ASSESSMENT OF THE PERSISTENCE OF VAPOUR EVOLVED
FROM THICKENED AND NEAT DIMETHYL SULFOXIDE
CONTAMINATION OF PRAIRIE TERRAIN (U)

RECORD OF FP No. 80

by

Stanley B. Mellsen

PCN 251SC-11

January 1987

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SUFFIELD REPORT 442

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ABSTRACT

A series of sixteen trials, seven with neat (DMSO) and six with 80% DMSO and 20% water to reduce the freezing point temperature, and three with polyvinyl alcohol added to the latter solution to thicken the solution to a zero-shear viscosity of seven poise were conducted on prairie terrain. Explosive dissemination was used on all trials. Vapour sampling and drop sizing results were obtained. The persistence of DMSO and 80/20 DMSO/water on prairie terrain was found directly proportional to the mass median diameter of the drops and the recovery rate of the vapour from prairie terrain agrees favourably with the predictions of an existing DRES mathematical model.
INTRODUCTION

1. Dimethyl Sulfoxide (DMSO) has been proposed for use as a total intake simulant. If it is to be suitable for use as a simulant in field experiments, then knowledge of its evaporative characteristics is necessary. The purpose of this report is to describe the results of a total of sixteen field trials using DMSO. The first seven trials were done using neat DMSO. The freezing point of the neat liquid is 18.6°C, which is impractical for many field situations. The freezing point is lowered greatly by addition of a small amount of water. Therefore, the intake simulant chosen for the remainder of the trials was a solution
of water in DMSO which provided a freezing point of \(-25^\circ\text{C}\). A total of six trials using unthickened solution were done and the final three trials were done using a thickened solution which produces larger drops.

**TRIAL OBJECTIVES**

2. a. To contaminate an area of prairie terrain, 24 m crosswind x 16 m downwind, to a mean contamination density of 2 g m\(^{-2}\) with DMSO using explosive dissemination from polyethylene bottles.

b. To determine drop size and ground contamination densities produced from the dissemination.

c. To sample vapour dosages sequentially at heights 0.3 m to 1.5 m above ground.

**EXPERIMENTAL DETAILS**

3. a. **Material**

Six 250 mL linear polyethylene bottles were charged with a nominal total of 1500 mL for each trial. The screw cap of each bottle was modified to provide a well for up to 400 gr of Primacord. A No. 12 detonator was used to initiate the burst. The three variations of DMSO used in the series of trials, with only one type used in each trial, are listed as follows:

(1) Pure DMSO (99.9%)

Pure DMSO with 0.1% amaranth added to improve the
contrast of drops on detector paper was used. The physical properties of pure DMSO are shown in Table A1 (Appendix A).

(2) Water/DMSO Solution

The liquid consisted of 20% water dissolved in 80% DMSO by volume. 0.1% amaranth was added to improve the contrast of drops on detector paper as for the pure agent. The freezing point and viscosity of the solution can be estimated using Figures A1 to A4 (Appendix A).

(3) Thickened Water/DMSO Solution

4:1 dimethyl sulfoxide/water solution, thickened with polyvinyl alcohol (PVA) with an added dye was used. The concentration of PVA was 5.26% by weight. The grade of PVA was Dupont Elvanol 71-30 (fully hydrolyzed). The dye used was 0.1% methyl violet since amaranth in DMSO/H₂O/PVA did not give satisfactory color with the 3-way detector paper used in the trials. The zero-shear viscosity was estimated to be 6.99 poise [1].

b. Layouts

The sampling layout covered a 24 x 14 m rectangular area on the DRES Vertical Grid Site with ground contamination sampling positions on a 2 x 3 m grid and five vapour sampling positions on the downwind edge. Gallows of 1.5 cm steel rods, with arms at 1 and 2 m above ground to support the bottles were emplaced as indicated (Figures 1 and 2).
c. **Ground Contamination Sampling**

On all trials, sampling of drop sizes was carried out with 20 x 20 cm sheets of 3-way detector paper mounted on cardboard sheets while contamination densities were sampled with similar sized polyethylene sponges, 3 mm thick (Figure 3).

d. **Vapour Sampling**

(1) **Bubblers**

Vapour dosage samples were taken in bubblers charged with 3 mL distilled water and aspirated at 1 L min⁻¹. A blank and five sequential samples were taken at heights of 0.3, 0.5, 1.0 and 1.5 m on all trials.

(2) **IR Analyzers**

Foxboro Miran 1-A Infrared Gas Analyzers, each equipped with a 20 m pathlength gas cell, were used to provide real-time monitoring of DMSO vapour concentration. Samples were taken at a height of 1.0 m. The IR analyzers were not always available.

e. **Meteorology**

Meteorological observations were made at a position cross-wind from the layout. Windspeeds at 0.5, 1.0, 1.5 and 2.0 m
above ground, wind direction at 2 m, air and ground temperatures and relative humidity were recorded for the duration of the sampling.

PROCEDURE

a. General

The layout was oriented according to the expected 2 m wind direction for each trial. After taking a blank sample, the bubbler arrays were covered with clear plastic sheeting to protect them from direct spray. The liquid-charged bottles were then armed and suspended at 1 m above ground from the gallows for windspeeds of 10 km per hour or greater. For lower windspeeds the bottles were suspended 2 m above the ground. About five minutes before the liquid was to be disseminated the infrared analyzers were started, to allow time for warm up and to sample vapour immediately after dissemination occurred. At time zero, the bottles were exploded electrically and vapour sampling by the bubblers commenced. As quickly as possible, the plastic covers were removed from the vapour samplers. The sponge samplers were removed and placed in wide mouth bottles which were immediately sealed and transported to the laboratory for analysis. The detector paper samplers were placed in racks and allowed to dry before measurement of the drop sizes.

b. Zero

Zero in all trials was generally in the forenoon, usually between 0930 and 1130, so that weather conditions were suitable
and ample time was available to complete the vapour sampling before the end of the normal working day. The date and exact time of zero is shown for each trial in Appendix B along with the meteorological observations.

c. Vapour Sampling Schedules

(1) Bubblers
- z to z + 1 minute
- z + 1 to z + 2 minutes
- z + 2 to z + 5 minutes
- z + 5 to z + 10 minutes
- z + 10 to z + 30 minutes
- z + 30 to z + 90 minutes
- z + 90 to z + 150 minutes

(2) Infrared analyzers

Continuous operation from z - 5 minutes.

d. Analysis

The bubbler vapour samples and ground contamination samples were analyzed by high pressure liquid chromatography (HPLC). Stain sizes on detector papers were measured by a Quantimet System 23 Image Analyzer. The results were then analyzed mathematically for drop-number distribution.
7. RESULTS

a. Weather Conditions

The series of sixteen trials reported herein were carried out from early May to early November with trials in every month during the interval. This provided a wide range of ground temperatures. The two meter wind speed was always between four and thirty-one km per hour. Most of the trials were carried out in sunny weather, but some were carried out under partial or full cloud cover. Air and ground temperatures, windspeeds at various heights and wind direction at two meters are given in detail in Appendix B. Relative humidity is also shown for some of the trials.

b. Ground Contamination

(1) The shape and size of the stains from neat DMSO and unthickened 80/20 DMSO/water are indicated by a typical sampling card (Figure 4). A typical sampling card for thickened 80/20 DMSO/water is also shown (Figure 5). The total number of drops of various sizes counted from representative areas of the cards in each trial are shown in Tables C1 to C3 (Appendix D). These results are also plotted along with fitted curves (Figures 6 to 21). The mass median diameters, \(D_0\), and overall mass median diameters when the distributions are bimodal are shown in Figures 6 to 21 and tabulated along with the mass median diameter of each distribution in Table C4. Also, tabulated is the primacord charge used in each of the six bottles in each trial.
(2) The relationship between drop size and stain size as determined experimentally [2] is shown in Appendix C along with the method of fitting curves to the data points shown in Figures 6 to 21. Also shown in Appendix C is a comparison of the ground contamination density obtained from drop size-number count and sponge data analysis.

(3) The detailed ground contamination density data as measured by sponge samplers are shown in Appendix D.

c. Vapour Sampling

Sequential vapour dosages from bubblers at 0.3, 0.5, 1.0 and 1.5 m over the period z to z + 150 minutes are given in Tables E1 to E16 (Appendix E). Vapour concentrations measured by infrared analyzers with comparison to cumulative dosages from bubblers are given in Tables F1 to F6 (Appendix F). The comparisons were made to the bubblers sampling at the height of the intake of the infrared analyzer which was one metre.

d. DMSO Recovery

(1) Ground Sampling

Using a point-count method in which each sample represents a 3 x 2 m area, the ground contamination was calculated in terms of weight per meter of crosswind width from the mean contamination density over the 18 x 16 m sampling area. The results are shown in Table G1 (Appendix G).
(2) Vapour Recovery

Vapour recovery, the integrated flux of agent through a 1 m crosswind width of the vertical plane, was calculated from the vapour dosage and wind profile data. The results are given in Table G1 (Appendix G) along with the ground contamination information.

8. DISCUSSION OF RESULTS

a. Comparison of Vapour Recovery to Predicted Recoveries

The time profile of vapour recovery has been shown to be predicable by means of a mathematical model [3]. The model considers the evaporation of liquid sprayed on a rough natural surface which may absorb the sprayed material in both the liquid and vapour phases and the subsequent atmospheric diffusion of the vapour evolved. To compare experimental data with a predicted curve, standard conditions of wind-speed and ground temperature were selected and the observed lengths of the vapour sampling intervals were normalized to these conditions. A wind speed of 18 km h\(^{-1}\) at 2 m and a ground temperature of 20°C were used. The data from all sixteen trials except from trial FP 80-2 were plotted as shown (Figures 22 to 36). The results of trial FP 80-2 were not plotted because freezing temperatures occurred throughout most of the trial and little vapour was evolved. The predicted curves, which assumed no absorption of DMSO into the substrate, were fitted to the data points of each trial and provided a good fit, indicating negligible absorption. The data was further normalized by the model normalizing parameter, T, derived from these curves of vapour recovery.
These results are shown in Figures 37, 38 and 39 for all sixteen trials except for FP 80-2.

b. The Relationship Between Mass Median Diameter and Persistence.

The parameter $T$ determines the rate of vapour recovery and, hence, persistence at a given ground temperature and wind speed. It is related to $M$, the mean liquid loading on the substrate [3]. $M$ has been found to be a function of contamination density, as well as the mass median diameter (mmd) of the drop. As mmd of neat liquid increases above 0.5 mm, $M$ appears to become more directly related to drop diameter [4]. This latter relationship appears to hold in general for the trials with DMSO, where $M$ was derived from the value of $T$ obtained from the curve fit to the experimental data. The direct proportionality relationship of $M$ to mmd between the larger drops of the thickened liquid to the small drops of neat liquid is indicated in Table 2, where the average values given in Table I for each trial, are shown. For higher contamination densities, the small drops would tend to overlap more and thus change the relationship. Apparently the $M$ values derived for 80/20 DMSO/water are not appreciably different than those for neat DMSO; on the basis of a direct proportionality relationship between $M$ and mmd. From this and the similarity of evaporative characteristics illustrated in Figures 37, 38 and 39, it is apparent that the water does not significantly alter the volatility of DMSO contamination on grassland.
c. Comparison of Infrared and Bubbler Sampler Results

The cumulative dosages calculated from the real time concentration measurements of the infrared analyzers were compared to the cumulative dosages measured by the bubbler samplers. The results, which are shown in Appendix F for FP 80-6, 8, 9, 10, 11, 12 and 14, indicate the following general characteristics.

(1) The dosages in the time interval 2 to 10 minutes agree favorably in most of the trials. Note that the bubblers are covered with plastic sheets for approximately one minute following trial zero which causes total dosages to differ somewhat.

(2) At times later than ten minutes, the dosages from the infrared analyzers deviated increasingly with time from the bubbler dosages in some of the trials. This was due to the fact that the concentrations approached the lower limit sensitivity of the infrared analyzers. Baseline drift was also observed occasionally, and this caused greater error with smaller concentrations than larger. Baseline drift could be eliminated by allowing a warm up time of 30 minutes. Only 5 minutes warm up was used, however, because of trial constraints. The power must be shut off during bottle arming, which prevents the more desirable longer warm period.

(3) The results shown for FP 80-9 and 10 show similar discrepancies, which could also have been due to calibration errors in the analyzers, but was probably due to the fact that the intake nozzles were erroneously placed at a lower height than the bubbler intakes.
CONCLUSIONS

9. The persistence of DMSO and 80/20 DMSO/water on prairie terrain was found to be directly proportional to mass median diameter of the drops.

10. The recovery rate of the vapour from prairie terrain agrees favorably with the predictions of an existing DRES mathematical model.

11. The normalized recovery rate of thickened 80/20 DMSO/water was not found to be affected by temperatures below the freezing point of pure DMSO.

12. The dosages obtained by the bubblers and IR analyzers agreed favorably between 2 and 10 minutes after zero. At later times when the IR analyzers became inaccurate, they deviated increasingly with time in most of the trials.
REFERENCES


<table>
<thead>
<tr>
<th>Trial No</th>
<th>Type</th>
<th>T(min)</th>
<th>2R (g m⁻¹)</th>
<th>D₀ (mm)</th>
<th>3R (g m⁻²)</th>
<th>M(g m⁻²)</th>
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<tr>
<td>1</td>
<td>0.16</td>
<td>13</td>
<td>0.29</td>
<td>0.81</td>
<td>9</td>
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<tr>
<td>2</td>
<td>NEAT</td>
<td>-</td>
<td>5</td>
<td>0.35</td>
<td>0.31</td>
<td>-</td>
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<tr>
<td>3</td>
<td>DMSO</td>
<td>0.50</td>
<td>12</td>
<td>0.28</td>
<td>0.75</td>
<td>29</td>
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<td>4</td>
<td>0.19</td>
<td>9</td>
<td>0.41</td>
<td>0.56</td>
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<td>0.16</td>
<td>3.06</td>
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<td>6</td>
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<td>0.31</td>
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<td>9</td>
<td>80/20 DMSO/</td>
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<td>11</td>
<td>0.47</td>
<td>0.69</td>
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<td>27</td>
<td>0.25</td>
<td>1.69</td>
<td>22</td>
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<td>11</td>
<td>WATER</td>
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<td>1.88</td>
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<td>14</td>
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<td>1.00</td>
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<tr>
<td>15</td>
<td>80/20 DMSO/</td>
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<td>0.68</td>
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<td>158</td>
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<tr>
<td>16</td>
<td>WATER</td>
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<td>15</td>
<td>1.11</td>
<td>0.94</td>
<td>117</td>
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</table>

1. For ground temperature 20°C, wind speed 18 km h⁻¹ at 2 m
2. Recovery per unit crosswind width of contaminated ground
3. Recovery per unit area of contaminated ground upwind of the vapour samplers
### Table II

**Comparison of Drop Sizes with Evaporation Rates**  
**Using Mean Values from Each Type of Liquid**

<table>
<thead>
<tr>
<th>Type</th>
<th>mmd mm</th>
<th>Contamination Density g m⁻²</th>
<th>M g m⁻²</th>
<th>T* min</th>
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<tr>
<td>Neat DMSO</td>
<td>0.26</td>
<td>1.7</td>
<td>41</td>
<td>0.71</td>
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<tr>
<td>Unthickened 80/20 DMSO/Water</td>
<td>0.25</td>
<td>1.8</td>
<td>51</td>
<td>0.87</td>
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<td>Thickened 80/20 DMSO/Water</td>
<td>0.84</td>
<td>2.2</td>
<td>141</td>
<td>2.42</td>
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Figure 1
LAYOUT DIAGRAM FOR EXPLOSIVE DISSEMINATION FROM BOTLES

- Detector paper and sponge rubber samplers
- Bubblers at 0.3, 0.5, 1.0 and 1.5 m
- GZ of bursting bottles, gallows positions
- Infrared gas analyzers at 1.0 m
Figure 4

SAMPLING CARD SHOWING STAINS FROM
UNTHICKENED 80/20 DMSO/WATER

UNCLASSIFIED
Figure 5

SAMPLING CARD SHOWING STAINS FROM THICKENED 80/20 DMSO/WATER

UNCLASSIFIED
Figure 6

DROP DIAMETER NUMBER DISTRIBUTION
FPP 80 - 1

UNCLASSIFIED
Figure 7
DROP DIAMETER NUMBER DISTRIBUTION
FPP 80 - 2
UNCLASSIFIED
DATA POINTS ●
FITTED EXPONENTIAL —
\( N = 86247 e^{-13.032 D} \)
\( D_0 = 0.28 \text{ mm} \)

Figure 8
DROP DIAMETER NUMBER DISTRIBUTION
FPP 80 – 3
UNCLASSIFIED
Figure 9

DROP DIAMETER NUMBER DISTRIBUTION
FPP 80 - 4

UNCLASSIFIED
Figure 10

DROP DIAMETER NUMBER DISTRIBUTION
FPP 80-5

UNCLASSIFIED
Figure 11

DROP DIAMETER NUMBER DISTRIBUTION
FPP 80 - 6

DATA POINTS •
Fitted exponential —

\[ N = 92803e^{-21.257D} \]

\[ D_0 = 0.17 \text{ mm} \]
Figure 12

DROP DIAMETER NUMBER DISTRIBUTION

FPP 80 - 7

UNCLASSIFIED
OVERALL MASS MEDIAN DIAMETER = 0.31 mm

Figure 13

DROP DIAMETER NUMBER DISTRIBUTION
FPP 80 - 8
UNCLASSIFIED
Figure 15

DROP DIAMETER NUMBER DISTRIBUTION
FPP 80 - 10

OVERALL MMD = 0.25 mm
OVERALL MMD = 0.22 mm

Figure 16
DROP DIAMETER NUMBER DISTRIBUTION

FPP 80 - 11

UNCLASSIFIED
Figure 17
DROP DIAMETER NUMBER DISTRIBUTION
FPP 80 - 12
UNCLASSIFIED
DATA POINTS ●
FITTED EXPONENTIAL —

\[ N = 68776e^{-34.91D} \]

\[ D_0 = 0.11 \text{ mm} \]

**Figure 18**

**DROP DIAMETER NUMBER DISTRIBUTION**

**FPP 80 - 13**

**UNCLASSIFIED**
OVERALL MMD = 0.72 mm
Figure 20

DROP DIAMETER NUMBER DISTRIBUTION
FPP 80 - 15
UNCLASSIFIED
Figure 21

DROP DIAMETER NUMBER DISTRIBUTION
FPP 80 - 16
UNCLASSIFIED
Figure 22

VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 Km h⁻¹
Figure 23
VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 km h⁻¹
Figure 24

VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 km h⁻¹
Figure 25

VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 Km h⁻¹
VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 km h⁻¹
Figure 27

VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 Km h⁻¹
Figure 28

VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 Km h⁻¹

UNCLASSIFIED
Figure 29
VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 Km h⁻¹
Figure 30

VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 Km h⁻¹
Figure 31

VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 Km h⁻¹
Figure 32
VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 Km h⁻¹.
Figure 33
VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 Km h⁻¹
Figure 35

VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 Km h⁻¹
Figure 36

VAPOUR RECOVERY DATA NORMALIZED TO GROUND TEMPERATURE 20°C AND 2 m WINDSPEED 18 Km h⁻¹
## APPENDIX A

### PHYSICAL PROPERTIES OF DMSO

**REFERENCE:** DIMETHYL SULFOXIDE TECHNICAL BULLETIN  
CROWN ZELLERBACH CHEMICAL PRODUCTS DIVISION  
P.O. BOX 4266  
VANCOUVER (ORCHARDS), WA 98663

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<tr>
<td>Boiling Point at 760 mm Hg</td>
<td>189°C (372°F)</td>
</tr>
<tr>
<td>Freezing Point</td>
<td>18.55°C (65.4°F)</td>
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<tr>
<td>Molal freezing point constant, °C/(mol)(kg)</td>
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<tr>
<td>Refractive index nD25</td>
<td>1.4768</td>
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<tr>
<td>Surface tension at 20°C</td>
<td>43.53 dynes/cm</td>
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<tr>
<td>Vapor pressure, at 25°C</td>
<td>0.600 mm Hg</td>
</tr>
<tr>
<td>Density, g/cm³, at 25°C</td>
<td>1.096</td>
</tr>
<tr>
<td>Viscosity, cP, at 25°C</td>
<td>2.0 (see Figs. 3&amp;4)</td>
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<tr>
<td>Specific Heat at 29.5°C</td>
<td>0.47±0.015 cal/g/°C</td>
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<tr>
<td>Heat capacity (liq.), 25°C</td>
<td>0.47 cal/g/°C</td>
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<tr>
<td>Heat capacity (ideal gas), Cp(T°K)=6.94+5.6x10^-2T-0.227x10^-4T^2</td>
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UNCLASSIFIED SR 442

Figure A1

Figure A2

Figure A3

Figure A4

VISCOSITY OF DMSO

VISCOSITY OF DMSO - WATER SOLUTIONS

FREEZING POINT CURVES FOR DMSO - WATER SOLUTIONS

UNCLASSIFIED
### METEOROLOGICAL OBSERVATIONS

**FP 80-1 - ZERO 1443 MDT - 15 OCTOBER 1979**

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APPENDIX B

METEOROLOGICAL OBSERVATIONS

FP 80-2 - ZERO 1118 MDT - 22 OCTOBER 1981

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## APPENDIX B

**METEOROLOGICAL OBSERVATIONS**

**FP 80-3 - ZERO 1109 MDT - 28 OCTOBER 1981**

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**UNCLASSIFIED**
### APPENDIX B

**METEOROLOGICAL OBSERVATIONS**

**FP 80-4 - ZERO 1057 MT - 02 NOVEMBER 1981**

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**APPENDIX B**

**METEOROLOGICAL OBSERVATIONS**

*FP 80-5 - ZERO 1001 MDT - 08 JUNE 1982*

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# APPENDIX B

**METEOROLOGICAL OBSERVATIONS**

**FP 80-6 - ZERO NOT RECORDED - 27 JULY 1982**

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METEOROLOGICAL OBSERVATIONS

FP 80-7 - ZERO 1222 - 21 JUNE 1983

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APPENDIX B

METEOROLOGICAL OBSERVATIONS

FP 80-8 - ZERO 1025 MDT - 02 MAY 1984

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APPENDIX B

METEOROLOGICAL OBSERVATIONS

FP 80-9 - ZERO 1018 MDT - 21 AUGUST 1984

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## APPENDIX B

### METEOROLOGICAL OBSERVATIONS

**FP 80-10 - ZERO 0924 MDT - 22 AUGUST 1984**

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APPENDIX B

METEOROLOGICAL OBSERVATIONS

FP 80-11 - ZERO 1011 - 22 MAY 1985

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APPENDIX B

METEOROLOGICAL OBSERVATIONS

FP 80-12 - ZERO 0941 - 23 MAY 1985

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APPENDIX B

METEOROLOGICAL OBSERVATIONS

FP 80-13 - ZERO 1019 MDT - 4 JUNE 1985

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APPENDIX B

METEOROLOGICAL OBSERVATIONS

FP 80-14 - ZERO 1032 MDT - 13 JUNE 1985

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### APPENDIX B

**METEOROLOGICAL OBSERVATIONS**

**FP 80-15 - ZERO 0944 MDT - 17 SEPTEMBER 1985**

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APPENDIX B

METEOROLOGICAL OBSERVATIONS

FP 80-16 - ZERO 1058 MDT - 25 SEPTEMBER 1985

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The relationship between liquid drop size and corresponding stain size produced on detector paper by impinging drops was determined by fitting a straight line to a series of stain sizes produced by a series of drops of known various sizes. The data, which was chosen in the most appropriate range of drop sizes, yielded the following drop sizes, $D$, from the various stain sizes, $S$, both in units of millimetres.

1. Neat DMSO on 3 way detector paper
   
   $D = 0.0567 + 0.184S$  \hspace{1cm} (C1)

2. Unthickened 80/20 DMSO/Water
   
   $D = 0.02789 + 0.183S$  \hspace{1cm} (C2)

3. Thickened 80/20 DMSO/Water
   
   $D = 0.05125 + 0.371S$  \hspace{1cm} (C3)

The data and fitted lines are shown in Figures C1, C2 and C3. The analysis of drop size sampling results assumes that cumulative number of drops, starting from the largest ones, is an exponential function of drop size, as given by the following equation.

$$N = N_T \exp(-bD)$$  \hspace{1cm} (C4)

where $N_T$ is the intercept at diameter $D = 0$, and $N$ is the cumulative number of drops. The mass median diameter, $D_o$, of each distribution is related to the slope $b$ of a semi-log plot by the following relationship.

$$bD_o = 3.672$$  \hspace{1cm} (C5)
For pure DMSO, equation C4 is generally followed. Analysis of data from the thickened 80/20 DMSO/water and some of the unthickened 80/20 DMSO/water showed that the plots tend to follow curves which can be synthesized by two straight line distributions on semi-log paper. This indicated a bimodal mass diameter frequency distribution, each component being represented by an equation of the type given by Equation (C4). The total mass, $Q$, in each of the two exponential distributions is given by

$$Q = \frac{\pi \rho N_T}{b^3}$$

(C6)

where $\rho$ is the density of the material.

A comparison was made between the total mass calculated from Equation (C6) and the mass measured from the analysis of the data from the sponges. To do this, typical data from FP-80-16 was used in which the detector paper and sponge from card E-3 were analyzed and compared. Also the average values obtained from all eight papers and sponges on line 3 were compared. The drop size data used is shown in Table C5 and plotted in Figures C4 and C5 along with fitted curves. The sponge data is taken from Appendix D, where all the ground contamination results from the sponges is shown. The results of the comparison are shown as follows:

**Ground contamination from card E-3:**
Detector paper stains - 3.23 g m$^{-2}$
Material absorbed by sponges - 4.05 g m$^{-2}$
Ratio: $3.23/4.05 = 0.798$

**Ground Contamination from line 3:**
Detector paper stains - 1.73 g m$^{-2}$
Material absorbed by sponges - 1.91 g m$^{-2}$
Ratio: $1.72/1.91 = 0.906$
### TABLE C1

**DROP SIZE SAMPLING RESULTS FOR NEAT DMSO**

<table>
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<tr>
<th>Stain Size (mm)</th>
<th>Drop Size (mm)</th>
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<th>FP80-3</th>
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### TABLE C1 continued

**DROP SIZE SAMPLING RESULTS FOR NEAT DMSO**

**FP 80-7**

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## TABLE C2

**DROP SIZE SAMPLING RESULTS FOR UNTHICKENED 80/20 DMSO/WATER**

### FP 80-8

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<td>233</td>
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### TABLE C2 continued

**DROP SIZE SAMPLING RESULTS FOR UNTHICKENED 80/20 DMSO/WATER**

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TABLE C2 continued

DROP SIZE SAMPLING RESULTS FOR UNTHICKENED 80/20 DMSO/WATER

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TABLE C4

MASS MEDIAN DIAMETERS FROM DROP SIZING DATA

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1 Overall mass median diameter
2 Mass median diameter of each distribution
## TABLE C5

DROP SIZE SAMPLING RESULTS FROM ROW 3 FP 80-16

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<td>≥5.00</td>
<td>1.908</td>
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</tr>
</tbody>
</table>
Figure C1

SPREAD OF DMSO DROPS ON THREE-WAY DETECTOR PAPER

DATA POINTS
FITTED LINE

\[ D = 0.0567 + 0.184 S \]
Figure C2

SPREAD OF 80% DMSO 20% WATER (V) DROPS ON 3-WAY DETECTOR PAPER

DATA POINTS •
FITTED LINE —
D = 0.05125 + 0.371 S
Figure C.3

SPREAD OF 80% DMSO 20% WATER DROPS ON 3-WAY DETECTOR PAPER

DATA POINTS
Fitted Line

\[ D = 0.02789 + 0.183S \]

STAIN DIAMETER \( S \) (mm)

DROP DIAMETER \( D \) (mm)
OVERALL MMD = 1.59 mm

DROP DIAMETER NUMBER DISTRIBUTION FPP 80 - 16

CARD E-3 3-WAY

UNCLASSIFIED
OVERALL MMD = 1.33 mm

Figure C5

DROP DIAMETER NUMBER DISTRIBUTION FPP 80 - 16
ROW 3 3-WAY
UNCLASSIFIED
**APPENDIX D**

**TABLE D1**

**CONTAMINATION DENSITY SAMPLES**

**CONTAMINATION DENSITY SAMPLES FOR NEAT DMSO**

\[ \text{g m}^{-2} \]

FP80-1 (100 grains primacord, bottles at 1 m)

Total liquid disseminated 1661 g

<table>
<thead>
<tr>
<th>Line</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>0.03</td>
<td>1.07</td>
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<td>0.67</td>
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<td>0.69</td>
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<td>2.88</td>
<td>3.93</td>
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<td>1.99</td>
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<td>0.27</td>
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</tr>
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</table>

Mean C.D. 1.55 g m\(^{-2}\)

**TABLE D2**

**CONTAMINATION DENSITY SAMPLES FOR NEAT DMSO**

\[ \text{g m}^{-2} \]

FP80-2 (100 grains primacord, bottles at 2 m)

Total liquid disseminated 1670 g

<table>
<thead>
<tr>
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<th>1</th>
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<td>1.87</td>
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<td>G</td>
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<td>4.60</td>
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<td>0.32</td>
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<td>1.82</td>
</tr>
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<td>1.83</td>
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<td>5.42</td>
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</tr>
</tbody>
</table>

Mean C.D. 2.45 g m\(^{-2}\)
# APPENDIX D

## TABLE D3

**CONTAMINATION DENSITY SAMPLES FOR NEAT DMSO**

\[ g \text{ m}^{-2} \]

FP8O-3 (100 grains primacord, bottles at 2 m)

Total liquid disseminated 1682 g

<table>
<thead>
<tr>
<th>Line</th>
<th>Row</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<tbody>
<tr>
<td>H</td>
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<td>0.34</td>
<td>0.09</td>
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<tr>
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<td>2.33</td>
<td>2.57</td>
<td>7.08</td>
<td>0.98</td>
<td>4.32</td>
<td></td>
</tr>
<tr>
<td>E</td>
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<td>1.29</td>
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<td>2.22</td>
<td>2.60</td>
<td></td>
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<td>D</td>
<td>3.25</td>
<td>0.64</td>
<td>2.56</td>
<td>4.89</td>
<td>1.97</td>
<td>1.36</td>
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<td>3.14</td>
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<td>1.74</td>
<td>4.20</td>
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<td>0.75</td>
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<tr>
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<td>0.46</td>
<td>0.50</td>
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Mean C.D. 1.71 g m\(^{-2}\)

## TABLE D4

**CONTAMINATION DENSITY SAMPLES FOR NEAT DMSO**

\[ g \text{ m}^{-2} \]

FP8O-4 (100 grains primacord, bottles at 1 m)

Total liquid disseminated 1683 g

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<tr>
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<th>Row</th>
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<th>2</th>
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<tbody>
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<td>0.24</td>
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<td>1.80</td>
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<td>2.73</td>
<td>3.57</td>
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<td>1.22</td>
<td>0.57</td>
<td>2.15</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>2.91</td>
<td>0.73</td>
<td>0.47</td>
<td>0.12</td>
<td>0.92</td>
<td>0.10</td>
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</tr>
</tbody>
</table>

Mean C.D. 1.81 g m\(^{-2}\)

---

**UNCLASSIFIED**
### APPENDIX D

#### TABLE D5

**CONTAMINATION DENSITY SAMPLES FOR NEAT DMSO**

\( g \text{ m}^{-2} \)

FP80-5 (100 grains primacord, bottles at 1 m)

Total liquid disseminated 1710 g

<table>
<thead>
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<td>2.57</td>
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<td>0.27</td>
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<td>1.19</td>
<td>3.27</td>
<td>1.37</td>
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<tr>
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<td>4.09</td>
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<td>1.74</td>
<td>4.14</td>
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<td>2.07</td>
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<td>4.82</td>
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<tr>
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<td>0.43</td>
<td>0.39</td>
<td>1.03</td>
<td>2.32</td>
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</tbody>
</table>

Mean C.D. 1.83 g m\(^{-2}\)

#### TABLE D6

**CONTAMINATION DENSITY SAMPLES FOR NEAT DMSO**

\( g \text{ m}^{-2} \)

FP80-6 (100 grains primacord, bottles at 2 m)

Total liquid disseminated 1728 g

<table>
<thead>
<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>G</td>
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<td>0.16</td>
<td>0</td>
<td>1.44</td>
<td>0.16</td>
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<tr>
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<td>4.14</td>
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<td>4.92</td>
<td>1.25</td>
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</table>

Mean C.D. 1.54 g m\(^{-2}\)
APPENDIX D

TABLE D7

CONTAMINATION DENSITY SAMPLES FOR NEAT DMSO
\[ g \text{ m}^{-2} \]

FP80-7 (100 grains primacord, bottles at 1 m)
Total liquid disseminated 1641 g

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<td>0.78</td>
<td>1.63</td>
<td>2.66</td>
<td>1.20</td>
</tr>
<tr>
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<td>2.43</td>
<td>4.37</td>
<td>2.38</td>
<td>4.22</td>
<td>4.56</td>
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<td>2.67</td>
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<td>4.17</td>
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<td>2.62</td>
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<td>0.33</td>
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Mean C.D. 1.94 g m\(^{-2}\)

TABLE D8

CONTAMINATION DENSITY SAMPLES FOR UNTHICKENED 80/20 DMSO/WATER
\[ g \text{ m}^{-2} \]

FP80-8 (100 grains primacord, bottles at 1 m)
Total liquid disseminated 1668 g

<table>
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<tbody>
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<td>0</td>
<td>0.15</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>G</td>
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<td>2.03</td>
<td>0.31</td>
<td>1.63</td>
<td>2.25</td>
<td>0.37</td>
<td>0.70</td>
</tr>
<tr>
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<td>1.98</td>
<td>1.95</td>
<td>7.20</td>
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<td>3.33</td>
<td>3.10</td>
<td>1.76</td>
<td>2.68</td>
<td>1.98</td>
<td>5.54</td>
</tr>
<tr>
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<td>2.76</td>
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<td>2.00</td>
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<tr>
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<td>2.39</td>
<td>2.48</td>
<td>2.94</td>
<td>1.06</td>
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<td>1.59</td>
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<td>0.79</td>
<td>0.20</td>
<td>2.92</td>
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</table>

Mean C.D. 1.96 g m\(^{-2}\)
## APPENDIX D

### TABLE D9

**CONTAMINATION DENSITY SAMPLES FOR UNTHICKENED 80/20 DMSO/WATER**

\[ g \text{ m}^{-2} \]

FP80-9 (100 grains primacord, bottles at 2 m)
Total liquid disseminated 1669 g

<table>
<thead>
<tr>
<th>Line</th>
<th>Row</th>
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<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
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<td>0.97</td>
<td>0.06</td>
<td>0.01</td>
<td>0.07</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
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<td>0.71</td>
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<td>0.56</td>
<td>1.84</td>
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Mean C.D. 1.35 g m\(^{-2}\)

### TABLE D10

**CONTAMINATION DENSITY SAMPLES FOR UNTHICKENED 80/20 DMSO/WATER**

\[ g \text{ m}^{-2} \]

FP80-10 (100 grains primacord, bottles at 1 m)
Total liquid disseminated 1665 g

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Mean C.D. 1.31 g m\(^{-2}\)

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### APPENDIX D

#### TABLE D11

**Contamination Density Samples for Unthickened 80/20 DMSO/Water**

\( g \ m^{-2} \)

**FP80-11 (100 grains primacord, bottles at 1 m)**

Total liquid disseminated 1635 g

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Mean C.D. 2.41 g m\(^{-2}\)

#### TABLE D12

**Contamination Density Samples for Unthickened 80/20 DMSO/Water**

\( g \ m^{-2} \)

**FP80-12 (100 grains primacord, bottles at 1 m)**

Total liquid disseminated 1677 g

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Mean C.D. 2.12 g m\(^{-2}\)

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**APPENDIX D**

**TABLE D13**

CONTAMINATION DENSITY SAMPLES FOR UNTHICKENED 80/20 DMSO/WATER g m\(^{-2}\)

FP80-13 (100 grains primacord, bottles at 1 m)

Total liquid disseminated 1664 g

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Mean C.D. 1.64 g m\(^{-2}\)

**TABLE D14**

CONTAMINATION DENSITY SAMPLES FOR THICKENED 80/20 DMSO/WATER g m\(^{-2}\)

FP80-14 (100 grains primacord, bottles at 1 m)

Total liquid disseminated 1385 g

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Mean C.D. 1.84 g m\(^{-2}\)

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TABLE D15

CONTAMINATION DENSITY SAMPLES FOR THICKENED 80/20 DMSO/WATER

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Mean C.D. 2.44 g m\(^{-2}\)

TABLE D16

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Mean C.D. 2.28 g m\(^{-2}\)
APPENDIX E

TABLE E1

VAPOUR DOSAGE SAMPLES mg min m⁻³

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UNCLASSIFIED
**APPENDIX E**

**TABLE E2**

**VAPOUR DOSAGE SAMPLES mg min m⁻³**

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APPENDIX E

TABLE E3

VAPOUR DOSAGE SAMPLES mg min m$^{-3}$

FP 80-3

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APPENDIX E

TABLE E4

VAPOUR DOSAGE SAMPLES mg min m$^{-3}$

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APPENDIX E

TABLE E5

VAPOUR DOSAGE SAMPLES mg min m⁻³

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## APPENDIX E

### TABLE E6

**VAPOUR DOSAGE SAMPLES mg min m⁻³**

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APPENDIX E

TABLE E7

VAPOUR DOSAGE SAMPLES mg min m⁻³

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### APPENDIX E

**TABLE E8**

**VAPOUR DOSAGE SAMPLES mg min m⁻³**

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### TABLE E9

**VAPOUR DOSAGE SAMPLES mg min m⁻³**

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TABLE E10

VAPOUR DOSAGE SAMPLES mg min m\(^{-3}\)

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APPENDIX E

TABLE E11

VAPOUR DOSAGE SAMPLES mg min m\(^{-3}\)

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UNCLASSIFIED
APPENDIX E

TABLE E12

VAPOUR DOSAGE SAMPLES mg min m⁻³

FP 80-12

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<td>7.3</td>
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|          | Z+2-      | Z+5-                        |
| S1       | 17.5      | 38.5                        |
|          | 13.4      | 29.8                        |
|          | 6.8       | 13.4                        |
|          | 3.8       | 6.3                         |
| S2       | 15.9      | 0                           |
|          | 9.6       | 24.1                        |
|          | 4.8       | 9.8                         |
|          | 1.6       | 4.9                         |
| S3       | 17.5      | 35.2                        |
|          | 14.6      | 30.0                        |
|          | 4.2       | 9.7                         |
|          | 5.8       | 5.8                         |

|          | Z+10-     | Z+30-                       |
| S1       | 33.3      | 20.3                        |
|          | 25.4      | 15.3                        |
|          | 7.8       | 7.5                         |
|          | 4.1       | 2.9                         |
| S2       | 25.2      | 31.2                        |
|          | 22.7      | 16.3                        |
|          | 10.5      | 7.5                         |
|          | 6.0       | 3.5                         |
| S3       | 41.1      | 20.6                        |
|          | 34.7      | 18.3                        |
|          | 9.7       | 4.8                         |
|          | 7.2       | 3.9                         |

|          | Z+90-     | Z+150                       |
| S1       | 4.9       | -                           |
|          | 3.7       | -                           |
|          | 1.6       | -                           |
|          |          | -                           |
| S2       | 26.9      | -                           |
|          | 4.7       | -                           |
|          | 2.2       | -                           |
|          |          | -                           |
| S3       | 7.8       | -                           |
|          | 7.0       | -                           |
|          | 2.1       | -                           |
|          |          | -                           |
## APPENDIX E

### TABLE E13

**VAPOUR DOSAGE SAMPLES mg min m⁻³**

**FP 80-13**

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### APPENDIX E

#### TABLE E14

**VAPOUR DOSAGE SAMPLES mg min m$^{-3}$**

**FP 80-14**

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APPENDIX E

TABLE E15

VAPOUR DOSAGE SAMPLES mg min m⁻³

FP 80-15

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**APPENDIX E**

**TABLE E16**

**VAPOUR DOSAGE SAMPLES mg min m⁻³**

**FP 80-16**

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<td>Z⁺₅⁻</td>
<td>Z⁺₁₀⁻</td>
<td>Z⁺₃₀⁻</td>
<td>Z⁺₉₀⁻</td>
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**UNCLASSIFIED**
TABLE F1

INFRARED ANALYZER RESULTS

DMSO CONCENTRATION MEASURED BY IR ANALYZERS WITH COMPARISON TO CUMULATIVE DOSAGES FROM BUBBLERS IN FP 80-6

<table>
<thead>
<tr>
<th>Trial Time Minutes</th>
<th>Concentration mg m⁻³ from IR Analyzer</th>
<th>Average Cumulative Dosage mg min m⁻³</th>
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<td></td>
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<td>IR</td>
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<td>Nearest two Bubblers at 1 m</td>
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<td>5.5</td>
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<td>1.5</td>
<td>11.9</td>
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</tr>
<tr>
<td>2</td>
<td>13.6</td>
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### UNCLASSIFIED

**APPENDIX F**

**TABLE F2**

**INFRARED ANALYZER RESULTS**

DMSO CONCENTRATION MEASURED BY IR ANALYZERS WITH COMPARISON TO CUMULATIVE DOSAGES FROM BUBBLERS IN FP 80-8

<table>
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<tr>
<th>Trial Time Minutes</th>
<th>Concentration mg m(^{-3})</th>
<th>Average Cumulative Dosage mg min m(^{-3})</th>
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### Table F3

**Infrared Analyzer Results**

DMSO concentration measured by IR analyzers with comparison to cumulative dosages from bubblers in FP 80-9 & FP 80-10.

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<th>Concentration mg m⁻³ From IR Analyzer</th>
<th>Average Cumulative Dosage mg min m⁻³ IR Analyzers</th>
<th>Bubblers</th>
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INFRARED ANALYZER RESULTS

DMSO CONCENTRATION MEASURED BY IR ANALYZERS WITH COMPARISON TO CUMULATIVE DOSAGES FROM BUBBLERS IN FP 80-11

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UNCLASSIFIED
APPENDIX F

TABLE F5

INFRARED ANALYZER RESULTS

DMSO CONCENTRATION MEASURED BY IR ANALYZERS WITH COMPARISON TO CUMULATIVE DOSAGES FROM BUBBLERS IN FP 80-12

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**INFRARED ANALYZER RESULTS**

DMSO CONCENTRATION MEASURED BY IR ANALYZERS WITH COMPARISON TO CUMULATIVE DOSAGES FROM BUBBLERS IN FP 80-14

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### Table G1

Comparison of Measured Total Vapour Recovery to Total Liquid Dispersed

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<th>% q</th>
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Assessment of the Persistence of Vapour Evolved from Thickened and Neat Dimethyl Sulfoxide Contamination of Prairie Terrain (U)

A series of sixteen trials, seven with neat DMSO and six with 80% DMSO and 20% water to reduce the freezing point temperature, and three with polyvinyl alcohol added to the latter solution to thicken the solution to a zero-shear viscosity of seven poise were conducted on prairie terrain. Explosive dissemination was used on all trials. Vapour sampling and drop sizing results were obtained. The persistence of DMSO and 80/20 DMSO/water on prairie terrain was found directly proportional to the mass median diameter of the drops and the recovery rate of the vapour from prairie terrain agrees favourably with the predictions of an existing DRES mathematical model.
vapour persistence
field experiment
chemical simulant
dimethyl sulfoxide
chemical sampling
evaporative rate