U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND
CHEMICAL BIOLOGICAL CENTER

ABERDEEN PROVING GROUND, MD 21010-5424

DEVCOM CBC-TR-1816

Manpower-Free Decon Rain: Proof of Concept

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March 2024

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REPORT DOCUMENTATION PAGE

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED START DATE	END DATE
XX-03-2024	Final	Mar 2018	Sep 2018

4. TITLE AND SUBTITLE
Manpower-Free Decon Rain: Proof of Concept

5a. CONTRACT NUMBER	5b. GRANT NUMBER	5c. PROGRAM ELEMENT NUMBER
5d. PROJECT NUMBER	**5e. TASK NUMBER**	**5f. WORK UNIT NUMBER**

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Director, DEVCOM CBC, ATTN: FCDD-CBR-MT, APG, MD 21010-5424 Leidos, Inc.; 11951 Freedom Drive, Reston, VA 20190-5651	DEVCOM CBC-TR-1816

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)	11. SPONSOR/MONITOR'S REPORT NUMBER(S)
U.S. Army Combat Capabilities Development Command Chemical Biological Center, 8198 Blackhawk Road, Aberdeen Proving Ground, MD, 21010-5424	DEVCOM CBC	

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES
This work was performed as a DEVCOM CBC FY18 Innovative Development of Employee Advanced Solutions (IDEAS) project.

14. ABSTRACT (LESS THAN 200 WORDS)
The ability to effectively decontaminate chemical warfare agent-contaminated vehicles is hampered by sorption of the agent into the exposed surfaces. The longer the agent resides on the surface, the more agent sorbs into the material, making it more difficult to effectively decontaminate. Decontamination for a rapidly deployable, highly mobile, lethal land force would be more effective if it could be initiated immediately after contamination. The innovation described herein entails the proof of concept for an enhanced decontamination capability whereby vehicle occupants trigger the projection of pre-positioned decontaminant-filled containers via launch tubes mounted on the vehicle exterior immediately following a contamination event. One liter high-density polyethylene bottles filled with sprayable decontamination slurry (DS) and C4-loaded burster tubes were burst over tarps sectioned into quadrants to determine the total coverage area. Material was effectively ejected from the bottle; however, slurry coverage was poor. This was attributed to horizontal dissemination and small droplet size of the DS. Both issues can be resolved by modifying the bottle so the DS is forced to burst downward from the bottom of the bottle.

15. SUBJECT TERMS
Decontamination dispersal	Decontamination slurry (DS)	Burster	Decontamination	Dissemination

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	C. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
U	U	U	UU	66

19a. NAME OF RESPONSIBLE PERSON	19b. PHONE NUMBER *(Include area code)*
Renu B. Rastogi	(410) 436-7545

STANDARD FORM 298 (REV. 5/2020)
Prescribed by ANSI Std. Z39.18

PREFACE

The work described in this report was authorized and funded as a fiscal year 2018 (FY18) Innovative Development of Employee Advanced Solutions (IDEAS) project. The work was started in March 2018 and completed in September 2018.

The use of either trade or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

This report has been approved for public release.

Acknowledgments

The authors acknowledge the following U.S. Army Combat Capabilities Development Command Chemical Biological Center (DEVCOM CBC; Aberdeen Proving Ground [APG], MD) individuals for their hard work and assistance with the execution of this technical program:

- Dr. Augustus Fountain (retired), Adam Seiple, and the DEVCOM CBC Innovation Goal Team for selecting and supporting this FY18 IDEAS project;
- MAJ John Williams II for providing the conceptual vision and warfighter requirement for the manpower-free deployment of a decontaminant;
- Elizabeth Hirsh for coordinating and obtaining Record of Environmental Consideration approval from the APG Garrison for outdoor decontaminant dispersal testing;
- Mark Hull for managing the outdoor test pad and coordinating range support; and
- Joseph Domanico and Giancarlo Diviacchi for computer-aided design drawing and three-dimensional printing of burster tubes.

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MANPOWER-FREE DECON RAIN: PROOF OF CONCEPT

1. PROJECT BACKGROUND AND CONCEPT

Effective decontamination of chemical warfare agent-contaminated vehicles, with associated reductions in contact and vapor hazards, is hampered by agent sorption into the exposed surfaces. As shown in Figure 1, the longer an agent resides on a surface, the more agent will attach to a material, which makes it more difficult to effectively decontaminate the surface. This is especially true with aqueous-based decontaminants or wash solutions because they neither readily penetrate coatings nor extract contaminants from materials for neutralization. Because the critical decontamination time period is so short, the operator wipe-down procedure prescribed by Field Manual (FM) 3-11.5 should ideally be performed within 15 min. Sorbent powder mitts in the M100 Sorbent Decontamination System (SDS; Figure 2) are used to decontaminate surfaces that are likely to be touched on a vehicle exterior.[1]

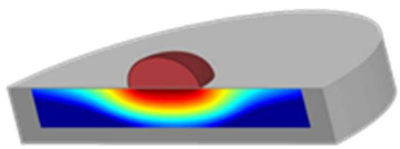

Figure 1. Agent sorption into a material.

Figure 2. Sorbent application using the M100 SDS.

This decontamination procedure requires one or more people and is limited to surfaces with which personnel are anticipated to come into contact. Vehicle surfaces that are left untreated following operator wipe down remain contaminated until a soapy water wash is initiated as part of operational decontamination. Operational decontamination must be coordinated with units possessing additional washing equipment resources and personnel. This delay in decontamination allows for more agent to attach to the materials, makes any decontamination efforts less efficient, and potentially increases the associated hazards to the warfighter.

For a rapidly deployable, highly mobile, lethal land force, decontamination would be more effective if it could be initiated immediately after contamination. Such a process would be especially beneficial if it reduced the need for warfighters to be actively engaged in the decontamination process and reduced the necessity for water and associated equipment used for surface washing.

This report describes an innovative, enhanced decontamination capability: immediately after a contamination event, vehicle occupants trigger a projection of prepositioned decontaminant-filled containers via launch tubes mounted on the vehicle exterior. These containers are designed to burst directly overhead (as shown in Figure 3) and create a dense cloud of decontaminant that will fall onto the contaminated vehicle and coat its surface. This concept is referred to as Manpower-Free Decon Rain.

Figure 3. Decon Rain concept.

Dischargers for the Decon Rain system are similar in configuration to those developed by the U.S. Army Combat Capabilities Development Command Chemical Biological Center (DEVCOM CBC; Aberdeen Proving Ground, MD) Sustainment Engineering Division for the Light Vehicle Obscuration Smoke System (LVOSS) grenade launcher. The dischargers are designed to be mounted on the roof of the high-mobility multipurpose wheeled vehicle (as shown in Figure 4), but they would be oriented to provide a more vertical trajectory.[2] The U.S. Army has already developed a chemical-filled projectile that can contain and deliver the decontaminant. The M9 simulator, projectile, airburst, liquid (SPAL; shown in Figure 5) was developed as a training device for soldiers to use in chemical attack field exercises in connection with the M257 launcher.[3,4] The M9 SPAL assembly contains a hard plastic bottle and an explosive charge subassembly with a dual-stage delay pyrotechnic time fuse to burst the container. It can be filled with up to 1 L of liquid decontaminant.[5]

Figure 4. Grenade launcher developed for the LVOSS.

Figure 5. SPAL training device for simulation of chemical attacks.

2. TEST MATERIALS, PROCEDURES, AND EQUIPMENT

2.1 Sprayable Decontamination Slurry Chemicals

Preliminary dispersal testing was performed using clover honey that was dyed red using 1-(methylamino) anthraquinone. The dye was added to facilitate visual and photographic contrast when the honey is viewed against white or blue tarps.

The sprayable decontamination slurry (DS) is a novel decontaminant formulation developed in-house at DEVCOM CBC that has been shown to be highly effective as a hardened military equipment decontaminant during laboratory studies.[6] The slurry used in dispersal testing was similar in composition to the standard formulation with the exception of the oxidative component, 1,3-dibromo-5,5-dimethylhydantoin (DBDMH), which was omitted to simplify the receipt of Record of Environmental Consideration approval. The exclusion of DBDMH did not change the rheology of the slurry. The slurry composition and chemical source information are outlined in Tables 1 and 2, respectively. The slurry was mixed fresh on each day of testing to avoid possible effects of storage time and ambient conditions.

Table 1. DS Composition

Component	Purpose	Physical State	Amount (wt %)
Sulfolane with 3% water	Organic solvent	Liquid	54.42
Zirconium hydroxide	CWA neutralizer	Solid	19.65
Pulverumtarnfarbe	Rheology modifier	Solid	15.98
Deionized water	Aqueous solvent	Liquid	9.05
Metal oxide pigment	Color	Solid	0.54
Pangel S9	Rheology modifier	Solid	0.36

CWA, chemical warfare agent.

Table 2. Chemical Source Information

Chemical	Source
Sulfolane	Alfa Aesar (Ward Hill, MA) , catalog no. A13466, 99% purity
Zirconium hydroxide, Type B	Guild Associates, Inc. (Dublin, OH)
Pulverumtarnfarbe white HC	MIPA SE (Essenbach, Germany)
Lansco 361 metal oxide pigment, green	Landers-Segal Color Co., Inc. (Warwick, RI)
Pangel S9	Tolsa USA, Inc. (Lovelock, NV)
Clover honey	Costco Wholesale (locally sourced; White Marsh, MD)
1-(methylamino) anthraquinone	Sigma-Aldrich (St. Louis, MO), 98% purity

2.2 C4 Explosive

Slurry was disseminated using a C4 secondary explosive loaded in a central burster configuration and detonated by an electrically initiated blasting cap.[7,8] Composition C4 is a moldable plastic explosive composed of RDX, binder, and plasticizer. The blasting cap and burster configuration was not changed over the course of the tests. The amount of C4 used was adjusted during the range-finding tests so the appropriate ratio of explosive to fill material could be determined. The amount of C4 was again adjusted after the initial slurry test, and 0.5 g of C4 loaded centrally in the burster tube was decided on as the standard configuration for slurry tests. The amount of secondary explosive used in each test is summarized in Table 3. Standard issue military C4, broken down from M112 demolition charge blocks, was used for all testing. C4 must be initiated by a detonator to function. For all tests, a standard military M6 electric detonator (blasting cap) was inserted directly into the C4. Adequate contact between the detonator and the C4 was ensured when items were placed into the burster tube.

Table 3. Secondary Explosive Used in Each Test Shot

Test Shot No.	Weight of C4 (g)
Honey	
1	9
2	5.5
3	0
4	1
5	2
6	3
Slurry	
1	1
2	0.5
3	0.5
4 (first)	0.5
4 (second)	0.5
5 (each of 2)	0.5

2.3 Dissemination Device

To prepare the DS for dissemination, a 1 L high-density polyethylene (HDPE) bottle was filled with the slurry, and a hollow 3D-printed burster was inserted into the bottle. The measured C4 charge was packed into the hollow interior of the burster so that the charge was centered from top to bottom. The bottle cap was screwed onto the bottle, thereby securing the C4-loaded burster inside the bottle (as illustrated using a cutaway bottle in Figure 6).

Figure 6. Dissemination device consisting of an HDPE bottle fitted with a C4-loaded burster before (left) and after (right) the lid was secured.

At the test pad before dissemination testing began, the burster with the blasting cap was inserted into a bottle prefilled with DS (Figure 7A). The bottle cap was screwed down to secure the burster assembly to the bottle (Figure 7B). Tape was used to secure the blasting cap to the C4-loaded burster, and then wire was wrapped around the bottle neck to facilitate hanging of the device (Figure 7C). The wire secured the assembled device to the aluminum test fixture 5 ft above the target tarp (Figure 7D). These photographs were taken during preliminary testing using red-dyed honey.

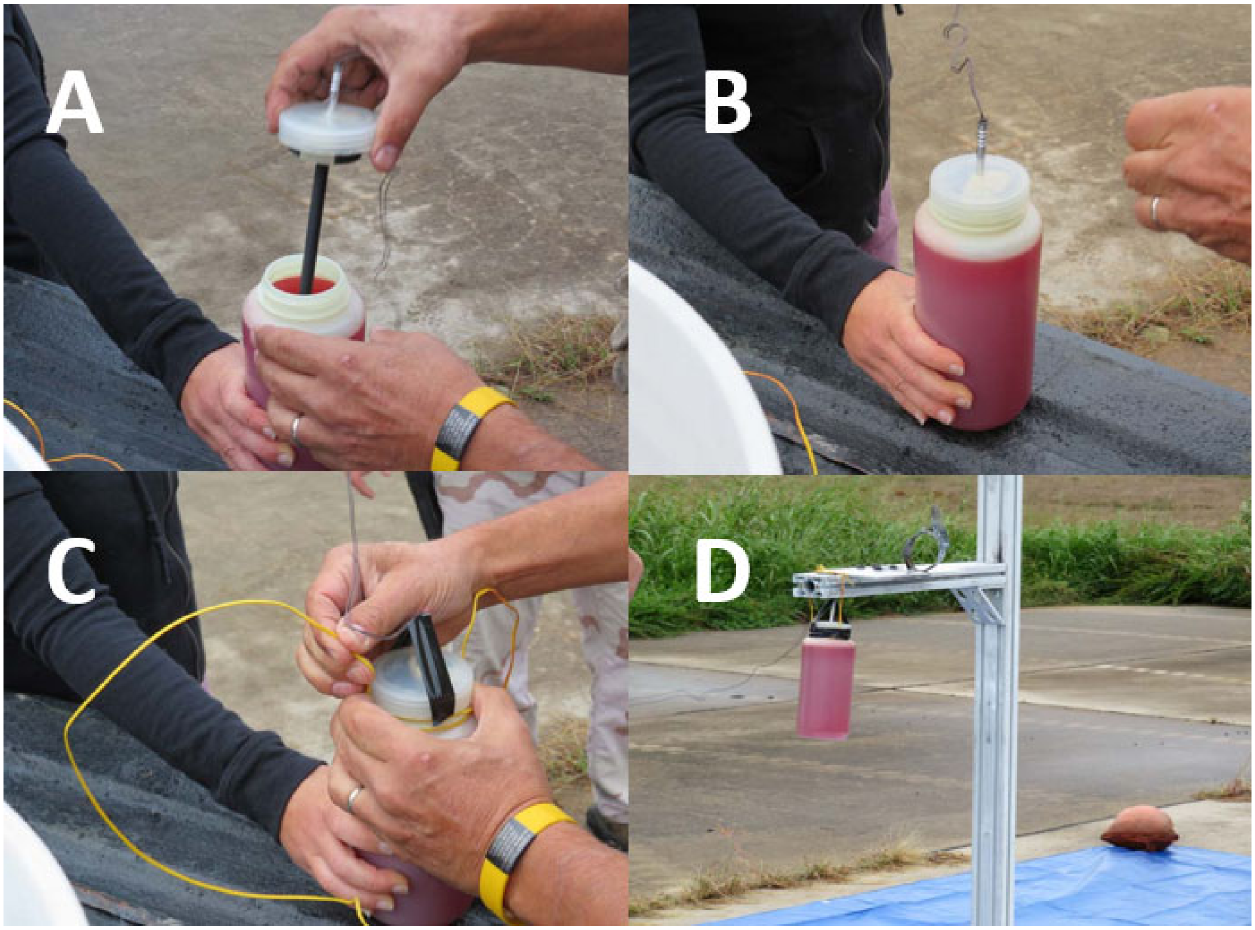

Figure 7. Preparation and setup of dissemination device on test pad. Burster being loaded into prefilled bottle (A), complete device for detonation (B), preparation of device for suspension (C), and device in place on the test pad immediately before detonation (D).

2.4 Viscosity Measurement

The response of the fill material (honey or slurry) to the detonation should be related to the viscosity of the fluid. To understand this property, the fluid viscosity was measured in two ways.

2.4.1 Cone and Plate Viscometer

A cone and plate viscometer can measure the viscosity of non-Newtonian fluids: a disk is submerged in fluid, and the resistance to rotation is identified as the torque. Measurements were performed by the DEVCOM CBC Chemical Analysis and Physical Properties Branch using a Wells–Brookfield cone and plate viscometer (Brookfield Engineering; Middleboro, MA; model no. LVDV-II + Pro) and were validated using Cannon viscosity standards (Cannon Instrument Company; State College, PA).

2.4.2 Vibro Viscometer

A vibro viscometer was used to identify fluid viscosity: a vibrating probe (similar to a tuning fork) was submerged into the fluid, and the frequency changes associated with the fluid viscosity were measured. These measurements were performed using a model SV-100 vibro viscometer (A&D Company; Tokyo, Japan), which has a viscosity range of 1–100 Pa·s.

2.4.3 Viscosity Results

The main purpose of measuring viscosity was to verify that honey was a suitable simulant for DS. The unusual behavior of the slurry made it a challenge to determine the absolute viscosity of the fluid. However, it was possible to determine to an initial approximation that honey was a reasonable simulant.

2.5 Dissemination Coverage Measurement

Two adjoining blue plastic tarps were positioned on the test pad surrounding the aluminum test fixture to protect the test pad from exposure to the disseminated materials and facilitate cleanup at the end of testing. These were overlaid with two smaller white plastic-backed paper tarps that each measured approximately 9 × 13 ft so that the coverage of the decontaminant could better be assessed. The white tarps were laid on top of the blue tarps in adjoining or diagonally opposite quadrants (Figure 8) with the plastic side up because the honey and DS spread on the paper in a way that interfered with determination of initial coverage. In subsequent honey tests, only one white tarp was used on top of the blue tarps to save time and materials. Results from the initial burst indicated that the dissemination was radially symmetrical; therefore, in the absence of appreciable wind, the information required could be collected with a tarp on a single quadrant. The white tarps were marked with blue chalk lines that further divided them into 24 sectors (each 2 × 2 ft) to facilitate photographic documentation. These white tarps were replaced and chalked after each test burst (see Figure 9). Each of the 24 sectors was photographed to document decontaminant coverage.

Figure 8. Arrangement of tarps on test pad to assess dissemination coverage (top of picture is south).

Figure 9. Schematic of witness tarp layout and segmentation.

We hoped to perform a quantitative analysis of the photographs to determine droplet sizes and area coverage. However, the reflectivity of the tarps as well as the folds and wrinkles on the tarp surfaces created a nonuniform background that was not ideal for digital image analysis. ImageJ software (U.S. National Institutes of Health [Bethesda, MD] and the Laboratory for Optical and Computational Instrumentation at the University of Wisconsin [Madison, WI]) was used to convert the tarp photographs to color-threshold binary images and to calculate the area of each 2 × 2 ft square covered by the slurry. Despite the system limitations, the general range and trends of droplet sizes and coverage and the dispersal range of the device could be determined. Wetting and spread of the slurry on surfaces of military interest, including chemical agent-resistant coating (CARC) paint, would differ from that on plastic tarps, so we did not go to great lengths to develop methodology for quantifying coverage on the tarps.

3. DISPERSAL PREDICTION

In these initial tests of explosive dissemination of DS, we did not expect uniform distribution of the fill because the dissemination system was not rigorously optimized and the testing was conducted outdoors in an uncontrolled environment. Table 4 and Figure 10 provide a general indication of the range of thickness that would be achievable with perfect dispersal and spread.

Table 4. Calculated Thickness Assuming Uniform Distribution of 1 L of Liquid

Radius (m)	**Coverage Thickness (µm)**
0.25	5096
0.5	1274
1	318
1.5	142
2	80
3	35
4	20

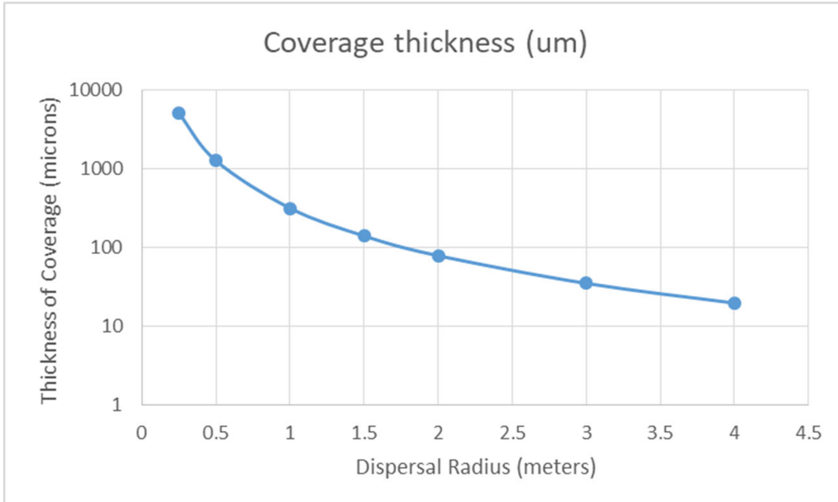

Figure 10. Theoretical slurry film thickness as a function of dispersal radius.

4. RESULTS

4.1 Range-Finding Dispersal Testing

The goals of these initial tests, using honey (with dye added, to provide visual contrast) as a viscosity-matched simulant for Decon Rain slurry, were as follows:

- range finding to determine optimal explosive size and configuration to disperse a liquid with the viscosity of DS over an area approximately the size of a tank, with minimal loss of fill to surrounding areas;
- trial runs for test setup and data collection, including tarp selection, number, and orientation; visibility of droplets on tarps; and process of setting up and securing tarps; and
- familiarizing personnel with field operations.

The test pad surface was covered with two blue tarps (plastic) overlaid with two smaller (9 × 13 ft) white tarps (plastic-backed paper) for the first shot, as described in Section 2.5 and shown in Figure 8. In later tests, only one white tarp was used on top of the blue tarps to save time and materials because results from the first shot made it clear that the information required could be collected with a single tarp. The single tarp was located in the area designated as Quadrant 1 in Figure 9.

4.1.1 Honey Shot 1

This shot was ~1 L of honey in an HDPE bottle. It was performed in a center-burst configuration with a blasting cap and ~9 g of C4. The blast height was ~4 ft. After the shot, the bottle was recovered ~15 ft from the center. The shot generated fine droplets that traveled at least 35 ft upwind and 55 ft downwind. The bottle was shattered into many pieces that were blown beyond the test setup area.

Figure 11 shows the stand post-test. The fill material that landed on the tarps was blackened from the blast. The base of the stand following this shot is shown in Figure 12.

Figure 11. Stand following the first honey shot. The bottle was shattered and blown beyond the test setup area.

Figure 12. Base of the stand following the first honey shot (9 g of C4).

4.1.2 Honey Shot 2

This shot was ~1 L of honey in an HDPE bottle. It was performed in a center burst configuration with a blasting cap and ~5.5 g of C4. More material stayed within the tarp region; however, the droplets were still very fine, and there was considerable spread well beyond the tarps. The base of the stand following this shot is shown in Figure 13. As occurred in the first shot, the material was discolored from charring or inclusion of soot. The bottom was blown out of the bottle, but it remained in place on the tarp (visible in Figure 13).

Figure 13. Base of the stand following the second honey shot (5.5 g of C4).

4.1.3 Honey Shot 3

This shot was ~1 L of honey in an HDPE bottle. It was performed in a center burst configuration with only the blasting cap; no C4 was used in this configuration. There was very little dispersion of the fill from this shot. A hole was blown in the side of the bottle (Figure 14) that allowed the honey to drip onto the tarp (Figure 15).

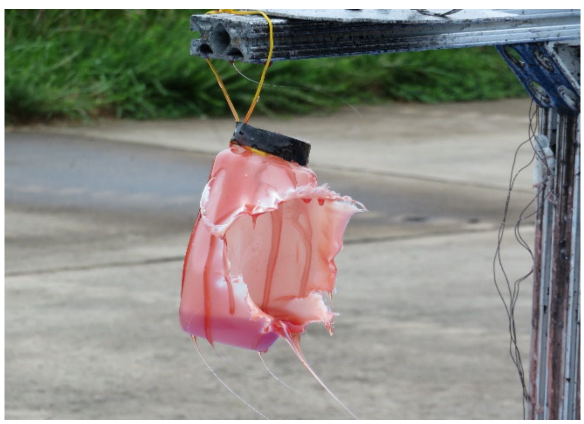

Figure 14. HDPE bottle after honey shot 3 (no C4).

Figure 15. Tarp following honey shot 3 (no C4).

4.1.4 Honey Shot 4

This fourth honey shot was ~1 L of honey in an HDPE bottle. The center burster was loaded with 1 g of C4. This shot was effective in rupturing the bottle (see Figure 16), but it blew out the bottom rather than the side, again resulting in a puddle of honey immediately below the suspended bottle (Figure 17). The downward fracture of the bottle was likely due to the location of the small charge within the burster and therefore within the bottle. Aside from the directionality of the release, the droplet size and distribution from this shot appeared to be appropriate for the DS test (i.e., the explosive charge and test setup seemed appropriate, but the downward projection was not).

Figure 16. HDPE bottle following honey shot 4 (1 g of C4).

Figure 17. Tarp under bottle after honey shot 4 (1 g of C4).

4.1.5 Honey Shot 5

This shot was ~1 of L honey in an HDPE bottle with a center burster containing 2 g of C4. The bottle after detonation and the droplet distribution on the tarp following this test are shown in Figures 18 and 19, respectively.

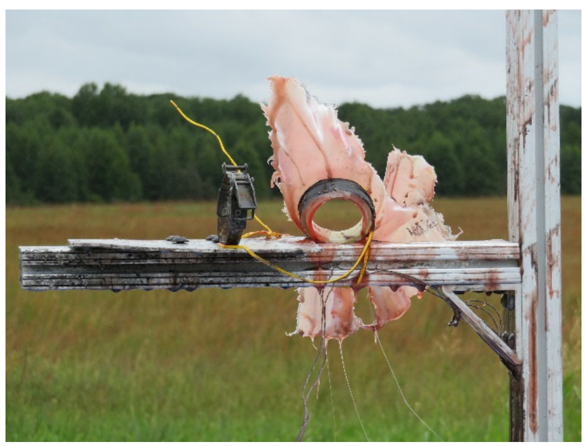

Figure 18. HDPE bottle following honey shot 5 (2 g of C4).


Figure 19. Tarp following honey shot 5, showing droplet distribution near outer corner of tarp.

4.1.6 Honey Shot 6

This shot was ~1 of L honey in an HDPE bottle with a center burster containing 3 g of C4. The bottle and the tarp immediately beneath the bottle following detonation are shown in Figures 20 and 21, respectively.


Figure 20. HDPE bottle after honey shot 6 (3 g of C4).

Figure 21. Tarp following honey shot 6 (3 g of C4).

4.1.7 Cloud Distribution

The goal of Decon Rain is to effectively cover a vehicle with the DS. For this purpose, it is important to maximize the amount of fill material directed onto the surface of the contaminated vehicle. Although there are uncontrollable environmental factors that will affect this, other factors can be controlled. For a given fill material, the design of the device will determine the final distribution of the dispersed material. High-speed video was recorded of each test so that the dispersal of fill materials given the central burster configuration with a range of explosive charges could be evaluated. There are two factors to consider: the initial directionality of the dissemination (i.e., whether the fill would be directed toward a vehicle below), and the ultimate extent of the cloud (i.e., how large of an area would it cover). For each shot, an initial still image was captured from the video to illustrate the directionality, and a second still image was captured to show the extent of droplet travel. These images are shown in Figure 22. It should be noted that the frame selection for these pictures was not linked to the timing of the detonation event; therefore, the first photograph for each event is relevant to shape and directionality but not to size and timing.

Figure 22. Honey shot 1 (9 g of C4): blast (top) and extent of cloud expansion (bottom).

Figure 23. Honey shot 2 (5.5 g of C4): blast (top) and extent of cloud expansion (bottom).

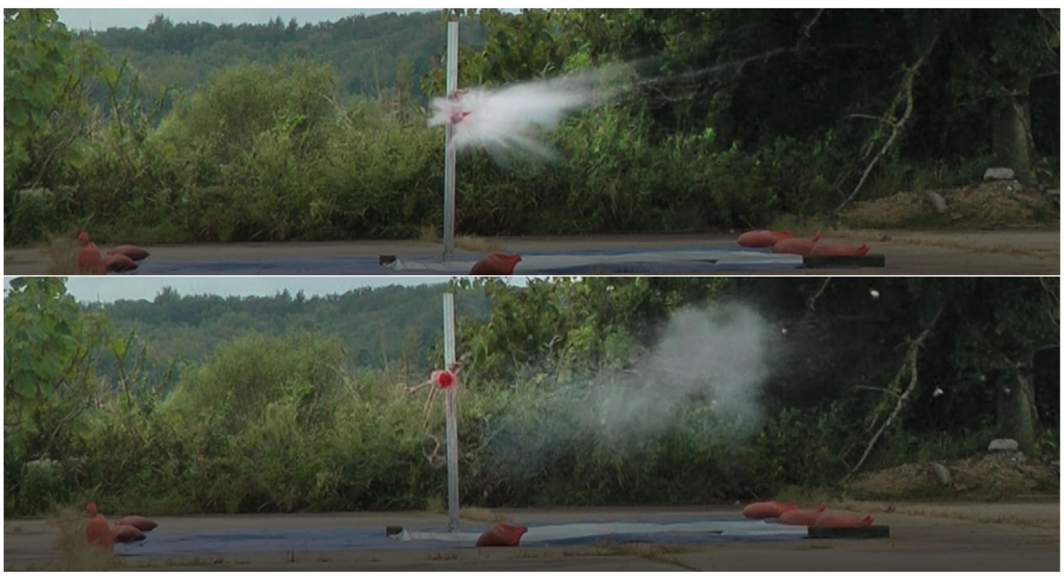

Figure 24. Honey shot 3 (no C4): blast (top) and extent of cloud expansion (bottom).

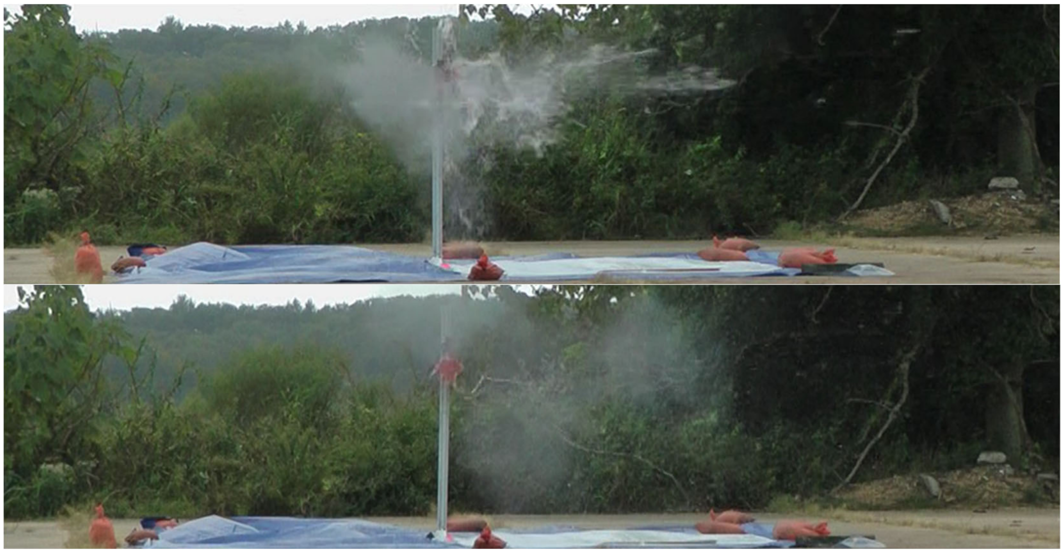

Figure 25. Honey shot 4 (1 g of C4): blast (top) and extent of cloud expansion (bottom).

Figure 26. Honey shot 5 (2 g of C4): blast (top) and extent of cloud expansion (bottom).

Figure 27. Honey shot 6 (3 g of C4): blast (top) and extent of cloud expansion (bottom).

4.2 DS Dispersal Testing: First Round

4.2.1 Day 1

The first day of testing was sunny and 85 °F. The wind was variable, mostly from the outer corner of quadrant 2 (square 4) toward the outer corner of quadrant 1 (square 4). The white tarps were marked with chalk lines to create a 2 ft grid. The devices were suspended 5 ft above the ground and centered in the test setup.

Three shots were fired; each shot used ~1 L of slurry. Between shots, the white tarps were changed, and each 2 ft square in each of the two quadrants was photographed (a total of 48 photographs of the white tarps, plus some general interest photographs of other areas).

Slurry tests 1–3 were performed on day 1 of testing. Each test consisted of one shot that contained C4 and the blasting cap in an HDPE bottle with approximately 1 L of the slurry:

- shot 1: burster plus 1 g of C4;
- shot 2: burster plus 0.5 g of C4; and
- shot 3: burster plus 0.5 g of C4 (replicate of shot 2).

4.2.2 Day 2

The second day of dispersal testing was cloudy and 65 °F. The wind was from the northwest, then it shifted and came from the north (blowing approximately from quadrant 1, square 4 to quadrant 2, square 4 [almost the opposite of day 1 test] and quadrant 1, square 1 to quadrant 2, square 1). The test layout was the same as that for the tests on day 1. The first test on day 2 (test 4) was designed to determine the potential coverage with the consecutive use of more than one device. This test involved two separate shots of identical devices. The second test of the day (test 5) compared consecutive detonation of two devices with simultaneous detonation of the same two devices.

4.2.2.1 Day 2, Slurry Test 4

In this test, two devices were detonated consecutively. Each device contained the blasting cap and burster plus 0.5 g of C4 and 1 L of slurry fill. The first device was suspended with its center 5 ft from the ground and 1 ft from the center of the support (on the side of quadrant 1, west of center [to the right in Figure 9]). The second device had the same contents as the first, but the bottle was suspended 1 ft from the center of the support on the opposite side (on the side of quadrant 2, east of center [to the left in Figure 9]). Because the goal of this test was to evaluate the total dispersal and coverage from two items detonated consecutively for comparison with the results of simultaneous detonation, a full set of tarp photographs was not taken between the two shots. The first device is shown post-detonation in Figure 28. The heaviest deposit of slurry from the first shot landed in an area covered by the white tarp (Figure 29). The second device is shown post-detonation in Figure 30. Most of the slurry from this device was deposited in an area not covered by white tarps, and the resulting deposition on the blue tarp is shown in Figure 31. It is clear from these photographs that the directionality of detonation has a significant effect on the resulting dispersal pattern. The first bottle fractured at the bottom, causing a fairly direct downward spray of the slurry fill. The second bottle fractured at the top and sides, causing more of the fill to project outward.

Figure 28. Test 4: first device post-detonation.

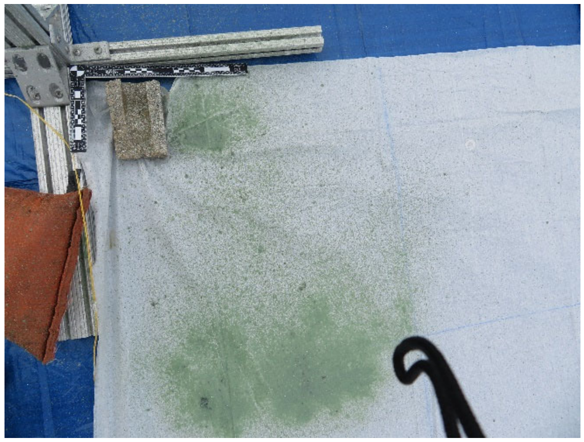
Figure 29. Test 4: deposition under first device after detonation.


Figure 30. Test 4: second device post-detonation.

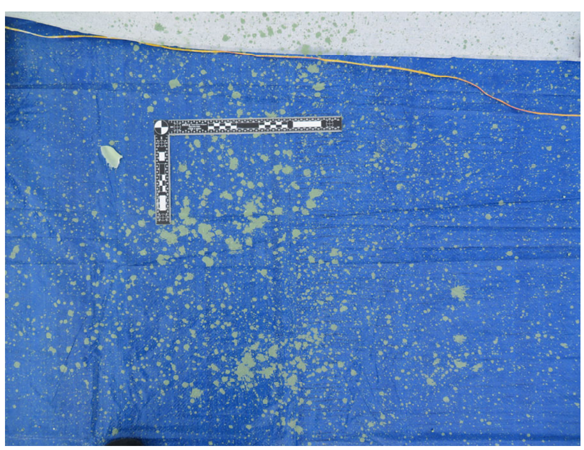
Figure 31. Test 4: deposition on blue tarp following detonation of second device.

4.2.2.2 Day 2, Slurry Test 5

In the final shot, two bottles were detonated simultaneously. Both bottles were at a height of 5 ft with a 2 ft separation between them. The bottle locations were the same as in test 4, but both bottles were detonated at the same time for this test. We hypothesized that the competing shock and intersecting clouds might result in larger droplets and more central fallout.

In test 5, one bottle was projected 65 ft west of the tarps; the other landed 35 ft southeast of the tarps. The recovered bottles are shown in Figures 32 and 33. Both bottles broke at the top and sides, like the second bottle of test 4. The blue tarp post-detonation is shown in Figures 34 and 35. In Figure 35, the contrast between the area of deposition and the area that was shielded by the white tarp is evident.

Figure 32. Test 5: bottle one post-detonation.

Figure 33. Test 5: bottle two post-detonation.

Figure 34. Test 5: resultant deposition on blue tarp.

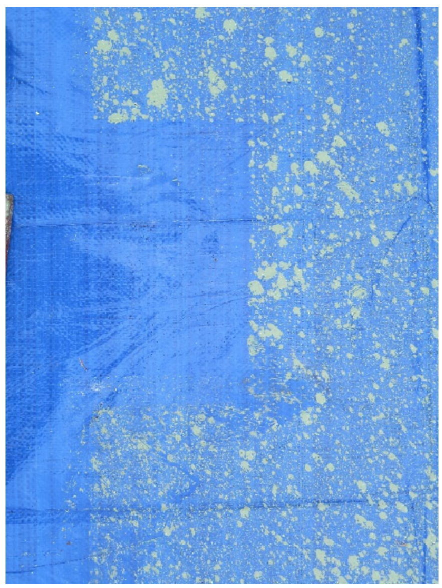

Figure 35. Test 5: coverage and droplet spread on blue tarp.

4.2.3 DS Cloud Distribution

As with the honey shots, high-speed video was recorded of each slurry shot, and still images were captured from the video. For each shot, an initial still image was captured to illustrate the directionality, and a second was captured to show the extent of droplet travel. These images are shown in Figures 36 through 41. As for the honey shots, the image selections were not linked to the timing of the detonation events, so the first image for each event is relevant to shape and directionality but not to size and timing.

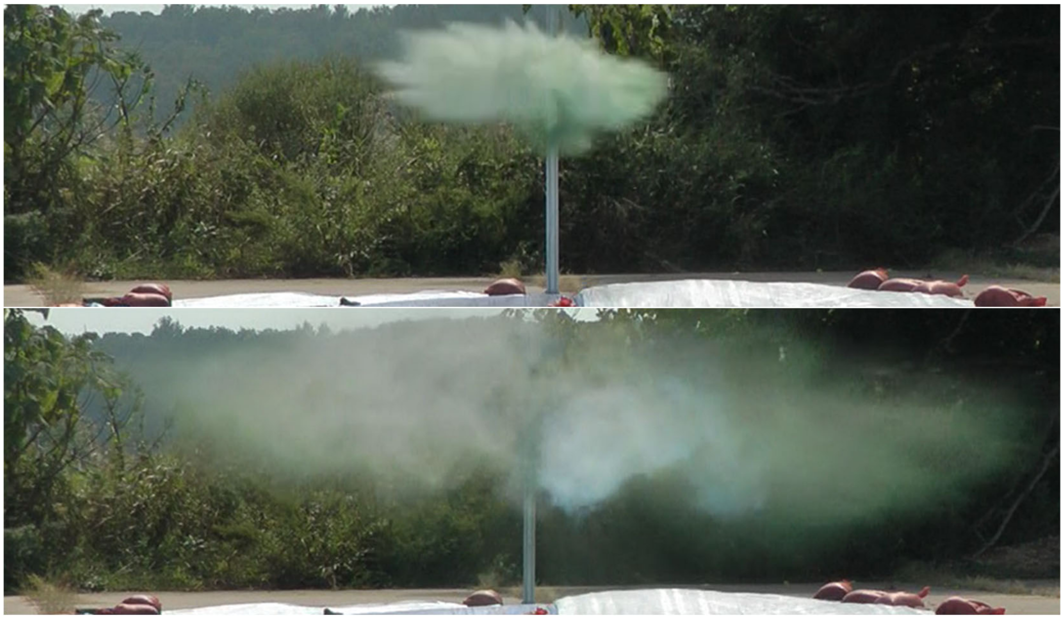

Figure 36. Slurry test 1 (1 g of C4): blast (top) and extent of cloud expansion (bottom).

Figure 37. Slurry test 2 (0.5 g of C4): blast (top) and extent of cloud expansion (bottom).

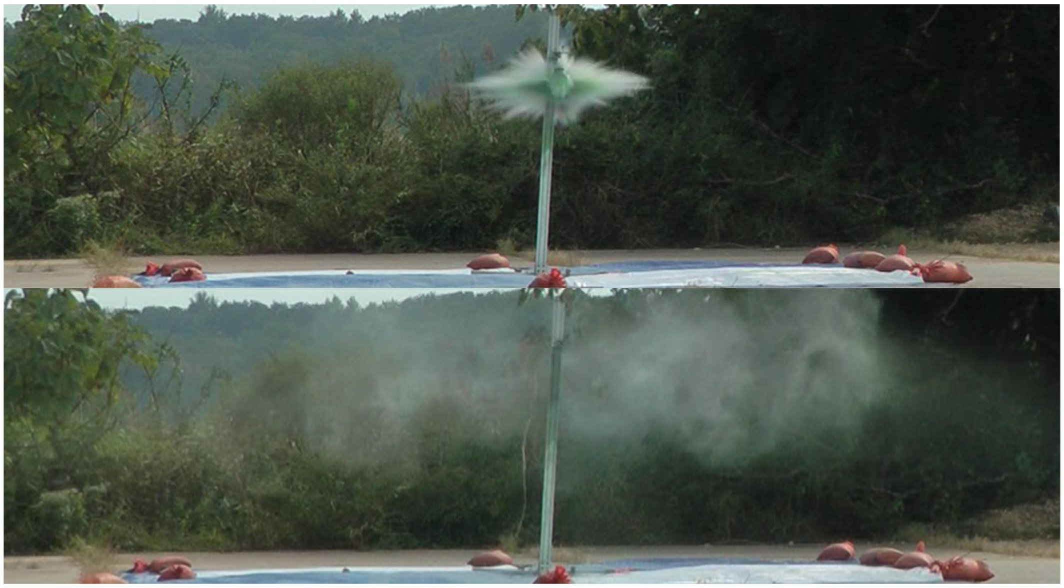

Figure 38. Slurry test 3 (0.5 g of C4): blast (top) and extent of cloud expansion (bottom).

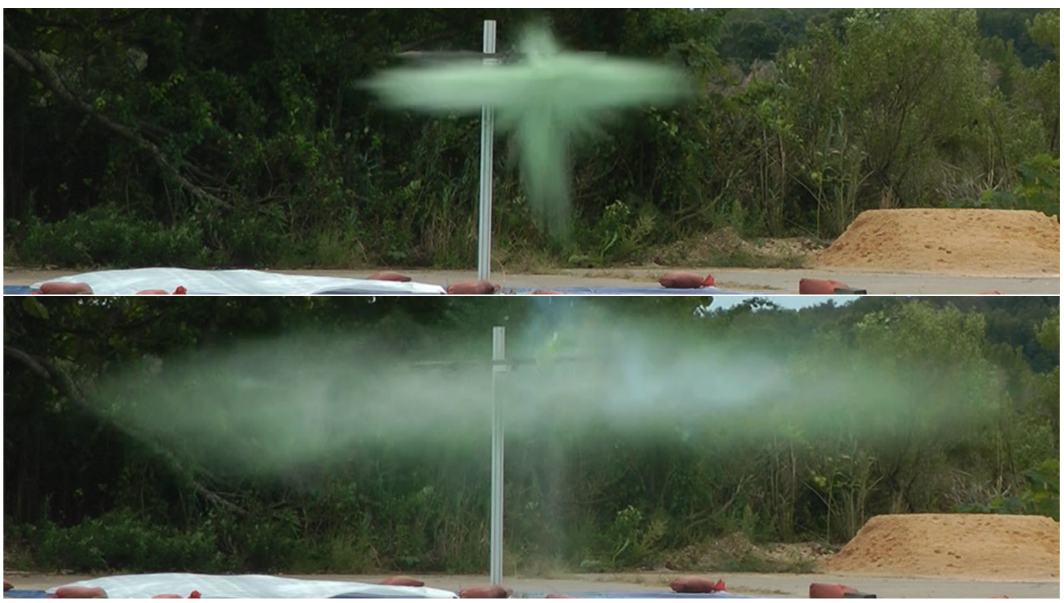

Figure 39. Slurry test 4 (two consecutive shots of 0.5 g of C4 each): blast (top) and extent of cloud expansion (bottom) for shot 1 on the right side of the test fixture.


Figure 40. Slurry test 4 (two consecutive shots of 0.5 g of C4 each): blast (top) and extent of cloud expansion (bottom) for shot 2 on the left side of the test fixture.


Figure 41. Slurry test 5 (two simultaneous shots of 0.5 g of C4 each): blast (top) and extent of cloud expansion (bottom).

4.2.4 Ground Deposition

The percentage of area coverage measured using ImageJ software on the binary images from each square is shown in Table . For tests without a full set of 24 images available, the results from the existing images were normalized to provide comparable test totals. The layout of the squares on the tarp and relative to the detonation is shown in Figure 9. Square 21 is the closest to being directly under the detonations. The photographs and processed binary images used for this analysis are provided in the Appendix.

Table 5. Area of DS Coverage on Each Test Square*

Square No.	Area of DS Coverage (%)									
	Test 1		Test 2		Test 3		Test 4		Test 5	
	Tarp 1	**Tarp 2**	**Tarp 1**	**Tarp 2**	**Tarp 1**	**Tarp 2**	**Tarp 1**	**Tarp 2**	**Tarp 1**	**Tarp 2**
1	0.34	0.25	0.40	0.05	5.73	0.05	2.86	2.47	0.99	1.70
2	0.19	0.51	0.26	0.24	3.69	0.16	2.48	1.64	2.32	1.25
3	0.19	0.61	0.68	0.39	0.46	0.20	1.00	0.58	1.23	1.10
4	0.37	0.28	0.38	0.40	0.20	0.43	3.23	0.3	1.64	1.41
5	0.17	0.34	1.03	0.22	3.49	0.05	4.97	3.76	1.90	1.38
6	0.17	0.75	0.60	0.23	7.31	0.44	2.01	4.66	1.27	0.96
7	0.19	0.83	0.35	0.49	0.74	0.32	2.85	1.34	2.40	1.16
8	0.43	0.52	1.22	0.67	0.35	0.37	3.01	0.65	1.60	1.71
9	0.20	0.12	0.42	0.59	10.10	0.39	7.21	4.33	2.63	1.67
10	0.53	0.88	3.10	1.56	5.60	1.15	7.69	2.95	2.36	0.93
11	0.77	0.80	1.37	0.80	1.50	1.10	3.22	0.58	3.90	1.89
12	0.64	0.46	0.52	0.72	0.65	0.61	3.60	1.16	2.18	3.35
13	4.74	0.16	0.47	1.54	22.54	1.37	7.87	3.90	5.31	1.61
14	0.89	0.57	0.06	2.18	6.32	1.56		3.14	5.29	2.24
15	1.71	0.64	1.94	0.59	5.68	0.76	7.50	2.34	6.13	2.33
16	0.89	0.77	0.15	0.74	2.70	0.77	5.69	1.76	5.81	2.11
17	2.42	0.99	4.65	1.04	25.54	1.84	27.41	3.44	9.02	2.00
18	1.41	1.11	2.42	2.86	6.54	1.74	12.46	3.99	8.71	3.28
19	0.71	0.15	1.71	0.97	5.83	0.85	5.27	2.09	18.60	5.54
20	0.09	0.32	1.36	0.98	1.52	3.02	6.25	3.55	10.41	7.33
21	ND	10.36	10.06	1.09	20.97	3.04	19.71	1.9	ND	3.77
22	ND	0.59	9.68	2.50	1.37	2.01	1.23	2.22	ND	9.94
23	ND	0.19	2.87	1.95	0.52	1.03	0.97	2.32	ND	24.56
24	ND	0.48	0.55	0.42	0.86	2.25	1.22	5.75	ND	11.65
Total	17.06	22.66	46.24	23.20	140.2	25.52	139.7	60.80	93.69	94.82
Normalized for area	20.47	22.66	46.24	23.20	140.2	25.52	145.3	60.80	112.43	94.82
Test total	43.13		69.44		165.7		206.1		207.25	

*Numbering of the squares is depicted in Figure 9.
ND, no data.

5. CONCLUSIONS

These tests demonstrated that DS can be explosively disseminated in such a way as to spread over an area approximately the size of a tank. The dispersal can be controlled by changes in the explosive charge and in the geometric and functional design of the device. Placement of the charge within the device, size of the charge, and selective strengthening or weakening of segments were all found to affect the extent and directionality of slurry dispersion. For all of the tests reported herein, a simple device design was used. Adding some engineering design elements to the internal geometry of the device could provide additional control over the dispersal pattern.

Because this project was a small proof-of-concept effort, we focused on a very small part of the picture: whether the slurry can be effectively disseminated explosively, and what general parameters affect the dispersal. To optimize the dissemination and verify the effectiveness of the decontamination approach, further work needs to be done. We used a simple center burster bottle device for ease and convenience, as the scope of this project precluded engineering design of a tailored device. An engineered device would provide greater control over the directionality and dispersal of the fill. Likewise, we used tarps to cover an approximately tank-sized area rather than attempting to simulate a tank in either shape or surface properties. The spread of the DS on a CARC surface would likely be different from that on a plastic tarp, and this would be central to the effectiveness of the slurry for decontamination.

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ACRONYMS AND ABBREVIATIONS

CARC	chemical agent-resistant coating
CWA	chemical warfare agent
DBDMH	1,3-dibromo-5,5-dimethylhydantoin
DEVCOM CBC	U.S. Army Combat Capabilities Development Command Chemical Biological Center
DS	sprayable decontamination slurry
FM	Field Manual
HDPE	high-density polyethylene
LVOSS	Light Vehicle Obscuration Smoke System
SDS	Sorbent Decontamination System
SPAL	simulator, projectile, airburst, liquid

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APPENDIX:
TARP IMAGES OF DEPOSITION FROM SLURRY TESTS

A.1 PHOTOGRAPHIC IMAGES

Figure A-1. Test 1, tarp 1. Upper left corner was immediately below the detonation.

Test 1 Tarp 2

Figure A-1. Test 1, tarp 2. Upper left corner was immediately below the detonation.

Test 2 Tarp 1

Figure A-3. Test 2, tarp 1. Upper left corner was immediately below the detonation.

Test 2 Tarp 2

Figure A-4. Test 2, tarp 2. Upper left corner was immediately below the detonation.

Figure A-5. Test 3, tarp 1. Upper left corner was immediately below the detonation.

Test 3 Tarp 2

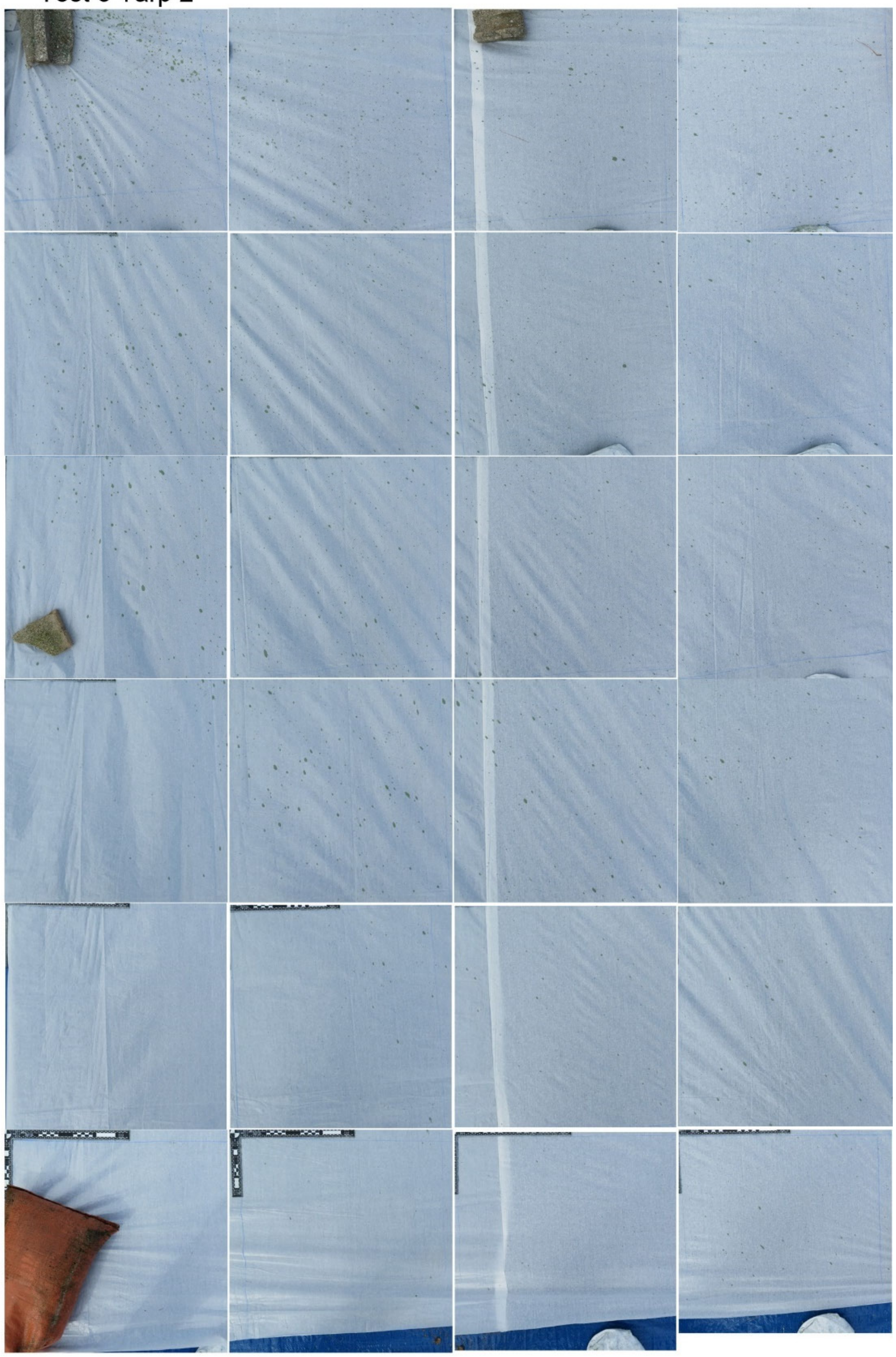

Figure A-6. Test 3, tarp 2. Upper left corner was immediately below the detonation.

Test 4 Tarp 1

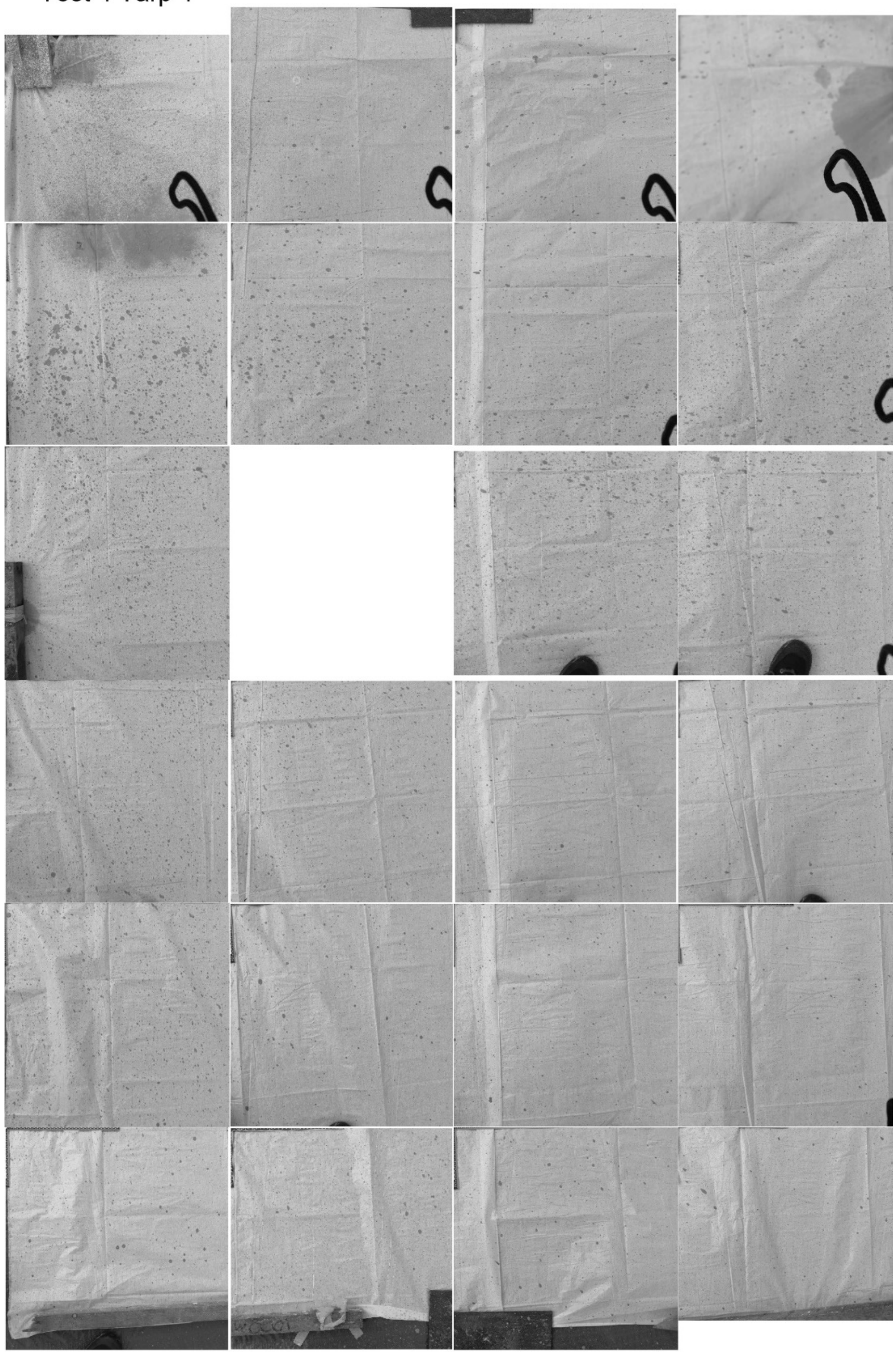

Figure A-7. Test 4, tarp 1. Upper left corner was immediately below the detonation.

Test 4 Tarp 2

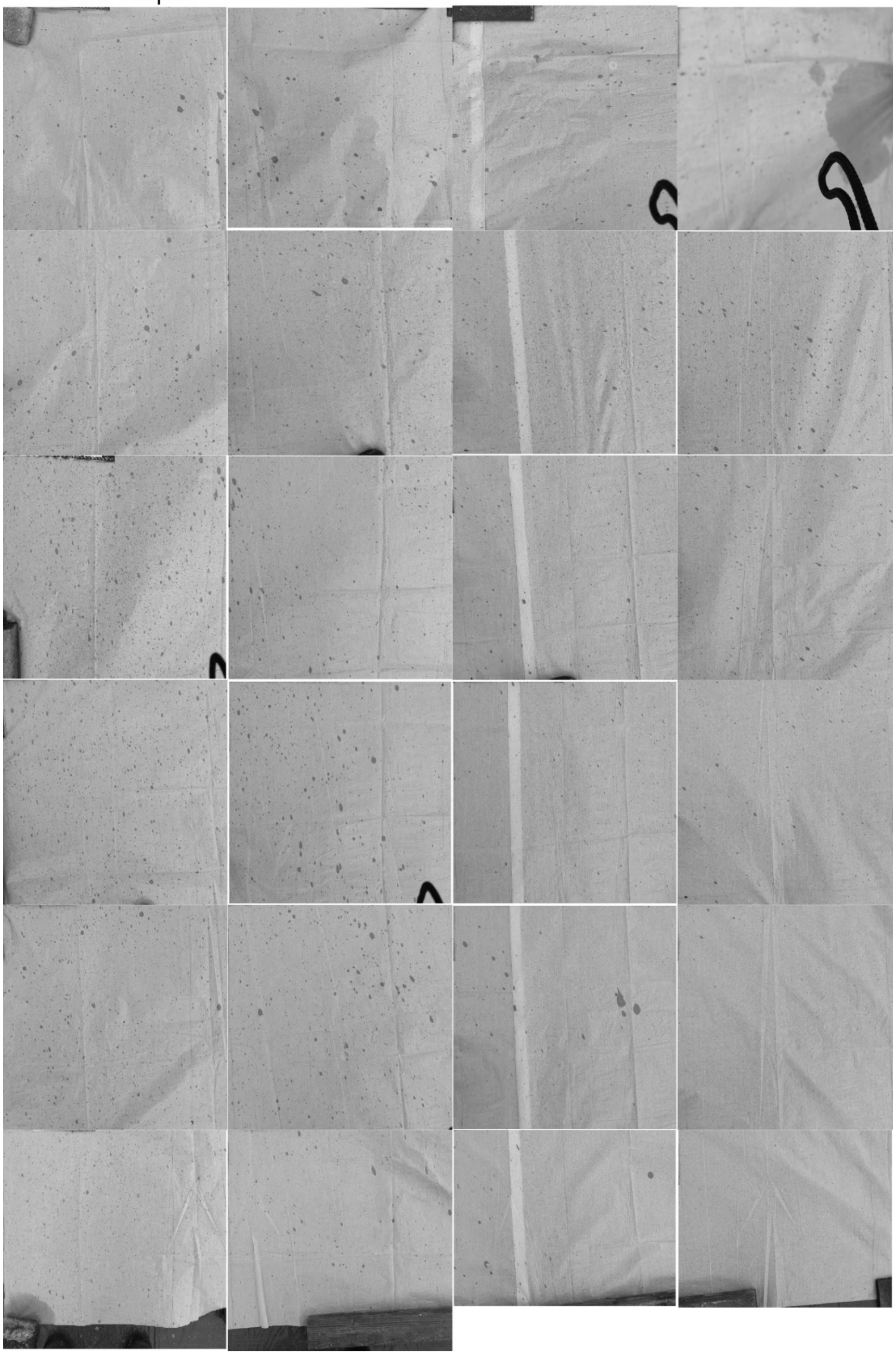

Figure A-8. Test 4, tarp 2. Upper left corner was immediately below the detonation.

Test 5 Tarp 1

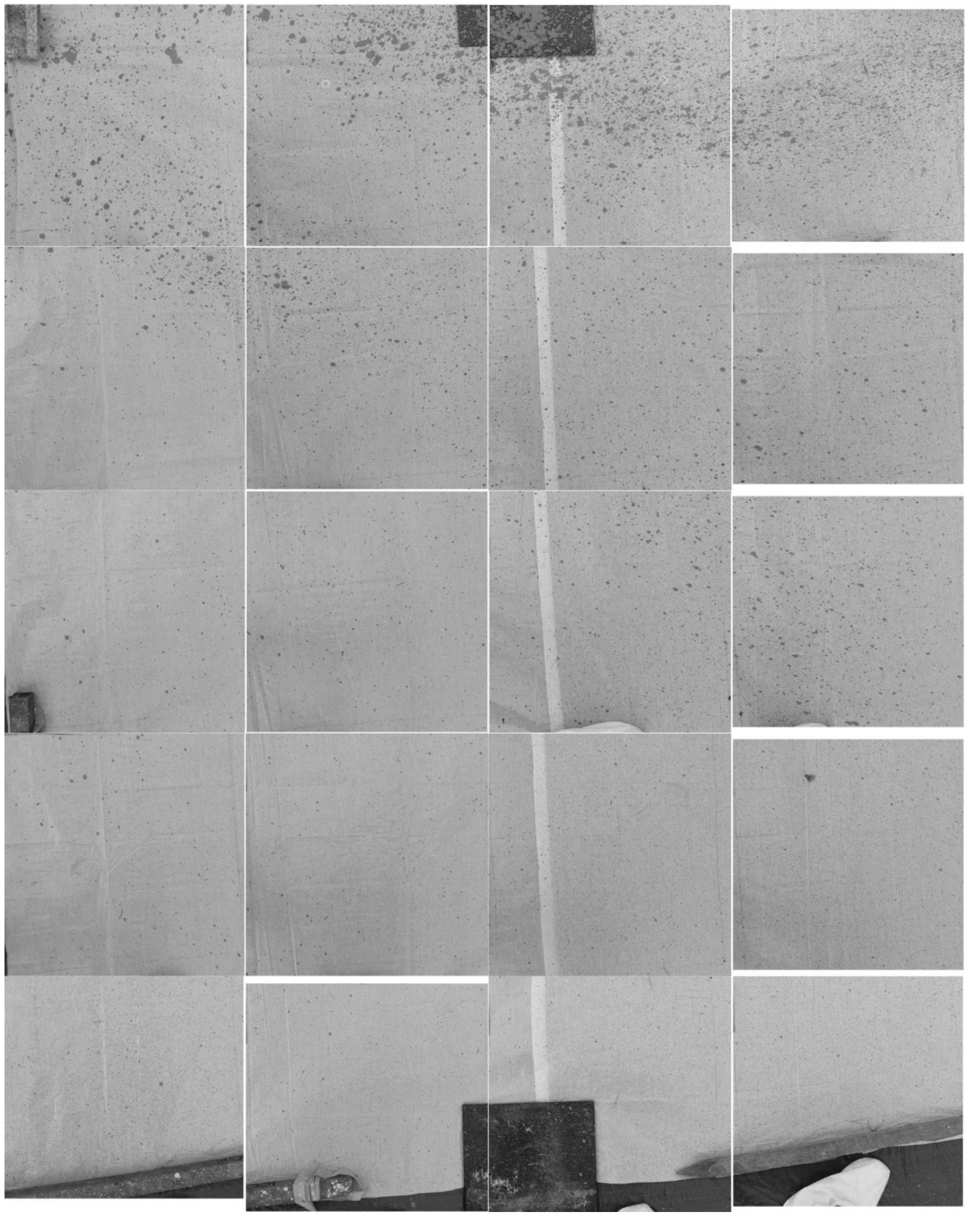

Figure A-9. Test 5, tarp 1. Upper left corner was immediately below the detonation.

Test 5 Tarp 2

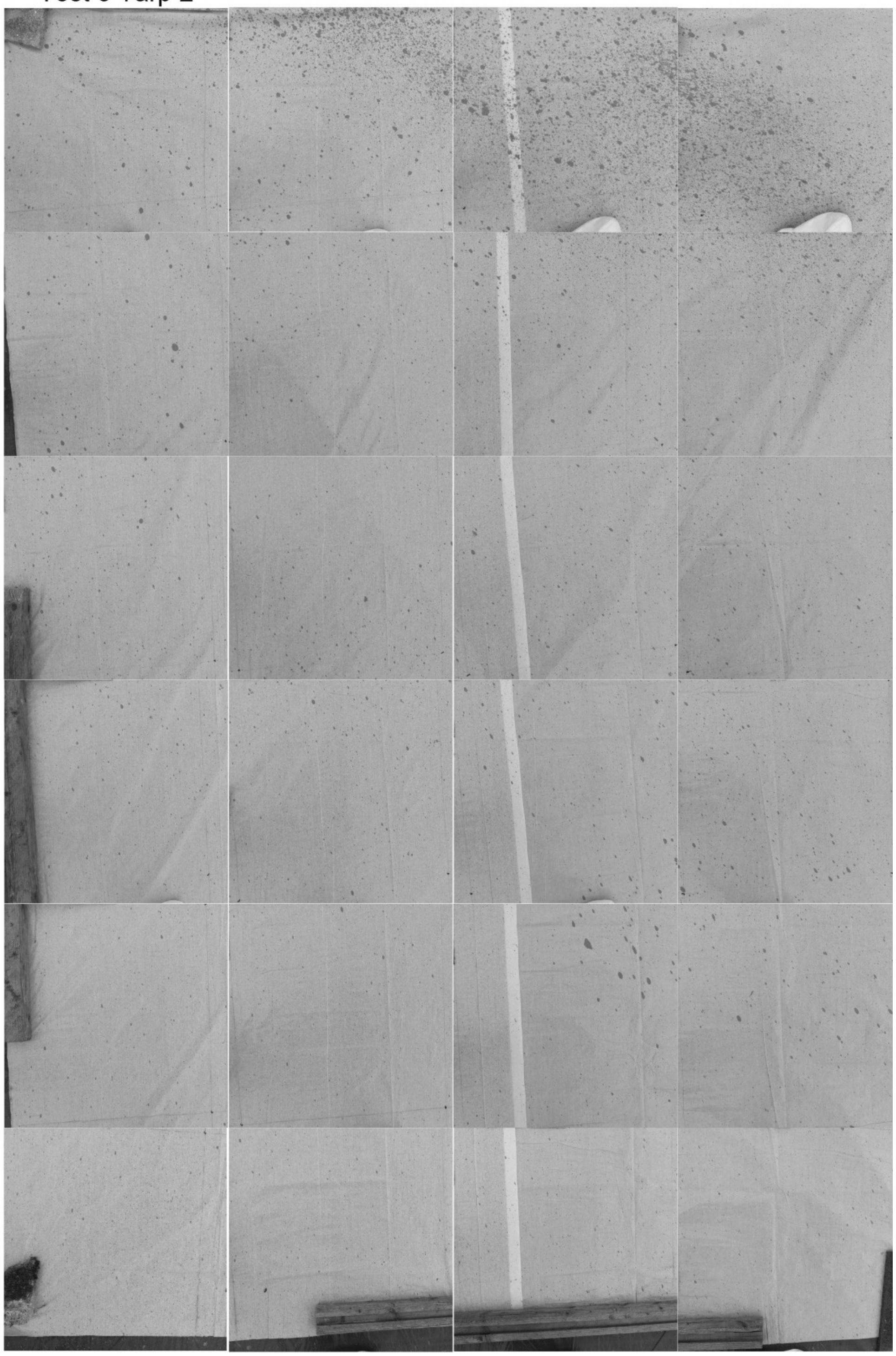

Figure A-10. Test 5, tarp 2. Upper left corner was immediately below the detonation.

A.2 BINARY IMAGES

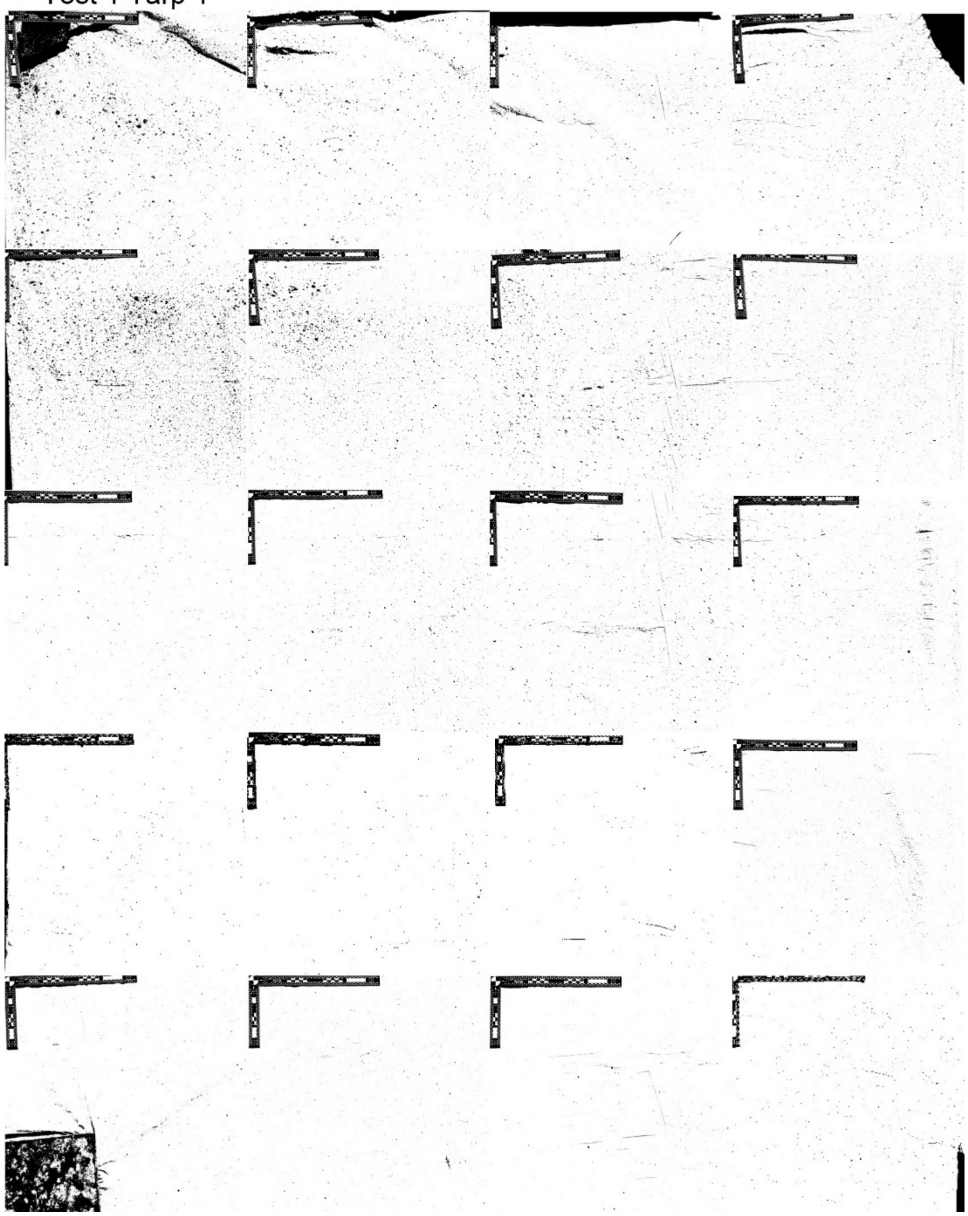

Figure A-10. Test 1, tarp 1. Detonation was above the upper left corner.

Test 1 Tarp 2

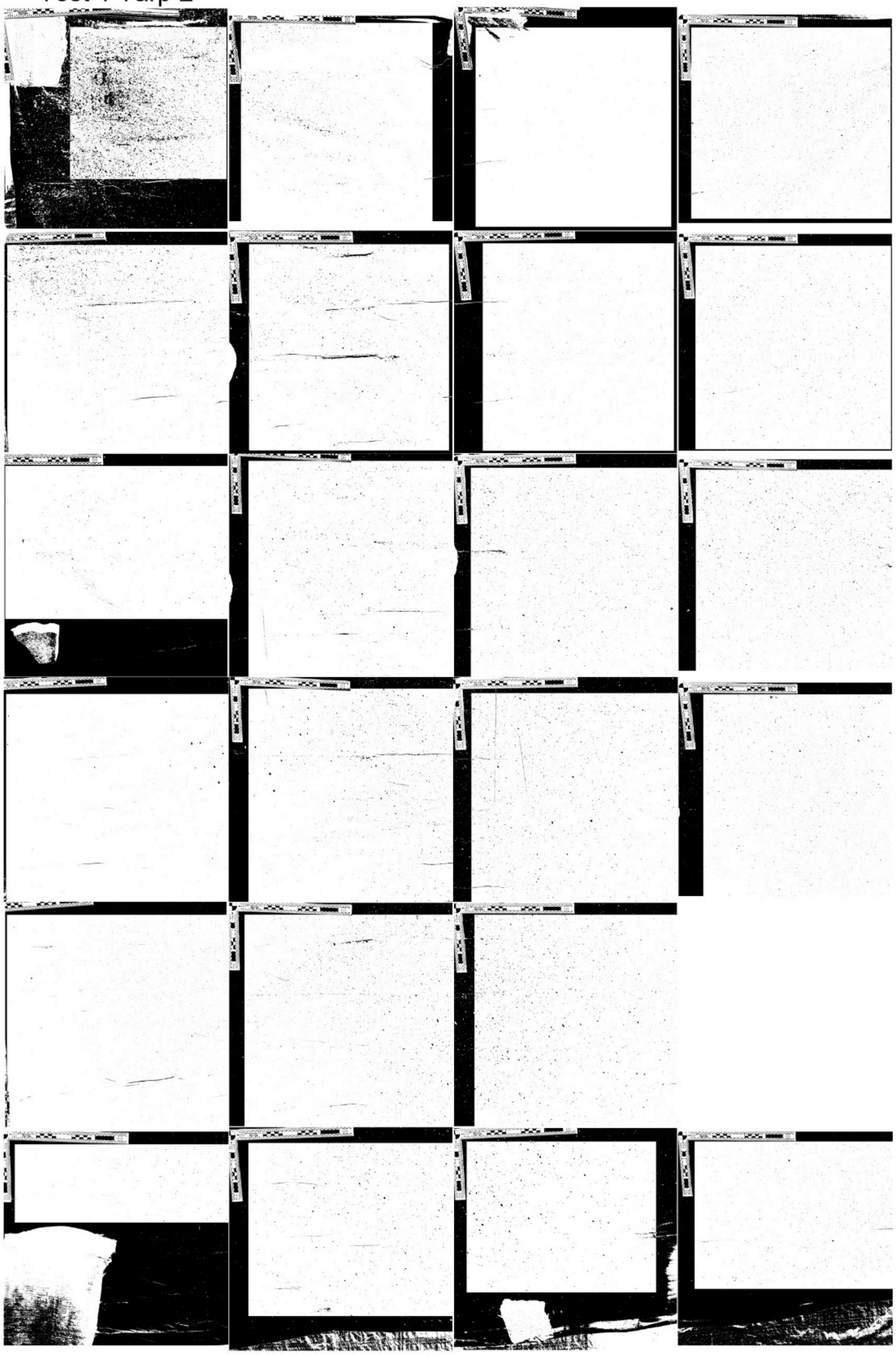

Figure A-11. Test 1, tarp 2. Detonation was above the upper left corner.

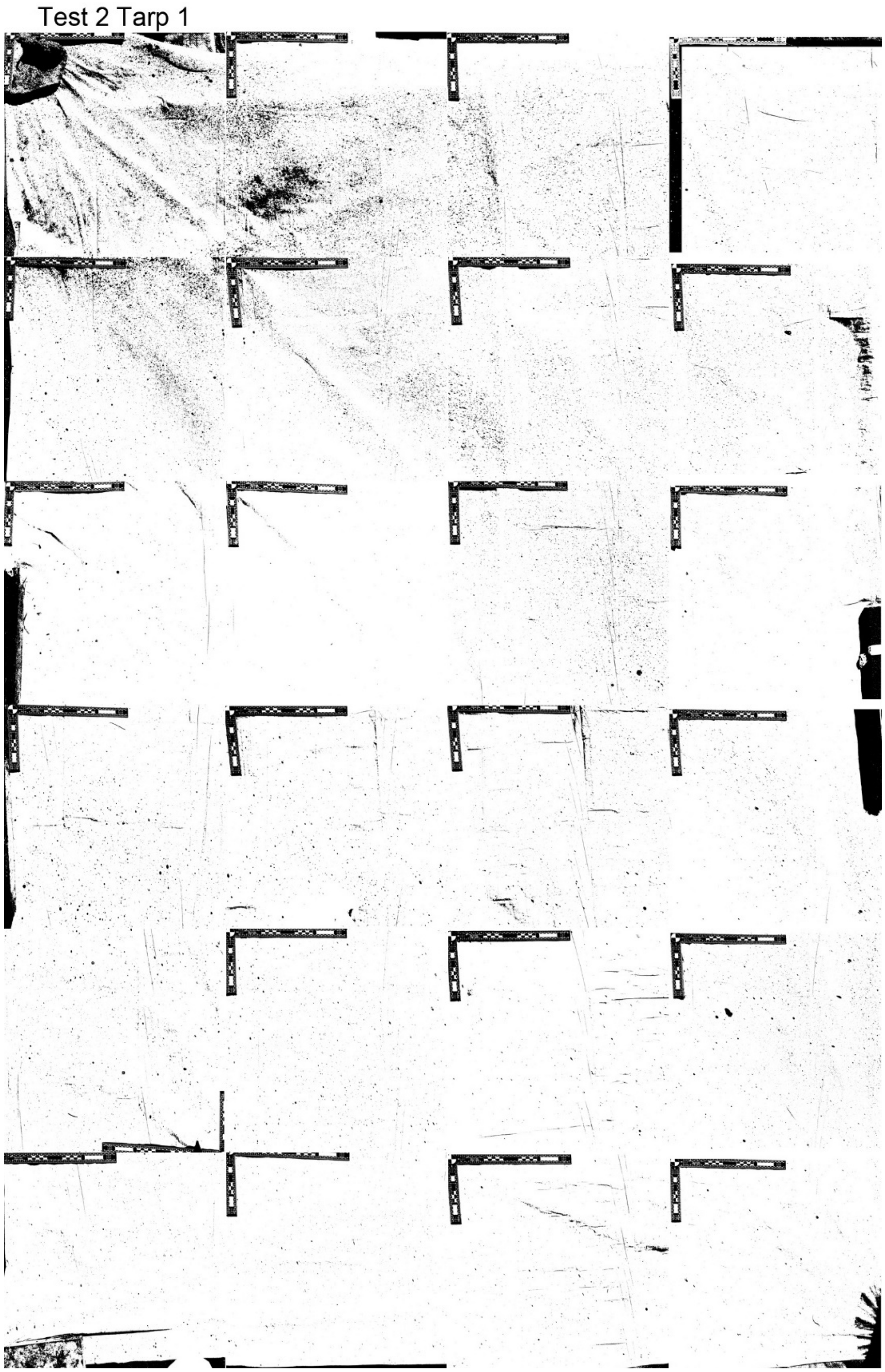

Figure A-12. Test 2, tarp 1. Detonation was above the upper left corner.

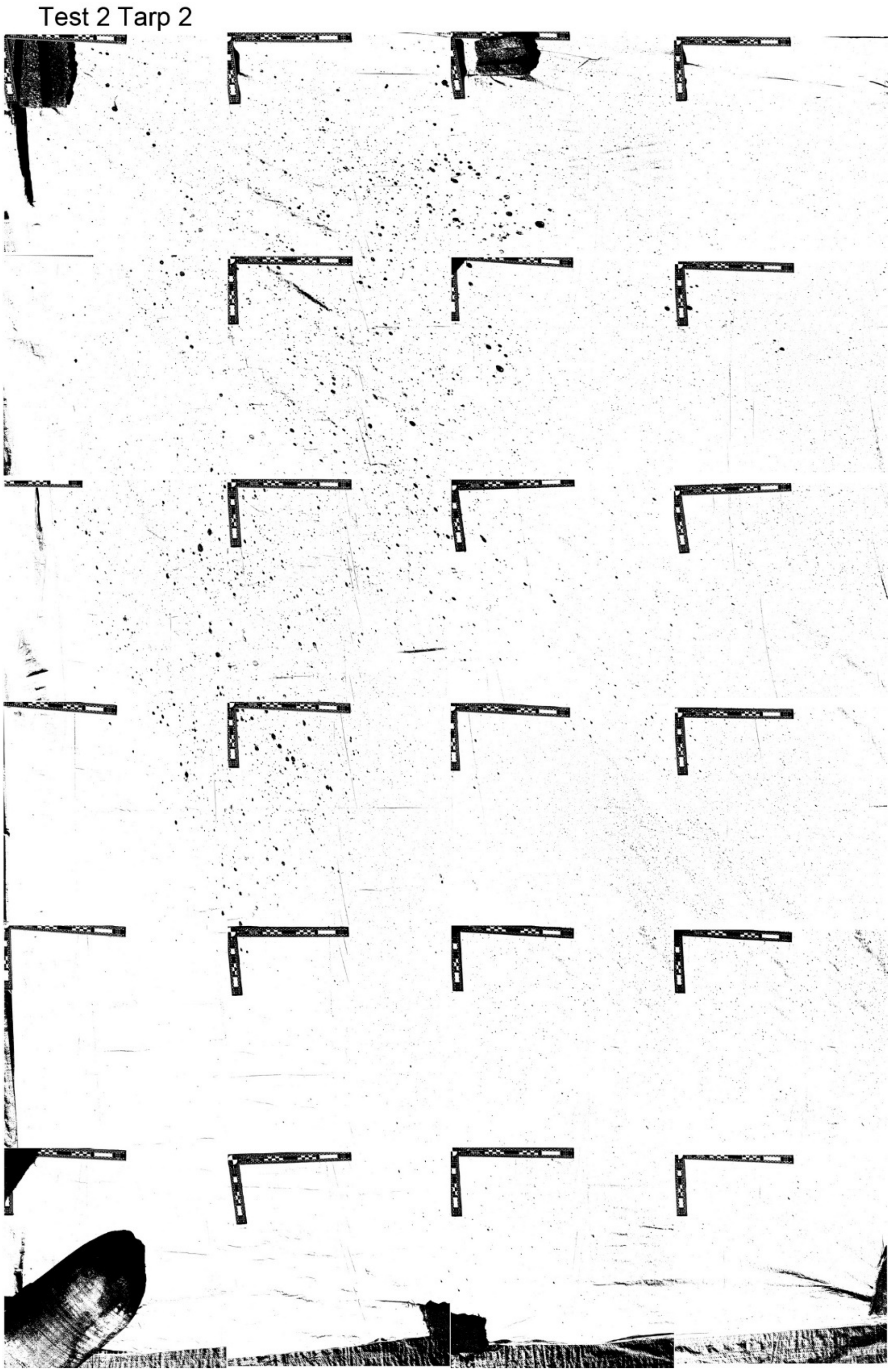

Figure A-13. Test 2, tarp 2. Detonation was above the upper left corner.

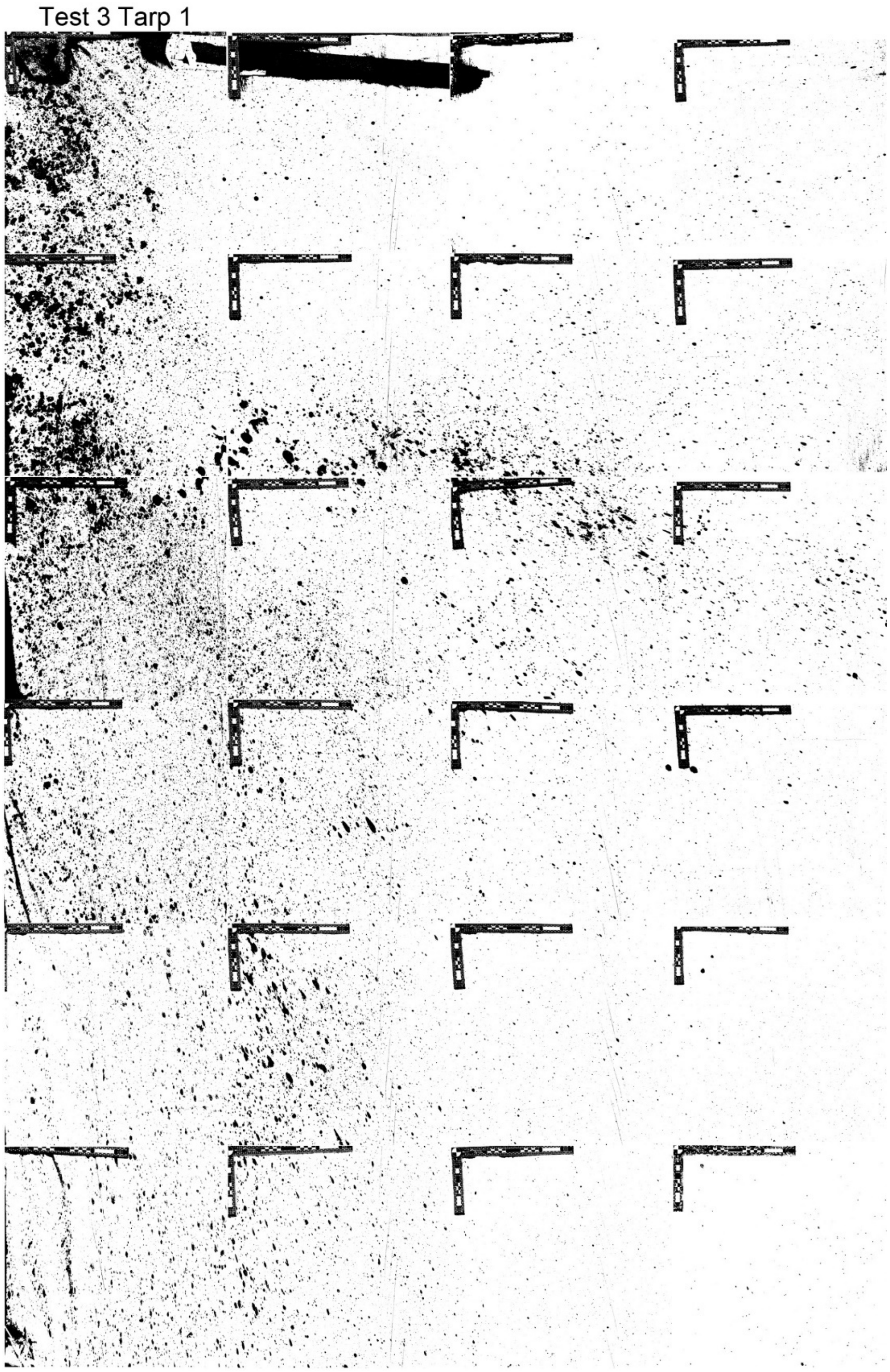

Figure A-14. Test 3, tarp 1. Detonation was above the upper left corner.

Figure A-15. Test 3, tarp 2. Detonation was above the upper left corner.

Test 4 Tarp 1

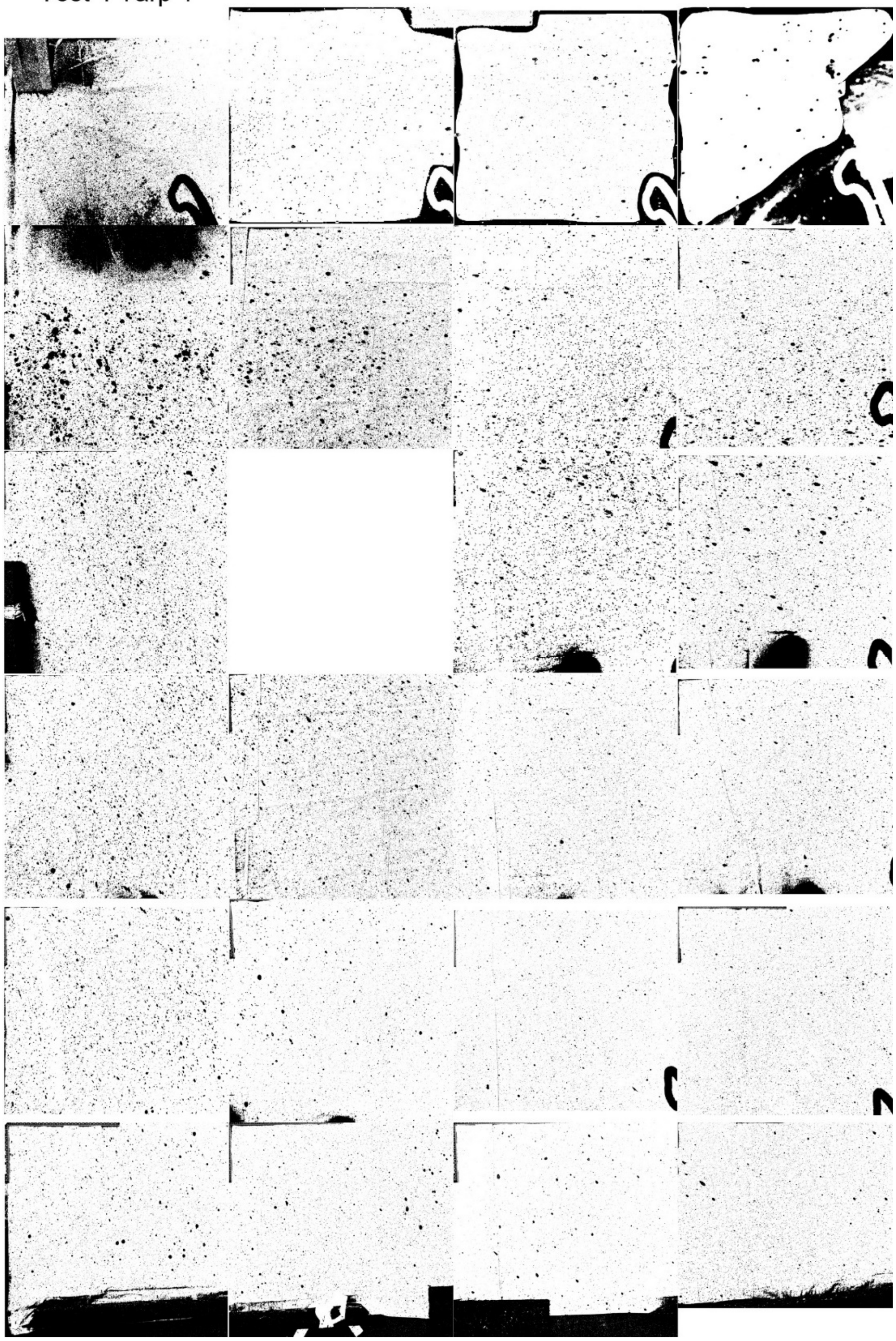

Figure A-16. Test 4, tarp 1. Detonation was above the upper left corner.

Test 4 Tarp 2

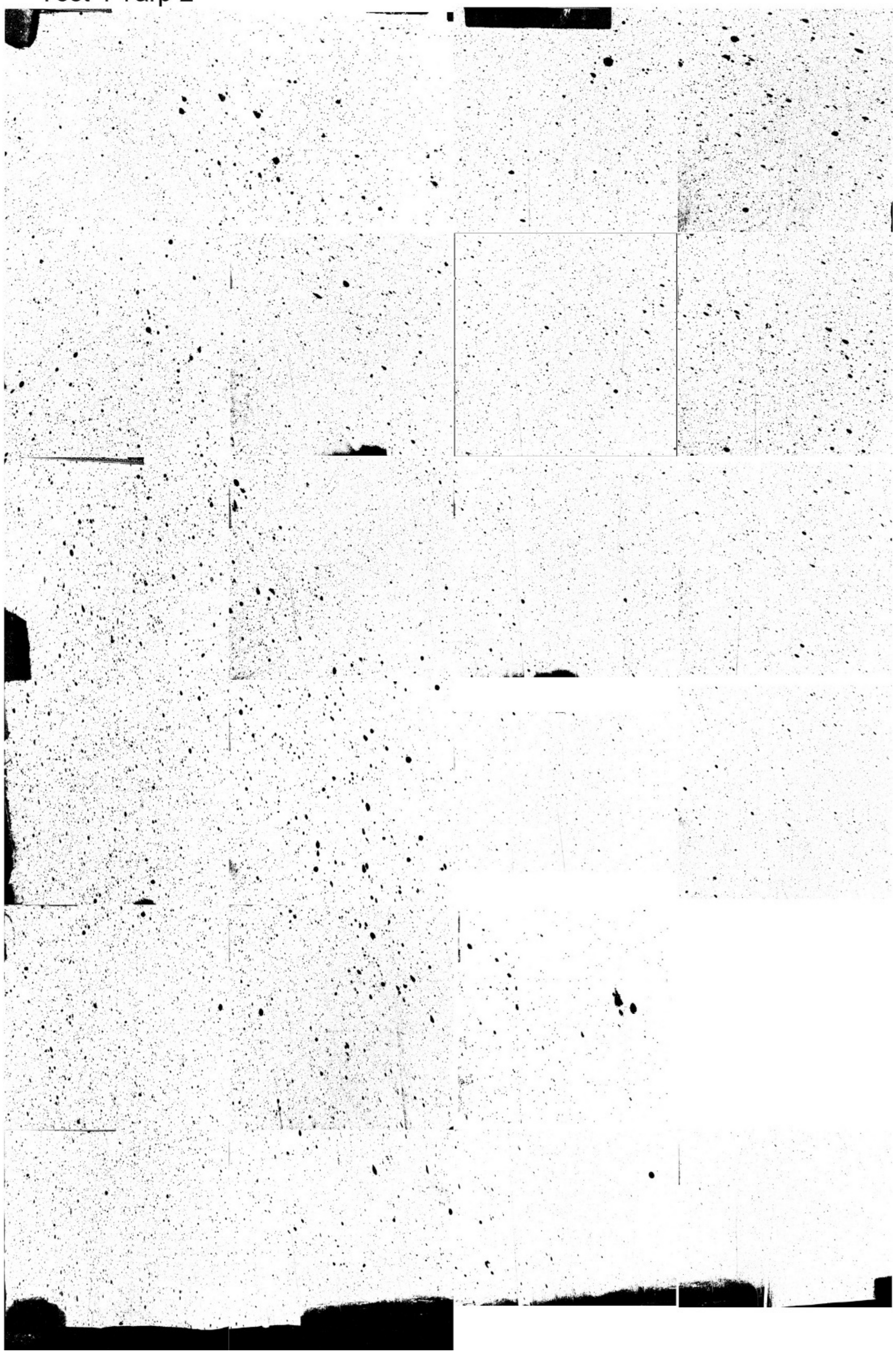

Figure A-17. Test 4, tarp 2. Detonation was above the upper left corner.

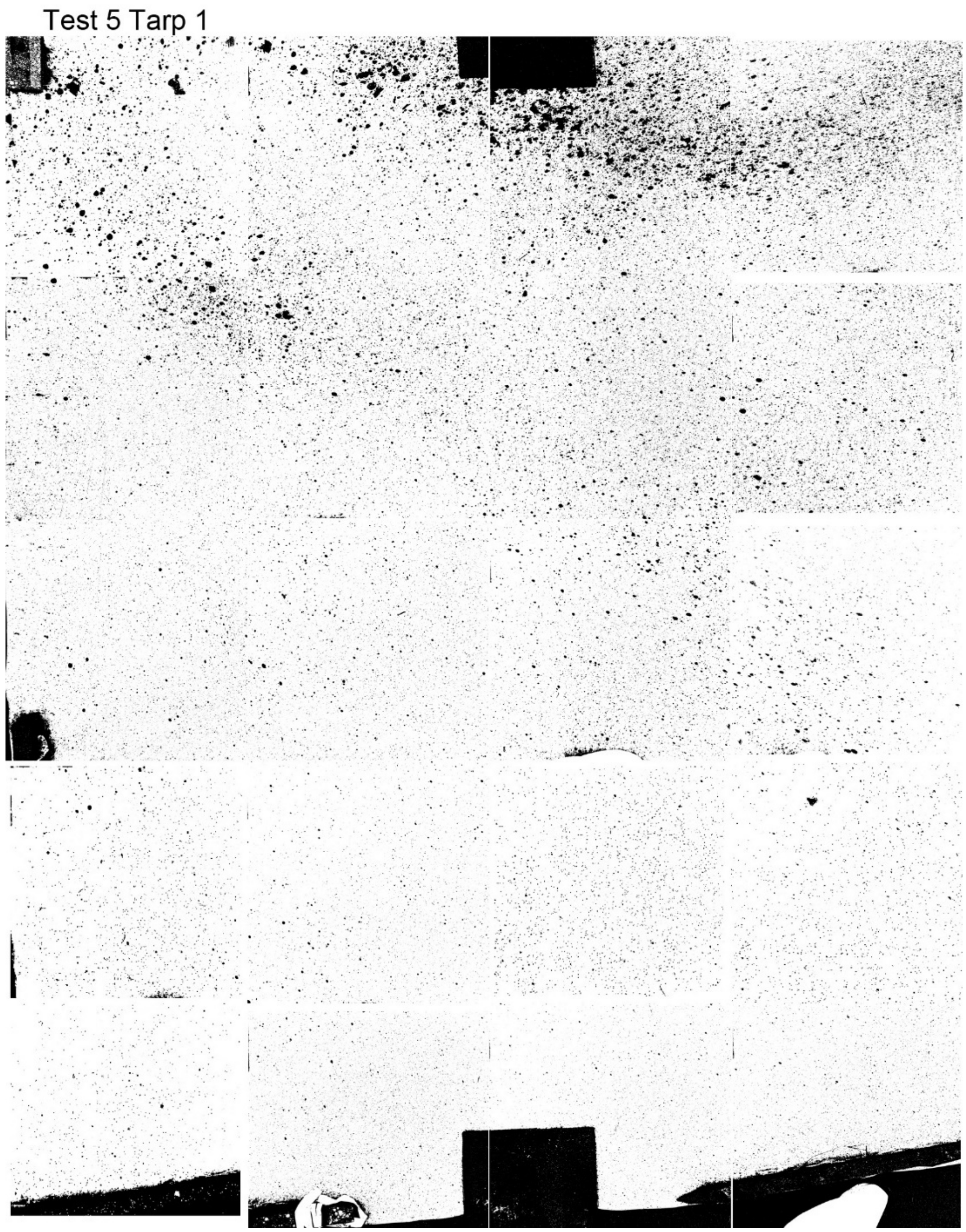

Figure A-18. Test 5, tarp 1. Detonation was above the upper left corner.

Test 5 Tarp 2

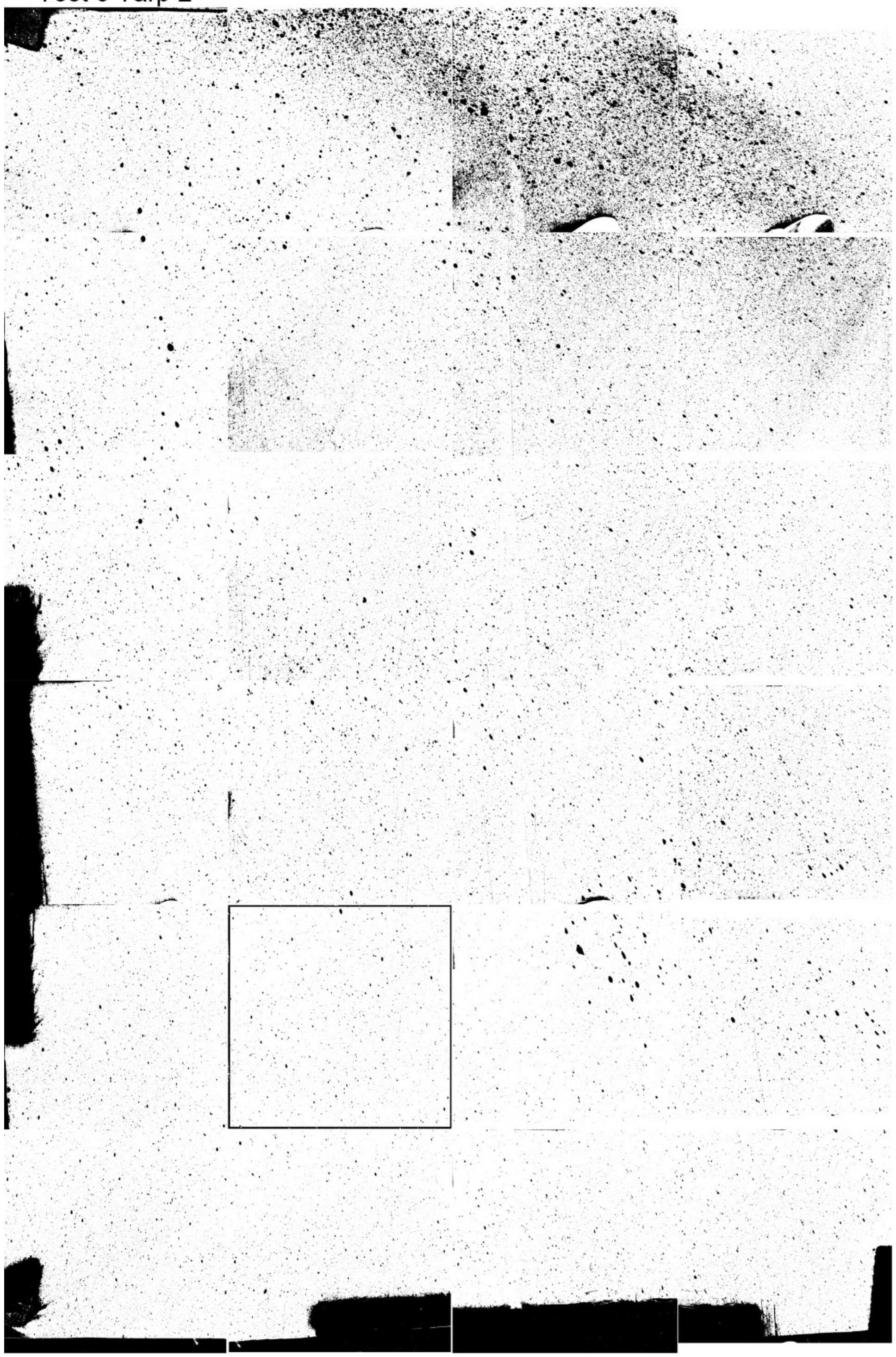

Figure A-19. Test 5, tarp 2. Detonation was above the upper left corner.

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