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new tool that can be used by the scientific community for environmental studies. During preliminary tests and measurements, some relevant scientific results have been obtained in the field of environmental radioactive pollution and of large scale transport phenomena of radioactive pollutants.

The instrument can still be improved, especially for what concerns weight reduction. A possibility could be the use of a data-logger, instead of the portable computer at present used. Furthermore, in order to be utilised for systematic measurements during glacial drillings, the instrument could be improved with a well suited displacement system to move along the bore-holes. Concerning glacial drillings it has not yet been possible to test the instrument at very low temperatures (about –50˚C) like the ones present in drillings in Antarctica.

The GEDI detector is included in the developing field of portable instruments essential for *in situ* measurements in mountain regions and in remote areas[23)]. Since these regions are the most suited to study the global change phenomenon -that is the climate and environment large scale transformation due to natural causes and to human actions - this kind of measurements is becoming more and more important.

Technical and scientific results of the GEDI experiment allow the formulation of new national and international research proposals, in the field of the nuclear physics technologies applied to Earth and environmental sciences.

5 – ACKNOWLEDGEMENTS

We would like to thank Prof. Claudio Smiraglia (Dipartimento di Scienze della Terra dell'Università di Milano), who introduced us in the wonderful world of field glaciology, for his constant attention to our work and results, Dr. Massimo Pecci (ISPESL-DIPIA) for his collaboration and fundamental contribution during the measurements and tests performed in Appennini and Himalaya. We also thank very much Dr. Valter Maggi (Dipartimento di Scienze Ambientali, Università di Milano "La Bicocca") who gave us the possibility to perform measurements on the Lys glacier, with the essential help of his team.

The scientific and mountaineering expedition "Roma 8000", during which the very high altitude measurements were realised, was supported and partially funded by the Comitato Ev-K2-Cnr, the Banca Sella and by ACEA.

A special thank for their support goes to Agostino Da Polenza and Piero Badaloni.

R1: Near the summit of a peak, quoted, 6400 m a.s.l., located at the northern side of the Cho-Oyu normal route advanced base camp.

R2: Near the Nangpa-la Pass (28°06'52" latitude N, 86°35'39" longitude E, altitude: 5705 m a.s.l.).

Fig. 11 shows the measured spectra in the above sites, in the ^{137}Cs gamma-ray energy region. The spectrum relative to site R1 shows a strong signal at an energy corresponding to the ^{137}Cs gamma emission.

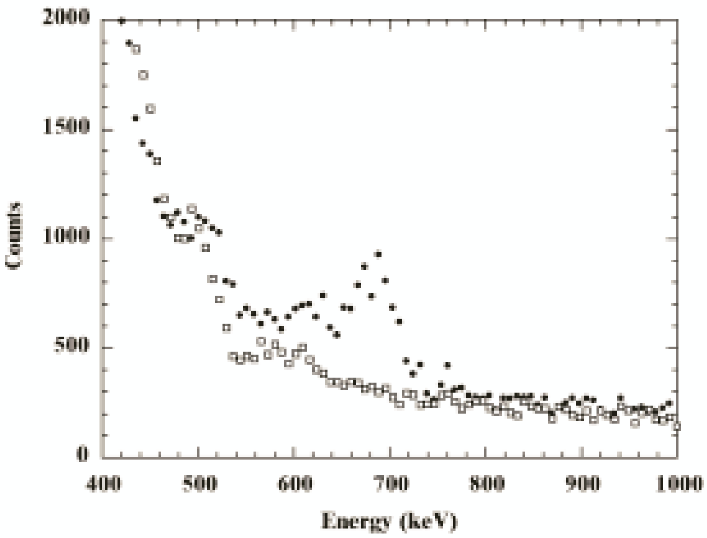

Figure 11 *– Radioactivity measurements performed in situ in the snow in site R1 (black dots) and in site R2 (white squares). Acquisition time = 3600 s. The site R1 spectra shows a strong signal at the Cs-137 gamma decay energy (662 keV).*

In the spectrum relative to site R2 this signal is absent, or comparable with the background mainly due to the cosmic rays. The strong broadening of the Cs peak towards low energy is probably due to the Compton scattering in the snow, as confirmed by our calculations taking into account the mean free path of the Cs γ-ray in the snow and the geometry of the detector.

It is difficult, at the moment, on the basis of our data, to explain the difference in the Caesium contents in the snow of the two sites and what is the origin of the Caesium contamination. The effect can be probably linked to the change in monsoon circulation happened during the days in which the measurements were performed. It is well known that the snow chemistry over the Tibetan plateau is dominated by desert dust from the vast arid regions of central Asia[19-22)]. This should be the case for the snow on the northern side of the Himalaya chain, carried by northern winds, that is the kind of snow where the measurement R1 was performed.

In any case this contamination can be attributed only to large scale diffusion and circulation processes. This suggests that it could be worth-while to make a deeper study of the distribution of radioactive contaminants in this area – and, in general, in all the Himalayan range – to understand the processes of diffusion and to locate the contamination sources.

4 – CONCLUSIONS AND PROSPECTS

The apparatus realised, in the framework of the GEDI experiment, to perform *in situ* γ-spectrometry on glaciers and snowfields, has shown its functionality and efficiency. Now it is a

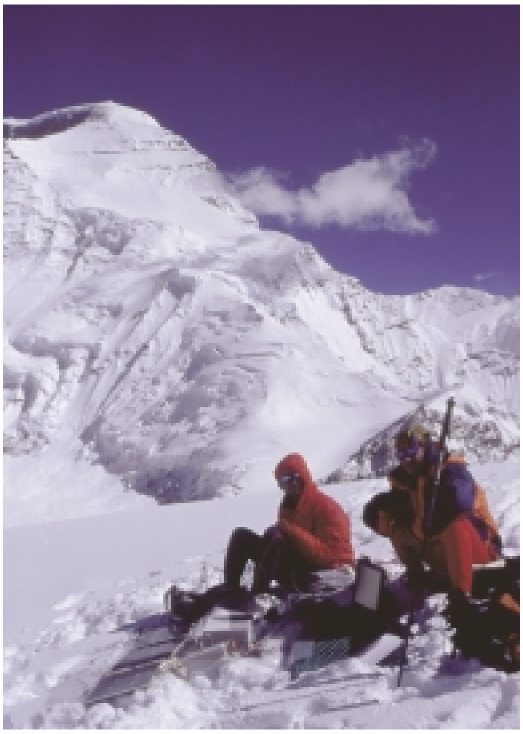

Figure 9 *– During radioactivity measurements at 6400 m a.s.l. on the western side of the Mt. Cho-Oyu (8201 m asl, visible on the back).*

The measurements where performed during the scientific and mountaineering expedition "Rome 8000" directed to the Cho-Oyu mountain (8201m a.s.l.), the sixth highest peak of the Earth. The purpose of the expedition was to perform, for the first time, glaciologic, geomorphologic and environment analyses of the Gyabrag glacier region on the northern side of the Himalaya range[16] and compare them with previous measurements performed on the southern side of Himalaya, in the Everest region[17].

In-situ radioactivity measurements in the snow were carried out in two different sites (shown in Fig. 10):

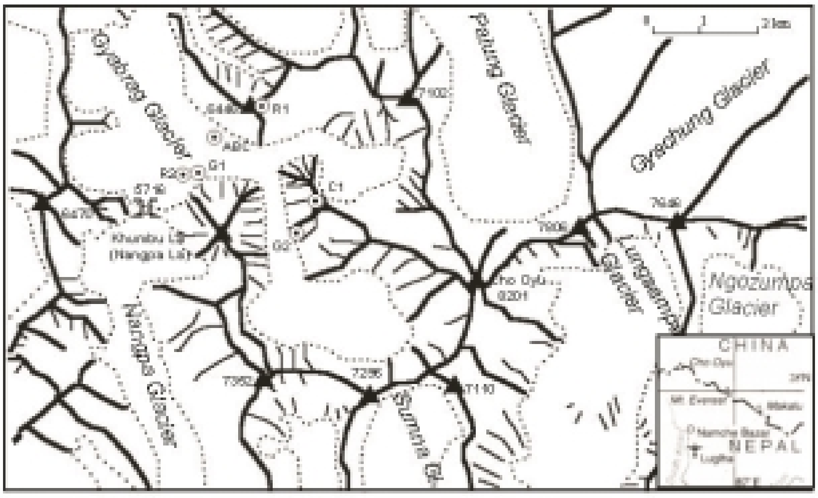

Figure 10 *– Map of the Cho-Oyu-Himalaya region and location of measurement points R1 and R2. Others main points are also reported (ABC: advanced base camp, C1: Camp 1, G1 and G2: snow sampling points for chemical analysis)*[18].

The origin of this contamination, related to a specific snow layer, is not easy to explain also if it can be ascribed to a residual environmental contamination due nuclear accident occurred at Chernobyl in 1986.

Recent studies have demonstrated that some sites were the ^{137}Cs concentration is not negligible are still present on the Alps[13)]. These concentrations, in some cases, also if time went on, grow due to melting and re-packing of snow layers. Since it is not possible to exclude that this phenomenon is happening also in some very localised places on the Appennini mountains, it would be convenient to monitor snow continuously, especially if the implications concerning water sources contamination are taken into account.

The big number of tests performed at the Gran Sasso d'Italia, gave us the possibility to optimise all the detection system, especially for what concerns the power supply using the solar panels which has shown to be extremely useful and reliable.

3.2 – Alps

The Lys glacier (Monte Rosa, Alps) is one of the few alpine glaciers suited for climatic and anthropogenic studies. During spring 1996 a 80 m deep ice core was drilled on this glacier at Colle del Lys (4240 m a.s.l.) showing, among other results, the presence of tritium, linked to the radioactive fallout of the year 1963[14)].

In June 2000 a second glacial perforation was performed at the same location and our instrument has been inserted for the first time in a glacial bore hole. The purpose was to find *in situ* by detecting the gamma emission of the ^{137}Cs contaminant the layers related to the 1963 nuclear fallout and to the 1986 Chernobyl accident, already detected in the past analysis of alpine ice cores in laboratory[15)], (Fig. 8).

The detector worked well up to a depth of about 25 m in the ice at an average temperature of –10°C. But unforeseen technical problems during the drilling prevented to reach the interesting 1986 Chernobyl ice layer that, according to the mean annual snow deposition rate previously measured, should be located at a depth of about 30 m.

Despite of the experimental result, this test showed the possibility to utilise our instrument in the high altitude and low temperature conditions of a glacial perforation.

***Figure 8** – During the measurements on the Lys glacier (Monte Rosa, Alps, Italy).*

3.3 – Himalaya

In september-october 2000, the instrument has been used, for the first time, in a very high altitude site on the northern slopes of the Himalaya chain (Fig. 9).

Figure 6 – *The GEDI group on the Calderone glacier (Gran Sasso d'Italia, Appennini, Italy) during tests of the GEDI experiment.*

Studying different snow layers able to give information on the concentration of pollutants related to different precipitation also many γ-ray spectra have been taken. The energy calibration of the detector is controlled at the beginning and at the end of each series of spectra using the characteristic γ -emission lines of a ^{60}Co source that are at 1173 keV and 1332 keV.

During a series of *in situ* measurements done in June 1999, the presence of a peak attributable to the γ -emission at 662 keV of ^{137}Cs was found (Fig.7).

In a new measurement performed in laboratory, on a snow sample taken from the same snow layer, using a HPGe (high purity Germanium) solid state detector having also better energy resolution, the presence of this contribution was confirmed.

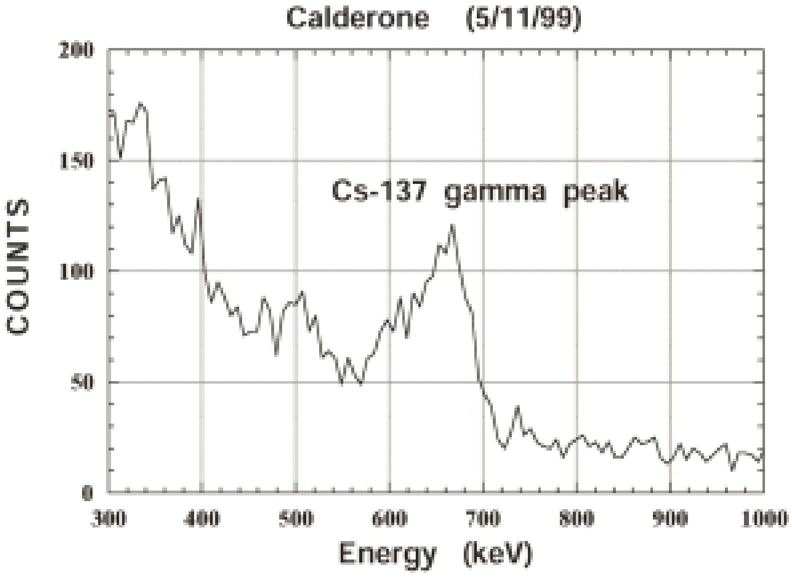

***Figure 7** – The ^{137}Cs peak measured "in-situ" on the Calderone glacier.*

This result is very important. It shows that the realised detector system is able to perform *in situ* detection of ^{137}Cs and it is the first ^{137}Cs measurement performed on the most southern glacier in Europe[12)].

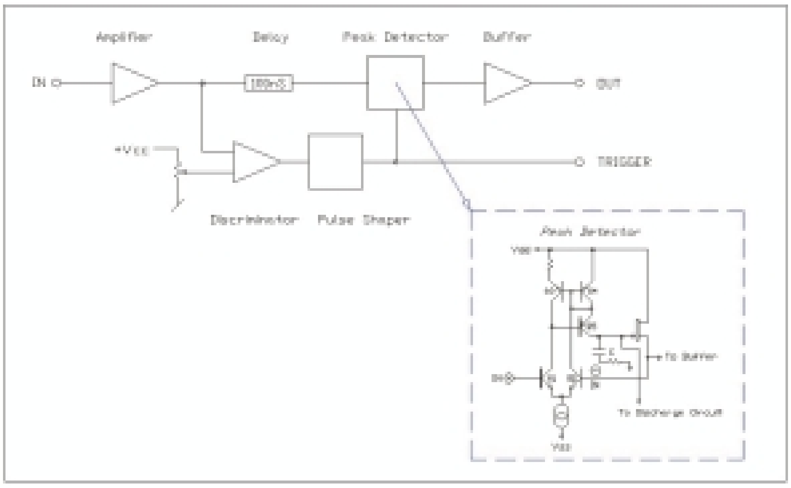

Figure 5 – *Peak detector circuit: general scheme and detail.*

The input signal is impedance matched, amplified and split up in two parts. The first one is sent to a discriminator to achieve a trigger signal of 20µs, the second is sent, through a 100 ns delay line, to the effective peak detector circuit shown in the amplified detail of fig. 5.

The output signal from the detector enters the positive input of the differential amplifier. The differential amplifier acts a high impedance Wilson's current mirror, that loads the capacitor C until the voltage on the negative input of the differential amplifier equals the positive input, thereafter the current mirror is turned off.

The capacitor remains loaded until the gate is on. At the end of the gate signal a 1µs wide pulse is generated. This pulse, through a current generator, discharges the capacitor C. (This operation is needed because if the capacitor is discharged too quickly, and with high discharge current, it can retain a residual charge that can interfere with the next charge).

The whole circuit includes many planning skills and will be described in detail in a future publication[11)].

The signals from the detector are processed by means of a LabVIEW software, able to reproduce a standard multichannel analyser system.

2.4 – Power Supply

All the electric elements of the detection apparatus are supplied by a system made up of a Dryfit lead gel battery (12V, 6.5 Ah) and silicon solar cells having an efficiency of about 15%. The solar cells are made from small panels having a surface of about 30 x 30 cm, realised by the SARED company, each of them able to supply a maximum power of 14 W (5.5 V and about 3 A). Two groups of panels, each one constituted by three panels connected in series, were used in parallel connection to achieve about 16V. The cells are connected to the storage battery and provide to its charging through a suited circuit. The whole system can provide a total power of about 85W which is enough to supply the detector, the resistive heaters and the portable computer.

3 – TESTS AND EXPERIMENTAL RESULTS

3.1 – Appennini

Preliminary tests of the detection system have been performed on the Calderone Glacier (Gran Sasso d'Italia Mountain - Appennini) at a height of about 2700 m a.s.l. (Fig. 6).

were attached to the case of the detector. The heaters could dissipate a maximum power of about 40 W and were controlled with a thermostat set to operate at a fixed temperature (usually 25°C).

A dedicated pulse generator circuit, shown in Fig. 4, has been built to manage the control of the temperature with negligible power dissipation in the circuit itself.

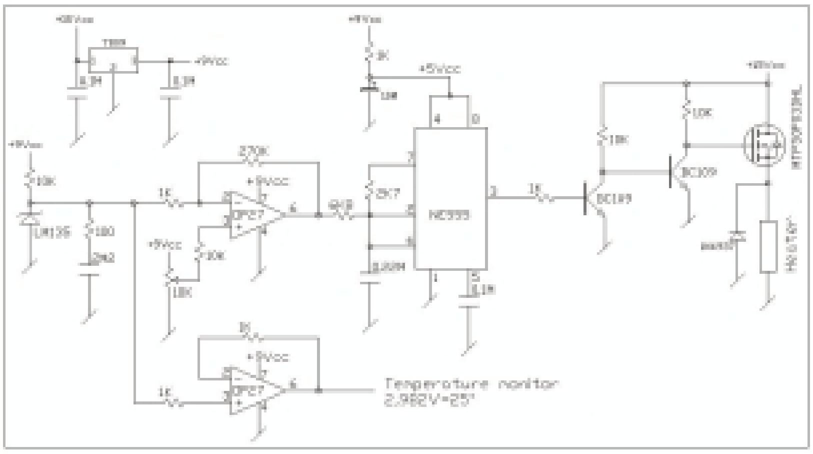

Figure 4 – *Electronic scheme of the circuit for the control of the temperature.*

The functioning of the circuit is based on difference between the voltage at the output of the thermal probe, that is set in contact with the detector, and a stabilised reference voltage chosen as a function of the temperature set as working condition for the detector.

A signal proportional to this difference is amplified and sent in a circuit which controls the charging and discharging of the condenser of a square wave generator.

The output of the generator controls a MOSFET, which acts as the on/off switch of the power supply of the heaters that wind the detector. When the temperature is 0.2 ˚C lower than the reference temperature the switch is on (power supply on), when it is 0.2 ˚C higher the switch is off (power supply off).

When the temperature is at an intermediate value, the oscillation period of the generator varies as a function of temperature. This kind of functioning and the use of a MOSFET give the possibility to reduce the thermal dispersion of this circuit.

2.3 – Data Acquisition System

Data acquisition is performed by using a Panasonic Toughbook CF27 portable computer. The computer is protected against water, dust and mechanical shocks and can work at temperatures down to –10 ˚C. A National Instruments DAQ Card (6062E) allows the input of signals from the detector.

Since the output signals of the detector are low and very narrow (~200-300 ns), and are not well matched with the input requirements of the ADC card utilised, a dedicated peak detector circuit was realised. Fig. 5 shows the circuit scheme.

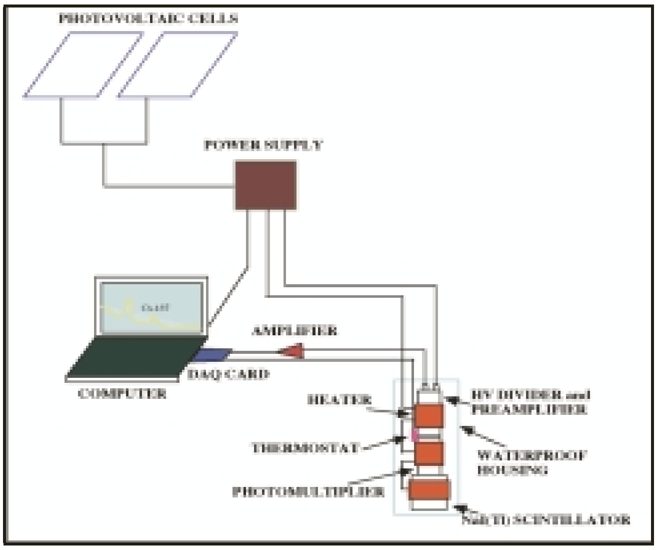

FIGURE 3 – *General scheme of the detection system.*

2.1 – Detector

The γ-ray detector chosen is a cylindrical thallium-activated sodium iodide (NaI(Tl)) scintillator, 7.6 cm in diameter, and 10.15 cm thick. The dimensions were chosen taking into account the diameter of the bore-holes drilled on glaciers (about 4 inches) and a reasonable compromise between weight and geometrical efficiency. The scintillator crystal was optically coupled to a photomultiplier tube and both were enclosed, with a voltage divider, a high voltage power supply and a preamplifier, in a waterproof stainless steel case. This solution produces a strongly integrated and easy to handle device. The whole unit was realised under our specifications from Crismatec company.

The energy resolution of the detector, measured in laboratory, was found to be $\Delta E/E=7.4\%$ at 662 keV. (ΔE is the full width half maximum (FWHM) of the photopeak). This resolution is enough to discriminate among the main artificial radionuclides emitting gamma radiation (Table 1).

TABLE 1: *Main γ-emitters fission products from thermonuclear reactions*

Fission products	Gamma-energy (keV)	Half-life
^{95}Nb	765	35 d
^{95}Zr	756-724	64 d
^{144}Ce	133	285 d
^{106}Ru	511	372 d
^{125}Sb	428	2.8 y
^{137}Cs	662	30.17 y

For mechanical protection, the detector unit, including resistive heaters and the electronics for the control of the temperature (see next paragraph), was encased in a cylinder of acrylic resin made from Delryn pipe.

2.2 – Temperature control

The detector can be, in principle, exposed to temperature as low as –50°C. Since NaI(Tl) is sensitive to thermal shocks and its output signal depends on temperature, resistive heaters

1.2 – Environmental Radioactivity

Among others elemental and chemical pollutants, radioactive debris from tests of nuclear weapons and from nuclear accidents – like Chernobyl – have been and are still being deposited in the environment, including glaciers and snowfields[5)]. It is well known that these debris can be used as time and depth markers to determine the subsequent accumulation of snow and the rate of snow deposition which is an important quantity for glaciological and climatological studies[6,7)]. In some cases the concentration of radionuclides can be correlated with environmental parameters to study transport and circulation phenomena in the atmosphere [see ref. 8 and ref.s therein]

Some dedicated instruments have been realised in the past to carry out *in situ* radioactivity measurements. This can be very useful when sampling is difficult or impossible and when it is necessary to locate quickly a place or a depth for a subsequent sampling.

A significant fraction of the fall-out radioactivity from bombs and Chernobyl consisted of ^{90}Sr (half-life = 28.8 years) and ^{137}Cs (half-life = 30.2 years). However only ^{137}Cs, which emits 662 keV γ-rays can be easily detected and discriminated *in situ* from others radionuclides by a variety of suited detectors.

In 1981, Pinglot and Pourchet[9)] proposed a method to measure *in situ* radioactive fallout monitoring the γ emission at 662 keV of ^{137}Cs, by using a NaI(Tl) scintillator detector coupled with a photomultiplier tube and a multichannel analyser. Their measurements showed that the gamma activity can be detected *in situ* and is strongly correlated with the radioactivity measured in samples. The limit of their system was the portability, being the weight of the whole detector system of about 250 kg !

In 1994, Dunphy, Dibb and Chupp[10)] realised a lighter system based on a NaI(Tl) scintillator detector computer controlled. Their measurements were done in Greenland near a permanent base by using a standard AC power source which is not usually available - or portable - in some remote areas, like high altitude glaciers.

For this reason we have realised for the first time a completely portable instrument that can be easily carried and handled by a small team without any external support and is able to work in very harsh environmental conditions.

2 – GAMMA-RAY DETECTOR SYSTEM

The realised system, shown in Fig. 3, must satisfy the following requirements:

1. Good efficiency in the ^{137}Cs emission region.
2. Low temperature working conditions.
3. Low power consumption.
4. Portability (including power supply).
5. Work in wet conditions and resistance to mechanical shocks.

In the following paragraphs the instrument is described in detail.

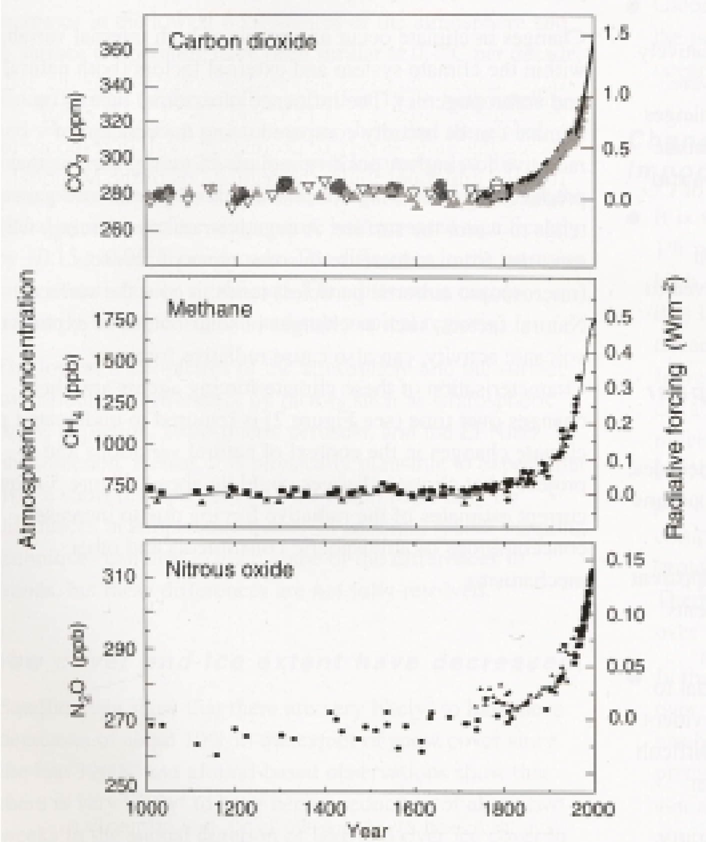

***Figure 2** – Global atmospheric concentration of three well mixed greenhouse gases showing the human influence on the atmosphere during the Industrial Era. Data coming from several sites in Antarctica and Greenland, and from direct atmospheric samples are shown by different symbols. (for more details see ref. 1, p.36).*

The “cold” glaciers, the ones where the effects of percolation due to melting are absent or very small, with the opportune morphology – saddles or ice-caps - are the most accurate archives of climate and terrestrial atmosphere conditions.

Glaciers of this specific kind are the biggest part of glaciers in Antarctica and Greenland and also a part of glaciers located in the main mountain regions, at altitudes depending on different factors among which first of all the latitude.

The information which can be achieved, nowadays[2)], from the analysis of ice-cores taken from the very deep drilling at the Antarctic station Dome-C, will cover the period that runs over the past 500.000 years bp (before present). The data achieved up to now by the drilling at the Vostok station, in East Antarctica have allowed a detailed reconstruction of the primary climatic, atmospheric and environmental parameters during the past 420.000 years bp[3)].

If glaciers are very accurate archives of information related to the past, snow is a precious spatial archive of the conditions of the terrestrial atmosphere. Snow that falls down in winter seasons is the archive of a big amount of information on the relative chemical and physical contents of the annual precipitation. Its analysis, on a sufficiently wide spatial scale and at different heights, can give a significant contribution in the understanding of transport and diffusion phenomena of chemical elements and compounds of human origin on a wide scale[4)]. The analysis of pollutants, present in snow and ice, is, on the other hand, very important from a hydrologic point of view especially when the water sources are snow and ice.

1 – INTRODUCTION

1.1 – Scientific framework

In the last few years, great attention has been given by governments and public opinion to changes in the environment, in particular the ones related to pollution and to climate changes on local and global scale, due to the consequences that these can have on the future of all Earth inhabitants. For this reason, these changes and their possible implications are nowadays being studied by a huge international scientific community.

It is quite sure that climate on Earth is changing as clearly reported also in the ultimate scientific report of the Intergovernamental Panel on Climate Change[1)].An increasing body of observations gives a collective picture of a warming world, showing a generalised increase of the global average surface temperature (Fig. 1) also if it is not yet possible to determine the exact amount of its growth in the future.

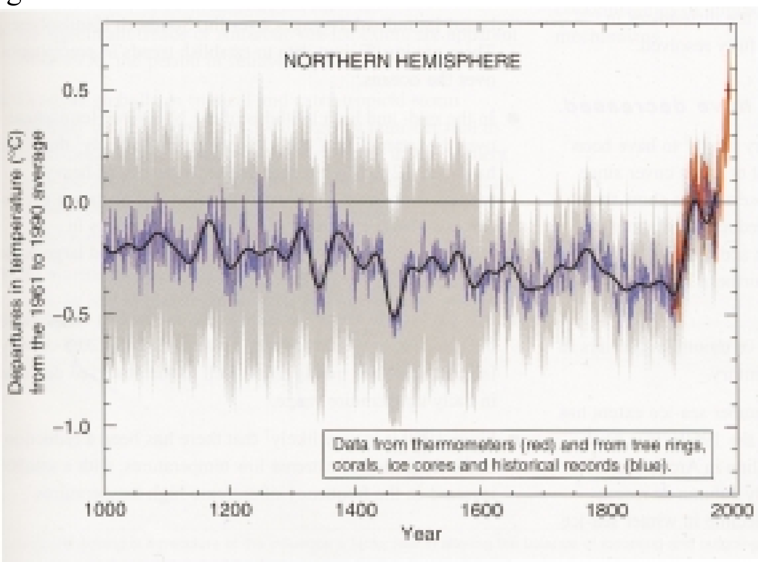

Figure 1 *– Year by year (blu curve) and 50 year average (black curve) variations of the average surface temperature of the Northern Hemisphere for the past 1000 years (from ref.1).*

Furthermore, actually it is not possible to determine exactly which is the effect of human influence on these changes, although many studies[1)] show that human activities (Fig. 2) continue to alter the atmosphere in ways that are expected to affect the climate.

In order to study these processes, it is necessary to acquire as much as possible data on the past climate and on the past chemical-physical composition of the atmosphere, to increase the precision of the mathematical prediction models and to understand the complex mechanisms that are at the basis of the climate change. It is also necessary to achieve information on the atmospheric transport and diffusion of elements and compounds of human origin.

The Cryosphere, the "frozen" ecosystem which includes ice, snow and permafrost[*], is very sensitive to the climate and environmental changes and so it is one of the most suited for their study.

[*] Permafrost is defined on the basis of temperature, as soil or rock that remains below 0°C throughout the year, and forms when the ground cools sufficiently in winter to produce a frozen layer that persists throughout the following summer.

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ENVIRONMENT AND NUCLEAR PHYSICS: THE GEDI EXPERIMENT

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Abstract

The aim of GEDI (Gamma Emission in Deep Ice) experiment[1] was the realisation of a portable γ-ray spectrometer for *in situ* radioactivity measurements on glaciers and snowfields. This kind of measurements is very useful in a wide set of environmental studies, in particular during glacial drillings for ice core studies and in pollution monitoring in high altitude or in remote areas, were sampling is difficult or impossible. In this paper the instrument realised and its performances on the field are described in detail.

The results of the first measurements performed on the Appennini and Himalaya range, showing the presence in the snow of small amounts of the artificial radioisotope ^{137}Cs, are also reported and discussed.

PACS: 92.40.Rm; 92.40.Sn; 92.40.Vq; 29.30.Kv; 29.40.Mc

[1] The GEDI experiment was founded by INFN Group V.