

**DESCRIPTION OF THE**  
**" AMS02M-2008 "**  
**AIR MONITORING SYSTEM**

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**AMS02M-2008 MANUAL**

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# DESCRIPTION OF THE " AMS -02 M " CONTINUOUS AIR MONITORING SYSTEM

## 1 INTRODUCTION

The hazards related to the application of nuclear energy should be minimised through proper safety facilities, still environmental monitoring and warning system are to be installed in order to assist the enforcement of protective measures for the population. The most important task of an air monitoring system is to give an alarm signal in the shortest time possible, when the radioactivity in the monitored area exceeds the natural level.

Resulting from nuclear accidents or explosions, artificial radionuclides of various elements can be released into the atmosphere. The most mobile ones are the noble gases ( Xe, Kr ) and volatile elements ( I, Cs and some others ). Warning levels can be established on the either the measurement of external dose rate primarily due to gamma-radiation from a radioactive plume ("skyshine radiation") or from contaminated ground surface or on the measurement of radioactive contamination adhered to floating aerosol particulates. In special cases the first warning signal may also be based on monitoring radioactivity of surface waters.

As aerosol filters coupled to air pumps are capable of accumulating particulates from large volumes of air onto a small surface, their radioactive content can be determined with good measuring efficiency thus allowing advantageously low detection and warning levels.

AMS-02 M is a special version of the AMS series of Bitt Technology. The AMS-02 units are generally characterized as a multi-detector equipment with an automatic sample changer and a limited time span, however the AMS-03 units are single-detector equipments with manual sample changing and an unlimited time span. The AMS-02 M is a "mule" version having two radiation detectors but manual sample changing and an unlimited time span.

## 1.1 MAIN TECHNICAL PARAMETERS

**Size:** 600mm x 400mm x 1100mm

**Weight:** approx 110 kg

**Power:** 230 V AC / 50 Hz / 350 VA

**Environment:** Temperature +15°C + 25°C  
Relative humidity: 0 - 70 %

**Collected air:** Temperature: -15°C + 50°C  
Relative humidity: 0 - 99 %

### **Units:**

Detectors:

Version 1 :

- 2" x 2" Na(Tl)

resolution  $\cong$  8 % ( $^{137}\text{Cs}$  662 keV)

peak-to-total ratio > 30 % ( $^{137}\text{Cs}$ )

background ~ 4 cps

- PIPS 1700 mm<sup>2</sup>

resolution  $\cong$  55 keV ( $\alpha$   $^{241}\text{Am}$ )

Pump: Nominal flow rate ~ 3.5 (normal) m<sup>3</sup>/h

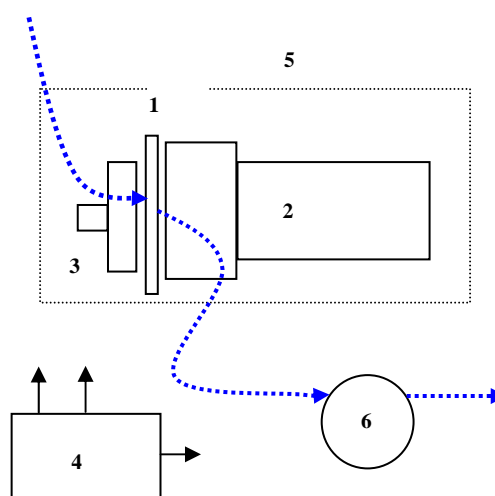
Filters: - 60 mm diameter glass fibre filter Schleicher & Schüll  
type 10 (DIN 24 184)

## 2 SCHEME

The equipment consists of the following units (fig.):

A. Unit for continuous sampling:

1. Aerosol filter
2. NaI(Tl) detector
3. PIPS-detector
4. Microcontroller unit
5. Lead shielding
6. Maintenance-free air flow pump



## 3 SET-UP

### 3.1 Sampling and measuring units

#### 3.1.1 Aerosol filter facing a PIPS alpha/beta detector and a NaI(Tl) gamma scintillation detector (regular version)

Filter: Aerosol filter (glass fibre filter Schleicher & Schüll, art.no. 10) with a minimum filtering capacity of 99% for particulates over  $0.5 \mu\text{m}$  (DIN 24 184).

PIPS silicon detector system:  $1700 \text{ mm}^2$  active surface,  
Resolution: 55 keV for the alpha range; 30 keV for the beta range

NaI(Tl) scintillation detector system: crystal and photomultiplier tube of 2" (5.06 cm) diameter.  
0.04 - 2 MeV energy range, gain is stabilised by heating the PM tube. Resolution: minimum 8.5 % for 662 keV  $^{137}\text{Cs}$  photopeak.

Geometry: The gamma detector is separated from the sampling compartment by its plastic cover. Distance between detector and filter surface: maximum 9 mm.

## **3.2 Actuating and other devices**

### **3.2.1 Lead shielding**

The sampling and measuring slot is housed in a lead block. External gamma-ray background is attenuated by at least one order of magnitude.

### **3.2.2 Air flow pump**

The air is pumped in through a heated inlet tube. The inlet tube is protected against precipitate and other things (e.g. insects). The output volume rate can be measured, but it cannot be regulated. The nominal volume rate of the maintenance-free pump is 10m<sup>3</sup>/h. The output is measured indirectly by pressure sensor and temperature sensor.

The output rate is converted in "normal cubic metre" (20°C, 1 bar pressure). All activity values are related to this value (in Bq/m<sup>3</sup>).

### **3.2.3 Computer**

Pulses from the continuously operating detectors are processed by multichannel analyser cards with an effective channel range of 1k. All of these cards are Microcontroller cards which are controlled by an internal or internal PC over an RS422 Interface.

The central computer performs different tasks:

- it contains and controls the data acquisition cards for the measuring detectors;
- it runs the data evaluation programs;
- it co-ordinates the air flow pump.

## **4 OPERATION**

### **4.1 Installation**

The AMS-02 M system is delivered in the configuration described in Section I. The system should be placed advantageously in a closed cabin or container standing in a grassy environment.

### **4.2 Loading the filter(s)**

The filter slot can hold one or more filter plates contained in a single frame. Advantageously only an aerosol filter is fitted into the frame but two plates can also be fastened together. The complete filter frame is inserted manually into the slot prior to operation. It is strongly advised to insert a "fresh" filter into the slot even for background measurements. Filter-shaped calibration standards (137Cs for the gamma detectors and 239Pu/90Sr for the alpha-beta detector) are required for regular gain and efficiency control.

### 4.3 Start-up

Mains power connections of the air flow pump and the computer should be plugged in. The "AMS 02 M" program starts automatically after switching on the equipment. The main program controls the presence and status of each device then the actual task can be determined interactively by the user using the peripherals of the computer. If required, detector setting control ("gain check" ) is performed for both detectors. The calibration sources (with activity below the appropriate exemption levels) are put consecutively into the filter slot for 100 – 300 seconds each. The program checks selected counting rates according to Section III. 1. The gain check can be intentionally omitted from the operational sequence but this procedure is not encouraged.

### 4.4 Background measurements

Background measurement with a "fresh" (that is, unused for at least 10 days before) filter is performed before air pumping starts. Although the external background is subject to diurnal, seasonal and meteorological changes, it was still necessary to set a maximum upper limit above which continuous sampling must not start, thus excluding e.g. the erroneous presence of the calibration source in the slot or in the vicinity of the equipment. Background measurement takes a default 900 seconds (15 minutes) with both detectors.

### 4.5 Sequence of normal operation

Air pumping is started after the termination of a background measurement. The air flow enters the slot and passes through the inserted aerosol (and iodine) filter(s). Pulses are collected for consecutive 5 minutes. Counts are evaluated for the recognition of non-natural radioactive contamination (see Section III.3.) If this occurs, a warning message is generated. Three subsequent signals are required to confirm a "warning" status; the "alarm" message can be generated by only one measurement resulting in an activity level higher than not only the warning but also the alarm level as well. The evaluating program records the volume of the processed air, so it can estimate the maximum and minimum activity concentration for a suspected contaminant.

Would a warning or alarm message be generated, a message box pops up on the display and the program halts until the old filter is replaced by a fresh one by the operator. The replaced filter should be kept for further detailed radioanalysis by off-line methods.

The detection limit for artificial radioisotopes is continuously improved during the sampling cycle, because the contaminants are supposed to arrive from distant emission sources and thus to have half-lives longer than that of the radon descendants and - in case of a low, but constant concentration in the sampled air - their activity on the filter will increase linearly while that of the "suppressing" radon descendants tends to level out asymptotically. On the other hand, this detector cannot "keep track" of the rapid changes of the radon level, leaving this task for the more appropriate PIPS detector.

The regular response message of the units with PIPS and NaI(Tl) detectors gives an estimation on the average radon equivalent equilibrium concentration (EEC, in Bq/m<sup>3</sup>) in the atmosphere using the data obtained with the aerosol filter.

After 24 - 48 hours of normal operation it is advisable to stop the current measurement cycle and change the aerosol filter for a new one exempt from natural radioactivity, otherwise the contribution of the descendants of the thorium-based <sup>220</sup>Rn ("thoron") would build up onto the aerosol filter changing the expected pulse height distribution and increasing the possibility of a false warning. The new cycle should again start with an optional gain test and a background measurement.

The effective half-lives of <sup>238</sup>U-based and <sup>232</sup>Th-based radon descendants are about 30 minutes and 10 hours, respectively. Due to the latter, a used aerosol filter is kept decaying for 8 – 10 days to get rid of thoron activity. Then the filter can be considered exempt from excess activity so it is reused until the flow resistance of the filter reaches a limit. Air flow rate is checked after each data evaluation. Would this test fail, requirement of a cycle-breaking "regular" filter change is indicated on the display.

## 5 DATA EVALUATION PROCEDURES

1. Gain check
2. Background measurements
3. Continuous sampling in normal and off-normal operation

### 5.1 Gain check

The pulse height versus energy calibration of the PIPS and NaI(Tl) scintillation detectors facing the aerosol (and possibly the iodine) filter(s) are checked by measuring <sup>239</sup>Pu/<sup>90</sup>Sr-<sup>90</sup>Y and <sup>137</sup>Cs test sources. The individual pulse height channels are separated into several regions (6 for PIPS and 8 for NaI(Tl) detectors). The proper gain setting of a NaI(Tl) detector can be indicated by the ratios of the net counts in the neighbouring regions to the net counts in the region of the peak of the test source:

$$\frac{YM[j] - YB[j]}{YM[p] - YB[p]} \leq FG_{13}[j] \quad \text{where } j = p - 1 \text{ or } p + 1 \quad [1]$$

p denotes the peak region, YM denotes the measured counts of the test source, YB denotes the background counts, FG13 is the gain check factor. The resulting message is "OK." or "FAILED". The measurement lasts 2x100 seconds (for background and sample, respectively). The measurement is extended twice to a consecutive 100 second cycle if the test fails. As the calibrating sources are very weak (that is, their activity is well below the respective exemption level), nuclear statistics are rather poor, so the peak analysis program may sometimes overlook a full energy peak.

The test source of the PIPS alpha/beta-detector is <sup>239</sup>Pu/<sup>90</sup>Sr-<sup>90</sup>Y. The upper limit of the first energy region is set so that it exceeds the pulse height of all possible beta particles. The <sup>239</sup>Pu - peak falls in region 2. Thus, the ratio of counts in regions 2 and 3 are compared to the gain check factor:

$$\frac{SM[3] - SB[3]}{SM[2] - SB[2]} \leq FG_4 \quad [2]$$

SM denotes the measured counts of the test source, SB denotes the background counts, FG4 is the gain check factor.

### 5.2 Background measurements

The continuous sampling and evaluation cycle starts with a fifteen-minute background measurement. As long as no excess (either natural or non-natural) radioactivity is observed on either of the filters, the measured data are attained to the external background and added to the aggregate background variables.

$$BG[i] = \frac{SBG[i]}{BN} \quad i = 1, \dots, 8 \quad [3]$$

$$SBG[i] = \sum_{j=1}^{BN} YB[i, j] \quad [4]$$

$$VBG[i] = \frac{\sum_{j=1}^{BN} (YB[i, j] - BG[i])^2}{BN * (BN - 1)} \quad [5]$$

The parameter *i* denotes the discrimination regions (8 for NaI(Tl), 6 for PIPS) BN is the number of measurements deemed as exempt from any radioactivity on the filter (see Section III.3. for this evaluation), BG's are the average background counts, SBG's are the sums of the appropriate background counts, VBG's are the variances of the BG's. Obviously, the array of background counts is determined separately for the two measuring positions.

### 5.3 Continuous sampling

Two kinds of situations may occur during the sampling cycle:

the sum of the observed counts is significantly higher than the total external background: the usual case with the aerosol filter for almost the whole cycle.

$$SN = \sum_{i=1}^8 YM[i] - \sum_{i=1}^8 BG[i] \quad [6]$$

$$VSN = \sum_{i=1}^8 YM[i] + \sum_{i=1}^8 VBG[i] \quad [7]$$

$$SN \geq k_{sign} * \sqrt{VSN} \quad [8]$$

SN is the sum of the net counts (i.e., that of the zone-by-zone difference between the measured counts YM and the background BG), VSN is its variance, ksign is the significance parameter, its value on a 95 % confidence level is 1.65. If criterion [8] is met, calculations are continued with the assumption of an underlying natural radon environment (Subroutine TEST). If this condition is not met, the sample is considered exempt from adsorbed radioactivity and the counts are used to iterate the aggregate background value.

#### 5.3.1 Subroutine "TEST"

##### 5.3.1.1 Evaluation of gamma counting

The relative differential distribution of the counts is calculated for the energy regions:

$$ND[i] = YM[i] - BQ[i] \quad i = 1, \dots, R \quad [9]$$

$$NQ[i] = \frac{ND[i]}{SN} \quad i = 1, \dots, R \quad [10]$$

$$RNQ[i] = \sqrt{\frac{(YM[i] + SBG[i]^2)}{ND[i]^2} + \frac{VSN}{SN^2}} \quad i = 1, \dots, R \quad [11]$$

ND[i]'s are the net differential counts, NQ's are the net ratios, RNQ's are the associated relative standard deviations. R is the number of energy regions. The calibrated relative differential spectrum of radon daughters CQ[i] is compared to the measured ratios (quotients) by defining a quality factor QF[i]:

$$QF[i] = NQ[i]/CQ[i] \quad i = 1, \dots, R \quad [12]$$

$$RQF[i] = \sqrt{RNQ[i]^2 + RCQ[i]^2} \quad i = 1, \dots, R \quad [13]$$

RQF[i] is the relative standard deviation of the quality factor, RCQ[i] is the experimental standard deviation of the calibrated quotient CQ in the i-th zone. Obviously, the expected value of QF is 1 if there is no source of radioactivity on the filter. It is worth noting that the relative spectral distribution of the actual composition of the radon descendants depends on the equilibrium between the consecutive descendants as well as on the presence or absence of significant concentration of 220Rn-series.

$$\frac{QF[i]-1}{RQF[i]} = Q[i] \quad [14]$$

$$Q[i] > SF \quad [15]$$

Q[i] is the resulting quality parameter for the i-th zone; it compares the difference between the actual and the expected values of the quality factor to its estimated standard deviation. SF is a semi-empirical significance factor with a value of 3 or  $2 \times (RQF[i] + 1)$ , whichever is smaller. If criterion [15] is met, the high value of Q[i] indicates the presence of a non-natural radionuclide. The serial number of the zone with the largest Q[i] value can lead to a rough assumption for the identity of the nuclide(s). Table III.1. shows the most probable radionuclides forming the contamination which may occur in the NaI(Tl) gamma spectrum.

Zone no.	Main gamma energy (keV)	Displayed message	Radionuclides
1	Bremsstrahlung	BETA	<sup>90</sup> Sr/ <sup>90</sup> Y etc.
2	80 – 250	NOBLE GAS	<sup>133</sup> Xe, <sup>133m</sup> Xe, <sup>135</sup> Xe, etc.
3	365	I-131	<sup>131</sup> I
4	530	I-133	<sup>133</sup> I
5	662	Cs-137	<sup>137</sup> Cs
6	700 - 1100	MIXED	<sup>134</sup> Cs, <sup>110m</sup> Ag, etc.
7	1100 – 1500	MIXED	<sup>60</sup> Co, <sup>59</sup> Fe, etc.
8	1500 - 1800	MIXED	<sup>42</sup> K, <sup>24</sup> Na, etc.

**Table III.1.**  
**Assumptions for potential contaminating radionuclides**

The deviation of the quality factors from their expected value of 1 indicates that a radioactive component other than the radon daughters is present on the filter. If the significance criteria for the quality parameters are not met for neither of the zones, the only presence of radon descendants is confirmed. The reproducible pumping rate enables the approximate assessment of radon concentration in the sampled atmosphere.

Would a significant zone count occur, not only a warning message is generated but the radioactivity present on the filter is also assessed using a rough estimation of the counting efficiency:

$$AC = \frac{2 * (YM[im] - BG[im]) * 1}{t_m \cdot EFF_{im}} \quad [16]$$

im is the number of the zone with the largest and/or most significant quality parameter Q[i] , tm is the measuring time, the mean counting efficiencies EFF [i]'s of the respective zones are pre-calibrated.

In case of normal operation only the marginal values of the atmospheric activity concentration can be calculated. Two assumptions are applied:

- The minimum airborne concentration ACCN is determined by using the total volume of air processed so far, that is, the maximum volume VOLX;
- The maximum airborne concentration ACCX is determined by using the volume of air pumped through the filter during the last measurement period, that is, the minimum volume VOLN.

$$ACCN = AC / VOLX \quad [17]$$

$$ACCX = AC / VOLN \quad [18]$$

In case of off-normal operation, that is, when a warning or alarm has occurred already, the volume of the air (VOL) that may contain the adsorbed contaminant is considered as the processed volume so the activity concentration ACC can be given more accurately since the artificial radioactivity can be assumed as present throughout the whole re-started sampling cycle:

$$ACC = AC / VOL \quad [19]$$

### 5.3.1.2 Evaluation of alpha/beta-counting

The formulation of the evaluation of the alpha/beta-spectrum is quite similar to the procedure described above. There are 6 energy regions (zones) in this case. The physical data of the most important natural alpha emitters are given in Table III.2. below:

Zone no.	Nuclide	Series	Alpha energy (MeV)
3.	218Po	238U – 222Rn	6.00
5.	214Po	238U – 222Rn	7.69
4.	216Po	232Th – 220Rn	6.78
3.	212Bi	232Th – 220Rn	6.07
6.	212Po	232Th – 220Rn	8.78

**Table III.2.**  
**Alpha emitting radon descendants**

Some well-known artificial alpha emitting radionuclides which are possible to occur in the environment are 238Pu, 239-240Pu and 241Am. Their peaks fall in zone 2. (between 4.0 and 5.7 MeV). Zone 1 contains all the beta pulses. (< 2.5 MeV). Net counts are calculated according to the equations below. Calibrated “cross-talk” of peaks in upper regions to the counts in lower regions is subtracted in addition to the background. Peak areas of radon descendants listed in Table III.2. are calculated “backwards”, starting with the undisturbed 212 Po peak from the high energy side.

$$ND[i] = YM[i] - BQ[i] \quad (i = 1, 2, \dots 6) \quad [20]$$

$$N[6] = ND[6] \quad [21]$$

$$N[5] = ND[5] - CT65 \cdot N[6] \quad [22]$$

$$N[4] = ND[4] - CT64 \cdot N[6] - CT54 \cdot N[5] \quad [23]$$

$$NT[3] = N[6] \cdot EQ63 \quad [24]$$

$$NR[3] = ND[3] - ( NT[3] + CT63 \cdot N[6] + CT53 \cdot N[5] + CT43 \cdot N[4] ) \quad [25]$$

$$N[3] = NT[3] + NR[3] \quad [26]$$

$$N[2] = ND[2] - \sum CTj2 \cdot N[j] \quad (j = 3 \dots 6) \quad [27]$$

$$N[2] \geq SF * \sqrt{Var(N[2])} \quad [28]$$

N: net alpha counts; CT: "cross talk" coefficient; EQ is a time-dependant equilibrium coefficient. The alpha counts of the possible artificial nuclides are determined as the significant positive content of region 2 that remains after subtracting all the cross-talk pulses.

The default value of the significance coefficient SF is 3 (given in the INI file). The possible significant counts of artificial beta emitters are determined in a similar way from the gross counts in region 1:

$$N[1] = ND[1] - \sum CTj1.N[j] - CT21.N[2] - N[6].EQ61.EC61 - N[5].EQ51.EC51 \quad [29]$$

( j = 3, ... 6 )

EC is the efficiency ratio between beta and alpha counting. The parameters SF, CT, EQ and EC must be pre-calibrated. If the values of N[1] and/or N[2] are significant, the activity concentrations are calculated by the likes of equations [17] - [20]. Depending on their amount, "warning" or "alarm" signals are generated.

### 5.3.2 Subroutine "RADON"

#### 5.3.2.1 Evaluation of gamma counting

The discrimination zones of the NaI(Tl) detector listed in Table III.1. can be divided into two parts in terms of the radon descendant spectrum: zones 1 - 3 contain the full energy peaks of 214Pb, Compton contribution from the peaks of 214Bi and the associated backscatter peaks; zones 4 - 8 contain contribution only from 214Bi (see Table III.3.) Therefore, an aggregate correction factor was determined for subtracting the contribution of 214Bi from the summed net counts of zones 1 - 3 considering the energy vs. efficiency and energy vs. peak-to-Compton-ratio functions of the two similar NaI(Tl) detectors. The aggregate efficiency factors applicable to zones 4 - 8 for 214Bi and zones 1 - 3 for 214Pb were calibrated.

$$CT_{Pb} = \sum_{i=1}^3 ND[i] \quad [30]$$

$$CT_{Bi} = \sum_{i=4}^8 ND[i] = NCT_{Bi} \quad [31]$$

CT's are the sums of the counts in the appropriate zones.

Radon descendants	Half-life (min)	Main photon energies (keV)	Abundance rel. to 1000 decays
218Po	3.05	-	-
214Pb	26.8	53.2	11
		74.8 + 77.1	176
		87.2 + 90.1	50
		241.9	75
		295.2	192
		351.9	371
214Bi	19.7	609.3	461
		768.4	49
		934.6	32
		1120.3	150
		1238.1	59
		1377.7	40
		1764.5	159
214Po	2.7e-6	-	-

**Table III.3.**  
**Decay parameters of short-lived radon descendants**

$$NCT_{Pb} = CT_{Pb} - FC_{45} * (ND[4] + ND[5]) - FC_6 * ND[6] - FC_{78} * (ND[7] + ND[8]) \quad [32]$$

NCT is the total of net counts attributed to the gamma emitting radon daughter, FC's are the calibrated correction factors for the discrimination zones. They were determined with a spectrum generating computer program and then modified according to the experimental results.

The activity of radon descendants in air can be described adequately with a set of differential equations:

$$A_{218Po} = \frac{dN_{Po}}{dt} = \frac{C_{Po} * VR}{\lambda_{Po}} - \lambda_{Po} * N_{Po} \quad [33]$$

$$A_{214Pb} = \frac{dN_{Pb}}{dt} = \frac{C_{Pb} * VR}{\lambda_{Pb}} - \lambda_{Pb} * N_{Pb} + f_{Po/Pb} * \lambda_{Po} * N_{Po} \quad [34]$$

$$A_{214Bi} = \frac{dN_{Bi}}{dt} = \frac{C_{Bi} * VR}{\lambda_{Bi}} - \lambda_{Bi} * N_{Bi} + f_{Pb/Bi} * \lambda_{Pb} * N_{Pb} \quad [35]$$

dt means differentiating according to the elapsed time, the A's are the activities adsorbed onto the filter, the N's are the number of the respective nuclides, the c's are the activity concentrations (in Bq/m<sup>3</sup>) of the respective nuclides in the atmosphere, λ's are the decay constants (in min<sup>-1</sup>). VR is the actual volume rate of the air pump (in m<sup>3</sup>/min) ,fPo/Pb and fPb/Bi are the equilibrium factors of the adsorbed particulates. According to literature references (e.g. "Measurement of radon and radon daughters in air" NCRP Report #97 / 1988, U.S. NCRP) these factors differ significantly from 1, that is, the proper state of equilibrium.

Widely accepted recommendations for the values are

CRn: C<sub>Po</sub>: C<sub>Pb</sub>: C<sub>Bi</sub> = 1 : 0.9 : 0.7 : 0.6 for the "bulk" outdoor atmosphere. However, these ratios of outdoor radon descendant concentrations cannot be used for describing the equilibrium factors which are valid for the solid layers sorbed onto the filter. As a rough approximation, the difference from the ideal state of equilibrium is taken as half of that of the recommended bulk outdoor mean:

f<sub>bulk,Rn/Po</sub> = fb1 = 0.9  
 f<sub>bulk,Po/Pb</sub> = fb2 = 0.7/0.9 = 0.78  
 f<sub>bulk,Pb/Bi</sub> = fb3 = 0.6/0.7 = 0.85  
 f<sub>filter,Rn/Po</sub> = ff1 = 0.95  
 f<sub>filter,Po/Pb</sub> = ff2 = 0.89  
 f<sub>filter,Pb/Bi</sub> = ff3 = 0.92

The arresting efficiency of the aerosol filter proved better than 98.5 % so no correction was required for it.

Substituting the respective bulk and filter equilibrium factors to equations [33] - [35] they can be solved for N<sub>Po</sub>, N<sub>Pb</sub> and N<sub>Bi</sub>, giving the number of the radon daughter nuclei present on the filter as a function of pumping time. The respective activities are simply generated by multiplying the equations with the respective decay constants λ<sub>Po</sub>, λ<sub>Pb</sub> and λ<sub>Bi</sub>

$$A_{214Pb} = A_2 = VR * C_{Rn} * fb_1 \left\{ \left( \frac{fb_2}{\lambda_2} + \frac{ff_2}{\lambda_1} \right) * (1 - e^{-\lambda_2 t}) + \frac{ff_2 * \lambda_2}{\lambda_1 * (\lambda_2 - \lambda_1)} * (e^{-\lambda_2 t} - e^{-\lambda_1 t}) \right\} \quad [36]$$

$$A_{214Pb} = A_2 = VR * C_{Rn} * fb_1 \left\{ \left( \frac{fb_2 * fb_3}{\lambda_3} + \frac{fb_2 * ff_3}{\lambda_2} + \frac{ff_2 * ff_3}{\lambda_1} \right) * (1 - e^{-\lambda_3 t}) + \left( \frac{fb_2 * ff_3 * \lambda_3}{\lambda_2 * (\lambda_3 - \lambda_2)} + \frac{ff_2 * ff_3 * \lambda_3}{\lambda_1 * (\lambda_3 - \lambda_2)} - \frac{ff_2 * ff_3 * \lambda_2 * \lambda_3}{\lambda_1 * (\lambda_2 - \lambda_1) * (\lambda_3 - \lambda_2)} \right) * (e^{-\lambda_3 t} - e^{-\lambda_2 t}) + \frac{ff_2 * ff_3 * \lambda_2 * \lambda_3}{\lambda_1 * (\lambda_2 - \lambda_1) * (\lambda_3 - \lambda_1)} * (e^{-\lambda_3 t} - e^{-\lambda_1 t}) \right\} \quad [37]$$

For the sake of brevity, the indices were changed : "1" denotes 218Po (the first daughter product), "2" denotes 214Pb and "3" denotes 214Bi. The expressions within the primary parentheses of equations [36] and [37] can be referred to as  $tf_2$  and  $tf_3$  (time dependent factors), respectively.

The activities of 214Pb and 214Bi can be expressed from the measured net counts as well:

$$A_{214Pb} = A_2 = \frac{NCT_{Pb}}{t_m * EFF_{Pb}} \quad [38]$$

$$A_{214Bi} = A_3 = \frac{NCT_{Bi}}{t_m * EFF_{Bi}} \quad [39]$$

$t_m$  is the measuring time, the EFF's are the experimental efficiencies combining the total counting efficiencies, peak-to-total ratios and gamma-abundance of the considered major gamma lines (See Section IV for details).

Two separate solutions can be obtained for CRn, the estimated radon equilibrium concentration in the atmosphere, if the appropriate equations [36] and [38], [37] and [39] are combined:

$$C_{Rn}(2) = \frac{NCT_{Pb}}{t_m * EFF_{Pb}} * \frac{1}{VR * fb_1 * tf_2} \quad [40]$$

$$C_{Rn}(3) = \frac{NCT_{Bi}}{t_m * EFF_{Bi}} * \frac{1}{VR * fb_1 * tf_3} \quad [41]$$

The arithmetic mean of the two values is displayed by the program as an estimated radon equivalent equilibrium concentration EEC in units Bq/m<sup>3</sup>.

### 5.3.2.2 Evaluation of alpha/beta-counting

The count rates of the alpha emitting radon descendants are calculated by equations [20]-[27] in Section 5.3.1.2. The activity concentration is given below:

$$A_{218Po} = NR[3]/(t_m * EFF_3) \quad [42]$$

$$A_{214Po} = N[5]/(t_m * EFF_5) \quad [43]$$

Equivalent equilibrium concentration is in turn given:

$$EEC = 0.105 * A_{218Po} + 1.041 * A_{214Po} \quad [44]$$

## 6 SENSITIVITY

The smallest detectable artificial radioactivity was calculated and determined for all detectors of the system, considering only realistic sampling and measurement situations. The figures given in Table IV. 1. below are in Bq/m<sup>3</sup> units. They relate to the detector types, source-to detector geometry and - last but not least - to the data processing subroutines applied in the AMS-02 system only.

Isotope	Filter/detector	Duration of air filtering before warning message				Measurement time
		5 min	1 hour	12 h	168h	
<b>normal mode</b>						
<sup>131</sup> I	aerosol/NaI(Tl)	5.6	2.6	0.20	0.02	300 s
<sup>137</sup> Cs	aerosol/NaI(Tl)	4.8	2.2	0.15	0.01	300 s
α-activity	aerosol/PIPS	1.5	0.5	0.05	0.005	300 s
<sup>137</sup> Cs(β)	aerosol/PIPS	3.5	1.5	0.015	0.002	300 s

**Table IV. 1.**  
**Sensitivities (limits of detection) of the AMS 01 system**  
**Artificial Activity concentration [Bq/m<sup>3</sup>]**

Data pertain to an assumed elevated natural radon background of 10 Bq/m<sup>3</sup> EEC.  
Air flow rate is 3.5 m<sup>3</sup>/h.

### Total sensitivity of the detection system

after a 5-minute measurement cycle, regardless to natural or artificial origin of the sample:

Aerosol filter/NaI(Tl) detector		
<sup>137</sup> Cs-equivalent (gamma) activity:	1.0	Bq/filter
<sup>131</sup> I-equivalent (gamma) activity:	0.6	Bq/filter
Aerosol filter/PIPS detector		
<sup>239</sup> Pu-equivalent (alpha) activity:	0.07	Bq/filter
Aerosol filter/PIPS detector		
<sup>90</sup> Sr-equivalent (beta) activity:	0.4	Bq/filter

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