# A Unique Aerial Platform Equipped for Large Area Surveillance
## *A Real-Time Tool for Emergency Management*

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**Abstract.** Aerial platform equipped with a sampling line and real-time monitoring of sampled aerosol is presented. The system is composed by: a) a Sky Arrow 650 fixed wing aircraft with the front part of the fuselage properly adapted to house the detection and acquisition equipment; b) a compact air sampling line where the isokinetic sampling is dynamically maintained, aerosol is collected on a filter positioned along the line and hosted on a rotating 4-filters disk; c) a detection subsystem: a small BGO scintillator and Geiger counter right behind the sampling filter, a HPGe detector allows radionuclide identification in the collected aerosol samples, a large NaI(Tl) crystal detects airborne and ground gamma radiation; d) several environmental (temperature, pressure, aircraft/wind speed) sensors and a GPS receiver that support the full characterization of the sampling conditions and the temporal and geographical location of the acquired data; e) acquisition and control system 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. With this system quantitative measurements can be available also during the plume phase of an accident, while other aerial platforms, without sampling capability, can only be used for qualitative assessments. Transmission of all data will be soon implemented in order to make all the data available in real-time to the Technical Centre for the Emergency Management. The use of an unmanned air-vehicle (UAV) is discussed as future option.

***KEYWORDS: Aerial platform; in-plume sampling; emergency management; air contamination; ground contamination; real-time measurements.***

## 1. Introduction

With aerial monitoring systems in use, equipped with large volume NaI(Tl) or HPGe detectors, the quantification of the source activity, or the ground contamination, through the analysis of the $\gamma$ ray spectra measured, 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 not a suitable knowledge to model the radiation source; therefore 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, does 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, like RODOS [1] and ARGOS [2], support integration of Airborne Gamma Monitoring Systems (AGMS or AGS) but the provided information is of relative use during the plume phase of an accident when, instead, the measurement of $\gamma$ emitters concentration in air, extension of the plume, in situ environmental and meteorological

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parameters would be an invaluable help to forecast transport and dispersion of the plume and ground contamination levels.

A different tool for the emergency management should be provided. An aerial platform instrumented for in-plume measurements, aiming to characterize the extension, composition and concentration of the radioactive mixture in the plume, as well as to measure in situ meteorological parameters. During last years research and manufacturing activities have been developed to reach these goals [3,4].

## 2. The aerial platform

### 2.1 Aircraft

The aircraft must comply with some constraints demanded by sampling methodology and operative conditions. The sampling probe has to be located in a place where aerodynamic perturbation induced by the movement of the platform is negligible. This requirement calls for a fixed wing aircraft to avoid effects of rotor blades on the surrounding air velocity field and for a plane which offers the possibility to install the sampling unit in its front part with the probe located ahead of the aircraft. The profile of the front cap of the airplane must be modified to allocate the sampling unit. Safety conditions for the flights must be satisfied at an altitude range from some tens of meters to a few kilometers while take off and landing operations should be possible in a grass type airstrip of a few hundreds meters (Short Take Off and Landing – STOL type aircraft).

These requirements are fulfilled by the Sky Arrow 650 – manufactured by Iniziative Industriali Italiane SpA (Rome, Italy) in its RAWAS (Remotely Assisted Working Aerial System) and ERA (Environmental Research Aircraft) versions – which is certified by National Airworthiness Authorities for territory and environmental research/monitoring and "Electronic News Gathering". Entirely made of advanced composite material, the structure is corrosion free, strong yet light weight. The non-structural part of the fuselage can be remodelled to a certain degree to locate the instrumentation. It is designed for operating in open space networking and can be integrated into the most updated communications technologies available.

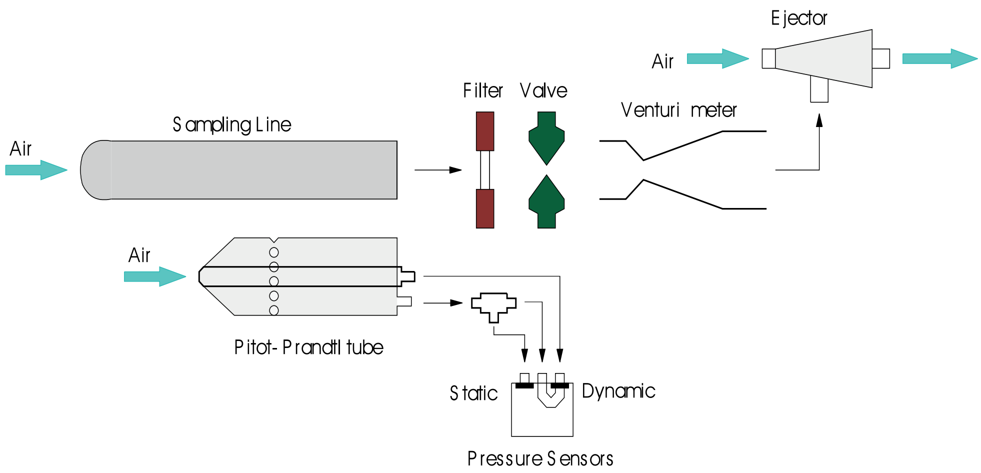
### 2.2 Isokinetic sampling

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 shall be parallel to the gas streamlines and the gas velocity entering the probe shall be identical to the free stream velocity entering the inlet. This is equivalent to the absence of deformation of the stream lines in the neighbourhood of the inlet. A failure in the isokinetic sampling may result in a distortion of the size distribution and a misrepresentation of the concentration.The sampling line then should be provided with a flow regulation (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 shall regulate the suction of the air and compute the needed sampled air volume in the current and nominal (STP, Standard Temperature and Pressure) conditions.

The aircraft speed is measured by a Pitot-Prandtl tube mounted in the front part of the aircraft below the sampling probe. It allows the measurement of the total and static pressure and by their difference the aircraft speed respect to the wind speed is deduced. Along the line a Venturi tube (Venturi meter) measures the actual volumetric flow rate by measuring the differential pressure across a calibrated resistance (a streamlined constriction in the duct to minimize losses) in the flow stream. The Venturi meter also provides pressure and temperature in order to obtain the volumetric flow at STP. The ejector at the end of the sampling line is used to overcome the impedance due to the filter and other fluidodynamic resistances along the line.

The whole sampling line is schematically shown in Fig. 1

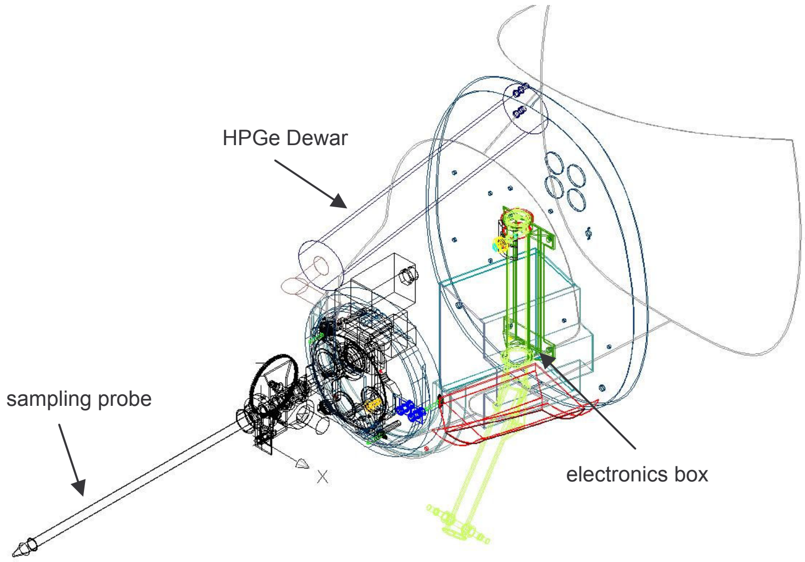
**Figure 1:** Schematic view of the isokinetic sampling line




## 2.2 Air-sampling unit

The sampling unit is located in the front part of the aircraft, which has been properly designed and modified for its correct installation as shown in Fig. 2.

**Figure 2**: Installation of the sampling unit in the Sky Arrow aircraft




The sampling line is essentially a controlled suction line with filters to collect aerosol samples and radiation detectors; its most important subcomponents are (Fig. 3):

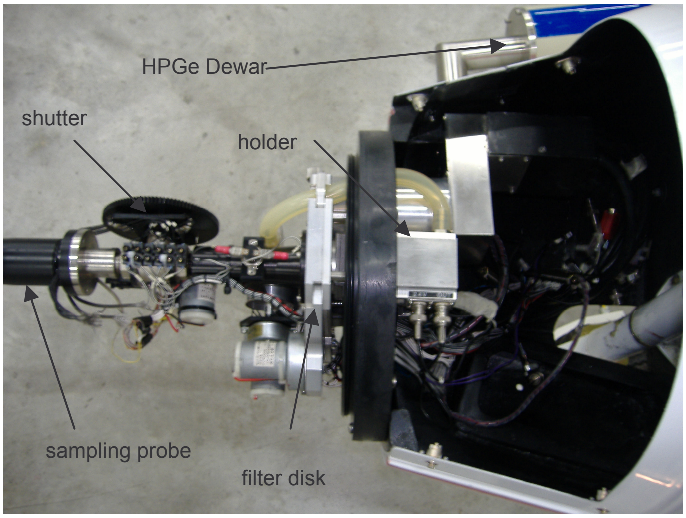
- the probe;
- the Shutter (a controlled valve that opens or shuts the line);
- the sampling filters and the filter-case disk;
- the Holder (a small movable box containing a small BGO detector and a Geiger counter);
- the needle valve that permits to maintain the active isokinetic sampling;
- two radiation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

The sampling probe has to be located where aerodynamic perturbation induced by the advancing of the platform is negligible. Its nose extends ahead by 450 mm and is warmed to prevent air condensation and aerosol deposition along the line, if external temperature in flight goes below the dew point. Resistances are fed from 12 Vdc and manually operated by the pilot. A diode, installed along the line, is used to measure the nose temperature and monitor the correct operation of the heating bands.

Downstream the suction line a valve (Shutter) determines the aperture of the line itself, while the carrier gas is driven behind the filter and reaches through the flow-meter the ejector whose differential pressure helps in maintaining the flow along the line.
The filters (up to 4) are housed on an aluminium disk that can rotate around its axis by means of a connected step motor. The exposed filter is determined by the disk rotation and two optical marks assure the correct filter positioning and its identification. The rotating filter disk is placed downstream the line and has four 47 mm diameter filter holders, one for each of the possible independent aerosol collection during the same flight mission.

During the sampling, the whole line is airtight. On the other hand, in order to permit the disk rotation, the part in contact with it is moved apart a few millimetres before starting the disk movement; this is accomplished by a two steps motor and corresponding optical sensors. The Holder box guarantees the airtight of the line and contains two small detectors that perform online measurements of gross beta and gamma radioactivity of the aerosol collected on the exposed filter.

**Figure 3**: The sampling unit with its components




Active isokinetic sampling of aerosol is reached by continuous automated regulation of a needle valve, aiming to assure a flow speed at the inlet equal to the airplane relative speed. The regulation is performed increasing or decreasing the line impedence in order to maintain the flow measured by the Venturi meter equal to the relative aircraft/wind speed, determined by the Pitot-Prandtl sensor multiplied by the inlet probe aperture area. The inlet flow scales with aircraft speed and can be regulated within an error of ±1% in the aircraft speed operative range between 30 and 71 l/min for a speed of 80 km/h (~ 43 knots) and 194 km/h (~ 105 knots), respectively.

### 2.3 Environmental and in-flight parameters sensors

The air-transported SNIFFER includes many sensors to measure environmental parameters, that are used in the flow regulation algorithm: a) diodes as temperature sensors; b) pressure transducers to measure pressure and flow velocity indirectly.

Two diodes allow the determinations of the temperature values used in the flow regulation algorithm. One is located near the nozzle inlet and it measures the external air temperature. The other diode is right after the regulation valve and it provides the temperature of the air flowing into the sampling line at intervals (of several tens of milliseconds) synchronized with the flow regulation action. A third diode, as previously mentioned, is installed on the probe nose and it provides information about the correct operation of the heating bands. Pressure data are provided by pressure transducers supplied by DMA-Marchiori of Rome.

Finally a GPS receiver provides at prefixed intervals (around 10 seconds) precise information relative to aircraft speed and geoposition. Such information allows the correlation of the acquired data to a space-temporal reference and therefore correctly maps acquired data on a geographical map in a precise temporal extend.

### 2.4 Radiation detectors

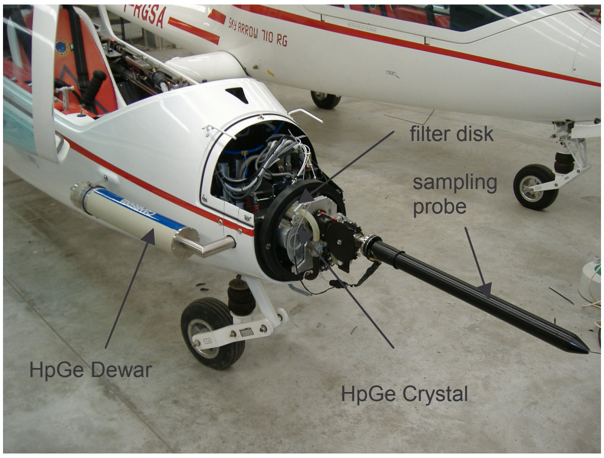
The radiation measuring system includes all the detectors that, under the supervision of the acquisition and control system allow the quantitative estimation of the radionuclide activities and the determination of the atmospheric contamination.

The subsystem consists of four detectors.

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 (1 $cm^3$) BGO crystal, 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.

**Figure 4**: HPGe installation and sampling line

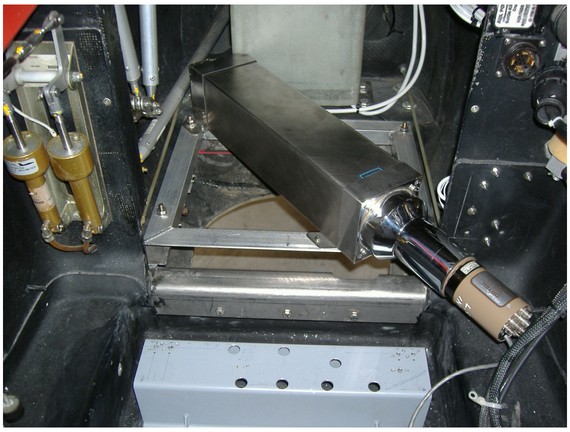



A high resolution HPGe (High Purity Germanium) detector allows radionuclide identification in the sample collected on the filters. It has been designed in collaboration with Camberra Semiconductor, taking into accounts the constrains imposed by the sampling unit and its aerial platform. The system cooling 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, 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 aircraft fuselage but installed externally to it to minimize its influence on penetration efficiency of the aircraft and to facilitate Nitrogen refilling.

External to the sampling unit, a high volume NaI(Tl) detector ($400 \times 100 \times 100$ 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.

Figs. 4 and 5 show the installation of detectors on board.

**Figure 5**: Installation of the NaI detector on the rear part of the aircraft



### 2.5 Control and data acquisition

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) [3] in PC104 and PC104 Plus standard. The two boards communicate by 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 (DAC DM121 produced by DMA-Marchiori of Rome) to handle the flow regulation valve;
3. a standard PC104 card (Mesa 4I22) (0) 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 handle the commands from operator by means of the 3 keys keyboard. Periodically it reads GPS stream data and store 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 acquisitions, read data acquired and save them on files at fixed times (defined during the mission plan); eventually it changes the filter (by operator action or at planned intervals).

The operator screen (Fig. 6) 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.

**Figure 6**: Monitor screen in the pilot cockpit


Acquired and processed data (from GPS sensor as well), and all information about the status of the system are saved on files in two fast flash cards connected to the two CPU boards.

## 3. Flying test campaign

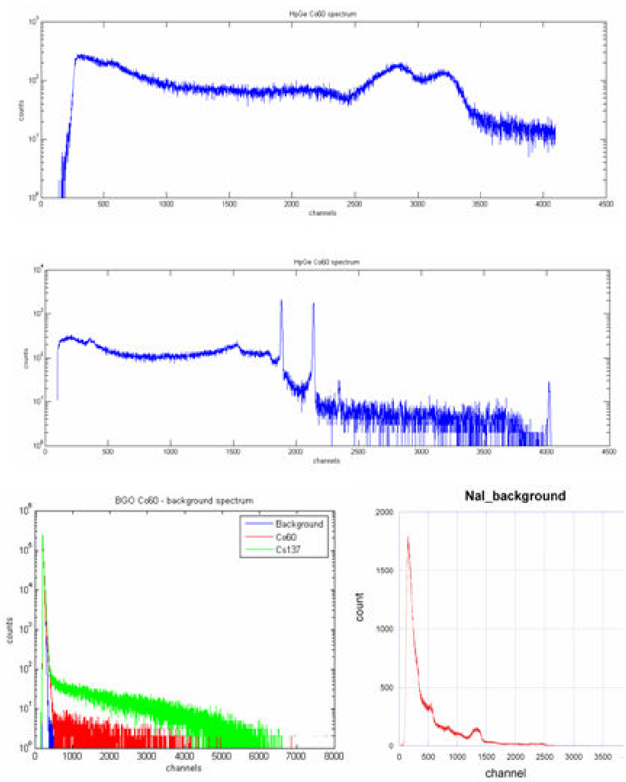
All the instrumentation has been installed on a customized Sky Arrow airplane. The whole system (modified fuselage, external HPGe Dewar and board instrumentation) has been tested and the full electromagnetic compatibility with the aircraft instrumentation has been achieved after some minor modifications to the electronics assembly. The instrumented aircraft has got the provisional authorization to flight and after devoted test flights obtained the full certification to perform environmental campaigns, fulfilling the full set of criteria of the Italian Airworthiness Authority. A first campaign of flights were carried out during 2007 to commission and calibrate the various components. The system obtained also the permission to fly over the Rome urban area (Fig. 7) in October of the last year, in connexion with a campaign devoted also, with different instrumentation, to assess the levels, at height, of some pollutants connected with vehicle traffic.

During these tests, the instrumentation performed quite in agreement with the design specifications. At the end of every flight mission measurement 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 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 been also 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.

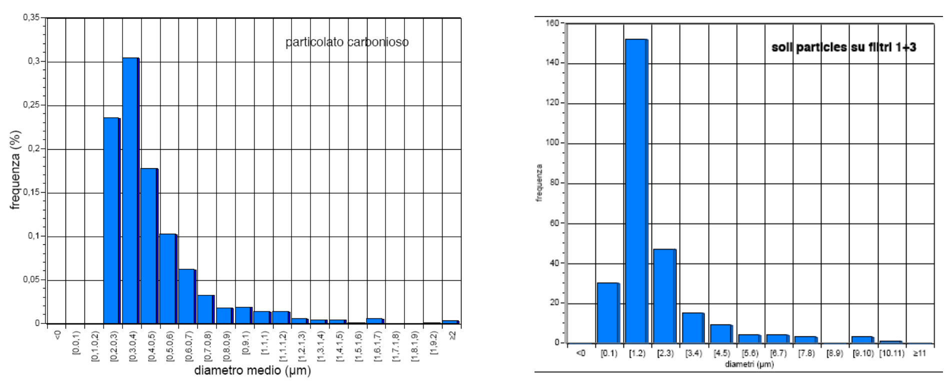
The different energy resolution of the three $\gamma$ radiation detectors is clearly in Fig.7.

**Figure 7** : Spectra with source calibration of a) NaI b) HPGe c) BGO detector, respectively. In the bottom right a typical NaI background (natural radiation) spectrum collected during flights is shown




After each flight the exposed filters were analyzed by a SEM (Scanning Electron Microscope) to characterize the dimension distribution (Fig.8) of the aerosol collected. This practice could also be valuable in case of a nuclear emergency to have a measurement of the aerodynamic diameter to be used both for the plume transport calculations and detriment assessment connected with aerosol inhalation.

**Figure 8** : Mean diameter distribution of collected aerosols. Two different distributions are measured, one related to "fine" particles and the other to "coarse" particles.




## 4. Outlook and conclusions

Having now in hand a certified aircraft equipped for environmental radiological measurements, the first objective is to acquire a full understanding of the operability of the system, performing a campaign of measurements trying to characterize the performances of the system in term of minimum activity and minimum surface contamination detectable in addition to have a reliable protocol for calibration.

A major improvement of the system will be, in a near future, the ability to transmit the acquired data (and be controlled) in real time to (from) a ground-based control room. The current system does need a modest data bandwidth of the order of 350 bytes/s (downlink) and few bytes/s (uplink). This narrow band is currently available in at least two quite different technologies: the radio transmission (VHS at 450 MHz) and the satellite communication (such as Globalstar). The satellite transmission guarantees a large scale coverage but must rely on a private company which will route the data into Internet. On the other hand the VHS radio communication needs line-of-sight between the antennas and therefore, a second airplane, operating as transponder, may be required in case of rather inaccessible area (with complex orography). In both solutions, the data should reach the Operations Centre control room via a standard Internet connection.

Since the beginning of the project one objective was that the instrumentation should be, for weight and power consumption requirements, also compatible with its use on an unmanned air-vehicle (UAV). In emergency near field operations, near the plume release point, the level of in-plume radiation could be un-compatible with a monitor system operated by a man, whatever his function could be. UAV, moreover, can be managed in flight without any piloting skill, thus allowing system operations also to scientists and engineers more familiar with payload issues instead than aeronautics. Other advantages would derive from the possibility to perform automatic flight, which can be planned using user friendly graphical tools and a continuous position and altitude above ground control. Different flight patterns that maximize sampling efficiency can be prepared and executed. During automatic flight the operator can always resume UAV control in order to perform an unplanned and detailed sampling of suspect areas. It is worth mentioning that UAV are now becoming common tools in military and civil protection operations and at present national and international regulations are being modified in view of a more spread utilization.

In Fig. 9, the Archimede UAV in development by International Aviation Supply s.r.l. (Brindisi-Italy) is shown. It is derived from Sky Arrow design and, in principle, should be rather straightforward to transfer the design of the sampling line already used. Arrangements are already started to look more specifically to the problems that such a project could face.

**Figure 9** : Archimede UAV, the Sky Arrow unmanned version. A favourite candidate for an UAV version of the sampling system equipped aircraft

In conclusion, a first version of an aircraft equipped with a sampling line to be used for real-time measurements of in-plume $\gamma$ emitters has obtained the needed certification to fly, it is operative (Fig. 10) and a campaign of environmental measurements can now to start to study, among other items the operability and field behaviour of the system. This tool can result as a unique help during the plume phase of an accident to provide quantitative data on the nature and extension of the plume to computer decision support for nuclear emergency management.

**Figure 10 :** The Sky Arrow equipped with sampling line and real-time γ detectors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