

Mobile In-field Measurements in Nuclear or Radiological Threat Situations

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Abstract. Real-time measurements and the fast analysis of the results are of crucial importance in a radiological emergency. For a timely response, the Finnish Radiation and Nuclear Safety Authority launched a project in 2003 to develop an advanced measurement vehicle for use in different threat scenarios, such as the release of radioactive materials from a nuclear incident. The vehicle is equipped with several measuring systems including two air-sampling lines, two high-resolution gamma spectrometers and an alpha spectrometer. The equipment can be operated while the vehicle is moving. The system is designed to provide measurement information, either raw data or analysis results, to the local database or to a remote database using XML messages through a communication link.

1. Introduction

If there is a nuclear threat, the authorities must have reliable information on the prevailing radiological conditions in the environment of the incident site. In modern emergency preparedness, dispersion models are absolutely necessary in order to identify the areas at risk. However, often the information in the release is unavailable or if it is, the estimates include large uncertainties. In addition, the dispersion analysis itself, although based on a large-scale weather model, may be unreliable, particularly in complex weather conditions. Today there are no means to forecast the fine structure of fallout. We know of no single weather model or dispersion model that predicts rain fall always in the right place at the right time. There are tools, radar for example, to get this information in real time, but there are no means to get this to the dispersion model within a fast enough time frame. Therefore, the only way to get reliable information on the radiological conditions is to perform measurements.

Environmental monitoring provides the key radiological information in the early phase of an incident. For decisions on countermeasures, the results must be available in real time, or with short delay. This requirement can be partially accomplished by building stationary networks. Another equally important approach is to have mobile teams that are equipped and trained to perform the measurements.

Mobile measurements are useful only if they can be performed fast enough at the relevant locations. These requirements put serious constraints on measuring equipment, analysis and communication systems. The instruments must be functional all the time, a well-trained crew must be available at short notice and the crew must have the means to perform sampling and analysis while moving. In addition, the communication link to the control centre must be in working order even in the aftermath of a disaster.

In January 2003, the Finnish Radiation and Nuclear Safety Authority launched a project to develop an advanced measurement vehicle for use in different threat scenarios, such as the release of radioactive materials from a nuclear reactor or from a Radiological Dispersion Device (RDD). In addition, the system needed to have the capability of finding orphan sources. The construction, known as SONNI (Sophisticated *On-site Nuclide Identification*), is expected to be fully operational at the end of 2004.

For a timely response in an incident, SONNI must fulfil the following requirements: (1) take air samples and analyze them using high-resolution gamma spectrometry or alpha spectrometry, (2) perform an *in-situ* high-resolution gamma spectrometric survey, (3) find orphan sources using sensitive low-resolution crystals, (4) perform dose rate measurements in short time intervals, (5) write all measuring data, position information (GPS) and analysis results into a database, (6) develop software for data management and analysis, and (7) transfer XML-coded results and raw data in real

time to the control centre via cellular phone or satellite communication link. The present paper provides details on the implementation of these demanding requirements.

2. Systems in the SONNI vehicle

The equipment installed in the SONNI vehicle is divided into distinct operational systems. Strict functional requirements form the guideline for the design of the layout and component selection for the different systems. The requirements define 19 distinct items that include infrastructure, sampling, radiation measurement and related auxiliary systems, data management and crew protection.

2.1. General layout

The space in the SONNI vehicle is divided to three areas: cockpit, operations area and storage area. The cockpit and the operations area have easy access between them, but the storage area is isolated and accessed only from outside through the back doors. The storage area is used to store the instruments used independently outside the vehicle, contaminated equipment and ground samples, or any samples with high activity. For layout design, see Figure 1.

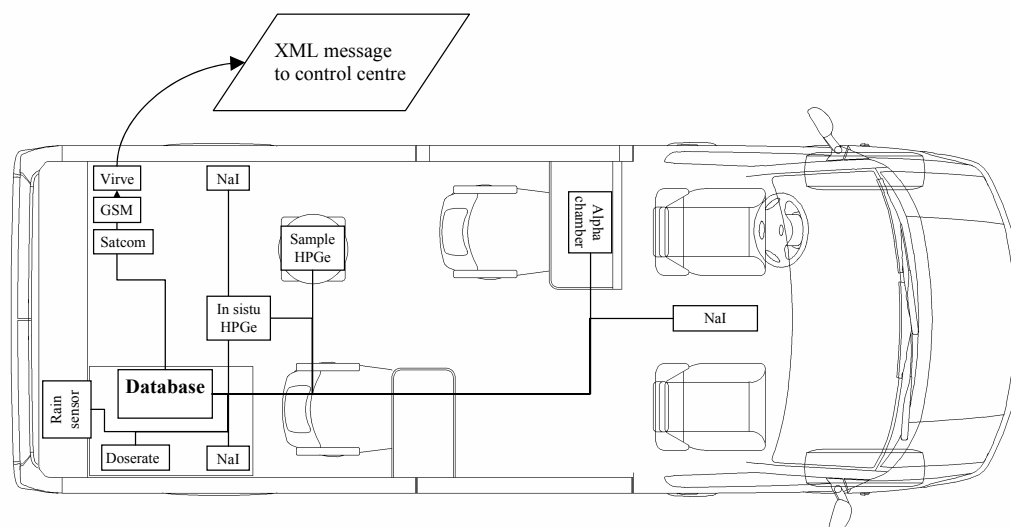


FIG. 1 Layout of the measuring systems in SONNI.

SONNI is operated with a crew of four. However, almost full functionality can be achieved for short periods with only two persons. The crew consists of a driver and three system specialists. One of the specialists sits next to the driver and has the main tasks of navigation assistance, use of the geographic information system (GIS) and operation of one of the air samplers. The other two specialists sit in the main operations area of the vehicle. The second specialist's main tasks are spectrometric measurements of samples and operation of the other air sampler. The third specialist's main duties are data analysis and *in-situ* measurements. With a full crew, all systems can be operated with safety belts fastened in the moving vehicle. With an undermanned crew, all non-physical tasks (data acquisition and analysis, etc.) can be redistributed between the manned workstations. Thus, even with a crew of two persons all systems, except one of the air samplers, can be operated in a moving vehicle. In a stationary vehicle, one person can operate all systems.

2.2. Sampling systems

SONNI has two fixed air samplers (Figure 2). Both samplers have a stainless steel diffuser extending 60 cm outside the vehicle. The purpose is to create free flow conditions at the sampling point. In

addition, a detachable shroud extending further than the diffuser is used to attenuate crosswind effects. Airflow through the samplers is adjustable up to $10 \text{ l}\cdot\text{s}^{-1}$. Sampling is done with either glass fibre filters or back-supported membrane filters. The filters are laminated inside semirigid plastic to produce an easily handled filter cassette design (Figure 3). A circular cut-out in the laminate produces a sampling area with a diameter of 77 mm. The sample holder of the gamma analysis system accepts these filter cassettes without any extra sample manipulation. However, for counting in the lead shielding the filter cassette is jacketed inside a thin plastic bag. This precaution is used to prevent contamination of the measurement system.

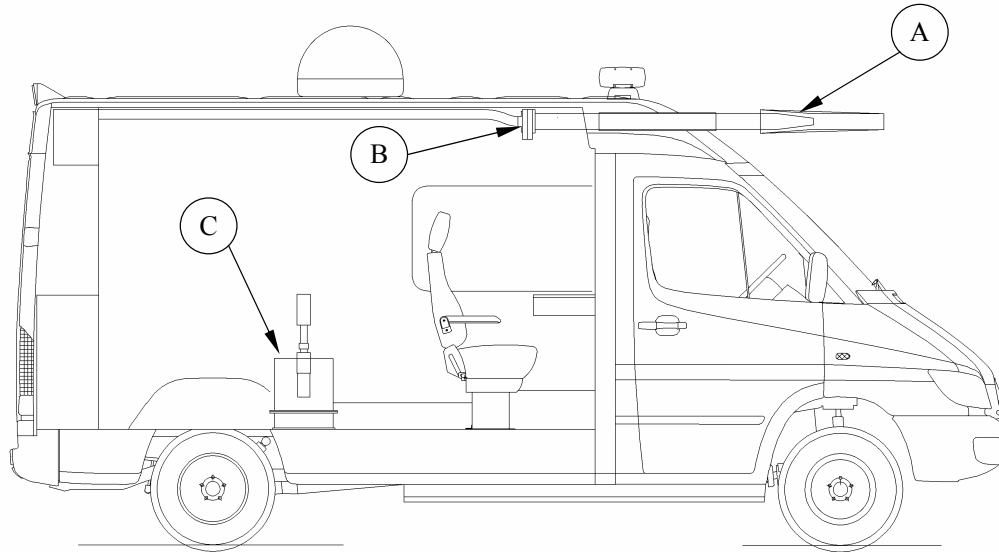


FIG. 2 Air sampling systems. (A) Air inlet, including diffuser and shroud. (B) Filter and its holder unit. (C) Lead castle and HPGe detector. While the vehicle is moving, the operator can change the filter and put the sample into the lead shield for counting.

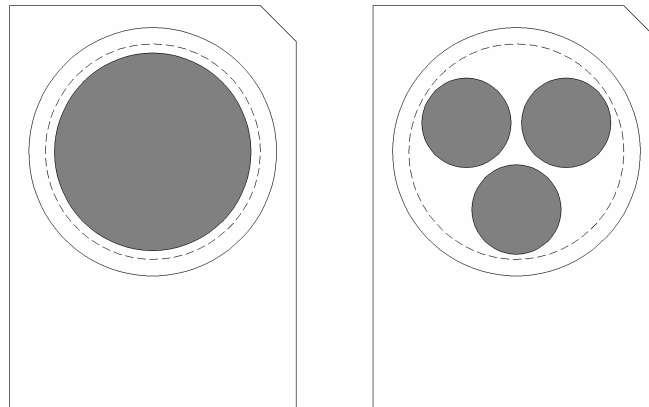


FIG. 3 The filter and its support structures. Left: glass fibre filter (77 mm), right: a modified structure consisting of three membrane filters (37 mm). The filters are supported by laminated plastic, which is easy to handle in a moving vehicle; filter changing is similar to inserting and ejecting floppy discs from a computer.

Several stand-alone air samplers are stored in the storage area of the vehicle. These samplers are portable and battery powered; they can be dropped at any location for fully autonomous sampling (10 m^3). The devices use the standard laminated filters of the fixed samplers. A tool was built to cut large filters to the standard size of 77 mm. This arrangement also makes it possible to count samples of the

Finnish national network for airborne radioactivity. The design is intended to keep the measurement geometry, and consequently the efficiency calibration of the detector, as simple as possible.

2.3. Data acquisition systems

The HPGe crystals in SONNI are electrically cooled coaxial detectors with carefully chosen dimensions. The sample measurement crystal is optimised for the 77-mm diameter sample geometry. The lead shield of the sample measurement detector is securely fastened to the floor of the vehicle and the detector faces downwards. The sample holder slides out from the bottom of the lead shield. The *in-situ* measurement crystal has a length to diameter ratio close to one. The detector is mounted on the ceiling of the main operations area far away from the bulk of the equipment. For added redundancy, the detector mountings are designed so that in case of a break down, the remaining detector can be installed in either position; thus, the function with the highest priority can be maintained.

SONNI has three NaI(Tl) scintillation detectors with sizes of 5" x 4" and 2" x 2". The large detectors are mounted on the opposite walls of the main operation area facing the sides of the vehicle. Steel shieldings of 15 mm around the detectors create fields of view opening outwards (Figure 4). This type of detector configuration enables good detection and localization of radiation sources. The small detector is mounted inside a 15-mm thick steel tube opening in the direction of travel. The tube creates a 15-degree field of view. This type of collimation makes it possible to scan the incident site from a distance. In addition, it gives some early capability to detect a large source on the road in other vehicles among the traffic. If video imaging is installed, time-stamped measurements can be used to identify the source of the radiation or the suspect vehicle.

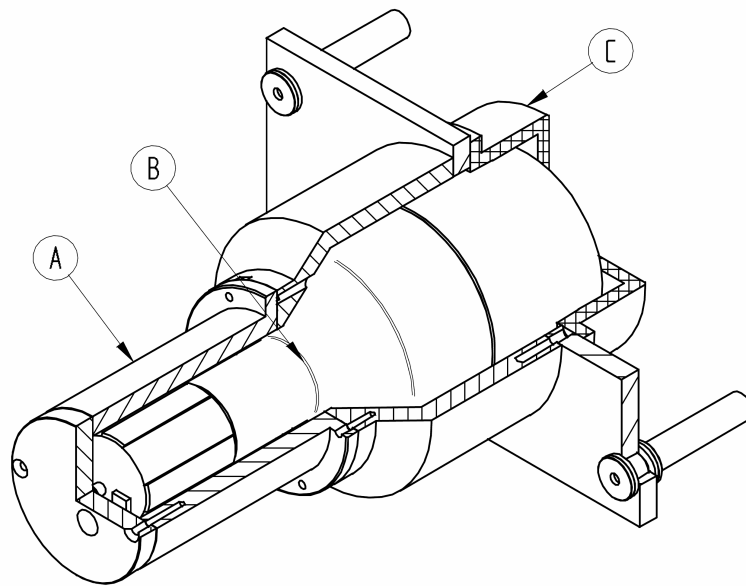


FIG. 4 Finding orphan sources. Two large NaI crystals are installed on both sides of the vehicle. (A) steel (15 mm), (B) detector surrounded with rubber cover (not shown), (C) plastic.

Alpha spectrometry in SONNI is performed with a standard NIM-rack mounted vacuum chamber and a PIPS detector. The main innovation is the minimization of sample handling. In all simplicity, 37-mm diameter discs are cut out from the sampled filter and attached to the spectrometer's sample holder. Adequate spectral resolution without any sample chemistry can be obtained with a properly selected sampling time, the remaining pressure inside the chamber and measurement time [1].

Dose rate with rain information (yes/no) and GPS positioning form the basic radiological information needed in an emergency. SONNI has Geiger-Müller tubes with a useful measurement range from $0.05 \mu\text{Sv}\cdot\text{h}^{-1}$ to $10 \text{Sv}\cdot\text{h}^{-1}$.

2.4. Auxiliary systems

Only 8 systems listed in the SONNI system requirements document are described above. The auxiliary 11 systems range from basic infrastructure and electrical power to communications and data management.

SONNI has power systems of 12 VDC and 230 VAC. Both systems have distribution connectors in all parts of the vehicle. In total of 110 A of DC power and 5 kW AC power is available for the equipment. An uninterrupted power system and an external generator back up power are provided for the critical systems.

The radiation protection of the crew is implemented with personal protective suits and powered air respirators. Personal doses are monitored with personal electronic dose meters that provide both dose rate and dose alarms. In highly contaminated areas, the filtered air from the fixed samplers can be diverted to the crew area. The additional air pumped in by the samplers creates an overpressure, thus preventing the contaminated air leaking in through incomplete seals on the doors and windows.

Operational communications are crucial in an emergency. SONNI has three independent means of communications. An Inmarsat satellite communication link provides voice communication and a 64 kbps data link practically anywhere in the world (except extreme polar regions). Triband 900/1800/1900 GSM mobile phones provide voice and data communications. The GSM phones support both GPRS (general packet radio system) and HSCSD (high speed circuit switched data). On Finnish territory, the Public Authorities Network (known as VIRVE and based on the TETRA standard) is available for secure communications with the control centre.

SONNI has two high performance computer servers running under Linux and Windows. All data acquisition, analysis and management are performed with these two computers. The crew can access the servers with laptop computers via the local area network of the vehicle. In the event of server failure, the remaining computer can take over the tasks of the failed computer and all critical data acquisition tasks can be transferred to the workstations.

3. Data analysis and management concept in the SONNI vehicle

All data gathered in SONNI are transferred to a local database immediately after its acquisition is finished. The spectral data and positioning information are saved in a relational database known as LINSSI [2] whereas the dose rate data are saved in tables that are compatible with other Finnish emergency preparedness applications.

The LINSSI system running under MySQL includes the database and the scripts needed to administer and update the database. Users connect to the system via a graphical user interface (GUI). The GUI for the scripts utilizes a web browser.

The analysis software has its own GUI. For the analysis, SONNI uses UniSAMPO [3] and SHAMAN [4] software which are interfaced with LINSSI scripts through temporary files. All relevant information starting from the collection of the sample to the final analysis results is saved. Simultaneously, auxiliary systems write their data to the database in short intervals, typically of the order of one second (GPS) or one minute (rain detector). The database design allows merging this information with the sample data and analysis results. The results can be forwarded to GIS for display, or they can be sent via the chosen communication link to the control centre as XML coded messages.

The raw spectral pulse height data (phd) are initially saved in the ASCII format specified by the Comprehensive Nuclear-Test-Ban Treaty Organization [5]. At the end of the measurement, the

database contains enough information to generate complete phd files, including calibrations. The database provides an excellent means to interface the raw data with different analysis software.

4. Discussion

The Finnish Radiation and Nuclear Safety Authority has long experience of using an advanced vehicle for emergency preparedness [6]. The present operational vehicle was built ten years ago but now it is out of date. However, the experience gained was crucial for the design of the new vehicle. The old construction formed the basis for the sophisticated sampling, data acquisition, data management and communication systems that had to be in-field capable.

Experience shows that *in-situ* gamma spectrometry is a fast method of detecting and identifying airborne radioactivity at high concentration levels of 10 - 100 Bq m⁻³. Potential hazardous fission product concentrations are detected immediately. Sampling and counting in the lead shield improves capability drastically, but at the cost of time delay. Typical nuclide-specific detection limits are of the order of 0.1 Bq m⁻³ for short sampling (10 min) and data acquisition (10 min) periods.

SONNI is able to perform fallout measurements. However, for this purpose airborne gamma spectrometry is superior because it is a fast method, covers large areas and involves no contamination problems [7]. Therefore, SONNI should be used for fallout mapping only in carefully chosen locations such as urban areas after an RDD attack. SONNI is also most useful in finding lost or stolen radioactive sources but again, the search area should not be too extensive in size. A ¹³⁷Cs source of 2 GBq gives a clear signal at a distance of 50 m; a careful statistical analysis can pinpoint the existence of the source up to 100 m.

The strategy of using advanced measuring capability in a threat situation needs to be analyzed in detail. It is clear that SONNI provides the most useful information at the early stages of an incident. In a threat situation, when the release has not yet occurred, the vehicle is able to confirm this. Reporting reliable zero values in a certain area is very important for a precise summary of event development. When release occurs, the vehicle should be situated downwind from the release site. Nuclide-specific concentration measurements as a function of time are a reliable description of how a situation develops and they form a firm basis for estimating the radiological risk to the population. The other variables, dose rate and fallout, are quantities that reflect the total amount of accumulated radioactive material near the measurement site.

The vehicle may be contaminated during the mission but this cannot be regarded as a big loss when compared with the value of the information gained. Air samples can be well counted in the lead shield although the surrounding radiation field increases. The crew is in safe while the vehicle is pressurised, they have respiratory masks and the best possible instruments to measure the prevailing exposure in real time.

In brief, SONNI is an excellent tool for emergency preparedness, providing laboratory-scale functionality on wheels. This capability can be applied quickly in different threat situations.

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