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Automated high-volume aerosol sampling station for environmental radiation monitoring

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ABSTRACT

An automated high-volume aerosol sampling station, known as CINDERELLA.STUK, for environmental radiation monitoring has been developed by the Radiation and Nuclear Safety Authority (STUK), Finland. The sample is collected on a glass fibre filter, which is attached into a cassette. To operate the station the user needs only to add cassettes with filter papers into a stack of unused filters. The cassettes are automatically loaded into a filtration unit one at a time. In the filtration unit the airflow through the filter is 800 m^3h^{-1} at maximum. During the sampling, the filter is continuously monitored with Na(I) scintillation detectors. In case of unusual radioactivity the system will trigger an alarm.

After the sampling, the large filter is automatically cut into 15 pieces that form a small sample and after ageing, the pile of filter pieces is moved onto an HPGe detector. These actions are performed automatically by a robot. The system is operated at a duty cycle of 1 d sampling, 1 d decay and 1 d counting. Minimum detectable concentrations of radionuclides in air are typically 1—10 μBq m^{-3}. The low detection limits were achieved by optimising the counting system, including the shape of the sample and the detector.

The station is equipped with various sensors to reveal unauthorised admittance. These sensors can be monitored remotely in real time via Internet or telephone lines. The processes and operation of the station are monitored and partly controlled by computer. The status of the system is available for the authorised users through Internet.

Due to modular design the station can be applied to various purposes. The present approach fulfils the requirements of CTBTO for aerosol monitoring. The concept suits well for nuclear material safeguards, too.

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TIIVISTELMÄ

Ilman radioaktiivisuusvalvontaan kehitettiin automaattinen ja osittain tietokoneohjattu valvonta-asema CINDERELLA.STUK, joka kerää näytteen ilman sisältämistä hiukkasista, käsittelee näytteen, analysoi näytteestä radioaktiiviset aineet ja raportoi tulokset. Näyte kerätään erillisessä kasetissa olevaan lasikuitusuodattimeen, ja aseman operoimiseksi käyttäjän tarvitsee vain ajoittain lisätä puhtaita suodattimia kasetteihin. Kasetit siirtyvät automaattisesti suodatinyksikköön, jonka läpi imetään ilmaa jopa 800 m^3 h^{-1}. Keruun aikana suodatinta monitoroidaan Na(I)-tuikeilmaisimilla, jotka voivat tarvittaessa liipaista hälytyssignaalin.

Näytteenkeruun jälkeen suodatin leikataan automaattisesti 15 yhtäsuureen osaan, jotka päällekäin pinottuna muodostavat optimaalisen näytteen automaattista HPGe-mittausta varten. Keruujakso kestää 24 h ja ennen 24 h:n mittausta näytteen annetaan ikääntyä 24 h. Mittausjärjestelmän optimoinnin takia näytteestä voidaan havaita pieniä määriä radioaktiivisia aineita. Pienin havaittava aktiivisuuskonsentraatio on tyypillisesti 1—10 μBq m^{-3}.

Asiattoman käytön ja virhetilanteiden havaitsemiseksi laitteistossa on ilmaisimia, joiden avulla aseman tilaa voidaan seurata etäältä tietoliikenneverkon kautta. Järjestelmän tilaa koskevat tiedot ja mittaustulokset ovat tarvittaessa saatavissa internetin välityksellä. Modulaarisen rakenteen ansiosta asemaa voidaan käyttää erilaisiin sovelluksiin. Nykyinen laitteisto täyttää CTBT-organisaation asettamat ilman radioaktiivisten aineiden monitorointia koskevat vaatimukset. Laitteistoa voidaan käyttää myös ydinmateriaalivalvontaan.

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1 INTRODUCTION

Air sampling and high-resolution gamma spectrometry are the fundamental tools for surveillance of airborne radioactive materials. Separate instruments, high-volume air samplers and high-purity germanium detectors (HPGe), hardware components and software are commercially available. However, human control and interference are required in sampling, sample preparation, measurement and analysis. An efficient monitoring programme with a good detection capability of airborne radioactive materials requires special expertise that takes years to establish.

Automation of the sampling and measurement provides substantial advantages. The throughput of a monitoring programme could be increased while labour costs are reduced. In addition, automation provides means to establish a sophisticated system on remote sites where advanced expertise may not be available.

A good operation mode in air sampling is based on a daily cycle, i.e. the filter is changed once a day. This allows backtracking the origin of interesting findings using meteorological models. An ideal system for detecting airborne radioactive substances consists of the following components:

- sampler (blower);
- filters in separate cassettes (handling flexibility in emergency);
- computer control of the equipment operation;
- automated sample preparation and manipulation;
- automated on-site high-resolution gamma spectrometry;
- automated knowledge-based software for spectrum analysis;
- communication facilities between the sampler and the headquarters;
- www-interface for process data and results;
- secured operations and authentication means and
- alarm signal generation (real-time monitoring of the filter).

Automated surveillance of airborne radioactive substances has several applications. The national needs, particularly in Europe, are often directed by requirements of emergency preparedness. Short response time is essential should a nuclear accident occur. Measuring sensitivity, data surety and sample protection against tampering are important for the International Atomic Energy Agency (IAEA) and for the Comprehensive Nuclear-Test-Ban

Treaty Organisation (CTBTO). The IAEA may apply high-volume air sampling for safeguards on a limited area whereas the CTBTO has to verify the compliance with a treaty (CTBT) globally.

The sensitivity and timeliness requirements are contradictory, since short sampling time means high detection limits. Nevertheless, the present approach, known as CINDERELLA.STUK is designed to meet the highest needs of sensitivity, flexibility and timeliness. The system has modular design, highly efficient blower, reliable sampling unit, innovative sample preparation system and efficient detector. The modularity allows adopting the system for different environmental measurement tasks in a cost-efficient manner.

2 DESIGN OF THE AUTOMATED AIR SAMPLING STATION

The automated air sampling station CINDERELLA.STUK (Fig. 1) filtrates radioactive substances from air, monitors radionuclides collected on the filter in real-time, changes the filter and performs on-site HPGe measurements of the filter automatically. In addition, the station gathers, stores, analyses and presents radiation data, weather data and process data, which are integrated via local network.

2.1 Main components

The prerequisites for the automation are thorough design, high-quality components and reliable functioning. CINDERELLA.STUK has a modular structure that makes operation reliable and maintenance simple. The station has four main components (see Figures 1 and 2):

1. Air sampling unit consists of the sampling head, the inlet tube, the outlet tube and the pump. The unit includes also the pile of unused filter cassettes, the filtration assembly and the pile of used cassettes. Automated operations are controlled by a programmable micrologic unit.

2. Sample preparation unit has a filter manipulator, a cutting head, a vacuum pump and a sample storage tray.

3. Real-time activity monitoring and alarm unit has two Na(I) scintillation detectors located below the filter and a background radiation shield. The data is collected by software, which analyses and displays the data and sends the alarms forward.

4. The counting unit consists of an electrically cooled HPGe gamma-ray spectrometer and a lead shield.

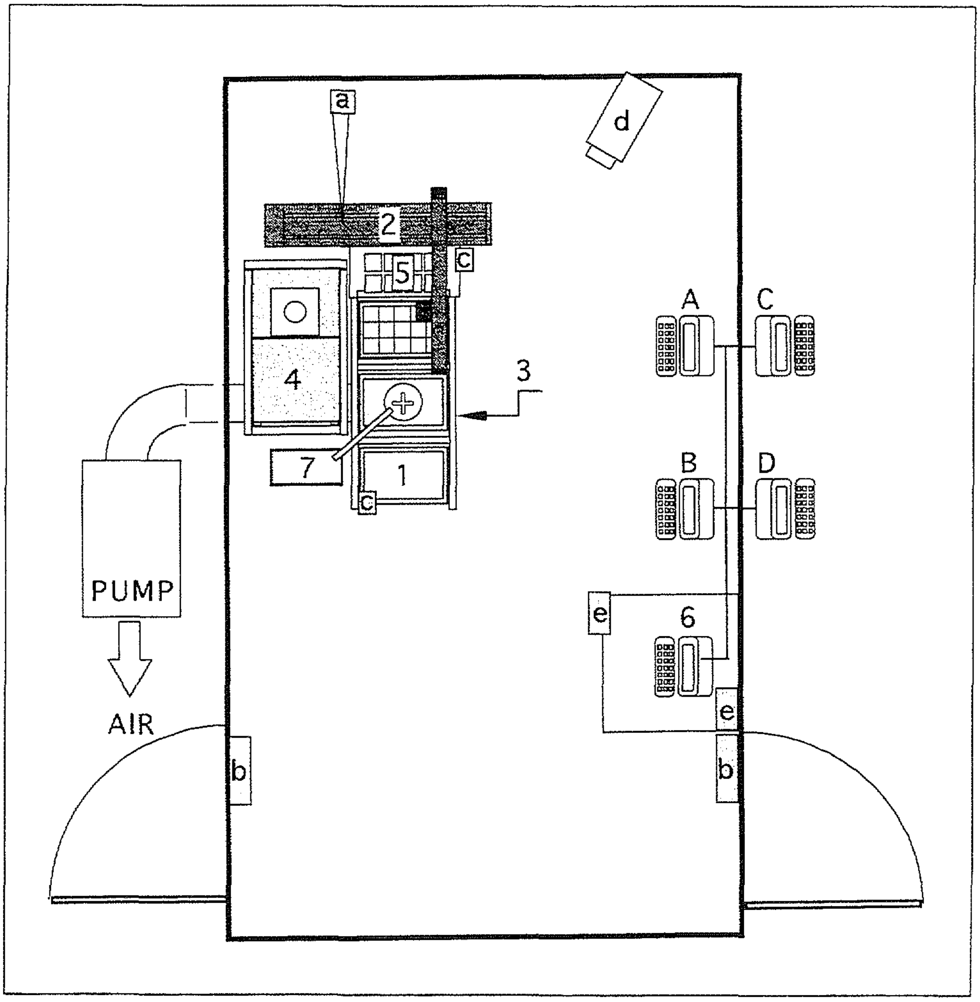

Figure 1. Overview of the CINDERELLA.STUK automated air sampling station located on the roof laboratory of the STUK headquarters in Helsinki, Finland. The equipment consists of 1) air sampling unit, 2) sample preparation unit, 3) real-time monitoring and alarm unit, 4) counting unit, 5) sample storage, 6) equipment for remote monitoring (see text for sensors a-e) and 7) aerosol authentication apparatus. Computers are for real-time monitoring (A), process monitoring, HPGe data acquisition and presentation (B), weather data measurements (C) and intranet/internet connections (D).

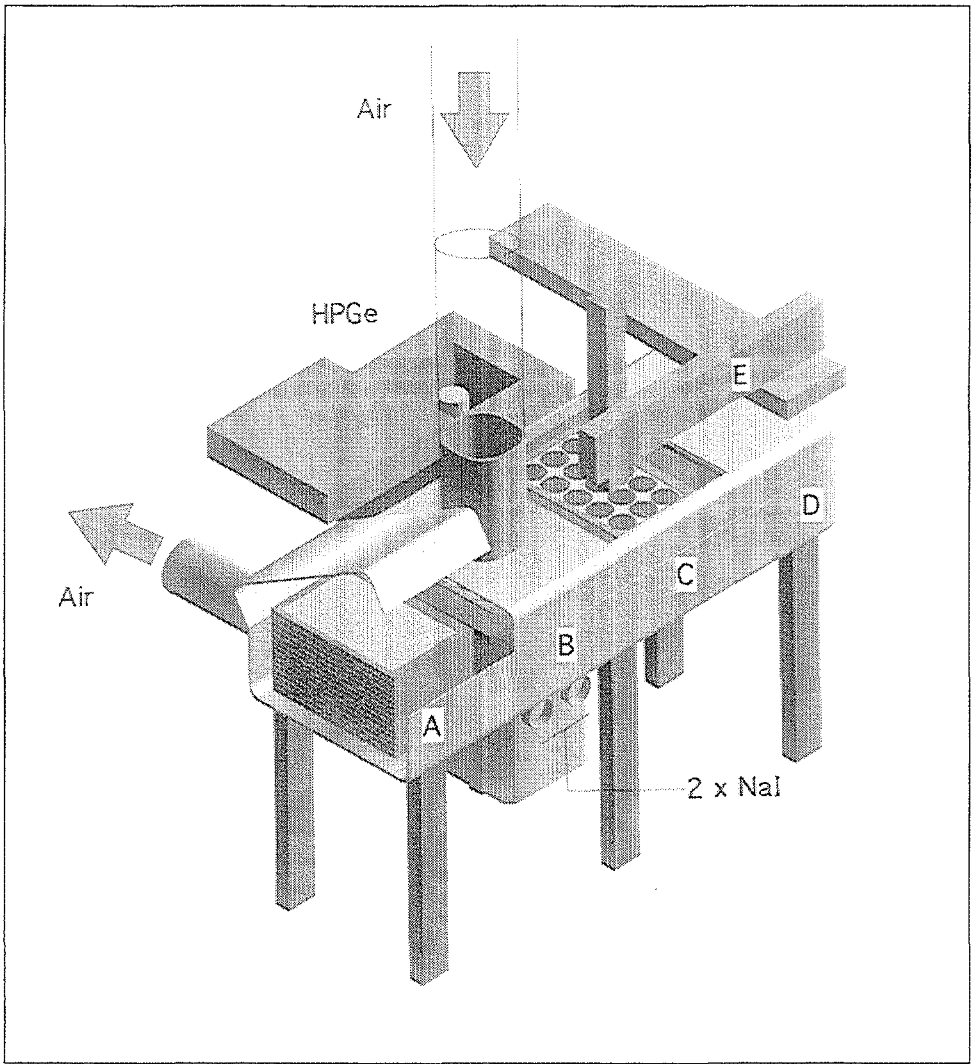

Figure 2. CINDERELLA.STUK air sampler. The clean filter storage (A) containing up to 7 cassettes and the filtration unit (B) are parts of the sampling unit. The new cassettes are automatically moved from the clean filter storage into the filtration unit. The real-time activity monitoring unit has two Na(I) scintillators below the sampling unit. After the sampling the filter is moved to the sample preparation unit (CDE). The exposed filter is cut in 15 pieces on the manipulation table (C). The used cassettes are stored in a pile (D). The sample manipulator (E) cuts the filter into pieces and places them into a beaker, which is, subsequently, transferred into the HPGe counting unit for gamma-ray analysis.

2.2 Supplementary systems

The station and the surrounding room are monitored continuously. Operator-defined remote access enables operation via Internet. The data surety is carried out by the firewall between the computers of CINDERELLA.STUK and the external world. The sensor data authentication is performed using a comprehensive remote monitoring approach developed by Sandia National Laboratories (Toivonen et al., 1997). The sample authentication is performed by labelling the filters with an unequivocal tag. Weather data measurements provide information that may be valuable for remote monitoring or for nuclear emergency situations. The supplementary systems are the following (Fig. 1):

5. The sample storage contains samples that are either go to or come from the gamma counting.

6. The remote monitoring system has a motion sensor (a), door sensors (b), air sampler door sensors (c), a video camera (d) and door sensors (e) for sensor data acquisition cabinet and software that provide remote sensing, sensor data acquisition, sensor data authentication and review capabilities.

7. Automated aerosol authentication apparatus sprays a tag chemical, e.g. particles of known size and composition, to the filter. The main components of the apparatus are the atomiser, the pressurised air supply unit and the aerosol reservoir.

Weather station measures wind speed and direction, air temperature and rain (not shown in Fig. 1).

The station has five computers for monitoring the processes and controlling the activity measurements. The system integration is performed by a local area network. This concept is simple, commercially available and provides reliability because all modules are independent and do not interfere with each other in uncontrolled way. Internet connections are carried out by the firewall computer that identifies the users by secure ID cards.

2.3 Advantages of the design

CINDERELLA.STUK has the following advantages:

- deposition losses in the sampling system are low due to vertical large-diameter sampling tube with no bends;
- the sampler utilises glass fibre filters that are commercially available and have good sampling efficiency (near 100 % between 0.2—10 μm);
- the flow through the filter is large due to high face velocity and large filter area;
- the high degree of automation minimises the need of manpower and reduces running costs;
- the high degree of automation facilitates rapid introduction of surveillance programme in locations where qualified personnel does not exist;
- the counting geometry is excellent because the final sample has small dimensions (cylindrical, 8 mm thick, 77 mm in diameter) ;
- minimum detectable activities are low due to high volume, good counting geometry, efficient detector and thick (10 cm) lead shielding;
- non-destructive sample treatment is ideal for possible further laboratory analyses (e.g. autoradiography);
- state-of-the-health indicators and remote monitoring devices verify error-free operation of the device and provide information on unpredictable conditions;
- modular design enhances reliability and facilitates maintenance; modular design allows selecting the optimum composition of hardware and software for the application involved, i.e., the simplest system may only have an automated sampler whereas the most advanced station could contain many technically advanced subsystems.

Many of these advantages are achieved by the sophisticated sample preparation system. Lots of development work and tests were needed to produce the accurate, reliable and functionally non-complex system. The filter change process is based on simple back-and-forth movement and it has functioned over a trial period of six months without any problems. Sample pre-processing is performed by a programmable robot, which is widely used in industry.

3 SAMPLING

Sampling, filter preparation and analyses are highly automated. During normal operation of the station the operator must only check once a week the availability of unused filters in the sampling unit.

3.1 Sampling unit

The sampler and its operation cycle are controlled by a programmable industrial micrologic, including an option for manual operation. The air flow rate through the filter can be set from 300 m^3h^{-1} to 800 m^3h^{-1}. The flow rate, the total filtered air volume and the filtration time are calculated and displayed continuously by a hardware unit and saved in 1 min intervals by a process monitoring computer.

The sampling head is similar to the one of Snow White (Toivonen et al., 1997), a high-volume sampler used in STUK's air surveillance programme (Leppänen and Niskala, 1996). The sampling head is located on the roof of STUK headquarters. Near the head the inlet tube is circular in shape. To avoid turbulent deposition into the frame of the filter holder the tube is designed to be rectangular with rounded edges near the filter. The length of the tube is 4 m and the diameter of the circular part is 0.2 m.[1] The tube has no bends.

Commercially available glass fibre filters are used for sampling. The filter is mounted into an aluminium cassette, which is loaded into a pile of clean cassettes. The cassette consists of a frame, a specially designed mask, that has 15 circular holes and a metallic grid, which supports the mask and the filter on it. The circular holes, 77 mm in diameter, are arranged in 3 × 5 matrix. The air flows through the holes only, and particles following the air stream are deposited into the filter comprising a 3 × 5 matrix of exposed circular sections with total area of 700 cm^2. Exposed areas are dark grey after a one day operation in urban environment due to large concentrations of particles emitted from traffic, industry and energy production (see Figures 3 and 4).

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[1] This diameter can be increased (0.25 m), if needed. An even better solution would be a rectangular inlet tube with dimensions that match the size of the filter.

3.2 Filter change and sample preparation

Large-area filters are necessary for high-volume sampling. However, small sample size is required for good HPGe counting efficiency. The problem of transferring a large filter into a small sample is solved by using a manipulator, which cuts the filter to 15 pieces and piles them into a sample beaker. Filter change, sample preparation and HPGe sample change procedures are fully automated.

In the manual sample treatment process used by the Aerosol Laboratory of STUK, the filters are pressed, crushed and pulverised prior the analysis. Finally, the filter is compressed into a tablet, which is placed in a beaker for gamma-ray analysis. After this kind of pre-processing only bulk analyses are normally performed. Separation of individual radioactive particles from the bulk material is very tedious or even impossible and requires decent laboratory procedures. The sample preparation and manipulation process performed automatically by CINDERELLA.STUK preserves the structure of the filter, which makes subsequent non-bulk analyses possible.

The automated duty cycle is 1 d sampling, 1 d decay and 1 d measurement. The details are as follows (Figures 3 and 4):

1. New cassette is moved from the pile of unused filters into the filtration unit (A → B).
2. Identification code is read from the cassette and a new measuring file is created.
3. The pump is started for sampling period of 24 h. During the sampling the filter is continuously monitored by Na(I) detectors (B).
4. After sampling the filter is transferred to the sample manipulator (B → C). At the same time, a new cassette is fed into the filtration unit (A → B) and a new sampling period is started.
5. Sample manipulator cuts the filter into 15 equal pieces of 82 mm × 84 mm and puts them into a beaker. The beaker is moved into the temporary sample storage for 24 h (see Figures 4a and 4b).
6. After measuring time of 24 h the manipulator opens the cover of the lead shield. When the cover is fully opened a limit switch gives a signal that triggers a quality assurance measurement for 10 min.
7. A previously measured sample is transferred from HPGe to the final sample storage (not shown in Fig. 3). The sample, aged for 24 h, is then transferred into the HPGe counting unit for gamma-ray analysis (Fig. 3 and 4c). Spectrum acquisition starts when the manipulator has closed the

cover of the lead shield and the limit switch has given a proper signal (Fig. 4c and 4d).

8. After measurement period of 24 h the manipulator opens the cover of the lead shield and deactivates the limit switch. The spectrum acquisition stops, spectrum is stored and analysis is started. The sample located on the HPGe is transferred to the sample storage.

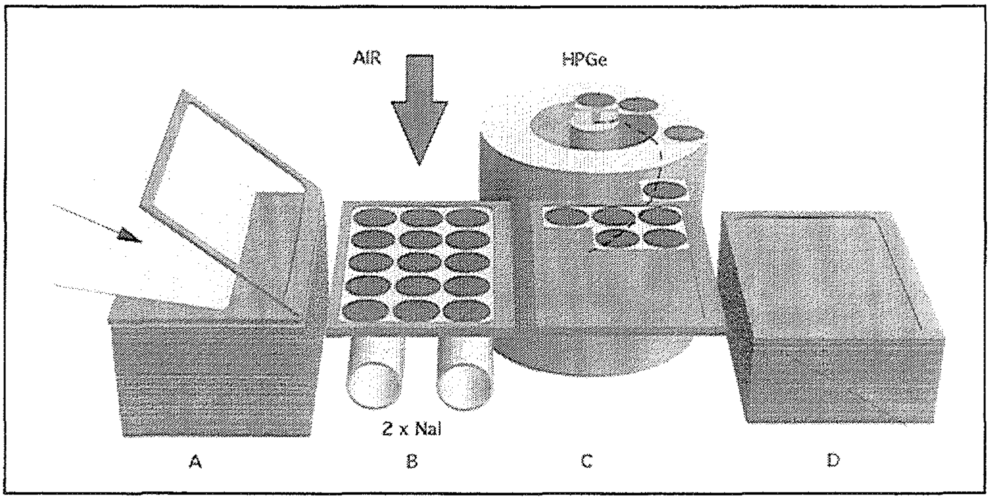

Figure 3. Automated filter change and treatment process. (A) Stack of unused filters, (B) filtration unit (2 scintillation detectors are below the filter), (C) sample preparation unit, (D) pile of empty cassettes. In this simplified mode of operation the treated sample is moved directly from the preparation unit to the HPGe without ageing. The normal mode of operation has a delay of 24 h before counting.

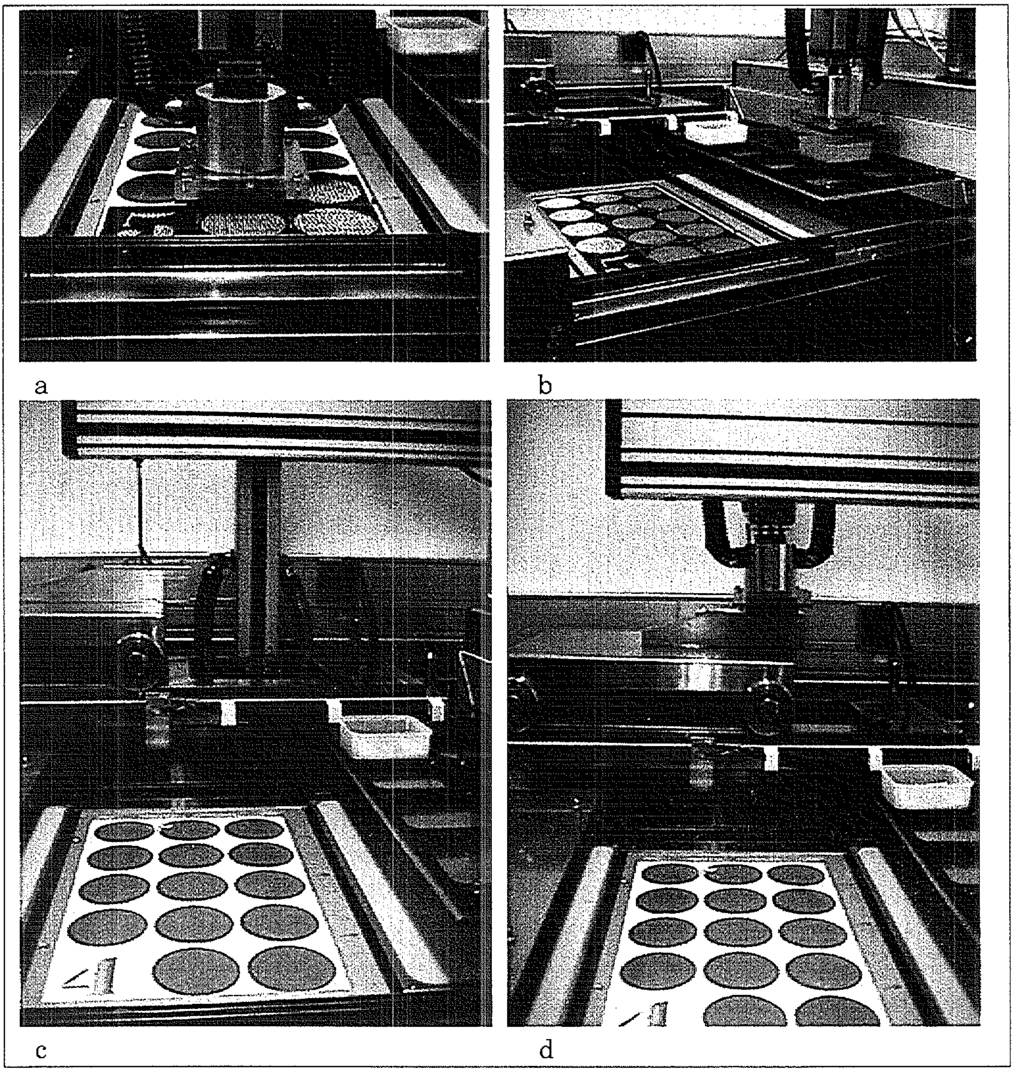

Figure 4. Automated sample manipulation process. (a) The arm of the manipulator is equipped with a rectangular cutting blade. The blade is pressed on the filter and a piece of filter is cut off. (b) The stack of pieces is moved to a sample beaker. (c) The beaker is placed on top of the HPGe crystal in the lead shield (copper and tin casing) after decay time of 24 h. (d) The manipulator closes the cover of the lead shield.

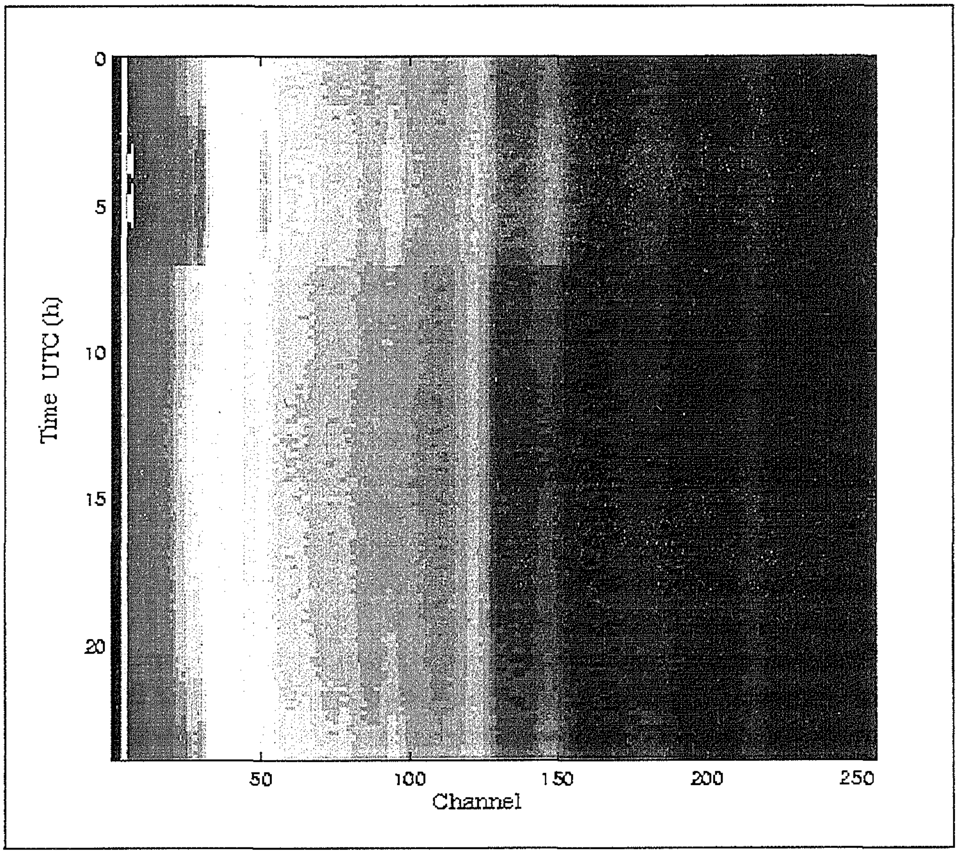

Figure 5. "Waterfall" colour display of Na(I) spectra measured under the filter. Air was constantly sampled through the filter. Channel or energy is on the x-axis and time is running on the y-axis. Each horizontal line (width in y-direction 1 pixel) represents a spectrum that is colour-coded according to the amount of pulses in the channels. Waterfall plot is a powerful way to display time series of spectra, since even small changes can be seen clearly both in time and in energy. Experienced user can analyse the situation at a glance. The present data was collected in the test period of the station. The filter was changed at 7 UTC (10 AM Local time), which is clearly seen in the figure as a dramatic drop of count rates. From 2 UTC to 7 UTC there was a strong inversion layer, keeping radon near the surface of the ground. Thus, the signals caused by radon progenies are clearly visible around channel number 50 (609 keV). During the daytime this signal was weak, because sunlight dissipated the inversion layer. However, the new inversion layer began to form in the evening at 20 UTC and the line around channel number 50 was turning red again.

4 REAL-TIME MONITORING OF THE FILTER

Real-time activity monitoring of the filter is performed with two Na(I) scintillation detectors and a special software, known as ACM (Activity Concentration Monitor). The detectors are cylindrical and 2" in diameter and 4" in length. These detectors are located below the filter inside PVC tubes of 80 mm in diameter (Fig. 3). A separate fan is circulating room air through the PVC tubes to avoid large temperature changes in the detectors.

Background shield (thickness 50 mm) is constructed of lead bricks. The shield reduces background radiation coming from directions other than the filter. Energy range is from 0 to 3 MeV in 256 channels (12 keV per channel) and the resolution of the NaI crystal is about 40 keV at 662 keV. Background potassium (^{40}K, peak at 1460.8 keV) is utilised for stabilising the energy calibration against drift caused by temperature changes.

The ACM software reads spectra in 1 min intervals from the multichannel analysers, calculates time-dependent cumulative spectra (sum of the counts) and saves the spectra to the disk of the computer. Sum spectra for the periods of 10 min, 2 h and 1 d are calculated for both detectors. ACM is able to display the raw data in several different views, such as spectrum channel contents, total count time series, region of interest count time series and very illustrative colour-coded spectrum time series (Fig. 5). The displays are saved on the disk for Internet distribution.

ACM software has a module that analyses the spectral data in real time. An alarm is triggered if changes in total count rate or in the shape of spectra occurs. Elevated count rates generated by natural or artificial radionuclides can be easily recognised using spectral information. The alarms will be routed via a server in STUK to the pagers of staff responsible of radiation monitoring in STUK. This service is expected to be operational in autumn 1998. The alarm level is expected to be far below 1 Bq m^{-3} for many fission products in 1 hour. However, a thorough analysis is not yet performed (see e.g. Leppänen and Toivonen, 1997).

5 ON-SITE HPGe MEASUREMENT OF THE FILTER

The CINDERELLA.STUK is equipped with an electrically cooled HPGe detector of 100 % relative efficiency. Diameter of the detector is 89.8 mm and height 54.4 mm (manufacturers data sheet). Counting geometry is optimal since diameter of the active part of the samples is 77 mm and height of the stack containing 15 filter pieces is about 8 mm.

The HPGe detector is placed in a lead shield, which is 100 mm thick. It has a copper (1 mm) and tin (2 mm) liner to minimise the amount of X-rays from the lead.

Before starting a new counting procedure, a quality control measurement of 10 min takes place. Quality control measurement is used to check energy, efficiency and peak shape calibrations. During this measurement the cover of the lead shield is opened and a multigamma calibration source, attached firmly on the outside surface of the cover, is moved above the detector. When the cover is closed there is 100 mm lead between the source and the detector; thus, the actual sample measurement is not disturbed.

5.1 Calibration

The peak efficiency calibration measurements of the HPGe detector were performed using reference point sources (^{241}Am, ^{57}Co, ^{137}Cs and ^{60}Co) at distances of 131 mm and 251 mm from the end cap of the detector. The activities of the point sources were between 5.5 kBq and 385 kBq. Four X-ray images of the detector were taken to verify the detector dimensions given in the manufacturer's data sheet and to find out the exact location of the detector inside the housing. These dimensions together with the beaker dimensions were used for the peak efficiency calculation of the sample geometry (Table I).

The efficiency calibration was calculated using the code DECCA (Klemola et al., 1997; Ugletveit et al., 1997). The code requires measured point source efficiency calibration (Fig. 6) as input together with the data in Table I. The code provides the peak efficiency for the measuring geometry (Fig. 6).

Table I. Parameters used in detector efficiency calculation with DECCA. The detector dimensions were obtained from an X-ray image.

DETECTOR		MATERIAL	Top	Side
DETECTOR RADIUS	45.4 mm	Ge dead layer	0.7 mm	0.7 mm
DETECTOR HEIGHT	54.8 mm	Al	0 mm	0 mm
CORE RADIUS	3.6 mm	vacuum	3.7 mm	7.5 mm
CORE HEIGHT	46.8 mm	Al	1 mm	1 mm
BEAKER		**MATERIAL**	**Top**	**Side**
BEAKER RADIUS	38.5 mm	Polystyrene	1 mm	0 mm
END.CAP-BEAKER	0.1 mm			
SAMPLE MATERIAL	H_2O			
SAMPLE DENSITY	0.15 mm			
SAMPLE HEIGHT	9 mm			
POINT SOURCE HEIGHT	251, 131 mm			
POINT SOURCE RADIAL DISPL.	0 mm			
INTEGR. ACCURACY	0.01 mm			

The peak efficiency calibration was verified with a sample comparison measurement with an HPGe detector in the laboratory of STUK. The overall inaccuracy of the efficiency curve was estimated from the point source activity inaccuracies (1.9% to 5%); the calculation method has an uncertainty of 5 % over the energy range of 50 keV to 3000 keV.

The present peak efficiency calibration procedure is simple and reliable, but produces no total efficiency calibration. However, sample self-absorption is inherently included in the efficiency curve.

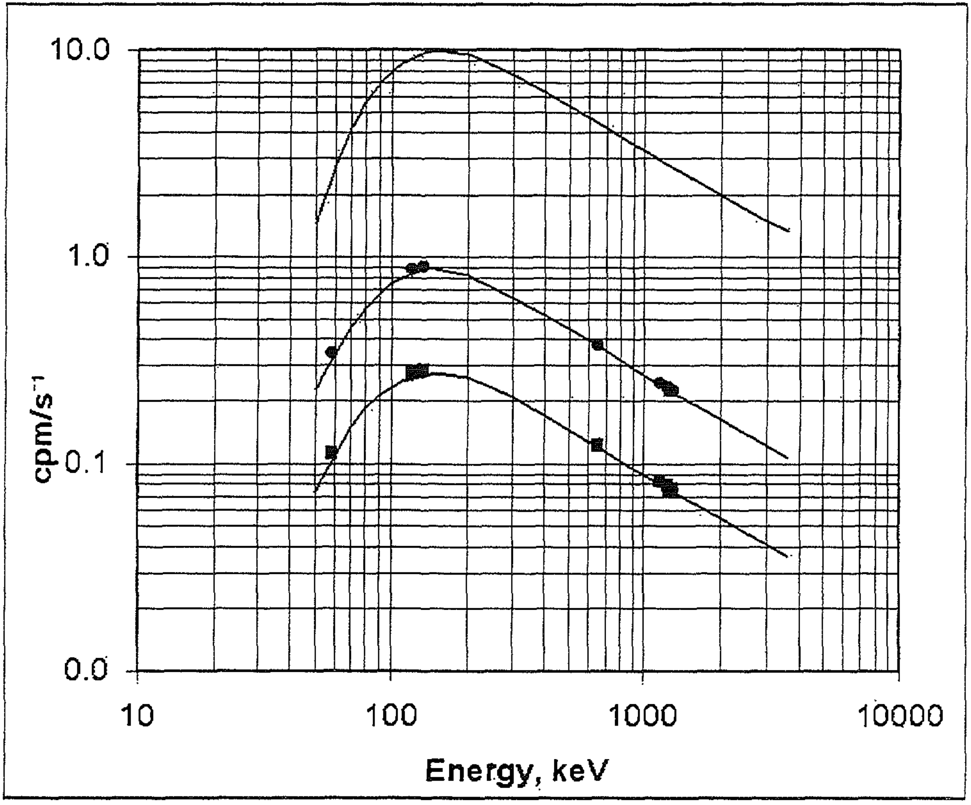

Figure 6. Efficiency calibration curves of the HPGe detector. Topmost curve is the counting efficiency of the prepared air sample. Curves marked with circles and squares are measured point source efficiency curves at the distances of 131 mm and 251 mm, respectively.

5.2 Minimum detectable concentrations

Minimum detectable concentration (MDC) is nuclide-specific and depends on air volume, activity of other nuclides in the sample (sample background), decay time before acquisition, acquisition time, detection efficiency and background shield (detector background). The measurement can be made in time slices and the time slice spectra can be combined in an optimum way to minimise MDC. MDC of various nuclides was estimated by running a test collection period of 1 d as a part of the efficiency calibration check of the detector (Table II).

Table II. Estimated minimum detectable concentration (MDC) for different nuclides based on method presented by Currie (1968). The baseline width in STUK software is ±1.25 FWHM. If the optimum width of ±0.7 FWHM is used (Hakulinen, 1993), MDC is reduced by a factor of 1.33. The duty cycle is 1 d sampling, 1 d decay and 1 d counting. Median of the sampling period is used for the reporting time. The air flow rate is 500 m^3 h^{-1} and the total air volume filtered is 12000 m^3. Density of the sample is 0.1 g cm^{-3}.

Nuclide	*Energy (keV)*	*MDC (μBq m^{-3})*	*Nuclide*	*Energy (keV)*	*MDC (μBq m^{-3})*
^{22}Na	1274.5	2.0	^{106}Ru	621.8	17.2
^{24}Na	1368.5	18.3	^{131}I	364.5	2.2
^{51}Cr	320.1	16.1	^{132}Te	228.2	2.5
^{54}Mn	834.8	1.9	^{133}I	529.5	9.7
^{58}Co	810.7	1.9	^{134}Cs	604.7	1.8
^{59}Fe	1099.2	3.7	^{136}Cs	818.5	2.0
^{60}Co	1332.5	2.0	^{137}Cs	661.6	2.0
^{95}Zr	756.7	3.3	^{140}Ba	537.4	8.9
^{95}Nb	765.8	1.9	^{140}La	1596.4	1.9
^{97}Zr	743.4	13.5	^{141}Ce	145.5	2.9
^{99}Mo	739.5	22.3	^{143}Ce	293.3	9.8
^{99}Mo^{99m}Tc	140.5	2.6	^{144}Ce	133.5	12.5
^{99m}Tc	140.5	365.0	^{237}U	207.9	7.7
^{103}Ru	497.1	1.9	^{239}Np	106.1	12.7

6 WWW REPORTS

Na(I) and HPGe spectrum acquisition results are available through a www server (Computer D in Fig. 1). The ACM server (Computer A in Fig. 1) produces GIF images of several different Na(I) spectrum displays. The latest images are shown on the html pages of the www service. Images in time resolution of 1 min, 10 min and 2 h are created for the spectra, total count-rate time series (see Figure 7), selected region of interest time series and colour-coded spectrum time series (waterfall plot, see Figure 5). The ACM computer copies also the raw spectra of the Na(I) detectors to an ftp service, from where they are available for later analysis.

The HPGe spectra are automatically saved in ASCII format, known as RMS2.0 (Mason, 1996), which will be adopted by CTBTO as a data exchange format. The spectra are copied to the ftp service. Two types of spectra are currently acquired: a quality control spectrum and an air sample spectrum. The spectrum analysis results are planned to be available on the www service during the autumn 1998.

Local weather information is available on the www server, including wind speed, wind direction, temperature outdoors, temperature indoors and temperature of the Na(I) detectors. The data are updated in intervals of 10 min. The www service provides also access to the status information of the sampling unit (Fig. 8).

The report and the raw data files are copied to the www server by using logical drives that are shared with the computers on the local network. The HPGe spectrum files can be sent with ftp to a remote site, too.

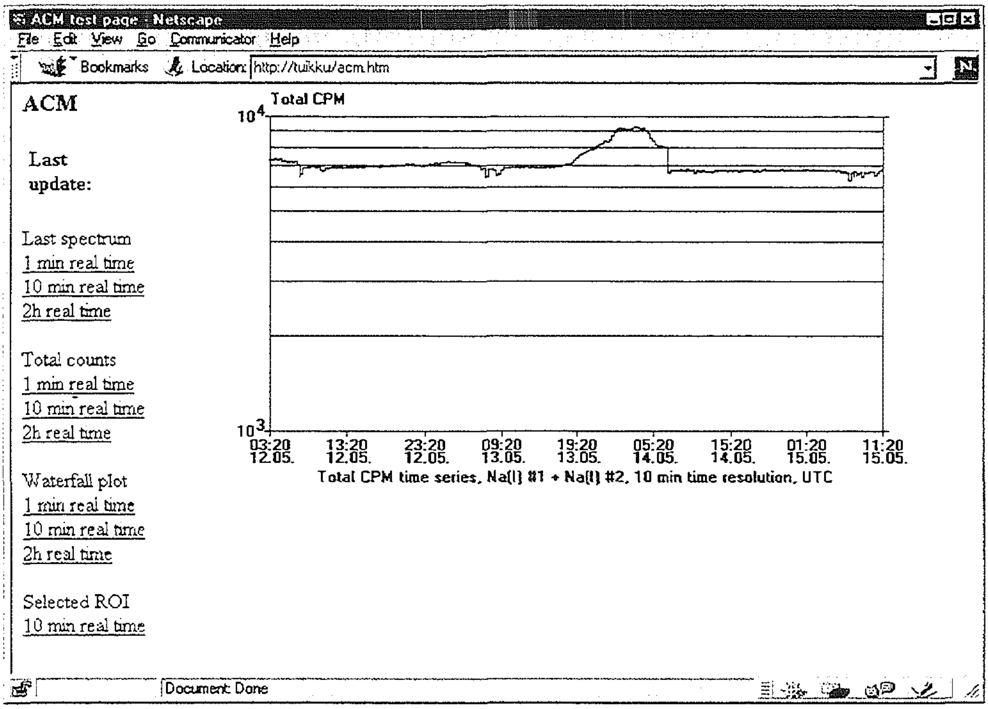

Figure 7. An html page showing Na(I) total counts as a function of time at time resolution of 10 min. List of other pages available is at the left. Increased count rate at the night between 13th and 14th of May 1998 is due to inversion layer in the atmosphere. Filter change takes place at 7 UTC every morning, which can be seen as small drop in the curve.

Status:

Last update (UTC): **28.04.1998 12:41**
Blower: **ON, 144 dm^3/s**
Wind: **1.4 m/s, direction 184 degrees**
Temperature: **23 °C**
ACM: **ON, total 124 CPS**
HPGe: **Acq. on, 7.5 h real time**

Figure 8. An example of status information on the www server of CINDERELLA.STUK.

7 REMOTE MONITORING OF THE SAMPLING STATION

The remote monitoring concept allows supervising the functions of the air sampler and provides access to the on-line weather data and radiation data. In addition, the concept is extended to comprise the monitoring of the room where the sampler is located. Implementation of remote monitoring techniques into CINDERELLA.STUK air sampling station is carried out by a joint effort of STUK and Sandia National Laboratories (Toivonen et al, 1997). The remote monitoring system and its safety features are designed to take into account the needs of national and international organisations. The IAEA and the CTBTO may utilise the present approach for special safeguards applications and for global monitoring of airborne radioactivity, respectively.

An essential prerequisite for remote monitoring is the prevention of tampering during sampling, sample preparation and analysis. A sensor network, integrated to the radiation monitoring system together with sample authentication procedures, provides a comprehensive and unique approach to reliable remote monitoring.

There are several possibilities to guarantee that environmental monitoring has been performed as designed. Natural radioactive substances in the samples show that sampling has been performed, the sample is fresh and the air volume through the filter is in correct range. On-line gamma-ray spectrometry reveals the mode of sampler operation (switched on or off) and it verifies that the filter is changed as required. Authenticated sensor data and video images reveal the measures taken at the sampling station. This data is at the disposal of the personnel and other authorised users at any time.

Although the sampling is performed under strict control, the original samples may be substituted with some other samples during possible retreatment and transport to other laboratories. A tag added to the filter during sampling reveals these kind of tampering efforts. The tag could be an invisible complex chemical dispersed onto the filter during the sampling sequence or it could be another signature, aerosol particles e.g., that are difficult to manufacture and can be detected only by special equipment.

A simple filter authentication system, based on aerosol particle spraying onto the filter, is implemented in CINDERELLA.STUK (Toivonen et al. 1997). Particles of known size distribution and composition are injected into the inlet tube of the sampler. The particles are deposited on the fibres of the filter. The tag can be detected using different methods (Fig. 9). Tampering will be revealed in the laboratory analyses if the observations do not match with the known characteristics.

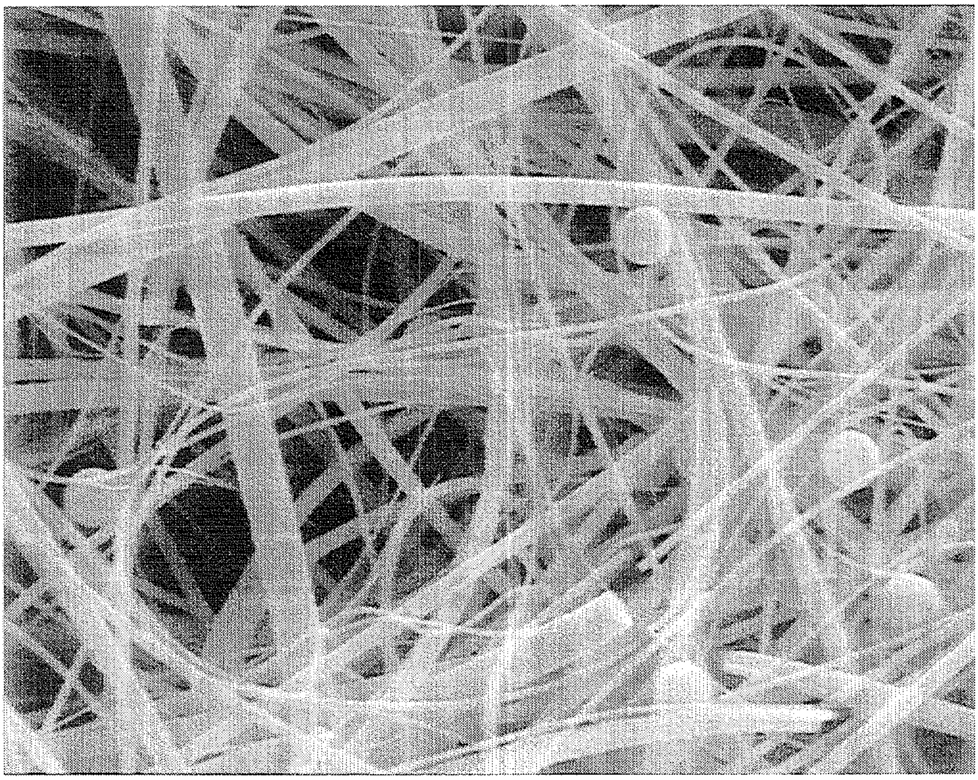

Figure 9. A scanning electron microscope picture of polystyrene latex particles sprayed on the glass fibre filter by the automated aerosol authentication apparatus of CINDERELLA.STUK. Diameter of the tag particles is 3 μm.

8 DISCUSSION

High-resolution gamma spectrometry may in some cases be too complicated to be performed on site and thus, it may be more reliable and cost-efficient to utilise services of a high-quality central laboratory that can perform advanced analyses (this infrastructure supports also other environmental applications). An efficient and cost-effective air sampling programme can be built by using the automated sampling unit of CINDERELLA.STUK without sample preparation and counting units. This simplified system would produce each week seven filters that need to be analysed in a laboratory. The transport of these filters must be carefully organised to avoid unnecessary delays and possible tampering.

The costs of analysing large amount of samples can be essentially reduced by sample composite techniques. The filters can be pressed manually to tablets and wrapped carefully in cellulose. Several small tablets can be easily analysed at the same time without essential deterioration of detection capability. If interesting materials are detected, the samples can be remeasured individually. This procedure provides timing accuracy of 24 h, which is necessary for backtracking the source of the debris but does not require sophisticated equipment on site. STUK has applied this procedure successfully since 1997.

Although the level of automation of CINDERELLA.STUK air monitoring station is high, the spectrum analysis is not yet automated. However, knowledge-based software for nuclide identification, developed at the Helsinki University of Technology (Aarnio et al., 1995), can be applied to create a high-quality spectrum processing pipeline. A recent version of this software has been strictly evaluated at the CTBT Prototype International Data Center (Ala-Heikkila et al., 1997), and the results in automatic pipeline processing of air-filter gamma spectra were excellent, both for routine spectra and for more complicated cases containing anthropogenic radionuclides.

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