Monitoring the environmental radiation by using a new gas-filled proportional counter probe as a quasi-spectroscopic system

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ABSTRACT: To evaluate the composition of complex gamma-fields, spectroscopic systems are increasingly gaining in significance in environmental monitoring especially triggered by the Fukushima incident in 2011. Nowadays, commercial solutions that provide accurate and valid information concerning the potential nuclide vector are based upon scintillators or semiconductors. However, the cost of acquisition and maintenance of such systems are high-priced aside from general stability problems if operated under ambient conditions. The “VacuTec Meßtechnik GmbH”, specialised in manufacturing radiation detectors since 1956, provides a new cost-efficient, innovative quasi-spectroscopic probe (hereinafter referred to as “PCP”) that combines a conventional Geiger-Mueller probe with a gas-filled proportional counter of high efficiency towards photon radiation. By means of a sophisticated deconvolution algorithm, the continuously updated pulse height spectra are deconstructed into a natural and a non-natural part. To be more precisely, the PCP evaluates the local natural background by comparing a current spectrum with a set of response vectors containing the radiometric “fingerprint” of the location where the PCP is installed stationarily, whereby a reliable differentiation is obtained between the local background and non-local contributions of artificial origin. Two Geiger-Mueller tubes, which are operated in an innovative dead-time independent measuring mode, provide dose rate data. Neutron detection with ^{3}He counter tubes is available optionally. We present results of on-going measurements under real conditions.

BASICS I: The detector response defines the system matrix A consisting of a set of basis vectors. Each basis vector represents a radiation component in the form of a discrete probability distribution. In its simplest version applied here, A is composed of two basis vectors only, i.e., the natural and the pre-set non-natural component. The natural component reflects the contamination-free situation locally, whereas the non-natural component is related to a nuclide typically released in the event of a nuclear incident. Taking into account the constraint $x \geq 0$, the equation

$$\nabla_{x,\lambda}\left[(y - Ax)^T(y - Ax) + 2\lambda v^T(y - Ax)\right] = 0$$

has to be solved. That way the measured spectrum y is reconstructed as linear combination Ax of the underlying basis set. The Lagrange multiplier λ ensures pulse number conservation. Eliminating λ, the solution can be written as follows:

$$Ax = P\left(1 + \frac{vv^T(1-P)}{v^T P v}\right) y \text{ with } P = A\left(A^T A\right)^{-1} A^T.$$

To obtain count rates, the solution has to be divided by the acquisition time.

BASICS II: Statistical effects are evaluated by calculating the covariance matrix $C(x)$ according to

$$AC(x)A^T = P\left(1 + \frac{vv^T(1-P)}{v^T P v}\right) C(y) \left(1 + \frac{(1-P)vv^T}{v^T P v}\right) P \text{ with } C(y) = y_i \delta_{ij}.$$

The quantity χ^2 tests the hypothesis that both the reconstructed spectrum and the measured spectrum match as to shape:

$$\chi^2 = \sum_{m=1}^{n} \frac{\left(\langle e_m|y\rangle - \langle e_m|Ax\rangle\right)^2}{\langle e_m|Ax\rangle}.$$

If and only if y can be considered as linear combination of the basis set, both $\langle\chi^2\rangle$ and its variance are given time-independently by n and $2n$, respectively. In contrast, any radiation being different from the underlying basis set is indicated by time-dependent $\langle\chi^2\rangle$ larger than n growing linearly with the number of pulses registered.

Both low and high dose Geiger-Mueller tubes are operated in a dead-time independent measuring mode based upon the idea of measuring time intervals between consecutive pulses instead of counting pulse numbers per time, which would be interfered by dead-time effects. After every single pulse, the tubes are quenched and restarted automatically with a defined recovering time much larger than the intrinsic dead-time. This method results in a linear count rate-dose rate relationship, which expands the usable measuring range by one to two decades. As is known, the time up to the next pulse obeys an Exponential distribution with a mean being the inverse pulse rate. Both Geiger-Mueller tubes are energy-compensated. Knowing the pulse-rates, the corresponding dose rates $\dot{H}^*(10)$ can be calculated. The dose rate values of both tubes are used to calculate an overall dose rate taking the statistical precision of the measurements into account.

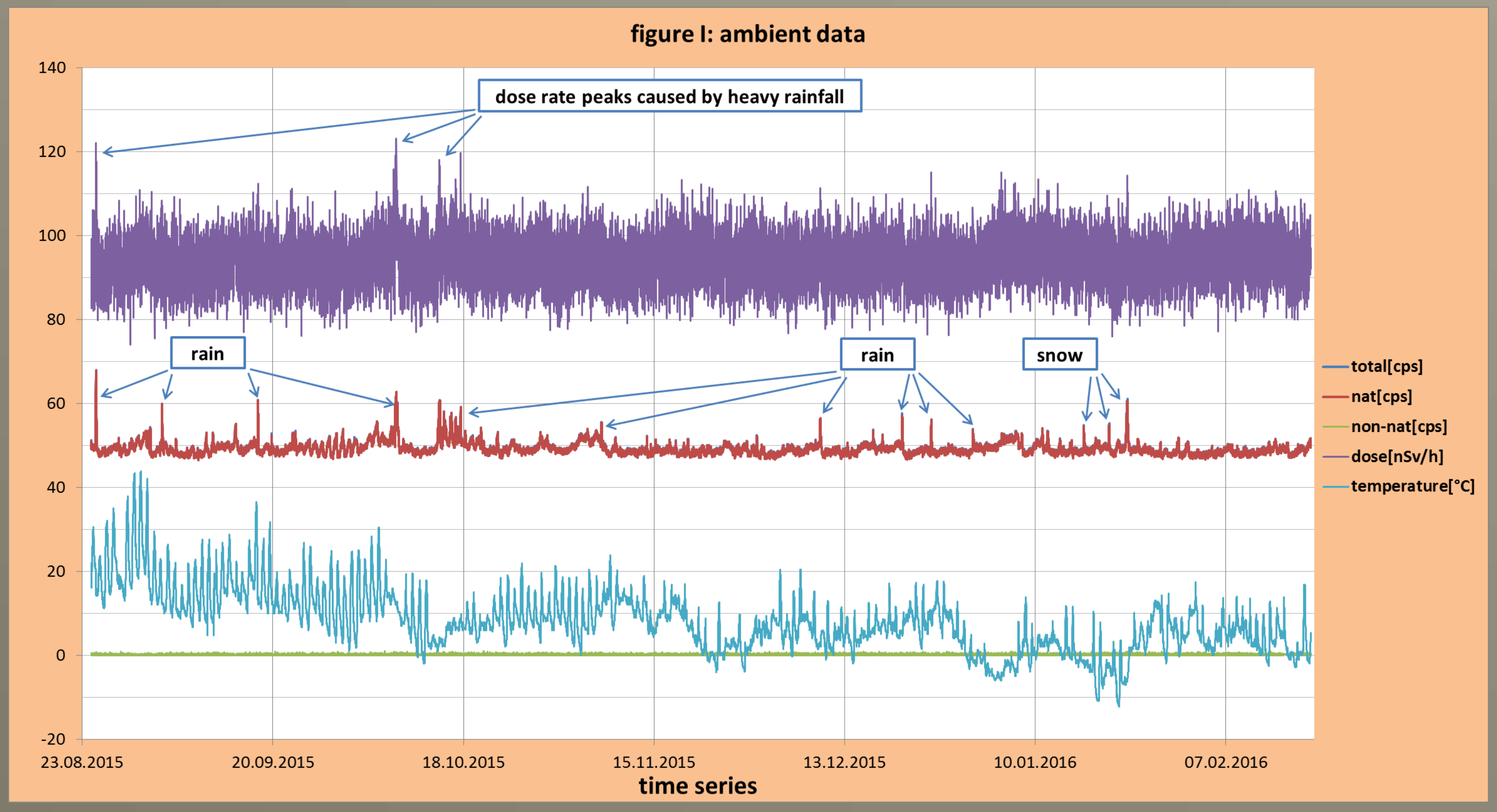
figure I: ambient data

AMBIENT DATA: One PCP was installed outdoors on the rooftop of our company building. Dresden, localised in the proximity of known uranium deposits, is characterised by a comparative high natural radiation level. Since August 2015, the PCP has been exposed to various weather conditions with temperatures ranging from +40 °C down to -20 °C. In figure I recorded data for dose rate “dose”, all rate components and the temperature are shown. The natural component “nat” and the non-natural component “non-nat” provide the overall count rate “total” exactly. The overall count rate displays distinct peak structures. These structures can be attributed definitely to precipitation events regardless of whether rain or snow. While a heavy thunderstorm occurred in late August 2015, the overall count rate increased by 40%. Generally, the non-natural component did never exceed its own statistical noise level. Accordingly, the natural count rate equals the overall count rate approximately. Hence, any increase of overall count rate is clearly allocated to the natural component so far. Another remarkable event occurred in early October 2015 related to a heavy downpour after a long period of dry weather. The individual characteristic of a precipitation induced radiometric event results from the interplay between various factors such as duration, intensity and frequency of precipitations. The data emphasise the sensitivity of the PCP in the face of numerous factors such as geologic, topographic and meteorological conditions together with the omnipresent cosmic background of variable intensity, which influence the natural radiation level directly or indirectly. However, eye-catching dose rate peaks are only to be ascertained in connection with heavy rainfall. Otherwise, the course of the dose rate is dominated by statistical noise and at best indicates general trends.

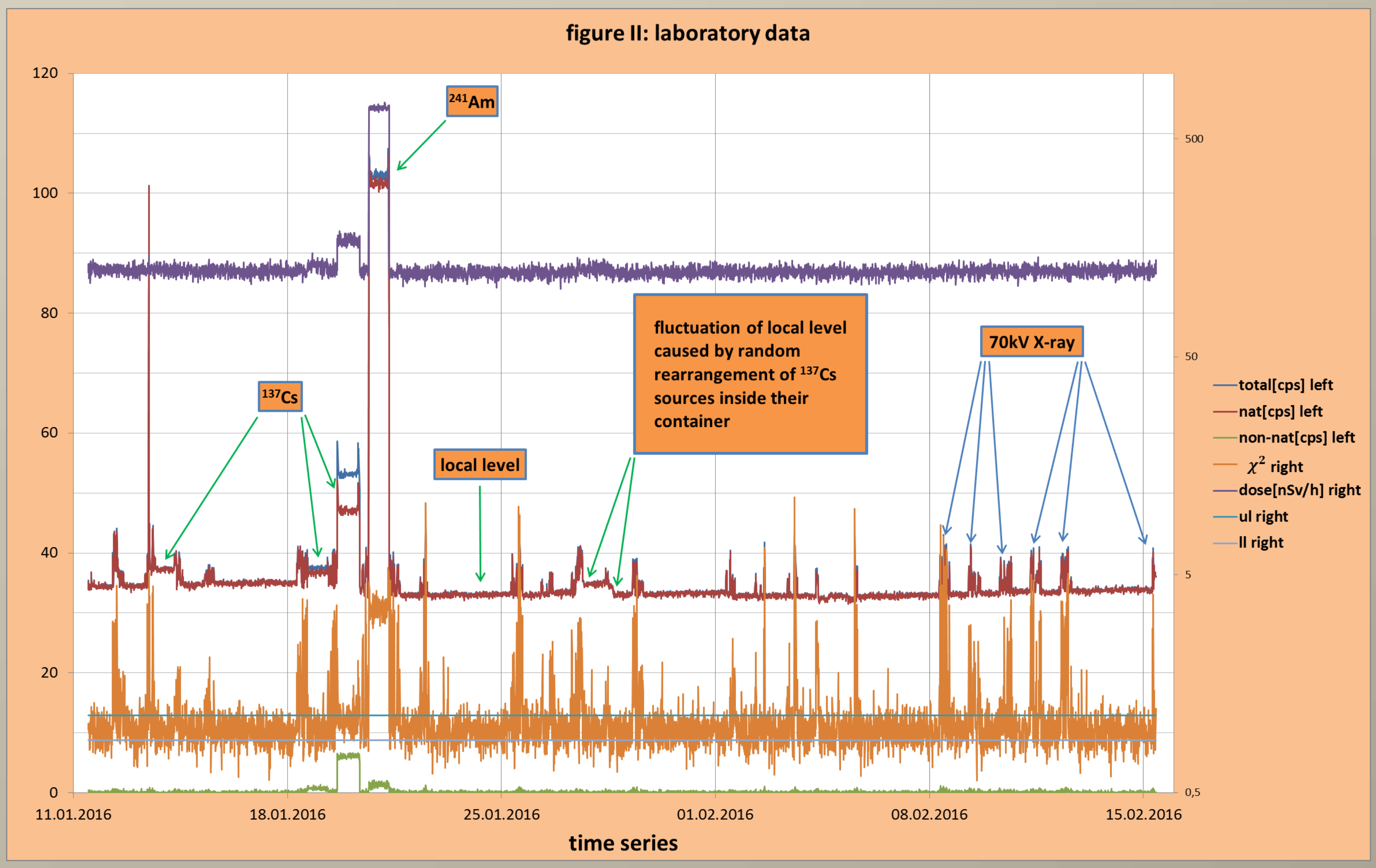
figure II: laboratory data

LABORATORY DATA: To simulate the “worst case scenario”, the PCP was tested next to our calibration facility, which provides various photon irradiation devices including ^{137}Cs and ^{60}Co sources of different activity as well as an X-ray system. The measuring setup was installed in an adjoining room. The data shown in figure II comprise the dose rate, both rate components, the overall count rate as well as χ^2. Distinctive effects were observed when the X-ray system was operating. Depending on the applied tube current, both the overall and the natural component increased considerably, while the non-natural component responded in a rather modest way. However, the risen χ^2 indicates the presence of spectral contributions differing from the local background. The additional radiation of a ^{137}Cs source emitting 662 keV photons only has induced a gain of pulses registered. Neither the non-natural component nor χ^2 has been affected noteworthy. This behavior can be explained with the low additional intensity and the fact that the detector responds to photons of higher energy in a rather uniform way. Surprisingly, even the random rearrangement of the ^{137}Cs sources inside their storage containment has raised the overall count rate significantly. Free ^{137}Cs emits 662 keV photons along with 30 keV X-ray photons. Hence, the detector response to 30 keV photons has been selected as pre-set non-natural basis component representing a typical radiation to be expected in the event of a nuclear power plant accident. To reproduce such an incident on the laboratory scale, the PCP was irradiated additionally using small ^{137}Cs sources of different activity. These sources have thin windows allowing low energy photons to escape. According to figure II, both the natural as well as the non-natural component increased apparently. Furthermore, the PCP has been exposed to a fairly strong ^{241}Am source emitting 60 keV photons. Obviously, this radiation did not fit to the underlying basis set, which is clearly visible regarding χ^2. Except for radiation originating from those sources, the corresponding dose rate has proved widely to be much less sensitive to fluctuations of the radiation level.

CONCLUSIONS: By deconvoluting continuously updated pulse height spectra, the PCP is capable of differentiating between natural and non-natural radiation components. The PCP may be integrated into monitoring networks as a substitute for commonly used counting probes based upon Geiger-Mueller tubes. In addition to conventional dose rate data, it provides basic evidence of the spectral constitution of the radiation being detected. Where ordinary Geiger-Mueller probes at best would just register unspecific fluctuations of the background level, the PCP allows a rough spectroscopic classification. For instance, a temporary increase of radiation, typically induced by natural occurring events such as precipitation, will be recognised as a non-hazardous variation of the natural background, whereby man-made causes may be excluded. Being very sensitive to any deviation from the local background radiation, the PCP indicates the presence of airborne or surface contaminations, however without analysing the hypothetical nuclide vector itself.

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