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Paper

RADIOLOGICAL DECONTAMINATION OF ARMORED PERSONNEL CARRIERS WITH CONTINUOUS AND PULSED WATERJETS AT UMEA, SWEDEN

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ABSTRACT

Radiological decontamination experiments were carried out at the National NBC Defence Centre in Umeå, Sweden, under the Swedish-Canadian accord. A Swedish light armoured vehicle was contaminated by driving it on a track upon which Sodium-24 in particulate form had been spread. The contamination pattern on the vehicle was characterized by a series of measurements with a Geiger-Mueller contamination probe and with Liquid Scintillation Counter measurements of swipes. A conventional high-pressure hot water (200-psi, 130^0) spray, similar to that used by the Canadian Forces, was then used to decontaminate the vehicle. The contamination pattern on the vehicle was then re-measured. This procedure was then repeated using forced pulsed water jet. The results of the two trials are compared herein. Contamination remained in some areas of the vehicle, particularly the wheel wells. This was due to large standoff distances where the jet was continuous. Nonetheless, overall the performance of forced pulsed waterjet was observed to be better than the hot water blasting. As the trials were conducted on an *ad hoc* basis, and only for short period of time (< ½ hour), the results indicate that further systematic investigation would be required to totally decontaminate the vehicles in the future.

1. INTRODUCTION

Nuclear and radiological hazards are a continuing problem for military forces in Canada and around the world. Although the probability of use of nuclear weapons has waned somewhat from its peak during the cold war, there still remains the possibility that armed forces could be involved in a conflict in which nuclear weapons are used. Recent events also highlight the possibility that terrorists could use nuclear or radiological weapons against civilian populations Eggen (2002). Thus, nuclear and radiological defences remain a high priority for militaries and governments.

Perhaps the most devastating aspect of a nuclear or radiological attack is the resulting radioactive contamination. Radioactive contamination is (in peace time) strictly regulated worldwide, and acceptable levels of contamination are extremely low Anon (2000a). In addition, radiological decontamination is generally very difficult because the contaminant must be physically removed (as opposed to biological or chemical contaminants, which need only be de-activated or destroyed *in situ*). This tenacity of radiological contamination means that demolition or disposal of contaminated buildings and equipment may be the best (or even the only) option following an attack. It thus behooves researchers to push forward the investigation of new and potentially more effective decontamination techniques.

This paper looks at the decontamination of a SISU XA-180 Light Armoured Vehicle after it was driven on a wet and icy road upon which radioactive particulates was spread (Umeå, Sweden). These data are considered useful for identifying the parts of the vehicle that become most contaminated when a vehicle is forced to drive through contaminated areas. Decontamination trials with the forced pulsed waterjets were attempted based on the earlier promising results reported by Tieu, et. al (2002b). For comparison, conventional high-pressure hot water (200-psi, 130^0) spray was also included, similar to the procedure followed by Tieu, et. al (2002b). The capabilities of the two methods are evaluated and compared.

It must be stated in passing no technical details on the forced pulsed waterjet technique is given here. The details are given by Tieu, et.al (2002b).

2. EXPERIMENTS

These experiments took place in the NBC test facility (NBC-Bana) of the Swedish NBC Defence Centre (Totalförsvarets Skyddscentrum) in Umeå, Sweden. Sodium-24 in the form of powdered sodium silicate was mixed with sand and loaded into the seven containers in the trailer depicted in Figure 1. The driver of the van pulling the trailer can activate a switch that empties these containers slowly through the vertical tubes shown below the plastic containers. The tubes are oscillated left and right to produce a more uniform deposition pattern on the ground. The radioactive material was set down on a 4.2-metre wide, 500-metre circumference track. The material was released at a constant rate, so variations in road contamination were achieved by driving the van at different speeds over different segments of the track. Road conditions were wet and icy, and the surface was roughed up by a snowplow prior to spreading of the material. Weather conditions during the trials consisted of light freezing rain.

Figure 2 shows two maps of the road. The first (on the left) is a sketch; the second is a "bubble plot" showing the dose rates at 1-m above the ground around the track, as measured by a BTI Microspec-3 mapping gamma-ray spectrometer Anon (1999). The areas of the bubbles are proportional to the dose rates. The dose rates in turn are proportional to the contamination level on the road. Based on the microshield calculations, Anon (1998), the total Sodium (Na-24) contamination level on the road was estimated to be about 0.56 MBq/m2, or 1.2 GBq on the track.

The test vehicle for the trials was a SISU XA-180 Light Armoured Vehicle, pictured in Figure 3. The XA-180 drove around the contaminated track 10 times, and then returned to the measurement area. The contamination pattern was then characterized with the ABP-100 alpha-beta probe, Anon (2002c), and with swipes. A Swedish team without previous experience of decontaminating the XA-180 then decontaminated the vehicle with the high-pressure hot water spray. This is the same system developed by DRDC Suffield, but without the CASCAD decontaminant foam, Anon (2001a). Following this procedure, the remaining contamination on the vehicle was re-measured. The XA-180 was then driven out onto the track again for 10 laps, before returning to the measurement area. As before, the contamination pattern was characterized. Decontamination trials were then attempted using the ***FP*** waterjet system. The remaining contamination on the vehicle was again re-measured. The operating parameters of the ***FP*** machine were:

Pressure: 55.2-MPa (8,000-psi)
Diameter of each orifice in the dual-orifice rotating nozzle body: 1.016-mm (0.040-in)
Total water flow: 27.4-litre/min (7.26-usgpm)
Total hydraulic power: 31.6-kW (42-hp)

The operating pressure was constrained so that the paint on the XA-180 would not be removed. Nonetheless, at some locations, loosely adhered paint was removed. It is indeed a pity the duration of the trials lasted only for about ½ hour. This is especially so in view of the fact that considerable efforts were made to get machine ready and in shipping it to Umeå.

3. CONTAMINATION OF THE VEHICLE

The most complete characterization of the vehicle contamination was performed with an ABP-100 alpha-beta probe. These measurements are given in Table 1 for both contamination trials (after each 10-lap circuit). The two sets of measurements bear some resemblance to one another, especially in the general trends described below. However, a comparison also reveals that individual contamination measurements at a given position on the vehicle are not reproducible for the two experimental trials. These pairs of measurements varied by up to a factor of five. The average values over the two trials are also shown superposed on the vehicle in Figure 4. The numbers in the circles correspond to the location numbers in Table 1 (those "below detectable levels (BDL)" are not listed.

The detectable limits varied with position due to the presence of a large radioactive source near the decontamination area. Measurements on the rear and driver's side had a detectable limit of 2.9 cps; measurements on the other two sides had a detectable limit of 4.7 cps. Measurements

above the detectable limits are assigned an uncertainty of 10%. This is likely an underestimate at low count rates and an over-estimate at higher rates, but it is a reasonable approximation for this work.

The contamination levels on the vehicle followed a relatively predictable pattern. Namely, very little contamination was observed on the front or rear of the vehicle, or anywhere on the upper half of the vehicle. On the other hand, significant contamination was noticed on the lower halves of the vehicle sides, especially in the wheel wells. It is worth noting that positions 26, 27, 31, and 32 (Fig. 4) are on or around the two propellers at the rear of this amphibious vehicle. However, because of the vehicle design, this part of the vehicle is essentially part of the wheel wells for the rearmost wheels. These were the most highly contaminated surfaces on the XA-180. It is quite reasonable that the wheel wells were contaminated to the highest level, since the tires are responsible for "kicking up" the contamination. However, it is also worth noting how little contamination accumulated in some of the other areas under the wet conditions prevailing during these trials.

No calibration of ABP-100 response to a Na-24 area source was performed. However, based on measurements of Sr-90 and Cl-36 beta sources, Haslip & Cousins (2000b), a reasonable calibration factor was approximately 30 cps/(Bq/cm^2). Thus, the measured contamination levels on the vehicle ranged between 0 and 13 Bq/cm^2 (0.13 M Bq/m^2). Since the average contamination level of the track was estimated at a few MBq/m^2, the maximum contamination level of the vehicle was 1-10% of the average road contamination. This is considered to be a non-negligible quantity for a drive of only 5 km. That does not imply that the contamination level would continue to increase. Previous work has shown that contamination of the vehicle would eventually reach equilibrium with self-decontamination processes, Ulvsand, Ågren, and Lidström (2000c). Indeed, the choice of 10 laps was based on the equilibrium point observed in previous trials in Umeå.

Contamination levels on the XA-180 were also assessed by swipe tests on vehicle surfaces. Swipes were measured in a Liquid Scintillation Counter (LSC). Such techniques are generally very sensitive assays of removable contamination, although obviously they are not effective for the level of fixed contamination. These locations were primarily in the wheel wells of the vehicle, where probe measurements are more difficult, due to the possibility of probe contamination. The two sets of measurements are shown in Table 2. As was noted above, general trends in contamination levels are consistent in the two data sets (e.g. location '**I**' is always less contaminated than any other surfaces), although the contamination levels at a given location were far from reproducible. In fact, these data were less reproducible than the probe measurements. The average measurements for each location are superposed on the vehicle as shown in Figure 5, where the letters in the circles correspond to the letters in Table 2. Values in the table are shown as "BDL" if they are consistent with zero given their uncertainties. These uncertainty estimates are felt to be conservative.

Because swipes were taken largely in similar areas, there are few general conclusions that can be drawn about vehicular contamination. However, one can easily see that the swipe data support the earlier observation that contamination did not collect on the upper half of this vehicle. No differentiation can be made, however, between the data collected from the other nine locations.

It is worth noting that both the probe data and the swipe data show that the contamination levels in the second trial were generally smaller than those in the first trial. One possible explanation is that the vehicle initially had dirt that is effective at trapping contamination. Once this material is removed in the first decontamination, the vehicle as a whole is not as easy to contaminate. In addition to reducing contamination levels on subsequent trials, this process may also inflate the decontamination efficacy in the first trial (when this material is present and easy to wash off). This must be kept in mind in trials involving multiple decontaminations of a single vehicle. In this trial, however, both vehicles were washed before the trials so other explanations must be sought. One possibility is that each circuit of the track redistributes the activity in such a way that contamination on subsequent circuits is less pronounced.

For a few locations, both swipe and probe measurements were made. Namely, probe locations 7, 8, 23, 24, and 25 correspond to swipe locations I, J, B, E, and H, respectively. It is tempting to compare these two sets of measurements so as to derive an exact calibration factor for the probe measurements. The situation was not that simple. Using a probe calibration factor of 30 cps/(Bq/cm2), it was found that the probe contamination values always exceeded those of the swipes. This implies that the calibration factor is underestimated. However, the discrepancy between the two sets of contamination values varied from a factor of 2 to a factor of 30, indicating that no reliable calibration factor could be derived from these data. This does not mean that the data are invalid. Rather, it emphasizes that the probe measures total contamination, while the swipe measures removable contamination. These considerations imply that the probe measurement should always equal or exceed the swipe measurement (as observed). Furthermore, the ratio between the two measurements should vary as the ratio of fixed to removable contamination varies (and a distribution of these ratios is observed). Indeed, as described in the next **Section**, that not all of this contamination was easily removable.

4. DECONTAMINATION

As described in **Section 2**, the experimental protocol consisted of contaminating the vehicle, measuring the contamination levels, decontaminating the vehicle, and re-measuring the contamination levels. This sequence of events was performed twice, once with conventional high-pressure hot spray, and once with the ***FP*** waterjet. This section presents the post-decontamination measurements.

Post-decontamination was characterized as before, with the ABP-100 alpha-beta probe and with LSC measurements of swipes. The ABP-100 measurements are presented in Table 3. As in the previous **Section**, many of the measurements fell below the detectable limits of 2.9 cps on the driver's side and rear, and 4.7 cps on the other sides. Measurements above the detectable limits are once again assigned an uncertainty of 10%.

The vast majority of these measurements were below detectable limits (BDL). In fact, the only measurements showing significant levels of contamination are at positions 23 through 30, the wheel wells and the driver's side propeller housing. Decontamination in these areas was hampered by two key factors. First, these surfaces are more difficult to access than vehicle sides. Second, there are spots of corrosion in the wheel wells that might be expected to accumulate contamination and be difficult to flush. This appears to have held true for both the conventional

and ***FP*** waterjet, although in the case of the latter, the standoff distance was too large to aim precisely at the spot (discussed later).

It is difficult to use this Table alone to evaluate the efficacy of the decontamination efforts. In general, the measurements have to be put into context, such as by relating them to initial contamination values. This is done in Table 4. This Table presents results only for locations at which there was initially some measurable contamination. Columns 2 and 3 show the ratio of the contamination level following decontamination to that before, for the two decontamination methods. Where the contamination level following decontamination was below detectable limits (BDL), the ratio is expressed as a 1 confidence limit. The rightmost column is a comparison of the two methods for that position. These comments are discussed in the following paragraph.

Approximately two-thirds of the locations were decontaminated below detectable limits by both systems. Three more locations had small but measurable residual levels of contamination after decontamination, although no measurable levels had been present before. This is presumably the result of contamination splashing from one location to another during the decontamination process. In these cases, however, the activities involved were small. This left five vehicle locations with significant non-null results. These are locations 23, 24, 25, 28, and 30, all of which are in the wheel wells. The results for each of these are summarized below:

Location 23: The conventional system left contamination producing 19 cps, while the ***FP*** system left contamination producing 5.7 cps. Ratios cannot be compared for this case because no initial measurement was taken for the conventional system, but the conventional ratio would likely have been somewhat larger than the ***FP***'s 5%.

Location 24: Both systems fared poorly. The ***FP*** system left about 75% more contamination (6.6 cps vs. 3.7 cps), but as a ratio of initial levels this is much larger (75% vs. 14%).

Location 25: The conventional system produced a sizable splashing effect, turning a 39 cps contamination level into an 81 cps contamination level. The ***FP*** system had almost no impact on the contamination, leaving 93% of the original contamination.

Location 28: The conventional system produced a small splashing effect, turning a 115 cps contamination level into a 159 cps level. The ***FP*** system left 55% of a 230 cps contamination area.

Location 30: The conventional method left no measurable contamination. The ***FP*** system left a 68 cps contamination level where no measurable contamination had been before, indicating spreading by significant splashing.

This analysis was also performed with the data from the swipes. Table 5 shows the contamination levels as determined by LSC measurements of swipes following the two decontamination attempts. Most of the results are below detectable limits, although a few spots still had measurable levels. The ratios of contamination levels before and after the decontamination attempt are found in Table 6, along with a comparison of the two methods.

Seven of the ten locations have essentially null results. Although the conventional method left measurable levels more often, its decontamination ratios are in accord with those of the ***FP*** system. Location '**I**' experienced some splashing following the conventional decontamination. The two exceptional cases are locations B and H. These are described below:

- **Location B**: Both methods left 10-20% of the initial contamination. This location correlates with probe position 23 (driver's side front wheel well), where residual contamination was also observed with the probe.

- **Location H**: Both methods left 30-50% of the initial contamination. This location corresponds to probe position 25 (driver's side rear wheel well), where decontamination was also observed to be poor according to the probe. It should be noted that the residual percentages are lower for the swipes than for the probes, implying a component of "non-removable" contamination.

Thus, there is evidence to support the theory that some contamination infiltrated into the corroded areas, making decontamination difficult. It should be noted, however, that the swipe measurements indicate the presence of removable contamination remaining on the vehicle. Based on the swipe results, the conventional and ***FP*** systems performed equally well.

5. DISCUSSION

The results from this investigation appear to indicate that the overall performance of the ***FP*** system was only slightly better than the conventional hot waterblast system. This is rather surprising in view of the earlier work done in Canada, Tieu, et. Al (2002b), where the results were far superior compared to the conventional system. This, in fact, was the reason for the project in Sweden. There are several reasons for the unexpected poor results, the most important being the duration of only 20 minutes allowed for testing with the ***FP*** machine. Therefore, the tests could be conducted only on an ***ad hoc*** basis. This was indeed unfortunate considering all the efforts that went into pre- and post preparations of shipping the machine to Sweden. The observations listed below clearly indicate the shortcomings in the project.

- The most important requirement was that the paint from the vehicle must not be removed. This requirement, combined with the fact that the engineer of VLN was not a trained operator, made it very difficult to test at appropriate operating conditions.

- The short duration made it virtually impossible to set up appropriate scaffolding etc., to ensure comfort and safety of the operator. Since he did not have the firm foothold, and due to large reaction forces, he could not possibly operate the gun steadily and effectively.

- In order to meet the condition listed above, and in order to decontaminate the entire vehicle, very large standoff distances were used (see Figs. 7 and 8). As discussed in the earlier work, at these standoff distances, the pulse disintegrates into droplets and the coherency is lost, Tieu, et. al (2002b). From this standpoint, there was no difference between the ***FP*** and the conventional systems. The slight advantage, or the disadvantage of migrating (spreading) by

splashing the radioactivity into other areas, stems from the fact the speeds of the ***FP*** droplets are significantly higher than the conventional system because of the higher pressure employed.

- Uncertainty in the measurement techniques employed to measure the levels of activity before and after decontamination trials, suggesting more precise instruments must be employed.

- These observations clearly indicate that, if the ***FP*** technique is to be accepted as a standard for decontamination of armored vehicles, more controlled procedure must be adopted. For instance, since the time is not a factor in decontaminating the entire vehicle, lower pressures (≅ 4,000-psi) can be employed without removing the paint, and employing multi-pass procedure to remove the activity spread by splashing. Furthermore, trained operators must be employed, or the operation can be semi-automated to control the standoff distances, etc.

6. CONCLUSIONS

A Swedish SISU XA-180 LAV was driven around a wet and icy contaminated track so as to become contaminated. Decontamination of the vehicle was attempted with two methods, a conventional high-pressure water spray and a ***FP*** waterjet. Neither method was able to achieve thorough decontamination of the vehicle. In comparing the methods, the ***FP*** method produced a slight advantage. However, the lessons learnt from this highly challenging, but unrealistically short duration project, indicate:

- ***FP*** technology has significant potential for radioactive decontamination of armored vehicles and would meet the NATO standards, if appropriate steps are taken (see Tieu, et. al).

- ***FP*** technology also shows promise for chemical decontamination of armored vehicles, despite the scatter in the data and the uncertainty of the measuring technique (see Tieu, et. al).

- International collaboration was indeed a very rewarding experience, and suggests effective team response to deal with critical situations (attack by terrorists) is possible.

7. ACKNOWLEDGMENTS

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8. REFERENCES

Eggen, D., "U.S. Detains Alleged Dirty Bomb Terrorist," *Washingtonpost.com*. (Washington, D.C.: The Washington Post Company), June 10, 2002a.

Anon, "Nuclear Safety Orders and Directives," *Director General Nuclear Safety*, Defence R&D Canada, 2000a.

Tieu, A., Yan, W., Vijay, M.M., Cousins, D., Haslip, D.S., Sparkes, S.E., Jones, T.A., and Estan, D., "Chemical and Radioactive Decontamination of Armored Vehicles Using the High-Frequency Forced Pulsed Waterjet Machine," *Proceedings of the 16th International Conference on Water Jetting*, BHR Group Limited, Cranfield, Bedfordshire, MK43 0AJ, England, 2002b, pp. 609-626.

Anon, "BTI Spectroscopic Survey System Microspec-3 Operating Manual," *Bubble Technology Industries Inc.*, Chalk River, ON, Canada, 1999.

Anon, "Microshield Version 5 User's Manual," *Grove Engineering*, Rockville, MD, USA, 1998.

Anon, "ADM-300 Multi-Probe Universal Survey Monitor," *Canberra Eurisys S.A.*, St. Quentin, France, 2002c, (http://www.eurisysmesures.com/produits).

Anon, "CASCAD Decontamination Foam," *NBC Team Ltd.*, Fort Erie, ON, Canada, 2001a, (http://www.nbcteam.com/decon.shtml).

Haslip, D.S., and Cousins, T., "Comparison of Performance of the Automess 6150 and the NRC ADM-300C," *Report DREO TM 2000-091*, Defence R&D Canada – Ottawa, ON, Canada, 2000b.

Ulvsand, T., Ågren, G., and Lidström, K, "Contamination and Decontamination of All Terrain Carrier 206 during Winter Conditions," *Report FOA-R—00-01661-861—SE*, FOI Umea, Sweden, 2000c.

9. GLOSSARY

This paper contains several definitions and units on radiological activity. For the convenience of the readers not familiar with Nuclear Radiation Physics, the following explanations are included.

Alpha, Beta & Gamma rays: These are the products of radioactive decay of an unstable atom, for example, decay of Uranium ($_{92}U^{235}$) atom.
Activity: The unit of radioactivity is the **bacquerel** (Bq) or the **curie** (Ci).
Background: This is the radiation from the outer space, usually called cosmic radiation.
Bacquerel = 1 decay/s, that is, one atom decays in one second.
Curie = 3.7 X 10^{10} decays/s (a very large unit). Therefore, 1 Ci = 3.7 X 10^{10} Bq. Millicurie (mCi) = 10^{-3} Ci; Microcurie (μCi) = 10^{-6}Ci; Nanocurie (nCi) = 10^{-9}Ci and Picocurie (**p**Ci) = 10^{-12}Ci.
Half-life ($T_{½}$): This is the duration after which only 50% of the original atoms remain.
Dosage: This is the term used to describe exposure (personnel or equipment) to a radioactive source. The unit of measurement = Rem/hr (R/hr); 1 millieR/hr = mR/hr = 10^{-3}R/hr). The allowed dosage ranges from 0.5 R to 5 R/year.

Table 1. Count rates on the ABP-100 alpha-beta probe for various locations on the XA-180. A contamination level of 1 Bq/cm2 would produce a count rate of approximately 30 cps. "BDL" stands for "Below Detectable Limits (locations not listed below)". Locations are identified in **Figure 4**.

LOCATION	FIRST ROUND CONTAMINATION (CPS)	SECOND ROUND CONTAMINATION (CPS)
5	4.0 ± 0.4	BDL
10	10.3 ± 1.0	28.5 ± 2.8
11	9.3 ± 0.9	BDL
12	52.5 ± 5.2	25.0 ± 2.5
16	45.2 ± 4.5	24.2 ± 2.4
17	BDL	7.8 ± 0.8
18	106.2 ± 10.6	26.4 ± 2.6
19	7.2 ± 0.7	6.2 ± 0.6
20	8.4 ± 0.8	7.2 ± 0.7
21	BDL	6.1 ± 0.6
22	BDL	6.3 ± 0.6
23	No measurement	110.8 ± 11.1
24	26.6 ± 2.7	8.9 ± 0.9
25	38.9 ± 3.9	165.4 ± 16.5
26	284.6 ± 28.5	165.4 ± 16.5
27	268.7 ± 26.9	144.5 ± 14.4
28	115.3 ± 11.5	229.8 ± 23.0
29	96.0 ± 9.6	30.0 ± 3.0
31	383.9 ± 38.4	190.2 ± 19.0
32	No measurement	126.3 ± 12.6

Table 2. Contamination levels on the XA-180 as determined by LSC measurements on vehicle swipes.

LOCATION	FIRST ROUND CONTAMINATION (Bq/cm2)	SECOND ROUND CONTAMINATION (Bq/cm2)
A	0.297 ± 0.031	2.347 ± 0.185
B	0.300 ± 0.031	0.304 ± 0.031
C	0.234 ± 0.026	0.139 ± 0.019
D	0.583 ± 0.052	0.224 ± 0.025
E	0.506 ± 0.046	0.052 ± 0.014
F	0.528 ± 0.048	0.024 ± 0.013
G	0.644 ± 0.057	0.091 ± 0.016
H	0.282 ± 0.030	0.132 ± 0.019
J	0.353 ± 0.035	0.093 ± 0.016

Table 3. Count rates on the ABP-100 alpha-beta probe for various locations on the XA-180 following decontamination. A contamination level of 1 Bq/cm2 would produce a count rate of approximately 30 cps. "BDL" stands for "Below Detectable Limits (locations not listed below)".

LOCATION	CONVENTIONAL DECONTAMINATION RESIDUALS (CPS)	VLN DECONTAMINATION RESIDUALS (CPS)
5	BDL	4.5 ± 0.4
6	BDL	3.4 ± 0.3
13	3.8 ± 0.4	BDL
23	19.2 ± 1.9	5.7 ± 0.6
24	3.7 ± 0.4	6.6 ± 0.7
25	81.4 ± 8.1	153.4 ± 15.3
26	4.5 ± 0.4	BDL
27	3.6 ± 0.4	BDL
28	159.0 ± 15.9	126.8 ± 12.7
30	BDL	68.0 ± 6.8

Table. 4. Percentage of initial contamination remaining on the vehicle following decontamination by the conventional and forced pulsed jet method.

LOCATION	DECON RATIO (CONVENTIONAL)	DECON RATIO (PULSED)	COMPARISON OF METHODS
5	< 72%	Splashing	Forced pulsed (***FP***) slight splashing
6	No initial	Splashing	***FP*** slight splashing
10	< 28%	< 10%	Both OK
11	< 31%	No initial	Both OK
12	< 5.5%	< 11%	Both OK
13	Splashing	No initial	Conventional slight splashing
16	< 10%	< 20%	Both OK
17	No initial	< 60%	Both OK
18	< 4.4%	< 18%	Both OK
19	< 65%	< 76%	Both OK
20	< 56%	< 65%	Both OK
21	No initial	< 78%	Both OK
22	No initial	< 75%	Both OK
23	Lots remains	5.1 ± 0.7%	***FP*** better
24	13.9 ± 2.0%	75 ± 10%	Both poor
25	210 ± 29%	93 ± 13%	Conventional splashing, ***FP*** poor
26	1.6 ± 0.2%	< 1.7%	Both OK
27	1.3 ± 0.2%	< 2%	Both OK
28	138 ± 19%	55.2 ± 7.7%	Both poor

Table 5. Contamination levels on the XA-180 as determined by LSC measurements on vehicle swipes. Measurements are made following decontamination.

LOCATION	FIRST ROUND DECONTAMINATION RESIDUALS (Bq/cm2)	SECOND ROUND DECONTAMINATION RESIDUALS (Bq/cm2)
A	BDL	BDL
B	0.032 ± 0.013	0.052 ± 0.009
C	BDL	BDL
D	BDL	BDL
E	0.021 ± 0.013	BDL
F	BDL	BDL
G	0.015 ± 0.012	BDL
H	0.127 ±0.019	0.039 ±0.008
I	0.028 ±0.013	BDL
J	0.013 ± 0.012	BDL

Table 6. Percentage of initial contamination remaining on the XA-180 following decontamination by two methods, as determined by swipe measurements.

LOCATION	DECON RATIO (CONVENTIONAL)	DECON RATIO (*FP*)	COMPARISON OF METHODS
A	< 3.7%	< 0.2%	Both OK
B	10.7 ± 4.6%	17.2 ± 3.3%	Both poor
C	< 5%	< 4%	Both OK
D	< 1.9%	< 2.4%	Both OK
E	4.2 ± 2.5%	< 10.6%	Both OK
F	< 2.3%	< 25.4%	Both OK
G	2.3 ± 1.9%	< 6%	Both OK
H	44.9 ± 8.1%	30.0 ± 7.3%	Both poor
I	Splashing	No initial	Conventional splashing
J	3.7 ± 3.5%	< 6.2%	Both OK

Figure 1. The vehicle used for spreading the radioactive sodium (Na-24) on the track. The seven plastic containers are each filled with an equal amount of sand and sodium.

Figure 3. A general view of the SISU XA-180 light armored vehicle.

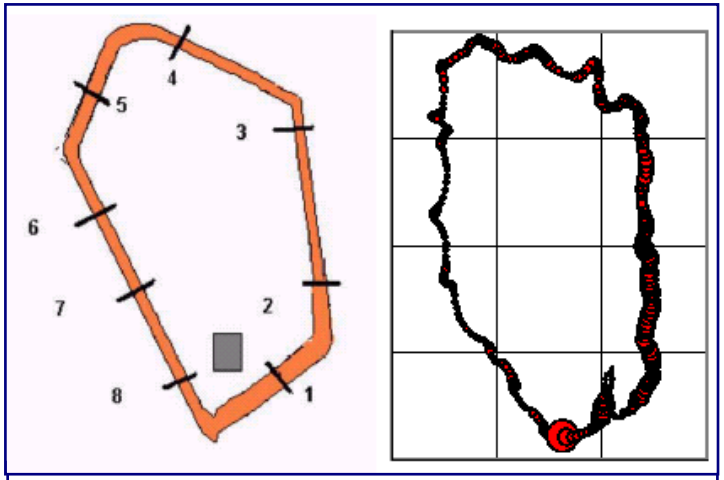

Figure 2. A sketch-map of the contaminated road at the test facility of the National NBC Defence Centre at Umeå.

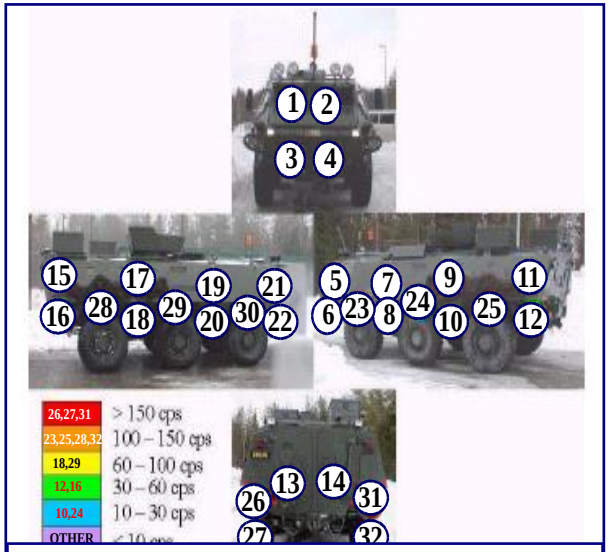

Figure 4. Contamination levels on the vehicle, as measured with the ABP-100 alpha-beta probe. (see Table 1)

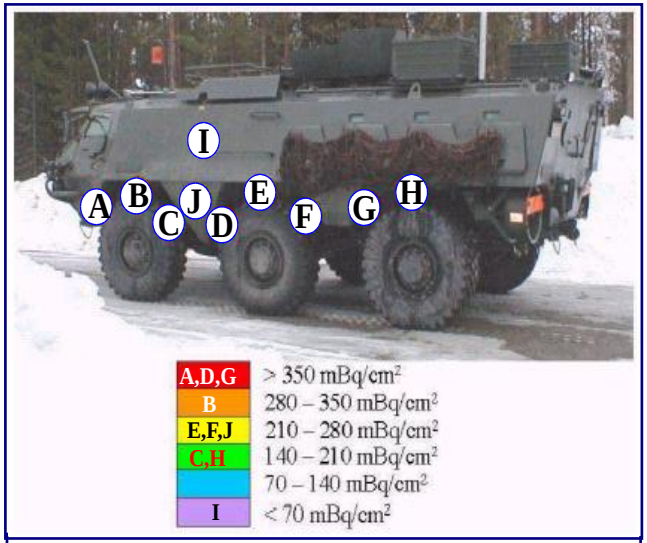

Figure 5. Contamination levels on the XA-180, based on swipe measurements. Locations A-H are on the wheel wells of the vehicle. The letters denoting the positions are used throughout the text.

Figure 7. General view showing decontamination in the wheel wells of the vehicle.

Figure 6. General view showing decontamination on the backside of the vehicle.

Figure 8. General view showing decontamination on the sides (& front) of the vehicle.