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Technical report

Search of orphan gamma radiation sources

Experiences from the Barents Rescue 2001 Exercise

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Abstract (not more than 200 words)

This report describes the Gamma Search Cell (GSC) exercise that was performed during Barents Rescue 2001. The aim for the GSC exercise was to give teams from Austria, Denmark, Estonia, Finland, Germany, Iceland, Latvia, Lithuania, Norway, Poland, Russia and Sweden the opportunity to search for 31 different gamma radiation sources under realistic conditions and to report their findings. The search was performed by helicopters and by cars.

The participating teams were very satisfied with the exercise and the opportunity it gave to practise and to exchange experiences with other teams.

The report gives information about the design of the exercise, search results and drawn conclusions. The results show the difficulties in these types of missions. The report ends with some ideas about future exercises.

Keywords

orphan sources, gamma search exercise, Barents Rescue 2001

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Sökning av försvunna gammastrålkällor.
Erfarenheter från övning Barents Rescue 2001

Sammanfattning (högst 200 ord)

Rapporten beskriver övning Gamma Search Cell som skedde inom ramen för Barents Rescue 2001. Syftet med övning GSC var att ge mätteam från Österrike, Danmark, Estland, Finland, Tyskland, Island, Lettland, Litauen, Norge, Polen, Ryssland och Sverige söka efter 31 olika gammastrålkällor under realistiska förhållanden och att rapportera sina resultat. Sökningen genomfördes med helikopter och bil.
De deltagande teamen var nöjda med övningen och möjligheten den gav att öva och utbyta erfarenheter med andra team.
Rapporten ger information om hur övningen formades, sökresultat och vilka slutsatser som kan dras. Resultatet visar på de svårigheter som denna typ av uppgifter ger. Rapporten avslutas med en del idéer om framtida övningar.

Nyckelord

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Table of contents

Background 5
- The aim of Barents Rescue 2001 5
- Choice of a scenario with orphan sources 5

Design of the Gamma Search Cell exercise 6
- The search areas 6
- Radiation safety 7
- The radiation sources 8
- The Radiological Emergency Assessment Centre, REAC 8

Search measurements 9
- Equipment 9
- Time schedule 9
- Airborne search 9
- Car-borne search 10

Results 10

Discussion and conclusion 13
- The exercise 13
- The post exercise seminar 14

Acknowledgement 15

References 15

Areas for airborne gamma spectrometry (AGS) 16

Areas for car-borne gamma spectrometry (CGS) 17

Photos of some selected sources and vehicles 18

Background

In 1999 the Swedish Government decided to start arrangements for an international exercise on the theme of a nuclear emergency that should take place in northern Sweden during 2001. The Swedish Rescue Services Agency was commissioned to plan and realize the exercise, named Barents Rescue 2001. Several Swedish authorities were also ordered to participate in the arrangements of the exercise, including the Swedish Armed Forces, who should provide practical support. The Barents Rescue exercise was designed in two main parts: an international alarm exercise (ALEX) and a command and field exercise (LIVEX). European countries were invited to participate directly or as observers. The LIVEX was designed to contain an exercise on the theme of orphan gamma radiation sources that should be searched and identified over large areas using airborne and car-borne measuring equipment. The aim was to make the search exercise as realistic as possible with real gamma radiation sources. This part of LIVEX was named the Gamma Search Cell (GSC). Teams from Austria, Denmark, Estonia, Finland, Germany, Iceland, Latvia, Lithuania, Norway, Poland, Russia and Sweden were invited and participated in the Gamma Search Cell. The exercise took place on the large military exercise grounds at Boden during three days, September 17 - 19, 2001. Altogether 9 airborne gamma spectrometry (AGS) teams, 3 airborne search (AS) teams and 19 car-borne search teams (CGS) performed search measurements. The planning, methods and results of the Gamma Search Cell exercise are shortly described here. A more detailed report with results from each team is available from the Nordic Nuclear Safety Research (NKS-54, 2002).

The aim of Barents Rescue 2001

The aim of Barents Rescue LIVEX 2001 was to improve the capability to lead rescue services for large accidents such as a nuclear accident or a radiological emergency and to cooperate internationally between civilian authorities with the support of national and international military resources. The aim was also to improve the capability to assess a radiological emergency based on actual measurements in the field.

Planning of the Barents Rescue exercise was done in international cooperation between the countries invited. Three international planning conferences were held during a period of about one and a half year before the exercise. A number of workshops were also held with detailed planning of different parts of the exercise. In the planning process it was decided that Barents Rescue should contain different sub-exercises with different themes and time-scales in order to illustrate different aspects of nuclear and radiological emergencies.

The early phase of a nuclear emergency was tested in the international alarm exercise ALEX in March 2001. It was a surprise alarm exercise involving a fictitious nuclear power plant in northern Sweden. Participating countries and authorities took part in the ALEX exercise from their own emergency response centres in each country.

Choice of a scenario with orphan sources

The final part of the Barents Rescue exercise, the LIVEX, was aimed at a joint international field exercise with monitoring and rescue teams in place in Sweden. During the main planning conference it was decided that a challenging exercise would be a large scale search for orphan gamma radiation sources, simulating a radiological emergency with lost radioactive sources.

Accidents with lost sources have occurred a number of times, for example the Cosmos-954 re-entry over Canada in 1978 (Gummer *et al*, 1980) and the Goiânia accident in Brazil 1988 (IAEA, 1988). Recently, two high activity strontium-90 sources were found by members of the public in the Republic of Georgia. The men who found the sources were unaware of the danger and suffered serious injuries from overexposure (L. Vedekind, 2002). Events with lost radioactive sources could need international assistance with airborne and car-borne measurements, medical treatment of irradiated people, evacuation and decontamination of highly radioactive areas, etc.

Large scale exercises on the theme of lost radiation sources have been rare. In the Nordic counties only one international exercise has been carried out on this theme. It was the RESUME-95 exercise in Finland in 1995 (NKS, 1997) in which one task was to localise a number of gamma emitting point sources from the air over a search area of about ten square kilometres. Measurements on foot were not allowed, but the exercise still provided valuable findings. Experiences from the RESUME-95 exercise was therefore implemented in the design of the larger Gamma Search Cell exercise, that used five search areas and a combination of airborne and car-borne measurements and measurements on foot.

The theme of lost sources was also used in the Command Exercise and the Field Exercise that were other parts of LIVEX. According to the LIVEX scenario an unknown number of radioactive sources were suspected to have been illegally buried in the large bogs and forests of northern Sweden in the 1950s and 60s. For some reason, perhaps due to a road construction, at least one of the buried sources had reappeared and caused radiation injury. Parts of this source, and possibly other sources, could have been spread over of thousands of square kilometres. The task for the search teams of the Gamma Search Cell was to locate as many sources as possible within the areas defined by the exercise management.

Design of the Gamma Search Cell exercise

The search for orphan gamma radiation sources over large areas was designed to be a practical experiment were different teams, measuring equipment, assessment methods and tactics could be compared. Rapid positioning and identification of sources found including the reporting of source data to a Radiological Emergency Assessment Centre (REAC) was encouraged to obtain a near realistic emergency situation.

The search areas

About 10 helicopter teams and 15 car-borne teams had preannounced their participation in the GSC-exercise. In a real emergency situation each team would have been assigned to a specific search area in order to cover as large areas as possible. In that case most teams would probably not have found any sources. Such a situation would not be appropriate for an exercise were each team should have the possibility to test their search methods on a number of different sources and geometries. Therefore a compromise between realism and usefulness had to be made. The exercise was set to continue for three days and each team should have the possibility to locate a number of sources each day, as far as possible without interference from other teams. This would need at least as many sources as there were teams and enough space for all search areas. For car-borne teams the road lengths had to be about a hundred kilometres each day. For airborne teams at least a couple of hours of flight time should be planned for each day. The I19 Regiment of the Swedish Armed Forces in Boden could offer suitable areas satisfying these demands. The Regiment arranged for the use of hundreds of square kilometres of its exercise grounds (firing ranges) northwest and southwest of Boden.

For car-borne teams, five search areas were defined (C1 - C4, C7). These should be covered during the three days of exercise. 1 - 8 sources were placed in each area. This meant that 3 - 4 car-borne teams had to use the same area at the same time. To allow all car-borne teams to have the same prerequisites within each area, information on identified source locations were kept secret between teams until the end of the exercise. A map of the areas for car-borne search is given in Fig 4.

For airborne teams five search areas of 2 x 5 km^2 (A1 - A5) were defined. The areas for car-borne search overlapped the areas for airborne search, except for area A5, were the strongest radioactive sources were placed. The area A5 was not allowed to be entered by car-borne teams. Fig 3 shows the areas for airborne search.

In a real situation the findings from airborne search would be followed up on the ground with hand held equipment. The exercise management decided that this practice should be allowed and encouraged in the exercise. Therefore, all car-borne teams were granted access to results from at least one airborne team. The information exchange between airborne and car-borne teams was assigned country by country. Countries without airborne teams could get access to Swedish airborne results. The time and area slots of airborne and car-borne teams were distributed so that car-borne teams generally could access areas that had been covered by airborne search the day before. Unfortunately, because of morning fog during all three exercise-days, less than half of the scheduled airborne measurements could be performed each day. So the cooperation between airborne and car-borne teams could not be fully accomplished.

Radiation safety

According to the LIVEX-scenario the source nuclides should be unknown and the sources hidden, buried or in other ways hard to find and to identify. The follow up of sources on the ground required search teams to get close to hidden sources. Since sources should be located by measurements of the radiation field and not by eye, the sources could not be visibly marked. Therefore, special safety arrangements were put into practice to allow the managing personnel and the search teams to operate safely in the search areas with hidden sources. The Swedish Radiation Protection Authority stated conditions for the use of the radiation sources in the exercise and issued the permission according to the Swedish legislation. Special arrangements were put in place in the weeks before the exercise so that the sources could be managed with minimal doses according to the ALARA-principle. The arrangements had to ensure that doses to search teams or to the public by mistakes were avoided. The sources were placed within physical barriers of different kinds to prevent people and animals to get in touch with them. Examples on how the sources were arranged are shown in Fig 9 - 13.

Access to the exercise grounds was legally restricted and physically stopped using roadblocks. Military radiation protection personnel guarded the areas around the clock. Identification procedures with special car signs and personal identification tags were implemented to ensure that only the approved search teams taking part in the GSC-exercise had access to the exercise grounds.

All persons participating in the Gamma Search Cell had to carry dosimeters. These were supplied by the exercise management at the start of the exercise and collected after the exercise. Teams could also use their own dosimeters, but it was obligatory to carry the special dosimeters supplied by the management. In addition, all participating search teams were encouraged use dose rate instruments. One specific person was assigned the responsibility for radiation safety.

The radiation sources

The sources were borrowed, rented or bought from national institutions and companies handling radioactive sources. These were the Swedish Armed Forces, radiography companies, laboratories and one hospital. The sources used were twentyfour Co-60, eleven Cs-137, two Mo-99, two Ir-192, one I-131, one Am-241 and three blocks of stone with natural uranium ore, totally 44, ranging in activity between 0.0004 - 41 GBq. Fig 5 and 6 shows the Co-60 sources from the Swedish Armed Forces.

The sources were placed in shelters, sheds, vehicle carts, cages or in free air with special arrangements for the radiation protection requirements. The positions of the radiation sources were determined by hand held GPS equipment. Most of the sources were shielded in different ways. Up to 15 tons of concrete-filled boxes were used to build shields for protection and to create confusing radiation fields. Fig 7 and 8 shows the shielding material and an example of its use around a source.

In some cases two sources were combined of which just one was supposed to be measurable from the air. If and when a car search team then entered the area to verify the air finding they were supposed to find another source, positioned some distance away. The sources 4:2 and 4:3 and the sources 4:6 and 4:7 were arranged according to that idea.

Other combinations of sources were also made especially for car-borne teams. At some locations two sources were placed within a distances of 20 - 40 metres. One source could generally be found from the car, but the second could only be located by a survey on foot in the surroundings. The sources 2:1 and 2:2 and the sources 4:4 and 4:5 (see Fig 11 - 12) were of this kind. The twin sources 7:3 and 7:4 were collimated towards each other to take out the inverse square law.

In search area A5 the source 5:4, a Cs-137 source of 1.9 GBq, was placed in a carriage and moved after a car on a closed road path of about 4 km length. This source was only intended for airborne search.

The Radiological Emergency Assessment Centre, REAC

The search teams were led from a command and control centre named the Radiological Emergency Assessment Centre, REAC that was established with the help of military resources in Boden in the week before the exercise. Both civilian and military personnel manned the centre. It directed the search teams and handled the safety of the teams. REAC also received, processed and displayed the radiation measurements from all teams. The military Air Wing handled air control and safety for the airborne teams. Places for liaison officers for Russian speaking teams were granted in the REAC and the Air Wing. About 30 people worked in the command centres during the exercise days.

The task for each team was to determine the position, radionuclide, activity and dose rate of as many sources as possible within the assigned search area and time allotted and to report the findings as soon as possible to REAC. Helicopter teams should report source findings to REAC within one hour after landing. Car-borne teams should report source findings as soon as possible after a source was located.

Source findings should be reported in a specific form, the Source Identification Report (SIR). Reporting could be made by telephone, fax, radio or email to REAC. Track measurement data could be reported on data media or by email in the so-called NKS-format. The NKS-format was designed for mobile measurement data and first used during the Resume 99 exercise in Gävle. In addition, teams could report more detailed measurement data at their own choice.

A password protected web site was used to display results from all participating teams in the Gamma Search Cell. Each team had access to their own results on the web, but different teams could not see each other's results until the end of the exercise. At that time all results were made available to all participants together with details on source data. General information about teams, the progress of the exercise and other information of general interest were provided on a web site open to the public.

Search measurements

Equipment

Participation in the Gamma Search Cell was open to teams using fixed wing aircraft, helicopters and cars. Measuring equipment was generally gamma spectrometers based on sodium iodide crystals or semiconductor detectors based on high purity germanium. One airborne team used non-spectrometric instruments based on GM-tubes. In addition geological survey instruments and dose rate meters were used for hand held measurements close to the sources.

Time schedule

Most participating teams arrived in Boden on Wednesday, September 12. An opening and information meeting was held on September 13. Information on activities concerning reference measurements and pre-exercises was given in the mornings of September 14 and 15. Detailed orders for each exercise day were given in the evening of September 16, 17 and 18. On September 16 a pre-exercise was conducted during three hours. In the afternoon of September 13 the official LIVEX opening ceremony was held. The main exercise took place during September 17 - 19. Source locations and results from teams were presented in the morning of September 20.

Airborne search

Helicopters were allotted to five search areas of 2 x 5 km^2 (A1 - A5). Only one helicopter was allowed into a search area during a time slot (A single exception was made for three Swedish military helicopters measuring in formation in area A5 during the last hour of the exercise). The time allotted to each search area was about 50 – 55 minutes. During the three exercise days there were 7 - 8 time slots per day for each search area. However, due to fog in the mornings, only afternoons could be used for airborne search. REAC provided airborne teams with maps of the search areas.

Helicopters were allowed to fly at their own choice within the borders of the search areas, but were not allowed to land there. The minimum flight height was 60 m due to the safety distance to sources. There was unassigned space between individual search areas allowing helicopters to make close turns just outside the area. One fixed wing aircraft participated also (SEA). It was given time slots when helicopters were not in the air.

A specific training area 3 x 3 km^2 (A6) was assigned. In this area two radiation sources (Co-60 and Cs-137) were well marked and visible from the air. The training area was open from September 13 until September 19. In addition, two radiation sources (Co-60 and Cs-137) were available for reference measurements at the aviation field.

Car-borne search

Car-borne search teams were given different areas and roads to search each day. REAC provided all teams with with road maps showing search roads, areas, entry and exit points. Four (A1 - A4) of the five search areas assigned to airborne search were also open for car teams and teams on foot with portable equipment. These corresponded to the car-borne search areas C1 - C4. About 300 km of roads were available for car-borne search and divided into five areas (C1 - C4, C7). Typically 3 - 6 car teams shared one area. Teams were allowed to leave their car and perform search on foot in the terrain with portable equipment, except for area A5 that was only assigned to airborne search and not open for car-borne search or search on foot.

Car-borne teams had access to radiation sources for training and reference measurement in the specific training areas at A6 and at the helicopter airfield. Access to the training area at the airfield was allowed from September 13 and at the A6 area from September 14.

Results

The search results for all teams are graphically presented in Figure 1. The presentation is based on the Source Identification Reports (SIR) used during the exercise and the team's written reports. In some cases it is not quite clear if a source has been located. For example, a source with the correct radionuclide could have been reported with coordinates more than 100 metres off the position measured at the placement of the source. Since the uncertainty in the GPS-positioning is in the order of 20 metres a judgement from the authors are sometimes made to determine if a source is found or not. By which method a source was found is not possible to see from the graphic.

On the average about half of the sources were located by the airborne and car-borne teams. Some of the sources were not found at all. For example, the source 2:5 (six level indicators) with a total of 1.5 GBq of Cs-137 collimated upwards and 0.06 GBq of Co-60 collimated sideways was not found either from the air or from the ground. The reason why it was not found from the air is probably that the beam was too narrow to be detected. A helicopter had to pass directly over the source to come into the radiation field. The reason why the Co-60 was not detected by car-borne teams was the combination of the narrow beam, the low activity and the distance (about 50 m) from the road.

The source 2:3 (a hospital Mo-Tc-99m generator) with the activity 0.7 GBq, was also not fond either from the air or the ground. I practice, it was impossible to detect from the road by car-borne measurements because of the sideways shielding and the long distance (about 100 m) from the road. This was also not the intention. The source was intended to be detected from the air with a subsequent follow-up with hand-held equipment on the ground.

Three blocks of stone 7:6, 7:7 and 7:8 (about 50 kg) containing uranium ore were all placed in area C7 in wooden boxes and tied to the outside of the railings on bridges over steams. The distance to the cars passing by would be 1 - 2 metres. None of these sources were detected.

One airborne team detected once the moving source 5:4 in area A5 with 1.9 GBq Cs-137. Another airborne team spotted the car and carriage visually and tried to follow it along the winding road. The team, however, lost the car out of site in the woods and did not report the source.

All airborne (AGS) teams detected the strong sources 5:5 of 41 GBq Ir-192 and 5:3 of 9.8 GBq Co-60. The source 5:2 containing 2.6 GBq Cs-137 was missed by two AGS teams with spectrometers and one airborne team with a GM-detector. It should normally have been detected, but it was placed only 60 metres from the stronger Co-60 source 5:3. Therefore, its radiation "drowned" in the primary and scattered radiation from the Co-60 source. It should, however, probably be possible to identify with a more close analysis of the pulse height distribution from a spectrometer.

The source with the strongest output was 5:1, a 40 GBq Co-60 source for radiography. It was buried about 50 cm under a road, so it produced mainly scattered radiation. This source was detected by four of seven airborne teams.

The weakest source that was found from the air was 4:1, a 0.4 GBq Cs-137 source. Two out of seven teams reported it.

The weakest source that was found by a car-borne team was 2:6, a 0.0004 GBq Am-241 (calibration source) placed in a carriage at the roadside near the entry point to areas C1 and C2. Only one team located the source. It was done by hand held equipment. The carriage was searched because the team had decided to measure near all vehicles in the designated search area.

The total results are summarized in a very simple way in Figure 2. The percentage given is of the total number of possible findings, i.e. the number of sources times the number of teams looking for them. The number is corrected for teams that did not measure in a certain area.

The number of possible findings was 150 for AGS and 432 for CGS. In practise the possible number of findings for the AGS-teams is less than 150, due to the fact that some sources were arranged in such a way that they should not be seen from the air.

Summary of search results for AGS, AS and CGS teams

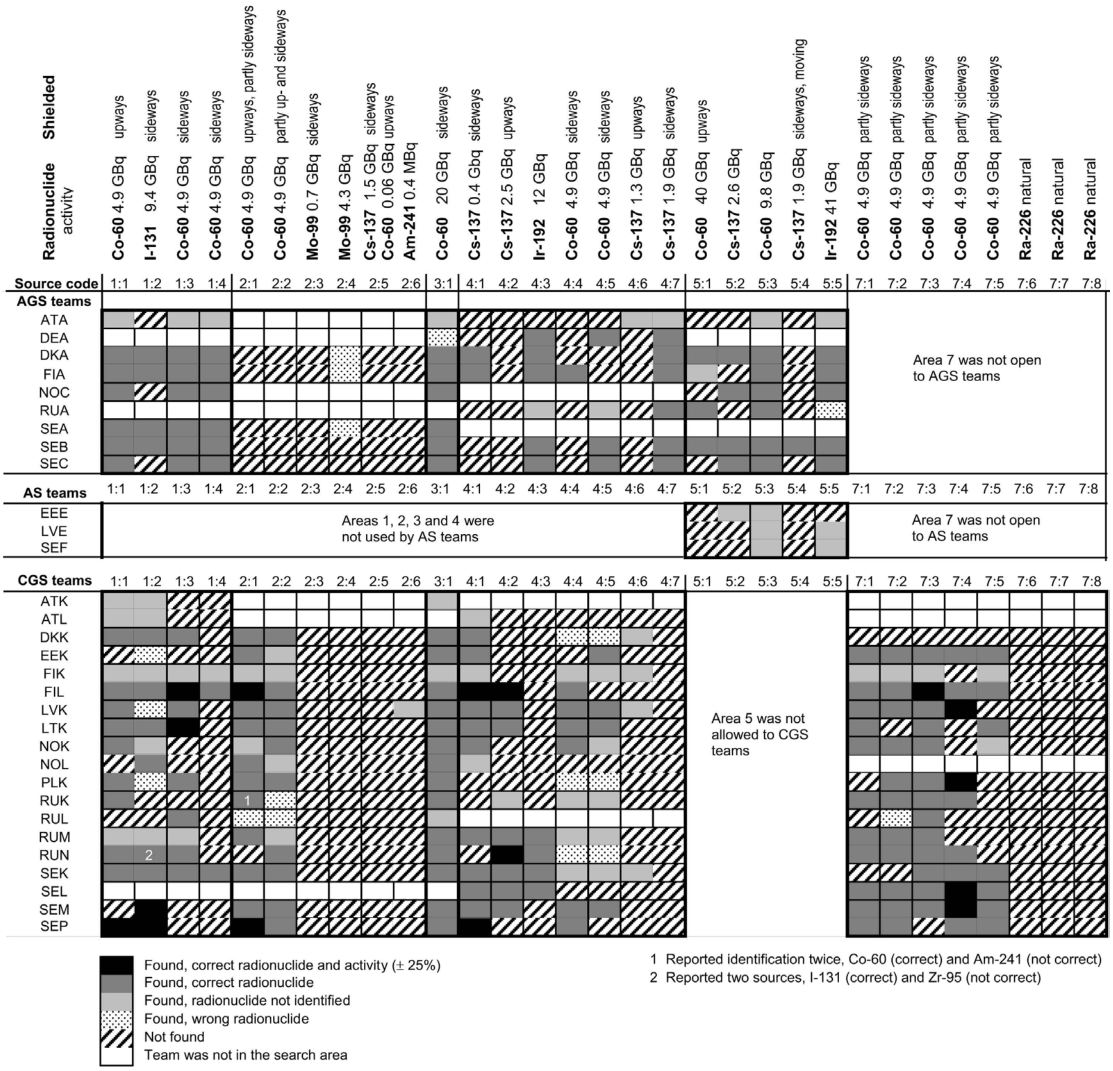

Fig 1. Compilation of search results for 31 teams in six search areas containing altogether 32 hidden point sources of 7 different radionuclides. The methods were airborne gamma spectrometry (AGS), airborne search (AS) with non-spectrometric equipment and car-borne gamma spectrometry (CGS) combined with search on foot with hand held equipment. All AGS teams, but one, used helicopters. The Swedish team SEA used a fixed wing aircraft. The Austrian team ATA used non-spectrometric equipment. The first number in the source code is equal to the search area number. Detailed information on sources and full results as reported by each team is given in the report NKS 54, 2002.

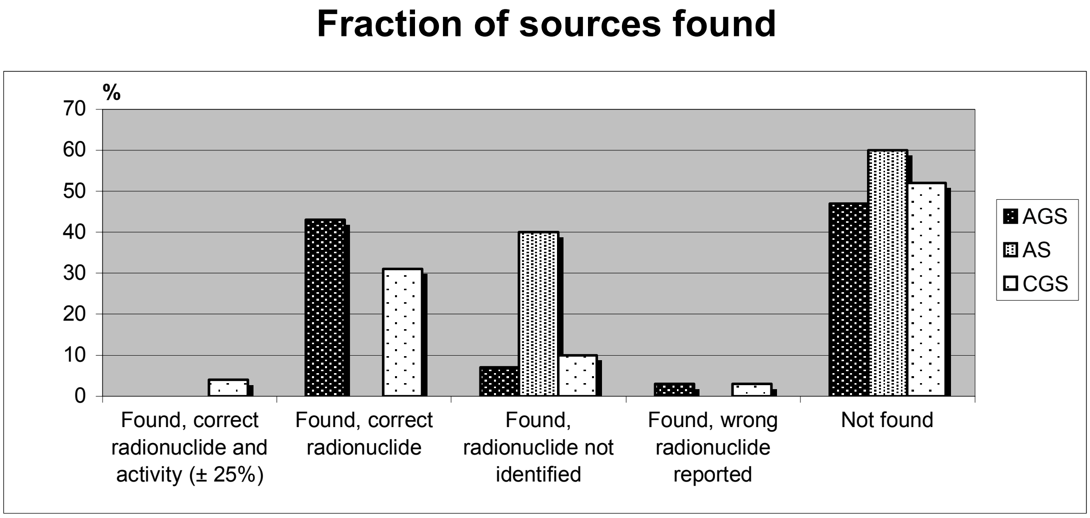

Fig 2. Fraction of sources found using the methods airborne gamma spectrometry (AGS), airborne search with non-spectrometric equipment (AS) and car-borne gamma spectrometry (CGS) combined with search on foot with hand held equipment. AS was only performed in one search area (A5) due to a limited time schedule.

Discussion and conclusion

The exercise

It is a difficult task to find and identify hidden radioactive sources; the results of the Barents Rescue Gamma Search Cell exercise clearly indicate that. It is of course possible in a real accident that the source activities are stronger and that the search teams know which radionuclide and what source type to look for. Nevertheless, the exercise gave the participating teams a good opportunity to practise and test their equipment and search strategies.

Most teams found it very valuable to have their equipment tested under field conditions, mounted in vehicles and bumping around on gravel roads or in helicopters and with a limited time at their disposal. Many problems had to be dealt with like broadening of full energy peaks and optimisation between detector systems. Other examples of problems were background discrimination, how the system alerts when passing a source, on-line or post processing of data and accurate positioning. No team found all sources, and a few sources were not found at all. The results for the different teams show a big variety, but every team found at least some sources.

The mornings during the three exercise days were too foggy to allow flying in the area. Therefore, there became a shortage of available time slots for flying compared to what was scheduled. This affected the results because all teams did not get suitable time slots to cover all search areas. This in turn hampered the planned cooperation between air search teams and ground search teams.

The “twin sources” 2:1 / 2:2 and 4:4 / 4:5 were placed close together. It can be noticed that in several cases just one of them was reported. For air search it is understandable that it is difficult to separate two sources of the same kind. Car search teams, however, should have a search strategy that ensures that other sources are fond that possibly can be located close to the first source.

Just as it was planned, some sources that were found by car search did not turn up in the air search reports and vice versa. This is important knowledge from a preparedness point of view. To find all sources, complementary search methods must be used.

It is necessary to use spectrometric equipment to identify radionuclides, but it seems to be hard and time consuming to estimate the source activity and none of the air teams managed to do it. Good knowledge of parameters like dose rates, distances and thickness of shields is necessary, something that is very difficult to obtain in airborne search alone. Car search teams that have been successful in estimating the activity have used a combination of methods to gain knowledge of these parameters. Often, one can use dose rate meters to estimate the distance to the source by using the inverse square law. By analysing the relation between the full energy peak and the compton continuum in the pulse height distribution one can probably get some idea of the thickness of the shield.

Car search teams have reported that some sources were found with other methods than radiation measurements. In some cases teams looked for other signs than radiation, like white poles or suspicious buildings. So the fact that a source is reported as found does not necessarily mean that something can be said about the effectiveness of the equipment used.

Many computerised programmes exist for analysis and presentation of data. An evaluation of their functionality when used by more or less experienced operators, sometimes under stress, could be wise to perform. The fact that different teams and nations use different programmes makes cooperation and exchange of data and results more difficult. Standardization would facilitate information exchange.

A more detailed and systematic analysis of, by which method and equipment sources were found, can tell whether large detectors give better results than small detectors, or if one detector system or method is better than another. This can be an issue for future work to improve preparedness for radiological emergencies.

The post exercise seminar

A follow-up meeting for all participating teams was held at Rosersberg in Sweden on October 23 - 24, 2001 where participants presented their measurements and discussed experiences from the exercise.

A common opinion of the teams was that airborne and car-borne gamma spectrometry is important for the search and identification of orphan radioactive sources in a radiological emergency. The teams felt that they were able to find and identify lost sources, but the search might not be effective in all situations. Success will depend on a number of things such as expected radionuclide, source activity, shielding and distances to sources and also sheer luck. Reporting should not only cover the position, radionuclide and activity of a source but also include other important quantities and observations such as uncertainty, beam direction, dose rate as a function of distance and safe distances.

Some teams pointed out that their online analysing procedures needed much manual attention and that the operator became very tired after hours of work. This could lead to missed sources. Better software is needed for online and post processing, with minimum operator interface. Equipment with alarm triggers, like sound, will improve the effectiveness.

The teams pointed out that, when units from different organisations are working together there could be problems with reporting and exchange of information due to different systems and different ways to present measured data. It is important with standardisation of the reporting and to have good practices for data evaluation and presentation.

In case of a radiological emergency, search teams will need accommodation, food, communication equipment and technical and scientific support. There should be a command and control centre established in the area (like the REAC). Airborne gamma spectrometry could be effective for scanning areas, although shielded or weak sources might not be detected from the air. Car-borne gamma spectrometry is best suited for search along roads and for local follow up of findings from the air. Coordination between airborne and car-borne teams is important. Possible mobile sources will be hard to find. A lot of personnel will be needed, both for the field operations and for the analysis in the command centre.

It was concluded that all teams were satisfied with the exercise and that future development would benefit from further cooperation between the authorities, institutions and teams that have the task to locate lost sources in the event of a radiological emergency.

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The Swedish Rescue Services Agency (SRV), the Swedish Radiation Protection Authority (SSI), the Swedish Defence Research Agency (FOI) and the Swedish Armed Forces (FM) were responsible for planning and conducting the Gamma Search Cell-exercise in the Barents Rescue LIVEX 2001.

The Nordic Nuclear Safety Research, NKS, supported participating teams from the Nordic countries. NKS collected measurement information from all teams to facilitate a subsequent scientific evaluation of measured results. Generally all participating teams have allowed the use all data that have been reported and documented. When using data from other teams in scientific reports, these teams should be duly referenced and acknowledged. The detailed team's reports are published in the report NKS-54, which is available from the Nordic Nuclear Safety Research.

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Areas for airborne gamma spectrometry (AGS) and air search (AS)

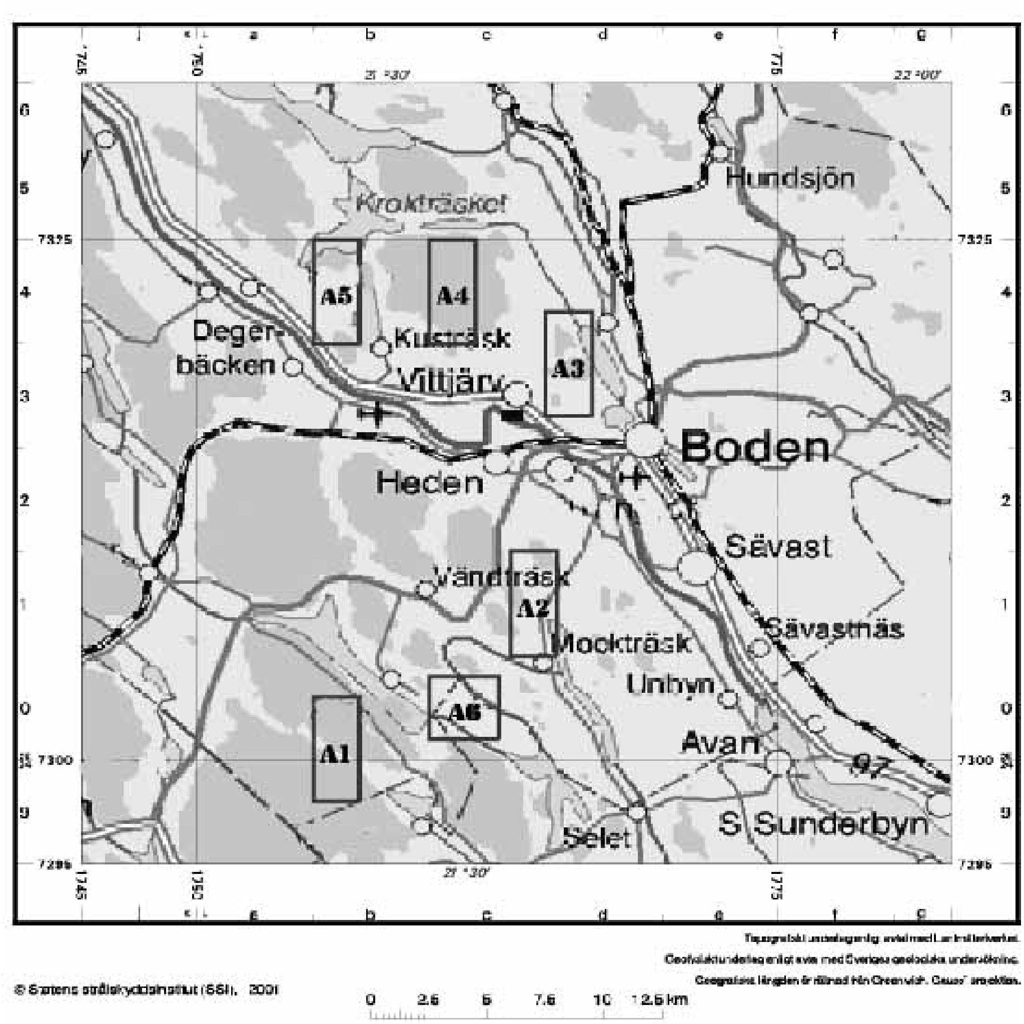

Fig 3. The five search areas (A1 - A5) for airborne search teams were rectangles 2 x 5 km^2. Within these areas 24 sources were placed with the radionuclides Co-60, Mo-99, I-131, Cs-137, Ir-192, and Am-241. The Am-241 source, however, was so weak that it could not possibly be located from the air. It was only intended for car-borne teams. The area A5 was not allowed to be entered by car-borne teams. The area A6 was defined for training purpose. It was a square of 3 x 3 km^2. In the training area one Co-60 source of 4.9 GBq and one Cs-137 source of 2.6 GBq were placed and their positions clearly marked so that they could be visibly seen from the air. Airborne team had access to the training area the days before the exercise and also during the exercise. Only one helicopter was allowed in each area at each time slot of 50 minutes. The military Air Wing of Boden held command of the air control.

Areas for car-borne gamma spectrometry (CGS) and search on foot

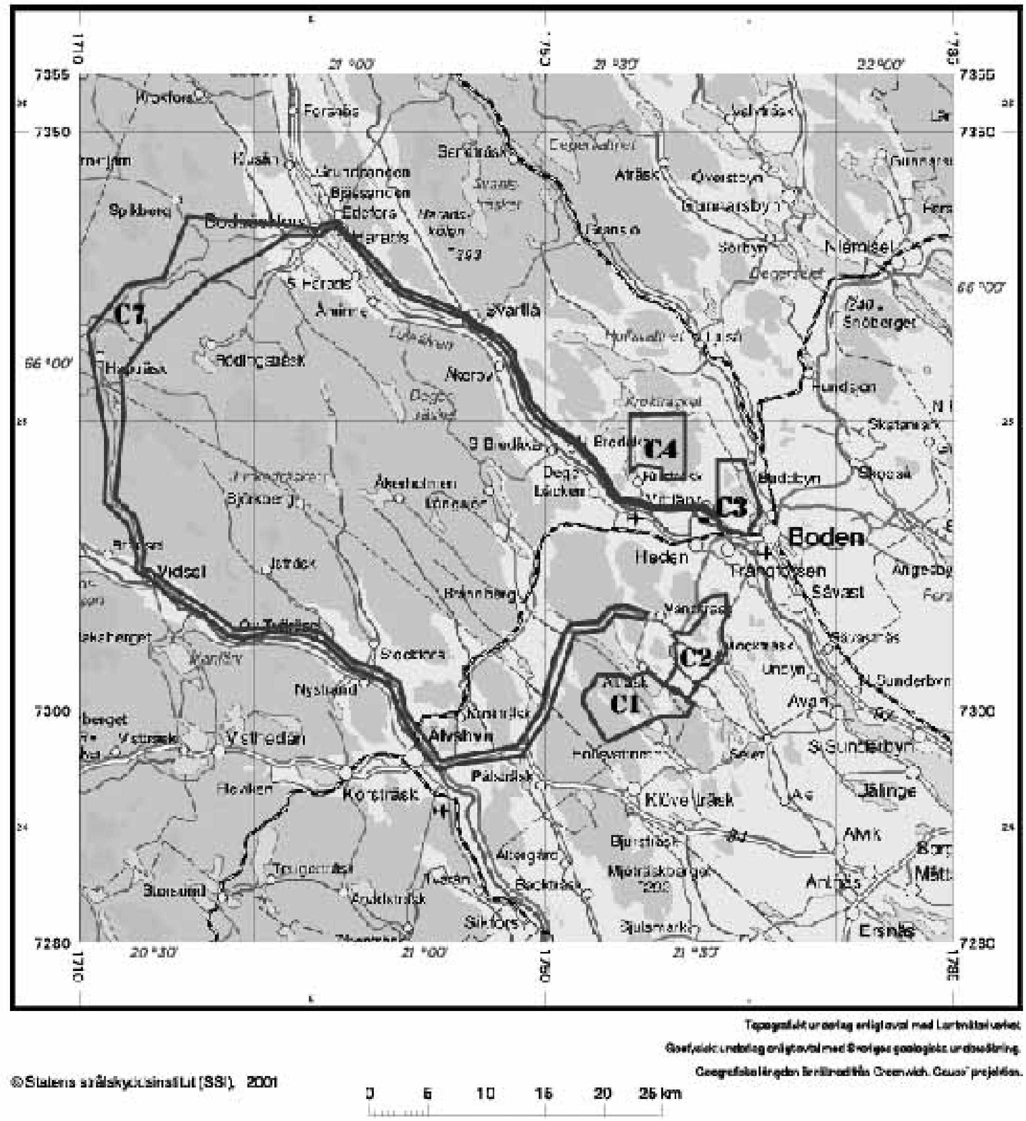

Fig 4., Five search areas (C1 - C4, C7) were defined for car-borne teams. The areas C1 - C4 overlapped the areas A1 - A4 for airborne search. The area C7 was only used for car-borne search. Within the C1 - C4 areas 19 sources were placed with the radionuclides Co-60, Mo-99, I-131, Cs-137, Ir-192, and Am-241. Within the area C7, 5 sources with Co-60 and 3 sources with natural uranium ore were placed. The search areas should be covered during the three days of exercise. About 3 - 4 car-borne teams had to use the same area at the same time.

Photos of some selected sources and vehicles

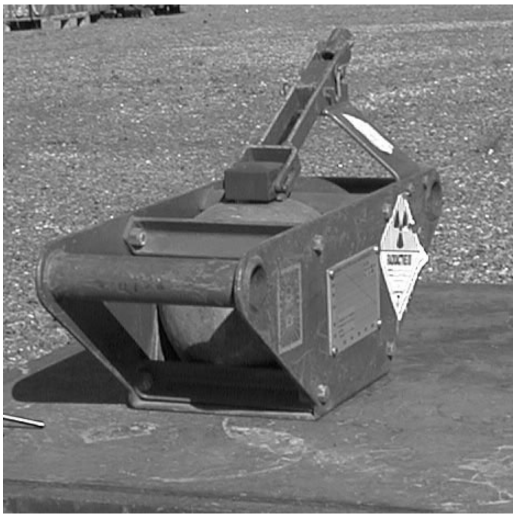

Fig 5 One of the 4.9 GBq Co-60 sources used by the Swedish Armed Forces for NBC-training. 18 such sources were used in the search areas. At 5:3, two sources and at 3:1, four sources were placed together to increase the total activity. The picture shows the source in its shielded position.

Fig 6. The Co-60 source elevated to radiation position. The source is mounted at the bottom of the vertical rod. The white arrow points to the source position.

Fig 7. Blind ammunition box of wood filled with concrete. A large number of these boxes were used for shielding of the sources during the exercise. The outer dimensions are 720 × 185 × 200 mm and the wood is 22 mm thick.

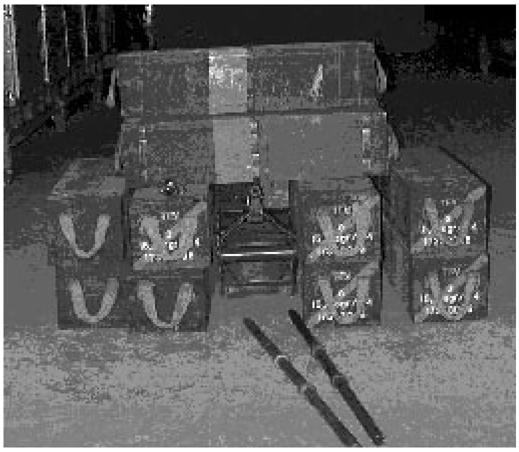

Fig 8. Blind ammunition boxes were placed in various geometries around the sources to obtain shielding in desired directions. The picture shows the upward and sideways shielding of the source 7:3 providing some collimation of the radiation field towards the front.

Fig 9. Sources were placed within physical barriers to prevent people and animals to come too close to the sources. Some of the sources were placed in wooden cages. The picture shows the wooden cage for source 1:1 containing 4.9 GBq Co-60. The shielding is not yet applied. The source is manoeuvred with a rod through one of the slits in the cage.

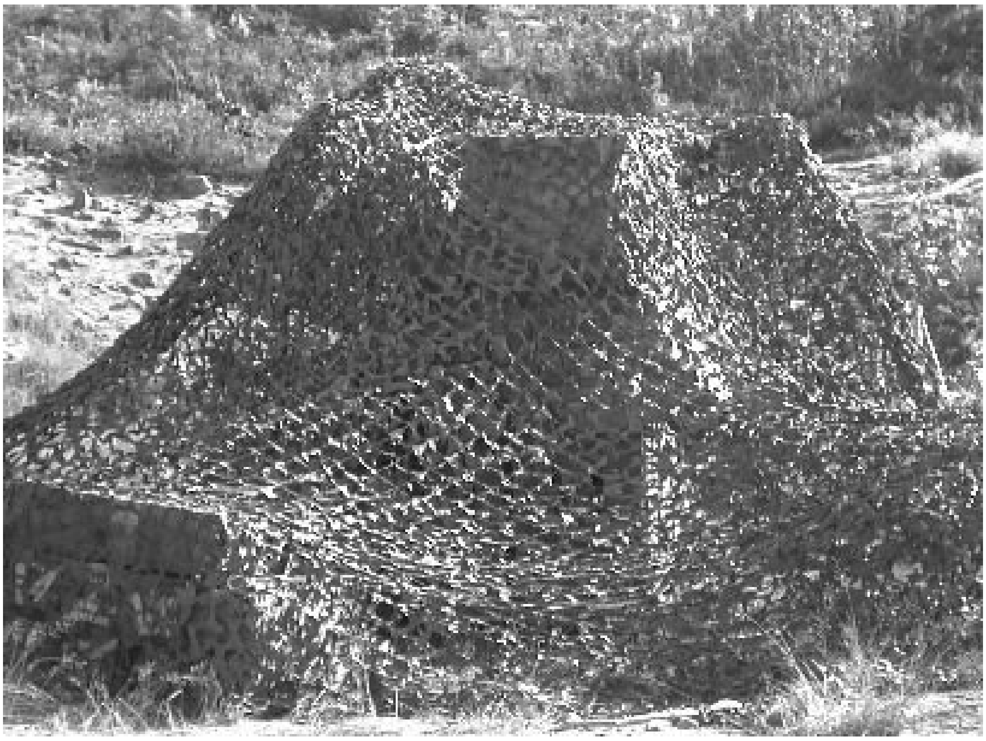

Fig 10. The Co-60 source 1:1 in a wooden cage with shielding applied. The source was masked to prevent it to be located by eye from the air.

Fig 11. The sources 4:4 and 4:5, each with 4.9 GBq of Co-60 were placed in concrete fire trenches and covered with steel plates and stones. The distance between the two trenches was 50 m. Some of the teams found only one of the sources.

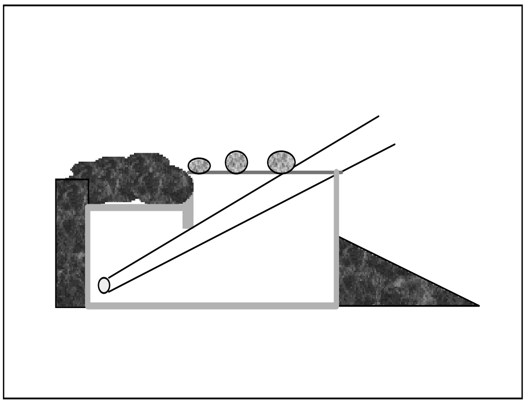

Fig 12. Sketch of how the sources 4:4 and 4:5 were arranged. The primary beam could be detected from the air. Car-borne teams on the road to the left of the source could only detect scattered radiation from skyshine. Measurements on foot were needed to detect the primary beam.

Fig 13. Some sources were placed in tracked vehicle carts. The picture shows the masked cart of source 2:3 containing an opened hospital Mo-99 - Tc-99m generator of 0.7 GBq. The source was collimated upwards and never detected, nor by airborne or car-borne teams.

Fig 14. The strongest Co-60 source of 40 GBq (5:1) was a radiographic source placed in a drainage drum at a depth about 50 cm under a road in area A5. The source position under the road is indicated in the picture with a ring.

Fig 15. The road drum, the source guide and the transport container for the radiographic Co-60 source in area A5.

Fig 16. The Swedish army helicopter HKP-9 (MBB BO 105) used by the Swedish AGS teams SEB from the Swedish Radiation Protection Authority and SEC from the Swedish Defence Research Agency. The measuring equipment of team SEB was a 5"x 5" sodium iodide detector (1.6 litres) with a GDM 40 RPS analyzer and a 70 % high purity germanium detector with a Dart analyzer.

Fig 17. The Finnish AGS team FIA from the Defence Forces Research Institute of Technology using the Swedish civilian helicopter Eurocopter 350. The measuring equipment was a 6x4 inch sodium iodide detector with MicroNomad analyzer and a 70% high purity germanium detector with a Dart analyzer.

Fig 18. The car of the Latvian CGS team LVK from the Lielrigas Regional Environmental Board, Radiation Safety center. Measuring equipment was a 4 litre sodium iodide detector from Exploranium mounted on the top of the car. Positioning was made by a differential geopositioning system (DGPS). Measurements data were transferred to a laptop computer and processed using Nucspec v.2.1 and Mapinfo software.