Close Reality in Radiological Emergency Exercises

Robert Finck[a], Jan Johansson[a], B. Åke Persson[a], Christer Samuelsson[b], Karl Östlund[b]

[a]Swedish Radiation Safety Authority, 171 16 Stockholm, Sweden

[b]Lund University, Department of Medical Radiation Physics, University Hospital, 221 85 Lund, Sweden

Abstract. The paper describes the experiences of conducting close reality field exercises for first responders, customs officers, defence CBRN-forces and specialist teams with international participation in combined efforts to take action in various kinds of radiological emergencies. Large field exercises of this kind have been held twice in Sweden; *Barents Rescue* 2001 with teams from 12 countries and *DEMOEX* (Decontamination and Monitoring Exercise) 2006 with teams from 5 countries and observers from 15 countries. In these exercises, low, medium and a few high activity radiation sources were used. In *DEMOEX* short-lived radioactive material was dispersed to create radioactive contamination. The practical arrangements were optimised to keep radiation doses as low as possible and still provide a realistic "feel" for the participants. All exercises took place within areas banned to public admittance, although observers were guided in the areas and could follow parts of the exercises. In this paper, three exercise scenarios are described: decontamination of a house and garden after fallout, search of orphan radiation sources in an extensive area and assessment of the radiation situation in a village after a radiological dispersal device event, "dirty bomb". The exercises were designed to allow all kind of teams to work together in a safe way. The experiences acquired will be used to improve methods, equipment and organization, to be implemented in a real emergency situation, should it ever happen.

KEYWORDS: Radiological emergency exercise; decontamination, orphan sources, radiological dispersal device, dirty bomb, first responders, DEMOEX.

1. Introduction

Fortunately, nuclear accidents or radiological emergencies are rare. This means that first responders, including the field commanders, that have to handle the unknown situation generally have very little or no practical experience from similar situations, unless they have undergone practical training in a radiation environment. In Sweden, as in many other countries, such practical training of first responders for radiological emergencies is uncommon. This could lead to delay or wrong decisions on actions in the rescue work. This was obvious during a realistic field exercise conducted in Sweden in 2007 when weak radioactive sources were used to create a small but measurable registration on hand held dose rate meters. Because of the fear of radiation, rescue workers with only some theoretical knowledge of ionising radiation hesitated to rescue and to give (simulated) first aid to wounded people. The medical treatment was of these reasons delayed for more than one hour.

There is a need of practical training to increase the skill of rescue workers, as well as expert teams, to handle different radiological emergency situations. In this training it is advantageous for the rescue workers to meet with ionising radiation to experience, in practice, the physical properties of dose rate depending on; source distance, effects of shielding and actions to handle the risk of contamination. However, according to ICRP [1] the source related principles for planned exposure situations should apply in all situations, as in these types of emergency exercises. These exercises, therefore; should be carefully planned and supervised to be carried out with high safety to avoid any unnecessary radiation exposures. Naturally, field exercises could in some cases be performed without radioactive sources using instruments simulating radiation. However, when advanced instrument readings are important parts of an exercise, such as in localisation of orphan sources, it is necessary to use real radioactive sources. For this purpose weak and medium activity sealed radioactive sources are optimal in many cases, since they are relatively easy to handle from the radiation protection point of view. However, to obtain a more complete knowledge of possible radiation situations, it is necessary for rescue personnel, as well as for expert teams for field measurements, also to experience the effects of strong radiation sources with its skyshine effects. This exercise scenario, in turn, requires specific safety actions to keep the radiation protection situation for the trained personnel in stringent control regarding the approach to the radioactive source. It is also necessary to train actions to handle emergency situations experiencing the risk of contamination and demonstrating the huge practical difficulties to decontaminate personnel, buildings and areas. In Sweden two large exercises on these themes have been conducted. They were *Barents Rescue* 2001 with teams from 12 countries [2,3] and *DEMOEX* (Decontamination and Monitoring Exercise) 2006 with teams from 5 countries and observers from 15 countries. In both exercises strong radiation sources (category 2 sources according to the IAEA categorization system [4]) were used for large area search exercises. In *DEMOEX* decontamination of a building and personnel was exercised using a dispersed short-lived radionuclide. These exercises are described and discussed here.

2. The contamination experiment

2.1 Background

Swedish legislation requires all county rescue services to have explicit planning for decontamination of the environment in case of an accident with dispersion of radioactive material. There is, however, very little practical experience in Sweden concerning this subject. It was therefore decided by the Swedish Radiation Protection Authority and the County Administration in Halland to set up an exercise (within *DEMOEX*) using a house specially built for a decontamination experiment. The purpose was to test decontamination procedures and effects on typical Swedish building material. First responders rescue services and a national defence CBRN-unit provided equipment and personnel for radiation safety monitoring and personal decontamination, while expert teams took samples and measured the effects of cleaning in different stages of the process.

2.2 House and ground contamination

On an 800 m^2 fenced area a house was erected for the contamination/decontamination experiment. The nearby surroundings of the building were patchy grass and small bushes. The building was founded on concrete blocks placed directly on the ground and had thermally insulated walls, a roof drainage system surface, one entrance door and four windows. With the purpose of comparing decontamination efficiencies, the 45 degree saddle roof was given four different surfaces. Thus the four quarters of the roof was covered by fired clay roofing tiles, concrete roofing tiles, roofing-felt and corrugated sheet metal respectively. With the purpose of imitating an old surface typical for a housing stock, used tiles obtained from a scrap yard were utilized. Three of the exterior wall surfaces comprised painted wooden panels whereas one was concrete plastered. The latter concrete gable wall was not painted. The painted panel on one of the longer wall was sandpapered in order to imitate an aged and weatherised surface.

On the outside of the house plastic tubes were mounted along the ridge and on the walls close to the eaves. Prior to putting this watering system in place 1 mm holes facing the house surface was drilled at every 8 cm along each tube. During contamination the tube system was pressurized and by opening and closing valves the roof and individual walls could be contaminated (sprayed) one at a time. The roof was contaminated once and each wall twice. In total 50 l of water containing 400 MBq of ^{99m}Tc was used. The water was prevented from streaming too fast down the wall surface by means of scrubbing the wall with a flat floor mop. An additional activity of 2x25 MBq was externally applied to the three painted walls with the floor mop in order to create additional in homogeneities. The original plan of using ^{24}Na as a contaminant had to be abandoned due to an unforeseen reactor stop. The ^{99m}Tc-was delivered from a nearby hospital.

The *DEMOEX* house was contaminated on day 1 of the exercise and the ground around the house on the morning the following day. Gamma detectors with remote data logging surveyed the dose rate levels inside and outside of the house. For the contamination of the ground a special system arranged on a trailer was constructed. Water tanks with the stock solution of ^{99m}Tc fed a 4.5 m long straight plastic tube mounted close to the ground. The trailer was towed by a small ATV (All-Terrain-Vehicle), running 4-8 times over the area to be contaminated (Fig. 1). The girder on hinges, holding the plastic tube, could be elevated in order to facilitate the passing over bushes. The total ^{99m}Tc activity dissipated on the ground, around the house and on three "hot-spots" and a small reference area distant from the house, was 4 GBq. The part of the contaminated area in front of the house was irrigated with large amounts of clean water in order to mimic a heavy rainfall.

Fig 1. About 750 m^2 around the house was contaminated by means of the trailer system.

Fig 2. The hot water trolley at work on the concrete roofing tiles of the *DEMOEX* house.

2.3 Decontamination of house surfaces and ground

All machinery and outfits used for the decontamination operation was of standard type and commercially available. When cleaning the roof a person in a skylift manoeuvred the cleaning nozzle. The roofing-felt and corrugated sheet metal surfaces were smooth enough for applying a roof cleaning hot water trolley. The hot water trolley (Fig 2) was also tested on the roof tiles but due to the irregular surface the front-end trolley was later replaced by shaft based nozzles. Used water from the roof was recycled and filtered by means of an industrial vacuum cleaner taking water from a drainpipe vessel.

Unfortunately, the time did not permit the use of the hot-water system on the walls. Instead a conventional cold-water high-pressure system consuming about 20 l/min was used (Fig.3). Before cleaning, the wall was saturated with water by spraying at a pressure about 30 bar from bottom and up. By this procedure the re-uptake of contaminants in the cleaning phase, starting from the top, is minimized. The pressure during cleaning was limited to 120 bar. At higher pressures both the cement plaster and the paint were detached from the wall. The contaminated ground around the house was decontaminated about 6 hours after the activity had been dispersed. A 10 to 15 centimetres thick layer of the ground surface was carefully remove by a 3.5 tonnes excavator. In total, an area of 360 m^2 was decontaminated giving a waste volume of about 40-50 m^3.

Fig 3. Decontamination of walls by means of a cold-water high-pressure system.

Fig 4. A part of the contaminated topsoil layer around the house was removed.

2.4 Measurements and samples

Dose rate and count rate meters on tripods inside and outside the house monitored the radiation intensity during the whole contamination exercise. Handheld gamma detectors were utilized to monitor surface activity before and after cleaning. In addition small surface samples were removed from roof and outer walls for subsequent laboratory analysis. Wooden core samples from panel walls and samples from the roof cleaning water were also gathered. A mobile laboratory on site from the National CBRN Defence Centre analysed about 40 samples of different house materials during *DEMOEX*. Soil core samples were taken in contaminated area around the house before and after excavating. 24 sampling points were chosen in the contaminated square about 30x30 m^2 symmetrically containing the house.

2.5 Safety precautions

For monitoring of airborne radionuclides, five air filter stations were placed around the fenced area, four stationary units and one mobile. The position of the mobile unit was always in the downwind direction of the house. All persons working or being trained inside the fenced 800 m^2 area had to wear protective clothing. Leaving the fenced area one had to pass the exit station manned with a staff responsible for monitoring and if necessary decontaminate all persons leaving the area. To be allowed to work in the ground-contaminated zone close to the house, a special assignment was needed.

2.6 Results and discussion

In addition to decontamination practices and experience within the industrial decontamination field [6], numerous publications, for instance [5,7,8], from the work done in the former Soviet Union (the CIS countries) after the Chernobyl accident, have been published. Several authorities and organizations have published guidelines for how to decontaminate residential areas [9,10,11]. Despite many differences, old ^{137}Cs in the case of Chernobyl and fresh ^{99m}Tc in this case, the decontamination efficiencies obtained are similar.

The initial dose rate 1 meter above both house exterior surfaces and on ground surfaces was in the order of 1 microsievert per hour. The three hot spots created within the fenced area but at a distance from the house showed about 100 times this value. The low and short-lived activity dispersed did not call for any rigorous safety measures, neither for the personnel exercised nor for the inhabitants in adjacent villages. Still, considering that sprinkling radioactive substances outdoor is a sensitive matter to the layman and media, it was decided in the planning phase of the contamination exercise, that high-volume filter samplers should survey the fenced area. The obvious fact that the weather condition at the time of the exercise is not known beforehand, also favoured such decision. As a bonus, the air sampling filter system and the staff handling them could be exercised. As expected, spectrometric analysis of the filter media did not reveal any trace of ^{99m}Tc.

In an exercise like *DEMOEX* the chosen dose rate level of 1 microsievert per hour from dispersed activity is close to ideal. This dose rate means that all person categories participating can work several hours a day without bothering about radiation risks and the activity of ^{99m}Tc generating this dose rate is high enough for expeditious external measurements and radionuclide identification in the laboratory.

The contamination of the house worked according to plan. With the technique used, a significant fraction of the activity stayed on the surface spayed. The efficiency of the decontamination varied between 15 and 45 percent for the different roof materials. The concrete roofing tile showed the lowest value. A porous structure favours apparently an efficient absorption of the contaminant. This was also notable for the plastered wall. Keeping the plaster surface undamaged, a removal efficiency of 15% was obtained. The corresponding figure for the painted and sandpapered panel wall was 52%. Cleaning the roof materials several times proved to be a successful method. As an example, the contamination on the concrete roofing tiles was reduced by 70 percent after three repeated cleaning rounds.

The decontamination of the ground was very successful. For the two areas were the surface layer was removed, only 9.5 percent and 2.2 percent respectively of the contamination remained. One should, however, remember that topsoil removal is time consuming. With the 3.5 tonnes excavator used, it took about 4 working hours and required a worker with shovel collecting spillage to finish the 360 m^2 area around the *DEMOEX* house. The excavator used was well suited for the purpose and can move more freely than ordinary compact wheel-loaders such as Bobcats, used frequently for instance in CIS countries after the Chernobyl accident [5]. The advantage of an excavator is that it can remove the contaminated layer without re-entering the cleaned surface. Keeping the bucket slightly angled toward the dirty surface will minimize the spill of topsoil onto the cleaned soil surface.

2.6 Conclusions

The full-scale contamination experiment of house and ground was very successful. Several different personnel categories were given the opportunity to work during realistic conditions without being exposed to other than negligible doses. Also the staff responsible for dispersing the radioactive substance received insignificant exposures owing to a specially developed activity spraying systems. For decontamination of the Swedish type of house and the surrounding garden we have shown that standard off-the-shelf equipment is useful and effective in the hands of experienced and well-instructed personnel. As expected, for the fresh and superficial ground contamination created, removal of the upper 10-15 cm of soil layer is a very efficient decontamination method. However, it is time consuming and generates a lot of waste. High-pressure water cleaning of the unpainted cement plastered wall is not very effective unless the cement is removed all together. Similarly, the decontamination efficiency for painted wooden panelled walls can be improved below the 50 % achieved, by removing the paint.

3 Orphan sources search exercises

3.1. Background

Accidents with lost sources have occurred several times. In 1978 the satellite Cosmos-954 re-entered the atmosphere over Canada and dispersed its reactor core over a wide, sparsely populated area. Search operations by air and on ground to recover the radioactive debris had to cover over 100000 km^2. Numerous large items and over 4000 very small radioactive fragments were found [12]. In 1987 in Goiânia in Brazil a 50 TBq ^{137}Cs teletherapy source was stolen from a closed down clinic. The source was opened and became partly dispersed. Hundreds of people were exposed during 17 days before part of the source was found quite by chance. Four people died from radiation injuries. The localization work and recovery of most of the dispersed source was extensive [13]. Other accidents with lost sources have been investigated and reported by the IAEA [14,15,16,17,18].

Events with lost radioactive sources may need international assistance with airborne and car-borne measurements, medical treatment of irradiated people, evacuation and decontamination of highly radioactive areas, etc. The IAEA has issued a manual that describes the international system of emergency notification and assistance and provides guidelines concerning assistance [19]. To be able to provide assistance in case of a lost source scenario, emergency teams must have suitable measuring equipment and must be properly trained. This kind of training and exercises has been performed in Sweden in the last ten years. Two large search exercises with international participation have been conducted.

3.2 The search exercises

The search exercises for orphan sources were conducted in uninhabited areas in Sweden put at disposal by the National Defence and banned to public admittance. In the *Barents Rescue* exercise, teams from Austria, Denmark, Estonia, Finland, Germany, Iceland, Latvia, Lithuania, Norway, Poland, Russia and Sweden participated during three days in September 2001. There were 9 airborne gamma spectrometry (AGS) teams (helicopters and one fixed wing aircraft), 3 airborne search teams with total gamma measurements in helicopters, and 19 car-borne search teams (CGS). 44 sealed radiation sources were used; ^{60}Co, ^{99}Mo, ^{131}I, ^{137}Cs, ^{192}Ir, ^{241}Am and natural uranium ore ranging in activity between 0.04 MBq (^{241}Am) and 41 GBq (^{60}Co). The total exercise area within which the sources were placed covered hundreds of square kilometres. For airborne teams, five search areas 2x5 km^2 were defined. For car-borne teams, five search areas with about 100 km of road to cover each day were defined. The airborne and car-borne search areas partly overlapped, allowing airborne and car-borne search teams to cooperate. However, due to foggy morning weather conditions the airborne search was restricted during the first hours, which also limited the possibility to train cooperation between the teams.

In the *DEMOEX* search exercise, teams from Denmark, Finland, Iceland, Norway and Sweden participated during three days in October 2006. Observers from several countries were also invited. The search area covered 50 km^2 within which 45 radiation sources were used; ^{60}Co, ^{131}I, ^{137}Cs, ^{192}Ir, ^{226}Ra, ^{241}Am and a ^{238}Pu-^{13}C neutron source, having activities in the range from 37 MBq (^{60}Co, ^{137}Cs) to 11 GBq (^{241}Am). Five AGS teams performed airborne search using helicopters and one fixed wing aircraft. 10 teams performed car-borne search. Car-borne teams were allowed to leave the car and perform search on foot with hand held equipment. All sources were sealed and placed securely with physical barriers to avoid the risk that anyone in the search teams inadvertently should come to close to a source. In one specially guarded and fenced off area a radiographic source with 1 TBq ^{192}Ir was placed. This source was shielded in the directions parallel to the ground, but open to the air above to produce air scattered radiation (skyshine).

Rapid positioning and identification of sources found including the reporting of source data was encouraged to obtain a near realistic emergency situation. There were no specific scenarios defined, but the task for all teams in all search areas was to localize as many sources as possible, determine the radionuclides and estimate the source activities, taking possible shielding of the sources into account. The search teams were led from a command and control centre named the Radiological Emergency Assessment Centre, REAC, that was established on site a few days before the exercises. It directed the search teams and handled the safety of the teams. REAC also received, processed and displayed the measurement results from all teams.

3.3 Results and discussion

In the *Barents Rescue* 2001 exercise, the AGS and CGS teams on average detected about half of the sources placed in the search areas [2]. Some of the sources were not found at all. For example, a 1.5 GBq source of ^{137}Cs collimated upwards was not fond from the air. The reason why is probably that helicopters had to pass directly over the source to come into the radiation field. A 0.06 GBq ^{60}Co source was neither found from the air nor from the ground, probably because of the low activity and the distance (50 m) from the road. When placing the sources for the *Barents Rescue* 2001 exercise there was not enough time to test the detection distances on site of all 44 sources. Therefore, some of the sources became placed too far away from the road to be possible to detect by CGS teams.

When planning the *DEMOEX* exercise the detection distances for all sources were theoretically calculated in advance and the sources placed in such a way that it should be possible to detect all of them if the detectors were sensitive enough and the team observant. The theoretical calculation of detection distances was based on the formulas given by Currie [20] in combination with measured values of the background radiation field in the exercise area. The calculated detection distances are given in Table 1. These values were tested on some of the exercise sources using a 4 l NaI(Tl)-spectrometer and a hand held search instrument (Saphymo SPP2). The theoretical values seemed to agree well with results from the test measurements on the exercise sources.

In the DEMOEX car-borne search exercise there were large differences in the number of localised sources for different kind of teams. There were expert teams who found nearly all sources in the different exercise areas and there were inexperienced teams that found few sources. In the airborne search some teams found most of the sources and one team found only a few sources and also reported some nonexistent sources. The outcome was probably due to instrument operator skill to separate the weak signal from a hidden source from the variations in the natural background.

Table 1. Detection distances in metres for point sources of ^{137}Cs and ^{60}Co when using a rapidly responding hand held search instrument and a 4 l NaI(Tl)-spectrometer with 1 s or 5 s acquiring time. The low figure in the distance interval is where it is almost certain to detect the source and the high figure is where it is almost certain not to detect the source. It should be noted that it is difficult to distinguish a small increase of scattered radiation coming from a strong distant source from variations in the natural background. For the search instrument the figures are very approximate.

Activity GBq	^{137}Cs			^{60}Co		
	Search instrm	NaI(Tl), 1s	NaI(Tl), 5s	Search instrm	NaI(Tl), 1s	NaI(Tl), 5s
10	120 – 170	140 – 190	170 – 230	200 – 250	200 – 270	250 – 300
1	40 – 60	60 – 90	80 – 120	70 – 110	90 – 130	120 – 180
0.1	12 – 20	24 – 35	35 – 50	26 – 40	35 – 50	50 – 80
0.01	4 – 6	8 – 14	12 – 20	8 – 12	12 – 20	18 – 30
0.001	1 – 2	2 – 4	4 – 7	2 – 4	3 – 6	6 – 10

3.4 Conclusions

After the exercises there were follow-up meetings where teams could express their thoughts concerning the exercises. The teams generally 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 instruments, analysing technique, operator skill, and sheer luck. 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.

Large search exercises with participants from different countries have shown to increase the ability to cooperate between different organisations before a common task. There are many practical things that have to be solved. There should be a command and control centre established in the area (like the REAC). It is important with standardisation of the reporting and to have good practices for data evaluation and presentation. Airborne gamma spectrometry could be effective for scanning large 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.

4 A “Dirty Bomb” exercise

4.1 Background

Despite all safety precautions, accidents involving radioactive sources happens every now and then. Hitherto, such accidents have generally been caused by negligence in safety procedures or by disorder in the handling of radioactive sources or radioactive waste. Much effort has been devoted to planning and response to nuclear accidents and radiological emergencies. In the last years an additional threat has grown. It is the possibility that terrorists could use radioactive material to cause injury to people and disrupt society. The use of radioactive material to intentionally harm people have occurred, but terrorist attacks have not yet involved radioactive material, probably because of the difficulty to get hold of enough of the suitable material. The possibility, however, of a radiological attack by a perpetrator using some sort of radiological dispersion device cannot be ruled out. There is also a serious concern about the possibility of sabotage on nuclear facilities and the theft or diversion of nuclear weapon material to be used in improvised nuclear devices.

A perpetrator would need to get hold of radioactive material and would also need some sort of device or method to bring the radioactive material out to cause harm. Little is known about possible radiological dispersion devices and their effects. Still, society with its rescue personnel have to be prepared to handle the unknown situation where people suddenly could be exposed to radioactive material, possibly in combination with "conventional evilness" such as explosives or fires. Although, the exact knowledge of what a perpetrator may create with radioactive material is limited [21], it is possible to perform exercises with the objective to simulate a radiological dispersal device event. Possible difficulties for the rescue personnel are the combination of fire or explosives, dispersed strong radiation sources, risk of radioactive contamination and injured people who need immediate medical care. In the *DEMOEX* exercise teams of first responders and experts had the possibility to try to work in a radiation environment created to simulate the radioactive debris from an unspecified kind of radiological dispersal device, a "dirty bomb".

4.2 Creation of a simulated radiological dispersal device event

The radiation environment for a simulated radiological dispersal device event was set up in a military "exercise town" with a "Main Street" and side streets. Wooden one- and two-storey buildings formed the "city". Fires, wrecks and debris from "car bombs" were used to make the scene realistic (see Fig 5). Some of the houses had cellars and some of the cellars were connected through tunnels under the streets. This could make it possible to bore holes from the tunnels up towards the surface of a street. Such a hole could be used to place the source hose from radiographic equipment. This made it possible to place the source at a suitable (and safe) distance below the street surface. The source could be put into place and retracted by remote operation. Depending on the source position under ground it would produce a radiation field that could simulate ground contamination (use of a strong source at some depth) or a point source on the ground (use of a weak source just below the ground surface). A complex radiation field could be built by using a number of remotely controlled sources under ground. This could be done with full radiation safety for the exercise teams, since they cannot come in direct contact with the sources. Close approach to stronger sources could also be prohibited by using wrecks or locked buildings near the source. If an unexpected emergency would happen during the exercise, remotely controlled sources can quickly be retracted to diminish the radiation field.

Fig 5. The "dirty bomb town" with a bus wreck and a strong source in a tunnel under the bus.

Fig 6. Personal decontamination in a facility set up by first responders.

To provide a realistic radiological dispersal device environment, teams should experience the risk of being contaminated. In *DEMOEX*, this was done in a safe way by using the short-lived radionuclide ^{18}F ($T_{½}$ = 1.83 h). The radionuclide was produced daily for medical diagnostic purpose and it was transported from the hospital in Lund to the exercise area each morning. A small amount of the radionuclide was dripped on the ground across a narrow path where exercise teams had to pass on their way on “Main Street”. Teams had to use CBRN-protection clothing and respiratory protection. When passing out from the area, each person had to go through personal monitoring and decontamination in a mobile decontamination facility set up by first responders (see Fig 6).

Within the exercise area, teams should measure dose rates, try to identify the radionuclide and draw a simple map with dose rate isolines. Teams were also allowed to take smear samples from surfaces expected to be contaminated. After leaving the area teams should report their findings to the “rescue leader”. Expert teams conducted more detailed measurements with portable gamma spectrometers, while ordinary first responder teams with less elaborate measuring equipment entered the area just to measure dose rates. Medical first aid was not included in this exercise.

The time that teams were allowed to spend in the simulated radiological dispersal device environment was limited to 30 minutes. Wrecks and fire pans blocked areas with maximum dose rates. This limited the dose to the teams to a few microsievert. All participants had to wear TL-dosimeters. No one had any detectable dose on his or her dosimeter after the exercise.

4.3 Conclusions

Exercise participants have expressed that they experienced the radiation field, the risk of being contaminated and the personal decontamination procedure as if they had been into a possibly heavily contaminated area, although the actual contamination on clothing and shoes was minute, but measurable. The artificially built radiation environment made it possible to conduct a close reality exercise safely with very low radiation doses to the personnel. In future exercises of this kind it would be possible to test methods and safely train first responders and expert teams to perform their rescue work in an environment that simulates a radiological dispersal device event.

5. General conclusions

Two large field exercises, The *Barents Rescue* 2001 and *DEMOEX* 2006, conducted in Sweden with teams from a number of different countries have shown that it is possible to create close reality field exercises for first responders and expert teams working in cooperation in a radiation environment. It is possible to perform such exercises with real radioactive sources with high radiation safety and very low radiation doses if they are carefully planned and supervised. It is necessary to use real sources when advanced instrument readings are important parts of an exercise, such as in localisation of orphan sources. Also for rescue exercises including decontamination procedures it is of great value for the training of first responders as well as experts to experience “real” radiation situations. Experiences from these exercises can lead to better understanding and improved methods concerning problems connected to situations where radioactive material is out of control. The decontamination exercise in *DEMOEX*, for example, gave input to better knowledge of practical decontamination procedures and effects, even if this was only a secondary object for the exercise. All participants of *Barents Rescue* and *DEMOEX* carried TL personal dosimeters with a lower detection limit of about 100 microsievert. No one, the staff handling all radioactive sources included, exceeded this level.

Acknowledgement

The authors are indebted Mats Isaksson, Klas Rosén, Torbjörn Nylén, Agneta Hånell Plamboeck, and Thomas Ulvsand for their measurement work. The Swedish National Defence kindly provided the exercise areas, supporting personnel and equipment to carry through the exercises.

REFERENCES

[1] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Elsevier, Oxford (2007).

[2] ULVSAND, T. FINCK, R.R., LAURITZEN, B., editors, NKS/SRV Seminar on Barents Rescue 2001 LIVEX Gamma Search Cell, held at Rescue College, Rosersberg, October 23-24, 2001, Proceedings, Nordic Nuclear Safety Research Report NKS-54, (2002).

[3] ULVSAND, T. FINCK, R.R., Search of orphan gamma radiation sources, Experiences from the Barents Rescue 2001 Exercise, Swedish Defence Research Agency, Technical Report FOI-R-0797-SE, (2003).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Categorization of Radioactive Sources, IAEA Safety Guide No. RS-G-1.9, IAEA, Vienna (2005).

[5] ROED, J., ANDERSSON, K.G., BARKOVSKY, A.N., FOGH, C.L., MISHINE, A.S., OLSEN, S.K., PONAMERJOV, A.V., PRIP, H., RAMZAEV, V.P., VOROBIEV, B.F., Mechanical Decontamination Tests in Areas Affected by the Chernobyl Accident, Report Risoe-R-1029(EN), Risoe National Laboratory, Roskilde, Denmark and Federal Radiological Centre, St. Petersburg, Russia, (1998).

[6] NUCLEAR ENERGY AGENCY, Decontamination Techniques Used in Decommissioning Activites, http://www.nea.fr//html/rwm/reports/1999/decontec.pdf, (2002).

[7] ANDERSSON, K.G., ROED, J., EGED, K., KIS, Z., VOIGT, G., MECKBACH, R., OUGHTON, D.H., HUNT, J., LEE, R., BERESFORD, N.A., SANDALLS, F.J., Physical Countermeasures to Sustain Acceptable Living and Working Conditions in Radioactivity Contaminated Residential Areas, Report Risoe-R-1396(EN), Risoe National Laboratory, Roskilde, Denmark, February (2003).

[8] FOGH, C.L., ANDERSSON, K.G., BARKOVSKY, A.N., MISHINE, A.S., PONAMERJOV, A.V., RAMZAEV, V.P., ROED, J., Decontamination in a Russian Settlement, Health Phys. 76(4), p421-430, (1999).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Cleanup of Large Areas Contaminated as a Result of a Nuclear Accident, Technical Report Series, No. 300, (1989).

[10] ANDERSSON, K.G., ROED, J., Nordic Preparation Guide for Early Clean-up in Radioactivity Contaminated Residential Areas, J. Environmental Radioactivity, vol 46, p207-223, 1999.

[11] EUROPEAN COMMISSIONS FIFTH FRAMEWORK PROGRAMME, Sustainable Restoration and Long-term Management of Contaminated Rural, Urban and Industrial Ecosystem (STRATEGY project), http://www.strategy-ec.org.uk, (2002).

[12] GUMMER, W.K., CAMPBELL, F.R., KNIGHT, G.B., RICHARD, J.L., Cosmos 954: The Occurrence and Nature of Recovered Debris, AECB INFO-0006 May (1980).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiania, IAEA, Vienna (1988).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Tammiku, IAEA, Vienna (1998).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Istambul, IAEA, Vienna (2000).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Gilan, IAEA, Vienna (2000).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Lilo, IAEA, Vienna (2000).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Yanango, IAEA, Vienna (2000).

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Emergency Notification and Assistance, Technical Operations Manual, Emergency Preparedness and Response, IAEA, Vienna (2004).

[20] CURRIE, L.A., Limits for qualitative detection and quantitative determination. Application to Radiochemistry, Analytical Chemistry, 40, 586-593 (1968).

[21] HARPER, F.T., MUSOLINO, S.V., WENTE, W.B., Realistic Radiological Dispersal Device Hazard Boundaries and Ramifications for Early Consequence Management Decisions, Health Physics 93(1), 1-16 (2007).