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Co-ordination and modernisation of methods for AGS and CGS measurements of multi-nuclide contamination Report from a seminar

Edited by Uffe Korsbech
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Abstract

Earlier projects within NKS have unveiled that Nordic teams performing Airborne or Car-borne Gamma-Ray Spectrometry (AGS and CGS) used different definitions and methods for data processing and presentation. The differences were clarified and proposals for how to obtain consistent results in the future were suggested. The investigations almost all concerned caesium-137 being the only artificial nuclide that today could be measured in the environment with ordinary AGS and CGS equipment. Therefore it was decided to initiate within NKS an examination of how to map other fall-out nuclides with AGS and CGS. As a first step a seminar was arranged on 17-18 October 2002. Here the participants presented how they would handle the mapping of four pre-defined fall-out scenarios. The presentations and discussions at the seminar showed that carrying out the measurements for some of the scenarios would be difficult or even impossible with ordinary equipment and data processing techniques presently used by some of the teams. Mapping of very high levels of contamination could be a problem. Also mapping of a mixed-nuclide fall-out with iodine-131 at a concentration close to the action/no-action levels could be difficult. The seminar resulted in a list of problems deserving attention. Among those was the question on when to prefer high sensitivity NaI detectors and when to prefer high resolution HPGe detectors. A common definition on "detection levels" was also needed. Here the generation of sets of spectra with different levels and combinations of fallout nuclides was proposed. Among the outcomes of the seminar were two proposals for future NKS projects; one concerned mapping of low levels of iodine, and the other was a method for generation of strip factors from ordinary survey spectra.

Key words

Mapping, contamination, AGS, CGS, fallout, multi-nuclide, iodine-131, Caesium-137, dose rates, detector saturation

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REPORT FROM THE NKS SEMINAR AT DEMA 17-18 OCTOBER 2002

ON

Co-ordination and modernisation of methods for AGS and CGS measurements of multi-nuclide contamination

with contributions from
DEMA, DTU, NRPA/NGU, RISØ, SSI/SGU/FOI and STUK

Edited by Uffe Korsbech

February 2003

Contents

Introduction and summary

A seminar on “Co-ordination and modernisation of methods for AGS and CGS measurements of multi-nuclide contamination” was held at DEMA (Danish Emergency Management Agency) on 17-18 October 2002. Persons from DEMA, DTU, FOI, LUND, NGU, NILU, NRPA, RISØ, SGU, SSI, and STUK joined the seminar. The goal of the seminar was to discuss common problems and common solutions related to mapping of fresh contamination containing different nuclides and at different levels of contamination.

On beforehand the participants had received a description of four different fallout scenarios where the tasks were to perform dose rate or iodine-131 concentration mapping with Airborne Gamma-Ray Spectrometry (AGS) or/and Carborne Gamma-Ray Spectrometry (CGS). One scenario concerned mapping of high dose rates at ground level, and two scenarios concerned mapping of iodine-131 (together with other fission products) at levels close to presumed "action levels" (2 to 20 kBq/m^2). The fourth scenario concerned mapping in a town of a mixed contamination at levels that might have to be followed by restrictions. The scenarios are described in the section "Scenarios discussed at the seminar". The participants were invited to present solutions to scenario problems at the seminar.

DEMA discussed the mapping of high dose rates using AGS and/or CGS and the presentation unveiled that smaller NaI detectors than those commonly in use today - and perhaps also smaller Ge detectors - were needed for both AGS and CGS measurements. Mapping of mixed nuclide fallout at low levels would be carried out with Danish standard data processing techniques including NASVD (Noise Adjusted Singular Value Decomposition). However, mapping of iodine-131 contamination may be difficult if the relative concentration of fallout nuclides vary in time and space.

SSI with SGU and FOI presented how a Swedish mapping according to the "iodine scenarios" could be carried out - partly based on the experiences from mapping of Chernobyl fallout in 1986 and later. HPGe detectors would be used for mapping fallout nuclides. Mapping of iodine-131 at the assumed low contamination levels and mixtures might be a problem. The other scenarios were also discussed. The main elements of the presentation are shown in Appendix A.

STUK presented the how the Finnish measurements could be performed. Both AGS and CGS equipment are available. High contamination levels could for example be handled with a HPGe detector flying at higher altitude than 100 m. Some low level iodine mapping could be done with a HPGe detector flying at low altitude, but probably the lowermost levels of interest would have to be measured with a NaI detector. Where to use primarily HPGe detectors and where to use NaI detectors ought to be clarified. For mapping of a town both CGS and AGS (helicopter) would be needed.

Both SSI and STUK stressed that AGS and CGS will have to be supplemented with *in situ* measurements and sampling.

DTU presented a special technique for processing NaI spectra that in some cases may solve the "iodine-131 mapping problem" at the 2 to 20 kBq/m^2 level. However, only preliminary investigations had been carried through.

After the seminar a common contribution from NRPA and NGU was received. It described the Norwegian equipment for AGS and CGS measurement and how to handle the four scenarios discussed at the seminar. Neither AGS nor CGS equipment will be used until after the release of radioactivity has ceased in order to avoid contamination. However, some measuring systems can be used in rented cars and hired aircrafts wherefore contamination of the carriers is a minor problem. AGS measurements will at first be used for a determination of the outer borders of a contaminated area. In order to be able to handle very different dose rate levels it is the idea to include detectors of different volumes. Norwegian participants pinpointed that due to the mountainous terrain in Norway the flight lines for AGS mapping are more difficult to plan for than in other countries, and constant surveying altitude cannot be obtained. According to NGU the calibration of the equipment for measuring multi-nuclide fallout will be carried out based on the results from dose rate instruments.

The presentations and comments added afterwards are described in greater details in the later sections.

The seminar participants afterwards discussed the topics of the presentations, and ideas and problems were exchanged. Some of the problems and possible solutions are listed in the section "Special AGS and CGS topics discussed". A significant part of the discussions concerned the question on where to use HPGe detectors and where to use NaI detectors, or to put in another way, where to prefer high resolution detectors instead of high sensitivity detectors and vice versa. It was a general feeling that this was a question that had to be investigated. Another question concerned how to get stripping parameters for NaI detectors to be used for different tasks. Also the possibilities for getting realistic sets of "contamination spectra" for test of different data processing techniques were discussed. Another topic of common interest was the definition of detection level. A common agreement on how to use the term in different situations is missing.

At the seminar it was concluded that the possibilities for one or two new NKS projects ought to be investigated. A common headline could be to develop and/or test methods for measuring other nuclides than Th, U, K, and ^{137}Cs with AGS and CGS. The project ideas are described in some detail in the section "Discussed possible common NKS projects"

The seminar also included a presentation (by Risø) of the results of the RESUME 2002 international exercise in Scotland in May 2002 where a few Nordic AGS and CGS teams participated. Some results are shown in Appendix A, and a major report on the results of the exercise is expected mid 2003. The RESUME 2002 exercise is the first European benchmark exercise for AGS. The Cs-137 deposition examined in the exercise included a range of activity levels, and the data base generated from the measurements can be used for further investigation of data processing and mapping techniques. Measurements protocols developed within the ECCOMAGS project are expected in the future to form a European standard for dose rate and radionuclide deposition mapping.

Scenarios discussed at the seminar.

A few months before the seminar the participants received a description of four different fallout scenarios and the measuring tasks that should be solved. The BOK1.2 activities had

unveiled significant differences among the Nordic (and other) countries with respect to processing and result presentation for CGS (carborne gamma-ray spectrometry) and AGS (airborne gamma-ray spectrometry). Most differences now have been clarified and proposals for how to ensure consistent results for measuring teams operating in the same or neighbouring areas have been put forth. Also the question on how to relate CGS and AGS to each other have been examined. However, all efforts have been directed towards ^{137}Cs being the only manmade nuclide distributed in the environment in amounts that easily can be measured today with standard CGS and AGS equipment

In case of a future nuclear accident with widespread contamination one may expect that several nuclides will be included. Therefore, within the Nordic countries there is a need for also being able to obtain consistent results for mapping a contamination including several nuclides.

Therefore DEMA+DTU proposed that a NKS seminar on how to map fallout with several nuclides should be arranged in the autumn of 2002; and NKS agreed. The major goal of the seminar was to clarify the present situation. But it was also foreseen that the seminar would show that something should be done in order to improve the situation.

The seminar was a two-day seminar on 17-18 October 2002 at DEMA (BRS: Danish Emergency Management Agency) in Birkerød (15 km North of Copenhagen).

It was assumed that each country/group presented at the seminar the methods and ideas for how to perform a mapping with AGS or CGS in case of a fallout with different levels of contamination. The questions to be clarified should primarily concern technical matters on measurements and interpretations. It was suggested that at least some of the following situations were evaluated:

Scenario 1. Contamination with a Chernobyl-like mixture of fission product at levels that may demand a fast evacuation of people from (unknown) parts of an area of 40 km x 20 km. (The Chernobyl-like fission product mixture should not include Zr, Nb and similar refractory metals.) With NaI crystal detectors it will not be possible to identify and quantify the contamination except perhaps for a couple of nuclides. The estimated dose rates could for example be within the range from 0.1 to 5 mSv/h. The radioactivity could be assumed to originate from a nuclear power plant accident not very far from the area to be investigated and rain has caused a very inhomogeneous distribution of activity. The release has ceased.

Scenario 2. Contamination with a Chernobyl-like mixture of fission product at levels that might demand restrictions on farming activities for some parts of an area of 20,000 km^2. The background may be that a nuclear power plant accident far away has caused a contamination of a large area at levels that somewhere could cause iodine contamination of dairy products above the accepted level. Iodine only forms a part of the contamination, but it is important to obtain a mapping of the iodine fallout. It could be supposed that the emergency management people want a fast indication of the extent of the contaminated area (above a specified limit). The primary concern of course is the contamination level of foodstuffs e.g. the amount of ^{131}I in milk. In order to get a "derived limit" (kBq/m^2 of ^{131}I for grass or similar) one needs a realistic transfer factor that may be different for different

countries. For Danish farming conditions the transfer factor is 0.1 Bq/l per Bq/m^2 for the summer time. (For English conditions the transfer factor probably is 0.15 Bq/l per Bq/m^2) Assuming a level of 370 Bq/l for milk the derived limit for grass will be 3700 Bq/m^2 for surface contamination of Danish grass areas.

Scenario 3. Contamination with a Chernobyl-like mixture of fission product at levels that are expected everywhere to include ^{131}I, ^{132}I, and ^{132}Te at levels at least a factor 2 below the level where farming restrictions should be introduced. The area to be examined is at least 20,000 km^2 and the task really is to ensure that the levels are low everywhere. Due to dry deposition strong local variations in contamination levels are not expected, but fog in the morning hours may have introduced some local enhanced contamination levels. Only the iodine concentration is of interest. The radioactivity has been released from a running nuclear reactor two days before the decision on mapping is taken. Farming restrictions have been set up for the whole area, and the goal primarily is to obtain a fast declassification of the area. The description covers a situation where preliminary indications tell that the contamination "peaks" are below the level for doing something - but not far below. Therefore the factor 2 is introduced. It is assumed that the goal (hope) of the radiation protection authorities is to be sure that the contamination level no-where is above the "do-nothing level". The accuracy of the results and the degree of coverage of the area therefore are of great interest.

When comparing scenario 2 with scenario 3 one should note that for scenario 2 the task probably will be to get the best numbers (for contamination levels) whereas the task for scenario 3 is to ensure that the contamination is everywhere below a specified limit.

Scenario 4. An urban area of 10 km diameter (town and nearest surroundings) should be examined for enhanced levels of contamination following a nuclear accident that has caused a low level contamination of the rural areas farther away from the town. Special weather conditions and the "urban effect" on deposition could, however, locally have caused contamination levels that should trig counter measures. The release of radioactivity occurred 12 days earlier from fresh nuclear reactor fuel, but only volatiles (as iodine, tellurium, caesium, ruthenium and barium (with lanthanum) and noble gasses) were released. The restrictions that might come up probably would be on outdoor activities of children (0-10 years) and kitchen garden products. Iodine probably will be the only element of concern but the other nuclides will blur the gamma spectra, i.e. it may not be a simple task to measure the iodine concentration with scintillator detectors.

Additional scenarios and problems

A. The seminar participants may instead select their own scenario.

B. Another task could be to find/state a lower level of detection of iodine-131 (kBq/m^2) using different survey techniques i.e. detectors, platforms, speed of survey, altitude (of aircraft) - and definition of detection level.

C. It could also could be a task to find/state a lower level of detection of mixed iodines + tellurium. Assume for example the initial activity ratios (source terms from WASH-1400 BWR-3 release at 2 hours after shut down and with a typical fuel burn-out):

General monitoring strategies after a fresh fallout

Contribution from SSI at the NKS Seminar 17-18 October 2002

By Olof Karlberg

Background

This discussion is based on the present measurement strategies in Sweden, and will consequently include other measurement methods than AGS/CGS.

It is believed it is important to look at all possible methods at the same time, and depending on the situation, try to find the most effective way to get the job done. Only looking at the AGS/CGS method could lead to the impression that it can solve all problems. However, since this seminar is focused on AGS/CGS method, it could be a good topic for another seminar.

*Scenario 1***.** In this scenario, the dose rate is high and the main concern is to find areas where evacuation or indoor staying is necessary. Due to the high dose rate and consequently the risk for measurement overflow and contamination of the valuable equipment, AGS/CGS will not be used directly within the area.

Instead, dose rate measurements will be carried out, either with handheld instruments or with systems including GPS and radio communication for on-line data transfer. The latter system could be used in cars or aeroplanes for mobile mapping (if possible), or just placed at a point for continuous monitoring.

Samples will be taken inside the area for determination of the nuclide composition. AGS/CGS will be used outside the area to ensure that no hot spots areas are missed.

*Scenario 2 and 3***.** In this scenario, the food production issue is dominating. Here, AGS will be used in combination with sample collection and in-situ gamma spectrometry. Since AGS and in-situ gamma spectrometry cannot differentiate between the activity on the ground and on the crops itself, it cannot be used directly to ban or allow food production in the area.

In Sweden, a sample collection organisation has been established. Crop, milk and soil samples are collected at some farms, where the transfer factors are established. These factors are then used at other farms, where only crop samples are collected, or, with knowledge of the ground to crop distribution, with use of AGS estimates.

AGS is here very important to exclude areas from further investigation, using a conservative assumption that all activity is in the crop fraction, given that a reasonably good estimate of the iodine is possible.

Scenario 4. Again, AGS is useful to find hot-spot areas for more detailed investigation. However, one must remember that the mapping results are not easy to interpret, due to the

complexity of the urban surfaces. I.e. single trees with very high activity due to dry deposition might not be seen in AGS mapping. Consequently, CGS is more useful. CGS can also rapidly detect dose rates at places where people normally are.

Also, if the remaining dose is so large that decontamination is necessary (road sweeping, fire housing, tree/ leaf cutting), one has to use sample collection, collimated in-situ spectrometry etc. to find the deposition on individual surfaces.

How to perform AGS mapping of fresh fall-out

By Simon Karlsson, Beredskap och Miljöövervakning, SSI

Scenario 2 background:

- Chernobyl-like mixture of fission products
- 20,000 km^2 (140 x 140 km)
- Restrictions on farming activities may be demanded
- Mapping of iodine is important

Equipment

A hybrid system, consisting of one large HPGe and one 4 or 16 litre NaI could be used for the measurements in scenario 2. The obvious benefit in using a hybrid system is that both the high efficiency of a NaI detector and the good resolution of a HPGe detector can be used. A similar system has been used at SSI since 1999 but the data processing and analysis has been made separately for each system. A combined utilisation like the one described here should be considered for the future.

The HPGe-detector should be calibrated to measure ground activities per square meter assuming surface geometry. Preferably this should have been made prior to the fall-out through theoretical calculations of photon fluences at survey height in order to perform activity calculations as soon as possible. To support these calculations and find possible correction factors a suitable place for daily comparisons with in-situ measurements at ground level should be established. For convenient comparison with ground measurements it is preferable to use a helicopter as AGS platform.

The NaI-detector should be calibrated for measurements of ground level dose rates according to SDI-methods. Unit-spectra for K, U and Th should be available in order to perform stripping of those spectral components and calculate man-made dose rate. The stripping from natural nuclides can be difficult considering the 1596 keV peak from La-140, but it has been done successfully before (Mellander H, 1986).

Method

The survey method to use will to a large degree depend upon national strategies, fall-out conditions and the time available. Probably one would first like to make a quick survey over the whole area to estimate the size of the affected area and the large-scale variations in fall-out level and nuclide composition. For an area of 140 km x 140 km this could take 6 - 8 hours using 20 km line distance. From these results and by considering the aims of the following measurements a more detailed survey can be planned.

Considering the conditions in scenario 2 where a both fast and exact indication of I-131 activities is needed within the 140 km x 140 km area, the problem will be to weigh survey time towards spatial resolution. What line spacing to choose will depend on many factors, but lets say that we have two helicopters and the survey needs to be finished within 1 week (~100 flying hours). Flying at about 200 km/h will give a line spacing of approximately 1 km. The flight is planned with 140 lines of 140 km each so the helicopters will be able to fly 14 lines each day. The survey altitude could be around 100 meters, the integration time should be the same for both systems (1-5 seconds) and the systems should be synchronised to measure within the same time interval.

Because of the low efficiency, the HPGe needs a relatively long counting time for good statistics in the I-131 window. This will be achieved by averaging measurements over an area of suitable size. For integration during ½ - 1 hour either a square of around 14 km x 14 km can be used or 1 - 2 full flight lines. It is important that the nuclide composition does not change within the area used for the summing, either through radioactive decay or because of initial differences in composition. Measurements from within a square can easily be selected through the coordinates and might be preferred here to avoid possible geographical differences in nuclide composition. A square of 14 x 14 km will take 10 hours to complete since each flight line is 140 km. If the nuclide composition will change significantly during these 10 hours due to radioactive decay it might be better to do the integration over one or two full flight lines instead. The last solution will be to change in the flight plan so that the squares are flown one at a time. This will take more time due to more turns but one 14 km x 14 km square can now be measured in 1 hour instead of 10 hours.

After the area has been decided upon the average iodine-131 activity per square meter is calculated through the 364 keV peak on the HPGe-detector. Next the average man-made dose rate is calculated from the NaI-detector data in the same area. By assuming that the relationship between the total man-made dose rate and the iodine activity is constant within the specified area, the iodine-131 activity can be calculated from the man-made dose rate in every NaI-spectra. The benefit with this method is that the calibration is continuously updated. The large-scale difference in nuclide mixture is corrected for as well as the effects of the radioactive decay. One disadvantage is that there will be a delay in the calculation of I-131 activity until the area averaging has been performed.

The man-made dose rate should always be calculated for the NaI, since that is the best way to find out whether an area is affected by the fall-out or not. The method described can be used to find out more information about any nuclide of special interest in the fall-out. The largest source of error will probably be the stripping of natural nuclides (due to statistics in the K, U and Th windows and the problem with La-140). It should be stressed that AGS

measurements will always be used in combination with ground based and laboratory measurements in situations where farming restrictions may be needed.

Report of the NKS workshop ”mapping mixed nuclide fallout”

Contribution from STUK at the NKS Seminar 17-18 October 2002

By T. Siiskonen and M. Moring

Introduction

Finnish radiation and nuclear safety authority (STUK) has its own emergency vehicle designed especially for the field measurements. The vehicle is equipped with sensitive dose rate meters (pressurised ion chamber and Geiger-Muller counter), an air sampling unit and HPGe-based gamma spectroscopic system for *in situ* or sample measurements. Position information is obtained from GPS. Data can be visualised in real time and sent to headquarters through a GSM data connection.

Gamma spectrometer is calibrated for fall-out and airborne contamination (plume) measurements. A ^{137}Cs contamination at level 1 – 5 kBq/m^2 and 1 – 10 Bq/m^3 can be detected, respectively. Detection limits (Currie's L_D) naturally depend on integration time, limits given above refer to 2 min (fall-out) and 10 min (plume) measurements. Environmental samples (air filters, soil samples etc.) can also be measured. Sampo software is used for gamma spectrum analysis.

Finnish Air Forces has a jet plane and a helicopter, both of which can be equipped with NaI or HPGe detector. These detectors are installed in a movable, shock protected and thermally stabilised casing. On board there are real time data analysis and visualisation software. A fall-out map is generated online and is transferred to the ground segment via GSM connection. With the HPGe detector, a ^{137}Cs fall-out 2 – 10 kBq/m^2 can be detected, depending e.g. on height, integration time and nuclide mixture.

Scenarios and proposed solutions

Scenario 1: Contamination with Chernobyl-like mixture of fission products of an area of 40 km times 20 km. Expected dose rate is relatively high, 0.1 – 5 mSv/h.

Because of the relatively high dose rate, the mapping must be carried out as quickly as practically possible, even with penalty of worse spatial resolution. A helicopter with HPGe detector is suitable for the survey. In addition, car patrols should be used for the dose rate measurements at found hot spots. Care must be taken in order to avoid high doses to the crew and contamination of the equipment. With an HPGe detector the isotopic composition of the fall-out is obtained easily. Also, the lower sensitivity of HPGe compared to NaI detector prevents the saturation of the detector system. However, flying altitude above 100 m is required because of the high pulse rate.

The mapping speed with helicopter is about 150 km/h. If 1 km spacing is used between the flying lines, the survey could be conducted in about 7 hours. Judged by the possible dose (35 mSv), this is too long. With 2 km flying line spacing, the survey could be carried out in 3 hours. The helicopter can fly about 3h 15m with one fuelling. During that time, the

maximum dose is 15 mSv. If more detailed mapping is required, new flying lines can be added afterwards.

Short spectrum integration times are possible since the dose rate is high. Thus the spatial resolution along the flying line is good. With 5 s integration time the resolution is about 200 m.

Scenario 2: Contamination with Chernobyl-like mixture of fission products of an area of 20 000 km2. The iodine contamination is of interest. At some parts the iodine contamination may be high enough to imply protective actions for agriculture.

Since the expected contamination level of iodine is rather low, the flying altitude must be less than 100 m. If we equip the helicopter with HPGe, the iodine fall-out of roughly 1 – 5 kBq/m^2 could be detected (with 1 min integration time). This is less than or equal to contamination that should cause protective actions in farming (around 5 kBq/m^2). Note that only farming areas need to be explored.

We assumed that the fall-out occurred in the area where agriculture uses only a fraction of the available land. This assumption is fairly realistic in Finland, except on the western coast. If the whole area is to be surveyed, the jet plane is only realistic choice. The drawback is an increased detection limit (to some 10 kBq/m^2). With 5 km line spacing the survey could be done in one or two days.

Ground units must be used for environmental sampling (crops, soil, milk etc.) as well as at possible hot spots for dose rate measurements. The role of ground units is highlighted if a jet plane is to be used.

Scenario 3: Contamination with Chernobyl-like mixture of fission products of an area of at least 20 000 km^2. The task is to ensure that iodine contamination is low everywhere. Expected levels are at least factor of two below the level where farming restrictions should be introduced. The release occurred two days ago.

This scenario resembles scenario 2. The contamination levels are, however, even lower. In airborne survey, the flying altitude must be less than 100 m. If we assume that the primary contaminants are iodine and tellurium, NaI detector is useable: the gamma lines of ^{131,132}I and ^{132}Te are well separated. However, the primary gamma line of ^{132}I nearly overlaps with ^{137}Cs primary line. With NaI setup, iodine fall-out can be detected at a level of 1 kBq/m^2 or less.

Again, cars should be used for environmental sampling (and dose rate monitoring).

Scenario 4: Urban area of 10 km diameter is contaminated with volatile (iodine, tellurium, caesium, barium etc.) release. Expected contamination is rather low. The release occurred 12 days ago.

This scenario is the most challenging concerning the measurement geometry. In order to diminish the complications, measurements should be made as close to ground as possible. Collimated measurements are, in principle, possible. Since the release is 12 days old, the

short lived nuclides have decayed. Therefore NaI system is useable. With the helicopter and cars, the area could be surveyed in one day. Ground patrols with collimated (if available) detectors and dose rate meters are essential.

Discussion
In the workshop, discussions concerning the contamination of the ground vehicles arouse. Solutions like better shielding (lead lining) and decontamination (washing, removable surfaces) were mentioned. Possibility of making the detector system movable from one car to another was also discussed.

It was felt that more precise determination and definition of the detection limits are needed. This is crucial, since the detection system, attenuation in the air, distribution in the soil, number of nuclides present, sky shine etc. all contribute to the detection limit. Without exact definitions, direct comparisons of the different systems and results are impossible. The detection limits discussed above are based on Currie's definition of L_D [L.A. Currie, Analytical Chemistry **40**, 586 (1968)].

A long discussion arouse about the choice of the detector. In particular, the superior energy resolution of HPGe detector was contrasted against the better sensitivity of NaI detector. Obviously, the choice depends on conditions (pulse rate, nuclide mixture, price etc.). More clarifying work is needed.

Extracting data from mixed-nuclide fallout spectra.

Contribution from DTU at the NKS Seminar 17-18 October 2002
By Helle Karina Aage

Scenario
The scenario covered by this special presentation most closely represent scenario 2 or 3, i.e. low level contamination with a Chernobyl-like mixture of fission products including ^{131}I. However, the data used for the special presentation represents dose rates far below what one should expect in scenarios of type 2 and 3. The special presentation thus is special in its own way.

Constant ratios
One of the main topics when mapping isotope ground level contents from mixed-radionuclide fallout is whether is a appropriate to assume that the ratios of the different isotopes can be assumed to be constant, - or at least assumed to be constant during the time it takes to perform a survey of the contaminated area.

Detector size
Another main problem of great importance (especially related to Scenario 1) is whether one is able to perform correct measurements at all due to detector saturation.
It was concluded for the Danish AGS-system that at present it is not possible for Denmark to measure and map high contamination levels. It would be necessary to use a smaller NaI detector or – possibly an HPGe detector.

Equipment

From the conclusion of the Danish detector sizes being too large for high contamination levels it was decided to examine the response from a smaller 3" x 3" NaI(Tl) detector. DTU has as part of examination of low level alarms for the Danish Early Warning Systems, EWS, performed a series of irradiation measurements with different sources and source strength. The EWS is a stationary measurement system, which means that the only variations observed at those stations are related to radon daughters (or fallout).

Purpose

1. To investigate if it is possible to extract a manmade mixed fallout spectrum or even better a spectrum containing only iodine with none of the spectra containing natural radionuclides. If such spectra can be extracted it is possible to calibrate their spectrum shapes to concentrations/dose rates performed as *in situ* measurements. For a constant contamination ratio one would then just calculate for each measured spectrum how many of these "synthetic" spectra each measured spectrum represents and thus obtain the amount of radionuclides.
2. To use the Pseudo concentration method for calculation of the concentrations
3. The examine what happens if the ratios are not constant.

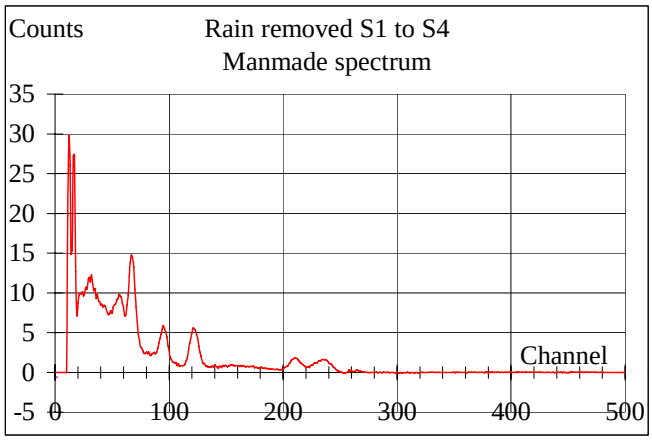
Method

Measured spectra from an EWS were NASVD processed, and a mixed "fallout" spectrum was extracted. Measurements were performed using a standard 10-source Amersham calibration source set. DTU had no access to iodine sources and therefore a ^{133}Barium source represented ^{131}I (gamma energies in close range). The ^{133}Barium source was measured as a single source and the rest of the source kit measured together as another source.
The two sources were measured at different distances from the detector – the majority of the measurement were performed with the same dose rate ratios, source 1:source 2, with a few measurements of a different ratio. Additional measurements with heavy mineral sands and potassium nitrate were made to simulate landscape changes (this was necessary because the EWS is stationary).

The data were examined by use of the NASVD method, now incorporated in the NUCSpec software too (NUCSpec ver. 2.1, Danish Emergency Management Agency, Nuclear Safety Division). Measurements with a too large spectrum drift in the system were removed from the data sets. A "synthetic" manmade spectrum containing no counts above the highest gamma-energy (^{60}Co) was calculated by setting the window counts of the natural radionuclides to zero. This spectrum was calculated from the spectral components from the NASVD processing and included no natural radionuclides.

Synthetic spectra

It was not possible to create a synthetic barium spectrum (iodine spectrum) from the measured data. The reason for this was that not sufficient spectral components existed, i.e. too few background variations. A synthetic mixed spectrum was extracted, however.



Synthetic mixed spectrum created from 4 NASVD components.

The pseudo concentration method (Aage et al. " A New technique for processing airborne gamma ray spectrometry data for mapping of low levels of contamination". Appl. Radiat. Isot. 51, 651-662, 1999) In the pseudo concentration method one fallout spectrum from N components and N-1 linearly independent natural spectra are created from a series of NASVD processed data. Each spectral component is then calibrated for its content of fall-out.

$\mathbf{v}_1 = a_{11}\mathbf{s}_1 + a_{12}\mathbf{s}_2 + a_{13}\mathbf{s}_3 + a_{14}\mathbf{s}_4$ Fall-out
$\mathbf{v}_2 = a_{21}\mathbf{s}_1 + a_{22}\mathbf{s}_2 + a_{13}\mathbf{s}_3 + a_{24}\mathbf{s}_4$ No fall-out
$\mathbf{v}_3 = a_{31}\mathbf{s}_1 + a_{32}\mathbf{s}_2 + a_{33}\mathbf{s}_3 + a_{34}\mathbf{s}_4$ No fall-out
$\mathbf{v}_4 = a_{41}\mathbf{s}_1 + a_{42}\mathbf{s}_2 + a_{43}\mathbf{s}_3 + a_{44}\mathbf{s}_4$ No fall-out

Rewritten as matrix equations where $d_{i,j}$ (j_{max} = N) represents the content of fallout in spectral component $\mathbf{s}_i$:

$\mathbf{V} = \mathbf{AS}$ thus $\mathbf{A}^{-1}\mathbf{V} = \mathbf{S}$ $\Rightarrow$ $\mathbf{DV} = \mathbf{S}$

The pseudo concentration, h_i, is calculated as:

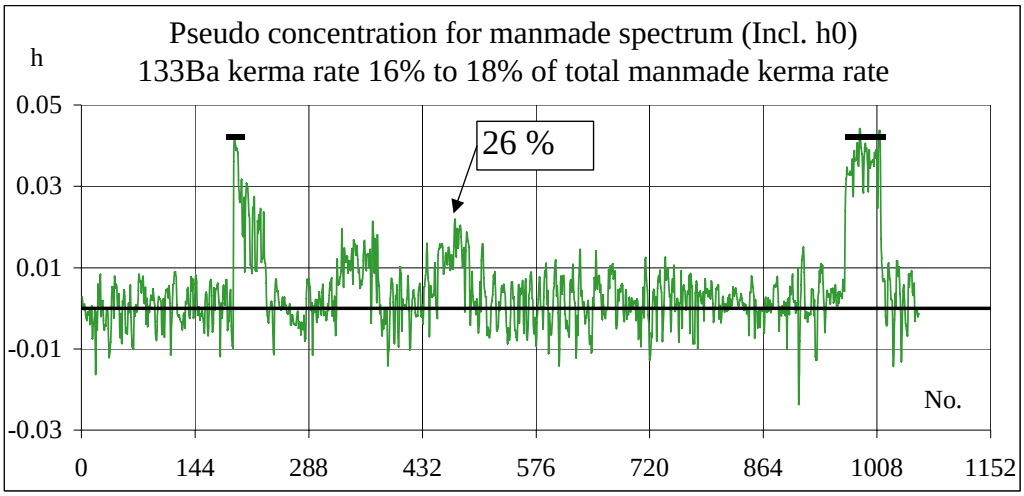
$h_{j1} = h_0 + (b_{j1} \times d_{11} + b_{j2} \times d_{21} + b_{j3} \times d_{31} + b_{j4} \times d_{41})/LTC_j$

$h_0 = -(b_{backgr,1} \times d_{11} + b_{backgr,2} \times d_{21} + b_{backgr,3} \times d_{31} + b_{,backgr,4x} \times d_{41})/LTC_{backgr}$

h_0 represents the content of fallout in the mean spectrum and can be calculated from measurements containing no manmade activity.

Results
The pseudo concentrations were calculated according the equations above and plotted as a function of spectrum number. The true concentrations were not calculated. It was concluded that the mean values of h (for a given air kerma rate) and the air kerma rates were well correlated - with some exception. The measurement series where the ratio of barium to total (air kerma rates) was changed in favour of barium, the percentage dose rate from barium was increased form 16-18% to 26%, gives too low values of the pseudo concentra-

tions. It was therefore concluded that the method could be used in practice but that care must be taken to identify areas where the assumption of constant ratios is not valid. Also, in the experiments conducted here the attenuation in the EWS housing and the increasing probability for scatter in the surroundings was not taken into account in the calculations. It is seen in the table that the peak marked 26% shows a low value for h, the same does the peak just left to it (17%). For both measurements the distance to "other sources" was quite large. A plot of the amplitudes of the spectral components could very fast identify these geographic locations by mapping the amplitudes instead of ground level concentrations.



Measurements made

Spectrum No.	Total manmade dose rate air kerma nGy/h	Distance to source (m)		Percentage from iodine (Barium to total ratio)
		Barium	Others	
192-211	5.42	4.15	5.42	16
213-240	2.78	5.42	7.67	18
339-383	1.74	7.67	9.47	17
487-527	2.00	5.42	9.47	26
1058-1102	5.42	4.15	5.42	16

Measuring techniques and methods for measuring fresh multi-nuclide contamination using airborne and carborne equipment

Contributions from NRPA and NGU.

By Svein Thorshaug, Mark Smethurst, and Eldri Naadland Holo

Background

In June 2002 a parliamentary bill on supplementary appropriations for the preparedness organisation in Norway was approved. As a follow-up of these appropriations it was decided to carry out a joint effort in order to improve the level of operation for the equipment used for airborne (AGS) or carborne (CGS) gamma ray spectrometry. A project was initiated by the Norwegian Radiation Protection Authorities (NRPA) and is currently in progress.

There are four separate systems for mobile gamma ray spectrometer surveying available within the Norwegian nuclear emergency preparedness organisation. The main objective of the project is to improve the interoperability of the different systems and to make the mobile equipment operative as a whole. Today only the system from Geological Survey of Norway (NGU) is used on a regular basis and there is a need for developing a strategy for the deployment of the system in general.

Equipment description

NGU has developed a system that can be used with different kind of transportation platforms, including fixed-wing aircraft, helicopters and vans. The system is used for geological surveying on a routine basis and is described in more detail in subsequent sections of the document.

The Norwegian Institute for Air Research (NILU) utilises a system based on a 16 L NaI detector controlled by an ADC (model 1510) and MCA (model S100) from Canberra. The system can be operated from a fixed-wing aircraft or a van.

The Norwegian Air Force has two measuring systems both based on a 16 L NaI detector controlled by a GR-820 spectrometer. Installation of new equipment in one of the Air Force's carriers is subject to an extensive testing and quality assurance process. One system has been permanently installed in a P3-N Orion with home base in Andøya in the north of Norway. This system was used for surveying after the Kursk accident. The other system is currently operated from one of the Air Force's SAR helicopters (Sea King) based on a temporarily permission.

NGU is located in Trondheim while NILU is located at Kjeller approximately 20 km outside of Oslo. The geographical distribution of the mobile equipment helps shorten the time it takes for the carrier to reach the fallout area in case of an emergency situation.

Discussion

Scenario 1 represents a situation of a more severe character than what would be the result of an accident with one of the Norwegian research reactors. It is probably more applicable in case of an incident with a nuclear-propelled vessel along the coast or in a military port of call, or if participating in joint international operations following a nuclear accident in

another country. Scenario 2 and 3 describes what could be the consequences for Norway in case of an accident at a reactor in a neighbouring country. Reactors of primary concern in this regard, partly due to lack of security arrangements, are Kola NPP, Leningrad NPP and Ignalina.

The ability of the authorities to effectively allocate AGS/CGS resources in case of an accident depends on whether international agreements on early warning are followed. These agreements can provide the authorities with information on the quantity and composition of the released material. Furthermore, important information will also be available from meteorological dispersion models and from the automatic radioactivity monitoring networks. The available information will be imported into the decision support system (ARGOS). Data processing in ARGOS provides valuable inputs for the authorities when deciding on an AGS/CGS strategy.

The complexity of the topology of the area to be mapped has to be considered. For uncomplicated and relatively flat terrain, such as in Denmark, a surveying plan with regular flight line distances and altitudes can be carried out. This is not always the case in Norway where one sometimes has to perform the surveying based upon a compromise solution between the predefined mapping plan and the complexity of the terrain

For all four scenarios the size of the area of interest has been indicated. This implies that surveying already has been effectuated and that one already has an opinion regarding which areas that are influenced by the fallout prior to the deployment of the mobile measuring equipment. This will not necessarily be the case in the immediate phase following a nuclear accident.

In general the authorities will apply a combination of different measuring methods as a response to all the scenarios. Establishment of ground level dose rates and surface concentration and activity will be based on *in situ* measurements and sample analysis. In order to protect the crew and to avoid contamination of the carrier one should know that the release has ceased and that the plume has passed before AGS/CGS are effectuated. Airborne measurements will first be used as rapid mapping from the outside as an effort to determine the outer boundaries of the contaminated area. The carrier can be either a helicopter or a fixed-wing aircraft, for example ORION. The results from airborne measurements will then subsequently be used primarily to exclude areas with low levels of contamination from further investigation and as guidance for allocation of ground level measurement efforts. Detailed surveying of the contaminated area should be performed at a later stage.

The immediate response of the operator when experiencing increased levels of radioactivity and possibly saturation of the measuring equipment will be to either go to higher altitudes or to leave the area all together. Simple count rate measurements from higher altitudes (> 200 m) are still valuable even though they cannot be transformed to ground level dose rate values by the SDI method.

The four different scenarios clearly illustrate the importance of scalability. A system based on a large (16 L) NaI detector will probably be of limited use for scenario 1 due to saturation. A system based on a small NaI detector (0.5” x 0.5”) or an HPGe detector will probably be a better solution. However, such a system will not be optimal for low level contami-

nation scenarios like scenario 2 and 3 due to the lower sensitivity. Ideally one should have a hybrid system consisting of several types of detectors that could be applied according to the level of contamination.

Some remarks on the approach of the Geological Survey of Norway to the mapping of multi-nuclide contamination in the environment

Initiation of a measuring programme

The Geological Survey of Norway (NGU) is equipped to carry out mobile gamma ray spectrometer measurements in the event of a release of radioactive materials into the environment. The decision to carry out such measurements lies with the Norwegian emergency management team for nuclear accidents in partnership with the Norwegian Radiation Protection Agency. The NGU may be called upon to (a) map or delineate widely distributed fallout due to a remote reactor accident, (b) map localised fallout from a nearby reactor accident, and (c) search for localised ("point") sources of radiation such as re-entered satellite reactor parts. The remarks in this contribution focus on issues related to the mapping of widely distributed multi-nuclide contamination like that produced in scenario (a) above.

Measuring equipment and mobilisation

Should the NGU be called upon to carry out mobile measurements, the NGU is able to mobilise *either* an airborne gamma ray spectrometer system (AGS) *or* a carborne system (CGS). Both systems are based on the same instrument, an Exploranium GR-820 spectrometer with a large (16.7 L) NaI detector. In both cases the detector is mounted inside the vehicle to minimise direct contamination of the measuring device. Both systems are controlled by the same open-source software package. An open source software solution was chosen so that software could be changed on the fly to overcome unforeseen difficulties.

The mobilisation time for the CGS system is estimated to less than one day. This system is intended for use in the NGU's own four-wheel-drive van, but can easily be mounted in a rental van should the NGU's vehicle become heavily contaminated during the measuring programme.

The NGU has no agreement on the use of a specific helicopter or aeroplane for AGS measurements. Should such measurements be necessary, the NGU will negotiate the use of an aircraft from commercial or military sources. A mobilisation time of 24 to 48 hours is expected for AGS measurements.

Routine calibration

The CGS system is calibrated for U-238, Th-232, K-40 and Cs-137 (ESC) and air kerma rate. The AGS system is calibrated for the same parameters, but for an exposed detector position under the aircraft. This position will not be used if there is a risk of contamination.

On the fly calibration

The software controlling the AGS and CGS measuring systems processes data in real time and adjustments of calibration values can be carried out before, during and after measuring. In this way rapid calibrations can be made against other instruments and in areas of known contamination. The calibration values so produced will take effect immediately. In the event of mapping fresh multi-nuclide fallout, on the fly calibration will be carried out

as soon as possible and used, for both CGS and AGS type measurements. Ideally the on the fly calibration will be carried out at least twice a day, before and after each measuring period. Also, if it is possible for the measuring system to return to a controlled and/or monitored location regularly, contamination of the system can be evaluated with greater accuracy. It is expected that the CGS system will be moved to new less-contaminated vehicles from time to time should the period of mapping be prolonged.

Reported data
In the event fresh multi-nuclide fallout, including short-lived nuclides, calibration will be carried out on the fly against a series of dose rate instruments. Processed data will be transferred to the authorities immediately upon completion of a measurement period. The data will then be imported into the commercial geophysical data processing and map-making package Geosoft Oasis Montaj for final processing and map production. Data will be reprocessed to take account of observations made by other measuring teams during the day, mobile and stationary. Digital maps will be made of the data from the mobile instruments and from the stationary instruments used for cross-calibration purposes.

Measurement strategy
Should mobile measurements be required, the choice between car and airborne platforms will depend on the nature and scale of the radiation release and on the nature of the affected area. Factors will include topography, accessibility by road, population distribution and so on.

For both CGS and AGS measurements, cross-calibration sites will be established and an attempt will be made to quickly locate the worst affected region(s) through coarse mapping followed by detailed fill-in. Should contamination of the vehicle/aircraft become too great, a rental vehicle or alternative aircraft will be used. Should the main measuring instrument saturate, the detector will be shielded, replaced with a smaller detector, or transported away from the most radioactive region. If the last alternative is chosen, the mobile instrument may only be used to determine the edge of the affected region.

Attention will be paid to the radiation doses received by the measuring crews. The minimum crew consists of a driver/pilot and an instrument operator. Three NGU personnel are trained as instrument operators. This provides the possibility to change crew twice.

Processing issues
It is intended to extend the NGUs nuclear emergency measuring system to include the logging of a radar altimeter for use in the processing of AGS data. Until then the NGU will attempt to 'drape' fly emergency measurements and apply a fixed-altitude correction to measurement data.

Summary
The NGUs strategy for CGS and AGS measurements of fresh multi-nuclide fallout is to calibrate our large NaI detector against direct measurements of dose rate made at reference sites before, during and after each measuring excursion. Although full spectrum data will be analysed, we do not expect to be able to offer a great deal of information on the composition of rapidly changing fresh fallout and will therefore focus on rapid delivery of dose measurements over wide areas that can later be verified through *in situ* measurement.

Danish monitoring of fallout with AGS and CGS equipment.

Summary of a Power Point presentation at the seminar

The Danish mobile gamma-ray spectrometry systems include two AGS system with 16 L NaI detectors and two CGS systems with 4 L NaI detectors. In addition a semi-mobile HPGe detector (31%) is available. The AGS systems are prepared for mounting in Danish army helicopters (Fennec), and the CGS systems can be mounted in special cars belonging to DEMA. At present neither the AGS systems nor the CGS systems will be able to perform scenario 1 measurements; too high count rates will saturate the detectors. When flying higher than 125 m the outer boundaries of a highly contaminated area can be defined but ground level dose rates cannot be calculated because of missing information on the intensities of photons up to some 500 keV.

The goal for DEMA is to have at any time six AGS operators and six CGS operators available; therefore it will be possible to exchange crews in case of too high accumulated doses.

For the other scenarios with lower levels of contamination the NASVD processing of data will always be used with the aim of being able to extract fallout spectra. With both AGS systems operable a detailed mapping of 20,000 km^2 will last one day in the summer and probably two days in the winter.

Special AGS and CGS topics discussed

At the seminar at BRS on 17-18 October 2002 the following problems and possible project tasks were discussed:

1. Computer generation of fallout spectra to be added to measured spectra. For NaI detector systems such spectra are needed for examining the quality (accuracy, stability and detection level) of different data processing techniques. For HPGe detector systems similar spectra may also be important for examining detection levels etc.

2. Test of the area specific stripping method (for NaI detectors). The method extracts strip factors directly from measured spectra without artificial radioactivity. How far can the method be used for AGS - and what are the pit-falls? With or without taking the altitude into account. (Can the task be done on/with spectral component amplitudes?) The method that can be used for almost any combination of windows has been used for a few sets of CGS spectra, for which it worked as expected. The method will be valuable for point source search and perhaps also for mapping low level contamination. The stripping can be done for narrow as well as wide energy windows.

3. Use of the "pseudo concentration method" for extraction of e.g. ^{131}I signals from mixed spectra generated as described above (1.). The composition of fallout nuclides is assumed to vary across the measured area. This (post processing) method would be

valuable if low level mapping of ^{131}I should be performed for an area that also is contaminated with other nuclides existing in varying amounts.

4. Use of the "pseudo concentration method" (NaI detectors) for extracting a mixed "fall-out spectrum" and its concentration. The composition of fall-out nuclides is assumed to be constant across the measured area but the level may vary. If the relative concentrations of ^{131}I and other fall-out nuclides are almost constant one may use the "composite fallout spectrum" as an indicator for ^{131}I. The fall-out spectrum is processed according to the pseudo concentration method. It is expected that very low contamination levels can be processed and acceptable results could be obtained.

5. NaI vs. Ge detectors. Lower levels of contamination that can be measured? Upper levels? How to co-operate information from different detectors? For many tasks - e.g. mapping of medium and high level contamination - HPGe detectors are reliable and simple to use, and they can be used for some high level contamination mappings where large NaI detector systems cannot be used due to saturation. On the other hand NaI detectors are better for searching low level signals from point sources and for mapping low level contamination generating very few counts in a HPGe detector.

6. Use of the "mixed fallout spectrum" generated as in "4" together with 2-3 NASVD spectral components generated from "fallout free" spectra from the same area or a similar area. Here one uses the "mixed fallout spectrum" and 2-3 spectral components as basic "unit spectra", and by a standard least squares technique each measured spectrum is decomposed into a fall-out signal and 2-3 natural signals. By comparisons with ground level data the "mixed fallout spectrum" is calibrated for content of fallout nuclides. For AGS measurements with altitude variations one may have to include 3-4 spectral components in order to handle the influence from varying altitude on the measured spectra.

7. Measuring high ground level dose rates with AGS. It was recognised at the seminar that standard NaI detectors of any size down 0,3 L are too large for using the SDI technique for a high level contamination (0.1 mSv/h to 5 mSv/h at 1 m). At altitudes up to 125 m all detector systems will saturate, and for higher altitudes the information on low energy gamma emitters is lost rendering the SDI method unusable - i.e. inaccurate and erroneous. Therefore the use of smaller NaI detectors was discussed. Small airborne HPGe detectors do not saturate and can give information that may be "translated" to ground level dose rates. The use of large airborne HPGe detectors for determining ground level doses was also discussed, but it was not clarified whether they could be used for the task due to high count rates. Development of parameters to be used for the SDI method for small NaI detectors and small HPGe detectors was discussed.

8. Clarifying the meaning of "detection level" for AGS and CGS. For laboratory measurement and partly also for *in situ* field measurements there are a few well defined "detection levels". Sometimes also the term "detection level" has been used for AGS and CGS although there is no clear description of what really is meant. This is an area that ought to be investigated especially when there is a need for comparing different measuring systems ands data processing techniques.

9. The presentations and the discussions at the seminar unveiled that the presently available AGS systems based on NaI crystal detectors probably are unfit for measuring high ground level dose rates; they will be "saturated". Flying higher (than 100-125 m) in order to reduce the count rate is not the solution; information on the low energy (below 500 keV) photon emitters is lost due to attenuation and scatter in the air. The same problem may come up for large HPGe detector systems. Small collimated detectors may be able to give acceptable results when using a technique similar to the SDI method. A better than "an order of magnitude" solution may perhaps be obtainable by using any radiation monitor - dose rate meters, GM counters, ionisation chambers - and by performing an intercalibration with ground level data as part of the survey. The sensitivity of this method for altitude variations and varying fallout nuclide composition should be evaluated. (If fluence spectra for different altitudes above different gamma emitters are available it may be a minor task to calculate the response for different small detectors.) For a CGS system one just can use any dose rate meter connected to the data recording system of the car.

Responses from the participants

The Norwegian participants: The topics discussed are very relevant also for the Norwegian measuring teams. However, just now and for the coming year Norway will be busy with getting the equipment running. No significant effort within a NKS project therefore should be expected from the Norwegian participants within the first year.

NGU also pointed out that in Norway airborne surveys are carried out with fixed wing aircrafts that often for Norwegian topology will have to fly higher than 100 m - and with a fast varying altitude.

Lund: HPGe detectors give signals that are easy to understand. NaI detector results may have to be processed in a complicated way that is not easy to understand. Therefore people may feel a little doubtful on the results. The most important task for the large NaI detectors is to detect low level signal than can not be observed with HPGe detectors. Spectra for the important nuclide ^{131}I can be obtained for any detector. Iodine-131 sources are readily available at many hospitals.

SGU has a lot of data from the 1986 surveys of Chernobyl fall-out in Sweden. The spectra include a limited number of channels (24), but an ^{131}I signal (at 365 keV) can be seen in some cases. Those 1986 data may be included in an analysis of methods for mapping fresh fallout. Within the first year after a fallout of fresh fission products it will be easier to map ^{134}Cs than mapping ^{137}Cs. SGU is interested in participating in a (part of a) NKS project. The amount of manpower to be invested and the specific project(s) will have to be discussed "at home".

STUK: One cannot expect that the relative composition of fallout nuclides will be the same everywhere. This will depend on the "release chronology" and the meteorology. With HPGe detectors varying compositions can be followed; but the lower limits for a reliable mapping is not clarified. Participation in a NKS project will have to be discussed at STUK.

A Finnish group has already done some work on synthetic detector spectra for HPGe detectors. This group may be interested in generating AGS spectra for HPGe detectors.

SSI/FOI: The problems discussed at the seminar are important. However, HPGe detector systems should be included together with NaI systems. From an emergency point of view it is important to have fast answers; the accuracy may be less important. Some of the methods discussed at the seminar may be valuable for warning stations where minor variations in spectrum shape should be detected. A participation in a NKS project and the manpower eventually to be invested has to be discussed at home.

DEMA: The seminar has pinpointed a number of problems that has to be solved. DEMA is only able to invest a minor amount of manpower in a NKS project.

The problems with contamination of measuring equipment and car at an early mapping after a fallout were shortly discussed at the seminar. It was concluded that it is important to protect the detector systems. Removable surfaces may be part of the answer. Intense washing may clean the car itself. Air filters (and motor oil) should be exchangeable.

Discussed possible common NKS projects

I. Mapping concentrations of ^{131}I and other fallout nuclides.

1. The pivot for this project should be mapping of ^{131}I at different contamination levels especially at levels close to "action levels" assumed to be in the range from 1 to 20 kBq/m^2
2. The project should include both NaI and HPGe detector systems as well as co-operating NaI + HPGe detectors.
3. The data processing to be included should be existing and new methods if available.
4. Besides theoretical considerations also processing of "contaminated spectra" should be carried out in order to perform tests as realistic as possible.
5. The "contaminated spectra" could be generated as described below. They should be based on measured spectra with natural radioactivity to which are added computer generated/adjusted signals from artificial radioactivity
6. The data processing methods are tested for being able to extract information on the amount of radioactivity included in the "contaminated spectra".
7. The meaning of "detection level" and similar terms should be clarified in relation to AGS and CGS measurements.
8. The tests are carried out with natural spectra measured in the field with the actual systems to be examined.
9. Although ^{131}I is the most important nuclide to be measured other nuclides should also be included in the investigations.

Generation of "contaminated spectra"

a. Spectra for a number of "contamination nuclides" should be available for the detector system to be investigated - for example ^{131}I spectra for 50m and 100 m altitude (AGS)

and for CGS. Spectra could be measured spectra or spectra generated by Monte Carlo calculations - or by other means. For the actual use of the spectra they need not to be 100% correct.

b. A contamination with one or several nuclides is selected, and an "ideal" contamination spectrum corresponding to this mixture is generated.
c. The first of a sequence of natural spectra is read, and the energy calibration ís calculated (energy calibration: relation between channel number and photon energy deposition in the detector).
d. The "ideal" contamination spectrum is given the same energy calibration (by "resampling").
e. Poisson noise is added to the ideal contamination spectrum.
f. This spectrum is added to the measured natural spectrum.
g. The resulting spectrum is a spectrum that might have been measured if the area from which the measured natural spectrum originates had been contaminated with the mixture of nuclides selected above.
h. In this way a sequence of artificial spectra with a constant or a varying amount - absolute and/or relative - of contamination can be generated corresponding to a hypothetical contamination of the measured area, flight line or car path.
i. Whenever possible real world measured spectra with contamination nuclides should be included in the investigations in order to ensure that the synthetic generation of "contaminated spectra" produces realistic spectra - although 100% correct spectra are not needed for the purpose.

During the project one should ensure that the technique for generating "contaminated spectra" is described in such a way (and with a sufficient amount of details) that it enables future users of AGS and CGS systems to use the technique for different (new) detector systems and computers with a minimum investment of manpower. This could for example be obtained by including the following elements (but other methods may also fulfil the demand):

A. For each (of e.g. 10) contamination nuclides there are generated the fluence rates at nine different heights for example 1m, 2m, 25m, 50m, 75m, 100m, 125m, 150m, 175m, and 200m. The results are stored as 90 files (9 x 10) that are made available to all NKS teams engaged in field measurements.

B. For a detector system to be investigated the fluence rate at e.g. 100 m altitude is "folded" with a model detector response whereby an "ideal" spectrum for the nuclide and altitude in question is generated. (The model detector should be of the same type as the actual detector and have the same volume and almost the same shape (geometry). It may, however, deviate from the actual detector by having another energy calibration.) The spectra could be normalised to 1 s measurements with 1 kBq/m^2 surface contamination - or to another specified period and contamination level. Hereby up to 90 files are generated for each model detector. By having perhaps 6-8 different model detectors one ends up with 500-700 files each of which represents a spectrum for specific nuclide for a specific model detector at a specific altitude. In order to simplify the calculations one may assume linear energy calibrations for all model detectors.

C. The following steps now have to be carried out for an actual detector: After having generated a composite spectrum with the selected mixture of nuclides this composite spectrum is adjusted to fit to the energy calibration for the actual detector. Later - when this spectrum should be added to the measured natural spectra - it is further adjusted to have the same energy calibration as the measured, natural spectra. This additional adjustment is a simple linear resampling i.e. spectrum is "compressed" or "elongated" probably with a factor between 0.99 and 1.01. The former adjustment mentioned above often will be a non-linear adjustment for NaI detectors.

D. Some existing programs for generating detector responses (spectra) carry out the calculations A and B as one step. Yet it will be important to have also files with the fluence rates.

It should be stressed that it is not important to obtain 100% correct spectra. The counts of the full energy peaks should be as correct as possible, but the spectrum shape of the "Compton region" of a spectrum is of lesser importance.

If spectra are measured with a suitable number of sources (AGS spectra in calibration setups and/or AGS/CGS spectra based on field measurements with point sources) the spectra to be used by others should finally be resampled to a model detector with linear energy calibration.

II. Area specific stripping of lower windows for AGS and CGS NaI systems

For a number of tasks it is of interest to be able to strip away the contributions from natural radioactivity to low energy window count rates. Many systems have already the parameters needed for stripping away the influence of natural radioactivity on a ^{137}Cs energy window. For AGS height dependent stripping parameters are needed.

The parameters, however, also are (slightly) dependent on landscape topology, vegetation, soil moisture content etc. Therefore it would be a valuable improvement if it becomes possible to determine the best stripping parameters for an area actually to be surveyed. In principle this is a straightforward mathematical task that can be carried out with an existing or a new set of survey spectra with only natural radioactivity.

Assume first that the area in question has been surveyed with the same equipment before it got contaminated. Also assume that topology, vegetation density, soil moisture etc. have been constant for the area - and the equipment has been stable during the measurements. By having only three groups of natural gamma emitters - potassium and the decay products following uranium and thorium - it is possible to describe the count rate of any energy window as a linear combination of the contributions of K, U, and Th. Furthermore, the concentrations of K, U, and Th have (for each altitude) a fixed relation (matrix parameters) to the count rates of three windows centred (or not centred) around the characteristic full energy peaks of K, U and Th. Therefore, the count rate of any (low) energy window also can be described as a linear combination of the count rates of the windows for K, U, and Th.

The task therefore becomes to find the three parameters that describe the linear combination. This is done by the standard least squares fit i.e. one demands that the observed (low) energy window count rates for all measured spectra are described as the same linear combination of the count rates for the K, Th, and U windows for the same spectrum + an error. This error is due to the statistical variations. If the demand for constant topology, vegetation density, and stability etc. is neglected/reduced, additional "errors" may come up. But the equations still generate the three parameters that are the best for stripping within the selected area.

When the contaminated area is surveyed one uses the stripping parameters (from the least squares fit) for elimination of the contribution from natural radioactivity to the (low) energy window count rate i.e. one gets the net count rate caused by the contamination.
If spectra from earlier measurements within the area in question are not available one may calculate the parameters for another similar area i.e. an area with the same topology, vegetation, moisture content etc. or one may include in the actual survey also areas with no contamination - or just an area with a low and (almost) constant contamination.

If one is searching for point sources (or "hot spots") one may just use the survey spectra themselves for generation of the best stripping parameters. If hereby a (weak) point source signal is included in the processing, the result just is that the stripping causes a slightly negative (low energy) window signal for spectra not including the point source signal.

The "area specific stripping" has been tested by DTU for some CGS measurements - and it here works as expected. (Aage and Korsbech, "Search for lost or orphan radioactive sources based on NaI gamma spectrometry", Appl. Radiat. and Isot. 58, 103-113, 2003.) For AGS the method has not yet been tested. For any fixed altitude the situation is similar to that for the CGS measurements. But in order for the method to be useful for AGS, the stripping parameters for any height should be available - for example by interpolation between altitudes for which the stripping parameter have been determined.

A NKS project should concentrate on testing the applicability of the method. Where can it be used and where not. The accuracy of the method - defined in some way - should also be examined for different scenarios.

Appendix A. The RESUMÉ 2002 Exercise

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Introduction

The RESUMÉ 2002 exercise (Rapid Environmental Surveying Using Mobile Equipment) was held in May 2002 in SW Scotland as part of the European ECCOMAGS project. The primary aim of the exercise was to evaluate the ability of Airborne Gamma Spectrometry (AGS) teams in Europe to produce consistent dose rate and radionuclide deposition data and to demonstrate mapping capabilities following a nuclear fallout. Ten AGS teams, three car-borne teams, and seven teams performing in-situ and dose rate measurements took part in the exercise. From the Nordic countries, DEMA, SSI, and SGU participated with AGS teams.

AGS survey tasks comprised measurements at calibration sites (Castle Kennedy, Inch Farm and Wigtown Merse), surveys of common areas (X, Y, Z) to enable inter-comparisons within AGS systems and with ground-based measurements, and a composite mapping task where the teams were asked to perform measurements over contiguous survey areas. The combination of the results from many teams demonstrated speed of data capture, and the abilities of teams from diverse countries to cooperate effectively in a nuclear emergency.

Initial data from the exercise are shown in the figures below, presented at the NKS seminar at DEMA in October 2002. The data are currently being analyses by the ECCOMAGS Design and Evaluation Group (DEG, Fig. 1), the final ECCOMAGS data report due in early summer 2003. This report will form the basis for validation of measurement protocols for the use of airborne gamma spectrometry to estimate ground level environmental gamma dose rates and deposited activity on the ground using AGS, initiated under the 4th European Framework Programme (1).

In Figs. 2-3, instrumentation of the airborne and car-borne teams is described. Fig. 4 shows the exercise area with common areas, contiguous areas and calibration points. Based on approx. 69,000 observations (Fig. 5) composite maps of ^{137}Cs deposition (Fig. 6) and dose rate (Fig. 7) were produced immediately following the exercise. In producing these maps, scaling factors were applied to teams participating in the contiguous areas survey, based on their Inch Farm calibration site measurements (Fig. 8). In this figure also reference values of ^{137}Cs deposition and dose rate obtained in a pre-characterization study are shown (2).

Data recorded during the exercise comprise raw data, processed data as well as maps produced by each team. Fig. 9 summarizes the submission of processed data and maps by the AGS teams: All teams surveyed all common areas, and almost all teams were able to perform hovering maneuvers over the calibration sites. Only one team (SSI) has submitted processed data recorded by their germanium detector system.

For the statistical data analysis, measurement data for the common areas are being regridded (interpolated) to facilitate spatial comparisons between teams. In Figs. 10-11 different weight functions *f(r)* employed for regridding data are shown. In part based on a visual in-

spection of regridded maps, using NaI data of the SURRC team (Fig. 12), it was decided to use the set of parameters R = 500m, p = 2, and = 75m for the statistical data analysis.

Further information on the exercise and the ECCOMAGS project including a description of initial results of the exercise can be found in Ref. (3) and at the project web-site, **http://www.gla.ac.uk/ECCOMAGS**.

References

1. European Calibration and Coordination of Mobile and Airborne Gamma Spectrometry (ECCOMAGS). Deliverable D2 - Measurement Protocols. Contract # FIKR-CT-2000-20098. (2872-2002).

2. D.C.W. Sanderson, A.J. Cresswell, J.J. McLeod, M. Giannitrapani and E.M. Scott, EC-COMAGS project, RESUME 2002 – International Inter-comparison Exercise. Report on Phase 1 Pre-characterization Conducted November 2001.

3. D.C.W. Sanderson, A.J. Cresswell, J.J. McLeod, E.M. Scott, H. Mellander, I. Winkel-mann, C. Burgeois, S. Byström, B. Lauritzen, " An International Comparison of Airborne and Ground Based Gamma-ray Spectrometry: Initial Results from the RESUMÉ 2002 ECCOMAGS Exercise. Submitted to *Journal of Environmental Radioactivity*.

ECCOMAGS project

- RESUME 2002
  - SW Scotland, May 2002
  - Validation of measurement protocols
- DEG
  - Exercise planning
  - … Exercise support
  - (Initial) exercise intercomparison report
  - Data comparison and analysis
  - … Seminar January 2003
- NKS
  - Participation in DEG: data exchange format, data comparison and analysis

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ECCOMAGS team description

Team	Platform	Speed (km h^{-1})	Survey height (m)	Altimetry system	System name	Detector	Sampling time	Detector position
BFS	helicopter	110	60	yes	BFSA, BFSB	12 l NaI(Tl)	2 s	inside aircraft
					BFSG	50% HPGe	60 s	inside aircraft
CEA	helicopter	60	60	yes	CEAA	16 l NaI(Tl)	2 s	below aircraft
					CEAG	2 x 70% HPGe	2 s	below aircraft
DEMA	helicopter	150	60	no	DEMAA	16 l NaI(Tl)	1 s	inside aircraft
HSK	helicopter	110	100	yes	HSK	16.8 l NaI(Tl)	1 s	inside aircraft
SGU	fixed wing	240	100	yes	SGU	16.4 l NaI(Tl)	1 s	inside aircraft
SSI	helicopter	150 - 170	60	no	SSIA	4 l NaI(Tl)	2 s	inside aircraft
					SSIG	70% HPGe	10 s	inside aircraft
SURRC	helicopter	110 - 150	100	yes	SURRCA	16 l NaI(Tl)	2 s	inside aircraft
					SURRCG	50% HPGe	4 s	inside aircraft

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ECCOMAGS team description

Team	Platform	Speed (km h^{-1})	Survey height (m)	System name	Detector	Sampling time	Detector position
DEMA	Car	40 – 50	2.2	DEMAC	4 l NaI(Tl)	2 s	on roof, right
IGM	Car	40	2	IGM	4 l NaI(Tl)	1 s	on roof, right
SSI	Car	50	2.1	SSIC	4 l NaI(Tl)	5 s	on roof, center

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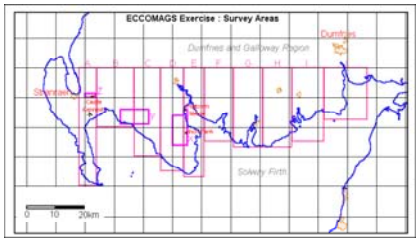
ECCOMAGS - Survey areas



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ECCOMAGS – survey areas

Composite maps flight lines

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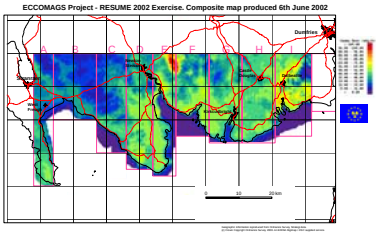
ECCOMAGS –composite maps, June 6th



Dose rate

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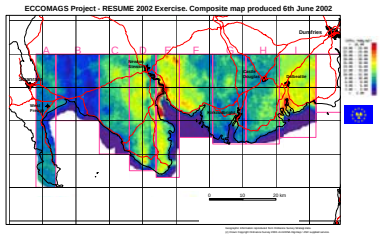
ECCOMAGS – composite maps, June 6th



^{137}Cs depostion

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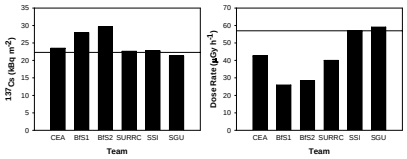
ECCOMAGS – calibration measurements



Inch Farm calibration site

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Exercise report: Description of data

System	Calibration points			Common areas			Data format	Common area maps	
	CK	IF	WG	X	Y	Z		^{137}Cs	dose rate
BFSA	(X)	X		X	X	X	prd	X	
BFSB	(X)	X	(X)	X	X	X	prd	X	
CEAA	X	X	X	X	X	X	xls	X	
DEMAA	X*	X*	X*	X	X	X	prd		X
SGU	X	X	X	X	X	X	prd		
SSIA	X	X	X	X	X	X	nks		
SSIG	X	X		X	X	X	nks		
SURRC	X	X	X	X	X	X	prd	X	X

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Data analysis: Regridding functions

$$f(r) = \begin{cases} \dfrac{1}{r^p + \Gamma^p}, & r < R \\ 0, & r > R \end{cases}$$

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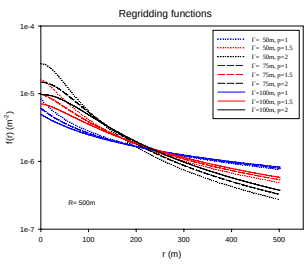
Data analysis: Regridding functions



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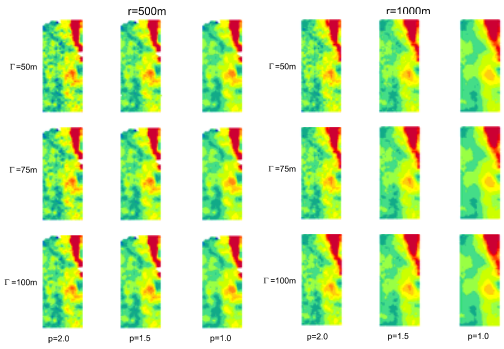
Regridded maps, SURRC – area X



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Bibliographic Data Sheet **NKS-85**

Title	Co-ordination and modernisation of methods for AGS and CGS measurements of multi-nuclide contamination. Report from a seminar.
Authors	Uffe Korsbech[1], Helle Karina Aage[1], Eldri Naadland Holo[2], Svein Thorshaug[2], Olof Karlberg[3], Simon Karlsson[3], Bent Lauritzen[4], Mikael Moring[5], Teemu Siiskonen[5], Mark Smethurst[6]
Affiliations	1. Technical University of Denmark, 2. Norwegian Radiation Protection Agency, 3. Swedish Radiation Protection Institute, 4. Risø National Laboratory, Denmark, 5. Radiation and Nuclear Safety Authority, Finland, 6. Geological Survey of Norway (NGU)
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Date	February 2003
Project	NKS-B
No. of pages	29
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No. of illustrations	4
No. of references	6
Abstract	Earlier projects within NKS have unveiled that Nordic teams performing Airborne or Car-borne Gamma-Ray Spectrometry (AGS and CGS) used different definitions and methods for data processing and presentation. The differences were clarified and proposals for how to obtain consistent results in the future were suggested. The investigations almost all concerned caesium-137 being the only artificial nuclide that today could be measured in the environment with ordinary AGS and CGS equipment. Therefore it was decided to initiate within NKS an examination of how to map other fall-out nuclides with AGS and CGS. As a first step a seminar was arranged on 17-18 October 2002. Here the participants presented how they would handle the mapping of four pre-defined fall-out scenarios. The presentations and discussions at the seminar showed that carrying out the measurements for some of the scenarios would be difficult or even impossible with ordinary equipment and data processing techniques presently used by some of the teams. Mapping of very high levels of contamination could be a problem. Also mapping of a mixed-nuclide fall-out with iodine-131 at a concentration close to the action/no-action levels could be difficult. The seminar resulted in a list of problems deserving attention. Among those was the question on when to prefer high sensitivity NaI detectors and when to prefer high resolution HPGe detectors. A common definition on "detection levels" was also needed. Here the generation of sets of spectra with different levels and combinations of fallout nuclides was proposed. Among the outcomes of the seminar were two proposals for future NKS projects; one concerned mapping of low levels of iodine, and the other was a method for generation of strip factors from ordinary survey spectra.
Key words	Mapping, contamination, AGS, CGS, fallout, multi-nuclide, iodine-131, Caesium-137, dose rates, detector saturation

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