MOVING FILTER PARTICULATE MONITOR
BAI 9100

Introduction

The Moving Filter Monitor BAI 9100 has following key features:

- The filter transport can be continuous or stepwise. The filter tape is led over a slotted capstan drive through which the sampling air is drawn. This ensures a uniform dust collection with a continuous smooth filter advance without risk of rupturing the filter.

- The detector is mounted directly over the dust collection area and promptly measures the particulate radioactivity.

- In the standard version a Beta plastic scintillator detector BAI9300B with high dynamic range is used, resulting in a wide measurement range. As an option, an Alpha-/Beta Scintillator detector BAI9300AB can be employed to detect Alpha and Beta activities simultaneously in separate counting channels.

- For the Alpha-Beta measurement, the influence of natural radioactivity is compensated by the Alpha/Beta ratio method or optionally with the Alpha-Beta pseudo coincidence difference method (ABPD).

- As an option, a Gamma detector can be installed inside the collection unit facing the activity deposited on the bottom side of the filter. The Gamma detector can be any scintillator detector or a HPGe high resolution semiconductor detector.

- The Moving Filter Monitor can be combined with an Iodine and/or a noble gas monitor.

- The dust collection and detector assembly is shielded by an enveloping 4π lead shield. This results in a low intrinsic background and low ambient radiation sensitivity. For application in fluctuating gamma fields, a gamma dose rate detector can be mounted to compensate for these fluctuations.

- The large collection area allows a high flow rate of up to 25 m^3/h and hence low detection limits.

- As an option, a delayed measurement can be offered which detects the activity on the filter ~120 h (5 days) after collection, virtually eliminating any Radon progeny influence from the sample. Consequently, the detection limit for artificial Beta activities is below 1 mBq/m^3.

- If required, an automatic measuring range extension can be achieved by fast advance of the filter tape.

- Data recording and evaluation is carried out by the 19” flexible multi counting channel data-logger LB9000.

The Monitor BAI 9100 D consists of the following building blocks:

- **Dust collection unit BAI9100D:** This collection unit allows prompt Beta or Alpha-Beta measurement as well as prompt Gamma measurement. The Beta or Alpha-Beta detector is mounted on top of the dust collection area, which ensures measurement while collecting activity. The particle detector measures directly above the dust collection area in order to eliminate delays. The sample air is drawn through a flat nozzle through the glass fibre filter. Additionally, a measurement position for a particle detector is available with up to 120 h remote delay after collection depending on the filter speed.
- **Detectors:**
  - **Beta detector BAI9300B:** Plastic scintillator and integrated preamplifier BAI9207-1. The detector delivers digital norm pulses that are fed to the evaluation electronics.

    Alternative available:

  - **Alpha-/Beta detector BAI9300AB:** with ZnS coated plastic scintillator and preamplifier unit LB2030 for simultaneous, separate Alpha and Beta activity measurement. The analogue signal from the detector is converted into digital norm pulses in the preamplifier LB2030 which are fed to the evaluation electronics.

  - **Gamma detector:** see details on p.12.

- **Cassette in Aluminium (Option Stainless Steel):** with IP68 protection and a transparent Plexiglas front door which envelops the medium wetted parts. The capstan drive mechanism and the filter tape sensors are mounted on the back side of the cassette. The capstan drive mechanism ensures a virtually tension free filter advance and makes it less prone to filter rupture even with a humid filter tape. The cassette is built to 19” standard and is suited for mounting into a 19“ enclosure. The front door is secured with two screw closures and an optional „Door Open“ sensor.

- **PLC unit:** to drive and monitor the stepper motor filter advance mechanism.

- **Pump unit:** equipped with a maintenance free lateral blower pump, suited for temperatures up to 45°C and designed for a sample airflow of up to 25 m³/h with flow sensor or an optional flow meter (Vortex or calorimetric measurement principle).

- **Evaluation electronics:** LB9000 data logger. The core of this logger consists of a state-of-the-art panel PC running on a Windows 10 IoT environment. Berthold detectors and sensors are interfaced by means of intelligent peripheral modules and communicate with the panel PC using an internal CAN bus.

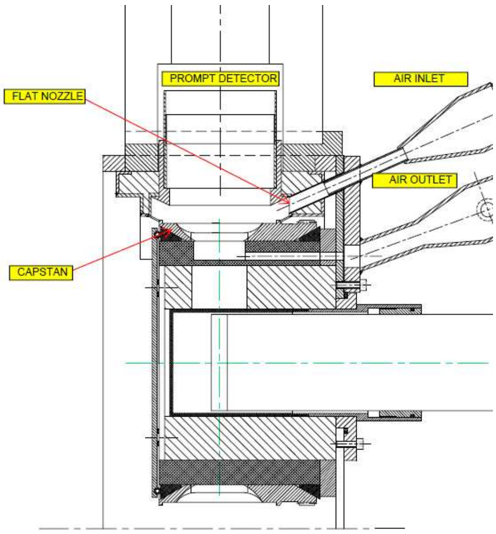
- **19“ enclosure:** contains the above-mentioned components.

- **Special requirements are available upon request.**

Operating Principle

The sample air is drawn in the cassette with a lateral blower pump unit via a flat nozzle and passed through a glass fibre filter tape which retains the particles on a 50 x 50 mm² strip. The filter tape is advanced in pre-programmed large steps or continuously in small (0.3 mm) steps with a DC stepper motor to ensure a homogenous particle distribution on the filter tape. Filter transport and end-of-tape is monitored with two inductive sensors. The filter rupture sensor is located on the left idler beside the capstan, whereas the filter end sensor is located on the filter feed spool.

Operating Principle of the Moving Filter



The sample air is drawn with the pump via the inlet flange on the top side of the monitor and is brought to the dust collection area located directly under the prompt particle detector through a smooth inner surface stainless steel pipe. The aerosols are trapped in the filter tape and measured with the prompt detector. The filter tape is conducted from the feed spool over the capstan and guide rolls to the filter take-up spool. The tape is advanced through the capstan rotation by means of a stepper motor which ensures a steady rate of filter advance.

In Step Mode operation, the monitor behaves like a fixed filter monitor (Activity Release Balance). Depending on the required cycle time the filter is advanced (changed) automatically in pre-set intervals (for instance daily).

To obtain a wider dynamic measuring range in Step Mode, the measuring and stepping intervals can be increased, whereas in continuous mode the filter speed can be augmented. The cycle time or filter speed can be pre-set through internal parameters or activated via an external trigger input.

As an option the airflow rate can be continuously measured with a flow meter. The calorimetric flow meter measures the normalised sample volume flow (NTP volume flow to ISO 2533 normalised to 1013 hPa, 15°C and 0% relative humidity). This type of flow measurement has no moving parts like a turbine and requires therefore little or no maintenance. The flow meter is installed after the cassette and before the pump unit. The analogue output signal is connected to the evaluation electronics for further processing, monitoring, and registration.

Hardware

Detectors

The detectors used for prompt and delayed measurement are scintillation-PMT types. The plastic scintillator detector BAI9300B is used for Beta measurement only, the ZnS coated plastic scintillator detector BAI9300AB is used for Alpha and Beta measurements.

The separation between Alpha and Beta radiation is obtained through pulse height discrimination inside the LB2030 preamplifier.

In the LB2030 the analogue signal is processed through two pulse height window discriminators after amplification and pulse shaping in a first amplifier stage. The discriminators split the analogue signal in two separate Alpha and Beta norm pulse outputs. Either the norm pulse output signals from the LB2030 preamplifier or the direct output of the Beta detector is connected to the digital counter inputs of the evaluation electronics.

Evaluation Electronics

The flexible multi-counting channel data logger LB9000 with up to 20 channels interface and monitor the 9100D detector and sensor signals. The application software allows the free setting of system- and measurement parameters. Additional service functions are available such as background, calibration, Radon compensation (pseudo coincidence factors), and performance tests.

The data logger is equipped with the following interfaces: USB, Ethernet and RS232 for data transmission and collection of relevant measurements as well as monitoring to the operating parameters. The data is stored in a FIFO buffer.

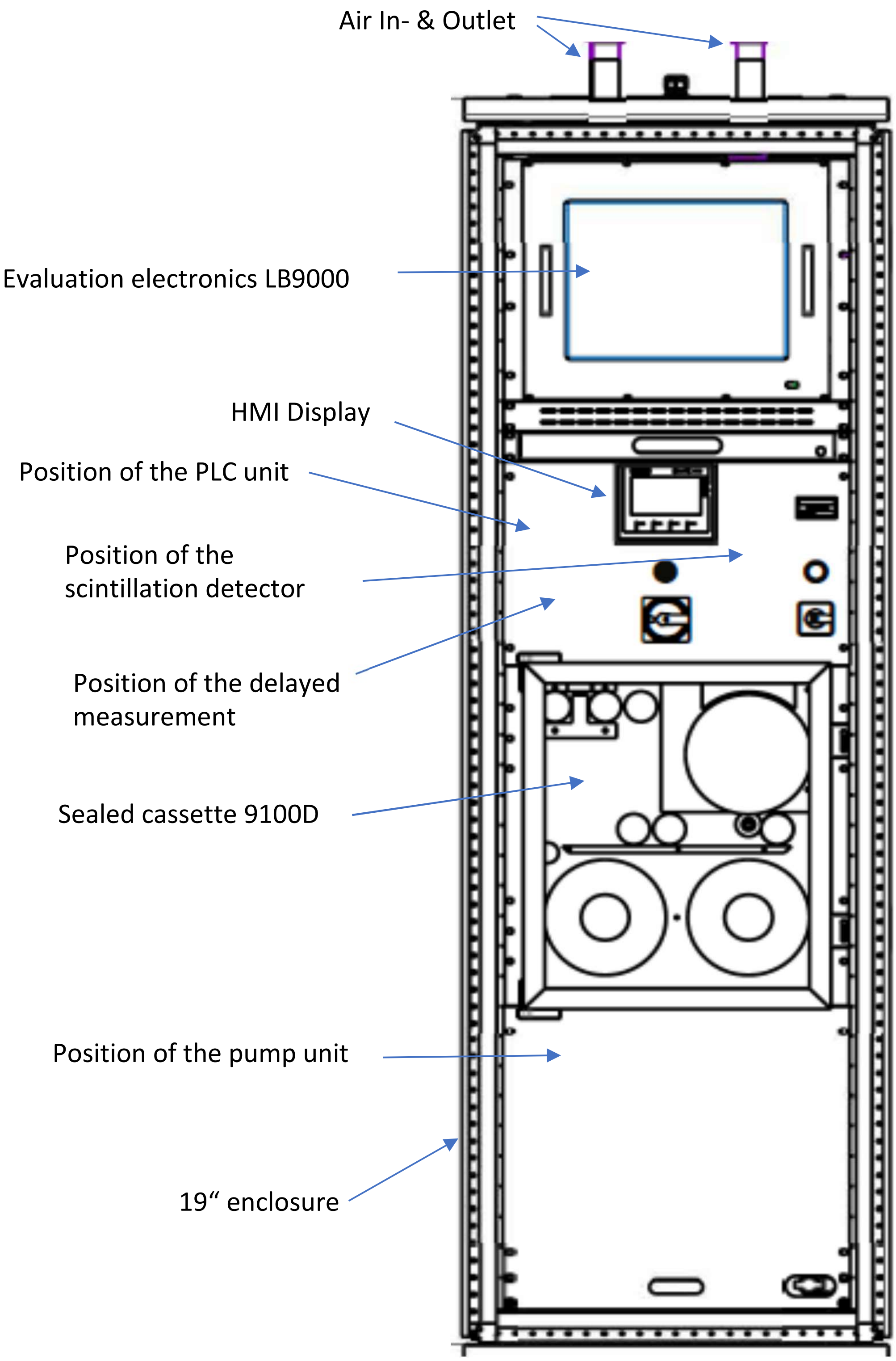
Further details on the electronic module can be found in the data sheet of the LB9000.

Software packages

Berthold LB9000	See separate product description LB9000
Controls & Measures	Beta / Alpha detector(s) Technical alarm cassette (Filter End, Filter Jam) Flow sensor
Reports	Bq/m^3 artificial Beta activity Bq/m^3 gross Alpha activity Bq/m^3 artificial Alpha activity with ABPD and CAM-PIPS detector Bq/m^3 Radon progeny with ABPD and CAM-PIPS detector Flow rate in m^3/h Integrated values of the above (Bq/m^3) System status: Alarms, Failures, current status
Communication	See LB9000 F^{2}C protocol

Communication	See LB9000 Manual

Components of the Moving Filter Particulate monitor BAI9100 D



Radiological performances

Radon progeny compensation

The solid discrimination of the natural activity is required to optimise the sensitivity for artificial radioactivity. For a dedicated Beta monitor, this can be achieved using the Beta/Alpha ratio compensation method whereas for an Alpha/Beta monitor the ABPD compensation method is recommended.

Beta/Alpha ratio compensation

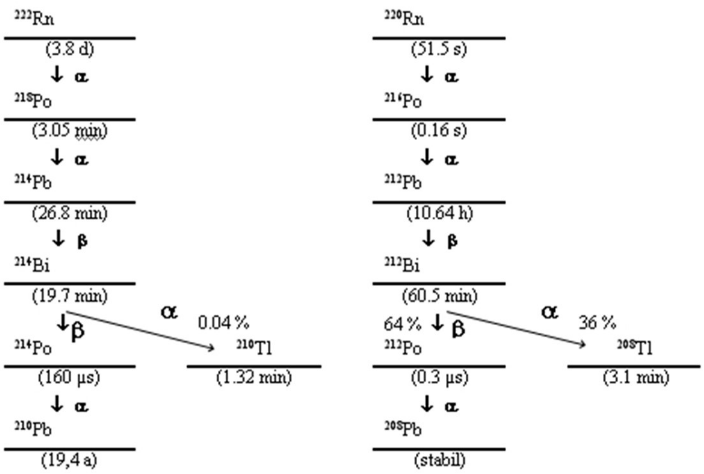
This compensation method relies on the assumption that all Alpha activity is resulting from natural occurring isotopes. The Beta radiation is indicated as net artificial activity by correcting the gross activity for the natural component using the Beta/Alpha ratio formula:

$$Beta_{art\ net} = K_b * (B - aA),$$

with A and B the background corrected count rates from Alpha and Beta channels, K_b the calibration factor for the Beta channel and a the compensation factor derived from the Beta/Alpha count rate ratio measured without presence of artificial activity.

ABPD-compensation and measurement principle

Alpha **B**eta **P**seudo-Coincidence **D**ifference method

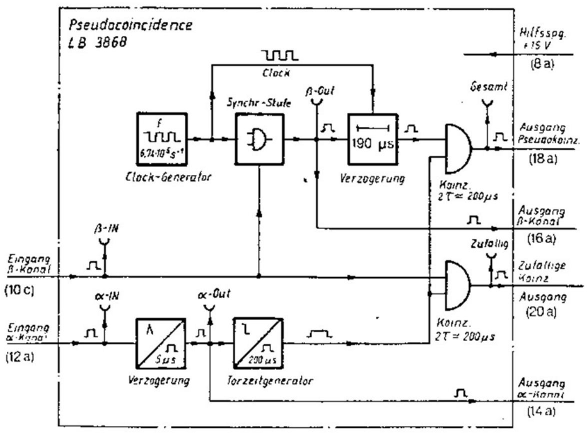


The ABPD method uses the specific measurement of the Bismuth-214 decay into Polonium-214 and the Bismut-212 decay into Polonium-212 to compensate for natural activity.

The method is implemented in an electronic circuit with a coincidence gate opened for a given time (>160µs) as soon as a Beta decay is detected. If during this gate time the detector registers an Alpha signal too, a pseudo-coincidence pulse is generated, which is a measure for the natural activity in the sample. In practice the electronics uses the Alpha counts to trigger the gate, whereas the Beta counts are sent through a delay line. The reason for this is to obtain a wider dynamic range because in equilibrium the natural Alpha decays are about 1.6 times shorter than the natural Beta decays.

A good pseudo-coincidence stage should contain a second circuit to detect random coincidences. These should be used to compensate the pseudo-coincidence stage for random coincidences at higher count rates to avoid overcompensation, i.e., suppression of potential artificial radioactivity events.

The ABPD module block diagram shown here has two implemented stages the pseudo-coincidence stage (Bi-214/Po-214 and Bi-212/Po-212 decays) and the random (A/B) coincidence stage.



Alpha/Beta detection Limits

- Continuous filter speed 10 mm/h
- Based on DIN 25482
- $k_{1-\alpha} = k_{1-\beta} = 1.96$ (false positive, false negative conf. level)

Prompt measurement with Alpha/Beta-Detector without presence of natural activity

Alpha

Meas. time [s]	Det. limit [s^{-1}]	MDC [Bq/m^3]
600	0.012	0.001
1800	0.007	0.001
3600	0.005	N/A
7200	0.004	N/A

Beta

Meas. time [s]	Det. limit [s^{-1}]	MDC [Bq/m^3]
600	0.226	0.021
1800	0.131	0.012
3600	0.092	0.008
7200	0.065	0.006

Prompt measurement with Alpha/Beta-Detector and ABPD-Compensation

assumed Radon daughter volumetric activity concentration of 3.7 Bq/m^3:

Alpha

Meas. time [s]	Det. limit [s^{-1}]	MDC [Bq/m^3]
600	1.506	0.143
1800	0.869	0.083
3600	0.615	0.058
7200	0.435	0.041

Beta

Meas. time [s]	Det. limit [s^{-1}]	MDC [Bq/m^3]
600	2.921	0.266
1800	1.687	0.153
3600	1.193	0.109
7200	0.843	0.077

assumed Radon daughter volumetric activity concentration of 37 Bq/m^3:

Alpha

Meas. time [s]	Det. limit [s^{-1}]	MDC [Bq/m^3]
600	4.761	0.452
1800	2.749	0.261
3600	1.944	0.185
7200	1.374	0.131

Beta

Meas. time [s]	Det. limit [s^{-1}]	MDC [Bq/m^3]
600	9.238	0.841
1800	5.334	0.485
3600	3.772	0.343
7200	2.667	0.243

Prompt measurement with Alpha/Beta-Detector and Beta/Alpha ratio compensation
assumed Radon daughter volumetric activity concentration of:

3.7 Bq/m³

Beta

Meas. time [s]	Det. limit [s^{-1}]	MDC [Bq/m³]
600	1.065	0.097
1800	0.615	0.056
3600	0.435	0.040
7200	0.307	0.028

37 Bq/m³

Beta

Meas. time [s]	Det. limit [s^{-1}]	MDC [Bq/m³]
600	3.367	0.306
1800	1.944	0.177
3600	1.375	0.125
7200	0.972	0.088

Delayed measurement with Alpha-Beta Detector

Alpha

Meas. time [s]	Det. limit [s^{-1}]	MDC [Bq/m³]
600	0.226	0.015
1800	0.131	0.009
3600	0.092	0.006
7200	0.065	0.004

Beta

Meas. time [s]	Det. limit [s^{-1}]	MDC [Bq/m³]
600	0.152	0.014
1800	0.088	0.008
3600	0.062	0.006
7200	0.044	0.004

Gamma detection system

The Berthold BAI 9100 D provides space to accommodate a gamma detection system in order to reveal the nuclide vector of the sample. Naturally, the efficiency and the background performance of the particle detector are superior to the gamma system. Nevertheless, the gamma detector will add vital information to the data by identifying the constituents. The contribution of Rn for instance can be identified easily and the data from ABPD can be verified independently.

The detector can either be a scintillation detector or a high resolution HPGe system with respective cooling.

The software will record peak integrals from a region of interest (ROI) analysis and transfer each ROI to a virtual channel of the LB 9000. Compton background is calculated automatically through a typical peak analysis. The influence of ambient radiation can be considered manually.
The LB 9000 software allows to choose any ROI for alarming or further data processing. The ROI analysis procedure assures a very quick data analysis without interrupting the measurement tasks of the LB 9000.

Status Monitoring Functions of the System

The system is equipped with self-monitoring functions for the critical operating parameters which will report any alarm or failure condition:

- Pump function.
- Filter tape status: filter end, filter ruptured or jammed.
- PLC unit.
- Collection unit – door status (option).
- Detector failure.
- Exceeding of a pre-alarm threshold.
- Exceeding of an alarm threshold for Alpha and Beta

More details on the functions of the data-logger can be obtained from the corresponding data sheet.