Evaluation of the Contamination by Explosives and Metals in Soils at the Älvdalen Shooting Range
Part I: Investigation Strategies and Sampling

Guy Apelman, Sonia Thiboutot, Richard Martel, Christina Edlund, Rose-Marie Karlsson, Mats Ahlberg, Jan Sjöström, Ulf Qvarfort, Kent Bladfält, Nico van Ham, Willem Duvolois

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Report title
Evaluation of the Contamination by Explosives and Metals in Soils at the Älvdalen Shooting Range
Part I: Investigation Strategies and Sampling

Abstract (not more than 200 words)
In May 2003 representatives from the Netherlands, Canada and Sweden participated in a joint field investigation of the shooting range Älvdalen in Dalarna, Sweden. The investigation was part of a trilateral agreement, Project Arrangement Number 2003-02, between the three countries concerning Environmental Aspects of Energetic Materials. The aim was to demonstrate how to approach and characterize a site contaminated by explosives.

The shooting range has an area of about 540 km^2, of which 120km^2 constitute target areas. The ammunition fired at the range are blank ammunition, practice ammunition, live ammunition, smoke ammunition, pyrotechnics, live explosives and ignition charges.

Three specific areas in the shooting range were examined, a hand grenade range, an anti-tank range with target area and firing positions (Karlgrav) and an impact area for long distance shooting (Rivsjöbrändan).

Samples from the three areas will be analyzed for TNT and the results will be presented in Part II: Analyses, Results and Discussion.

Keywords
Sampling strategies, explosives, energetic materials, shooting range

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Bedömning av föroreningar av explosivämnen & metaller i mark på Älvdalens skjutfält
Del 1: Provtagningsstrategier och provtagning

Sammanfattning (högst 200 ord)

I maj 2003 deltog representanter från Nederländerna, Kanada och Sverige i en gemensam fältundersökning av Älvdalens skjutfält i Dalarna. Undersökningen var en del i ett trilateralt avtal; Project Arrangement Number 2003-02, mellan de tre nationerna rörande miljömässiga aspekter av energetiska material. Syftet var att demonstrera hur en plats med denna typ av kontaminering kan undersökas och karakteriseras.

Älvdalens skjutfält är ca 540 km^2 stort och ca 120 km^2 utgör målområden. Ammunition som används inom området är exempelvis: lös ammunition, övningsammunition, skarp ammunition, rökammunition, pyroteknisk utrustning, skarpa sprängmedel och tändladdningar.

Tre specifika områden inom skjutfältet har undersökts, en övningsbana för handgranater, ett sk anti-tank område med målområde samt avfyrningsplatser (Karlgrav) och ett målområde för skjutning på längre avstånd (Rivsjöbrändan).

Prover som tagits i de olika områdena kommer att analyseras med avseende på TNT och resultaten kommer att presenteras i Part II: Analyses, Results and Discussion.

Nyckelord

Provtagningsstrategier, explosivämnen. skjutfält

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Foreword

This report is published under the Project Arrangement Number 2003-02 entitled Environmental Aspects of Energetic Materials to the trilateral cooperative science and technology memorandum of understanding between Canada, The Netherlands and Sweden.

The international context of demilitarization, the closure of military bases and the more stringent aspects of environmental laws have led to the establishment of new areas for research and development. Many activities of the Forces such as the firing of ammunition, demolition, and the destruction of obsolete ammunition by open burning and open detonation may lead to the dispersion of energetic compounds and other munitions-related contaminants in the environment. It is within this context that a trilateral collaborative effort has been initiated under an annex of the Memorandum of Understanding (MOU) between

The Defence Research and Development Canada Valcartier (DRDC Valcartier) of the Department of national defence of Canada (DND), TNO Prins Maurits Laboratory of The Netherlands Ministry of Defence and FOI Swedish Defence Research Agency of the Swedish Ministry of Defence are working together. The main objective of this trilateral agreement is to conduct research programs to study the environmental impact of energetic materials that are found in the respective Dutch, Canadian and Swedish ammunition stockpiles. The cooperation also deals with problems concerned with dumped ammunition and remnants from war. It was agreed under the MOU that the expertise developed for site characterization would be shared allowing the development of a unique expertise within each department to better understand the impacts of live fire training and dumped ammunition in order to be in a readiness state to answer any inquiries and take corrective actions if needed. The objectives of the cooperation is explicitly listed in the project arrangement as follows:

To exchange information related to the impacts of the live firing training on the environment and perform international site characterization.

- To understand the fates of explosives in soils and groundwater
- To understand the problems of unexploded ordnances, UXO, underwater and on land.
- To study the effects of corrosion on UXO leading to open shells and contamination of the environment.

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Canada	The Netherlands	Sweden

1. Introduction

Energetic materials are prominent components of munitions and weapons that can be found in war zones, training ranges and on production sites. During the last decade, many needs emerged related to the identification, quantification, delimitation and elimination of energetic contaminants dispersed by munitions, or present in explosives dumps, trials or destruction fields, firing ranges and production sites [1, 2, 3]. Another important aspect of explosives in the environment is also related to the presence of unexploded ordnance (UXOs) which is a worldwide problem and has attracted a lot of interest. In Europe as an example, many terrains were bombarded during World War I and II and environmental issues coming from the presence of UXOs may exist in some locations. Within this context of growing awareness of environmental issues, some countries initiated R&D programmes to assess and develop expertise related to the environmental risks associated with explosive compounds.

Many military sites used as impact areas, training ranges, demolition and open burning/open detonation (OB/OD) ranges, which are used to destroy out-of-specification materials, are contaminated with energetic substances as described in the literature [1, 2, 3]. To evaluate the contamination of these sites, sampling and characterization of various ranges were performed over the last ten years. A protocol describing the different methods of sampling and the analytical chemistry was developed [4]. Research results to date have demonstrated that explosives are not common contaminants, since they exhibit limited aqueous solubility and are dispersed in a heterogeneous pattern of contamination. In the United States, efforts have been made to develop the analytical chemistry, to establish the best sampling procedure and to understand the complex fate of explosives in the environment [2, 5 - 21].

Since 2003, the Defence Research and Development Canada Valcartier (DRDC Valcartier) of the Department of national defence of Canada (DND), TNO Print Maurits Laboratory of The Netherlands Ministry of Defence and FOI, Swedish Defence Research Agency of the Swedish Ministry of Defence are working together in Project Arrangement Number 2003-02 entitled Environmental Aspects of Energetic Materials. The main objective of this trilateral agreement is to conduct research programs to study the environmental impact of energetic materials. It was agreed under the MoU that the expertise developed for site characterization would be shared allowing the development of a unique expertise within each department to better understand the impacts of live fire training and to be in a readiness state to answer any inquiries and take corrective actions if needed.

The first training area to be characterized within this trilateral Programme was the Älvdalen shooting range in Sweden. The selection of the Älvdalen shooting range in Sweden to conduct the first characterization to assess the environmental aspects of live firing activities was made based on the fact that this site is the largest training area in western Europe. Moreover, it offers test areas for a wide range of explosives and ammunition. This site is therefore the most representative and the worthiest of studying among training areas in Europe. Furthermore, the comparison of results from Älvdalen shooting range with those available in Canada will be very fruitful [22 - 26]. Consequently, in May 2003, representatives from the Netherlands, Canada and

Sweden participated in a joint field investigation of the shooting range Älvdalen in Sweden. The aim was to demonstrate how to approach and characterize a site contaminated by explosives. The Älvdalen shooting range in Dalarna county of Sweden has been used since 1969 and is one of the largest shooting ranges in the country. It has an area of 540 km^2 and allows shooting of maximum distances with artillery pieces and other long range weapons.

To better assess the contamination and characterize an area, an appropriate definition and understanding of the hydro geological context of the site is required. Characterizing the groundwater quality, especially on large ranges, is critical because metals and energetic materials are mobile in the environment and may migrate off-site in groundwater, presenting a threat to human health and to the environment. Groundwater flow has to be carefully assessed by determining its velocity and direction. The quality of the groundwater has also to be evaluated since it is often used for irrigation purposes, as a drinking water source by the base and to sustain aquatic ecosystems. Consequently, any contamination could impact human health and aquatic ecosystems. The hydro geological study of the Älvdalen shooting range will not be covered in this report but should be done in the future.

In this report, all of the surface work including the description of the ranges and the strategies used to samples these areas carried out in May 2003 is described. The results for explosives and metal analyses will be reported in a subsequent report. The approaches and strategies used for the characterization of the Älvdalen shooting range are similar to the ones used in different sites in Canada but were adapted to the Swedish sites in some occasions [22 - 26]. A total of 99 soils including 5 duplicate, 4 background soil samples, and 9 (duplicate samples) water samples were collected during the sampling event in May 03.

2. Range history/Description

The Älvdalen shooting range is located in north-western county of Dalarna (Figure 1). The shooting range was inaugurated in June 1967 and is the only range in Sweden that allows shooting on maximum distances with artillery pieces and other weapons with long range. The shooting range has an area of about 540 km^2, of which 120km^2 constitutes target areas. The field has a largest length and width of 30 km (Figure 2). The main parts of the range are at an elevation of approximately 600 m above sea level, with the highest peak at 821 m, Storvarden. The shooting range is mainly used by the Artillery regiment for education of conscripts and officers. Another activity is the testing of weapon and vehicle systems. The range is also used for the destruction of ammunition. The surrounding nature, good infrastructure and housing facilities attracts both public and civilian organisations, which choose the range as a suitable place for conferences and courses. Due to limited human access to the area large mammals like bears are common in the area.

2.1 Description of sample areas

Hand grenade range

The range is used for individual practicing of throwing different types of fragmentary grenades. It has been in use since 1967. Today is it used about 15 times a year and about 200-300 grenades are detonated. Typically type of grenades used are; fragmentary grenade m/56, m/90 and fragmentary grenade m/45.

Anti-tank range; target area and firing positions (Karlgrav)

The range is used today by units from group to platoon size for firings with weapons with calibre from 5,56 mm to 155 mm. The shooting range has a moving target with a length of 350 m. There are seven firing positions/banks every hundred meters from the target area, from 100 to 700 meters. The range has been used since the opening of Älvdalen shooting range in 1967. Types of weapons typically used are: armour piercing ammunition, anti-tank recoilless rifles, anti-tank defence pieces, machine gun 36 mm and 58 mm, 10,5 cm Howitzer, 15,5 cm Howitzer F and 15,5 cm Howitzer 77.

The range is used on a yearly basis for simpler group practices with hand firearms to field firing with platoons. In other countries, for instance in Canada, anti-tank ranges are not used for small arms practice so, a situation different from Canada's anti-tank may be observed being a mixture of issues encountered in anti-tank and in small arms ranges [22, 26].

Target area Rivsjöbrändan, crater area

This is one of the Älvdalen fields most used target areas. Hundreds of drill shells and bursting shells are fired on a yearly basis. Thousands of grenades have been fired at the field. It has been in used since 1967 as a central target area for artillery weapons but other arms are also used. Many weapon types have been used on the area.
The craters are caused by artillery fire.

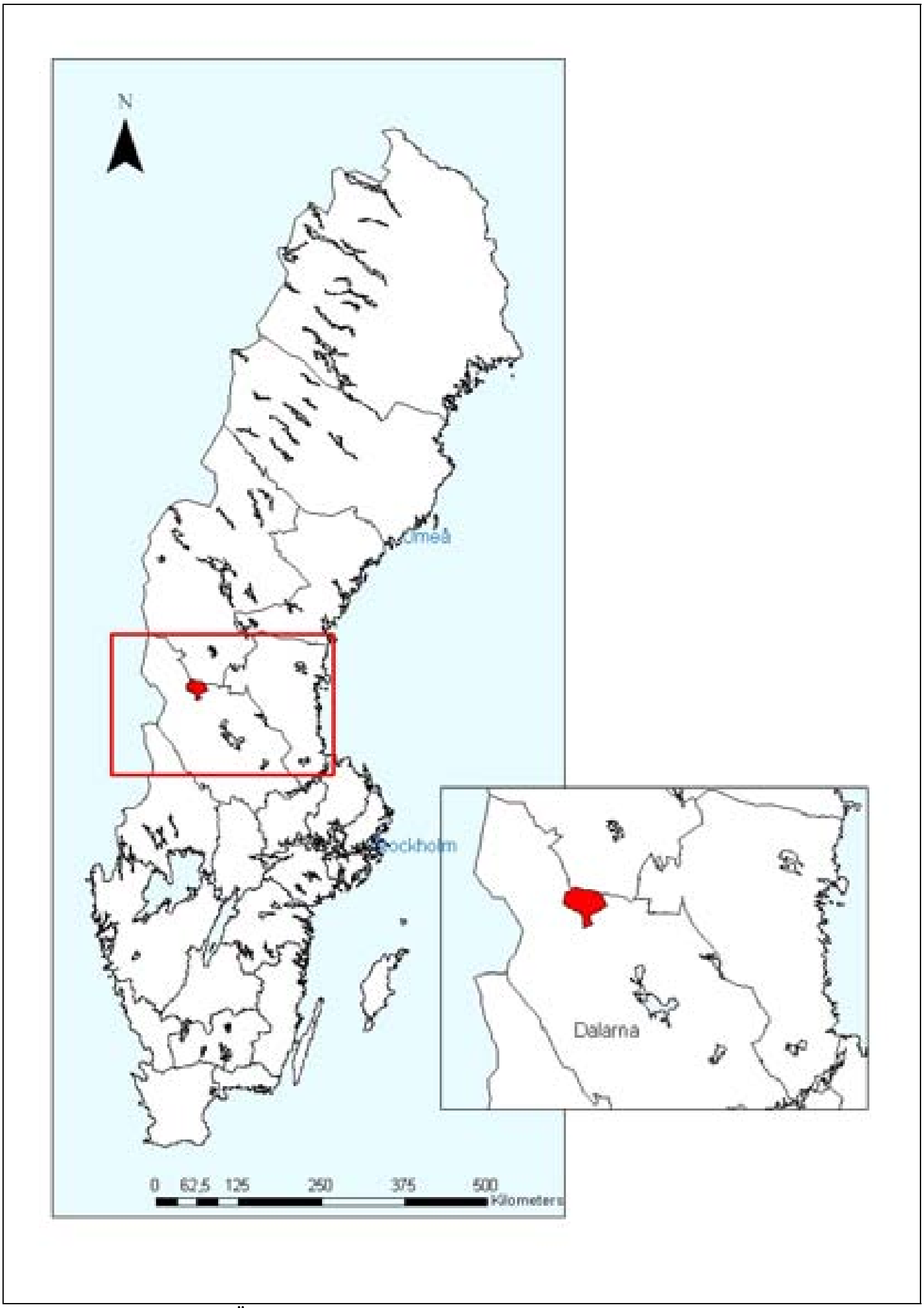

Figure 1. The location of Älvdalen shooting range in the county of Dalarna, Sweden.

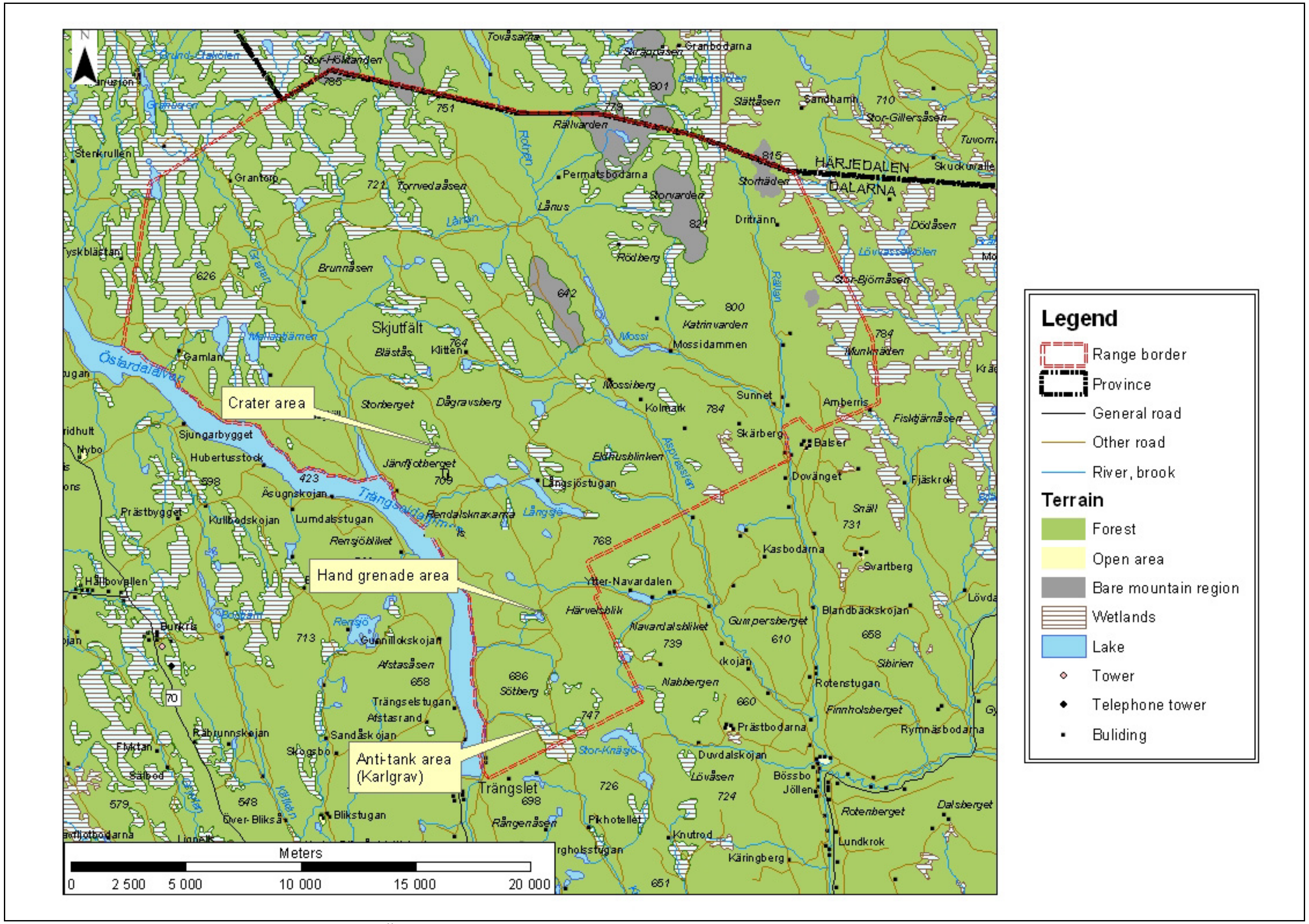

Figure 2. Overview of the surroundings at Älvdalen shooting range.

2.2 Environment

About 75% of the range is covered with forests, dominated with pine trees. The ground vegetation consists mainly of heather and lichens. There are nine nature reserves within the area, those can only be tread by single persons or small troops on foot. There are permanent populations of brown bear and lynx in the area. A few observations of wolves and wolverines are made on a yearly basis. One of the most obvious and immediate environmental effects from the activity at the range is the construction of roads. In 1997 there were about 240 km of roads in the area. Another evident effect is the noise generated by the shooting, however, since bears, moose's and many other animals and birds are abundant in the area it seems like the noise is not a disturbing problem to the wildlife. It does not seem like the animals avoid the noise; on the contrary the population density of animals seems to be higher in shooting ranges compared with surrounding areas [27]. This can be explained by the fact that the activities on a shooting range result in limited access to the area for people in general. It also prevents the area from being exploited for other purposes such as building of weekend cottages.

Destroyed and burnt forests occur in the target areas. The shattered, burnt or fallen trees do, however make important habitats for several insects, plants and birds, therefore the environmental consequences of the shooting is not entirely negative.

The ground is locally worn from heavy vehicles and bomb craters, and also from ploughing of roads in winter. Unexploded ammunition can be found in target areas where they make up a potential danger. Therefore the surface of the ground is checked twice a year and unexploded ammunition and metal garbage are being indicated and removed. Besides explosives, the shooting generates releases of copper and lead to the ground and furthermore, exhaust from vehicles due to transportation and shooting exercises is released to the air. Water, sediment and fish within the shooting range are continuously subjects to sampling as a part of an environmental monitoring programme.

2.3 Geology

The bedrock of the Älvdalen shooting area is dominated by acid vulcanite (Dala porphyry) in the western part and by granite-syenite (Järna granite) in the eastern part. In the north-westernmost part, there are some occurrences of sandstone (Dala sandstone) and conglomerate. Around and north of Lake Mossi some dolerite is present. Within the granite-syenite area, narrow dikes of dolerite are rather frequent. In connection to these dikes, dolerite quarries are quite commonly seen, both those in production as well as abandoned ones. [28].

Quaternary deposits in the area consist mainly of glacial till, and some peat and glaciofluvial deposits. Along the northern part of Lake Trängslet, in the south of the shooting area, exposed bedrock or very thin soil cover is present. [29].

Generally speaking the bedrock and its glacial till soils in the western part of the area, in combination with the cold climate, results in very rough conditions for vegetation and animals. However, within the eastern part there are markedly better conditions for vegetation and wildlife due to more favourable geology and climate. [30].

2.4 Climate and hydrogeology

The effective annual precipitation in the area is 400-500 mm/year, i.e. precipitation reduced by evapotranspiration. Average annual temperature is 2-4 °C; based on the years 1961-1990. [28, 31].

Normally during January-March there is no groundwater recharge whereas during April-June the snow melt will infiltrate the soil and feed the groundwater. In the summer (July-mid September) more or less all precipitation evaporates and in the autumn (mid September-October) the precipitation exceeds evaporation that allows recharge of the aquifer [28].

2.5 Activities

2.5.1 Ammunition

The ammunition fired at the range are blank, practice, live and smoke ammunition, pyrotechnics, live explosives and ignition charges. Testing of different weapon systems also occur as well as destruction of old ammunition through burning of gunpowder and explosives or by detonation of shells and other types of ammunition. The number of days with shooting activities at the range was 157 during the year 2002. In table 1 the types of ammunition used at the range in 2002 are listed.

Table 1. The amount of ammunition fired at the range on a yearly basis with numbers for the year 2002 (Swedish Armed Forces Artillery Regiment 2004).

Type of ammunition	**Amount during the year 2002** (number of shots)
Blanks	20200
Small-bore ≤ 12 mm	25150
Large-bore > 12 mm	10862
Hand grenade	62
Other detonated explosives	620
Pyrotechnics	116
Smoke shell	95
Armour piercing missile	2
Destruction of ammunition by blasting	225411 kilogram

2.5.2 Open detonation (OD)

At this location obsolete explosives and ammunitions also high-energy components are detonated at atmospheric pressure in the field. Low contamination of explosives has been found near used open detonations sites in Sweden [27]. Studies in Canada have shown no contamination close to open detonation sites and a large study from USA has demonstrated that the gaseous emissions were “harmless for the environment” [32]. Studies in Sweden have shown that, open burning of ordnances if done in low temperatures, can lead to high concentrations of metals and explosives in soil eventually also in surface water and groundwater [33].

2.5.3 Large scale tunnel tests

In order to study propagation of blast waves in tunnel systems FOI started a project in 1995 at this location with tests in full scale. In 2000 a scaled underground storage was built. In this underground facility test series have been performed in order to get experimental results to validate design. During the years several full scale tests have been performed. Twelve tests with a total charge each of 4000 kg TNT for studying blast waves and six tests for the study of the underground storage facility. The charge in four of those six tests were 10 kg TNT, 500 kg TNT, 2500 kg TNT and 10 000 kg TNT, respectively. In one of the tests the charge consisted of 1450 pieces of 15,5 cm artillery shells corresponding to a total charge of 10 000 kg TNT. In another test with 10 000 kg a mix of one third of artillery shells (TNT) and two thirds of propellants were used.

3. Experimental

3.1 Field investigation

The joint field investigation took place in May, 2003 and the samples were taken on the 21st and 22nd of May. The list of participants is presented in appendix 1, the visits to the field were arranged and authorized by Capt. Kent Bladfält, Commanding officer at Älvdalen shooting-range. Each day, a morning briefing was held before sampling in order to have a rundown on the sampling area in point and proper sampling technique. The area of interest for the day was examined through maps and a sampling plan was outlined and discussed. When on-site, discussions about the strategies were held and the sampling took place when everything was understood and accepted.

3.2 Sampling strategy

In accordance to the Canadian strategy for soil sampling, applied in this work, mainly surface soil is sampled (i.e. the uppermost 5 centimetres). Explosives are solid at ambient temperature, and contamination often occurs as variously sized particles; they dissolve slowly and sparingly in aqueous solution and possess low vapour pressure. Therefore, explosives compounds are only transported through soil once they are dissolved in water. Hence, the highest levels of explosive contamination are most likely to occur directly on or near the soil surface, even at sites that have remained inactive for many years.

Nevertheless, the spread of contamination will vary, depending upon the specific explosive and the nature of the soil matrix. In many cases, subsurface soil sampling is needed to define the stratigraphy of geologic material and to evaluate as a first approximation the depth of the water table. Subsurface soil sampling allows estimation of the extent (vertical and lateral) of the contamination in soil and the number of samples required to get accurate results, and the mass of contaminants in soil (e.g. in source zone). Moreover, the crystalline nature of explosives and their potential association with munition casing fragments often result in a heterogeneous distribution of contaminant particles in the source region. Therefore, the sampling protocol must include testing procedures that are not biased by the degree of sample heterogeneity. Information regarding soil sampling, spatial heterogeneity and water sampling can be found in Annex 2.

Often sampling plans have been written for the collection of discrete samples at a specified number of sampling locations. However, several studies have shown the futility of this practice; due to the extreme short-range spatial variability that often exist for explosives in surface soils [4, 7, 12, 20, 34]. The heterogeneous dispersion of explosives in soil matrices has also been noted when taking samples from biopiles. Even with extensive homogenisation of the treated soil, high spatial heterogeneity of explosive concentrations has been observed. To compensate for the high heterogeneity of the soils, compositing is done with at least 30 sub-samples to get a representative samples [25].

Therefore, composite sampling is strongly recommended when characterizing the ground surface at a potentially explosive-contaminated site. In a small area, (1 m x 1 m) multiple units (30 or more, each of the same approximate amount) should be randomly collected and placed into a single container. For large-scale areas, systematic gridding is useful for establishing sampling nodes, at which an area between 3 and 10 m square should be randomly sampled by obtaining 50 or more individual increments.

Many different types of military sites where different activities are conducted may be contaminated with explosives residues. Depending on the activities, different sampling strategies have to be applied and developed. In general, low explosive concentrations are encountered in training areas with a few exceptions, such as in grenade ranges, anti-tank ranges, firing positions and in hot spots generated by low order detonations such as explosion craters in target areas. [22 - 26].

For metal concentrations, the worse case scenarios are generally found in rifle ranges, scrap disposal and open burning areas. Special precautions will have to be taken to mitigate the effect of these metals on the environment. An important aspect of training activities in most types of sites is unexploded ordnance (UXO). These UXOs represent a safety issue and are a worldwide problem. They can also be seen as potential source of explosives that may leach to groundwater upon corrosion of metal shells. For a further discussion about the UXO situation at Älvdalen, refer chapter 3.4 Safety.

The present field investigation and sampling programme focuses on a hand grenade range, an anti-tank range including a target area and firing positions (Karlgrav), and an impact area (Rivsjöbrändan).

3.2.1 Hand grenade range

Circular sampling

At the grenade range most of the grenades are believed to have been detonated in the middle of the square area since the site was quite small. Hence the mid point constitutes the preferred target and may represent the best point source, i.e. at this position; the soil is expected to be most contaminated with regard to explosives etc. Outgoing from this centre point, the samples were collected according to a circular procedure. Samples were collected in a donut shaped surface at different radius from the center point. In practice this means that a pole was installed in the centre and that a string was attached to this pole. One person holds the end of the string and walks slowly 360 degrees around the centre point (see Figure 3). By doing this, donut shaped areas were created between the selected radius and a second person collected many subsamples between these radius in the donut shaped areas. Soil was sampled along the 0-1, 1-3, 3-5 and 5-10 meter areas by the help of markings on the slowly circulating string. This sampling technique was first developed and applied to targets in CFB Shilo, Manitoba, Canada, and proved successful to evaluate the contamination [23 - 24]. This sampling strategy has the advantage of giving a spatial representation of the explosives contamination around targets. In the case of grenade range, according to the fact that the centre can be seen as a target, the concentrations should decrease as the samples are taken farther away from the centre point. That strategy was also used to evaluate target concentrations in air training areas in Cold lake, Alberta, Canada. The strategy was adapted to take into account the fact that the firing position is moving coming from a flying object and excellent results were obtained [25].

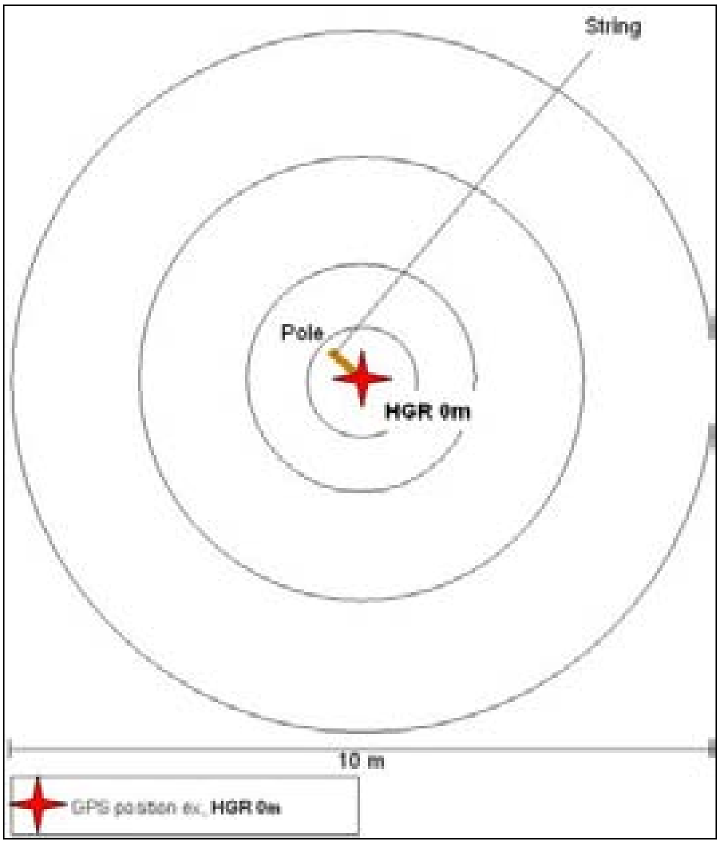

Figure 3. Schematic sketch of the circular sampling method at the hand grenade range. Stars mark locations where GPS readings were recorded.

Linear sampling

In addition to the circular sampling, soil was also collected using the linear sampling strategy. This strategy was first used in battle runs in CFB Shilo, Manitoba, Canada, where we wanted to evaluate if the concentrations were increasing with distances from the firing positions [23 - 24]. This strategy is good at giving the progression of the concentrations away from the firing line. In grenade ranges, this is usually the best strategy and it was applied in many grenade ranges in Canada [22 - 24, 26]. Samples were collected along lines at 0, 20, 40, 60, 80 and 100 % away from the firing position by walking along these lines and building the composite samples (Figure 4). Using this strategy should confirm that the highest concentrations will be found close to the centre point. The circular sampling and the linear sampling strategy are two different tools to measure the same thing, and both should demonstrate the concentrations are higher in the middle of the range and are slowly decreasing when farther away from the centre point.

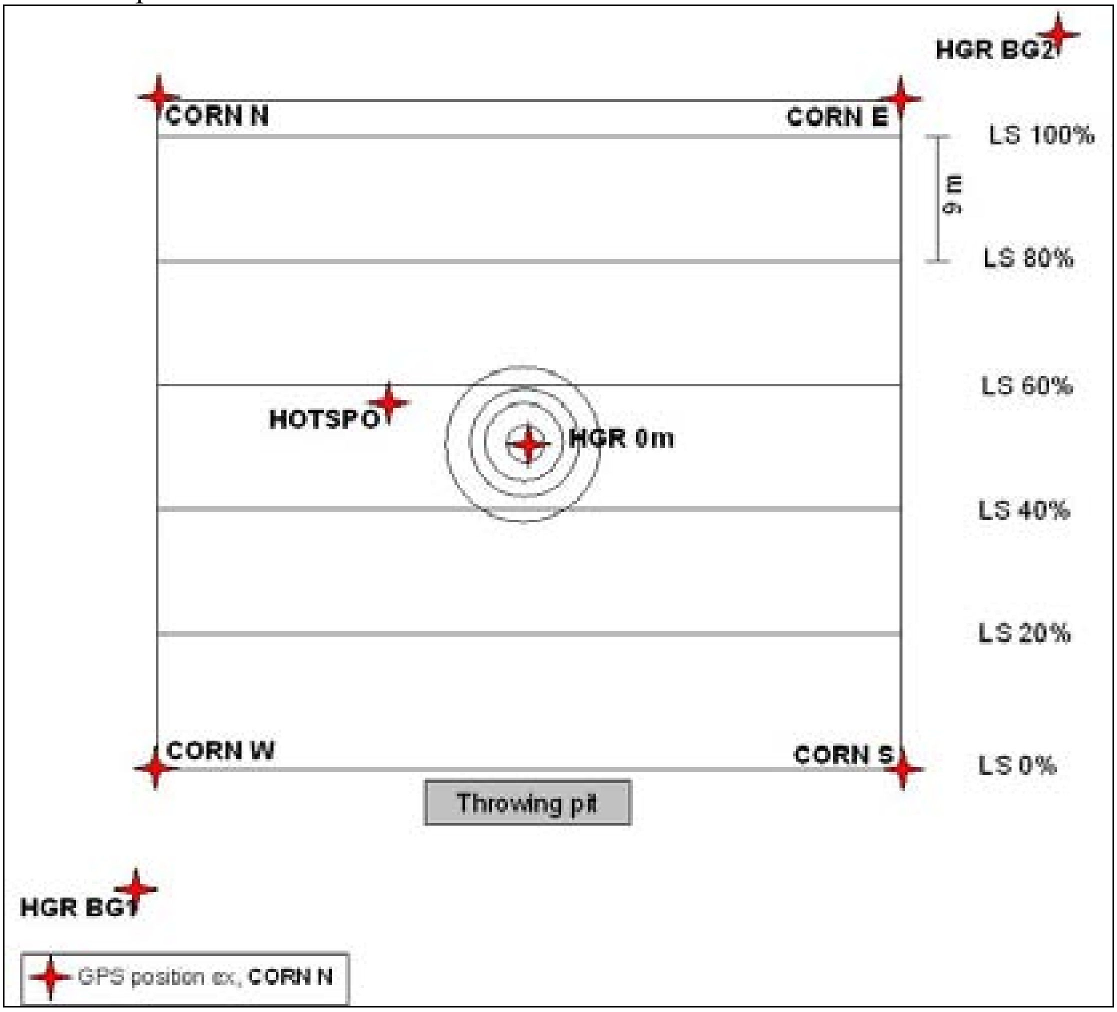

Figure 4. Schematic sketch of the linear sampling method at the hand grenade range. Stars mark locations where GPS readings were recorded. The size of the range is about 50x50 m.

Point sampling

This type of sampling strategy was applied for hotspots as well as for each corner of the grenade square and consist of collecting 30 sub-samples in a small area around the hot spots or in this case, in a small area at the corners of the range. The corner samples were colleted to provide a hint of the spreading gradient – as to explosive contaminants – within the surficial soil. Also one or several reference samples were collected at some distances outside the grenade range area (typically some 100 meters outside the area). The latter samples reflect unaffected soil; i.e. as a background value. It was observed in a similar study in CFB Gagetown, New Brunswick, Canada, that all samples were contaminated by explosives and metals, meaning that contamination is spreading outside the range and consequently, background samples collected just beside the range can still be contaminated [22].

3.2.2 Anti-tank range, target area and firing positions (Karlgrav)

In general such areas can be divided into a target area and firing positions. The target area investigated in the present report constituted an elongated hill slope, which in turn was divided into three sub areas; one square in the middle and two similar on each side (Figure 5 and 6).

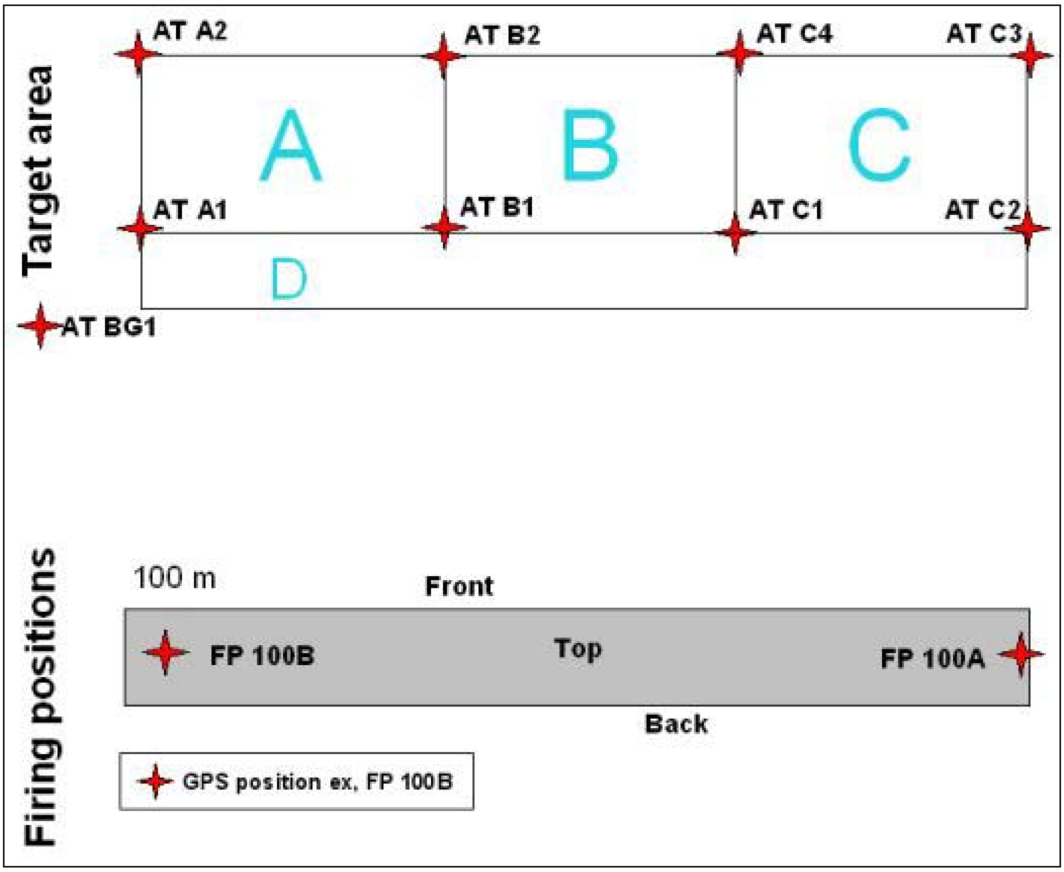

Figure 5. Schematic drawing on the sampling at the anti-tank area. Seven firing positions were investigated, 100-700 meters and GPS readings were recorded on each firing position (stars)

Figure 6. The target area at Karlgrav. (Photo G. Ampleman, DRDC, 2003)

Within each sub square, several soil samples were taken in a "randomized" manner and pooled to build the composite sample. The hereby pooled samples will provide an overall view of the contamination situation of the target slope as expressed by each sub square. In front of the target slope there was an open ditch in which water was sampled. Mobile explosives and metals from the target slope could be expected to drain out into this draining ditch. A reference soil sample was taken outside the target area.

In front of the target area there were seven firing positions at 100, 200, 300, 400, 500, 600 and 700 meters distances. Each such position constitutes a stretched out bank (perpendicular to the target area) upon which different types of arms have been fired. Soil here was sampled in front of, on the top of and behind each of these firing positions (Figure 5). In the soil at firing positions of anti-tank ranges, one may expect to find propellant residues such as NG, NC and 2,4 DNT, as in the study of CFB Gagetown, New Brunswick, Canada, where 100,000 ppm of NG was found [26]. Since this anti-tank range was also used for small arms activities, it is highly possible that lead and copper be identified in the target area. At the target areas, explosives residues are more likely to be found especially HMX which is less soluble than TNT. RDX is also part of the anti-tank weapon war head but in a lesser quantity. Usually, since it is the most soluble nitramine, it is more mobile and will probably be transported by percolating soil water and further down into groundwater or in surface waters (streams, ditches etc). For this reason water samples were taken in a ditch system situated within the area of firing positions, plus also from a small stream that flowed through it. The sampling in the small stream allowed taking "unaffected" water from an upstream position.

In addition water samples were taken in ponds in order to determine the presence of soluble compounds leached out from the surrounding soil and/or from UXO in the water.

3.2.3 Target area Rivsjöbrändan, crater area

This type of area is used for training for anti tank weapons during more realistic conditions, such as long range shooting at discarded tanks. As a consequence of this type of activities, the area has many unexploded ordnance (UXO) and explosion craters. Sampling near UXO was avoided in the present study due to safety reasons; however, leakage of for example HMX may occur from damaged UXO and the soils surrounding damaged or cracked UXO shells are usually contaminated by explosives. In anti-tank range, shoulder type weapons are used that contain octol, a mixture of HMX and TNT as the explosives. This type of weapons suffer a high DUD rate and consequently, it is not rare to find items that hit the tanks, broke into pieces liberating their explosives content into the environment. It is why the anti-tank range are usually highly contaminated by HMX which stays at the surface for very long period of time. In this site, anti-tank weapon were used but not the shoulder type ones. Most of the time when many craters are observed, the weapons have functioned properly the detonations have went well. Most of the time in crater ranges, low concentrations are found since detonations proceeded as intended. In these cases, the strategy is to collect samples in hot spots if found or in craters. Therefore, in this range, in “randomly” selected craters, soil was sampled in the bottom, along the side wall and immediately outside the edge of the crater pits (Figures 7 and 8). The bottom sample reflects the contaminants released by the detonation; the side sample shows the degree of spreading and the sample outside the crater reveals if explosive contaminants have affected the nearby surroundings.

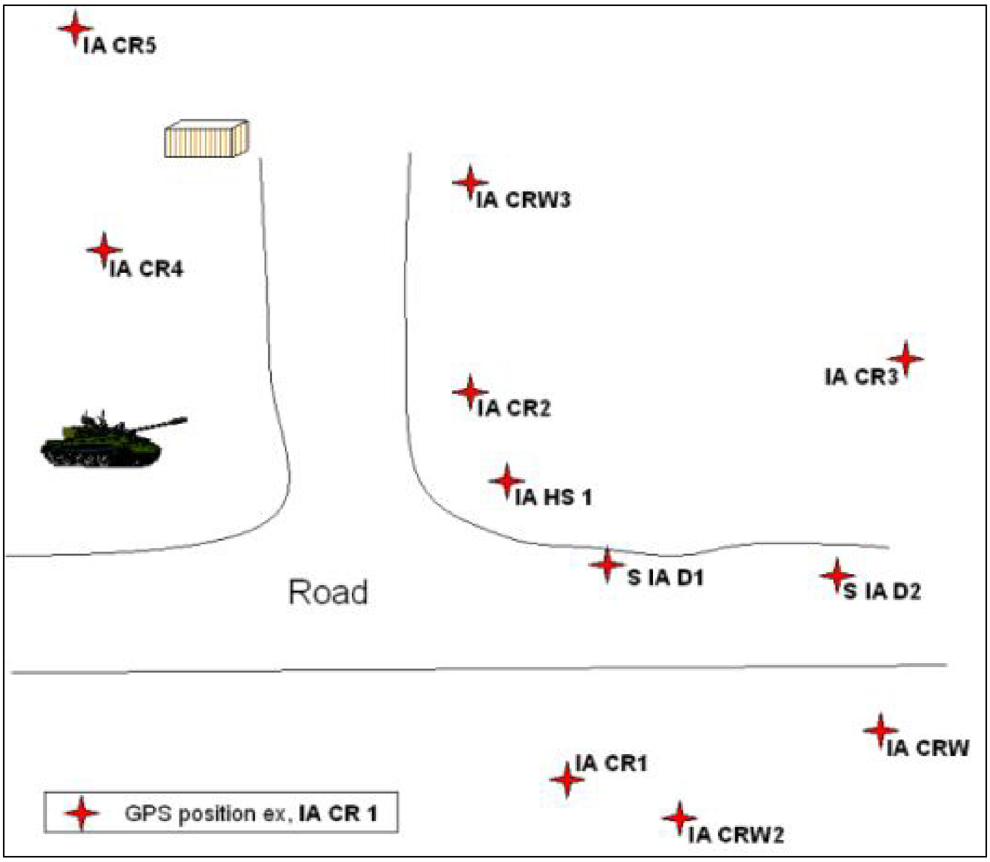

Figure 7. Sketch showing GPS readings (stars) and sampling locations at the crater area.

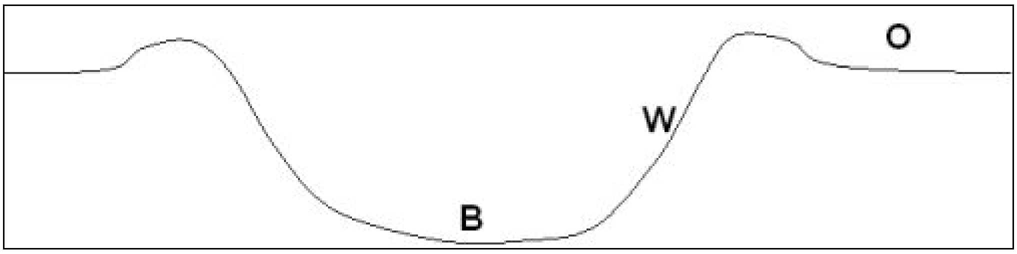

Figure 8. Sampling at explosion craters. Samples were taken at the bottom (B), on the walls (W) and outside (O) of each crater.

3.3 Sampling and sample nomenclature

Soil samples were collected in polyethylene (PE) bags (Figure 9). All water samples were collected in two different bottles, one plastic (acid-washed) bottle for metals analyses, and one dark glass bottle for explosives analyses containing sodium bisulfate for stabilization (1.5 g for 1 liter). Spoons of stainless steel were used for collecting the soil samples and they were cleaned with acetone and water and wiped with a tissue paper between each sample. Some samples were taken for field analysis with XRF (X-Ray Fluorescence Spectrophotometer) on the spot and are therefore marked "XRF". As a total 99 soil samples and 9 duplicate water samples were taken (Appendix 2).

Figure 9. Soil sampling with polyethylene bags. (Photo G. Ampleman, DRDC 2003)

The following nomenclature was used to name the samples. Soil samples (S) and surface water samples (W) were collected during the investigation. No ground water samples were taken since no wells were available. The marking DUP indicates that a sample is a duplicate. Three locations were investigated; a hand grenade range, a practice range mainly for different handheld weapons here called the anti-tank range and an impact area with craters from anti-tank ammunition. Samples taken at the different areas investigated have been marked accordingly. Abbreviations used to mark the samples are presented in Table 2. The samples have been marked GR for hand grenade range, and LS or HS for linear sampling or hotspot, respectively.

Table 2. Abbreviations used in the marking of the samples

Sample area	Abbreviation	Explanation
General markings		
	S	Soil
	W	Water
	BG	Background
	DUP	Duplicate
Hand grenade range	**Ex. S-GR-HS(1-3)**	
	GR	Grenade square
	LS	Linear sampling
	HS	Hotspot
	GR-HS	Hotspot (circular sampling)
Anti-tank range	**Ex. S-FP-100m-B**	Note: Some samples are marked i.e. SR-AT-A, where SR means shooting range
	AT	Anti-tank target area
	FP	Firing position
	B	Back, can also be F (front) or T (top)
Impact area	**Ex. S-IA-CRATER1-B**	
	IA	Impact area
	CRATER1	No of crater sampled out of five
	B	Sample from the bottom of the crater, can also be W (crater wall or O (outside of the crater).

At the hand grenade range, linear sampling in lines across the area (Figure 10) and circular sampling up to 10 meters from a hotspot (Figure 11) were conducted. The top layer (0-5 cm) of the soil was collected. The linear sampling took place across the whole range at six distances from the throwing pit. The distances are given in % of the total distance of the range. At the hotspot shown in the Figures 10 and 11, samples were taken at three depths (0-5 cm, 5-10 cm and 10-15 cm).Two background samples were also taken in two opposite directions from the range at which distances from the fence. Four additional samples were collected along the fence, outside of the range.

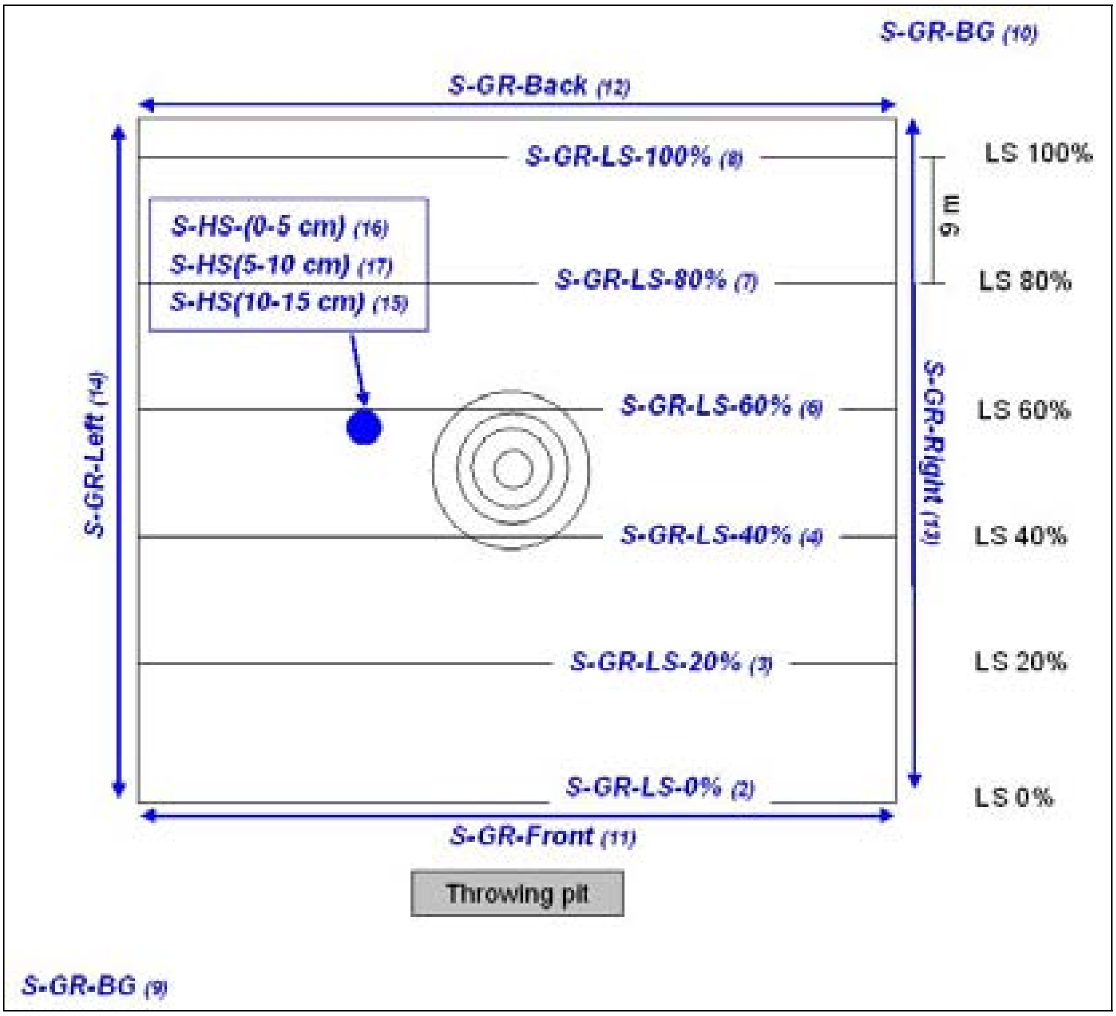

Figure 10. Sampling at the hand grenade range. Blue notations are samples.
Example of marking: S-GR-LS-20%; S for soil, GR for hand grenade range, LS for linear sampling and 20% indicates the 20% line.

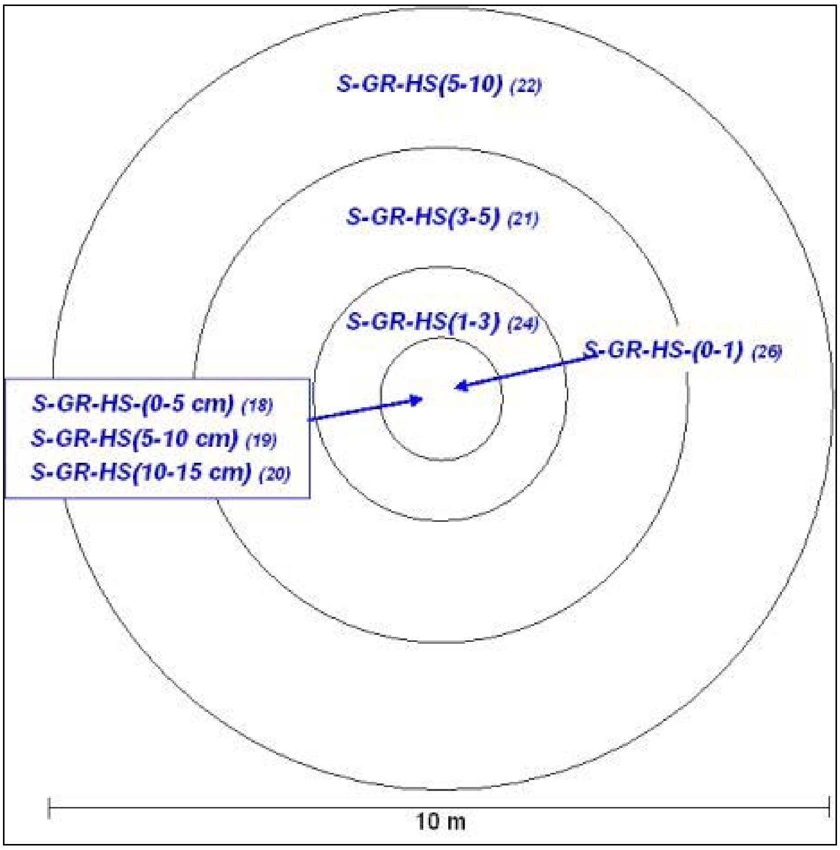

Figure 11. Detailed outline of the circular sampling in the grenade range.

At the shooting and target area, of the anti-tank range, on the practice range for different handheld weapons the target area was divided in four sub areas, A-D (Figure 12). Soil was collected randomly by scraping sample from the top (5 cm) layer of the ground in each square and placed into a single PE bag.

Seven firing positions/banks at distances from 100 m to 700 m from the target area were identified and sampled as well. Samples were taken on the top of the bank, in front of and on the backside. Soil was collected from one spot and not along the whole side of the banks. An example of marking of a sample from the anti-tank target area is: S-AT-A, where S is soil, AT is anti tank and A means that the sample comes from sub area A. Samples from the firing positions are marked like S-AT-FP-100m-B, where 100m, indicates the bank at 100m from the target area and B means that the sample is taken on the back of the bank. A number of water samples were also taken.

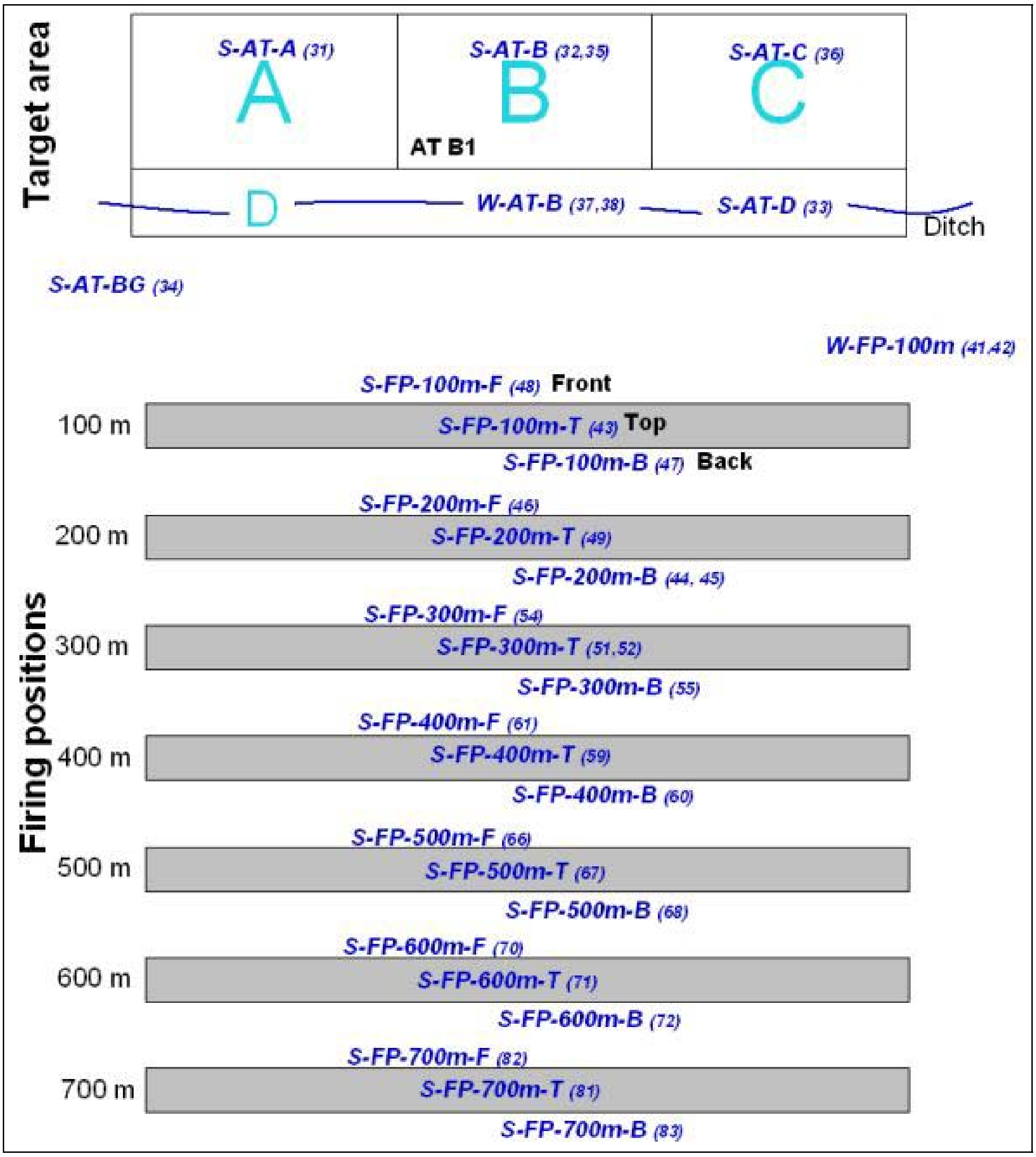

Figure 12. Sampling at the anti-tank range.

Five craters in the impact area were included in the survey; the samples were taken in the bottom, on the walls and on the outside of the craters (Figure 8 and 13). Example of marking: IA-CRATER3-O, where IA is impact area and O stands for sample taken outside of the crater.

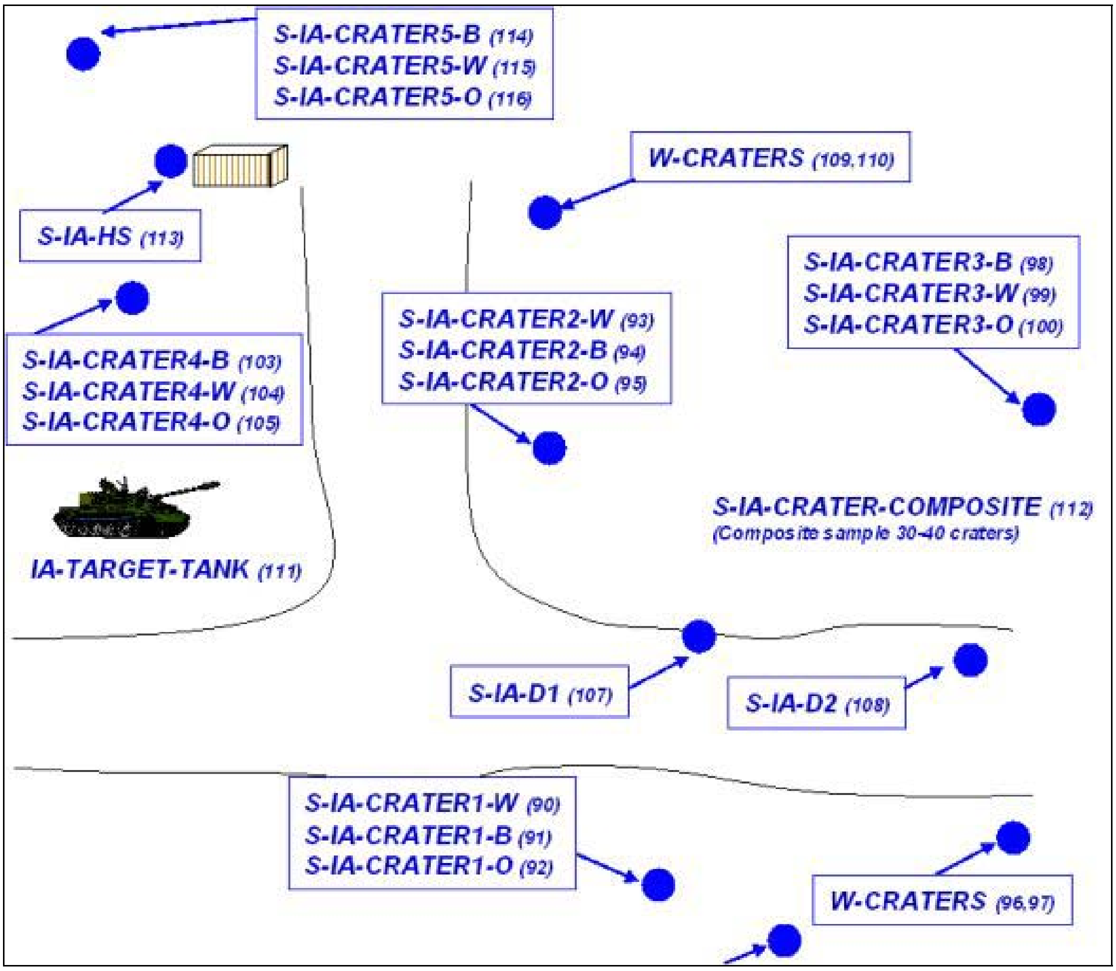

Figure 13. Sampling of craters at the impact area.

3.4 Safety

The sampling of an UXO-contaminated area represents an increased level of risk for personnel (Figure 14). The Range Control Officers gave a safety briefing to people involved in the sampling program. This briefing explained the precautions to be taken to avoid contact with UXOs and also described the various types of UXOs that may be found on ranges. A safety and emergency plan was also put in place for any incident that could have occurred while sampling. This plan was under the responsibility of the shooting Range Control unit. When on site for sampling, Capt. Bladfält was always accompanying the sampling team and he was equipped with a radio to contact range control in case of an emergency. Moreover, more range control personnel were always with the sampling team. They gave us a lot of information related to the history of the site, the types of weapon used in the ranges and also other relevant information pertinent to our sampling event. General cautiousness is necessary and some things to particularly remember is:

Do not pick up any items from the ground unless you put it there yourself.
Consider all unexploded items as potentially dangerous.
Be careful of large items of scrap as they may cover, contain or conceal UXOs.

Figure 14. Unexploded grenades and bombs are present at all times when sampling at a place like this. Hence, safety must be put in first place at all times. (Photo C. Edlund FOI and G. Ampleman, DRDC 2003)

4. Summary and conclusions

This report describes the shooting range and the sampling strategies for the different areas that were investigated. In a following report results from the analysis of the samples taken will be published.

The shooting range has an area of about 540 km^2, of which 120 km^2 constitutes target areas. The field has a largest length and width of 30 km. Three specific areas in the range has been part of this investigation; a hand grenade area, an anti-tank range with target area and firing positions and a impact area, the Rivsjöbrändan crater area.

A collaborative effort between Canada, Sweden and The Netherlands was put in place to exchange information and expertise on environmental aspects of energetic materials and one of the greatest accomplishments to date has been the characterization of the Älvdalen shooting range in the county of Dalarna, Sweden. Many scientists from Canada, The Netherlands and from Sweden participated to this event. On site, many ranges were visited and sampling procedures were demonstrated as well as strategies appropriate for each range were discussed, adopted and demonstrated. Mainly, three sampling strategies were applied, the circular, the linear and the point strategies. The circular sampling strategy consisted in sampling soils in donut shaped areas delineated by the surface generated using a rope turning around a centre point at different radius. The linear strategy consisted in sampling soils on lines at different percentage of the length of the range. By doing this, samples were built by compositing 30 sub-samples walking on these lines. The point strategy consisted in collecting sub-samples to build a composite sample in small specific locations such as hot spots or craters. By applying these strategies, three ranges were sampled, the hand grenade, the anti-tank and the impact area ranges where a total of 99 soils including 5 duplicate, 4 background soil samples, and 18 water samples were collected during the sampling event in May 2003. Metals and explosives analyses were done and the results will be discussed in a subsequent report. It can be mentioned that this sampling event was a success since the expertise in sampling and characterization was developed and that the characterization of the shooting range was accomplished in a very short period of time. The exchange of information and reports between the countries was also accomplished successfully.

As a total 107 samples were taken, nine duplicate water samples, 84 soil samples for laboratory analysis and 14 samples were taken for field analysis with XRF. A selection of the samples will be analyzed for TNT and metabolites and the results will be presented in a second report: Investigation of munitions related residues at the Älvdalen shooting range. Part II: Analysis, Results and Discussion.

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APPENDICES

Appendix 1. Participants in the field investigations in Älvdalen

	Participant	Organization
Canada	Guy Ampleman	DRDC/DRDC Valcartier
	Sonia Thiboutot	DRDC/DRDC Valcartier
	Richard Martel	INRS-Eau, Terre & Environnement
The Netherlands	Nico Van Ham	TNO-Prins Maurits Laboratory (PML)
	Willem Duvalois	TNO-Prins Maurits Laboratory (PML)
	Pieter I. J. van der Weele	Ministry of Defence
Sweden	Mats Ahlberg	FOI, Swedish defence Research Agency
	Rune Berglind	FOI, Div. of NBC-protection
	Christina Edlund	FOI, Div. of NBC-protection
	Sofia Frankki	FOI, Div. of NBC-protection
	Per Leffler	FOI, Div. of NBC-protection
	Birgitta Liljedahl	FOI, Div. of NBC-protection
	Rose-Marie Karlsson	FOI, Div. of NBC-protection
	Ulf Qvarfort	FOI, Div. of NBC-protection
	Jan Sjöström	FOI, Div. of NBC-protection
	Annica Waleij	FOI, Div. of NBC-protection

Appendix 2. GPS locations of soil and water samples

No	Object	Matrix	Date	COORD. (DEG/MIN.HUNDREDS)		Comment
				North	East	
	HAND GRENADE SQUARE					
1	S-GR-HS	S	2003-05-21			HOTSPOT, SUSP. compound or TNT, grains (TNT/rdx)
2	S-GR-LS-0%	S	2003-05-21			linear sampling, EVERY 3 POLES IN FENCE,
3	S-GR-LS-20%	S	2003-05-21			linear sampling TOT 16 POLES,
4	S-GR-LS-40%	S	2003-05-21			linear sampling 100% AT NO 15, 3M BETWEEN POLES
5	S-GR-LS-40% DUP	S	2003-05-21			linear sampling
6	S-GR-LS-60%	S	2003-05-21			linear sampling
7	S-GR-LS-80%	S	2003-05-21			linear sampling
8	S-GR-LS-100%	S	2003-05-21			linear sampling
9	S-GR-BG	S	2003-05-21	612662	134779	BACKGROUND FRONT
10	S-GR-BG	S	2003-05-21	612662	134793	BACKGROUND BACK
11	S-GR-FRONT	S	2003-05-21			
12	S-GR BACK	S	2003-05-21			
13	S-GR-RIGHT	S	2003-05-21			
14	S-GR-LEFT	S	2003-05-21			
15	S-HS-(10-15)	S	2003-05-21	612662	134786	SUSPECTED HOTSPOT
16	S-HS-(0-5)	S	2003-05-21	612662	134786	"
17	S-HS-(5-10)	S	2003-05-21	612662	134786	"
18	S-GR-HS-(0-5)	S	2003-05-21			
19	S-GR-HS-(5-10)	S	2003-05-21			
20	S-GR-HS-(10-15)	S	2003-05-21			
21	S-GR-(3-5)	S	2003-05-21			CIRCULAR SAMPLING, 3-5 M
22	S-GR-(5-10)	S	2003-05-21			CIRCULAR SAMPLING, 5-10 M

No	Object	Matrix	Date	COORD. (DEG/MIN.HUNDREDS)		Comment
				North	East	
23	S-GR-(1-3) DUP	S	2003-05-21			CIRCULAR SAMPLING, 1-3 M, DUP
24	S-GR-(1-3)	S	2003-05-21			CIRCULAR SAMPLING, 1-3 M
25	S-GR-(0-1) DUP	S	2003-05-21			CIRCULAR SAMPLING, 0-1 M DUP
26	S-GR-(0-1)	S	2003-05-21			CIRCULAR SAMPLING, 0-1 M
	ANTI-TANK AREA					**SOIL SAMPLES**
31	SR-AT-A	S	2003-05-21			
32	SR-AT-B	S	2003-05-21			
33	S-AT-D	S	2003-05-21			
34	S-AT-BG	S	2003-05-21			COULD ALSO BE NO 53
35	S-AT-B-DUPL	S	2003-05-21			
36	S-AT-C	S	2003-05-21			
37	W-AT-B-m	W	2003-05-21			METAL ANALYSIS, PLASTIC BOTTLE
38	W-AT-B-o	W	2003-05-21			organic ANALYSIS, GLASS BOTTLE
41	W-FP-100M-o	W	2003-05-21			SURFACE WATER DITCH, GLASS BOTTLE, STAB WITH ~1 G Na2SO4
42	W-FP-100M-m	W	2003-05-21			SURFACE WATER PLASTIC BOTTLE
48	S-AT-FP-100M-F	S	2003-05-21			FIRING POSITION 100 M FRONT
43	S-AT-FP-100M-T	S	2003-05-21			FIRING POSITION 100 M TOP
47	S-AT-FP-100M-B	S	2003-05-21			FIRING POSITION 100M BACK
45	S-AT-FP-100M-B DUP	S	2003-05-21			FIRING POSITION 100M BACK DUPLICATE
46	S-AT-FP-200M-F	S	2003-05-21			FIRING POSITION 200 M FRONT
49	S-AT-FP-200M-T	S	2003-05-21			FIRING POSITION 200 M TOP
44	S-AT-FP-200M-B	S	2003-05-21			FIRING POSITION 200 M BACK
54	S-AT-FP-300M-F	S	2003-05-21			FIRING POSITION 300 M FRONT
51	S-AT-FP-300M-T	S	2003-05-21			FIRING POSITION 300 M TOP

No	Object	Matrix	Date	COORD. (DEG/MIN.HUNDREDS)	Comment

				North	East	
52	S-AT-FP-300M-T DUP	S	2003-05-21			FIRING POSITION 300 M TOP CUPLICATE
55	S-AT-FP-300M-B	S	2003-05-21			FIRING POSITION 300 M BACK
64	W-AT-FP-300M-m	W	2003-05-21			PLASTIC BOTTLE, <300M, DITCH
65	W-AT-FP-300M-o	W	2003-05-21			Glass BOTTLE, <300M, DITCH
53	S-AT-FP-BG	S	2003-05-21	612449	134764	COULD ALSO BE NO 34
61	S-AT-FP-400M-F	S	2003-05-21			FIRING POSITION 400 M FRONT
59	S-AT-FP-400M-T	S	2003-05-21			FIRING POSITION 400 M TOP
60	S-AT-FP-400M-B	S	2003-05-21			FIRING POSITION 400 M BACK
62	W-AT-FP-400M-F-m	W	2003-05-21			PLASTIC BOTTLE
63	W-AT-FP-400M-F-o	W	2003-05-21			GLASS BOTTLE
77	W-AT-FP-400M-B-o	W	2003-05-21			glass BOTTLE
78	W-AT-FP-400M-B-m	W	2003-05-21			metallic BOTTLE
75	W-AT-500-400M-REF-m	W	2003-05-21			PLASTIC BOTTLE (OBS FP)
76	W-AT-500-400M-REF-o	W	2003-05-21			GLASS BOTTLE (OBS FP)
66	S-AT-500M-F	S	2003-05-21			FIRING POSITION 500 M FRONT
67	S-AT-FP-500M-T	S	2003-05-21			FIRING POSITION 500 M TOP
68	S-AT-500M-B	S	2003-05-21			FIRING POSITION 500 M BOTTOM
70	S-AT-FP-600M-F	S	2003-05-21			FIRING POSITION 600 M FRONT
71	S-AT-FP-600M-T	S	2003-05-21			FIRING POSITION 600 M TOP
69	S-AT-FP-600M-B	S	2003-05-21			FIRING POSITION 600 M BOTTOM
79	S-AT-FP-600M-B	S	2003-05-21			PER LEFFLER TOXANALYS
82	S-AT-FP-700M-F	S	2003-05-21			FIRING POSITION 700 M FRONT
81	S-AT-FP-700M-T	S	2003-05-21			FIRING POSITION 700 M TOP
83	S-AT-FP-700M-B	S	2003-05-21			FIRING POSITION 700 M BOTTOM
86	S-HOW-BACK	S	2003-05-21			
87	S-HOW-MIDDLE	S	2003-05-21	612640	134740	
88	S-HOW-FRONT	S	2003-05-21			

No	**Object**	**Matrix**	**Date**	**COORD. (DEG/MIN.HUNDREDS)**		**Comment**
				North	**East**	

89	S-HOW-TOTAL	S	2003-05-21			
27	SR-AT-A-XRF	S	2003-05-21			XRF 1
28	SR-AT-B-XRF	S	2003-05-21			XRF 2
29	SR-AT-C-XRF	S	2003-05-21			XRF 3
30	SR-AT-C2-XRF	S	2003-05-21			XRF 4
118 (31)	SR-AT-C3-XRF	S	2003-05-21			XRF 5 marked with two numbers
39	S-FP-100M- XRF	S	2003-05-21			XRF 7 TOP
40	S-FP-100M- XRF2	S	2003-05-21			XRF 8 TOP
50	S-FP-AT-100M-TOX	S	2003-05-21			PER LEFFLER TOXANALYS
57	S-FP-400M-XRF-F	S	2003-05-21			XRF 14
56	S-FP-400M-XRF-T	S	2003-05-21			XRF 13
58	S-FP-400M-XRF-B	S	2003-05-21			XRF 15
74	S-FP-600M-XRF-F	S	2003-05-21			XRF 20
72	S-FP-600M-XRF-B	S	2003-05-21			XRF 22
73	S-FP-600M-XRF-T	S	2003-05-21			XRF 19
80	S-FP-700M-XRF	S	2003-05-21			XRF 26
84	PERM PROVPLATS-XRF-MIDDLE	S	2003-05-21			XRF 27
85	PERM PROVPLATS-XRF-B	S	2003-05-21			XRF 28
	IMPACT AREA CRATERS					
91	S-IA-CRATER1-B	S	2003-05-22	613013	134332	CRATER 1, BOTTOM
90	S-IA-CRATER1-W	S	2003-05-22	613013	134332	CRATER 1, WALL
92	S-IA-CRATER1-O	S	2003-05-22	613013	134332	CRATER 1, OUTSIDE
No	**Object**	**Matrix**	**Date**	**COORD. (DEG/MIN.HUNDREDS)**		**Comment**
				North	**East**	
93	S-IA-CRATER2-B	S	2003-05-22	613011	134332	CRATER 2, BOTTOM
94	S-IA-CRATER2-W	S	2003-05-22	613011	134332	CRATER 2, WALL

95	S-IA-CRATER2-O	S	2003-05-22	613011	134332	CRATER 2, OUTSIDE
98	IA-CRATER3-B	S	2003-05-22	613012	134329	CRATER 3, BOTTOM
99	IA-CRATER3-W	S	2003-05-22	613012	134329	CRATER 3, WALL
100	IA-CRATER3-O	S	2003-05-22	613012	134329	CRATER 3, OUTSIDE
103	IA-CRATER4-B	S	2003-05-22	613009	134329	CRATER 4, BOTTOM
104	IA-CRATER4-W	S	2003-05-22	613009	134329	CRATER 4, WALL
105	IA-CRATER4-O	S	2003-05-22	613009	134329	CRATER 4, OUTSIDE
114	S-IA-CRATER 5-B	S	2003-05-22	613005	134315	CRATER 5, BOTTOM, CLOSE TO CONTAINER
115	S-IA-CRATER 5-W	S	2003-05-22	613005	134315	CRATER 5, WALL, CLOSE TO CONTAINER
116	S-IA-CRATER 5-O	S	2003-05-22	613005	134315	CRATER 5, OUTSIDE, CLOSE TO CONTAINER
106	S-IA-HS LOW ORDER	S	2003-05-22	613011	134332	HOTSPOT
107	S-IA-D1	S	2003-05-22	613012	134332	ALONG ROAD DITCH 1
108	S-IA-D2	S	2003-05-22	613013	134331	ALONG ROAD DITCH 2
96	IA-CRATERS-o	W	2003-05-22	613013	134331	CRATER WATER SAMPLE 1, GLASS BOTTLE
97	IA-CRATERS-m	W	2003-05-22	613013	134331	CRATER WATER SAMPLE 1, PLATSTIC BOTTLE
101	IA-CRATERS-o	W	2003-05-22	613013	134332	CRATER WATER SAMPLE 2, GLASS BOTTLE
102	IA-CRATERS-m	W	2003-05-22	613013	134332	CRATER WATER SAMPLE 2, PLATSTIC BOTTLE
109	IA-CRATERS-o	W	2003-05-22	613007	134321	CRATER WATER SAMPLE 3, GLASS BOTTLE, CLOSE TO CR 4
110	IA-CRATERS-m	W	2003-05-22	613007	134321	CRATER WATER SAMPLE 3, PLASTIC BOTTLE, CLOSE TO CR 4
111	IA-TARGET-TANK	S	2003-05-22			COMPOSITE SAMPLE AROUND TANK
112	S-IA-CRATER COMPOSITE	S	2003-05-22			COMPOSITE SAMPLE FROM 30-40 CRATERS
113	S-IA-HS	S	2003-05-22	613006	134314	HOTSPOT AROUND CONTAINERS
117	BEAR	-	2003-05-22			BEAR FAECES, GAMMELHÄSTTJÄRN

Appendix 3. Packing list – equipment and materials

Packing list - Material required

- ✓ Laboratory gloves (2 boxes)
- ✓ Protective gloves (2 pair)
- ✓ Tissue paper (3 boxes of Kleenex)
- ✓ Wet tissue (2 boxes)
- ✓ Acetone (2 x 2,5 L)
- ✓ Distilled water (5 L)
- ✓ Sodiumbisulfate (500 g)
- ✓ Shovels (2)
- ✓ Metallic spoons (10)
- ✓ Garbage bags (10)
- ✓ Buckets (for rinsing solvent) (2)
- ✓ Permanent ink markers, black (6)
- ✓ Measuring tape 100m (1)
- ✓ Woodsticks (2 inch per 2 inch per 2 feet) (30)
- ✓ Ice packs (30)
- ✓ Camping coolers (5)
- ✓ Sprayer bottles (8)
- ✓ Batteries 1,5 V (12)
- ✓ Digital camera
- ✓ GPS
- ✓ XRF
- ✓ Sample protocol
- ✓ Glass bottles 1L for water samples (12)
- ✓ Glass bottles with Teflon sealing (70)
- ✓ Bags for soil samples appropriate for analyze of both metals and organic compounds (200)
- ✓ Sealers for the bags (200)
- ✓ A freezer available to store samples after each day at 4 ºC or – 20 ºC