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Contamination and Decontamination of a Light Armoured Vehicle

Work performed under the Swedish-Canadian accord

D.S. Haslip, D. Estan, T. Jones, E.J. Waller, B.E. Sandström,
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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 water 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 with a new decontamination method, a forced pulsed water jet. The results of the two trials are compared herein. The two systems were found to produce similar results, with a slight edge going to the pulsed water jet system. It is important to note, however, that in both cases contamination remained on the vehicle, particularly in some of the wheel wells. Moreover, it was impossible to run the forced pulsed water jet system at a higher pressure without removing a significant fraction of the paint on the vehicle. These results indicate that water-based techniques alone are incapable of thoroughly decontaminating a vehicle, unless one is willing to operate at pressures high enough to remove paint, for example.

Résumé

Des épreuves de décontamination radiologiques ont été effectuées sous l'entente Suédoise-Canadienne au Centre National de la NBC-défense à Umeå, Suède. Nous avons contaminé un véhicule suédois légèrement blindé en le conduisant sur une voie sur laquelle nous avions distribué du sodium-24 en forme de particules. Nous avons mesuré la contamination sur le véhicule avec une sonde de contamination "Geiger-Mueller" et avec des échantillons obtenus par frottage. Un jet d'eau à haute pression, semblable à celui employé par les forces canadiennes, a été alors utilisé pour décontaminer le véhicule. Puis, nous avons remesuré la contamination sur le véhicule. Par la suite, nous avons répété ce procédé avec une nouvelle méthode de décontamination, un jet d'eau à ultra-haute pression à impulsion. Les résultats des deux épreuves sont comparés ci-dessous. Les deux systèmes ont produit des résultats semblables, cependant, le système à impulsion était légèrement supérieur. Il est important de noter, par contre, qu'aucun système n'a pu faire une décontamination complète, particulièrement dans les passages de roue. D'ailleurs, il était impossible d'utiliser le système à impulsion à une pression plus élevée sans enlever une fraction significative de peinture sur le véhicule. Ces résultats indiquent que les techniques à base d'eau sont incapables de décontaminer complètement un véhicule, à moins qu'on soit disposé à utiliser un système à des pressions assez élevées pour enlever la peinture, par exemple.

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Executive summary

Introduction: Radiological decontamination experiments have been performed 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 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 water 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 with a new decontamination method, a forced pulsed water jet. The results of the two trials are compared herein.

Results: The two systems were found to produce similar results, with a slight edge going to the pulsed water jet system. It is important to note, however, that in both cases contamination remained on the vehicle, particularly in some of the wheel wells. It is possible that the pulsed water jet could have removed more of the contamination if run at a higher pressure, but higher pressures would have seriously damaged the paint on the vehicle.

Significance: These results indicate that water-based techniques alone are incapable of thoroughly decontaminating a vehicle, unless one is willing to operate at pressures high enough to remove paint, for example.

Haslip, D.S.; Estan, D.; Jones, T.; Waller, E.J.; Sandström, B.E.; Lidström, K.; Ulvsand, T.; and Ågren, G. 2002. Contamination and Decontamination of a Light Armoured Vehicle. DRDC Ottawa TM 2002-107. Defence R&D Canada – Ottawa.

Sommaire

Introduction: Des épreuves de décontamination radiologiques ont été effectuées sous l'entente Suédoise-Canadienne au Centre National de la NBC-défense à Umeå, Suède. Nous avons contaminé un véhicule suédois légèrement blindé en le conduisant sur une voie sur laquelle nous avions distribué du sodium-24 en forme de particules. Nous avons mésuré la contamination sur le véhicule avec une sonde de contamination "Geiger-Mueller" et avec des échantillons obtenus par frottage. Un jet d'eau à haute pression, semblable à cela employé par les forces canadiennes, a été alors utilisé pour décontaminer le véhicule. Puis, nous avons remesuré la contamination sur le véhicule. Par la suite, nous avons répété ce procédé avec une nouvelle méthode de décontamination, un jet d'eau à ultra-haute pression à impulsion. Les résultats des deux épreuves sont comparés ci-dessous.

Résultats: Les deux systèmes ont produit des résultats semblables, cependant le système à impulsion était légèrement supérieur. Il est important de noter, par contre, qu'aucun système n'a pu faire une décontamination complète, particulièrement dans les passages de roue. Il est possible pour le système à impulsion d'enlever encore plus de contamination s'il est utilisé à des pressions plus élevées, cependant, à de telles pressions, la peinture sur le véhicule aurait été sérieusement endommagée.

Signification: Ces résultats indiquent que les techniques à base d'eau sont incapables de décontaminer complètement un véhicule, à moins qu'on soit disposé à utiliser un système à des pressions assez élevées pour enlever la peinture, par exemple.

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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 Canadian forces could be involved in a conflict in which nuclear weapons are used. This includes conflicts in which terrorist groups could employ nuclear weapons. Such groups could also resort to the use of radiological weapons as a weapon of terror or as an economic weapon. Recent events also highlight the possibility that terrorists could use nuclear or radiological weapons against civilian populations [1]. Thus, nuclear and radiological defence 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 [2]. 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 report looks at the contamination of a SISU XA-180 Light Armoured Vehicle after it was driven on a wet and icy road upon which radioactive particulates had been spread. These data will be useful for identifying the parts of the vehicle that become most contaminated when a vehicle is forced to drive through contaminated areas. The paper also looks at the decontamination of this vehicle via two methods: a conventional high-pressure water spray, and a forced pulsed water jet technique developed by VLN Advanced Technologies Incorporated [3]. The capabilities of the two methods are evaluated and compared.

2. Experiment

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 white 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 rain.

Figure 2 shows two maps of the road. The first 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 [4]. 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. Microshield [5] calculations demonstrate that for a

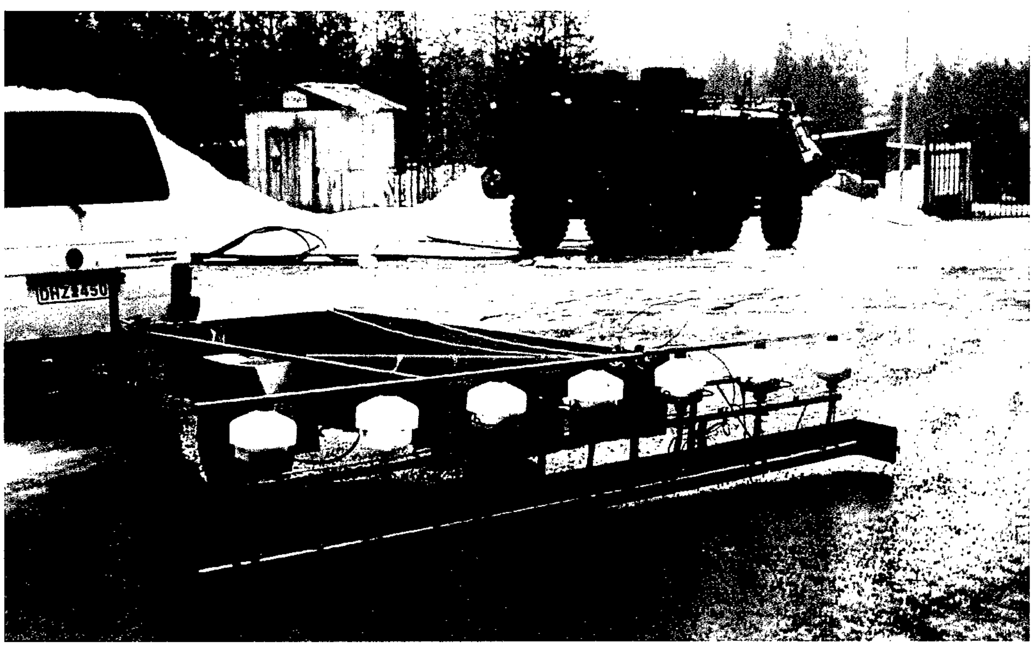

Figure 1. *The vehicle used for spreading the Na-24 on the Swedish track. The seven plastic containers are each filled with an equal quantity of sand and radioactive sodium.*

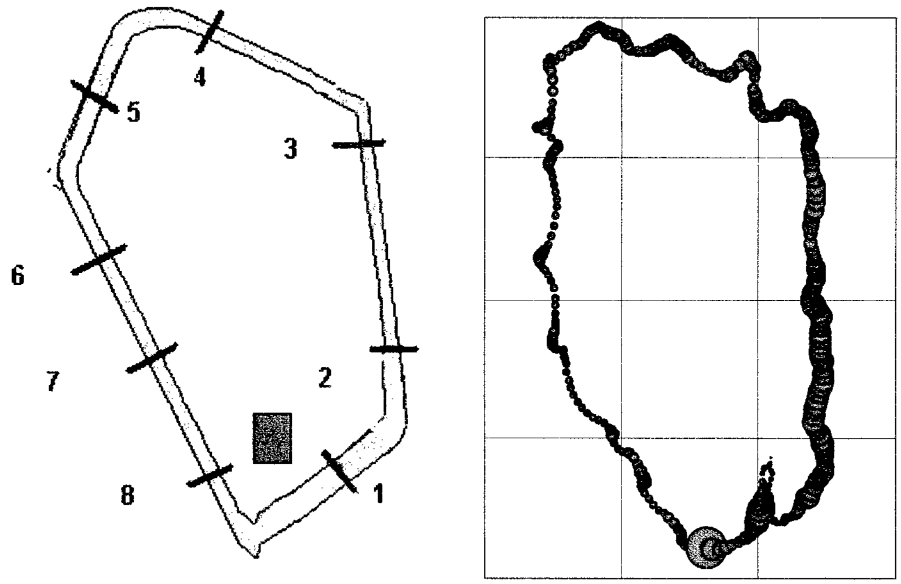

Figure 2. (Left) A sketch-map of the contaminated road at the test facility of the National NBC Defence Centre in Umeå. The grey rectangle at the bottom of the figure indicates the main building of the school, which was where the measurements and decontaminations took place. The numbered lines indicate the presence of stations where road contamination was measured. The circumference of the track is approximately 500 m, and its width is 4.2 m. (Right) A "bubble plot" of the dose rates at 1 m above the track, measured approximately 2 hours before the experiment commenced. The positions of the bubbles are based on the GPS co-ordinates at which the measurements were taken; the areas of the bubbles are proportional to the dose rates at those points. For reference, the largest bubble (at the bottom of the plot) corresponds to a dose rate of 23 μSv/h. The grid squares in this plot are 50 m on a side.

4.2-metre wide track, 1 MBq/m^2 of Na-24 contamination produces a 1-metre dose rate of 4.5 μSv/h. Since dose rates over the track averaged approximately 2.5 μSv/h, one could conclude that the average contamination level on the road was about 0.56 MBq/m^2. This in turn implies that the total contamination on the track would only have been about 1.2 GBq. Bowls with a size of 0.015 m^2 that were placed on the road during the spreading of the activity contained even less activity (on average 0.23 MBq/m^2, implying 0.5 GBq total activity on the track). Since we know that the amount of activity in the seven plastic containers of the spreading device was around 9 GBq, one could assume that a large portion of that activity never left the containers. The weather conditions of the day were moist and this affected the Na-24. Sodium silicate has a strong tendency to take up water and adhere to other materials. It was obvious that it stuck to the aluminum vessel used for the transport of the radioactive material. It was likewise apparent that the two outermost containers of the spreading vehicle were far from empty, and it appears conceivable that the Na-24 also stuck to the plastic walls of the spreading device and to the interior of the outlet system. The chemical properties of sodium silicate could explain the low activity in the bowls since it appears likely that the sodium silicate was not homogeneously distributed on the road. In addition, it must be assumed that a substantial amount of radioactive material was washed off of the road because of the rain. A more detailed examination of the road conditions will be conducted in a future report.

Figure 3. The SISU XA-180 Light Armoured Vehicle.

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 [6] and with swipes. A Swedish team without previous experience of decontaminating the XA-180 then decontaminated the vehicle with a high-pressure water spray. This is the same system developed by DRDC Suffield, but without the CASCAD decontaminant foam [7]. 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. A team from VLN Advanced Technologies Inc. then attempted to decontaminate the vehicle with their forced pulsed water jet system. The remaining contamination on the vehicle was again re-measured. The VLN water jet system is capable of running at extremely high pressures, however for this work pressures were constrained so that the paint on the XA-180 would not be removed. That being said, paint was removed from the vehicle wherever it was the least bit loose.

3. Contamination of the Vehicle

This section looks at the contamination of the vehicle after it was driven around the contaminated track. Emphasis is placed on where the contamination accumulates, how the contamination levels compare to those on the ground, and how the two types of contamination measurements compare to one another.

The most complete characterization of the vehicle contamination was performed with an ABP-100 alpha-beta probe. While such measurements are often not the most sensitive assay of contamination, they have the advantages of being field-expedient and of measuring total contamination, both removable and fixed. These measurements[1] 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 can vary by up to a factor of five. The average values over the two trials are also shown superposed on pictures of the vehicle in Figure 4. The circles in that figure are colour-coded according to the count rate, and the numbers in the circles correspond to the location numbers in Table 1.

Many of the measurements in the table are shown as "BDL", meaning "Below Detectable Limits". These 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 follow a relatively predictable pattern. Namely, very little contamination collects on the front or rear of the vehicle, or anywhere on the upper half of the vehicle. On the other hand, significant contamination can accumulate on the lower halves of the vehicle sides, especially in the wheel wells. It is worth noting that positions 26, 27, 31, and 32 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 are the most highly contaminated surfaces on the XA-180. It is quite reasonable that the wheel wells are contaminated to the highest level, since the tires are responsible for "kicking up" the contamination. However, it is also worth noting how little contamination ends up in some of the other areas under the wet conditions prevailing during these trials.

[1] Note that all contamination measurements presented in this section and the next have been corrected to 0800 hours on the day of the experiment.

__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 are identified in __Figure 4.__

LOCATION	FIRST ROUND CONTAMINATION (CPS)	SECOND ROUND CONTAMINATION (CPS)
1	BDL	BDL
2	BDL	BDL
3	BDL	BDL
4	BDL	BDL
5	4.0 ± 0.4	BDL
6	BDL	BDL
7	BDL	BDL
8	BDL	BDL
9	BDL	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
13	BDL	BDL
14	BDL	BDL
15	BDL	BDL
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
30	BDL	BDL
31	383.9 ± 38.4	190.2 ± 19.0
32	No measurement	126.3 ± 12.6

No calibration of ABP-100 response to a Na-24 area source has been performed. However, based on measurements of Sr-90 and Cl-36 beta sources [8], a reasonable calibration factor is approximately 30 cps / (Bq/cm^2). Thus, the measured contamination levels on the XA-180 range between 0 and 13 Bq/cm^2 (0.13 MBq/m^2). Since the average contamination level of the track was estimated at a few MBq/m^2, we see that the maximum contamination level of the XA-180 is 1-10% of the average road contamination. This is a non-negligible quantity for a drive of only 5 km. That is not to say that the contamination level would continue to increase; previous work shows that contamination of the vehicle eventually reaches equilibrium with self-

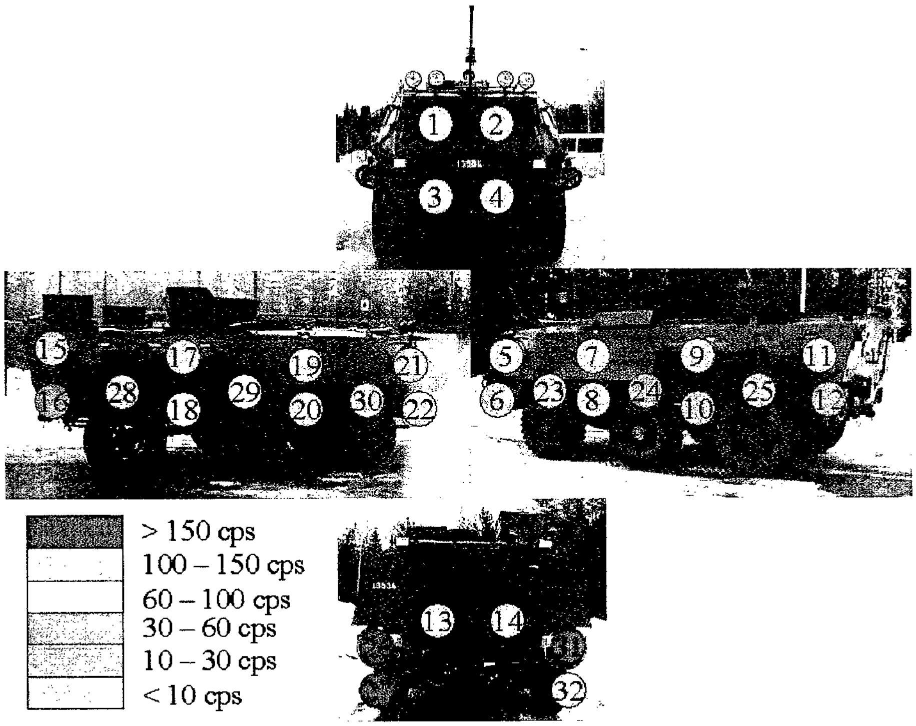

Figure 4. *Contamination levels on the XA-180, as measured with the ABP-100 alpha-beta probe. Each circle denotes a measurement location, colour-coded according to the magnitude of the measurement (actually the average of the two contamination measurements). Each bubble contains the location number by which the locations are identified in this document.*

decontamination processes [9]. 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 can say nothing about the level of fixed contamination. Swipes were taken primarily in the wheel wells of the XA-180, 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 are far from reproducible. In fact, these data are less reproducible than the probe measurements. The average measurements for each location are superposed on a picture of the XA-180 in Figure 5. As above, the circles are colour-coded according to the measurements, and 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. The uncertainties are the sum in quadrature of a 10% uncertainty on the background-subtracted value and an 8.8% uncertainty on the unsubtracted quantity (this latter is an observed variation in several measurements of a control sample). These uncertainty estimates are felt to be conservative.

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

LOCATION	FIRST ROUND CONTAMINATION (Bq/cm^2)	SECOND ROUND CONTAMINATION (Bq/cm^2)
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
I	BDL	BDL
J	0.353 ± 0.035	0.093 ± 0.016

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.

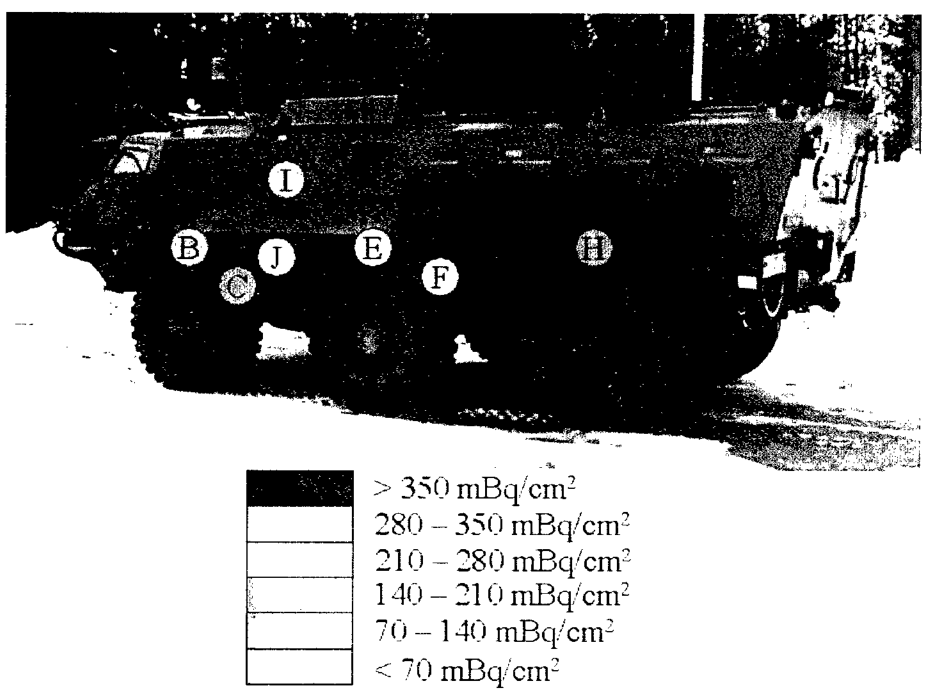

Figure 5. Contamination levels on the XA-180, based on swipe measurements. Locations A-H are located in the wheel wells of the vehicle. The letters denoting the position are used throughout this document.

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. This has been observed in other trials as well [10]. One possible explanation is that the vehicle initially has dirt on it 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 is unfortunately not so simple. Using a probe calibration factor of 30 cps / (Bq/cm^2), we find that the probe contamination values always exceed those of the swipes. This implies that the calibration factor is underestimated. However, the discrepancy between the two sets of contamination values varies from a factor of 2 to a factor of 30, indicating that no reliable calibration factor can 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 (it is also interesting to ask whether one should expect a single swipe to remove all of the "removable" contamination under these very wet conditions. These considerations imply that the probe measurement should always equal or exceed the swipe measurement (as observed) and that 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, we shall see in the next section that not all of this contamination is 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 spray decontamination and once with pulsed water jet decontamination (provided by VLN). This section presents the post-decontamination measurements, and the conclusions that can be made regarding the efficacy of the two decontamination methods.

Post-decontamination, the vehicular contamination 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 are below detectable limits. 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 is 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 VLN attempts.

It is difficult to use Table 3 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. The 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, the ratio is expressed as a 1σ 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. Two locations (26 and 27) were also decontaminated to a great degree, although not necessarily below detectable limits. Three more locations (5, 6, and 13) 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 are small. This leaves 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 summarised below:

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/cm^2 would produce a count rate of approximately 30 cps. "BDL" stands for "Below Detectable Limits".*

LOCATION	CONVENTIONAL DECONTAMINATION RESIDUALS (CPS)	VLN DECONTAMINATION RESIDUALS (CPS)
1	BDL	BDL
2	BDL	BDL
3	BDL	BDL
4	BDL	BDL
5	BDL	4.5 ± 0.4
6	BDL	3.4 ± 0.3
7	BDL	BDL
8	BDL	BDL
9	BDL	BDL
10	BDL	BDL
11	BDL	BDL
12	BDL	BDL
13	3.8 ± 0.4	BDL
14	BDL	BDL
15	BDL	BDL
16	BDL	BDL
17	BDL	BDL
18	BDL	BDL
19	BDL	BDL
20	BDL	BDL
21	BDL	BDL
22	BDL	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
29	BDL	BDL
30	BDL	68.0 ± 6.8
31	BDL	BDL
32	BDL	BDL

Table 4. *Percentage of initial contamination remaining on the XA-180 following decontamination by the conventional and VLN methods. Data are only given for locations at which contamination was observed before decontamination in at least one of the two trials. For trials in which the contamination level after decontamination was "BDL", the decontamination ratio is expressed as a 1σ confidence limit. The phrase "No contamination" is used to indicate the case where both the initial and final contamination levels were below detectable limits. The phrase "Splashing" is used to indicate the case where the initial contamination level was below detectable limits but the contamination level after decontamination level following decontamination was above these same limits (indicating that contamination had splashed onto this location during the decontamination process). The final column gives a short statement in which the results of the two methods are compared.*

LOCATION	DECON RATIO (CONVENTIONAL)	DECON RATIO (VLN)	COMPARISON BETWEEN METHODS
5	< 72%	Splashing	VLN slight splashing
6	No contamination	Splashing	VLN slight splashing
10	< 28%	< 10%	Both OK
11	< 31%	No contamination	Both OK
12	< 5.5%	< 11%	Both OK
13	Splashing	No contamination	Conventional slight splashing
16	< 10%	< 20%	Both OK
17	No contamination	< 60%	Both OK
18	< 4.4%	< 18%	Both OK
19	< 65%	< 76%	Both OK
20	< 56%	< 65%	Both OK
21	No contamination	< 78%	Both OK
22	No contamination	< 75%	Both OK
23	Lots remains	5.1 ± 0.7%	VLN better
24	13.9 ± 2.0%	75 ± 10%	Both poor
25	210 ± 29%	93 ± 13%	Conventional splashing, VLN 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
29	< 4.9%	< 16%	Both OK
30	No contamination	Splashing	VLN splashing
31	< 1.2%	< 2.4%	Both OK
32	---	< 3.7%	Both OK

- Location 23: The conventional system left contamination producing 19 cps, while the VLN 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 VLN's 5%.

- Location 24: Both systems fared poorly. The VLN 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 VLN 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 VLN system left 55% of a 230 cps contamination area.

- Location 30: The conventional method did not change the original BDL result. The VLN system created a 68 cps contamination level where no measurable contamination had been before, indicating a significant splashing.

Overall, one would have to give a slight edge to the VLN system in terms of performance, but the advantage is small and it should be noted that neither system was able to thoroughly decontaminate the vehicle. In a few notable cases (both rear wheel wells), the systems were unable to significantly reduce sizable contamination levels. These surfaces were the most heavily corroded, indicating that the contamination had entered the rusty area and could not be removed by the two systems.

This analysis can also be 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 have 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. This is elaborated in the following paragraph.

Seven of the ten locations (A, C, D, E, F, G, and J) have essentially null results. Although the conventional method left measurable levels more often, its decontamination ratios are in accord with those of the VLN system. Location I experienced some splashing following the conventional decontamination. The two exceptional cases are locations B and H. These are described below:

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/cm^2)	SECOND ROUND DECONTAMINATION RESIDUALS (Bq/cm^2)
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 (VLN)	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

- 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 measurements. 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, a disappointing result to be sure. Based on the swipe results, the conventional and VLN systems performed equally well.

It should be noted that the VLN system could have been operated at a higher pressure, and that decontamination under these conditions might have been more thorough. However, it has already been noted that under these conditions the paint on the vehicle would have been removed. Thus, one can conclude that a purely water-based decontamination method is unlikely to provide thorough decontamination unless one is willing to remove the paint from the vehicle. This work can say nothing about the efficacy of such an approach. One could presumably improve the conventional method by using scrub brushes to loosen contamination, but it is known that this method is also incapable of providing thorough decontamination [11].

5. Conclusions

A Swedish SISU XA-180 LAV was driven around a wet and icy contaminated track so as to become contaminated. The contamination pattern following such a trip is largely as one would expect. Namely, there is very little contamination of the front or rear of the vehicle, nor is there any contamination on the upper halves of the two sides. Conversely, relatively high contamination levels can develop on the lower halves of the two sides, particularly in the wheel wells. It should be noted that the conditions were very wet, which likely tends to keep contamination closer to the ground than might be the case under dusty conditions. Maximum contamination levels on the vehicle were between 1 and 10% of the average road contamination, after 5 km of driving.

Decontamination of the vehicle was attempted with two methods, a conventional high-pressure water spray and a forced pulsed water jet. Neither method was able to achieve thorough decontamination of the vehicle. In comparing the methods, the VLN method produced a slight advantage, too slight to justify the massive logistical requirements of the method. The most problematic sections of the vehicle were the rearmost wheel wells on both sides of the vehicle. According to contamination probe results, no more than 50% of the contamination was removed by either method. According to swipe measurements (which measure only removable contamination), up to 70% of the contamination was removed.

These results first indicate that neither method was able to remove all of the "removable contamination". This is indeed a disappointing result (that either method left patches of contamination that could be removed with a swipe), and underscores the difficulty of decontamination. The second significant result of the decontamination trial is that a sizable fraction of the total contamination may have migrated into the vehicle surface where it could no longer be termed "removable". This result is bolstered by the fact that the rear wheel wells had patches of corrosion in which ingress of contamination could easily occur. The patches in these areas were larger than anywhere else on the vehicle. This again underscores the challenge of decontamination, particularly when the contaminant is radioactive.

It should be noted that the VLN method could have been operated at higher pressures, and that such operation may have produced better results. This work cannot speculate on what those results might have been. However, it is clear that if the system had been operated at higher power, a significant fraction of the paint would have been removed from the vehicle. This undesirable consequence must be weighed against the possible advantages.

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Radiological decontamination experiments were carried out at the Defence School 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 water 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 with a new decontamination method, a forced pulsed water jet. The results of the two trials are compared herein. The two systems were found to produce similar results, with a slight edge going to the pulsed water jet system. It is important to note, however, that in both cases contamination remained on the vehicle, particularly in some of the wheel wells. Moreover, it was impossible to run the forced pulsed water jet system at a higher pressure without removing a significant fraction of the paint on the vehicle. These results indicate that water-based techniques alone are incapable of thoroughly decontaminating a vehicle, unless one is willing to operate at pressures high enough to remove paint, for example.

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