:

$$E = s/s_\mu \cdot (dE/dx) \cdot W * 1.4$$

where s is the calorimeter signal (charge); s_μ is the signal produced by a minimum ionizing particle in one active gap and 1.4 is an empirical factor which accounts for a signal deficit due to the transition and other fine effects.

III. The Test Results

a) Scintillator as a Sensing Medium

To check the validity of all assumptions made to extend the pulse height and rate measurement from a small sample to a large calorimeter system the described procedure was applied to a scintillator as a sampling medium. The noise was predicted and compared with the actual radioactive noise measurement in real uranium-scintillator and uranium-liquid argon calorimeters.

Fig. 2a shows the distribution of a signal (s_μ) due to the minimum ionizing particles crossing the scintillator. Figs. 2b and 2c show the spectra (in linear and log scale) obtained when a 1.7 mm uranium plate was put close to the scintillator. (Lower spectrum was obtained with twice the amount of the material between the plate and the scintillator to allow an extrapolation to zero as used in actual calorimeter.) The rate of pulses and the total DC signal (anode current from the phototube) was measured at the same time. We have thus obtained the following quantities

i) rate of pulses ν
ii) DC signal $\nu\bar{a}$ and
iii) spectrum of pulses with $\bar{a}$, $\overline{a^2}$ etc.

Campbell's theorem for the fluctuations requires the knowledge of the product of $\nu\,\overline{a^2}$ only. Thus we have one useful constraint to check the self-consistency of the measurement.

The optimal treatment of the data, the knowledge of the response function F(t) and the size of built uranium-scintillator, and uranium-liquid argon calorimeters allows the direct noise prediction for these devices.

The table below compares our predictions with the observed numbers.

	Equivalent Noise Energy	
Calorimeter	Our Predictions	Observed
Liquid Argon (1) *	53 MeV	65 MeV
R-807 (2) **	7 MeV	10 MeV

*Calorimeter section consisting of 75 1.7 mm thick U^{238} plates. The surface area of each plate was 780 cm^2.

**Electromagnetic section consisting of 10 2 mm thick 20 × 20 cm^2 plates.

Our predictions give the noise systematically too low by about 30%, probably due to the radioactivity from the entire amount of uranium in real calorimeters. We have checked the importance of this "volume" effect. Placing an additional thick block of U^{238} behind the first U^{238} plate, the rate in the scintillator increased by 6%.

The same measurement with proportional chambers did not show any rate increase or any change of the pulse high spectrum. Therefore we were not correcting our proportional chamber results for this "volume" effect.

b) Gas as a Sensing Medium

Fig. 3a shows two considered geometries for a uranium gas sampling calorimeter. The design at the right hand side reflects some

newer ideas for the calorimeter construction using the dust of uranium oxide and epoxy;(4) at the left hand side there is a classical parallel plates geometry. Consequently, we have built two test proportional wire chambers shown in Fig. 3b to investigate the effect of the radioactivity. An analogous measurement and analysis as with the scintillator was made with the proportional tube having UO_2-epoxy mixture as a cathode. The predicted noise level for such a calorimeter of the size of liquid argon-uranium calorimeter of Reference (1) was found to be about 1200 MeV or 17 times higher than the noise level in reference 1.

It was noted, that almost all contributions to the noise were coming from very large pulses (compared with pulses due to minimum ionizing particles) at relatively low rate. The large pulses were due to α-particles entering directly the gas of the chamber and depositing ionization with an energy equivalent in GeV region.

The α-particles, however, can be stopped by a very thin sheet of material between the gas and uranium which should result in a substantial decrease of the noise.

The second measurement was carried on with a planar chamber having a 25μ mylar window with a 5μ aluminum foil to try to keep the material to a minimum between the sensitive gas volume and the uranium plate. For the mechanical reasons we could not place the chamber right next to the uranium plate. Fig. 4 shows measurements at several distances between the chamber and the plate. Extrapolation to the zero distance is shown.

The predicted noise level for the uranium-gas sampling calorimeter of the same size and with the same time response as liquid argon-uranium calorimeter was (140 ± 20) MeV. The noise level is thus only twice as high as in uranium-liquid argon combination for the same impulse response F(t). However, the read-out of a gas sampling calorimeter can be made faster than liquid argon read-out. A realistic decrease of duration of the response functions F(t) by a factor of two reduces the noise level of the gas sampling calorimeters by square root of two, bringing it down practically to the liquid argon level.

If even a lower noise level is required, more material can be placed between the gas and the uranium but this may also affect the compensation mechanism.

CONCLUSIONS

i) Radioactively induced noise does not exclude uranium-gas sampling calorimeters with a linear read-out if α-particles are stopped before entering the gas volume.

ii) The compensation mechanism of uranium-gas sampling calorimeter was not tested in the present paper. It is our "educated guess" that it should be the same as in liquid argon (or scintillator)-uranium calorimeters.

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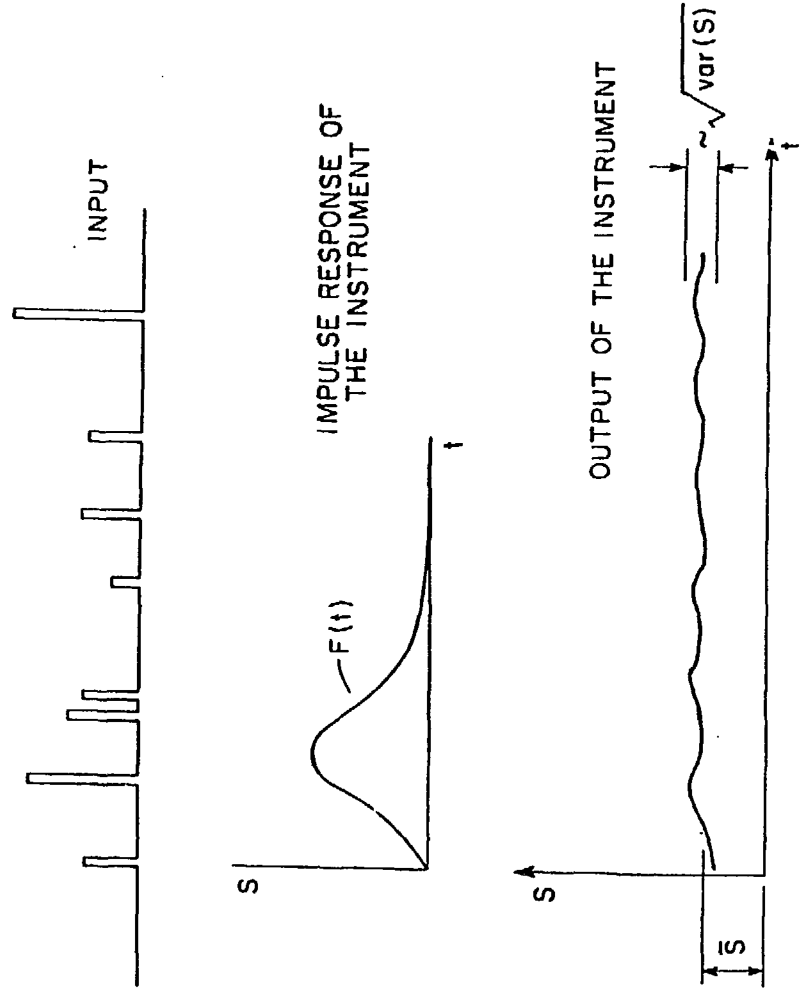
Figure Captions

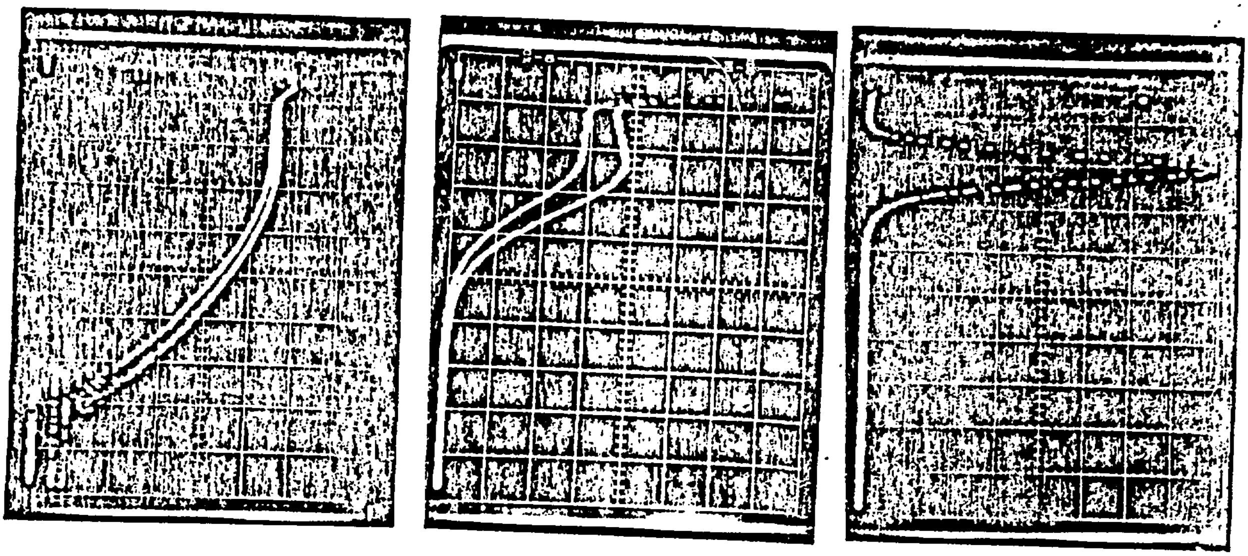
Fig. 1. Assumptions and the statement of Campbell's theorem. The upper part shows a sequence of random impulses of a random amplitude. At the center, the impulse response F(t) of the instrument. The bottom part shows the response of the instrument to the input random sequence.

Fig. 2. a) Distribution of minimum ionizing particles crossing the scintillator. Spectrum obtained with a 1.7 mm uranium plate close to the scintillator; b) linear scale; c) log. scale with one division corresponding to the factor of 10.

Fig. 3. a) Considered geometries for uranium-gas sampling calorimeters; b) proportional chambers to study corresponding geometries.

Fig. 4. Counting rate and DC current as functions of the distance between the chamber and the uranium plate. Values at the extrapolations to the zero distance were used.





a)

b)

c)

Fig. 2

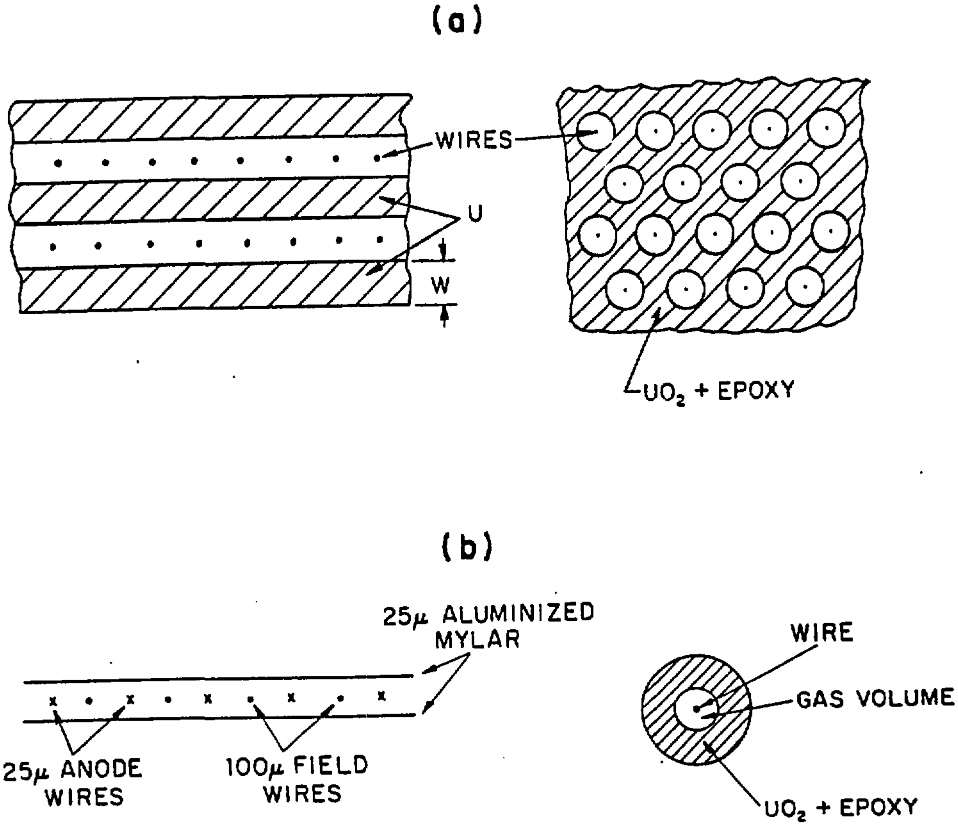


Fig. 3