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Emergency Monitoring Strategy and Radiation Measurements

Working Document of the NKS Project Emergency Management and Radiation Monitoring in Nuclear and Radiological Accidents (EMARAD)

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Abstract

This report is one of the deliverables of the NKS Project Emergency management and radiation monitoring in nuclear and radiological accidents (EMARAD) (2002–2005). The project and the overall results are briefly described in the NKS publication “Emergency Management and Radiation Monitoring in Nuclear and Radiological Accidents. Summary Report on the NKS Project EMARAD” (NKS-137, April 2006).

In a nuclear or radiological emergency, all radiation measurements must be performed efficiently and the results interpreted correctly in order to provide the decision-makers with adequate data needed in analysing the situation and carrying out countermeasures. Managing measurements in different situations in a proper way requires the existence of pre-prepared emergency monitoring strategies. Preparing a comprehensive yet versatile strategy is not an easy task to perform because there are lots of different factors that have to be taken into account.

The primary objective of this study was to discuss the general problematics concerning emergency monitoring strategies and to describe a few important features of an efficient emergency monitoring system as well as factors affecting measurement activities in practise. Some information concerning the current situation in the Nordic countries has also been included.

Key words

Emergency preparedness; Radiation monitoring strategy; Emergency measurements

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Foreword

The management of various nuclear or radiological emergencies requires that the authorities have pre-prepared plans and various background material at their disposal. The purpose of the NKS project EMARAD (Emergency Management and Radiation Monitoring in Nuclear and Radiological Accidents, 2002–2005) was to produce and gather data and information foreseen to be useful in preparing emergency procedures and radiation monitoring strategies.

The participating institutes and experts in the project were:

Denmark:	Risø National Laboratory (Kasper Andersson, Jørn Roed, Søren Thykier-Nielsen)
Finland:	Radiation and Nuclear Safety Authority STUK (coordinating organisation; Riitta Hänninen, Tarja Ilander, Eila Kostiainen, Juhani Lahtinen, Kaj Vesterbacka) VTT Technical Research Centre of Finland (Jukka Rossi, Seppo Vuori)
Iceland:	Icelandic Radiation Protection Institute (Kjartan Gudnason, Sigurdur Emil Pálsson)
Norway:	Norwegian Radiation Protection Authority NRPA (Inger Margrethe Eikelmann)
Sweden:	Swedish Radiation Protection Authority SSI (Robert Finck); University of Lund (Christer Samuelsson)

This report presents the results of the EMARAD-related work dealing with monitoring strategies and emergency measurements. The project as a whole is described in the NKS publication “Emergency Management and Radiation Monitoring in Nuclear and Radiological Accidents. Summary Report on the NKS Project EMARAD” (NKS-137, April 2006).

Some results of the strategy-related EMARAD work presented in this report have been published in scientific journals or presented in conferences.

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1 Background and introduction

In a nuclear or radiological emergency, radiation measurements provide essential data needed by the authorities and other decision-makers in trying to evaluate the radiological emergency situation and in trying to carry out proper countermeasures on time. All measurements must be performed efficiently in various conditions, which requires that there are pre-prepared emergency monitoring strategies and measurement plans. These strategies define and describe the main factors, principles, procedures and methods related to measuring and sampling activities in different radiation situations.

In order to help individual countries to establish national emergency monitoring strategies, international organisations have published general guidelines for emergency response and radiation measurements [e.g. IAEA 1999, OECD 2000], and the Sixth Framework Programme of the European Union is likely include a sub-project that specifically aims at creating a radiation monitoring strategy guide for the EU member countries [EC 2004]. In addition, there are many other international publications and guides that partly deal with items having interfaces with emergency monitoring strategies. NKS, too, has been active in this respect: there are several publications on matters having a link with monitoring strategies, such as [NKS 1998, NKS 2000a, NKS 2000b, NKS 2001, NKS 2002b, and NKS 2002c]. Furthermore, in scientific literature one can find many interesting papers concentrating on one or more aspects of monitoring strategies, especially in the context of nuclear accidents [e.g. van Zonderen 1997, Weiss 1997, Zähringer and Pfister 1998, Crick et al. 2004, Gering et al. 2004a, Lahtinen 2004, Lahtinen et al. 2006].

In practice the resources allocated to radiation monitoring activities vary from country to country, as do correspondingly the quantity and quality of the measuring equipment. This fact is a reality also at the Nordic level. The approaches chosen by individual countries depend on the combination of several factors including, among other things, national and international legislation; general economic and social circumstances; status of technical infrastructure; population, area and topography; nuclear and radiological threats identified; country's own experience of the consequences of earlier accidents; status of radiation monitoring arrangements in the neighbouring countries; and public attitude towards emergency planning and civil defence.

Judging from the above, international harmonisation of radiation monitoring systems and monitoring strategies will not be an easy and straightforward task to accomplish. Nevertheless, a shared similar understanding of the factors affecting monitoring strategies and related practices is enough for creating and maintaining a mutual co-operative atmosphere needed in different kinds of severe nuclear or radiological emergencies.

In chapter 2 of this report the problem of defining an emergency monitoring strategy is reviewed at a general level while chapter 3 discusses some of the principal factors to be considered in a strategy as well as gives information on the practical measuring systems. A concise summary of the aspects to be accounted for in a good strategy is presented in chapter 4. Some basic features of the Nordic approaches are described briefly in chapter 5. Conclusions are given in chapter 6.

2 The problem of defining an emergency monitoring strategy

In general, a good emergency monitoring strategy starts from the advance identification of potential hazard situations and extends to environmental sampling performed during the late phases[1] of an accident or other kind of an event. It combines the arrangements and systems applied in routine monitoring with the special requirements set by emergency monitoring, and the use of fixed monitoring stations with that of mobile measurement teams. It contains elements for analysing, transmitting and presenting measurement data, as well as for linking the data with the input/output of different forecasting and decision support systems. It also takes into account the intrinsic characteristics of potential threat scenarios and includes options for adapting all measuring activities according to prevailing environmental conditions. Moreover, various links with the practical constraints set by societal and economic issues are factors needed to be considered in strategies.

Creating a monitoring strategy is a complicated task and requires the use of a systematic approach. The problem as a whole can be dealt with in different ways. One possibility is to first identify all factors affecting a strategy and then to pose a series of appropriate questions, to discuss them thoroughly and, finally, to answer them in a strategy plan and related documents [Lahtinen 2003, Lahtinen 2004]. In a more limited sense this kind of "question – answer" approach has been used in [IAEA 1999] and [OECD 2000].

There exist different views about how detailed a monitoring strategy should be in structure and what kind of elements it should contain. The starting point of this study is to consider strategies in a broad sense, and, depending on the subject in question, they may be taken to include features and items that could equally be presented under the heading "Practical action plan" or even "Instructions".

In general, the factors needed to be considered in a strategy can be roughly categorised as belonging to one of two groups:

- "Static" factors (or data, as in [OECD 2000]) whose status or related contents are known or available before any nuclear or radiological emergency arises. Examples include population distribution, geography and topography, land use, legislation and official agreements, fixed potential sources (nuclear facilities etc.) and other recognised threat scenarios, routine monitoring arrangements and resources allocated to emergency monitoring (measuring equipment, capacity of laboratory measurements, extra manpower, decision-aiding systems with auxiliary support material). These factors cannot normally be changed quickly, at least not during the early phases of an accident.
- "Dynamic" factors whose contents will become clear only at the beginning (or during the course) of an accident or a specific event. The scenario (source term, location) and prevailing environmental conditions (e.g.

[1] Time phases (early, intermediate and late phases) related to nuclear or radiological accidents is are discussed in section 3.1.2.

weather) are the most evident items in this group. In addition, the amount and nature of resources actually available at the time may be quite different compared to those listed up in the connection with the static group: there may be a holiday season and some of the key personnel are absent, some of the equipment may be broken or there may emerge serious hardware or software problems with computers and data communication systems.

On the basis of the above, the following strategy-related questions (among others) can be asked [see also Lahtinen 2004]:

- *Why is there a need for radiation monitoring strategies and radiological measurements?* In what kind of situations are they going to be applied? What are the different potential threats? Which dose paths and radionuclides constitute the main hazard in different scenarios?
- *What exactly is the purpose of specific measurements*? Predicting and tracking plume trajectory and detecting any release, i.e. an early-warning system? Implementation of population protection countermeasures? Mapping of fallout or locating a hidden radiation source?
- *Which quantities should be measured?* External dose rate or concentrations of radioactive substances in air? Individual doses? Or must one take a grass or food sample and analyse it?
- *When should the measurements take place and what is the timing and order of different measurements?* During the release phase of a nuclear accident or after the plume passage? Apart from external dose-rate measurements, monitoring and sampling must urgently cover also all the other exposure pathways relevant in the early phase of an accident or immediately after it (such as ground-level air and to some extent milk, too).
- *Where and in what kind of environmental conditions are the measurements performed?* In urban or rural environment or at sea? On the ground or up in the air? At what distance from the release source? On a sunny summer afternoon or in the autumn during a heavy storm? How to protect staff and avoid contamination of the measuring equipment?
- *How to measure?* Using fixed monitoring stations or mobile measuring teams? What kind of measuring devices should be used? How should performing of different kinds of mobile measurements be co-ordinated in order to make the maximum use of the resources available? Which are the limitations of the measuring systems? Are the measurement results reliable and representative? What is the required sensitivity of the measurement system used?
- *How are the measurement results handled and processed and how are they utilised?* How are the results transmitted and presented? What is the best way to combine results received from fixed monitoring stations and those from mobile teams? How to integrate the results of different kinds of measurements into a comprehensive but at the same time unequivocal status report? Are the results compared with the output of dose prediction models or integrated with decision-aiding systems?
- *How are the information about the overall situation, the forecasts and predictions used to direct measuring and sampling activities?* What kind

of information is given, for example, to the mobile measuring teams and in which way is this information transmitted?

- *How to co-ordinate the measurement activities between different organisations?*
- *How is the exchange of information and data between different parties, including the public information, arranged?*
- *What kinds of resources are actually available at the time of the incident?* Measuring instruments and manpower? Accommodation and change of shift during a long-lasting emergency? Have the mobile patrols been trained properly and do the team members work in a well-organized manner?
- *The role of international co-operation?* Is it possible to share measurement resources in certain types of accidents?

These questions are not wholly independent of each other and thus are neither the answers.

3 Monitoring and strategy

3.1 Radiation monitoring in an emergency

3.1.1 Aim of measurements

Basically, there are different reasons for performing various radiation measurements [cp. OECD 2000 and Weiss 1997]:

- <u>Detecting any release and generating an alarm signal</u> in order to alert the emergency organisation. This requires that there exists an early warning system. Early-warning networks are usually based on dose-rate monitoring devices (Table 3.1). However, it should be understood that there are radiologically very important nuclides that cannot easily be detected with dose rate measurements (Table 3.2).
- <u>Implementing urgent countermeasures</u>. Here, urgent population countermeasures include sheltering, evacuation and the use of stable iodine prophylaxis. The corresponding operational intervention levels are often expressed as external dose-rate values. In case of stable iodine prophylaxis there is thus the problem of establishing an adequate relation between observed dose rates and assumed values of iodine concentrations in the air. In practice the intervention level is often based on the nuclide composition of a typical release occurring during the early phase of a nuclear power plant accident.

Table 3.1. Dose-rate-monitoring early-warning networks in some European countries.

The table represents the situation in the late 1990's. Note that the figures given are not directly comparable in all respects (some numbers of detectors include the detectors around the NPPs while some do not). Note also that the equipment is different in different countries (there are GM counters, proportional counters, ionization chambers and NaI detectors)

Country	**Number of detectors**	**Detectors/ mill. inhabit.**	**Detectors/ 1000 km^2**
Austria	336	44	4.0
Belgium	186	19	6.0
Denmark	11	2.1	0.26
Finland	290	57	0.86
France	145	2.6	0.26
Germany	2200	28	6.2
Netherlands	280	19	6.7
Norway	12	2.8	0.037
Portugal	15	1,4	0.16
Spain	900	23	1.8
Sweden	37	4.3	0.083
Switzerland	115	17	2.8
UK	92	1.6	0.38

Table 3.2. Concentrations of some radionuclides in air causing a rise of 0.1 σSv h^{-1} in external dose rate levels.
An one-hour effective dose received through inhalation is also shown (for adults) in the table.

Nuclide	**Half-life**	**Concentration** [Bq m^{-3}]	**Inhalation dose resulting from an exposure of one hour** [σSv]
I-131	8.04 d	1700	11
I-132	2.30 h	270	0.03
I-133	20,8 h	1000	1.5
Cs-134	2.06 y	400	8.0
Cs-137[a]	30.1 y	1200	47
U-235[b]	$7.04 \cdot 10^{8}$ y	4100	1200
U-238[b]	$4.47 \cdot 10^{9}$ y	6 000 000	$5.1 \cdot 10^{7}$
Pu-238[b]	87.7 y	6 900 000	$7.6 \cdot 10^{8}$
Pu-239[b]	24 131 y	7 000 000	$8.4 \cdot 10^{8}$

[a)] In equilibrium with ^{137m}Ba.
[b)] Alpha emitters. Intensity of gamma and X-rays is very low and thus detection with ordinary dose-rate monitoring devices is difficult (with the exception of ^{235}U, perhaps).

- Predicting and tracking the plume trajectory. Meteorological data and dispersion forecasts are very useful in this context, helping to determine the optimum measurement places. Sometimes mobile measurements (both car-borne and air-borne) are the best means of locating the plume.
- Informing all parties involved. In any nuclear or radiological emergency situation, there emerges a need of informing different parties ranging from the government and other countries to local public. Knowledge of the current radiation situation and its likely evolvement are the basic elements of producing proper and timely information.
- Protecting emergency and recovery workers. For the protection of this population, decision makers and emergency authorities will need various data, measurement results and information on contamination levels.
- Implementing agricultural countermeasures and food restrictions. In many severe radiological release situations, there will be the need to implement agricultural countermeasures (the use of clean feed, the sheltering or evacuation of livestock, etc.) or to impose restrictions on food consumption. Season, of course, is a very important factor in this context. Depending on the case, forecasts and predictions, radiation measurements or results of sample analyses can launch the implementation of a specific countermeasure. In the post-release phases of a nuclear accident, air-borne fall-out mapping may be of great value in determining the areas to be covered by countermeasures.
- Implementing intermediate- and late-phase countermeasures. These refer to population protection countermeasures as well as decontamination

countermeasures. Detailed measurement data and assessments will be fundamental to decisions to be taken (evacuation, relocating evacuated people, defining some areas as “clean”, etc.).

- Contamination control of merchandise and vehicles leaving or coming from the affected area. There should be pre-prepared monitoring plans concerning the (possibly) long-lasting contamination-control arrangements.

Generally, there are different types of measuring systems and methods that can be used to fulfil the need of adequate measurements for due purpose in due time (Table 3.3). The basic purpose of a specific measurement also affects the required characteristics (e.g. sensitivity, response time) of the measurement system used. Depending on the national conditions and priorities, the equipment may vary considerably from one country to the other both in quality and in quantity. This can be seen in Table 3.1, too.

3.1.2 Proper and timely measurements

The proper selection of emergency measurements needed at a given time depends largely on the nature of the accident or event and on the associated time scales. In case of an accident at a nuclear facility, the time scales can be, for example, classified as follows [e.g. OECD 2000]:

- The threat or pre-release phase. This is the time following the recognition of a problem situation. It lasts until some environmental release has started. Data from the site and meteorological dispersion forecasts are of importance. An emergency organisation should use this time period to check and refine its plan of the measurements to be carried out during the (possible) later phases.
- The early phase, where the risk consists of external irradiation from the release plume, inhalation of radioactive material and to an extent also from external radiation from ground deposits. In general, rapid measurement over appropriate areas of external dose rate is important. This phase typically extends for some hours from the start of the release. Data from the site, as well as meteorological dispersion forecasts are of importance.
- The intermediate phase, where the risk is due to external radiation from ground depositions, internal radiation from inhalation of resuspended particulate radioactivity and internal radiation from ingestion of contaminated fresh food and water. Dose rate measurements and mapping (car-borne or air-borne platforms) of fallout are needed. This phase may last from days to weeks after the early phase.
- The late phase, where the risk is caused by consumption of contaminated food in general and overall contamination of the environment. The phase may extend from weeks to several years.

Table 3.3. Important measuring systems and methods. Based primarily on [OECD 2000].

<u>External dose rate or dose</u>
- Stationary automatic systems for dose-rate monitoring (GM, ion-chamber, proportional counter, NaI(Tl))
- Portable or mobile systems for dose-rate monitoring (GM, ion-chamber, proportional counter, NaI(Tl))
- Integrated dose (TLD)

<u>Airborne radionuclide concentrations</u>[a]
- Stationary filter stations equipped for on-line measurement (gamma spectroscopy of moving filter, on-line gross beta measurement of moving filters)
- Stationary filter stations requiring filter collection for measurement (gamma spectroscopy in laboratory)
- Stationary filter stations equipped with advanced sampling devices (e.g. on-line iodine monitors)
- Stationary filter stations requiring filter collection for measurement of iodine (iodine sampling with impregnated charcoal and aerosol filters)
- Mobile air-sampling stations (on-line gross beta measurement or gamma spectroscopy, filter collection and analysis in laboratory)
- Aerial sampling at high altitudes (gamma spectroscopy of the filter in laboratory)

<u>Deposition measurements</u>[a]
- In-situ measurement of surface activity on the ground (in-situ gamma spectrometry with HPGe)
- Aerial measurements of surface activity (NaI, HPGe)
- Environmental samples (HPGe spectroscopy in laboratory)

<u>Foodstuff and environmental contamination measurements</u>
- Sampling and measurements in laboratory (gamma, beta, alpha)

<u>Individual dose measurements</u>
- External exposure (TLD, electronic dosimeters)
- External contamination (alpha, beta and gamma monitors)
- Internal contamination screening (contamination monitors or dose rate instruments (inc. thyroid monitoring)
- Internal contamination measurements (gamma-spectrometry with Ge- or NaI(Tl)-spectrometers)
- Excretion measurements (laboratory analysis)
- Individual accumulated dose (biological dosimetry)

[a] Note that deposition measurements and air-borne concentration measurements performed at the same location allow estimation of deposition velocities.

In certain connections – especially in countermeasure considerations – a slightly different phase classification is often used: a pre-release phase (time scale hours/days), a release phase (hours/days) and a post-release phase (weeks/months/years). Sometimes a division into emergency (hours, days) and post-emergency phases (weeks, months, years) is applied, too.

In many other types of scenarios the above time phases can be identified, too, though the durations of the phases may be different. There are also accidents with only one or two primary exposure paths. An example of these is a lost gamma source: the risk is often solely due to external radiation.

In the early phases of most accidents with radioactive releases to the environment, all data on external dose-rate levels and radionuclide concentrations in the ground-level air are of vital importance. If there are no automatic or fixed systems for providing this information, moving monitoring teams must be used. *In-situ* gamma-spectrometric measurements of ground contamination should also be implemented as soon as possible. The proper density and applicability of fixed monitoring systems and the necessity of mobile measurements depend of course on the scenario at hand: reasonably sparse fixed networks may effectively address scenarios like a power plant accident abroad while much denser networks and operational mobile measuring systems are needed in case of terrorist activities (e.g. “dirty bomb” explosions).

The urgency of large-scale environmental sampling and detailed fallout mapping (with ground-based or aerial mobile systems) depends on the characteristics of the release and season; usually, these matters will become important in the intermediate phase when the release has stopped. However, the preparatory work on arranging foodstuff monitoring and general contamination surveillance must begin as early as feasible. In case of known threat sites (e.g. nuclear power plants), there should be pre-defined sampling locations and procedures to be applied at short notice. Regardless of the details of the scenario, there must also be measuring techniques and systems available for taking continuously care of the protection of emergency workers and for performing individual dose assessments in general.

In addition to all above, an emergency monitoring organisation should be capable of responding to more uncommon measurement needs, such as alpha or beta detection with portable devices in case of intentionally dispersed poor gamma emitters (see Section 3.3.4). Concerning international co-operation, sharing of measuring resources could be a realistic option especially during the late phase of a nuclear accident (sampling, fallout mappings with mobile platforms).

3.1.3 Fixed monitoring stations vs. mobile measurements

If possible, all fixed monitoring networks (automatic or semi-automatic) should serve the purposes of routine monitoring, generation of the first alarm and performing of situational analyses (including serving in the emergency phase as a tool to help to predict doses to the affected population). The advantages and disadvantages of fixed automatic networks can be summarized as follows:

<u>Advantages</u>

- They operate continuously and need only a little extra manpower in an emergency.
- They can gather a lot of information about nation-wide radiation situation in a relatively short time.
- They are good PR; when the public is aware of the existence of a state-of-the-art radiation monitoring network it often feels that their tax money has been spent in a good cause.

- Upkeep and further development of a wide monitoring network enables direct communication channels between the central authorities and local administration (these channels can be utilized in training and dissemination of information).

Disadvantages

- There are routine maintenance costs. Apart from the station-related investments, these costs, however, are not necessarily directly proportional to the number of monitoring station sites.
- As the number of monitoring stations increases, the complexity of the system increases and, correspondingly, there may be more error situations.
- As the system becomes more complex, the special expertise needed to manage it increases.

The coverage and characteristics of fixed networks must be reviewed every now and then, paying attention to the changes in measurement technology and in the opinion of likely risks. One should keep in mind, though, that very often it is easier to cut down well-functioning activities than to re-establish them later under new circumstances.

As concerns mobile measurements, they have two important roles in the framework of emergency monitoring. On one hand, mobile measurements are needed to provide monitoring data from places not covered by the fixed networks and, on the other, in some occasions mobile measurements may be the principal means of obtaining adequate data about the current radiological situation. Ground-based vehicles and aircrafts can perform direct measurements, collect samples and transport various measurement devices to appropriate places. Mobile measurements constitute a tool used, for example, in fallout mapping and in searching for orphan radiation sources. In some cases the combination of ground-based and aerial measurements gives the best result. From a monitoring-strategy point of view, an important question is whether – given the likely threats, the nature of fixed networks and the amount of resources – to maintain many teams with simple measuring devices or only a few teams with highly sophisticated equipment.

Mobile measurements should be carried out in an optimum manner. All technical and practical factors affecting them must thus be identified in advance. For example, mobile teams are not operating continuously. Consequently, the time needed for preparations can be quite “long”, i.e. of the order of a few hours even at its shortest. Driving speeds of cars, as well as the flight lines and flight altitude of aircrafts must be suitable for carrying out the specific measurements in question[2]. Unfavourable environmental conditions (weather, topography) may impede measuring activities or prevent them totally. Emergency monitoring authorities should take all these aspects into account in the strategies. Training and in-field exercises are needed to maintain the expertise to use the measuring equipment effectively.

In addition to the proper measuring systems, mobile teams must also have adequate protective equipment. Team members must be trained to function as a

[2] In the future the UAVs (unmanned aerial vehicles) may offer an efficient platform for certain types of aerial measurements.

unified group of experts, which is able to work independently if needed and which can adapt to circumstances that may be stressful both physically and mentally. A further item to be considered in emergency plans and strategies is the problem of arranging accommodation and shift changes for teams operating far from the normal place of work.

3.2 Role of advance analyses of threats

Identifying the possible threats and analysing their potential radiological consequences in advance as thoroughly as possible is an important element in any strategy and thus one of the building stones of an emergency monitoring system. The range of accidents and events causing an emergency is large and covers nuclear explosions, accidents at nuclear facilities and vessels, crashes of nuclear-powered satellites, explosions of dirty bombs (radiological dispersal devices), lost or hidden radioactive sources, and others. Each case has special characteristics concerning the amounts and types of radionuclides potentially being released, time behaviour of release and primary exposure pathways. All of these are strongly reflected on the radiation monitoring activities and measurements needed to manage the situation at hand. Knowing the environmental consequences of potential scenarios in various environmental conditions allows authorities to prepare for them and to allocate resources for managing them. Practical experiences from the past accidents or events are of utmost value in this respect, too.

Calculation models, both probabilistic and deterministic, are valuable tools in different kinds of advance analyses. Probabilistic methods, however, are not always easily applicable in connection with monitoring strategy planning. Instead, results of deterministic studies with “worst case” scenarios (source term, environmental conditions) are widely used as a primary basis of ranking the threats and determining the nature and amount of resources needed. It is important that all analyses produce simple back-up tools (summaries, tables, figures, rules-of-thumb) and other support material that can be used in a real situation in case there are problems with more sophisticated systems. The same material also serves as a tool when preparing exercises for testing different monitoring strategies.

Threat analyses and other advance calculations can be used to help to define the minimum number and optimum locations for different types of fixed radiation monitoring stations around a known source site. It has been estimated, for example, that typically 20…40 dose rate monitors or iodine samplers are required to achieve reasonably acceptable detection probabilities concerning likely releases to the atmosphere in a nuclear power plant accident [Láng and Koblinger 1999]. In connection with the upgrade of the Norwegian gamma-monitoring network, the probable radiological threats and the corresponding density and placement of measuring probes have been briefly studied in [Lauritzen et al. 2005].

3.3 Source term

The nature of radioactive releases to the environment depends on a specific scenario. Some of the possible scenarios and the related source terms are described and discussed briefly below.

3.3.1 Nuclear explosions and power plant accidents

As regards environmental consequences, nuclear explosions and severe nuclear power plant accidents are the worst. In both scenarios lots of different radionuclides may be released into the environment and the radioactive cloud may be transported to great distances from the source point. There usually is a time period between the first recognition of a potential hazard situation and the very event causing the releases of radioactive substances: the political situation may have been getting more and more strained already during the previous weeks[3], or, concerning accidents at nuclear power plants and other facilities, the first notification of a possible emergency situation has been sent to authorities in due time before any release takes place. The period between the recognition and the actual release event allows authorities to alert emergency organisations and to plan and discuss in more detail different actions possibly needed to fight the specific threat they are facing. However, if a nuclear device is detonated by terrorists, there may be no warning time at all. Efficient material control and international co-operation between the authorities are needed to prevent illicit use of nuclear material for terrorist purposes.

There are a couple of major differences in the nature of the radionuclides released in the two scenarios above. These differences are due to the fact that both the composition of the original nuclear material and the time scale of the processes producing radioactive nuclides are different in the two cases. In a nuclear explosion device, the fissile material is either plutonium or highly enriched uranium and the explosion event during which radionuclides are produced is very short (of the order of fractions of a second), while in a nuclear reactor the fuel, which consists of low-enriched uranium or MOX, is irradiated for a long time, even for years. Consequently, the ratios of certain radionuclides are different in the two scenarios, and the observed differences (e.g. $^{137}Cs/^{134}Cs$, $^{140}Ba/^{140}La$, $^{95}Zr/^{95}Nb$) can be used as a basis when trying to find out whether the fallout is originated from a weapon or from a reactor. There is also a larger proportion of long-lived radionuclides in a reactor fallout than in a weapon fallout. Thus the radiation levels caused by a reactor accident decay slower than those associated with a nuclear explosion[4]; the initial radiation levels caused by a detonation of a large-yield bomb are though (naturally) much higher than the levels due to a reactor accident [Feller and Tsipis 1981].

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[3] Accidental fire or explosion using conventional explosives will probably not cause a nuclear weapon to detonate but may give rise to the release of weapon material (e.g. plutonium) to the environment.

[4] The decay of a weapon fallout follows approximately the famous "7:10 rule of thumb" which states that for every 7-fold increase in time after detonation there is a 10-fold decrease in the external dose rate. This simple rule is accurate to within 25 percent up to about two weeks and is applicable within a factor of two up to six months after the detonation.

From the monitoring point of view, most of the radionuclides released in the explosion of a nuclear weapon and in a severe nuclear accident are gamma emitters, which means that they can be detected with measuring systems representing well-known and widely-used technology (dose rate meters, gamma spectrometers). However, the radiological consequences in themselves are vast, and the proper management of the situation necessitates using a spectrum of radiation measurement technologies, as well as a programme of extensive environmental sampling to be adapted after the acute phase. Specifically, mobile car-borne and air-borne measurement teams are needed to map the fallout situation. The inflow of different kinds of measurement results is likely to be huge and automatic data handling systems (data bases, presentation systems etc.) are therefore a must. It should yet be kept in mind that in case of a nuclear explosion the whole technical infrastructure of the society may be disturbed or damaged to the extent that modern radiation monitoring systems and state-of-the-art ways of communication and data presentation are useless.

As concerns dose paths, in studies and consequence models related to nuclear explosions most of the interest in the past has been laid on the exposure caused by deposited activity and not so much on inhalation or immersion doses. In nuclear power plant accidents, however, inhalation is considered to often constitute a very important dose path.

3.3.2 Nuclear vessels

Accidents onboard a nuclear-powered ship or a surfaced submarine can result in a serious emergency if the vessel is sailing near the coast. However, as the thermal power of reactors is smaller than in commercial power reactors, the consequences of such accidents are likely to be less serious than those of an accident at a nuclear power plant. In addition, ship fuel – especially that used in submarines – has a greater enrichment than is customary in power plant fuel and, correspondingly, the proportion of long-lived transuranics is smaller.

The vessel reactors are mostly of the PWR type with a power of max. 200…300 MW_{th} per reactor. As regards submarines, the Russians prefer two reactors (fuel enrichment some 30…60 %) and the Americans one reactor (enrichment > 90 %).

3.3.3 Satellites and space probes

There are basically two types of nuclear power sources used in space applications: radioisotope thermoelectric generators (RTGs) and nuclear reactors. The RTG contains varying amounts – typically 1…10 kg – of a radioactive isotope, most often ^{238}Pu, ^{90}Sr or ^{210}Po, the natural decay of which generates heat that is used either to keep the systems on board the satellite at an optimal temperature or to power the systems and components through conversion to electricity via thermocouples. Currently, the RTGs are designed in the way that containment of the radioisotope fuel during re-entry and under many impact situations can be maintained[5].

[5] In November 1996 the plutonium battery of the Mars96 probe was impacted on the ground in South America (probably in Bolivia or Chile).

For high energy-demand in space applications, nuclear reactors are necessary. So far, reactors with a maximum power of about 50…100 kW_{th} have been used in satellites. The fuel used has been highly enriched ^{235}U (to save weight), and, for example, a reactor with a power of 100 kW_{th} requires 30 kg of ^{235}U. Reactor systems currently in orbit have been designed to disperse core material during the re-entry phase but in the case of unplanned re-entry the reactor can be boosted into a higher orbit.

A re-entry of a nuclear-powered satellite is usually foreseeable several weeks or months in advance, although there are some accident sequences that could occur within a much shorter time frame. The trajectory of the satellite can be calculated from observations and an estimate of the re-entry time made. The exact location of the re-entry and ground impact, however, cannot be predicted until – at best – only a few hours before the impact.

Regarding the re-entry of a reactor-powered satellite, the debris (large fragments, small particles, dust) will be dispersed over many thousands of square kilometres[6], and the main risk to people consists probably of exposure to external radiation from the debris. The urgency of searching the radioactive remains depends primarily on the population density within the area of deposition. In the case of RTG re-entries, if the containment of the fuel fails, the radioactive material may be dispersed into the environment. If the radioisotope in question is ^{238}Pu, which has a high ζ activity and which is very difficult to detect, there may emerge a potential radiation hazard also through inhalation.

In general, mobile radiation monitoring teams (ground-based, aerial) are likely to have an important role when searching and locating the remains of a satellite and when mapping the overall radiological situation. Priority should be given to dense populated areas and to searching highly radioactive pieces and particles. Apart from radiation measurement devices, infrared or other heat detection equipment can be used in the search.

OECD and later IAEA have published guides which provide a general overview of the management of emergencies caused by nuclear-powered satellites when they accidentally re-enter the earth's atmosphere and impact on its surface [OECD 1990, IAEA 1996].

3.3.4 Terrorism-like events and hidden radioactive sources

A dirty bomb (or a radiological weapon) is a conventional explosive packaged with radioactive material that scatters when the bomb goes off. Thus, a dirty bomb injures or kills through the initial blast of the explosive and by airborne radiation and contamination. The size of such bombs varies from very small devices to as big as a truck bomb, and there are different radioactive materials with military, industrial or medical applications that can be used in a bomb. Fresh spent nuclear fuel, as well as perhaps plutonium and uranium, would cause the largest environmental consequences but are also the hardest to obtain and handle. Gamma-emitting radioisotopes used in industry and medicine (such as ^{60}Co, ^{137}Cs,

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6 The debris from Cosmos 954 covered an area of 100000 km^2 in Canada in 1988.

^{192}Ir) are therefore more likely be put in a dirty bomb[7]. Pure beta emitters like ^{90}Sr (used e.g. in beacons and lighthouses) may also be applied in a bomb because then only a comparatively light radiation shield would be required to enable safe handling of the material before the explosion. The IAEA has published a document providing a logical system for ranking radioactive sources based on their potential to cause harm to humans and for grouping the practices in which these sources are used into discrete categories [IAEA 2003b]. Lists of important radionuclides and descriptions of potential sources can be found also e.g. in [USACHPPM 1999] and in [Fergusson et al. 2003].

The action of exploding dirty bombs will probably take place in urban environments and without any pre-warning, which sets certain requirements for emergency monitoring arrangements. Mobile teams, for example, will be needed urgently to measure radiation levels and to map contaminated areas and surfaces. In addition, typical dispersion and dose forecasting models may be of minor value in analysing the situation since only a few of them can manage dispersion in urban surroundings in case where the explosion takes place at the ground level or just above it. Radiological consequences of a dirty bomb explosion in a population centre will probably be local and rather limited – psychological effects on the public may be immense, however.

Radioactive material can release to the environment in intentional or unintentional fires, too, but the related problematics are rather similar to those discussed above. Stolen radioactive sources or material can also be used in blackmail, to irradiate persons or to contaminate food and water supplies.

Generally, searching for lost or hidden radioactive sources often calls for mobile measurements. In the case of poor gamma-emitting nuclides, like plutonium or uranium isotopes, locating a single orphan source can turn out to be a very laborious task.

Keeping track of all potentially harmful radioactive sources and material and assuring security of them in all conditions is an essential means in trying to prevent their illicit or malevolent use.

3.4 Environmental factors affecting radiation measurements

Environmental and surroundings-related factors affect both the behaviour of releases and performing of proper radiation measurements. Here we discuss only releases into the atmosphere.

3.4.1 Weather conditions

Prevailing weather conditions play an important part in the consequences of an accident with radioactive substances to the atmosphere. Airborne radioactive releases are transported by the wind, spread and diluted by (turbulent) atmospheric processes and deposited onto the ground by dry and wet scavenging.

[7] In [ANS 2003] ten materials are considered: americium, californium, cesium, cobalt, curium, iridium, plutonium, polonium, radium and strontium.

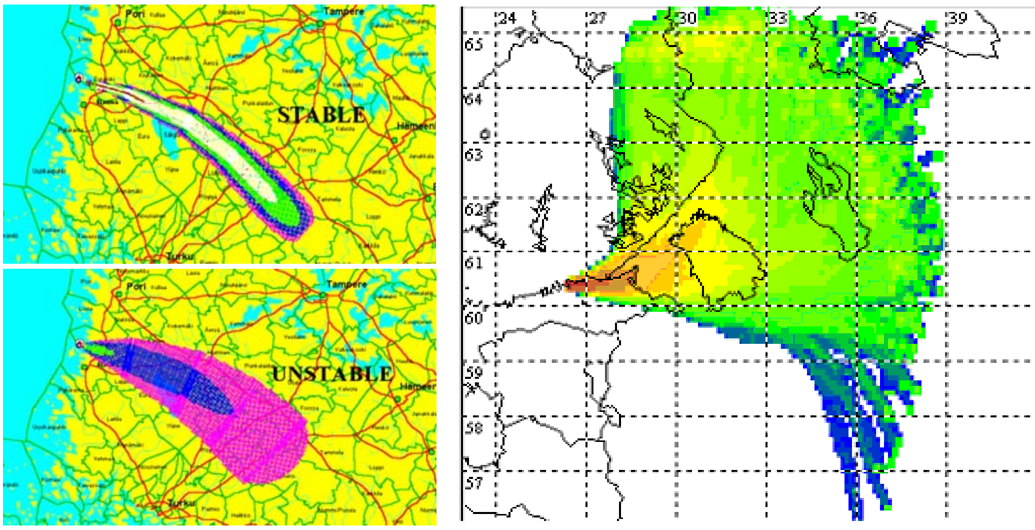
Meteorological situation also partly determines the initial elevation of a buoyant plume.

As a rough rule-of-thumb, in stable atmospheric conditions a plume causes high radiation levels on a small area while in an unstable situation radiation levels are lower but the affected area is larger (Fig. 3.1 a). Rain always increases dose rates at the ground level because of increased deposition. Furthermore, in the worst case bad weather (stormy wind, heavy rain, fog) might completely prevent performing of certain measurements, such as air-borne measurements.

In general, wind and turbulence conditions can change very rapidly both in space and in time (see Fig. 3.1 b); examples of these kinds of phenomena are land and sea breeze, as well as heating of the ground surface during a sunny summer day resulting in a drastic change of atmospheric stability during a period from morning to late afternoon. A release plume may also initially rise very high and move with the wind without causing any observable concentrations at the ground level till the mixing conditions change and the plume quite suddenly touches the ground (or there is a heavy rain shower).

It is clear from the above that the role of weather conditions must be included in radiation monitoring strategies and in the practical management of measurements during an emergency. Meteorological data and real-time dispersion and dose forecasting models provide the authorities with tools that can be used to estimate the influence of atmospheric conditions on measurements and to co-ordinate and plan measurement activities: when one should measure, where one should measure and also – in the case of mobile monitoring teams – where one should not go in order not to expose the patrol to too high radiation levels or not to cause an unnecessary contamination of measuring equipment. However, it must be kept in mind that all dispersion models have generic limitations or flaws caused by the simplified basic assumptions and incomplete algorithms underlying them. In addition, meteorological input data used in them may be too inaccurate or unrepresentative to be reliably applied in the situation at hand.

Sometimes problems can be encountered in connection with comparing measurement results with those calculated by forecast models: measurement results – especially dose rates – often represent the situation prevailing during a brief time interval (max. a few minutes) while different models usually produce output that consist of mean values averaged over a longer time period (which may be hours). This must be taken into account also in data assimilation, i.e. in improving calculation estimates on the basis of radiation measurements.



a) b)

Fig. 3.1. Examples of influence of atmospheric conditions on dispersion of release plumes.

a) Dispersion patterns in unstable and stable conditions. b) A hypothetical multi-hour release. Near the source the plume has remained confined all the time but at larger distances it has experienced very variable dispersion conditions.

Figure a) was produced by the Radiation and Nuclear Safety Authority (STUK) using a simple Gaussian model AINO [Lahtinen 2006] and b) by the Finnish Meteorological Institute (FMI) and the VTT Technical Research Centre of Finland using a state-of-the-art Lagrangian particle model SILAM [Sofiev et al. 2006].

3.4.2 Urban vs. rural surroundings

From the point of view of atmospheric dispersion, there are two principal properties that can be identified as characterizing the distinction between urban and rural land surfaces. These are a higher temperature (and, correspondingly, a greater heat flux) and a greater surface roughness. As a result, a release plume experiences enhanced mixing and dilution as it moves from rural environment to towns and cities. Furthermore, in the case of a release actually occurring in the middle of a population centre (e.g. explosion of a dirty bomb), the authorities must understand the nature of the influence of surrounding structures on short-distance dispersion: wake areas behind the buildings, channelling of air flows along the street tunnels, lots of surfaces exposed to deposition, and so on. General dispersion models are of limited use only in urban areas.

In urban surroundings the basic aim of countermeasures is to minimize all external doses (caused primarily by radiation from the release cloud and from deposition) as well as the dose due to inhalation of radioactive materials while in rural areas the countermeasures must also include those concerning the production of foodstuffs. This fact is naturally reflected on the types of radiation measurements needed.

3.5 Characteristics of an emergency monitoring system

In the preceding sections we have considered several important factors having influence on preparing monitoring strategies and on performing proper and timely radiation measurements. In this section we try to summarize the basic characteristics of a comprehensive operational emergency monitoring system.

3.5.1 General structure

A radiation monitoring system must be capable of operating in three modes: in routine conditions, in the early phases of an emergency situation and in the late phases. Generally, monitoring systems can be seen as consisting of different modules. The basic modules are [see e.g. Weiss 1997]:

1. Monitoring systems at fixed stations, which are either operated in a fully automatic mode (on-line) or in a semi-automatic mode (off-line). Typically, dose-rate measuring stations and air sampler stations represent this kind of systems. In most countries the national early–warning networks are based on automatic dose-rate monitoring networks (see Table 3.1). However, air samplers equipped with a system for real-time monitoring of the filter can be included in the early-warning network, too.

   In many countries there are additional fixed sites where dose rate measurements are performed with a portable meter either at regular intervals or in case of a real radiation situation.

   The regular environmental-sampling programmes can (in a way) be considered to belong to this monitoring module since the sampling sites are fixed.

2. Mobile measuring systems. These are special units (ground-based vehicles, ships, helicopters, airplanes) capable of performing *in situ* measurements as well as collecting various kinds of samples. Mobile units can also be used to take stand-alone measuring devices to the field.

3. High-standard special laboratories for the measurement of various types of environmental and food samples.

The modules can be combined and integrated in various ways; examples include moving “emergency laboratories” which often are capable of both carrying out *in-situ* measurements and analysing environmental samples. In practise, however, the proper management of an emergency requires the use of a few additional modules:

4. Technical systems for fast and reliable data transfer. Data transfer is a crucial element in the overall performance of any state-of-the-art radiation monitoring system.

5. Atmospheric (or hydrological) dispersion and dose prediction models and decision support systems. The interface between measurement results and computer-based forecast and decision support systems (DSS) is important

(e.g. data assimilation, guidance of measurement activities on the basis of forecasts). Regarding data assimilation, it seems that methods based on Kalman filtering are [e.g. Astrup et al. 2004, Gering et al. 2004b] and Bayesian analysis [French and Smith 1997] are of interest.

6. <u>Systems for creating and displaying the overview of the radiation situation</u>. These systems can be integrated with DSSs or they can be independent systems with appropriate interfaces with the prediction models and DSSs. Whichever the technical solution is, the system must contain components for gathering, processing, storing and displaying different data, as well as for sending the output (i.e. the situation analysis reports) to other parties and systems.

The way the different modules are used in a nuclear or radiological emergency depends on the situation at hand and on the technical characteristics of the modules. Decisions on the measurements and countermeasures needing to be carried out next are generally based on the knowledge of current radiological situation and its likely evolvement. Systems contributing to carrying out situation analyses effectively and reliably are therefore of vital importance in any emergency monitoring system.

All equipment, procedures and arrangements intended to be applied in an emergency should be used to some extent also in routine conditions or at least tested regularly (several times a year). It is only then that the working order of measurement systems can be guaranteed and the expertise of personnel maintained.

3.5.2 Measurements and sampling

An emergency monitoring authority must be prepared to cope with a variety of radiation situations with different source terms, time behaviour and exposure paths. The management of these situations calls for a selection of measuring and sampling devices and systems, a list of which was shown earlier in Table 3.3. Each of the systems mentioned in the table has specific advantages and disadvantages which have been discussed elsewhere (in, for example, [OECD 2000]). Here, only a couple of additional general-level remarks are presented.

It is important to know in advance all characteristics of a particular measuring system, including, for example, information about the behaviour of the dose-rate measuring devices at high dose rates and actual capacity of performing different types of laboratory measurements. There should also exist plans to be applied in case some devices are broken or otherwise unavailable, as well as well-documented calibration procedures for the most probable non-routine situations.

One possibility would be to systematically classify all available measuring instruments in a few groups according to their usability in monitoring of different radiological quantities (directly or indirectly). This classification should be complemented with a collection of pre-determined simple relations, such as those that could be applied for estimating dose rate levels from the observed radionuclide concentration in the ground-level air.

Radiation monitoring authorities and emergency organisations must realize that in a severe fallout situation there will be lots of environmental samples to be collected and analysed and, perhaps, lots of mobile measurements to be carried out. Consequently, there should be legislation or pre-negotiated arrangements and agreements allowing the use of all competent personnel and all adequate equipment available in a country. Just to give a couple of examples: municipal health and food laboratories can easily take care of some sampling and analyzing work needed in an emergency and conscripts or permanent military staff can be trained to perform (at least) the simplest types of mobile measurements (dose rate measurements with hand-held GM devices).

3.5.3 Data transfer

Fast and reliable data transfer is one of the key elements of a well-functioning emergency monitoring system. From a technical point of view, data communication can be based on telephone lines, wireless radio applications, internet connections or satellite phones. Currently there are several concepts applicable also to the data communications to and from mobile monitoring systems.

The important general requirements are that – if necessary – data can be encrypted and authenticated and that there exist back-up arrangements. For instance, one cannot always rely on public internet connections, which may be broken or overloaded in a real emergency and which seem to be quite vulnerable to malevolent actions.

Data formats are very important, too. They should be standardized but yet be flexible enough to allow the transfer of various kinds of radiological information. A promising format candidate is the XML (eXtensive Markup Language).

3.5.4 Data management and presentation

A modern radiation monitoring information system must be able to carry out several tasks:

- To gather/receive measurement results, forecasts and other relevant information.
- To store various kinds of data, i.e. the system should contain sophisticated data bases.
- To analyse measurement data and forecasts in order to create an overview of the situation.
- To communicate with the decision support systems and other prediction models.
- To display and disseminate different kinds of situational analyses and overviews.

The system itself can consist of one large multi-task module or a group of distinct modules, each performing one or more specific tasks and having appropriate interfaces with the other modules. There are, however, a few major basic problems that have to be considered in advance when designing such a system:

- How to combine and display different kinds of measurements results, such as, for example, dose rates from fixed networks and those measured by mobile teams?
- How to combine measurements and dose predictions in an optimum manner? Data assimilation aspects?
- How to create situation-analysis reports for different purposes (experts, decision makers, media, the public)?
- How to account for the uncertainty of data and avoid possible misinterpretations?
- How to arrange back-up systems and procedures?

All output – whether it is graphical or plain text – should be given and disseminated in a format agreed upon and understood by all parties involved: standardized formats should be used for all common output reports and displays. In addition, generation of the most typical output should be automated so as to decrease time delays and the probability of human errors.

3.6 Representativeness and interpretation of monitoring data

The quality of measurement results (e.g. uncertainty and representativeness) is an important parameter that should be considered in all monitoring systems and strategies because it is directly connected with the correctness and reliability of situation analyses.

There are many sources of uncertainty of results: equipment malfunctions, variations in natural background radiation, statistical uncertainties and user errors. Measurements may be carried out in an incorrect manner or the displayed result may be read erroneously. For example, when performing dose rate measurements with a portable meter, it is important to wait until the displayed result represents the real dose rate value with the intended integration time. In case of radiation levels close to the background, this may take several minutes.

There may be excellent user guides and well-organized user training, and in certain cases severe equipment failures can be identified by check measurements. Yet it is impossible to detect all errors and uncertainties. Small errors and deviations are usually not very significant during an emergency because it is the order of magnitude that counts. However, there are also exceptions: if the results are close to an intervention level, even a relatively small uncertainty in the monitoring data can influence strongly the decision on whether to implement a certain countermeasure or not.

In general, all calibrations of measuring devices are of major importance and should be checked regularly. A wrong calibration causes systematic errors that can be detected only through reference measurements or intercomparisons. One should also keep in mind that despite the high quality of measurements there can be errors in the final output values (doses) caused by erroneous dose conversions factors used. Naturally, all conversion factors and other data libraries should be updated when there is new widely-accepted information available.

Although the measurement data were correct, there is the question of the adequate representativeness and interpretation of results. As regards external radiation measurements, it is often impossible to determine whether the observed dose rates are caused by radioactive substances in the air, on the ground, both or by a hidden radiation source (Table 3.4). In addition, a narrow release plume may, in certain atmospheric conditions, meander strongly, which results in cyclical or near-cyclical variation of external dose rate observed at the ground level. If the physical distance between the receptor point and the plume axis is short, this variation can be large and cause misinterpretations when one tries to evaluate the local dose-rate trend on the basis of only a few consecutive measurements of short duration.

Another difficulty is related to the comparability of measurement data originating from different monitoring stations. It is important to know the characteristics and details of all measuring sites (e.g. exact location of the probe, surrounding man-made structures and vegetation). In Germany, for example, a systematic procedure for establishing a dose-rate monitoring site description and categorisation scheme has been developed [Zähringer and Pfister1998]. Besides different high man-made structures and vegetation around the detector (see Table 3.5), detector position above the ground, possible surface runoff, near-by gutters and sewers as well as small-scale surface unevenness are factors to be taken into account when analysing the representativeness of measuring sites.

Table 3.4. An example of source strengths of different geometries generating the same external dose rate levels.

Source strengths have been normalized so that dose rate levels caused by sources representing different geometries are the same as those caused by a unit-strength line source.

Gamma energy [MeV]	**Line source**[1] [Bq m^{-1}] Distance 50 m	**Point source**[2] [Bq] Distance 10 m	**Semi-infinite**[3] [Bq m^{-3}]	**Disk source**[4] [Bq m^{-3}] 50 m thick layer between 100–150 m above ground	**Surface source**[5] [Bq m^{-2}] Exposure at 1 m above ground
0,3	1.0	5.9	3.7E-05	3.2E-04	1.7E-03
0.5	1.0	5.5	3.3E-05	2.8E-04	1.6E-03
1.0	1.0	5.1	2.9E-05	2.3E-04	1.5E-03
1.5	1.0	5.0	2.6E-05	2.1E-04	1.5E-03
2.0	1.0	5.0	2.4E-05	2.0E-04	1.4E-03
2.5	1.0	5.0	2.3E-05	1.9E-04	1.4E-03

1) Represents situation aside of a narrow very long plume.
2) Single “hot particle”.
3) Thick and broad cloud touching the ground far from the release site.
4) Broad cloud floating above an inversion layer.
5) Fresh fallout on an open flat location.

Table 3.5. German procedure of point reduction for irregularities [Zähringer and Pfister 1998].
A subraction of 30 points corresponds to the categorisation "not acceptable".

	Point subtractions				
Distance from probe [m]	Buildings and high walls (h > 1 m)	Small walls and elevations (h < 1 m)	Large trees (h > 10 m, base area > 50 m^2)	Medium size trees (5 m < h < 10 m, base area 10 m^2…50 m^2)	Small trees, bushes (h < 10 m, base area < 10 m^2)
0…3	30	10	30	30	30
3…7	3	2	30	5	3
7…20	2	1	5	2	1

The discussion above was mainly concentrated on monitoring of external radiation but more or less analogous types of problems can be met in connection with other kinds of measurements, too. In case of environmental sampling, all samples of a certain type should be collected and analysed in the same way; if this is not taken care of in a proper manner, reliable comparison of results representing different sampling locations may turn out to be virtually impossible. The topographical features around air samplers are also important to know because in certain conditions they have a decisive influence on whether the sampler is exposed to a local small-scale flow pattern only or sucks the air reflecting large-scale movements of air masses.

3.7 International co-operation

An atmosphere suitable for co-operation prevails especially in the aftermath of severe nuclear or radiological accidents (such as the Chernobyl accident) and other shocking events (the terrorist attack on 11 September 2001). There are currently several international and bilateral conventions concerning notification in an emergency, as well as agreements on technical assistance and radiological data exchange such as the data exchange agreement of the countries belonging to the Council of the Baltic Sea States or participating in the European EURDEP data exchange project [EC 1996].

Different types of large exercises – including field-measurement exercises [NKS 1997, NKS 2000b, NKS 2002c] – are organised every now and then. IAEA also has plans of creating an international network of mobile expert teams with adequate monitoring equipment [IAEA 2000]. Furthermore, within the EU there are on-going study projects and discussions concerning the idea of establishing two or three European centres for managing air-borne measurements.

Naturally, all efforts aiming at reasonable international harmonisation of radiation measurements and monitoring strategies should be encouraged, although the starting point and overall conditions may vary considerably from a country to another. For example, different countries may also have different radiation-protection-related procedures as well as different monitoring strategies and arrangements. As a result, measured values from one country cannot necessarily be directly compared with those from another country. It is thus no wonder that the standardisation and harmonisation work has achieved the best results in “neutral” areas, like data formats intended for use in the international radiological data exchange. Regardless of the exact nature or contents of any agreement or arrangement, all systems and procedures should be tested on a regular basis.

International co-operation, support and sharing of various resources [IAEA 2000, Rojas-Palma et al. 2004, Toivonen 2004] must be included as a factor in a national emergency monitoring strategy[8]. In practise, the nature and quality of radiation monitoring systems in the neighbouring countries (especially in respect to potential source sites) is in itself a factor that probably has affected to a certain extent monitoring strategies of some countries.

However, no country should rely too heavily on any possible assistance assumed to be given by other countries or international organisations. Not only may there be simple technical problems with the systems and channels intended for use but also the radiological situation can be so severe that it influences several countries simultaneously – thus introducing questions of overall international resources and of ranking the needs of support of different countries.

[8] In practice, the nature and quality of radiation monitoring systems in the neighbouring countries (especially in respect to potential source sites) is in itself a factor that probably has affected to a certain extent monitoring strategies of some countries.

4 Good strategy in a nutshell

In this chapter we summarize briefly the basic characteristics of a good emergency monitoring strategy. A monitoring strategy should be versatile and realistic and it should have provisions for various back-up arrangements needed in case of problems with the primary measuring equipment or expert personnel. A strategy, however, must not give the impression that it is universal and covers all possible situations. There may be accidents or events not included (even) in a well-defined, comprehensive strategy plan. Thus, a strategy should not kill the creativity of the emergency authorities or the use of the common sense.

In an ideal case, an emergency monitoring strategy could be defined on the basis of the following items and aspects:

- The strategy has interfaces with various societal and economic factors and takes into account all stakeholders.
- Likely threats have been identified and their consequences analysed in advance. In addition, necessary extra resources have been allocated.
- There exists a well-functioning infrastructure (measurement systems, personnel), including an early-warning system, for carrying out routine monitoring activities.
- The relations between fixed and mobile monitoring systems are defined and their main uses understood.
- General dependence of radiation measurements on the accident characteristics, source term, season, environmental conditions, measurement location and measurement method are recognised and all possible difficulties related to the uncertainty and interpretation of results are understood.
- There are fast and reliable means of data communication.
- There exists a system for preparing situation analyses. Related problems, such as combining results from fixed networks and mobile measurements have been identified.
- There are interfaces between measurement results and different forecasts or decision support systems that both enable the correction of predictions on the basis of monitoring data and support the management of measurement activities on the basis of predictions.
- There are realistic yet flexible plans for sampling and laboratory measurements.
- Specific needs of mobile monitoring teams are taken care of (accommodation, team shifts etc.).
- There are proven back-up systems and procedures at all levels.
- Possibilities offered by international assistance and co-operation are recognized.

In many countries the actual situation tends to be worse, however. In that case the only possibility is to create a strategy which is consistent with the framework set by the existing reality and then use the above list as “a reminder of how it should be”.

The applicability of any emergency monitoring strategy must be tested regularly in different kinds of exercises (table-top exercises, drills, field exercises). A strategy should also be updated whenever appropriate. The need of update could be generated, for example, by the identification of a new threat scenario or by the acquirement of a new type of measuring equipment.

5 Situation in the Nordic countries

5.1 General background

The Nordic countries have had many years of close co-operation in the fields of radiological data exchange and research on matters of emergency preparedness, nuclear safety and radiation protection. Yet concerning radiation monitoring, the countries have taken partly different approaches (Table 5.1).

As regards the possible scenarios, there are threats more or less equally common to all of the Nordic countries (dirty bombs, lost radiation sources, use of nuclear weapons, accidents at far-locating nuclear facilities) and threats that are more emphasized in some countries than in the others. For example, Finland and Sweden have several nuclear power plants of their own and Denmark is very interested in the consequences of a severe accident at the Swedish Barsebäck plant while nuclear submarines are a cause of concern for Norway and Iceland. In addition, the Russian (Kola, Sosnovyy Bor) and Lithuanian (Ignalina) power plants constitute a potential hazard analysed thoroughly in almost every Nordic country. Many of the scenario studies carried out in the Nordic Countries are public but there are also confidential reports intended only for use of national authorities. An example of the public studies is a project [NKS 2002b] in which a common base of knowledge containing information about the nuclear threats in the vicinity of the Nordic Countries was established.

5.2 On Nordic emergency monitoring strategies

There are no public reports describing in a detailed manner an emergency monitoring strategy of a specific country or the factors affecting it. It can be judged, however, that there are clear differences in the strategies. In Finland, for example, there were already in the 1970's manual dose-rate-measurement stations almost in every municipality (> 400). Thus it was rather straightforward to gradually automate the system after the Chernobyl accident. A dense automatic network also means that there is no need of a great number of manual monitoring sites or mobile teams equipped with only simple measuring devices: the automatic system is able to produce an overview of the nation-wide external dose-rate situation within half an hour.

In addition to the automatic network, there are in Finland still many municipal monitoring sites where dose rates are measured regularly with a semi-automatic or manual system, as well as pre-determined locations (around the nuclear power plants, for example) where measurements are to be performed during an emergency. All aims of keeping up the expertise on performing manual measurements in a proper manner are still important and must be supported.

In contrast to Finland, the other Nordic countries have quite small automatic dose-rate monitoring systems. In Sweden the strategy and organization for radiation monitoring in case of a large-scale fallout developed first from a scarce automatic network and a few mobile monitoring teams with simple equipment to an organization with specially designed instrumentation and detailed planning for different time phases of an accident. However, mobile monitoring was found to be very difficult to conduct in a way needed to provide an optimum performance. It was also found that stationary monitoring provided more data per time unit and a larger amount of reliable information (using the same number of teams).

Consequently, about 900 sites[9] were chosen where manual measurements are planned to be made in a large-scale release situation. After the release has stopped, mobile monitoring will commence in order to obtain better geographical resolution of the possible fallout areas.

Table 5.1. Radiation monitoring systems in the Nordic countries**.**
Based primarily on [NKS 2000]. Note that the figures given may not be directly comparable in all respects. Note also that there are differences also in the nature and characteristics of measuring equipment in one country compared to the equipment in another country.

	Denmark	**Finland**	**Iceland**	**Norway**	**Sweden**
Gamma monitoring; automatic	11	330[b]	1	22	37[e]
Gamma monitoring; manual or semiautomatic	0	c. 150	0[c]	No	900[f]
Survey teams	Yes	Yes	Yes[d]	Yes	Yes
Aerosol sampling stations	1[a]	29[g]	1	7	5
Aerosol on-line monitoring	0	13	0	0	0
Airborne measurements; mapping	Yes	Yes	No	Yes	Yes
Airborne measurements; sampling	No	Yes	No	Yes	No
Environmental sampling	Yes	Yes	Yes	Yes	Yes
Food sampling	Yes	Yes	Yes	Yes	Yes
Field gamma spectrometry	Yes	Yes	No	Yes	Yes
Contamination checks of cars, goods	Yes	Yes	Yes	Yes	Yes
Whole body counters	Yes	Yes	No	Yes	Yes

a) One on stand-by.
b) Includes stations of the early-warning network and stations administrated by the Finnish Meteorological Institute and the Defence Forces.
c) Two stations planned.
d) Organized as needed.
e) Does not include gamma monitoring stations situated in the surroundings of nuclear power plants.
f) Measuring activities are not carried out continuously but upon request from SSI (in some 250 municipalities).
g) Includes the eight stations around the NPPs of Loviisa and Olkiluoto.

9 The natural background levels and seasonal variations at these sites were studied by performing a series of reference measurements during several years [Finck 1996].

From a monitoring strategy point of view, the choice of Sweden not to build a large automatic dose-rate monitoring system is reasonable, since all neighbouring countries (especially Finland) have well-functioning automatic gamma-monitoring networks.

As concerns Denmark and Norway, both countries have several monitoring sites with continuous on-line gamma spectrometry.

Practically taken in every Nordic country there are at present on-going activities related to upgrading or enhancing the monitoring systems. For example, Finland and Norway are modernising their automatic gamma monitoring networks, and Sweden has plans for improving the mobile system network as well as the laboratory network.

6 Conclusions

There exists a variety of different factors affecting the bases of national emergency monitoring strategies. The so-called static factors form a wide, partly nation-specific spectrum of subjects including: routine monitoring systems; population, area and topography; nuclear and radiological threats identified; country's own experience of the consequences of earlier accidents; and public attitude towards emergency planning and civil defence. In addition, there are dynamical factors, like the scenario and prevailing environmental conditions, which become clear only at the beginning of an accident or other event.

A good emergency monitoring strategy starts from the advance identification of potential hazard situations and extends to environmental sampling performed during the late phases of an accident. It combines the arrangements and systems applied in routine monitoring with the special requirements set by emergency monitoring, and the use of fixed monitoring stations with that of mobile measurement teams. It contains elements for analysing, transmitting and presenting measurement data, as well as for linking the data with the input/output of different forecasting and decision support systems. It also takes into account the various intrinsic characteristics of potential threat scenarios and includes options for adapting measuring activities according to prevailing environmental conditions. Furthermore, it has relevant links with the social and economic realities of the society, as well as with different kinds of international co-operation activities.

Generally, preparing a comprehensive yet versatile strategy is not an easy task to perform. One possibility, which is briefly presented also in this report, is to first identify all factors possibly affecting a strategy and then to pose a series of adequate questions, to discuss them thoroughly and, finally, to answer them in a strategy plan and related documents.

As regards an emergency monitoring system, it should have the following modules or sub-systems:

- Monitoring systems at stationary stations.
- Mobile measuring systems.
- High-quality special laboratories.
- Technical systems for fast and reliable data transfer.
- Atmospheric (or hydrological) dispersion and dose prediction models and decision support systems.
- Systems for creating, displaying and disseminating continuously an analysis report of the current radiation situation. Possible uncertainties of measurement results and misinterpretations concerning their significance and representativeness must be taken into account in the analysis reports and radiation-situation overviews.
- Back-up tools and arrangements.

The overall conditions and relative emphases put on various strategy-related factors are not similar in all Nordic countries and, correspondingly, there are differences also in the emergency monitoring systems and monitoring strategies. Nevertheless, a common understanding of the factors and conditions affecting radiation monitoring both at the strategy level and practical level contributes to regional and international co-operation.

Some results of the study addressed in this report have been published in scientific journals or presented in conferences [Lahtinen 2003, Lahtinen 2004, Lahtinen et al. 2006].

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10 Disclaimer

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The references to specific devices, tools and software do not indicate special endorsement by the NKS.

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Abstract

This report is one of the deliverables of the NKS Project Emergency management and radiation monitoring in nuclear and radiological accidents (EMARAD) (2002–2005). The project and the overall results are briefly described in the NKS publication “Emergency Management and Radiation Monitoring in Nuclear and Radiological Accidents. Summary Report on the NKS Project EMARAD” (NKS-137, April 2006).

In a nuclear or radiological emergency, all radiation measurements must be performed efficiently and the results interpreted correctly in order to provide the decision-makers with adequate data needed in analysing the situation and carrying out countermeasures. Managing measurements in different situations in a proper way requires the existence of pre-prepared emergency monitoring strategies. Preparing a comprehensive yet versatile strategy is not an easy task to perform because there are lots of different factors that have to be taken into account.

The primary objective of this study was to discuss the general problematics concerning emergency monitoring strategies and to describe a few important features of an efficient emergency monitoring system as well as factors affecting measurement activities in practise. Some information concerning the current situation in the Nordic countries has also been included.

Key words: Emergency preparedness; Radiation monitoring strategy; Emergency measurements.

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