# Experience at the Istituto Superiore di Sanità on Environmental Research and Monitoring with *In Situ* Techniques

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Technical Meeting on *In-situ* Methods for Characterization of Contaminated Sites
5 to 9 July 2010
Vienna, Austria

# Introduction

- Since the 80's the Istituto Superiore di Sanità has been using $\gamma$ spectroscopy to perform research particularly on *in situ* natural radioactivity ($^{238}U$ and $^{232}Th$ series and $^{40}K$ in soil and water, disequilibrium in the radioactive chains, etc) and radiological emergencies involving large areas (uncontrolled nuclear satellites re-enter in the atmosphere, Chernobyl accident)

- Afterwards, this technique was used to study contribution of natural radionuclides in building materials to the indoor radon, thoron and $\gamma$ dose rate. A method to estimate the radionuclide activity concentration in building materials and a procedure to evaluate gamma dose rate indoors from outdoor measurements were developed.

- At the mean time, in collaboration with Italian Gov Bodies and groups from Universities and Research Institutes, the SNIFFER aerial platform for radiological emergencies has been designed and developed. The platform is equipped with a peculiar air sampling unit and $\gamma$ detectors to perform a quantitative characterization of the atmospheric and ground radioactive contaminations.

# *In situ* gamma spectroscopy indoors

- Early investigations in 80's (Beck and coworkers).
- Other methods or developments as from 90's.
- At present, with different approaches (e.g. Monte Carlo, elaboration of spectra, computation + room model), the application of *in situ* gamma spectroscopy in indoor environment can be useful to
  - evaluate the gamma dose rate and the relative contribution of the various nuclides to determine it;
  - provide interesting information about building materials as radon, thoron and gamma ray source;
  - supply quantitative information about activity concentration of radionuclides in buildings materials
  - helps to estimate the indoor gamma dose rate from measurements on the external wall of a building (final elaboration in progress).

# A method to characterize building materials *in situ*

CHARACTERISTICS OF THE ROOM
- geometrical dimension of the room
- density of walls, floor and ceiling
- thickness of walls, floor and ceiling
- detector position

$\gamma$ DOSE RATE MEASUREMENTS

Reuter Stokes
or
plastic 3” x 3” scintillator

**$\gamma$ SPECTROMETRY *in situ***
**HPGe 26 % efficiency and**
**1.73 keV resolution**

Activity concentration ratios:
$C_{Ra}/C_{Ac}$ and $C_{Ra}/C_{Pb}$

Percentage contribution of $^{40}$K, $^{232}$Th and $^{226}$Ra to dose rate

ELABORATION WITH ROOM MODEL
$D_{RnDp}$, $D_{Th}$, $D_{K}$

**- ACTIVITY CONCENTRATIONS OF $^{40}$K, $^{232}$Th, $^{222}$RnDP AND $^{226}$Ra**

**- $^{222}$Rn EMANATION AND EXHALATION**

# Radionuclide activity concentrations
# Comparison between measured and estimated values in two test rooms

| Evaluation method | Test room 1 | | | Test room 2 | | |
|---|---|---|---|---|---|---|
| | $C_{Th-232}$ Bqkg$^{-1}$ | $C_{Ra-226}$ Bqkg$^{-1}$ | $C_{K-40}$ Bqkg$^{-1}$ | $C_{Th-232}$ Bqkg$^{-1}$ | $C_{Ra-226}$ Bqkg$^{-1}$ | $C_{K-40}$ Bqkg$^{-1}$ |
| **integrated method** | **190** | **110** | **890** | **350** | **260** | **2040** |
| **$\gamma$ spectrometry on sample*** | **187 ± 4** | **109 ± 2** | **956 ± 13** | **339 ± 8** | **254 ±14** | **2166±35** |

* concentration with total uncertainty (1 $\sigma$)

# Estimates of radionuclide activity concentrations in some dwellings

| dwell. | floor | building material | $C_{Rn\ dp}$ (Bq kg$^{-1}$) | $C_{Ac-228}$ (Bq kg$^{-1}$) | $C_{K-40}$ (Bq kg$^{-1}$) | $C_{Ra-226}$ (Bq kg$^{-1}$) | $\varepsilon$ | E (Bq m$^{-2}$ h$^{-1}$) | $C_{Rn\ exhal}$ (Bq m$^{-3}$) | $C_{Rn\ meas}$ (Bq m$^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5$^{th}$ | tuff | 152 | 327 | 1195 | 219 | 0.31 | 179 | 116 | 124 |
| 2 | 5$^{th}$ | tuff | 198 | 355 | 1603 | 269 | 0.26 | 196 | 89 | 135 |
| 3 | 5$^{th}$ | tuff | 219 | 445 | 1493 | 294 | 0.25 | 217 | 104 | 140 |
| 4 | ground | tuff | 144 | 313 | 885 | 204 | 0.29 | 254 | 161 | 338 |
| office | 1$^{st}$ | tuff | 166 | 299 | 1243 | 235 | 0.29 | 301 | 158 | 130 |
| 5 | 4$^{th}$ | concrete | 51 | 86 | 543 | 53 | 0.05 | 3 | 2 | 40 |
| 6 | 3$^{rd}$ | concrete | 117 | 210 | 917 | 137 | 0.15 | 33 | 15 | 58 |
| 7 | 4$^{th}$ | concrete | 86 | 170 | 665 | 105 | 0.18 | 30 | 21 | 86 |

# “IN-OUT” method

- The method utilises
  - gamma dose rate measurements on an external wall
  - a room-model requiring information on the geometry and structure of the dwelling
  - information about the radiation field obtained with *in situ* gamma spectroscopy
    - these data we already had for some dwellings in Rome and we could use them because spectroscopy parameters are fairly constant for the same kind of building material.
  - experimental data ($\gamma$ outdoors, $\gamma$ indoors, dwelling information) to validate the method obtained by questionnaires in SETIL study (etiology of childhood leukemia)
- Results :
  - evaluation of $^{226}$Ra, $^{222}$RnDP, $^{228}$AcDP and $^{40}$K activity concentrations of the building materials (an inverted use of the room model)
  - estimate of indoor gamma dose rate (application of room model + information about size and structure features of the rooms)
- Very useful in epidemiological studies where lack of exposure data for refusing or missing subjects can bias the survey results.

# Comparison between indoor dose rate, “IN-OUT” estimates and "simple" estimates – Preliminary results

| Region | External wall building materials | Dwellings | Estimated value “IN-OUT” / Measured value indoors | | | Measured value outdoors/ Measured value indoors | | |
|---|---|---|---|---|---|---|---|---|
| | | | Aritm. mean | Min–Max | S. D. | Aritm. mean | Min–Max | S. D. |
| Total | tuff/stone | 45 | 1.00 | 0.82–1.24 | 9% | 1.09 | 0.71–1.97 | 26% |
| | concrete/ briks | 46 | 1.05 | 0.79–1.32 | 12% | 1.07 | 0.64–2.44 | 33% |
| | all | 91 | **1.03** | **0.79–1.32** | **11%** | **1.08** | **0.64–2.44** | **30%** |

good accuracy and precision

# Evolution of “IN-OUT” method

- A more general, less site-dependent approach has been developed by assuming average values for many indoor parameters instead of using the detailed data from the questionnaires:
  - 212 dwellings (414 rooms) divided into two classes: tuff and concrete (data from Campania, Lazio and Piedmont).
  - Mean room dimensions – obtained by averaging the dimensions of all the rooms in each class –instead of the actual figures.
  - Mean number of main and partition walls – obtained by averaging the relevant information of all the rooms in each class .

# Evolution of “IN-OUT” method (cont.)

- for ceilings and floors adopted a different procedure for the two classes:
  - the actual values of concrete activity concentrations obtained by measuring the outdoor wall for each concrete dwelling
  - we used the mean values of concrete activity concentrations obtained by measuring outdoor walls for all tuff dwellings

- Determination of mean parameters to be used as input of the model were evaluated for each district to take into account the specific building features typical of three different geographic and meteorological area of Italy

# Summary of final results of the "IN-OUT" method

| Building material | No. of dwellings | Measured $\gamma$ dose rate ($nGy\ h^{-1}$) | | | | $\frac{\text{Outdoor value}}{\text{Indoor value}}$ | | $\frac{\textbf{IN-OUT estimate}}{\textbf{Indoor value}}$ | |
|---|---|---|---|---|---|---|---|---|---|
| | | Indoor | | Outdoor | | | | | |
| | | AM | SD | AM | SD | AM | COV | **AM** | **COV** |
| Tuff/stone | 67 | 204 | 49 | 220 | 80 | 1.08 | 28% | **1.0** | **17%** |
| Concrete/bricks | 145 | 113 | 52 | 122 | 72 | 0.85 | 37% | **0.99** | **21%** |
| All | 212 | 142 | 66 | 151 | 87 | 0.92 | 36% | **1.00** | **20%** |

# "IN-OUT" Conclusions

These results support the usefulness of the IN-OUT method to obtain an estimate of the indoor gamma dose rate in practical situations where detailed information on wall, ceiling and floor characteristics of selected dwellings is not available (epidemiological studies, urban surveys etc).

# The ISS aerial platform – Initial trigger

## 1978: A potential disaster

- Uncontrolled re-enter of the nuclear powered satellite Cosmos 954 with 30 kg of $^{235}U$
- Nuclear fuel scattered on an area of 120 000 km$^2$ (north-west Canada, red in map) fortunately with very low density of inhabitants
- Gamma spectrometers used for geological prospecting used on aerial platforms
- After 4 months of missions, only few percent of radioactive material recovered


From 1965 to 1988 at least 37 satellites of the Cosmos class with nuclear reactor were launched. 8 of them re-entered in atmosphere

# 1983: ISS – Fire Brigades collaboration

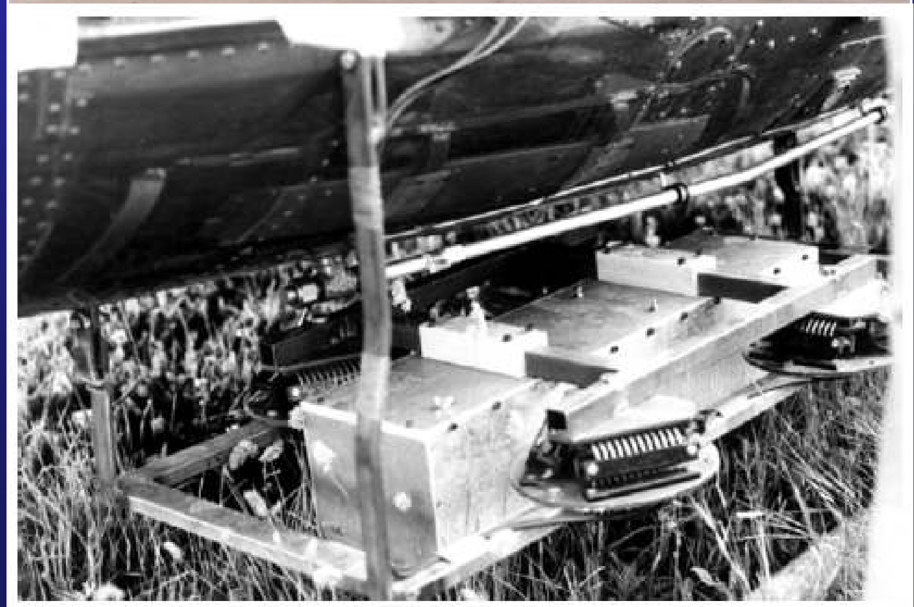
- To promptly respond to potential radiological accidents on large areas, the collaboration carried on a program on radioactivity monitoring from aerial platform:
  - Define the optimal equipments to face contingencies such as uncontrolled re-enter of satellites with radioisotopes on board

- Three situations were analyzed:
  1. Search and localization of radioactiveof orphan or lost sources or scattered on large areas
  2. Measurements of ground radioactive contamination on vast surfaces
  3. Quantitative sampling in radioactive cloud

# 1985: First Prototype based on helicopter

- The first solution based on NaI(TI) large crystal (16”x4”x4”)with electronic system hosted on board of an Agusta-Bell 412 helicopter of the Fire Brigades

- Detector mounted in the dumped (anti-shock and antivibrating) mechanical support outside the helicopter fuselage



# 1985: Prototype characterization

- Tests and measurements were performed by the Fire Brigades with the support of ISS
- Localization of $^{137}Cs$ source of ~ 3.7E10 Bq on 10x10 km$^2$
- Evaluation of sensitivity of the equipment (in “ideal” conditions) as a function of altitude (and speed)

$S = \exp(0.0475\ h + 6.341)$ with $S$ in Bq/m$^2$ and $h$ in m

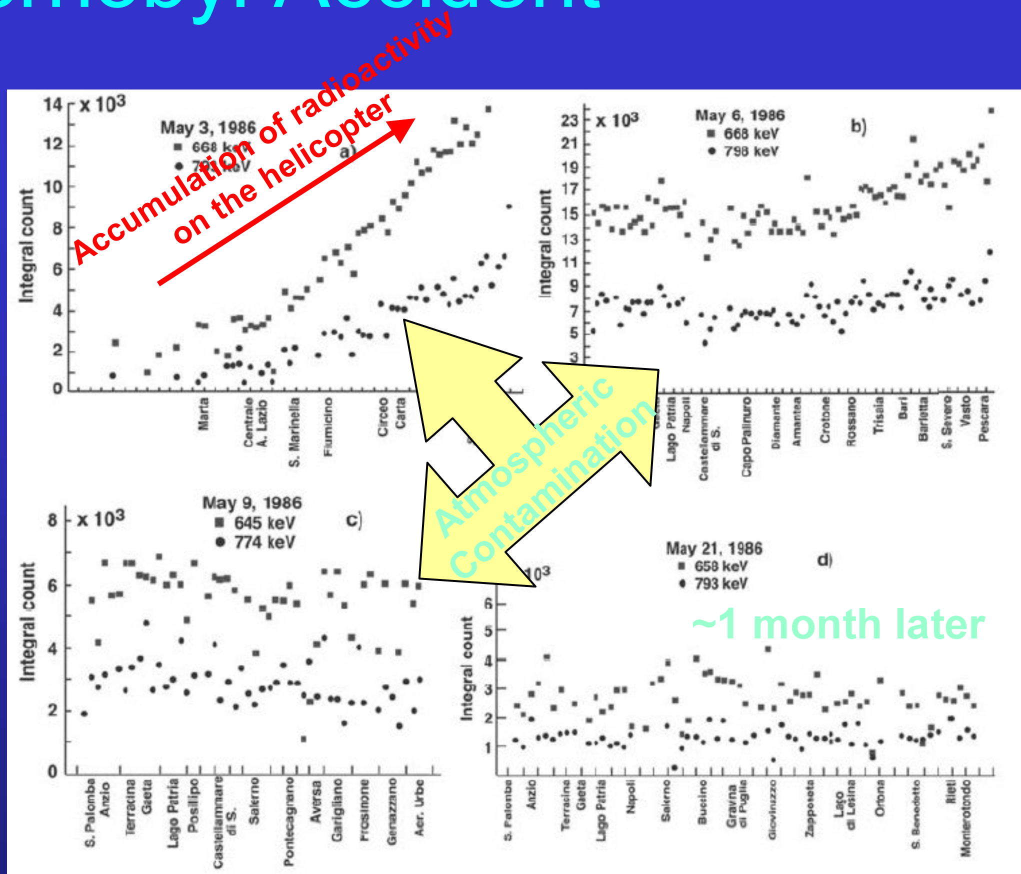
- Major limitation:

$$\text{Counts} = A_{ground} + A_{air} + A_{plane}$$

In presence of $\mathbf{A_{air}}$ (and consequently $\mathbf{A_{plane}}$ **-** induced contamination on airplane fuselage), Counts is not related only to the ground radioactivity $\mathbf{A_{ground}}$

# 1986: Chernobyl Accident

- The prototype system was used to survey the center-south of Italy
- Measurement at 100 m and 70 knots (110 km/h)
- NaI(Tl) spectra acquired every 2 minutes (4 km)
- Evident effects of atmospheric contamination made quantitative estimation of the ground contamination impossible
- Only semi-quantitative measurements during the most critical phase




**⇒ Need for a quantitative sampling of aerial particulate (aerosol)**

# 1988: Civil Protection program

New program devoted to:

– Fire Brigades: implementation in very short time of a “sub-optimal” but operative system based on the previous prototype

– ISS: feasibility study of the optimal system for aerosol sampling and radiological ($\gamma$-emitters) characterization

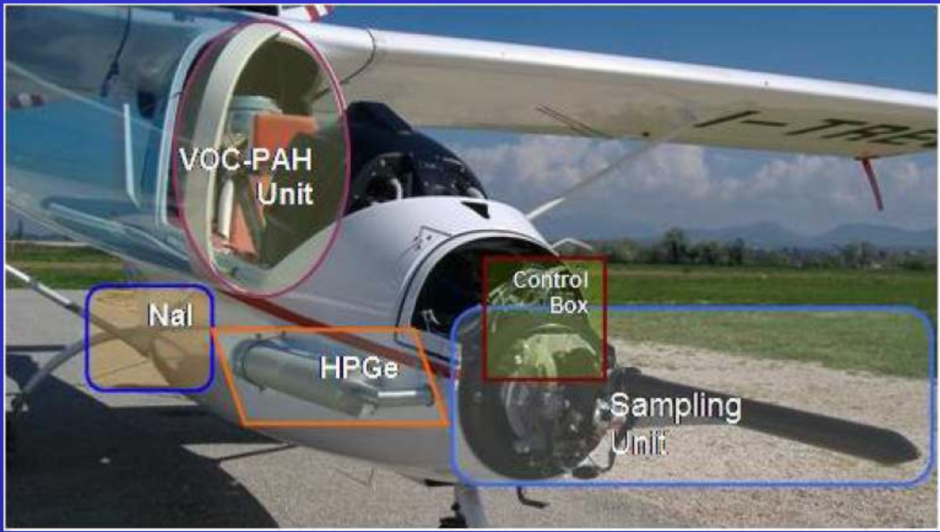

**ISS-SNIFFER system**

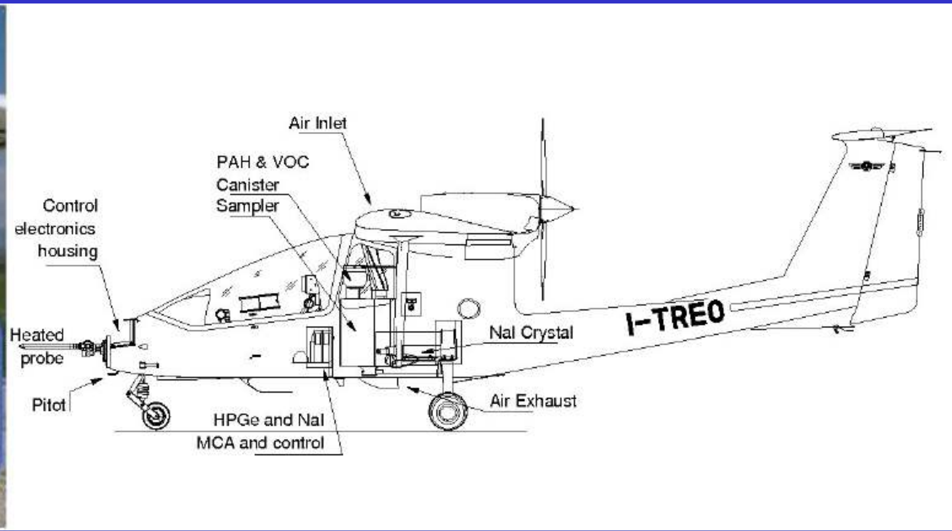
# SNIFFER system

- Measure and characterize atmospheric and ground contaminations
- Aerosol sampling for transportation generated VOC and PAH monitoring


Aerial Platform Sky Arrow by 3I (light aircraft)
- Fixed wing with back propeller
- Short Take Off and Landing
- Operate from few hundreds meters to few km
- Speed: 60-90 knot (110-170 km $h^{-1}$)
- Reconfigurable for unmanned operation

# SNIFFER-payload: components

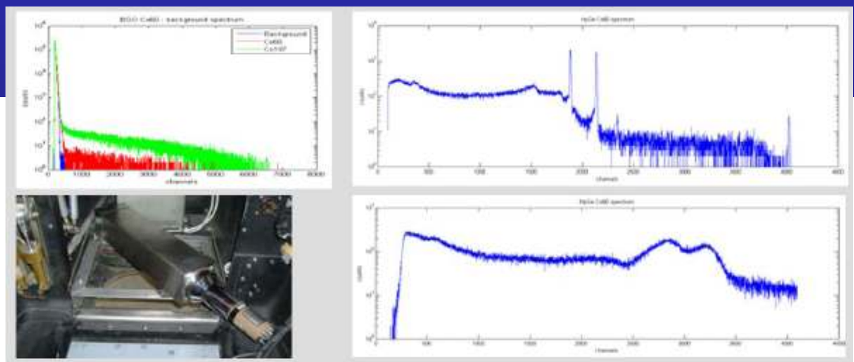


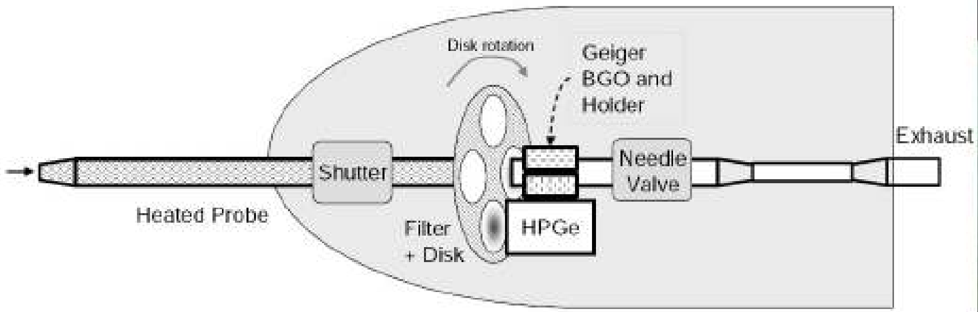



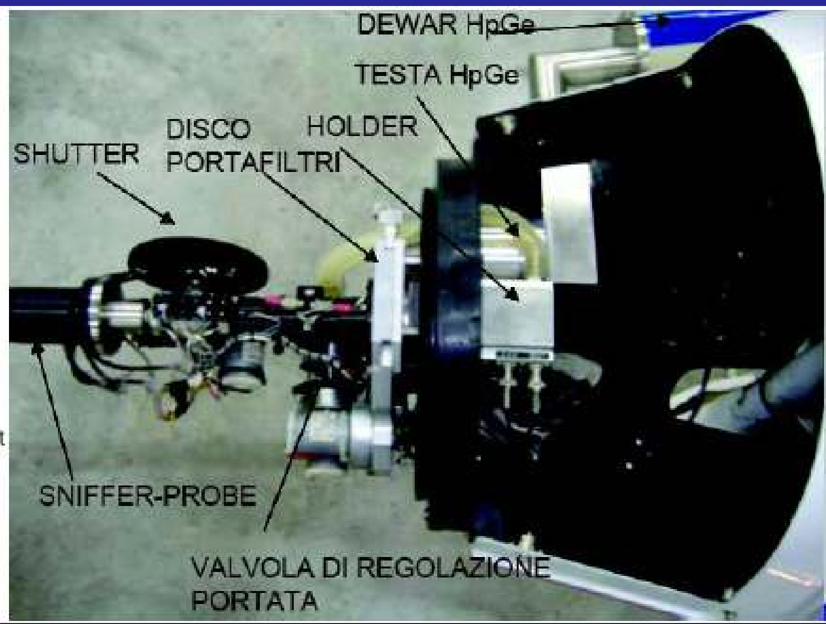

- Sampling unit in isokinetic condition (laminar flux)
- Nuclear Instrumentation:
  - BGO, Geiger, HPGe for aerosol characterization
  - NaI(Tl), for atmospheric and ground radioactivity measurement
- VOC and PAH sampling system
- Environmental Parameters (temperature, pressure, air flow, GPS-location) devices
- Control and acquisition system

# SNIFFER: Isokinetic Sampling Unit

- Aerosol flows along the front nose and is sampled on one out of 4 Teflon filters
- A remotely controlled needle valve is operated to keep the isokinetic condition by the control system
- $\beta$ and $\gamma$ small detectors face the sampling filter
- HPGe high energy resolution on the last sampled filter

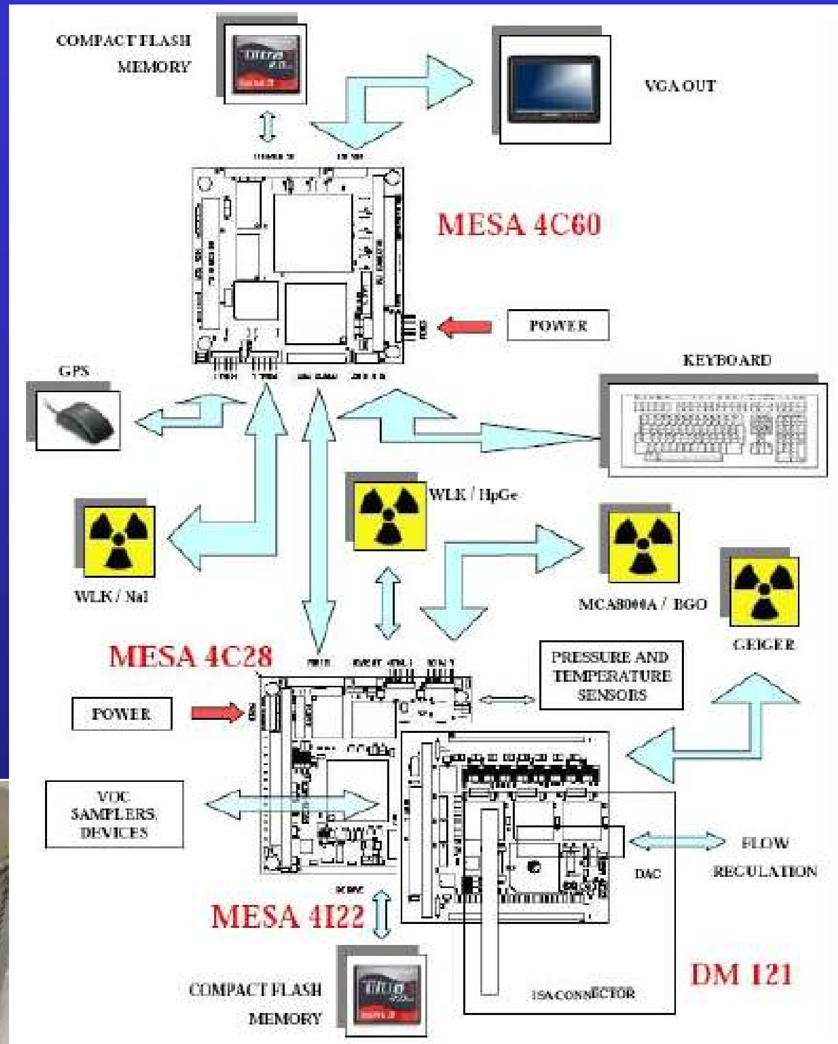




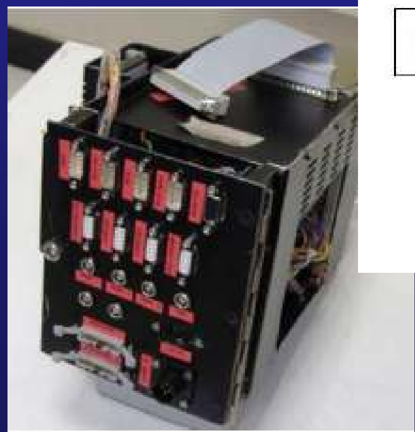



# SNIFFER: Control System

- Sophisticated custom system for automated control of all subcomponents and SNIFFER functionalities
- $\mu$P on 104 standard cards
- Acquired data on 2 redundant flash memories
- ~ 10000 lines of code







# SNIFFER: (possible) Future development

- Jukebox like filter holder (to have more that 4 samples)
- Air-ground real-time transmission to get online acquired data and re-program mission on need
- Adapt for unmanned aerial vehicle (almost straightforward)

**SNIFFER web site:**

http//www.iss.infn.it/webg3/g3iss/aereo/