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SNIFFER: An aerial platform for the plume phase of a nuclear emergency

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Abstract

When a nuclear or radiological accident results in a release of a radioactive plume, AGS (Aerial Gamma Spectrometry) systems used in many countries, equipped with passive detectors, can help in giving quantitative assessment on the radiological situation (land surface contamination level) only when the air contamination due to the passage of the travelling plume has become negligible. To overcome this limitation, the Italian Institute of Health has developed and implemented a multi purpose air sampling system based on a fixed wing aircraft, for time-effective, large areas radiological surveillance (to face radiological emergency and to support homeland security). A fixed wing aircraft (Sky Arrow 650) with the front part of the fuselage properly adapted to house the detection equipment has been equipped with a compact air sampling line where the isokinetic sampling is dynamically maintained. Aerosol is collected on a Teflon® filter positioned along the line and hosted on a rotating 4-filters disk. A complex of detectors allows radionuclide identification in the collected aerosol samples. A correlated analysis of these two detectors data allows a quantitative measurement of air as well as ground surface concentration of gamma emitting radioisotopes. Environmental sensors and a GPS receiver support the characterization of the sampling conditions and the temporal and geolocation of the acquired data. Acquisition and control system

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based on compact electronics and real time software that operate the sampling line actuators, guarantee the dynamical isokinetic condition, and acquire the detectors and sensor data. The system is also equipped with other sampling lines to provide information on the concentration of other chemical pollutants. Operative flights have been carried out in the last years, and performances and results are presented.

1. Introduction

With aerial monitoring systems in use, equipped with large volume NaI(Tl) or high purity germanium (HPGe) detectors, the quantification of the source activity, or the ground contamination, through the analysis of the measured gamma ray spectra, is only possible with the assumption of a source pattern (localized for a point-like source, diffused for ground surface contamination). In case of a more complex situation, when there is no suitable knowledge to model the radiation source, the measurements can only supply qualitative information. This is the case, both in near and far field, when the radioactive plume released by an accident is passing over the country. The lack of quantitative measurements and the derived uncertainty in forecasting the propagation of the radioactive contamination, do not help the emergency management in the most critical phase, *i.e.* when countermeasures have to be decided in a preventive way and some risk of negative effects is inevitably linked to their enforcement.

Computer-based decision supporting tools for nuclear emergency support the integration of Airborne Gamma Monitoring Systems (AGMS or AGS). Unfortunately, the provided information is of relative use during the plume phase of an accident when, instead, the measurement of the concentration of gamma emitters in air, the extension of the plume, and in situ environmental and meteorological parameters would be an invaluable help in order to forecast transport and dispersion of the plume and ground contamination levels.

2. Chernobyl experience and the need of a new tool

Main motivations for the research program launched some years ago stem from our experience gained during the Chernobyl accident in 1986. Detailed information on what we have learned in that occasion has already been reported elsewhere [1]. Here we summarize only what is needed to understand the inputs to our program.

Flying during the period beginning of May – mid June 1986 with an AGMS, mounted in an Agusta-Bell 412 helicopter and developed in the follow up of the COSMOS 954 event by the Italian Civil Defence (VVFF) and Italian National Institute of Health (ISS) [2], only qualitative measurements on radioactive contamination were possible due to the undefined geometry of the source composed by air and ground contamination.

Only starting from May 19th (25 days after the Chernobyl accident and 20 days after the arrival of the radioactive plume in Italy), measurements at different heights scaled as expected and only at that time it was possible to have quantitative measurements of ground contamination with the required accuracy.

During the last years research and development of the SNIFFER system, a new aerial platform instrumented for in-plume contamination measurements have been carried on. The SNIFFER aims to characterize the extension, composition and concentration of the radioactive mixture in the plume, as well as to measure in situ meteorological parameters [3–6]. In the following sections we report the main features of the SNIFFER system and the results obtained.

3. The equipped aerial platform

The SNIFFER payload allows the atmospheric and ground radioactive contaminants and air pollution monitoring on large areas in relatively short time.

The system is mounted on board of a fixed wings aircraft and consists of the following main components:

a) aerial platform; b) isokinetic sampling unit (probe, suction line and filters subsystem); c) radiation measuring equipments (BGO, Geiger, HPGe and NaI detectors and relative electronics); d) VOC - PAH (Volatile Organic Compounds - Polycyclic Aromatic Hydrocarbons) sampling unit developed for a program on environmental control of traffic pollutants (not discussed in this paper but see [7]); e) control and data acquisition subsystem (electronic cards, actuators and sensors).

The aerial platform complies with the constraints demanded by the installation of the needed equipment, the sampling methodology and operative conditions. The sampling probe is located in a place where aerodynamic perturbation induced by the movement of the platform is negligible. The profile of the front cap of the airplane has been modified to allocate the sampling unit. Safety conditions for the flights are satisfied at an altitude range from some tens of meters to a few kilometres while take off and landing operations are possible in a grass type airstrip of a few hundreds meters (Short Take Off and Landing — STOL type aircraft).

The chosen platform is the Sky Arrow 650, manufactured by Iniziative Industriali Italiane S.p.A. (Rome — Italy). In its RAWAS (Remotely Assisted Working Aerial System) and ERA (Environmental Research Aircraft) versions it is certified by the National Airworthiness Authorities for land monitoring, environmental research/monitoring and "Electronic News Gathering". Entirely made of advanced composite material, the structure is corrosion free and strong yet light weight. The non-structural part of the fuselage can be remodeled to a certain degree to locate the instrumentation. Designed for operating in open space networking, it can be integrated with the best state-of-the-art communications technologies available in the flight sector.

To guarantee the representative and significance of the gathered data, the sampling has to ensure isokinetic conditions, *i.e.* the inlet walls of the sampler have to be parallel to the gas streamlines and the gas velocity entering the probe has to be identical to the free stream velocity entering the inlet. This is equivalent to the absence of any streamline deformation in the neighborhood of the inlet. A failure in the isokinetic sampling may result in a distortion of the size distribution and a misrepresentation of the concentration. To fulfill the isokinetic condition, the sampling line is thus provided with a flow regulator (through a valve) operated by an automated control unit that, by means of sensors measuring the relevant environmental parameters, can assure isokinetic sampling. The control software regulates the suction of the air and computes the needed sampled air volume in the current and nominal (STP, Standard Temperature and Pressure) conditions.

The sampling line is essentially a controlled suction line with filters to collect aerosol samples and radiation detectors; its most important subcomponents are (Fig. 1):

a) the probe; b) the shutter (a controlled valve that opens or shuts the line); c) the sampling filters and the filter-case disk; d) the holder (a small movable box containing a small BGO detector and a Geiger counter); e) the needle valve that permits to maintain the active isokinetic sampling; f) two radiation detectors (BGO and Geiger); g) the Venturi flow meter (not shown in the figure).

To keep isokinetic sampling condition, the velocity of the entering stream must be adapted to that of the external air (relative speed of the aircraft respect to the air) through a continuous regulation of the inlet flow rate according to the operative and environmental parameters (aircraft speed, pressure and temperature).

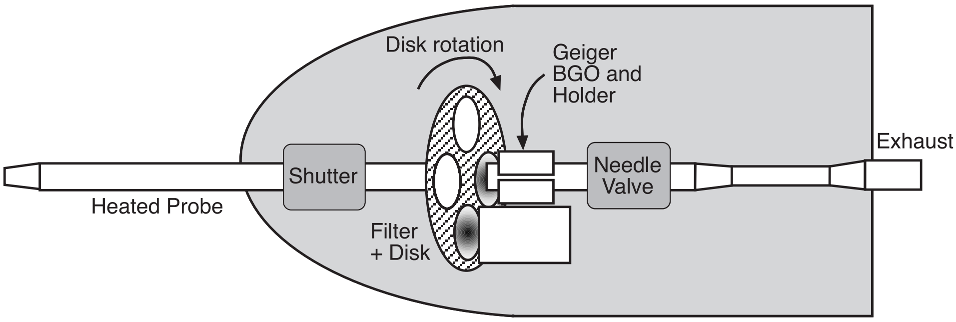

Figure 1: Scheme of the sampling line unit with its components and radiation detectors.

The sampling line is therefore operated by the control system that assures isokinetic sampling by means of sensors measuring the relevant environmental parameters. The control software regulates the suction (through the needle valve) according to what the environmental sensors measure.

The radiation measuring system includes four detectors that, under the supervision of the acquisition and control system, allow the quantitative estimation of the radionuclide activities and the determination of the environmental contamination.

Figure 2 shows the SNIFFER unit mounted on the front cap of the Sky Arrow. The front part of the sampling line, with its probe, shutter, filter-case disk and related motors that operate the needed movement of mechanical parts, is shown.

A small Geiger detector, having 10 mm external diameter, is mounted inside the holder box with the entrance mica window in front of the in-line filter. It is powered by the acquisition and control boards and the generated signals are sent to a pulse counter whose contents is periodically read and stored.

A small in-line gamma detector is made of a BGO crystal ($1\,\mathrm{cm}^3$), a photodiode and a signal preamplifier. It is located inside the Holder box, next to the Geiger counter, with the sensible window in front of the filter. It provides online information on the presence of radioactive contaminants on the exposed filter (and therefore on the sampled air) but, due to its very small size, it does not have enough energy resolution to permit the identification of the radioactive isotopes.

A high resolution HPGe (High Purity Germanium) detector allows radionuclide identification in the sample collected on the filters. It has been designed in collaboration with Canberra Semiconductor, taking into account

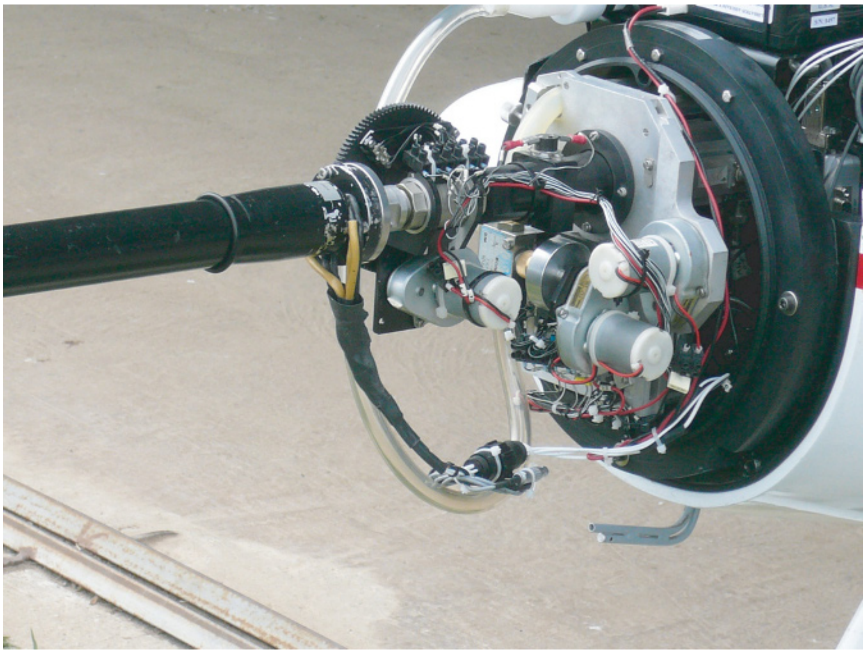

Figure 2: SNIFFER unit as mounted on the Sky Arrow.

the constraints imposed by the sampling unit and its aerial platform. The system cooling is assured by a dewar filled up of liquid Nitrogen, providing the proper cooling for up to four hours, compatible with the aircraft autonomy. Due to the crystal size (60 mm diameter and 35 mm height), the detector is not inserted into the sampling line, but is located in such manner that with a 90° rotation of the filter disk it can face the last exposed filter. The dewar is flanged to the aircraft fuselage externally to minimize its influence on penetration efficiency of the aircraft and to facilitate Nitrogen refilling.

External to the sampling unit, a large volume high sensitivity NaI(Tl) detector ($400 \times 100 \times 100\,\mathrm{mm}^3$, 17.5 kg in weight), is installed in the rear part of the aircraft, behind the shoulders of the pilot, in correspondence of an opening hole on the bottom of the fuselage.

Environmental contamination in its airborne (particulate) and ground contribution can be deduced from measurements. Air contamination is determined through the direct measurement of aerosol activity deposited on filter and ground contamination is derived from the large volume high sensitivity detector measurements, taking into account the measured air contamination and a suitable model of the influence of the air contamination and possibly other background contributions on the NaI detector.

A management unit is dedicated to the control of the devices of the SNIFFER (detectors, sensor and transducers) and to the acquisition of signals coming from them.

This sub-system is made of: 1) two 386-compatible CPU boards (Mesa 4C60 and Mesa 4C28) in PC104 and PC104 Plus standard. The two boards communicate via the respective parallel ports (laplink protocol) in a master-slave scheme. The use of the PC104 offers a reliable operation in a very compact solution, fitting the strong constraints on the available room for the electronics. 2) A PC104 card equipped with a series of Digital to Analog Converters to handle the flow regulation valve. 3) A standard PC104 card (Mesa 4I22) to manage the digital TTL input/output signals of the shutter, holder, filter disk, canister and sampler sensors and to drive the regulation of the Geiger high voltage. 4) A custom board consisting mainly of voltage regulators to provide the proper power supplies to several devices. 5) A custom board for signal conversion (sensor specific to TTL and vice versa).

The initialization and final phases are serialized on the two CPUs. Main control is delegated to the 4C60. During the acquisition the 4C60 receives messages from the 4C28 and handles the commands from the operator by means of the 3 key keyboard. Periodically it reads GPS stream data and stores them on the on-board flash card. On the other hand, the 4C28 is responsible of the regulation of the flow (via the regulation valve) in order to keep the isokinetic conditions and periodically reads the Geiger's counter. Besides it, stops the acquisition, reads the data acquired and saves them on files at fixed times (defined during the mission plan); eventually it changes the filter (on operator action or at planned intervals).

The interface with the operator (the pilot) consists of a monitor and a small keyboard, these two devices allow the operator to interact in real time with the acquisition and control system. The operator screen connected to the 4C60 VGA interface is virtually split into two windows: the upper one displays information about the status of the devices; on the lower window scrolling log messages are shown. The verbosity of the visualized messages can be controlled at configuration time. The operator keyboard allows three simple commands: i) start of the acquisition; ii) stop of the acquisition and end of the flight program; iii) change of the filter before the pre-programmed time if an anomalous level of radioactivity has been found.

In figure 3 the Sky Arrow platform equipped with the SNIFFER sampling units and related radioactive detectors as ready to take-off for an environmental campaign is shown.

Figure 3: Sky Arrow (version TREO) with in-flight sampling capability.

4. Results of demonstrative environmental campaigns

The instrumented aircraft had the provisional authorization to fly and after devoted test flights obtained the full certification to perform environmental campaigns, fulfilling the full set of criteria of the Italian Airworthiness Authority. The system obtained also the permission to fly over the urban area of Rome in October 2007, during a campaign devoted also, with different instrumentation, to assess the levels, at height, of some pollutants connected with the vehicle traffic.

Several demonstrative environmental campaigns have been carried out after the first calibration flights to check performance and operability of all the instrumentation.

During these tests, the instrumentation performed quite in agreement with the design specifications. At the end of every flight mission measurement the data stored in flash memories were retrieved, analyzed and compared with expectations according to the flight operations for what regards aircraft speed patterns, static pressure differences, flow variations respect

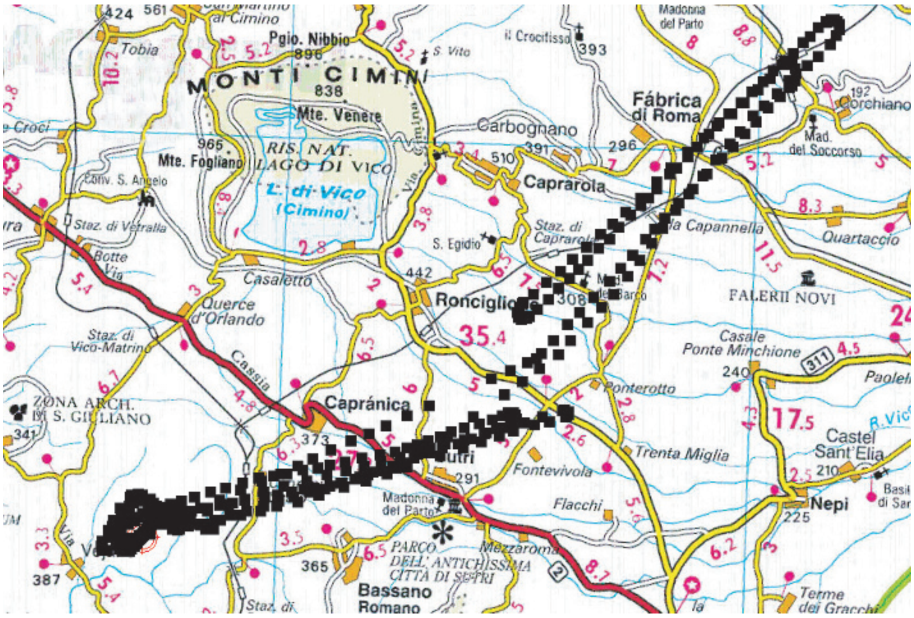

Figure 4: GPS data decoded for geolocation of single measurements during environmental campaign.

to the controlling valve aperture, isokinetic condition automatic regulation, pressure and temperature sensors performances.

The different detectors have been tested and calibrated, using mainly calibrated sealed sources of ^{60}Co and of ^{137}Cs. These sources have also been located very close to the filter position in the suction line to simulate a contaminated filter. Tests were done to check gain stability of the different detectors and connected electronics before and after the flights.

GPS data recorded during the missions were decoded and transferred to a map to allow a geo-time localization of the single measurements. During the campaign whose trace is shown in figure 4, two heights have been planned and for each height the aircraft has run 4 different speeds (60, 70,80, 90 knots aircraft-air relative speed), moving forth and back on a fixed direction.

While the filter γ activity characterization is made during the mission, characterization of the aerosol collected on the filters can be done at the end of the flight mission through detailed offline-analysis.

Different kinds of analyses can be carried out, in particular as routine analysis we can mention: 1) gravimetric analysis to evaluate the particle mass collected; 2) SEM (Scanning Electron Microscope) analysis to characterize the morphology and the composition of the particulate; 3) ICP-MS

(Inductively Coupled Plasma — Mass Spectroscopy) analysis to characterize metallic-like components in aerosols.

SEM pictures of the filter exposed during a flight along the border of the high traffic ring road encircling Rome have proven the existence of two different aerosol size distributions (fine and coarse) giving possible evidence of two different sources (anthropogenic activities and natural atmospheric erosion) of aerosol pollutants.

The analysis can be pushed further determining the spectrum of aerosol elemental composition that, in the case discussed, shows a high carbon content in the fine size population while there is a high concentration of silicates in the coarse size population.

Both such analysis, size distribution and elemental composition, can be a precious element of knowledge in case of an accident to better know the kind of pollutants and the possible pathways for radioactivity transport and migration.

5. Conclusions and outlook

A new type of Airborne Gamma Monitoring System has been demonstrated viable, combining a traditional system based on passive (NaI or HPGe) detectors with an active sampling system able to collect air sample and measure their γ emitters composition in real-time.

In this way, the main limitation of the traditional AGMS, that is the inability to provide quantitative measurements on the radioactive contamination during the early phase of an accident, when the plume or its residual fine aerosol content result in contamination dispersed in air, can be overcome. A precious tool for the quantitative radiological assessment can then be available for the emergency management since the early phase of an accident.

The feasibility has been proven for a manned airplane, then useful only in a far field situation. The instrumentation used, for its weight and power requirement can easily be adapted to an UAV (Unmanned Air Vehicle), suitable then to be used even in near field situations. A network of equipped UAVs can give a substantial support in the management even of a severe accident.

The promotion, within an International Cooperative Program, of a project to develop new measurement platforms with the above discussed (and demonstrated) characteristics and performances, represents an important opportunity for research, industry, safety and security.

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