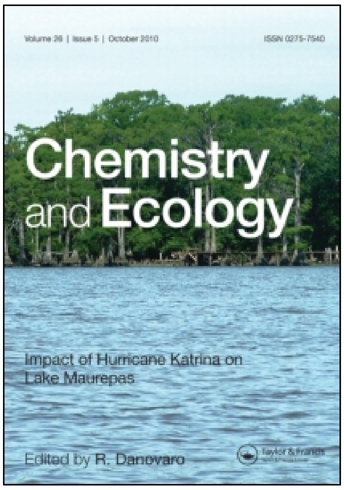

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RADIOACTIVITY MONITORED FROM MOORED OCEANOGRAPHIC BUOYS

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The principles and operation of a gamma radiation sensor mounted on oceanographic buoys are described. The sensor has proved rugged in severe weather conditions and has satisfactory detection limits and accuracy. Continuous monitoring of artificially produced γ-emitters such as ^{137}Cs, ^{134}Cs, ^{131}I, ^{133}I, ^{132}Te, and naturally occurring emitters such as ^{40}K and ^{214}Bi in open sea conditions can provide important information in critical situations.

KEY WORDS: gamma radiation, satellite transmission, ocean buoys

INTRODUCTION

The purpose of this work is to describe the methods and principles utilized for low-power, buoy operated, gamma radiation sensors with satellite transmission of data. The sensor, and its monitoring concept, has been developed with economic support from the State Pollution Control Authority of Norway (SFT) and Norwegian Radiation Protection Authorities (NRPA).

RADAM, is a 3″ × 3″ NaI detector with 1024 channel analyzer and computer, having gain control and temperature compensation (Figure 1). RADAM is a γ-detection instrument needing high voltage power supply which, with an acceptable current consumption (1 W), is internally converted from battery power. It has high efficiency and the energy resolution is sufficient for alarm or monitoring purposes where the nuclide's energy-bands do not overlap. For operation in areas where the external temperatures are changing during the observation period, the gain control and temperature compensation loop will secure that the energy calibration is maintained.

RADAM has been operational on oceanographic buoys since May 1992. The results from this period show that with the specially designed housing, the sensor is extremely rugged. The scintillator can operate under severe weather conditions (waves, temperature and temperature gradients). The comparison of *in-situ*

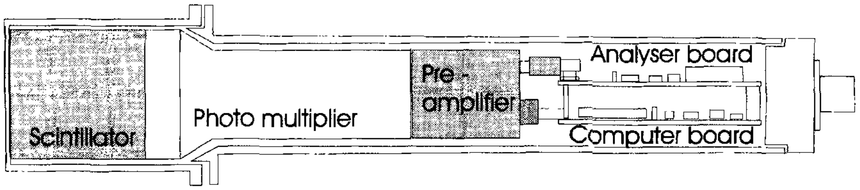

Figure 1 RADAM detection system.

monitoring with NaI scintillator and laboratory measurements with HPGe counter shows a very good correlation (see Figure 3). Moored buoys with γ-ray surveillance instruments are now deployed at several locations along the Norwegian coast, Thailand and the Netherlands. In the Barents Sea, a SEAWATCH buoy with a RADAM sensor has been deployed at Shtockmanovskoye (N73.011,E43.837), since November 1991.

For long-range γ-emitting radio-nuclides, *in-situ* measuring using NaI detectors are most appropriate. Widely used in laboratories and for terrestrial field monitoring purposes, the system has proved to be sensitive (low detection limit) and technically reliable, but in mixtures with several radio-nuclides the analysis of the spectrum requires care. For application at sea by attaching NaI detectors to oceanographic buoys, technical improvements of the system have been achieved. Furthermore, standardisation and calibration with respect to geometry, efficiency resolution, detection limit and drift of the system have been carried out so as to obtain qualitative and quantitative (Bq m^{-3}) information. The γ-emitting nuclides ^{137}Cs, ^{134}Cs, ^{131}I, ^{133}I and ^{132}Te will be the major contributors of concern in the case of any nuclear accident.

DETECTION LIMIT

A recommended method for estimating the detection limit is the *RISØ* method (a method used by 'RISØ Forsøksanlegg' in Denmark) (Gamma Vision, 1993). In these calculations the factor 4.65 gives a 95% level of confidence.

$$P = 4.65*(\sqrt{C})/T$$

where P is the detection limit, C is the background within the observed energy interval in region of interest-ROI) and T is the measuring period in days. A representative example for calculation of detection limit is based on *in-situ* measurements at Torbjørnskjaær during week #12-1993. Background counts within the ROI for ^{137}Cs is 12 000 cpd (counts per day). With a 24 hour measuring period we find that $P = 4.65*\sqrt{12\,000} = 509$ cpd or 0.00589 cps. From the calibration results we find that 556 counts equal 20 Bq, and thus:

Detection limit based on 24 hours' measuring period:	20 Bq m^{-3}*(509 cpd/556 cpd)=	19 Bq m^{-3}
Detection limit based on 7 days' measuring period:	20 Bq m^{-3}*193 cpd/556 cpd)=	7 Bq m^{-3}
Detection limit based on 30 days' measuring period	20 Bq m^{-3}*93 cpd/556 cpd)=	4 Bq m^{-3}

RADAM is calibrated for detection of ^{137}Cs because this is the largest contributor to radioactive pollution, and for ^{40}K because this dominates in sea water. If an 'uncalibrated' nuclide should be detected, it is possible to make quantitative estimations based on tests with a similar sensor.

SEAWATCH – SURVEILLANCE OF ^{137}Cs

SEAWATCH is a marine monitoring and forecasting system designed and developed by OCEANOR. The SEAWATCH project was first presented in autumn 1989 at the EUREKA Environmental Conference in Venice. A year later, in June 1990 at the ministerial conference in Rome, SEAWATCH was accepted as EUREKA project

453. As a EUREKA project, SEAWATCH was placed under the EUROMAR umbrella for projects related to marine monitoring technology. After a further development period of three years SEAWATCH has become a technically advanced marine monitoring system ready to serve different purposes for real-time information from the marine environment. Radioactivity is one of the parameters monitored by the SEAWATCH buoy concept (Figure 2). 'Torbjørnskjær' in the Oslo fjord (N58°96″, E10°72″) is a SEAWATCH buoy location that was found suitable as a test site for the RADAM system. This site is interesting as ^{137}Cs contributions can be received

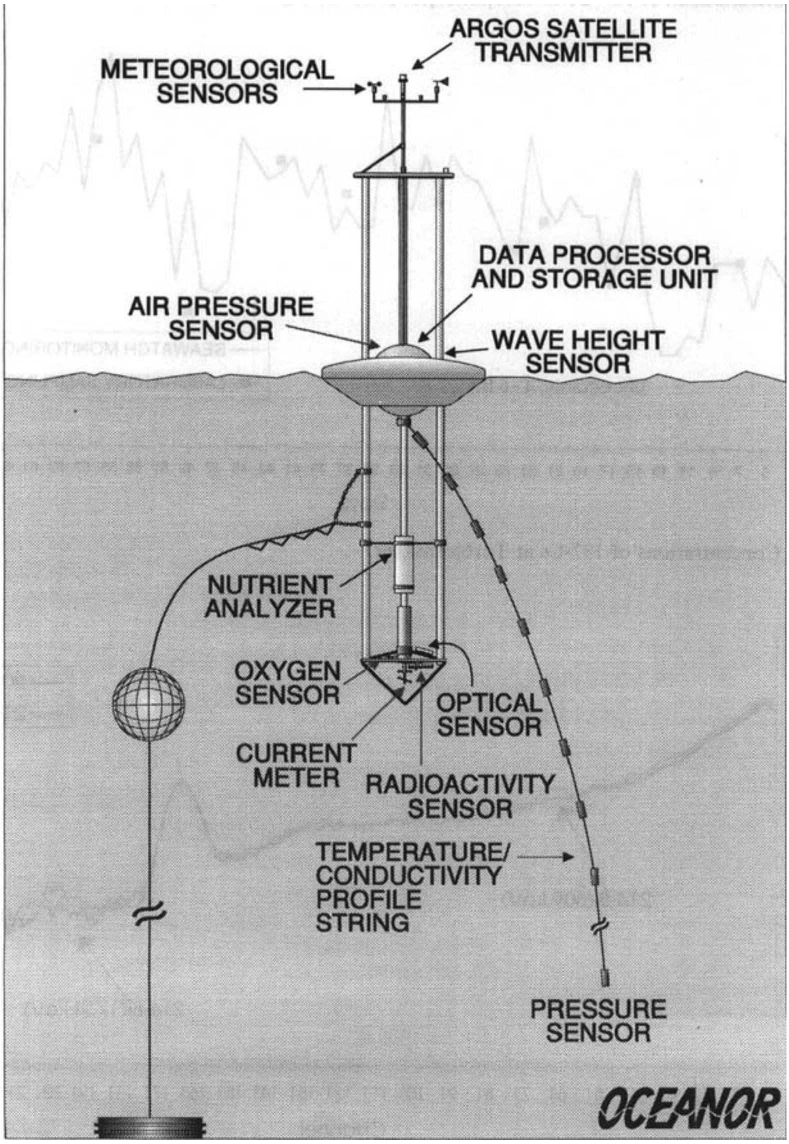

Figure 2 SEAWATCH buoy.

both from the Baltic Sea, Skagerrak and from different rivers. Another aspect of great importance is that water samples could be collected easily at this location. Samples were taken once a week and retrieved for laboratory analysis at the Institute for Energy Technology in Norway (IFE). At IFE the samples were counted with an HPGe detector, and in this way the results of *in-situ* γ-monitoring with the NaI scintillator could be validated. The results obtained from 10 weeks' testing (week 12–21, 1993) are shown in Figures 3 and 4. Figure 3 presents the result of ^{137}Cs

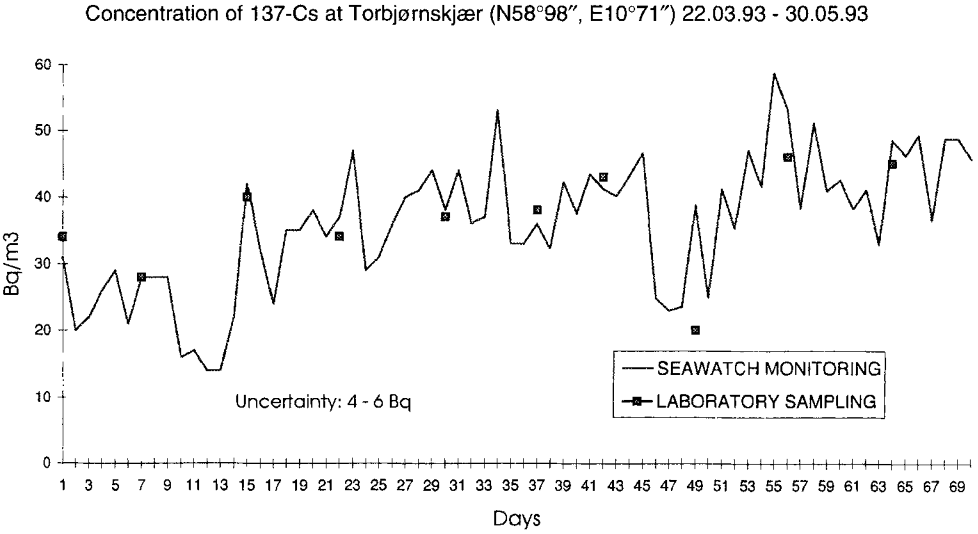

Figure 3 Concentrations of 137-Cs at Torbjørnskjær.

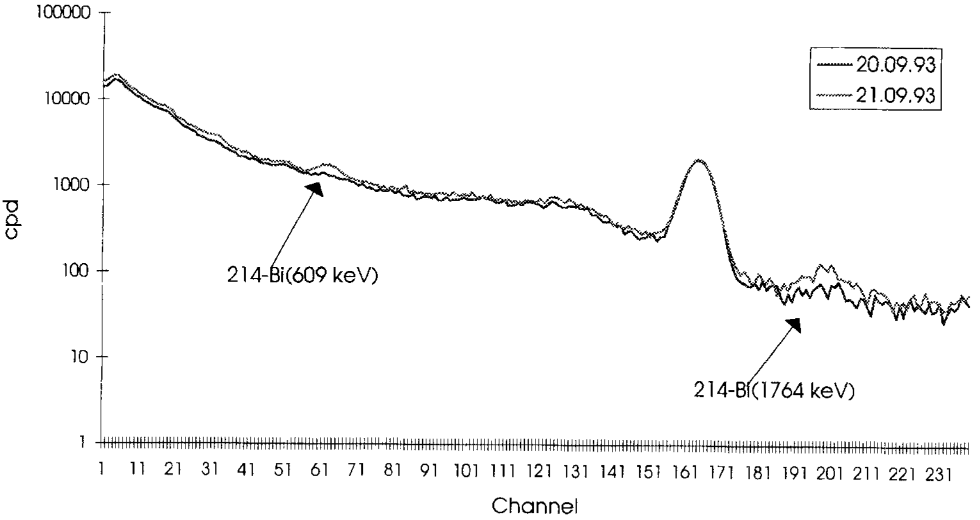

Figure 4 Gamma spectra of 214-Bi (from radon) at Torbjørnskær.

surveillance from Torbjørnskjær during a period of 10 weeks from 22 March 93, with both *in-situ* monitoring (SEAWATCH) and laboratory HPGe-counting of water samples. Figure 4 shows two 24 hour γ-spectra from *in-situ* monitoring at Torbjørnskjær. In addition to the 24 hour spectrum, the SEAWATCH buoy is transmitting change in GG (Gross Gamma, the total number of gamma incidents recorded by the sensor) on an hourly basis, so that we perceive as soon as possible whether concentration is significantly increased. The sensor itself is counting continuously, independent of the observation interval.

The advantage of continuous monitoring compared with traditional water sampling is clearly illustrated by the following example. From the total of water samples from our test site, selected results from the ^{137}Cs concentration measurements are given below:

Sample #1	12 June 1992	74 Bq m^{-3}
Sample #2	28 March 1993	28 Bq m^{-3}
Sample #3	5 May 1993	40 Bq m^{-3}
Sample #4	31 May 1993	28 Bq m^{-3}

Samples #1 and #4 suggest that we have had a reduction of 62% in ^{137}Cs during the full year record, however, between samples #2 and #3 we have had an increase of 42%. These observations are both correct, even if the last observation is inside the time frame of the first. It can be concluded that practical application of results from a limited number of measurements is often restricted. From a surveillance point of view, monitoring is much more informative that spot measurements.

Instrument specification is not the only concern to be taken within a monitoring assignment. There is also a question of the measuring method. From instrumentation technique, we know that qualified observation of a parameter that varies rapidly can be obtained only by continuously monitoring over long periods. If a function, f(t), has a bandwidth from 0 to f Hz. this function can be described by giving the co-ordinates of a number of discrete points, with a distance of 1/(2f) seconds between each point. In other words, the recommended sampling rate is at least 2 times the highest occurring frequency in the system (Solheim, 1983). For dynamic systems, high frequencies are not only expected, but also shown by our work. If one intends to measure global temperature change, it is obvious that spot measurements at fixed locations with extremely accurate instruments 3–4 times a year will not give a sufficient amount of data for an accurate pitcture of temperature variations from one year to another. From our work, we have found that the concentration of, for example, ^{137}Cs in the sea, can vary by a factor of 4 to 5 even at the same location at the same time between different years (from 16 Bq m^{-3} in June 93 to 74 Bq m^{-3} in June 92), and by a factor to 2 to 3 from one week to next, thus showing extensive temporal variations. This makes a good analogy to variations in temperature. Figure 3 shows the variation in ^{137}Cs at our test site, and together with the recommended sampling rate, it is obvious that continuously monitoring must be the only recommended measuring method. In the RADAM concept, the γ-activity is continuously monitored each second for 365 days a year. At every hour, gross gamma value is transmitted to a land station, while the complete spectrum is transmitted at midnight each day. Average concentrations can be calculated on the basis of 7 days, 30 days or 365 days counting time. From a fishery point of view, long-term averaging is much more informative than two or three water samples. To be able to establish qualified knowledge of variations in contamination level, we have to monitor for several years. This is one of the basic ideas of SEAWATCH.

Qualified Knowledge vs. Public Perception

For any country with significant consumption and export of fish, it has become increasingly important to document the level of possible contamination from any pollution source. Since we know that the number of nuclear reactors in the world are still increasing, we also know that the radioactive waste problem will increase. Experts will always express opinions, more or less qualified, about contamination levels in the sea. We have seen that a rumour, true or false, can cause a high level of concern in the population. The only way to eliminate the power of rumour, and economic damage resulting from loss of export earnings, is to obtain qualified knowledge of the contamination levels. To avoid this we must monitor so as to document and if justified, disprove possible concerns. In fact, the Barents Sea in general has significantly lower concentrations of ^{137}Cs (1–15 Bq m^{-3}) than, for example, Oslofjord (40 Bq m^{-3}), and and the concentration of the natural nuclide, ^{40}K, is of a magnitude of 250 times higher than the concentration of ^{137}Cs. These concentrations are the results of SEAWATCH monitoring through 1993. Strategically deployed sensors could cover the total water masses of a given area during a minimum of time. If a buoy is deployed in the coastal current, and the current speed is 1 knot, the SEAWATCH system will scan 45,000 m^3 water each day for radioactive contamination. Furthermore, if contaminated water is present somewhere along the coast, the water current will sooner or later lead it to within the detection range of the RADAM sensor.

Modelling

Continuous monitoring of the γ-activity, combined with information about ocean current speed and direction, salinity, temperature, waves and wind, provides a complete parameter set as input to transport models. Thus we can obtain qualified answers to the most important questions:

- ‘what are the variations in the contamination level at the station?’
- ‘from where does the contaminated water come?’
- ‘where and when will it end up?’

This is achieved by monitoring the γ-emitters in sea water as a part of the SEAWATCH marine surveillance, forecasting and information system. Combined with the other SEAWATCH parameters, models (e.g. ocean circulation model HYBOS and dispersion model NOMAD) give us important real-time information about locations where precautionary measures are needed.

3-Dimensional View of the Gamma Activity

Using continuous monitoring over the complete energy range, it is easy to project a 3-dimensional picture of the γ-activity from any measuring site for a period of, say, one year. This is shown in Figure 5. Since we know that dumping or leakage will often be recognised by a number of α-, β- and γ-emitting nuclides, we can be

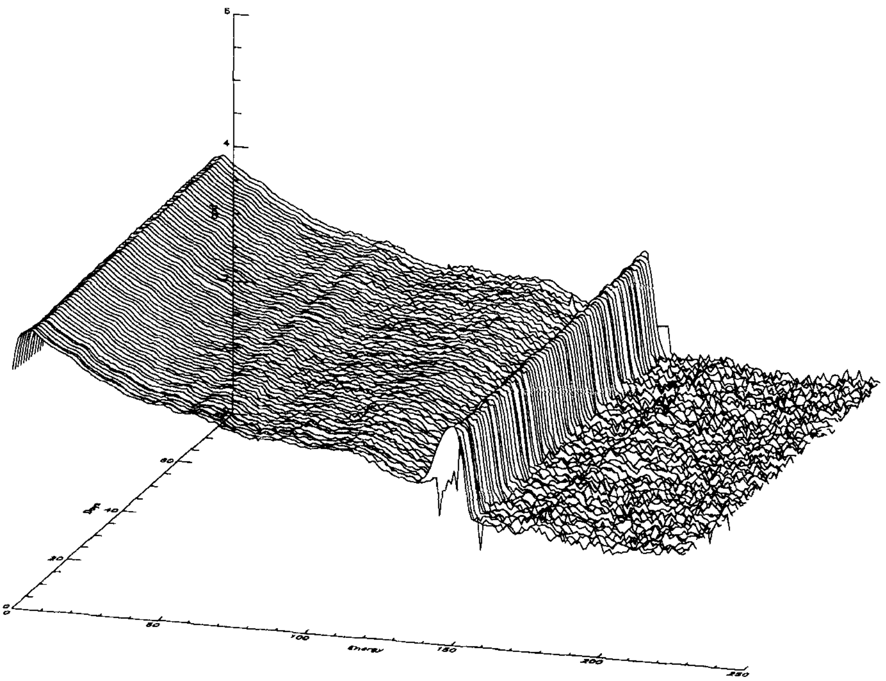

Figure 5 3D view of 70 days, 23 March to 1 June gamma monitoring at Torbjørnskjær.

assured that if we have no increase of any γ-emitting nuclide, no dumping or leakage has occurred at this location during the observed period.

Quality Assurance

We can be assured, using the SEAWATCH technology, whether or not the average level of contamination is below a pre-set action limit during the monitoring period. A Quality Assurance certificate could be provided on the basis of data records, that the average level of ^{137}Cs did not exceed a pre-set limit during the growth period of a fish crop we are selling.

Detection of Radon

In addition to detection of artificially produced gamma-emitters, the sensor easily detects variations in naturally occurring radio-nuclides. In terrestrial environments, radon is a well known source of concern. This is a gas that is not a γ-emitter, but some of it's daughters are, for example, ^{214}Bi. Radon or radon daughters are transported from land by wind and deposit on the ocean surface due to rain out. Within a few seconds, the ^{214}Bi is mixed down to within detection range, and thus detectable by the sensor. An incident from Torbjørnskjær is described below, and is shown in Figure 4. Increase of ^{214}Bi concentration was measured by OCEANOR first, in August 93, from a moored SEAWATCH buoy at Shtockmanovskoye (N73°01″,E43°84″) west of Novaya Zemlya in the Barents Sea.

During the 26th and 27th of September 1993, a front was observed approaching the Torbjørnskjær station region. The meteorological network also registered some precipitation in the region. During the 26th to 28th of September the wind (Figure 6), was blowing constantly from the E-NE direction, with a mean value of 6 ms^{-1}, thus transporting air masses from the SE part of Norway. At the time, the water temperature at different depths showed an upper mixed layer with a maximum of 15–20 m depth, and a cooling trend in the 20–40 m layer, developing a thermocline at about 20 m depth.

The depth of frictional influence:

$$D_E = \frac{4.3W}{\sqrt{\sin|\phi|}}$$

where W is the wind speed in ms^{-1} and ϕ the latitude of the site, is used to estimate the wind stress influence and the upper mixed layer length. In this case, W is 6 ms^{-1} and ϕ, the latitude of Torbjørnskjær location, is approximately 59°. Hence, D_E is 28 m, of same order of magnitude as the thermocline presented by the temperature profile. The meteorological and oceanographic conditions during the 26th and 27th of September 1993 were favourable to the increasing ^{214}Bi presence in the region. Furthermore, its detection at 3 m depth is understandable from the mainly wind-dominated mixing processes in the upper layer.

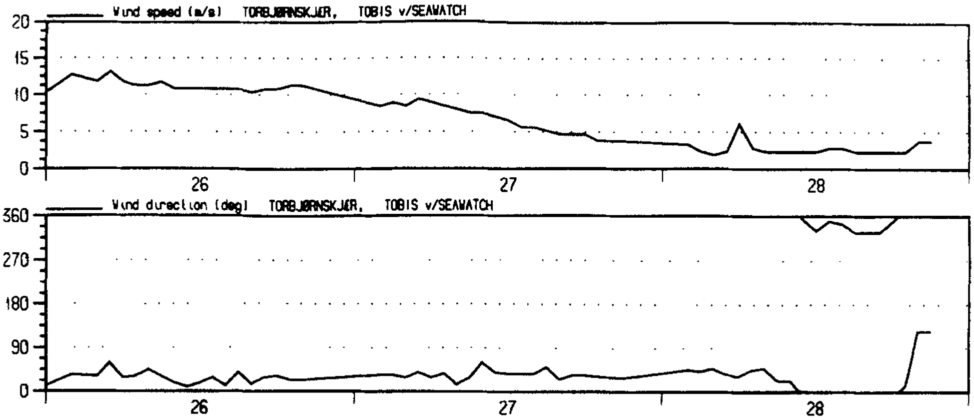

Figure 6 Wind speed (ms^{-1}) and direction (deg.) during 26–28 September at Torjørnskjær.

CONCLUSION

We have reached the following conclusions from the evaluation of the RADAM sensor (Table I):

The NaI scintillator is rugged enough to cope with severe weather conditions with extreme waves driven by hurricane force winds, and it can stand the high temperature gradients during deployment and recovery. It has satisfactory detection limits and accuracy. The method utilised to calculate the net contribution of a given nuclide is considered to be satisfactory. For long term surveillance there is still work to be done to improve this method, especially to reduce the interference from ^{40}K and ^{214}Bi.

Table I Applications within environmental surveillance.

Site	*Observation time*	*Purpose*
Close to nuclear installations	Alarm service 1 hour interval Long-term monitoring and averaging for low concentration discharges	Surveillance of discharges Low concentration disposals
Sensitive areas such as fishing banks, North Sea, Barents Sea, others	Medium observation time Long-term monitoring and averaging	Documentation of growth conditions of the fish
Sensitive areas due to leakage from dumping or storage sites, discharge from contaminated rivers etc.	Medium observation time Averaged concentration levels Alarm service	Public concerns, alarming if a leakage starts.
Contaminated isolated or high risk areas (remote land sites)	Medium to long observation time	Air bourne and deployed sensors Avoids radiation risk to man

For gamma-emitters, *in-situ* monitoring has proved to be most useful, especially if concentrations show large temporal variations as in the case of ^{137}Cs. Direct collection of water samples is still needed for the determination of α- or β-emitters. Analysis of a water sample reflects the time of sampling, providing only a 'snap-shot', but it is not a good representation of the dynamic changing conditions at the site of sampling. In addition, to detect artificially produced γ-emitters, the sensor is capable of measuring natural γ-emitters like ^{40}K or radon daughters like ^{214}Bi.

Continuous *in-situ* monitoring is the best method for surveillance of γ-emitters like ^{137}Cs, which show large temporal variations in concentration. Continuous monitoring is certainly preferable to sporadic sampling as it gives more complete information of the γ-activity. This has important political and psychological effects, and it will provide important basic knowledge to inform the public in a critical situation

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