Demonstration of equipment: Ultra sensitive sea water radioactivity monitoring system autonomous low power consumption equipped with wireless data communication

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1. HISTORICAL BACKGROUND

Since the beginning of the 60's, the very first nuclear facilities were applying a full environmental monitoring survey program: water, air, releases, ...

At that time, very few on-line measurements were carried out because of the technical limitation. Sampling and later laboratory analysis was of common practice. Only stacks, fences and liquid storage pools were equipped with a continuous monitoring system. Only alarm signals were transmitted remotely.

In 1975: the National Institute for Radioelements (I.R.E.) had a new challenge: prove permanently to the authorities that the environmental impact of the institute was negligible. It was the beginning of a new era: the nuclear industry started to be criticised, new telecommunication and computer technologies were emerging. At the same time, radiation detectors reached a sufficient level of performance and reliability. The scientific community could benefit from this evolution.

Since 1982, I.R.E became a pioneer when it sets-up automatic intelligent monitoring network with an availability better than 99.9% and able to give alarm and to be operated remotely. They were installed in the neighbourhood of Fleurus, Tihange and Chooz and were able to measure continuously the radioactivity in air and river water. They were coupled to a sampler where water was collected on a weekly basis to be able to detect short-lived radioisotopes like ^{131}I, ^{99m}Tc or β -emitters.

20 measuring points were installed (15 air and 5 water); they are still in operation with availability of 99.9%. The air probes measured the radioactive irradiation around the nuclear sites or at the fences; the river was monitored by NaI detectors (2" x 2") connected to a Single Channel Analyser. The principle of those was based on the overflow-shielded tub. They may be also based on the principle of the diving probe – without pump - more reliable. The use of SCA has the disadvantage that isotope identification is almost impossible and that the energy calibration is difficult.

Operation of the continuous monitoring of rivers has revealed several unexpected aspects of the radioactivity of water, such as effects related to Rn and its progeny during thunderstorms: alarms due to the increase of radioactivity, difficult to confirm, to understand and to manage. Routine releases from hospitals – ^{99m}Tc and ^{131}I – more easily to detect than the releases coming from the nuclear facilities.

Finally, it's important to underline that those networks were operational before the Chernobyl accident and that their interest for the Authorities was at that time very limited. After the accident, the probes sensitivity, reliability and interest was recognised and the concept was adopted.

During the 90's, I.R.E. developed a new philosophy of radioactivity measuring networks for river water based on the use of MCA.

This was a major improvement because in case of alarm it was possible to check the spectrum and to identify its origin. Moreover, the energy calibration was easily controlled and if needed, could be adjusted. Nevertheless, it was not yet gamma spectrometry as performed in laboratory.

This new improvement allowed shifting from public health levels to radioecological levels.

2. NEW DEVELOPMENTS IN THE FIELD OF WATER MONITORNG

2.1. Introduction

Following the recognition of their usefulness by the States and the scientific community, the automatic water monitoring networks were developed again to be able to measure seawater. For that purpose they had to be fully autonomous, low power consumption (solar panels power supply), wireless communicating (satellite, GSM, Radio) and very sensitive (few Bq/m^3).

It's important to note that radioactivity detection in sea has many constraints:

- The detection system sensitivity must be very high because of the dilution factor of the ocean. The analysis method has to be adapted: the detection of very low level of artificial Contamination is made difficult because of the natural radioactivity in seawater (i.e. more than 10 kBq of $^{40}K/m^3$).
- The system gas has to be completely autonomous, "wireless".
- Additional conventional measuring probes must be connected to the system to increase its interest (pH, t°, salinity, position, meteorology, ...).
- The system maintenance must be very limited (1/year).
- Wind and corrosion resistance must be high.
- The probe must be installed on a buoy.

Moreover, some improvements are needed to allow:

- Amplification Gain drift due to NaI sensitivity to t° has to be compensated.
- Net peak area computation in a specific energy range.
- Interference correction to avoid false alarms due to natural radiations.
- Very long counting time.

2.2. Analysis Technique

To reach the best possible sensitivity a gamma spectroscopy analysis is performed on data collected by a MCA. The analysis steps are described on the Figure 1. Should the amplification gain drift, the raw spectrum is compensated in the following way:

- Reference peak search and computation of its parameters.
- Evaluation of the drift magnitude.
- Calculation of the new channel position in the drift corrected spectrum.
- Distribution of events in the 2 adjacent channels.

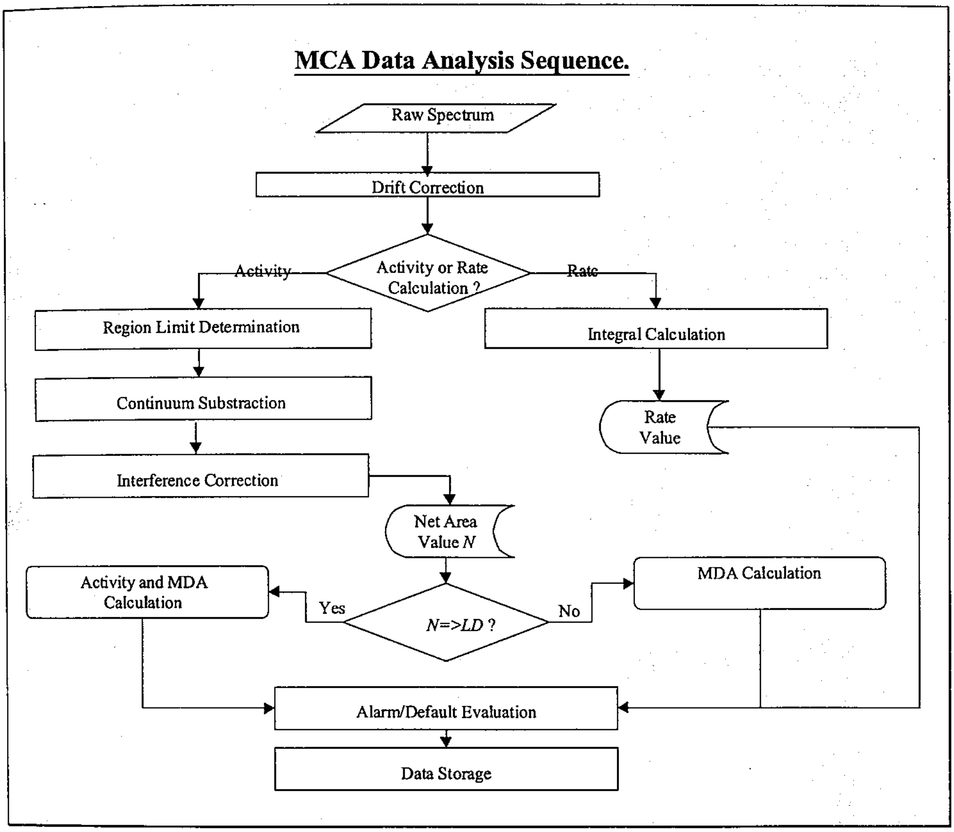


Figure 1: MCA Data analysis sequence

Net peak area are then computed:
- By continuum subtraction using a step function (Figure 2),
- By interfering peak contribution subtraction, which implies (Figure 3):
  - interference detection,
  - peak limits adjustment,
  - estimation of the height of the interfering peaks,
  - estimation of the contribution from these peaks in the peak of interest,
  - comparison of the net area of every peak of interest to their detection threshold.

The activity of every isotope is quantified:
- If the net area is below the detection threshold, the minimal detectable activity is computed.
- If the net area is above the detection threshold, the activity and the MDA are computed.

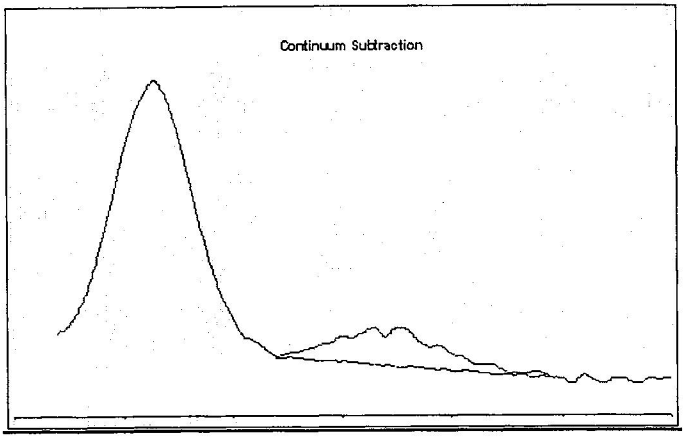


Figure 2: Continuum substraction

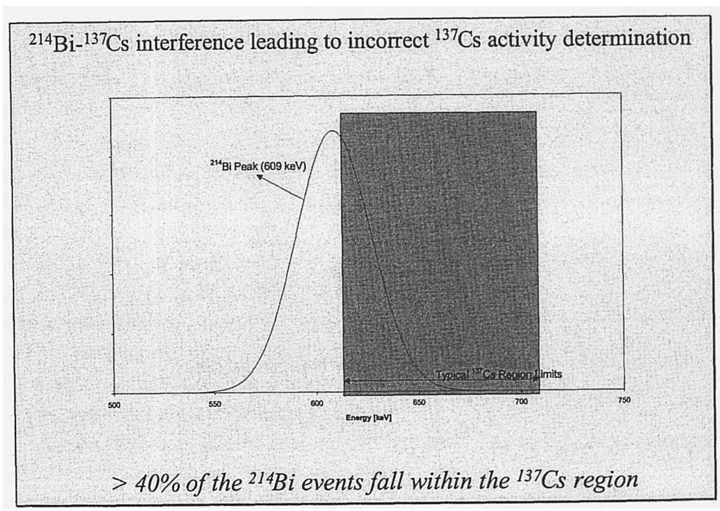


Figure 3: **Interfering peak contribution**

2.3. Validation

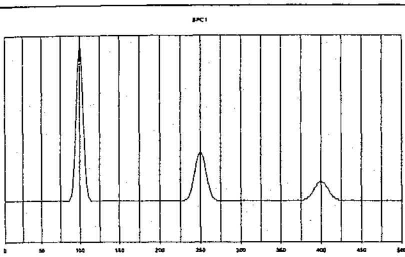
The Analysis technique validation has been performed on artificial and real spectrum, starting from the simplest to the most complex (Figure 4).

- SPC1: artificial spectrum without interference.
- SPC10: artificial spectrum with right/left interference (height of peak of interest is half of the interfering peak).
- SPCNaI: multi gamma real spectrum showing a large number of interference

The data validation has been performed:

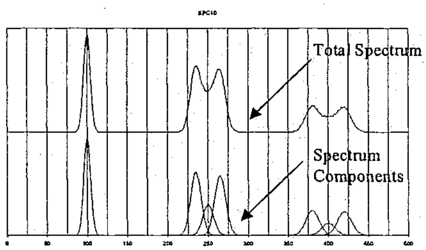
- For artificial spectra: by comparing the calculated quantities to the known ones.

- For real spectra: by comparing the calculated quantities to the quantities calculated by a commercially available gamma spectroscopy package using 3 different methods:
  - Automatic: automatic analysis using standard parameters. The software fixes the limits of the Region of Interest.
  - ROI: an experimented spectroscopist fixes the Region of Interest.
  - Expert: automatic analysis where the peak are fitted by an experienced gamma spectroscopist.



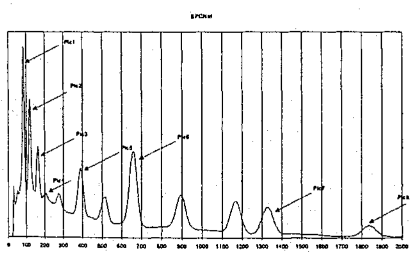
SPC1

Peak	Net (Mes/Real)	Continuum (Mes/Real)	Interference (Mes/Real)
1	1.00	1.00	-
2	1.00	1.00	-
3	1.00	1.00	-



SPC10

Peak	Net (Mes/Real)	Continuum (Mes/Real)	Interference (Mes/Real)
1	1.00	1.00	-
2	0.78	1.03	0.99
3	0.81	1.01	0.99



SPCNaI

Peak	Net (Mes/Real) Automatic	Net (Mes/Real) ROI	Net (Mes/Real) Expert
1	1.03	0.97	0.99
2	0.99	1.02	0.88
3	1.01	1.01	1.01
4	1.25	1.23	1.07
5	1.09	1.01	1.05
6	1.01	1.00	1.01
7	1.08	1.00	1.03
8	1.16	1.00	1.01

Figure 4: Analysis technique validation

The specifically developed analysis technique for this embedded application has the same level of performances as the one achieved in low level gamma spectroscopy laboratory using the same technique. It is a major improvement for the continuous radioactivity monitoring of environment because sophisticated analysis can be used on self standing systems and provide continuously results (close to "real time"). This is specially useful in emergency situation because reliable information can be provided to National/International Authorities allowing them to take quickly and effectively the most appropriate decisions

2.4. Calibration

In order to calculate activity levels, the detection system efficiency has to be pre-evaluated. For this purpose, a 20m³ tank (250 cm diameter, 300 cm height) has been specially designed.

Dimensions of the tank allow assimilating it to an infinite medium for gamma energies up to 2.4 MeV, without applying any correction factor (Figure 5). The thank is equipped with a water circulation pump (solution homogeneity) and with an anti-freezing system.

The thank has been filled with low-level natural radioactivity water (^{226}Ra and ^{40}K). ^{133}Ba (2kBq/m³) and ^{137}Cs (1kBq/m³) standards with their respective carriers were added to the water. The homogeneity of the solution has been controlled several times by sampling and laboratory gamma spectroscopy analysis.

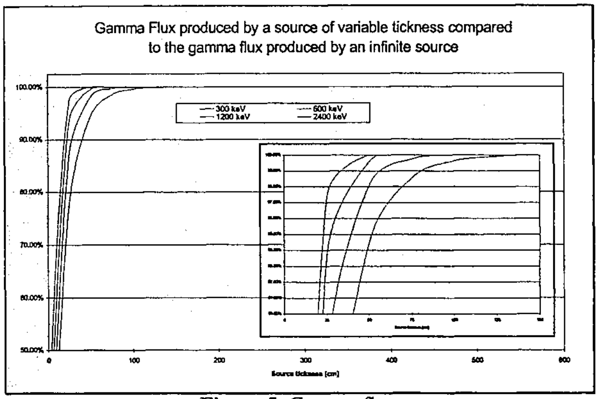


Figure 5: Gamma flux

The calibration factors were fixed by 50000 seconds measurements for different detector sizes 3" x 3" and 3" x 6" (figure 6).

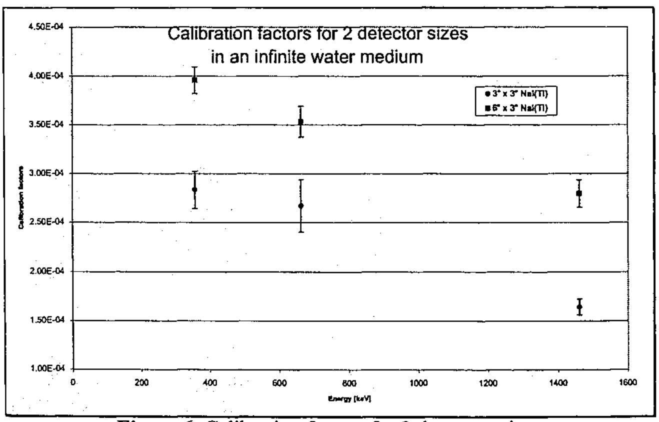


Figure 6: Calibration factors for 2 detectors sizes

2.5. System Performance

The detection limits for ^{137}Cs (30 days measurement time) are used as performance criteria. The typical detection limits achieved in the 80's and 90's are listed in the table 1. This table also gives the detection limits for river and seawater achieved with the system presented in this paper.

Table 1: Detection limits achieved in the 80's and 90's

Year	137 Cs Detection limit [Bq/m³] - sweet water	137 Cs Detection limit [Bq/m³] - sea water
80's	30 - 40	-
90's	10 – 15	-
Currently 3"x 3"	5 - 7.5	10 - 15
Currently 3"x 6"	2.5 - 5	5 - 10

This increase in sensitivity is not only due to the analysis technique improvement, but also to the optimisation of the counting geometry (material, size and thickness of the envelope). This stainless steel envelope contains :

- Measuring electronics (detector and MCA).
- An embedded processor.

3. SYSTEM FOR SEA MONITORING

The analysis technique development has been completed by a specific infrastructure required for sea applications. Nevertheless, it can also be used to measure rivers or lake without modification if the depth of the water is sufficient.(Figure 8).

For sea application, the basic detection system placed ***under water*** has the following components :

- A PC like card which handle :
  - data processing,
  - data communication,
  - connection with up to 4 instruments (pH, t°,....),
  - control of the power supply,
  - remote diagnostic and reparation as well as control of auxiliary equipment (sampler, ...).
- An interface card, allowing :
  - detector power supply,
  - management of the instruments power supply,
  - management of additional devices using contacts (sampler, ...),
  - status check of additional devices using contacts (flow rate,...),
  - monitoring of voltage power supply,
  - connection of 4 instruments using RS232 interfaces.
- A multi channel analyser.
- A NaI(Tl) detector (3" x 3" or 3" x 6").
- A watertight envelope.
- A probe for measuring the physical and chemical parameters of water (pH, t°, ...).

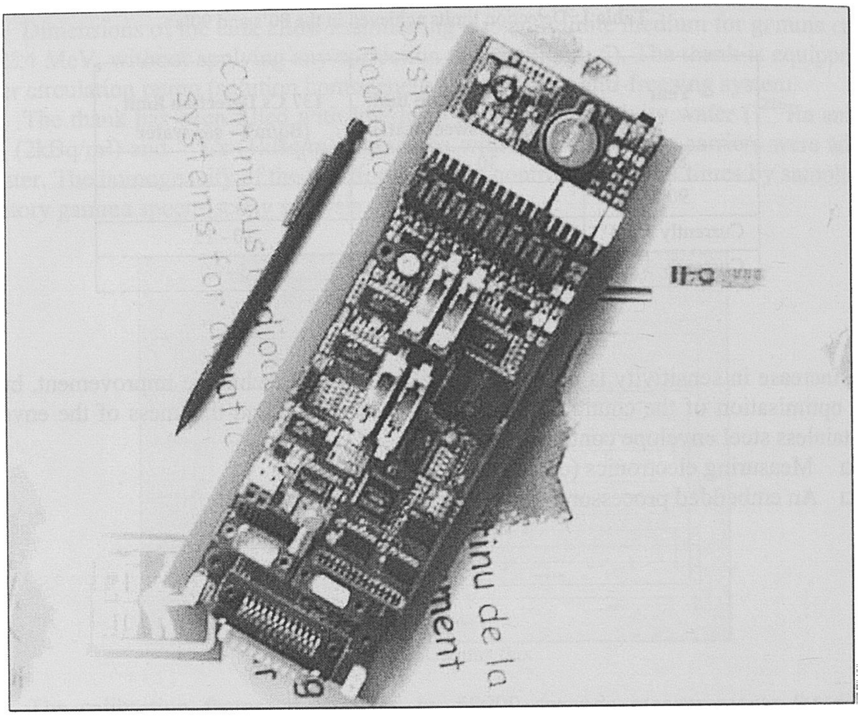


Figure 7: Teletransmission, analyse and collect informations

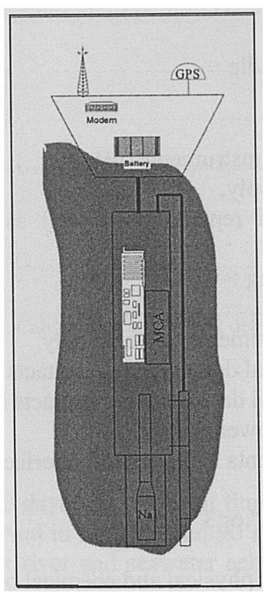


Figure 8: Schematical presentation of a measure system for seawater radioactivity

The above water part contains:

- A global positioning system (GPS).
- Solar panels electrical power supply.
- Backup batteries.
- Communication modem (GSM, radio, satellite).
- All these components consume all together less than 5 Watt. It's then possible to use solar energy as main electrical power supply.
- The underwater probe is physically connected to a control unit placed inside a floating buoy (off shore) or on a wharf (on shore). This unit contains :
  - backup batteries which allows 30 days continuous operation in case of main power supply breakdown (cloudy season, ...),
  - telecommunication device (RTC/GSM modems, radio and satellite).
- The analysis station communicates his results to one or several central stations having the following functionality :
  - full configuration of the networked probe,
  - network status map display,
  - spectra and results display (last measurement, last day, last week and last month results),
  - measurement report (text or chart),
  - alarms transmission.