RESPONSE OF A NAI(TL) SCINTILLATION DETECTOR IN A WIDE TEMPERATURE INTERVAL

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The temperature dependence of a NaI(Tl) scintillation detector's response has been studied in the temperature interval (-30^{0}C to +50^{0}C). Besides the common temperature drift of the light output and that of the decay time of the scintillator, some other very-long-term factors have been observed which give rise to a remarkable hysteresis of the output signal drift. They are most probably due to the PMT temperature instability. A post-processing method is proposed to compensate their effect and the results of its application are discussed.

Keywords: Scintillation detectors, long-term behaviour

1. INTRODUCTION

Scintillation detectors are amongst the most widely used instruments for measurement of the gamma-radiation. They have very good efficiency, reasonable energy resolution and moderate price. A significant drawback of the scintillation spectrometers is their relatively large gain drift which smears the observed photopeaks. It is mainly due to the following factors:

- the temperature dependence of the light output of the scintillator;
- the temperature dependence of the decay constant of the scintillations in NaI(Tl);
- the photomultiplier's temperature drift;
- the temperature behaviour of the detector front-end electronics;
- the ageing of the photomultipliers.

Fortunately, in most applications scintillation spectrometers are used either in laboratory conditions where the temperature changes are within 1-2 ^{0}C, or for short time measurements in the environment. So, in those situations the temperature effects are not so serious.

However, when used for continuous monitoring of the environmental radiation, the whole spectrometric system has to work long time in open air conditions (large temperature range, humidity etc.). Then the long-term characteristics of both the scintillator and the photomultiplier tube (PMT) are of crucial importance for the system performance.

The goal of the present work is a study of the long-term performance of a NaI(Tl) scintillation spectrometer in a temperature interval covering the whole operation range (-30^{0}C +50^{0}C) for outdoor radiation monitoring. A post-processing method is also suggested which is used to compensate the effects of gain instability.

2. EXPERIMENTAL

A cylindrical ∅45x40mm NaI(Tl) scintillator coupled to a XP2000 PMT is used. The scintillation detector and the front-end electronics (3.5µs RC-shaping chain and a buffering preamplifier) are put inside a refrigerator camera. The temperature inside the camera is controlled automatically within ±0.3^{0}C in the range (-29^{0}C+55^{0}C) following a preset temperature profile. Weak radioactive sources are used to produce gamma-rays (^{241}Am - 26keV, 60keV; ^{137}Cs - 662keV; ^{60}Co - 1173keV, 1332keV); the total count rate is about 4000 cps. In order to retain all modules inside the camera at the same temperature, the temperature change speed is kept rather slow (1-3^{0}C/h). As a consequence, the duration of one cycle is typically one week. The spectrometer behaviour is monitored by recording 2048 channel spectra every 300s. The photopeak centroids of the gamma-lines are computed by a least-squares analysis of individual spectra.

3. EXPERIMENTAL RESULTS

Fig.1 shows a typical change in the 1332keV ^{60}Co peak position during a temperature cycle: +20^{0}C (+1^{0}C/h) +55^{0}C (-1^{0}C/h) -25^{0}C (+1^{0}C/h) +20^{0}C. Besides the typical temperature drift, a deep hysteresis is observed that makes the system behaviour ambigious. Multiple loops make the picture still more complex as it can be seen from Fig.2.

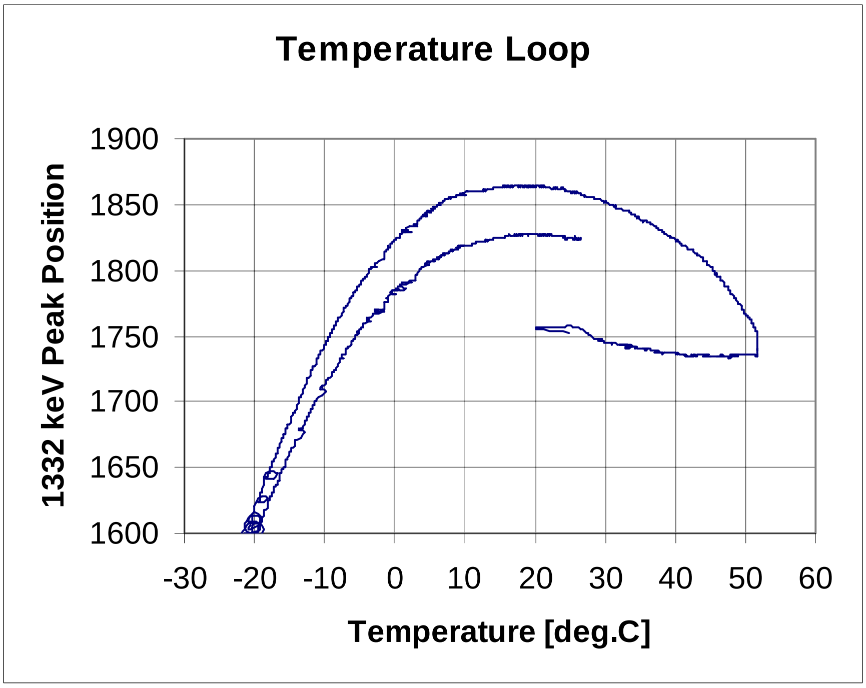

Fig.1.

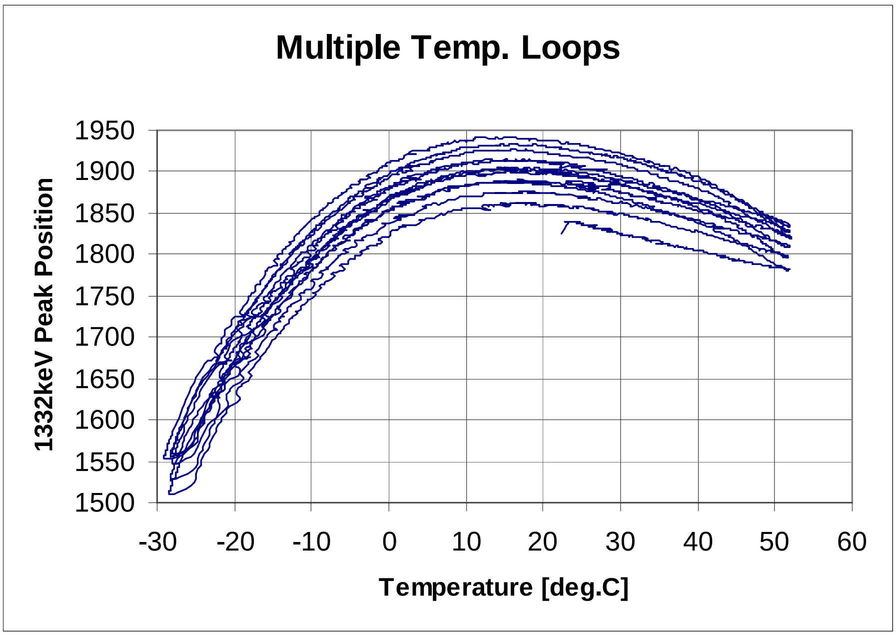

Fig.2.

The observed hysteresis effect is definitly related to a gain drift of the spectrometer rather than to a spectrum shift as a whole. To establish that fact we have applied a linear energy calibration procedure of the type:

$$P_i = a + b * E_i,\ i = 1, n \qquad (1)$$

where P_i is the position of the peak centroid at energy E_i, to all recorded spectra during the cycle, and then the coefficients a and b have been plotted *vs* temperature. Fig.3 shows the results corresponding to the temperature loop of Fig.1.

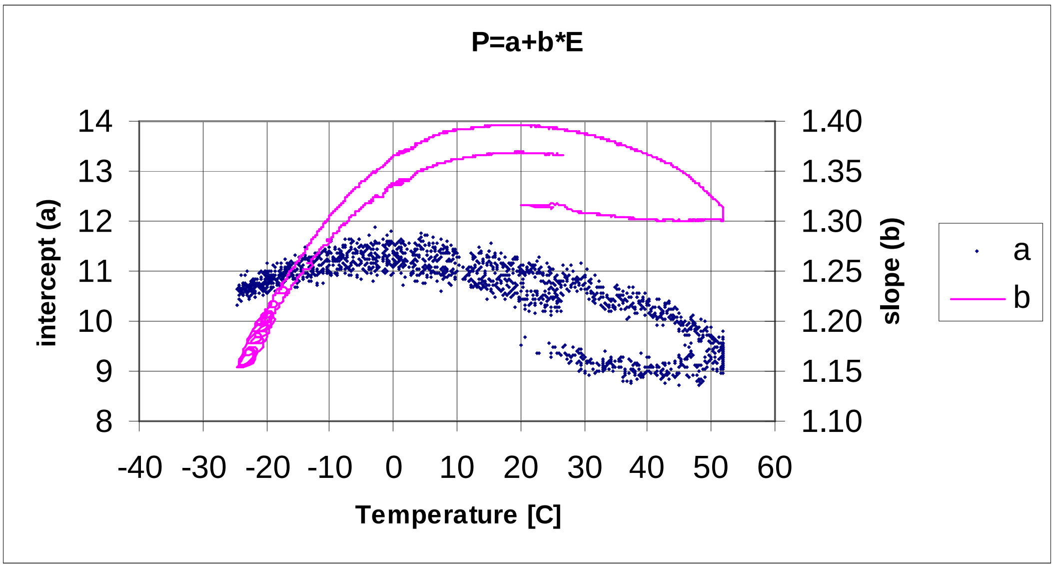

Fig.3.

It is seen that the hysteresis in the intercept (a) does not exceed 1 channel, while the gain hysteresis (b) is about 0.05chn/keV (i.e. 50 channels for 1000keV which is comparible with the gamma line width at that energy).

Additional experiments at a constant temperature preceeded by a temperature stress (temperature cycle: +50^{0}C (-3^{0}C/h) +20^0 (T=const)) (Fig.4) have shown that the observed hysteresis is due to a very long-term factor. The experimental data can be fitted as a sum of two exponents:

$$P = b + a_1.\exp(-\ln 2.t/\tau_1) + a_2.\exp(-\ln 2.t/\tau_2) \quad (2)$$

with the following values of the parameters:

parameter	value	σ
b	1985	0.6
a_1	28	0.4
τ_1	116	5
a_2	12.3	0.3
τ_2	10.3	0.3

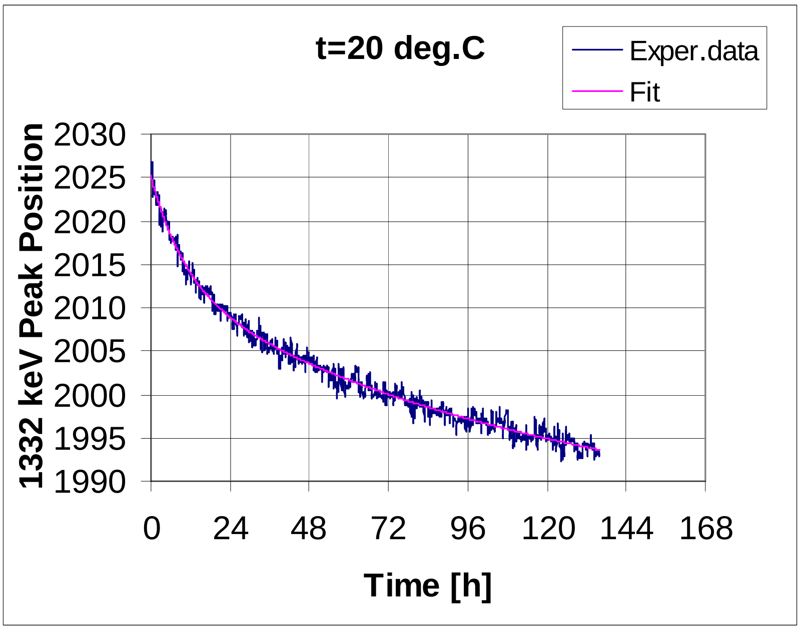

Fig.4

4. STABILIZATION METHOD

Summarizing the experimental results, we have observed two effects:

- strong temperature drift, mainly of the gain, and
- a long term hysteresis of the gain.

The second phenomenon excludes the possibility to use the current temperature value for gain stabilization of the spectrometer, since the present gain status depends also on its temperature history a couple of days ago. Obviously, an active feedback stabilization system has to be developed in order to compensate influence of the the observed effects on the spectrum quality.

At this stage of the investigation, we have decided to use a phenomenological post-processing method [1]. It is based on a least-squares comparison of successive spectral records with a reference spectrum (say, the first record) when the x-scale parameters (in the simplest linear approximation these are the zero-energy channel and the channel/energy ratio) are varied until a maximal consistency is achieved. Then the channel contents of the examined spectrum is redistributed (rebinned) according to the new values of the x-scale parameters. Spline technique is used to ensure continuity of the rebinning procedure. The method allows any analytical parametrization of the spectrum x-scale to be used; in most cases a linear or quadratic 'energy *vs* channel' function is relevant.

Fig.5 shows the ^{137}Cs peak position from the Fig.1 cycle before and after the application of the x-scale adjustment algorithm. The peak position variation is now diminished 5 times and falls well within the instrumental linewidth.

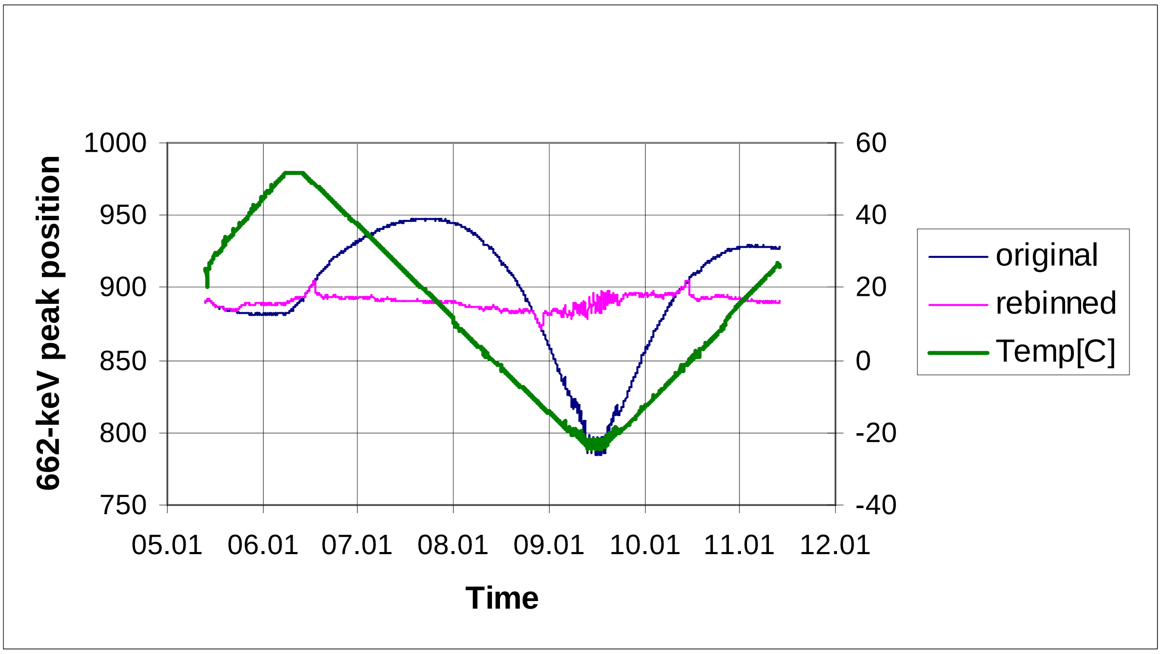

Fig.5

5. CONCLUSION

The total instability of a NaI(Tl) scintillation spectrometer is investigated in the whole temperature interval of open air environment operation. The well known temperature dependent factors (the light output and the decay time of the scintillator) determine the main profile of the spectrometer's temperature drift. Besides them, some very-long-term drift factors have been observed which give rise to a remarkable hysteresis of the output amplitude drift. Since we are interested of the response of the spectrometer as a whole, we have not yet performed a special survey to identify their origin. It seems that they arise from the PMT temperature instability. The important consequence is the fact that it is impossible to stabilize spectrometer gain on the basis of its current temperature only. At this stage, a post-processing method is proposed to compensate the gain drift. Its application results in diminishing the drift 5 times. A detailed study of the system stabilization by a deep feedback is forthcoming.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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