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Environmental Assessment

Generator, Mechanical, Smoke: For Dual-Purpose Unit, XM56 Yuma Proving Ground, Yuma, Arizona

C. J. Driver
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E. B. Moore, Jr.

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ENVIRONMENTAL ASSESSMENT

GENERATOR, MECHANICAL, SMOKE: FOR DUAL-PURPOSE UNIT, XM56 YUMA PROVING GROUND, YUMA, ARIZONA

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Dugway, Utah

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SUMMARY

The U.S. Army Chemical Research, Development and Engineering Center (CRDEC) is planning to perform a field test of the XM56 smoke generator at the U.S. Army Yuma Proving Ground (YPG), Arizona. The XM56, enabling the use of fog oil in combination with other materials, such as graphite flakes, is part of an effort to improve the efficiency of smoke generation and to extend the effectiveness of the resulting obscurant cloud to include the infrared spectrum.

The planned field operation includes a road test and concurrent smoke-generation trials. Three M1037 vehicles with operational XM56 generators will be road-tested for 100 h. Smoke will be generated for 30 min from a single stationary XM56 four times during the road test, resulting in a total of 120 min of smoke generation. The total aerial release of obscurant materials during this test is expected to be 556 kg (1,220 lb) of fog oil and 547 kg (1,200 lb) of graphite flakes.

This environmental assessment has evaluated the consequences of the proposed action. Air concentrations and surface deposition levels were estimated using an atmospheric dispersion model. Degradation of fog oil and incorporation of graphite in the soil column will limit the residual impacts of the planned action. No significant impacts to air, water, and soil quality are anticipated. Risks to the environment posed by the proposed action were determined to be minimal or below levels previously found to pose measurable impacts. Cultural resources are present on YPG and have been identified in adjacent areas; therefore, off-road activities should be preceded by a cultural resource survey. A Finding of No Significant Impact is recommended.

CONTENTS

SUMMARY . . . iii

1.0 PURPOSE AND NEED FOR THE PROPOSED ACTION . . . 1

2.0 DESCRIPTION OF THE PROPOSED ACTION AND ALTERNATIVES . . . 3

2.1 BACKGROUND . . . 3

2.2 TEST MATERIALS . . . 3

2.2.1 Chemical and Physical Characteristics . . . 3
2.2.2 Toxicity . . . 4
2.2.3 Environmental Fate . . . 6
2.2.4 Regulatory Status . . . 6

2.3 TEST PROCEDURES . . . 8

2.3.1 Location of Test Sites . . . 8
2.3.2 Dissemination . . . 10
2.3.3 Meteorological Requirements . . . 10

2.4 ALTERNATIVES TO THE PROPOSED ACTION . . . 10

2.4.1 No Action: Not Testing . . . 11
2.4.2 Reducing Scale of Test . . . 11
2.4.3 Testing at Another Site . . . 11

2.5 THE AFFECTED ENVIRONMENT . . . 11

2.5.1 Climate and Air Quality . . . 11
2.5.2 Land and Geology . . . 12
2.5.3 Soil . . . 13
2.5.4 Water . . . 13
2.5.5 Vegetation . . . 13
2.5.6 Wildlife . . . 14
2.5.7 Socioeconomic Factors . . . 14
2.5.8 Cultural Resources . . . 14

3.0 ENVIRONMENTAL CONSEQUENCES OF THE PROPOSED ACTION AND PROPOSED ALTERNATIVES . . . 15

3.1 ENVIRONMENTAL CONSEQUENCES OF THE PROPOSED ACTION . . . 15

3.1.1 Environmental Fate of Obscurant Materials . . . 15
3.1.2 Air Quality . . . 16
3.1.3 Soil . . . 16
3.1.4 Water . . . 17
3.1.5 Vegetation . . . 17
3.1.6 Wildlife and Threatened and Endangered Species . . . 17
3.1.7 Socioeconomic Factors . . . 18
3.1.8 Cultural Resources . . . 19

3.2 HAZARDOUS WASTE . . . 19

3.3 MITIGATION . . . 19

3.4 ENVIRONMENTAL CONSEQUENCES OF ALTERNATIVES . . . 19

4.0 CONCLUSIONS 21
5.0 REFERENCES 23

APPENDIX A - ATMOSPHERIC DISPERSION AND DEPOSITION MODELING. . . . A.1

APPENDIX B - AVERAGE METEOROLOGICAL CONDITIONS B.1

FIGURE

1 A Sketch of the U.S. Army Yuma Proving Ground and Surrounding Areas 9

GENERATOR, MECHANICAL, SMOKE: FOR DUAL-PURPOSE UNIT, XM56
YUMA PROVING GROUND, YUMA, ARIZONA

1.0 PURPOSE AND NEED FOR THE PROPOSED ACTION

A variety of offensive and defensive systems and materiels are employed on the battlefield. Warfare conditions and tactics require that land, sea, and air forces be trained with and have at their disposal the best defensive systems available. Among these systems, smokes and obscurants have long been employed to mask both troop and mechanized equipment movements. Smokes are widely used to visually mask the movements of both ground and sea forces. However, the modern battlefield has become much more complex, with visual detection being augmented or replaced by a wide range of electromagnetic methods for detection and targeting. One result is a need for specific types of electromagnetic obscurants and, consequently, for training and testing programs to ensure tactical readiness.

Fog oil (FO) has been used successfully for decades to obscure the visible spectrum. The design of a new generator enabling the use of fog oil in combination with other materials, such as graphite flakes (GF), is an effort to improve the efficiency of smoke generation and to extend the effectiveness of the resulting obscurant cloud to include the infrared spectrum. Tests of the prototype generator under actual field conditions are a necessary step in the process of development.

The U.S. Army Chemical Research, Development and Engineering Center (CRDEC) is planning to perform a field test of the XM56 smoke generator at the U.S. Army Yuma Proving Ground (YPG), Arizona, to determine operational qualities of the XM56 generator under actual arid desert conditions. The planned field operation includes a road test and concurrent smoke-generation trials. The road test will be performed on a track that may include both primary and secondary roads and cross-country terrain. Three M1037 vehicles with operational XM56 generators will be road-tested for 100 h. The vehicles will be on the track for 20 h of each 25-h period during the road test. Smoke will be generated for 30 min from a single stationary XM56 four times during the road test (120 min of total smoke generation). The smoke generated will include fog oil and graphite flake materials. The total period of smoke generation is anticipated to be 120 min during the 100-h road test. The total aerial release of obscurant materials during this test is expected to be 556 kg (1,220 lb) of fog oil and 547 kg (1,200 lb) of graphite flakes. In addition to the road and smoke tests, natural dust will be generated for several 5-min periods to determine the usefulness of the XM56 to disperse surface dust.

This environmental assessment of the proposed action has been prepared by Pacific Northwest Laboratory (PNL)[a].

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[a] Operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

2.0 DESCRIPTION OF THE PROPOSED ACTION AND ALTERNATIVES

Review of the planned dissemination of mixed fog oil and graphite flake obscurant and the separate dissemination of a dust cloud proceeded from the assumption that YPG provided a site for full-scale field testing. In the course of the review, consideration was given to materials, dissemination, aerial transport, environmental fate, and potential health and environmental impacts. Health concerns center on inhalation risk, and environmental concerns include potential terrestrial and aquatic (river) impacts. Once the potential risks were established, alternatives to the proposed tests were considered.

2.1 BACKGROUND

The U.S. Army Chemical Research, Development and Engineering Center (CRDEC) is planning to conduct a field test of the XM56 smoke generator at YPG during August 1991. The planned test is part of a Production Prove Out effort involving the development of a dual-purpose smoke generator. Test data will be evaluated and reviewed at a Technical Readiness Review to determine whether the XM56 is ready to proceed to Pre-Production Qualification Testing (PPQT).

2.2 TEST MATERIALS

Materials that will be disseminated using the XM56 generator are fog oil, graphite flakes, and natural dust. The chemical nature of the dust component is not addressed in this assessment. This is because the dust will not be generated in association with the other obscurant materials (the XM56 generators will be moved prior to generation of dust), and because several 5-min periods of dust generation will result in minimal disturbance. The chemical and physical characteristics, toxicity, environmental fate, and regulatory status of the graphite and fog oil are described.

2.2.1 Chemical and Physical Characteristics

Graphite Flake

Graphite is a soft scale form of carbon and can be natural or synthetic in origin. Synthetic graphite is currently used as an obscurant by the U.S. military. Synthetic graphite is formed by heating petroleum coke, a binder (usually coal tar pitch), and a petroleum-based oil. The graphite flake source material for the XM56 generator is a bulk powder that consists of platelet-shaped graphite particles of various sizes. The chemical composition of the bulk powder is predominantly carbon with trace impurities totaling less than 1% by weight. These trace impurities include small quantities of silica, aluminum, iron, calcium, titanium, and magnesium.

Graphite platelets in the bulk powder are predominantly smaller than 45 μm. The physical characteristics of graphite flake particles have been analyzed by scanning electron microscopy (unpublished data, M.W. Ligotke, PNL). Particles were roughly flake-like in shape, having one dimension much smaller than the other two. The largest flake dimensions were 10 to 20 μm. Flake thickness, although variable, typically ranged between 0.1 and 1 μm.

Fog Oil

Fog oils and other petroleum products have been used to provide white obscurant smokes. Currently, SGF-2 fog oil is used for year-round obscuration needs (U.S. Army CERL, 1986). The physical characteristics of fog oil are listed in Military Specification MIL-F-12070A. SGF-2 fog oil is a middle distillate product of crude petroleum oil. It is sometimes called "100 pale oil" because its viscosity is similar to that of SAE 20 motor oil. To be used as obscurants, distillates must be free of additives and meet the following requirements: flash point of 320 °F (minimum); Saybolt universal viscosity at 100 °F between 110 (maximum) and 100 (minimum); 0.1%

maximum carbon residue; 0.1 maximum neutralization number; and -40 °F maximum pour point. Because of the variety of crude oil source compositions, the variety of distilling and processing procedures, and the range of acceptable physical characteristics, individual batches of fog oil may differ in composition and appearance.

SGF-2 fog oil contains many hydrocarbon compounds, most of which are present in quantities less than 0.1%. No specific distribution of components can be listed, as individual batches of fog oil differ. An analysis of one sample indicated it to be about 50% aliphatic and 50% aromatic compounds (Ballou 1981), although the extent of the overlap between the compounds on the gas chromatography/mass spectroscopy (GC/MS) chromatogram was so large as to preclude identification of all but a few actual compounds. Katz et al. (1980) identified 42 to 60% of samples as aliphatics that included both straight and branched chain compounds with carbon numbers between C_{12} and C_{22}. The same study measured 2- and 3-membered ring aromatic compounds also ranging between C_{12} and C_{22}. Substituted indans, tetrahydronaphthalenes, naphthalenes, and biphenyls were the principal 2-membered ring compounds; phenanthrene, dihydrophenanthrenes, fluorenes, and acenaphthene were the 3-membered ring compounds identified.

Mixed Graphite Flake and Fog Oil

Data characterizing the physical condition of field-generated mixed aerosols of fog oil and graphite flakes are not available. The aerosols are expected to contain graphite flakes, fog oil droplets, volatile fog oil vapors, and graphite flakes coated with fog oil. The presence and extent of the fog oil coating on graphite flakes and the distribution of fog oil on the flakes as a function of flake size all depend on the degree of particle coagulation, which in turn depends on the relative generation rates, particle number concentrations, and residence times at high aerosol concentration. Because larger flakes deposit preferentially to the nasal and thoracic regions of the human respiratory tract, oil-coated flakes could cause increased oil exposures via this route.

The chemical stability of graphite flake particles coated with fog oil in the atmosphere and as surface deposits is not known.

Natural Dust

Information on the physical and chemical characteristics of surface dust from the candidate field sites is not available at present.

2.2.2 Toxicity

Graphite Flake

Pneumoconiosis has been reported in workers exposed to dusts containing natural or synthetic graphite (Hanoa 1983). However, fibrogenic constituents in the dusts inhaled by graphite workers, rather than the chemically inert graphite particles, may have been responsible for the pathogenesis. In animal studies by Martin et al. (1972) and Schlipkoter and Hilscher (1972), silica was implicated as the causative agent in mixed dust pneumoconiosis. In contrast, acute exposure studies with rats have demonstrated that graphite that lacked contaminating silica produced minimal, reversible pulmonary effects (Thompson et al. 1986, 1987; Anderson et al. 1987). Massive fibrosis has been observed, however, in workers exposed to quartz-free graphite atmospheres (Gaensler et al. 1966; Pendergrass et al. 1967). Apparently, fibrosis occurs when the amount of particles deposited in the lung overwhelms the ability of clearance mechanisms to remove the dust from the deep lung, and fibrotic lesions develop in response to the retained flakes. This mass loading effect was demonstrated for graphite dusts by Thompson et al. (1988). Rats exposed to 100 mg/m^3 graphite with less than 1% silica for 2 hours/day, 5 days/week, for 2 weeks

displayed pulmonary damage 3 months after the exposure. Possible reversibility of the effects was not monitored beyond the 3-month period.

Because the presence of crystalline silica in graphite and graphite products appears to increase fibrogenic potential, occupational exposure standards are currently based on the silica content of the dust. The American Conference of Governmental Industrial Hygienists (ACGIH 1986) has set the Threshold Limit Value (TLV) at 10 mg/m^3 total dust for synthetic graphite containing less than 1% free silica. This TLV is for a time-weighted average (TWA) exposure equivalent to an 8-h work day. For graphite dusts containing larger amounts of quartz, exposure must meet the appropriate TLV-TWA for silica to protect against respiratory fibrosis. The American Conference of Governmental Industrial Hygienists has issued a Notice of Intended Change for the graphite exposure standards that will limit occupational exposure to all forms of graphite (except fibers) to 2 mg/m^3 of the respirable fraction (ACGIH 1990). A more appropriate exposure limit for the type of exposures (single or episodic) experienced in field applications of obscurants is the short-term exposure limit (STEL). However, no acute exposure limits have been determined for graphite. Generally, short-term exposures should not exceed 5 times the TLV-TWA (5 times the TLV-TWA for graphite is 50 mg/m^3). If the 2-mg/m^3 TLV is applied, the potential STEL would be 10 mg/m^3. To avoid pulmonary damage, the short-term exposure should be less than the STEL.

The 30-min average airborne graphite flake and fog oil concentrations during obscurant dissemination trials were estimated to be less than 15 mg/m^3 at a downwind distance of 0.1 km (Section 3.1.1). Because these results are approximate and averaged over 30 min, it is probable that local events will cause short-term air concentrations exceeding the estimated STEL (50 mg/m^3) at distances downwind of the generator. These distances cannot be determined with certainty but should be less than 1 km (0.6 mi). It is unlikely, however, that an exposure within 1 km of the generator would last as long as the 15-min exposures upon which STELs are usually based. In addition, should graphite TLVs be changed to 2 mg/m^3 (Section 2.2.2), the resultant presumed STEL of 10 mg/m^3 can be expected to be exceeded within 1 km of the smoke generator.

The physico-mechanical properties of graphite flakes at high concentrations can cause injury to the skin and mucous membranes. Deposits in eyes, ears, and nasal passages may cause discomfort (ACGIH 1986). Rabbit eye/skin irritation tests with graphite were negative, and cutaneous toxicity studies in rabbits indicated that graphite has no effect via this route (Manthei et al. 1980).

Fog Oil

The TLV for oil mist is 5 mg/m^3. The STEL is 10 mg/m^3. Workers exposed to oil aerosols begin to complain at about 15 mg/m^3 (ACGIH 1986). Acute LC_{50} (the concentration at which 50% of test subjects died) occurs at or above about 10,000 mg/m^3 in most species studied (Muhly 1983). The LC_{50} for SGF-2 in rats is 5,200 mg/m^3 for 3.5 h of exposure. Acute and subchronic inhalation exposure to 1,500 mg/m^3 fog oil causes inflammation and edema in the lungs, although pulmonary function and gas exchange are not compromised (Grose et al. 1986). Subchronic exposure results is a progressive granulomatous lesion after the exposure has ceased (Grose et al. 1986). Induction of cytochrome by fog oil has been documented and may have significant implications in xenobiotic metabolism. Mutagenicity tests for SGF-2 were negative (Lee et al. 1989), and the oil has been shown not to be an eye irritant (Manthei et al. 1980).

Because of similar aerodynamic characteristics, the estimated maximum air concentrations of fog oil aerosols are similar to those for graphite (Appendix A, Figure A.3). As described above for graphite aerosols, the existence of air concentrations at or greater than the STEL are not anticipated at distances greater than 0.1 km from the generator, based on a 30-min averaging

period. Shorter-term concentrations may approach the STEL concentration at distances between 0.1 km and perhaps 1 km, but will likely be much less than 15 min in duration.

2.2.3 Environmental Fate

Graphite Flakes

Flakes may be deposited to soil, vegetation, or water. The fate of graphite flakes in soils and aquatic systems over long periods is not documented. The flakes may be incorporated into the soil surface, or may be resuspended by wind or mechanical disturbance (such as vehicular traffic or burrowing animals). Resuspension provides the potential for continued dispersal over a greater range than that of the initial deposition. Data on the resuspension of graphite flakes are not available; however, the potential for resuspension is greatest immediately after initial deposition and becomes small after the flakes are weathered and incorporated into the surface (especially after the first precipitation). Although specific rates are not known, the degree of resuspension from exposed surfaces and plant canopies could approach 100% prior to weathering, and flakes could be transported a few kilometers by ground resuspension, and longer distances from plant canopies (given that resuspension is most likely to occur during wind storms). After weathering has occurred, resuspension rates should be minimal.

Fog Oil

The short-term and long-term mobilities of fog oils have been addressed and ranked (Shinn et al. 1985). The results indicate that the dissolved organic components (presumably aromatics) in SGF-2 fog oil would be slightly mobile. Dissolution and dispersion of fog oil in natural waters depends on many complex factors, such as the amount of oil, water temperature, sunlight, mixing energy, presence of organic matter that can absorb oil hydrocarbons, and the degree of biotransformation (Liss-Suter and Villaume 1978; Poston et al. 1986). Photolytic reactions caused by exposure to sunlight may increase the soluble fraction of hydrocarbons in fog oils, which in turn increases the toxicity of the oil (Poston et al. 1986).

Fog oil aerosol residues deposited to soil surfaces are apparently volatilized rapidly (Cataldo et al. 1989). Depuration rates may differ in soils of differing porosity; finer-textured soils with more surface area may allow higher sorption and thus a high rate of initial volatilization. Coarser soils may allow more downward leaching of deposited residues and less initial volatilization (Cataldo et al. 1989). Thus, the relative retention of fog oil may vary by soil type. The hydrocarbons composing the fog oil residue are biodegradable and would be attenuated over time.

Mixed Graphite Flakes and Fog Oil

Deposition of mixed fog oil and graphite flake aerosol particles to ground surfaces will be similar to that of graphite flake aerosol (Section 4.1.1 and Appendix A) because the aerodynamic behavior of the mixed aerosol will be similar to that of a graphite flake aerosol. Resuspension of oil-coated graphite flakes from soil and vegetated surfaces will occur at lower rates than resuspension of uncoated graphite flakes; however, no supporting data are available for either case. Weathering processes that act to hold deposited particles to surfaces may be enhanced in the presence of fog oil because of liquid-phase adhesion and possible microbial degradation.

2.2.4 Regulatory Status

Air Quality

No national emission standards for hazardous air pollutants (NESHAPs) exist or are proposed for graphite (40 CFR 61). The Clean Air Act Amendments of 1990 do not identify graphite as a regulated source.

The Clean Air Act standards for particulate matter appear as national ambient air quality standards (NAAQS) in 40 CFR 50. The 24-h air concentration standard for particulate matter is 150 $\mu g/m^3$ (24-h average concentration). An area of approximately 64 km^2 in the southwest corner of YPG has been designated by the Arizona State Office of Air Quality as a non-attainment area for particulate matter under 10 μm in diameter. However, the proposed test sites lie well within the attainment area of YPG.

Carbon is neither a listed hazardous waste under the Resource Conservation and Recovery Act (RCRA) nor a hazardous substance under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

On March 29, 1990, the U.S. Environmental Protection Agency (EPA) published its toxicity characteristic leaching procedure (TCLP) final rule (55 FR 11798-11877). This rule replaced the extraction procedure (EP) toxicity test for use in determining whether a waste stream exhibits the toxicity characteristic, added 25 organic compounds to the list of toxic constituents, and set regulatory levels based on health-based concentration limits. Carbon is not a TCLP-listed constituent. Emergency Planning and Community Right to Know Act provisions are not applicable to carbon.

Fog oil is not subject to regulation as a criteria pollutant under the Clean Air Act. Nor are there NESHAPs for fog oil under the existing regulations of the Clean Air Act. Also, cyclic alkanes are also not listed as pollutants to be regulated in the 1990 amendments to the Clean Air Act. Constituents of fog oil in sufficient quantity may cause fog oil to be regulated; however, the obscurant tests will not result in regulated emissions. For example, emissions of volatile organic compounds from a point source in excess of 40 tons per year are regulated under the prevention of significant deterioration (PSD) regulations in 40 CFR 52.21. Standards of performance for vessels storing petroleum products that emit volatile organic compounds may be applicable if the capacity of the storage vessel is sufficiently large (40 CFR 60.110). The quantities included in these considerations are not expected during the planned YPG tests.

Reactions involving hydrocarbons, nitrogen oxides, oxygen, and sunlight produce chemically and biologically active compounds that are potentially harmful to health and environment. Air quality standards are related to the major toxic product of these reactions, ozone. The national standard for ozone is 235 $\mu g/m^3$ (not to be exceeded for more than one hour per year).

Water Quality

Discharges of oil into or upon the navigable waters (to include interstate wetlands, rivers, and streams) of the United States that violate water quality standards or cause a film or sheen on the surface of the water are prohibited (40 CFR 110.3-110.6). However, procedures and other requirements have been established to prevent the discharge of harmful quantities of oil into navigable waters from facilities that store and consume oil (40 CFR 112.1). A determination must be made to assess whether the facility that stores the fog oil could, due to its geographic location, discharge oil into navigable waters. Further investigation is required to determine whether a Spill Prevention Control and Countermeasure (SPCC) Plan is required.

Runoff to a sewer may create a fire or explosion hazard (OSHA). However, no "point discharge" of pollutants to waters of the United States is expected to occur as a result of testing and demonstrating the fog oil. Therefore, a national pollutant discharge elimination system (NPDES) permit under the Clean Water Act will not be required. Given that the fog oil will be tested on a military installation, it is not likely that the fog oil will affect any community water supply system, and so the Safe Drinking Water Act (SDWA) national primary drinking water regulations are not

applicable. An underground injection control permit is not required because underground injection of the fog oil is not planned.

Hazardous Substances and Hazardous Waste

Under CERCLA regulations, Section 101(14)(F), the definition of hazardous substance excludes "petroleum, including crude oil or any fraction thereof." Under RCRA, mineral oil (similar to fog oil) does not meet any of the characteristic of a hazardous waste and is not a listed constituent in the TCLP.

Mineral oil is not listed as a hazardous material under regulations of the Hazardous Materials Transportation Act (HMTA) in 49 CFR 171-179. However, under the HMTA, oil is classified as a flammable and combustible liquid subject to the labeling, packaging, and transportation requirements.

An assessment of the region where the fog oil is demonstrated and tested should be conducted to determine whether any threatened or endangered species or their habitats will be affected.

Arizona has been authorized by the EPA to regulate air quality in Arizona through the Arizona State Implementation Plan and to administer the base RCRA program, but not to administer the NPDES program. Neither the use of graphite nor the use of fog oil on the YPG is likely to exceed standards in the relevant regulations.

2.3 TEST PROCEDURES

The objective of the XM56 road test is to demonstrate the capability of the generator to produce a mixed smoke obscurant under arid conditions. Three XM56 smoke generators mounted on M1037 vehicles will be driven on a road course for a total of 100 h, and a single vehicle will be used approximately daily to generate a mixed fog oil and graphite flake smoke for 30 min from a stationary location. A total of 120 min of mixed smoke generation is planned. Two methods of generating a dust cloud from ground deposits will be performed separately. A draft copy of the proposed test plan, titled "Test Plan for the Production Prove Out Test-Government (PPT-G) of the Generator, Smoke, Mechanical: Motorized for Dual Purpose Unit, XM56 at Yuma Proving Ground" and dated June 1991, was used in the preparation of this environmental assessment.

2.3.1 Location of Test Sites

A sketch showing the location of YPG in the southwest corner of Arizona is presented in Figure 1. The figure also shows adjacent cities, highways, rivers, and national wildlife refuges. Within the boundaries of YPG are shown the approximate locations of seven potential test sites (labeled A through G). An additional test site, the Castle Dome Heliport, is not shown, but it was reportedly used previously by Dugway Proving Ground (DPG) personnel. An unpublished study performed by DPG in 1985 recommended only Sites F and G for smoke tests (reported by Allan and Wheeler, 1991). Sites A through E were rejected primarily because of uneven terrain and dense vegetation. Other reasons for rejecting Sites A and B included time of travel from the main base, required road construction, and proximity to artillery testing.

The Hellfire Test Site (Site F) is a relatively flat malpais area with little vegetation, according to the DPG assessment. It could be used for small-scale tests that require lines of sight shorter than 0.7 km. The site is about 72 km (45 mi) from the YPG main post. There are no electrical power or other utilities near the site. Use of the site for smoke testing could potentially interfere with the YPG laser tracking system; however, smoke tests could be scheduled to avoid interfering with the system. The nearest known staffed area is 20 km to the south.

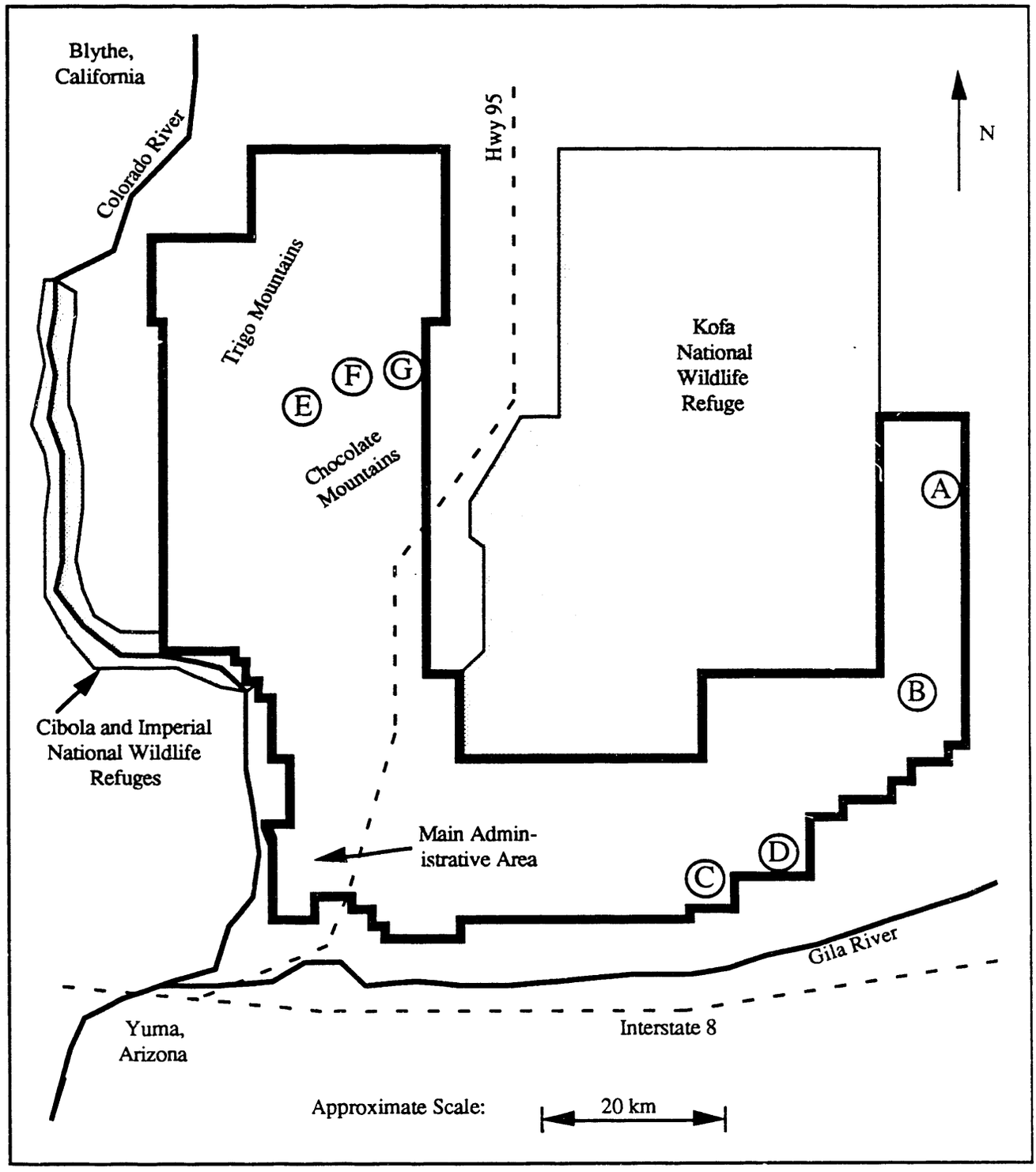

FIGURE 1. A Sketch of the U.S. Army Yuma Proving Ground and Surrounding Areas. The approximate locations of proposed field test sites A through G are also shown. Sites A through G were assessed by DPG staff in 1985. The Hellfire Test Site (Site F) and the Tyson Drop Zone (Site G) were recommended for smoke tests. The other potential sites were rejected.

The Tyson Drop Zone (Site G) is located east of the Hellfire Test Site, closer to the boundary of YPG. According to the DPG assessment, the Tyson Drop Zone is a malpais terrain with a flat area large enough to set up a 1.5-km square test grid with little removal of vegetation. Other site characteristics were reported to be similar to those at the Hellfire Test Site. Specific site landforms and geology are described in Section 2.5.2.

The Tyson Drop Zone is located about 7 km (4.5 mi) west of Hwy 95 on the Corral Road. The Cibola Lake Road branches off from the Corral Road about 1.5 km east of the Tyson Drop Zone and passes generally west-northwest in the area north of the test sites. The Hellfire Test Site is located in an indeterminate region west-southwest of the Tyson Drop Zone. Both sites are located on relatively flat terrain at an average elevation of about 420 m (1,400 ft). The boundary of YPG is within 2 km east of the Tyson Drop Zone. Although airborne concentrations of smoke particles should be low, public access to the Cibola Lake Road (north of the Hellfire Test Site) and travel on the Corral Road should be restricted or regulated during testing.

2.3.2 Dissemination

Dissemination of graphite flake and fog oil obscurant aerosols is a part of the test. Dissemination is planned to occur four times during the planned road test of three M1037 vehicles (HMMWV) mounted with XM56 dual-purpose smoke generators. Each vehicle will be subjected to the 100-h road test. The road test will include travel on primary and secondary roads and cross-country for 20 h of each 25-h period. Smoke generation will be performed at 25-h intervals, using a single stationary vehicle. The duration of each smoke-generation period is planned to be 30 min, for a total of 120 min of generation.

Graphite flakes will be generated at a nominal rate of 4.5 kg/min (10 lb/min), and fog oil at 302 L/h (80 gal/h). Generation of both obscurant aerosols will be performed simultaneously from the same vehicle. The total planned release of material is 545 kg (1200 lb) of graphite flake, and 605 L (160 gal) of fog oil. Graphite flake aerosols are generated mechanically using finely ground graphite and an air ejector. Fog oil aerosols are generated by vaporizing liquid fog oil in hot vehicle exhaust gases. Graphite flake aerosols consist of clouds of platelet-shaped solid particles, and fog oil aerosols consist of recondensed oil droplet clouds having less than about 1% vapor. Mixed graphite and fog oil aerosols have not been characterized, but are anticipated to include oil-coated graphite platelets in addition to single-material particles. See Section 2.2.1 for additional information. Predicted air concentrations and surface loadings are discussed in Section 3.1.1 and Appendix A.

2.3.3 Meteorological Requirements

Testing limitations presented by both normal and extreme meteorological conditions include the potential for flash flooding, rainy days not suitable for videotaping tests, and high temperatures. (Flash flooding may occur from the Chocolate Mountains via at least three drainage washes; a site survey should be performed to ascertain other possible flooding risks.) The development of an unstable atmosphere is a near certainty within several hours of sunrise on clear days due to the solar heating of the desert surface. This decreased atmospheric stability will in turn decrease the continuity of smoke plumes. Overcast conditions may decrease the visual contrast necessary for video documentation of the tests; however, cloud cover will increase atmospheric stability and thus contribute to conditions favoring the development of continuous smoke plumes. (see Section 2.5.1 for a description of the local climate).

2.4 ALTERNATIVES TO THE PROPOSED ACTION

Alternatives to the proposed field tests include no action (not testing), performing the tests at reduced scale, or performing the tests at another site.

2.4.1 No Action: Not Testing

A Production Prove Out Test is required by the U.S. Army to continue the development of the XM56 smoke generator. The test must be performed to provide data for a Technical Readiness Review that will determine whether the XM56 is ready to proceed to Pre-Production Qualification Testing. As a consequence, testing must be performed to prevent fielding an improperly designed production system.

2.4.2 Reducing Scale of Test

Tests at reduced scale can sometimes be substituted for full-scale tests. However, it is not feasible to reduce the scale of the planned XM56 smoke generator tests. To accurately represent actual operational characteristics, the generator must be tested at full-scale smoke production rates. Tests performed at reduced scale could fail to reveal system shortcomings that must be determined early in the design/production process for design changes to be cost effective.

2.4.3 Testing at Another Site

Full-scale tests of the XM56 generator may be performed at a variety of field sites and at one compatible wind tunnel. An arid site is required as one of three test sites. YPG provides arid conditions with reliable hot temperatures (105 °F) for 22 to 25 days during August and is suitable for smoke testing. The use of an alternative site may also be feasible, but no such site has been identified. Tests performed in a wind tunnel such as the CRDEC's BREEZE facility might provide an alternative (the wind tunnel can filter full-scale graphite flake emissions from an XM56); however, control of temperature and humidity is not practical.

2.5 THE AFFECTED ENVIRONMENT

The environment that will be impacted by the proposed tests consists of climate and air quality, the land and its geology, soil, vegetation, wildlife, scarce surface waters, and socioeconomic and cultural resources. Outside the boundaries of YPG, the Colorado River, Highway 95, and three national wildlife refuges are within a 40-km radius of the proposed test sites. The baseline, or pre-test status of environmental factors is discussed in this section.

2.5.1 Climate and Air Quality

The climate of YPG is classified as arid desert. The primary meteorological conditions influencing the proposed tests include wind speed, precipitation, cloud cover, and temperature. Average and extreme meteorological conditions for the Yuma area have been tabulated by the National Oceanic and Atmospheric Administration (NOAA 1983) for the city of Yuma and its airport (latitude 32°40' N, longitude 114°36' W). This location is approximately 80 km (50 mi) south-southwest of the proposed test sites. The prevailing wind direction between June and September is south-southeast, although strong winds have also been recorded from the southwest, southeast, east, and northeast during this period. The average wind speed is 12 to 15 km/h (7.3 to 9.5 mph) during this part of the year. August is the wettest month, with 1.1 cm (0.42 in.) average precipitation, and June is the driest with 0.03 cm (0.01 in.). High-intensity storms occur in August; more than 2.5 cm (1 in.) of rainfall has been recorded 8 times in the past 40 years, and 6.4 to 7.6 cm (2.5 to 3 in.) of rainfall has occurred twice (in 1977 and 1983). High-intensity rainstorms are associated with flash flooding in arroyos. In August, typically 22 days are clear, 6 are partly cloudy, and 3 are cloudy. Temperatures range between average daily minima of 22 to 27 °C (71 to 80 °F) and average daily maxima of 38 to 42 °C (101 to 107 °F) between June and September. The average daily minimum and maximum temperatures during August are 27 and 41 °C (80 and 105 °F), respectively. Temperature extremes for August range between 17 and

49 °C (63 and 120 °F). Relative humidities are higher than might be expected because of moist air drawn north from the Gulf of California, or perhaps from the Gulf of Mexico. Average humidities in August are 56% (predawn) and 24% (late afternoon).

Some climatic conditions are also monitored at the YPG by the Central Meteorological Observatory (CMO), located near the Main Administrative Area. An unpublished summary of climatological data is available from the CMO for the period 1954 to 1990. Selected data from the summary are listed in Appendix B. The greatest occurrence of winds is during April through August. During the summer, surface winds are generally light, averaging either 7 km/h (4.5 mph) as reported by the CMO, or about 15 km/h (~10 mph) as reported by the U.S. Army Corps of Engineers (USACOE 1987). The prevailing wind direction is southwest during the summer, but wind directions typically range between southeast and southwest. Rainfall generally occurs during two rainy seasons, one between early July and mid-September, and the other between early November and mid-February. The summer rainy season is the result of storms associated with pressure systems from the Gulf of Mexico. August is the wettest month, with an average rainfall of 1.4 cm (0.57 in.), which is 16% of the average yearly total; thunderstorms occur an average of 4 days during the month. Minimum and maximum temperatures are 26 and 40 °C (79 and 104 °F) during August. Minimum and maximum relative humidities at YPG during August are 25 and 52%.

Background air quality at YPG is generally good, except that dust particle concentrations may exceed standards because of agricultural operations and convective conditions (a portion of the southwest corner of YPG has been designated a non-attainment zone for particulate matter by the Arizona State Office of Air Quality). Sandstorms and dust storms can occur during any month and frequently reduce visibility to 5 to 8 km, but they are of short duration. Temperature inversions extending 200 to 500 m above ground level may develop and persist well into the morning (Dial and Hemion 1981). The combination of low wind speeds and temperature inversions tends to limit dispersion rates of airborne contaminants.

2.5.2 Land and Geology

YPG is located in the area between the Sonoran Desert and the Salton Trough sections of the Basin and Range physiographic province and is characterized by low, northwest-trending mountains separated by desert plains. Elongated wide basins separated by usually narrow mountain ranges are typical of YPG and adjacent areas (USACOE 1987). The Hellfire Test Site and the Tyson Drop Zone are located within the North Cibola Range (north of the Chocolate Mountains). The Kofa National Wildlife Refuge is situated between the two arms of YPG (to the east of the proposed test sites), and the Imperial and Cibola National Wildlife Refuges are located along the shores of the Colorado River to the west (see Figure 1).

The Tyson Drop Zone (Site G) is located about 7 km (4.5 mi) west of Hwy 95 on the Corral Road. The Cibola Lake Road branches off from the Corral Road about 1.5 km east of the Tyson Drop Zone and passes generally west-northwest in the area to the north of the test sites. The Hellfire Test Site (Site F) is located in an indeterminate region west-southwest of the Tyson Drop Zone. The sites are located on relatively flat terrain at an average elevation of about 420 m (1,400 ft). The area is represented on a portion of the Trigo Peaks, Arizona, 15' topographic map (Sheet 3150 IV, Defense Mapping Agency, Hydrographic/Topographic Center, Washington, D.C.). Predominant geographical features near the sites include the Chocolate Mountains to the south and the Trigo Mountains to the west and northwest. Felipe Hill, 620 m (2,050 ft) in elevation, is located about 2 km northwest of the Tyson Drop Zone. A watershed divide runs roughly north-northwest from the site, with the region to the north and northeast of the test site generally being drained by Tyson Wash, and the area west and northwest of the test site being drained by Mohave Wash. Trigo Wash drains the area beginning about 8 km (5 mi) to the northwest of the test sites (its watershed is located north of that of Mohave Wash). Gould Wash drains the area to the southwest of the test sites. All drainage washes are intermittent and may have

running surface water only after heavy rainstorms. Watersheds west of the test sites connect to the Colorado River, a straight-line distance of about 36 km (22 mi).

2.5.3 Soil

Soils at YPG are hyperthermic arid, according to the Soil Conservation Service, U.S. Department of Agriculture (USACOE 1987). This soil type occurs in environments with mean annual soil temperatures of at least 22 °C and with more than 5 °C difference between mean summer and winter temperatures at a depth of 51 cm or to bedrock. The YPG area lacks sufficient precipitation for the soils to produce crops unless irrigation is provided. These soils support plants and shrubs typical of the Sonoran Desert (USACOE 1987).

Soil development is poor in this arid environment, and mechanical weathering predominates on most types of bedrock. Chemical weathering is slow and limited. The bedrock is generally close to the surface or widely exposed with corresponding shallow soils and weathering mantle. Soils are thin and stony in the bedrock mountains and thick in the intervening lowland basins. Gravelly materials are very common over most of YPG. They form Reg and Hammada series of soils and desert pavement where the surface is greater than 40% gravel cover overlying a fine soil horizon (USACOE 1987).

2.5.4 Water

No perennial surface lakes or streams exist within the YPG boundaries. During periods of intense rainfall, ponding and flash flooding occur. Natural rock tanks occur in the more mountainous regions but are dry during the long periods without rainfall. Precipitation records from 1935 to 1980 indicated an average rainfall of 8.4 cm per year (3.3 cm per year) and an evaporation rate of 272 cm per year (107 cm per year). The combination of low precipitation and high evaporation may prevent deep infiltration of surface water and surface-deposited materials (USACOE 1987). Surface runoff that does not evaporate is transported to the Gila and Colorado rivers. Surface drainage from the western portion of YPG (including the two test sites) flows toward the Colorado River. Artificial structures that provide water for wildlife are the only known perennial water sources in the North Cibola Range. The nearest of these structures is about 10 km (6.2 mi) north-northwest of the test sites.

2.5.5 Vegetation

The flora of YPG is typical of a southwestern U.S. Sonoran Desert ecosystem. Based on the Merriam Life-Zone System, the area is classified as Arizona Upland and Lower Colorado subdivisions of the Lower Sonoran Zone (Lowe 1964). Two Lower Sonoran Zone plant communities, the Creosote-Bursage Community and the Paloverde-Mixed Cacti Community, are found in the vicinity of the test sites (including the probable downwind dispersion area). Two discrete plant associations are found within both communities. Most of the land in the proposed test sites supports the Creosote-White Bursage (*Larrea tridentata-Ambrosia dumosa*) Association, which is characteristic of the flat watersheds throughout YPG. Plant density is low in this association, but overall biological productivity is high due to the abundant growth of annual plant species. The second creosote association, the Creosote-Ocotillo (*Fouquieria splendens*) Association, is found in a relatively small area of the proposed test sites. The distinct plant association of the Paloverde-Mixed Cacti Community found in the vicinity of the proposed test sites is the Foothill Paloverde-Ironwood (*Olneya tesota*) Association. Saguaro, cholla, and hedgehog cactus (*Echinocereus* spp.) are common in this association . The Paloverde-Ironwood Association occupies the long, gently sloping bajadas adjacent to the montane Paloverde-Saguaro (*Cereus giganteus*) Association, which occurs on the slopes of Felipe Hill. The area downwind of the test sites supports the Foothill Paloverde-Mixed Cacti Association.

No endangered or threatened plant species occur on or downwind of the proposed test sites. However, the area may support one Category 1, two Category 2, and one Category 3 plant species that are candidates for listing as Threatened or Endangered Species by the U.S. Fish and Wildlife Service. The Category 1 species [Acuna cactus (*Echinomasus erectocentrus* var. *acunensis*)] and the Category 2 species [Agave cactus (*Agave schotti* var. *treleasii*) and Pringle lip fern (*Cheilanthes pringlei*)] occur in foothill habitats like those in and downwind of the test sites, but they have not been reported in the area (USACOE 1987). The Category 3 night-blooming cereus (*Cereus greggii)* prefers elevations above 1000 feet and has been found in alluvial washes north and west of the Hellfire Test Site, although no cereus has been reported on the site in previous surveys (USACOE 1987). Recently, the night-blooming cereus has been observed at the Tyson Drop Zone. This species has been designated by the U.S. Fish and Wildlife Service (USFWS) as a Category 3C species (i.e., more abundant than formerly thought) and is classified under Arizona Native Plant regulations as a "highly safeguarded native plant."

2.5.6 Wildlife

Wildlife inhabiting YPG is typical of most southwestern U.S. desert lands. Animal habitats are closely correlated with the plant associations described in Section 2.5.5. The plant associations of the Creosote-Bursage Community support several rodent species, the kit fox (*Vulpes macrotis*), mule deer (*Odocoileus hemionus*), Gila woodpecker (*Melanerpes uropygialis*), loggerhead shrike (*Lanius ludovicianus*), several passerine bird species, high densities of numerous species of reptiles, and two species of toad [Couch's spadefoot toad and the red-spotted toad (*Scaphiopus couchi* and *Bufo punctatus*)] during periods of adequate seasonal rainfall. Animals found in the Paloverde-Mixed Cacti Community include small rodents (predominantly the Arizona pocket mouse, *Perognathus longimembris*), bobcat (*Felis rufus*), gray fox (*Urocyon cinereoargenteus*), mule deer, Couch's spadefoot toad, and the red-spotted toad, as well as a high diversity and abundance of reptile and avian species. The desert tortoise (*Gopherus agassizii*) may be associated with the foothill areas on and downwind of the proposed test sites, although no sightings in this area have been reported. The tortoise is an Arizona State candidate species and is federally listed for the YPG areas as threatened.

2.5.7 Socioeconomic Factors

The major source of employment in Yuma County is agriculture, followed by wholesale and retail trade and government. YPG employees provide a large fraction of the area's income and contribute to the use of recreational resources.

2.5.8 Cultural Resources

Prehistoric archaeological resources have been found throughout YPG. Field surveys by the Los Angeles District of the U.S. Army Corps of Engineers (Farrell 1984; Schiltz and Clevenger 1985; Effland and Schilz 1986, 1987a,b) have described prehistoric site distributions for some areas of the Cibola Range, but many areas remain unsurveyed. Numerous historic archaeological sites have also been identified in the Cibola area (Hoffman 1984) and may be eligible for inclusion in the National Register of Historic Places. No recent ethnographic studies have been conducted in the area, and therefore the presence of traditional cultural and religious sites is unknown (USACOE 1987).

The proposed project areas, Hellfire Test Site and Tyson Drop Zone, have high potential for presence of prehistoric cultural resources. In 1987 and 1988, archaeological surveys were conducted in the North Cibola Range in the project vicinity. As a result of these investigations, 16 prehistoric and 1 historic cultural resource were identified.

3.0 ENVIRONMENTAL CONSEQUENCES OF THE PROPOSED ACTION AND PROPOSED ALTERNATIVES

The perceived impact of the planned tests, mitigation alternatives, and potential environmental consequences of alternatives to the planned tests are discussed in this section. Both expected, or average, conditions and extreme, or unusual, conditions are considered in determining the impact of the tests on the YPG environment.

3.1 ENVIRONMENTAL CONSEQUENCES OF THE PROPOSED ACTION

The proposed releases of graphite flake and fog oil obscurant aerosols have the potential to impact the environment of the North Cibola Range (the western arm of YPG, north of the Chocolate Mountains). Consideration of the environmental fate of the materials, and their impact on air quality, soil and vegetation, water, wildlife, and socioeconomic and cultural resources are presented in this section.

3.1.1 Environmental Fate of Obscurant Materials

The fate of graphite flake and fog oil material in the YPG environment involves both the distribution of material that results from the testing (air concentrations and surface deposits) and the persistence, degradation, and mobility of the deposited materials.

The distributions of graphite flake and fog oil aerosols downwind of the point of generation were estimated for several sets of atmospheric conditions using the Real-Time Volume Source Dispersion Model (RTVSM). Details of these calculations and descriptive figures are presented in Appendix A. In summary, 30-min average air concentrations of both graphite flake and fog oil aerosols are expected to range approximately between 0 and 15 mg/m^3 at a downwind distance of 0.1 km, between 0.1 and 1 mg/m^3 at 1 km, and between about 0.001 and 0.07 mg/m^3 at 10 km. In general, the concentrations during overcast conditions [atmospheric stability category (ASC) D], are anticipated to be greater than those during sunny or partly cloudy conditions (ASC A, B, and C). The difference is caused by greater thermal mixing during sunny conditions and is increasingly important with increasing downwind distance.

The deposition of graphite flake and fog oil materials to YPG surfaces downwind of the point of release were estimated for the various atmospheric conditions. Estimated deposition loading levels were greatly influenced by atmospheric stability category and plume height. In summary (for 120 min of smoke generation), deposition level estimates for fog oil range between 0 and 80 mg/m^2 at a distance of 0.1 km, between 0.6 and 6 mg/m^2 at 1 km, and between ~ 0.007 and 0.4 mg/m^2 at 10 km. Similar summary deposition level estimates for graphite flakes range between 0 and 25 g/m^2 at 0.1 km, between 25 and 250 mg/m^2 at 1 km, and between 0.1 and 4 mg/m^2 at 10 km. Estimated deposition levels were generally greater for cloudy conditions and were enhanced by corresponding decreased atmospheric dispersion.

The maximum probable, or worst-case, surface deposition levels were estimated based on 120 min of continuous smoke generation. Maximum surface deposition will occur under the center-line of the smoke plume. Peak worst-case deposition is likely to occur within a 90° arc bounded by the directions northwest and northeast as measured from the smoke generator. This conclusion is based on prevailing wind direction data available for YPG in August. For fog oil, estimated maximum surface loading levels decrease from 8 to 0.01 $\mu g/cm^2$ at downwind distances from 0.1 to 40 km. For graphite flakes, estimated maximum surface loading levels decrease from 1,000 to 0.01 $\mu g/cm^2$ as downwind distance increases from 0.2 to about 45 km. Surface deposition levels of graphite flakes are expected to exceed those of fog oil within about 40 km of the generator.

The environmental fates of graphite and fog oil are discussed in Section 2.2.3. Impacts of contact between the materials and the environment are discussed below. Revolatilization of fog oil and resuspension of loose graphite flakes, especially during wind storms, pose a chance that the materials will migrate from the original test site. However, the quantities of deposited materials are small, and rates of resuspension are expected to nearly cease as fog oil is degraded and graphite is incorporated into the soil column. In addition, during the period immediately following deposition, the presence of fog oil may act to increase the surface adhesion of graphite flakes.

3.1.2 Air Quality

Particulate levels from the planned tests and from fugitive dust from vehicle movement is not expected to have significant effect on the air quality of the area. Neither the 5-min tests to generate dust clouds nor the 30-min graphite flakes and fog oil tests will cause an excursion above the federal and local ambient air quality standards for particulate matter (235 $\mu g/m^3$ maximum 24-h average concentration not to be exceeded more than once per year). The release of fog oil during the tests will result in ozone levels considerably lower than the national standard for ozone (235 $\mu g/m^3$ not to be exceeded one hour per year). The U.S. Army Environmental Coordinator should be consulted for coordinating the tests with local regulatory agencies as required.

3.1.3 Soil

Soil microbial populations play a critical role in decomposing organic matter and in the cycling of important nutrients (nitrogen, phosphorus, sulfur, and some trace metals). Microbial decomposition processes in the soil can also detoxify xenobiotic chemicals. Any physical or chemical perturbation to the soil system that impacts the microbial processes also impacts the soil system and vegetation. Cataldo et al. (1989) reported no deleterious effects of fog oil residues on soil microbial activity. Cumulative doses of fog oil exposure had no deleterious effect on soil respiration, the activity of nitrobacter populations, or soil dehydrogenase activity.

Earthworm (*Eisenia foetida*) bioassays conducted with fog oil residues (Cataldo et al. 1989) showed no adverse effects of fog oil with exposure up to 800 $\mu g/cm^2$ soil. Earthworm survival *in vitro* where fog oil was uniformly amended to the soil was 100% until soil concentrations exceeded 3,600 $\mu g/cm^2$. Predicted maximum surface deposition rates for a 120-min release of fog oil is 30 $\mu g/cm^2$. Because this level is much less than those shown to be toxic, no impacts to soil invertebrates are not anticipated.

Studies of the toxicity of graphite flakes with earthworms indicated that the flakes were not toxic to soil invertebrates at concentrations up to 1% graphite by weight incorporated into soil (Bowser et al. 1989). No information is available on the effects of graphite flakes on the soil microbial community.

The effect of combined deposits of graphite and fog oil on soil microbes and invertebrates is unknown. Deposition of fog oil-coated graphite flakes to soil may lower resuspension rates (i.e., the fog oil acts to bond or adhere the flakes to the surface) and increase the potential for crusts to form on soil surfaces. A crust of flake material would be expected to change the energy balance in the affected area. Such a change would probably entail an increase in heat loading to the surface depending on surface conditions and climatic factors. Crusts can also inhibit seed germination and seedling emergence, but such effects are not anticipated because of the degradation of the fog oil component and the anticipated susceptibility of graphite crusts to erosive stresses such as sand-particle saltation during windy periods (Woodruff and Siddoway 1965).

3.1.4 Water

The proposed action should not have an adverse impact on surface water or groundwater at YPG. No surface-water systems are on or downwind of the test sites. Net movement of water in the desert climate is upward (272 cm/yr evaporation vs. 8 cm of precipitation); therefore the obscurants should not reach underground aquifers. In addition, fog oil is only slightly soluble in water and is biodegradable by soil microorganisms, further reducing the chances of contaminating water systems by this obscurant.

3.1.5 Vegetation

Few studies have been undertaken to determine the toxicity of graphite flakes to plants. One unpublished study by C. Phillips and R. Wentsel, was conducted to determine the potential toxicity of graphite flakes to terrestrial plants. The results of the study showed that graphite flakes do not have an adverse effect on vegetation when field-release concentrations are at or less than 0.5% by weight in the soil. The proposed graphite generation tests would result in a maximum soil concentration of 0.005% (located within 200 m of the smoke generator; see Appendix A, Table A.5), assuming total incorporation of deposited particulate into the soil to the depth of a typical rhizosphere (15 cm) and a soil bulk density of 1.25 g/cm^3 (Brady 1974). Even if the rhizosphere were 1.5 cm in depth for shallow-rooted plants, the soil concentration would be only 0.05%. These values are much less than those causing adverse effects to plants.

Deposition and accumulation of fog oil on soils can cause indirect effects on plant growth (Cataldo et al. 1989). Although few visual symptoms of toxicity appeared, plant biomass production was reduced when plants were grown at low humidity levels (20%) in soils exposed to fog oils. These studies showed no effect of fog oil residues on seed germination or soil nutrient levels. Chlorosis, necrotic spotting of foliage, and leaf or needle burn result from deposited doses of 100 to 500 µg fog oil/cm^2 of soil (Cataldo et al. 1989). In general, older growth is affected more severely than younger growth and effects are more severe for a perennial grass species than for woody species (Cataldo et al. 1989). The maximum fog oil deposition during the proposed tests is estimated to be 10 to 30 mg/m^3 (Appendix A, Table A.5), which is below the deposition rates causing sublethal damage.

When generated with fog oil, deposits of graphite flakes may be expected to be made at rates greater than those in the absence of fog oil because of the contact attraction of oil-coated surfaces. This was found to be the case for fog oil and brass obscurant mixtures (Cataldo et al. 1990). In general, the addition of fog oil to the aerosol would also be expected to increase the residence time of graphite flakes on vegetation and soil surfaces (Section 3.1.1). Although no data are available on the phytotoxicity of combined graphite and fog oil exposure, the low concentrations dispersed during the proposed tests, compared to the much higher levels of exposure required to cause phytotoxic response, suggest that the impact of the combined obscurants will be negligible to plant communities on YPG.

3.1.6 Wildlife and Threatened and Endangered Species

Most animals in the area survive by avoiding extreme heat during the summer. Many of the animal species that use the proposed test site are nocturnal and therefore will not be active during the obscurant generation tests. Human activity during the tests will cause most non-burrowing wildlife species that are active during the day to avoid the immediate area where deposition and airborne concentrations of the obscurants are at potentially harmful levels. Care must be taken to avoid habitats occupied by the desert tortoise and to minimize human disturbance, to which the tortoise is very susceptible. If a protected species occurs on the site selected, YPG will proceed

with consultation as directed by the Endangered Species Act of 1973, as amended, and will modify the project, if necessary, to prevent jeopardy to the protected species.

Wildlife remaining within about 1 km of the smoke generator may inhale potentially harmful levels of graphite or fog oil (Section 2.2.2). This assumes that wild animals have about the same sensitivity to air pollutants as humans and receive, on a body weight basis, equivalent doses in the environment. However, it has been shown that the volume of air breathed per minute per unit of body weight (i.e., the weight-specific minute ventilation) varies greatly among mammals (Phalen 1984). In general, small active mammals and birds have higher weight-specific ventilation rates than humans. Seasonal physiological changes, activities (e.g., flying), differences in breathing zones (e.g., near the turbulent ground surface or in burrows), and greatly varying home ranges further complicate the extrapolation of human STELs to wild animals. Therefore, the STELs for humans should be viewed as relative estimates of the safe limits for wildlife in field situations.

There are no data available specifically on the toxicity of fog oil obscurant aerosols on wildlife. Information on the toxic effects of oil to wildlife is generated from oil spills. The acute oral LD50 is 16 ml/kg diesel oil for rats (Starek et al. 1975). Oral ingestion of 5 to 20 ml/kg of mineral oil by rodents resulted in weight loss and histopathological lesions of the liver, spleen, and kidney. Death occurred in all animals by 10 days (Brahmachari 1958). However, intragastric administration of 24 ml/kg of diesel fuel did not result in mortalities to ducks (Hartung and Hunt 1966). Under temperature stress, the LD50 was 4 ml/kg for ducks administered diesel fuel intragastrically (Hartung and Hunt 1966). Sublethal effects have been observed in ducks receiving intragastric doses of 3 to 12 ml/kg of diesel fuel. Oral administration of 3.5 mg/kg No. 2 diesel fuel oil to quail interrupted egg production and produced egg yolk deposition anomalies (Grau 1977). Oral uptake of fog oil by wildlife feeding on oil-contaminated plants in the proposed test sites can be estimated using a forage consumption factor of 3% of the body weight (Buck et al. 1976). Assuming an edible biomass of 50 g/m^2 in Sonoran plant communities (W. Rickard, PNL, personal communication), the expected consumption of deposited oil at 500 m from the smoke generator would be less than 2 mg/kg. It would be unlikely that consumption of vegetation beyond 500 m would impact wildlife populations. However, closer to the generator, oil consumption could be 20 mg/kg at 200 m, and as high as 200 mg/kg at less than 100 m. These levels would pose a threat to foraging wildlife until deposits are diminished by evaporation and degradation. This estimate of oral uptake does not take into account indirect ingestion via grooming/preening activity. No data are available on the ingestion of fog oil-coated graphite. Oil-coated graphite may form a crust on vegetation surfaces altering leaf temperature, transpiration, and photosynthetic processes and changing the air/surface boundary layer. Such alterations may lead to reduced plant biomass for consumption by wildlife. Unpalatability of coated vegetation may also reduce available food sources. However, the area where deposition of the obscurants would be great enough to significantly decrease food resources is relatively small, and any food reductions would probably cause only transient changes in population density and diversity.

3.1.7 Socioeconomic Factors

Because there is no prime farmland at YPG, and because the tests are not likely to impact any farmland outside YPG, farmland impacts are not addressed for this action.

The proposed action is a small test that will not have a significant impact on the socio-economic structure of the area. No recreational resources are expected to be impacted by this test.

3.1.8 Cultural Resources

Prior to any ground-disturbing activities in the project area, all previously recorded cultural resources must be inspected and their present conditions assessed. Unsurveyed portions of project areas must be intensively surveyed prior to ground-disturbing activities.

Significant cultural resources will be avoided if possible. If cultural resources are found, they will be protected and left undisturbed by test participants, in accordance with Army Regulation 420-40. This shall be the responsibility of the YPG Archaeological Officer. Determinations of effect and mitigation plans will be developed with the State Historic Preservation Officer. This will ensure compliance with Section 106 of the National Historic Preservation Act.

3.2 HAZARDOUS WASTE

Under the regulations for CERCLA, the definition of hazardous substances under Section 101(14)(F) excludes petroleum fractions. Under RCRA, mineral oil does not meet any of the characteristics of a hazardous waste and is not a listed constituent in the TCLP. Mineral oil (similar to fog oil) is not listed as a hazardous material under regulations of the Hazardous Materials Transportation Act (HMTA) in 49 CFR 171-179. However, under the HMTA, oil is classified as a flammable and combustible liquid subject to labeling, packaging, and transportation requirements.

3.3 MITIGATION

The proposed action is short term and the concentrations of materials released are not great enough to cause adverse effects to vegetation, soil, water, or air quality. Only wildlife foraging on plants within 500 m of the generator are potentially at risk. Increasing the elevation of the plume by orienting the air ejector and exhaust gases at a slight upward angle could decrease deposited fog oil levels. Another alternative is to avoid smoke downwash by ejecting the material at an angle to the mean wind direction. (The impact of plume downwash on the smoke generator may preclude this option.) Regardless of the success of such mitigation approaches, no permanent damage to wildlife populations is likely to occur because of the small area affected, the possible unpalatability of graphite flake- and fog oil-encrusted vegetation, and the environmental instability of the fog oil.

Mitigation to limit resuspension of graphite can be accomplished by using chemical fixation processes to provide a temporary reduction in resuspension until natural weathering processes act to fix the flakes to the surface. Surface fixatives or water sprays could be effective in the near-source area. However, the concomitant generation of fog oil with graphite flake may also mitigate resuspension.

No test-specific mitigation or environmental monitoring will be required.

3.4 ENVIRONMENTAL CONSEQUENCES OF ALTERNATIVES

No sufficient alternatives to the planned action were determined. Not performing the test and reducing the scale of the test were rejected as alternatives to performing the tests at YPG. Testing in a full-scale wind tunnel facility was also rejected because limitations would compromise the test requirements (arid climate). Although performing the test at another arid site may be feasible, no alternative site was identified. In the absence of serious environmental risks in performing the test at YPG, the search for an alternative may not be needed.

4.0 CONCLUSIONS

The environmental assessment has evaluated the consequences of the proposed action. Degradation of fog oil and incorporation of graphite in the soil column will limit the residual impacts of the planned action. No significant impacts to air, water, and soil quality are anticipated. Risks to the environment posed by the proposed action were determined to be minimal or below levels previously found to pose measurable impacts. Ingestion of contaminated forage at potentially harmful levels is limited to an area within about 0.5 km of the smoke generator. Mitigation approaches were suggested to reduce contamination near the source. Protected species exist on YPG land, but their presence on and downwind of the proposed test sites has not been established. Because the area of potential impact is small (less than 0.5 km) and the residual impacts of the materials are limited in time, the potential for population impacts appear minimal. The proposed action will not impact the socioeconomic structure of the area. Cultural resources are present on YPG and have been identified in adjacent areas; therefore, off-road activities should be proceeded by a cultural resource survey. A Finding of No Significant Impact is recommended.

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APPENDIX A

ATMOSPHERIC DISPERSION AND DEPOSITION MODELING

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ATMOSPHERIC DISPERSION AND DEPOSITION MODELING

The U.S. Army Chemical Research, Development and Engineering Center (CRDEC) is planning to conduct a field test of the XM56 smoke generator at the U.S. Army Yuma Proving Ground (YPG) during August 1991. Three XM56 smoke generators mounted on M1037 vehicles will be subject to a road test for 100 h. A mixed obscurant smoke of fog oil (FO) and graphite flake (GF) aerosols will be generated by a single stationary vehicle four times during the road test. The duration of each smoke generation is planned to be 30 min, for a total of 120 min.

To assist Pacific Northwest Laboratory (PNL) in preparing an assessment of the impact of the planned tests, U.S. Army Test and Evaluation Command (TECOM) tasked the U.S. Army Dugway Proving Ground (DPG) with making diffusion model calculations of the air-quality impact of the fog oil and graphite emissions. This appendix summarizes the results of those calculations, made using DPG's Real-Time Volume Source Dispersion Model (RTVSM) (Bjorklund 1990). An updated version of DPG's Volume Source Diffusion Model (VSDM) (Bjorklund and Dumbauld 1981), RTVSM uses the same dispersion coefficients as the SHORTZ complex-terrain dispersion model (Bjorklund and Bowers 1982) and the same gravitational settling and dry deposition algorithms as the Industrial Source Complex (ISC) Dispersion Model (Bowers et al. 1979).

The analysis completed for the planned YPG tests included consideration of the dosage (time-integrated concentration), average concentration, and deposition of fog oil and graphite smokes. Calculations for estimating air concentrations were performed based on a 30-min release by a single smoke generator. For surface deposition levels, calculations were performed assuming a continuous release of smoke for 120 min. The exposure criterion for fog oil is the Threshold Limit Value (TLV) of 10 mg/m^3, which is applicable to an 8-h work day and a 40-h work week. The TLV for graphite is currently 2.5 mg/m^3 for the respirable fraction of natural graphite and 10 mg/m^3 for synthetic graphite (ACGIH 1990). A Notice of Intended Change has been published that would change the TLV for graphite to 2 mg/m^3 for the respirable fraction regardless of source (ACGIH 1990). Although short-term exposure limits (STELs) have not been identified for either source, a short-term exposure ceiling level of about 5 times the TLV may be appropriate. Consequently, downwind distances to airborne concentrations of 50 mg/m^3 (fog oil) and 10 mg/m^3 (graphite) have been estimated. These concentration estimates were based on concentrations averaged over the duration of a 30-min trial; local instantaneous concentrations may differ.

A.1 MODEL INPUTS

Fog oil (SGF-2) is a light-viscosity lubricant similar to SAE 20 motor oil. Fog oil smoke is formed by vaporizing fog oil, which then condenses into droplets with mass median diameters between about 1 and 2 μm (Liljegren et al. 1986; Cataldo et al. 1989). Graphite smoke consists of graphite flakes that are mechanically disseminated. The flakes are generally less than 10 μm in diameter, with thicknesses ranging from about 0.1 to 1 μm (unpublished data by M.W. Ligotke, PNL). For air-dispersed graphite flakes, the equivalent aerodynamic mass median diameter (the diameter of a unit density sphere having has the same terminal fall velocity) is about 3 to 5 μm. The gravitational settling velocities of fog oil droplets and graphite flakes are less than 1 cm/s, which is less than typical fluctuations in the vertical wind velocity within the surface mixing layer. Consequently, the effects of gravitational settling on the diffusion of fog oil and graphite smokes can be neglected because they are insignificant in comparison with the effects of atmospheric turbulence. It is possible that fog oil coats the graphite flakes during the two-material releases.

However, there has been no evidence during previous DPG tests that these materials combine to form particles that disperse differently from graphite flakes alone. If fog oil does coat graphite flakes, the upper bound on the resulting settling velocities of 0.4 cm/s (unpublished data, D.A. Cataldo, PNL) is still negligible.

The deposition rates of fog oil drops and graphite flakes are not well established. A study conducted at DPG in 1985 to determine the fate of fog oil smoke found that the quantities deposited at the ground or on vertical surfaces were below the level of detection (Liljegren et al. 1986). Because there was no evidence of significant fog oil deposition at the surface, complete surface reflection (i.e., no deposition) was assumed in the model calculations of airborne fog oil dosage and concentration. Worst-case estimates of fog oil deposition were obtained, however, by multiplying the dosages by a deposition velocity of 0.1 cm/s (McMahon and Denison 1979). Visual observations of previous graphite releases at DPG have indicated that there is significant deposition to the surface of those graphite flakes that mix, and data from tests with similar flake materials suggest that there may be complete deposition of all graphite flakes reaching the surface (Bowers et al. 1985). Because of the uncertainties about graphite deposition, complete surface reflection was assumed in the dosage and concentration calculations and zero surface reflection (i.e., complete deposition of all flakes reaching the surface) was assumed in the deposition calculations to place upper bounds on the potential impacts. This assumption, while potentially conservative, especially for graphite flake-only aerosols, may be appropriate for mixed graphite flake and fog oil aerosols because the presence of fog oil might act to enhance the deposition and retention of graphite flakes by ground surfaces. This conclusion follows from documented increases in the deposition rates of brass particles that were aerially mixed with fog oil (Cataldo et al. 1990). The presence of fog oil may increase the surface adhesion of graphite flakes as well as reduce subsequent resuspension rates.

The meteorological and source inputs used in the RTVSM calculations for the YPG road test are summarized in Tables A.1 and A.2, respectively. The RTVSM meteorological inputs in Table A.1 cover the range of meteorological conditions anticipated at YPG between 0800 and 1600 Mountain Standard Time (MST) during the month of August. Because of the similarities in the surface characteristics at DPG and YPG, the RTVSM default values for the wind-profile exponent and the lateral and vertical turbulence intensities are used in Table A.1. Also, because inspection of the isopleths of the mean summer morning and afternoon mixing heights given by Holzworth (1972) indicated that DPG mixing depths should be less than or equal to YPG mixing depths, the RTVSM default mixing depths were used in the model calculations. The RTVSM default meteorological inputs shown in Table A.1 are the values suggested by Dumbauld and Bowers (1983) for open terrain. The fog oil and graphite source strengths in Table A.2 are based on generation rates of 5.0 L/min (1.33 gal/min) and 4.5 kg/min (10 lb/min), respectively. Visual observations of the clouds from smoke generators indicate that the diameter of the cloud within about 1 m of the point of discharge is about 1 m. Assuming a bivariate Gaussian distribution, the initial standard deviations of the lateral and vertical concentration distributions are both 0.23 m. The effective source height is given by the sum of the dissemination height (approximately 1.5 m above ground level) and the buoyant cloud rise. The cloud rises used to obtain the effective source heights in Table A.2 were calculated using the equations developed by Bowers et al. (1990) for an earlier prototype of the XM56 smoke generator. These equations are essentially the Briggs (1971) equations for buoyant stack plumes with source-specific entrainment coefficients. It should be noted that Cases 4 through 6 in Tables A.1 and A.2 represent the most probable conditions at YPG during August days; Cases 1 through 3 are possible only with an overcast cloud cover.

A.2 RESULTS

Model results provided information for predicting air concentration and surface deposition of each component of the mixed smoke at center-line downwind locations between 0.1 and 40 km.

TABLE A.1. RTVSM Meteorological Inputs for the YPG Road Test[a]

Parameter	Value					
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
10-m Wind Speed (m/s)	1	4	8	1	4	8
Net Radiation Index	0	0	0	4	4	4
Turbulence Intensities[b]						
Lateral	0.175	0.157	0.122	0.384	0.332	0.227
Vertical	0.061	0.087	0.079	0.122	0.122	0.093
Wind-Profile Exponent	0.25	0.20	0.10	0.10	0.10	0.10
Mixing Depth (m)	200	300	300	2200	1800	1200
Pasquill Atmospheric Stability Category[c]	D	D	D	A	B	C

(a) The RTVSM default values of the turbulence intensities, wind-profile exponent, and mixing depth shown in this table are assigned based on the 10-m wind speed and net radiation index.
(b) Turbulence intensities are 10-min values.
(c) Not an RTVSM input; provided for information only. Atmospheric stability categories: A) extremely unstable, B) moderately unstable, C) slightly unstable, and D) neutral.

TABLE A.2. RTVSM Source Inputs for the YPG Road Test.

Parameter		Value
Source Strength: Air Concentration (30-min release)	Fog Oil	139 kg
	Graphite Flake	136 kg
Source Strength: Surface Deposition (120-min release)	Fog Oil	557 kg
	Graphite Flake	544 kg
Initial Cloud Dimensions[a]	Lateral	0.23 m
	Vertical	0.23 m
Effective Source Height	Cases 1 & 4	56.5 m
	Cases 2 & 5	15.3 m
	Cases 3 & 6	8.4 m

(a) Standard deviations of the initial lateral and vertical concentration distributions.

A.2.1 Air Concentrations

The calculated profiles of peak fog oil and graphite flake concentrations versus downwind distance, based on 30-min releases, are shown in Figures A.1 and A.2, respectively. Note that, because deposition has been neglected in the concentration calculations, the graphite results shown in Figure A.2 are likely to be increasingly overestimated as the downwind distance increases. Because fog oil deposition is not believed to be great, the only bias in the fog oil results shown in Figure A.1 arises from the conservative assumptions of the worst-case release scenario. Table A.3 lists approximate near-ground (breathing zone) air concentrations for the 6 test cases. The air concentration results are similar for both fog oil and graphite flakes because of their similar release rates and aerodynamic sizes. In summary, 30-min average air concentrations are expected to range between 0 and 15 mg/m^3 at a downwind distance of 0.1 km, between 0.1 and 1 mg/m^3 at 1 km, and between about 0.001 and 0.07 mg/m^3 at 10 km. In general, the concentrations during overcast conditions [Atmospheric Stability Category (ASC) D] are expected to be greater than those during sunny or partly cloudy conditions (ASC A, B, and C). The difference in dispersion is due to greater thermal mixing during sunny conditions and is increasingly important with increasing downwind distance.

The downwind distances associated with the TLV (10 mg/m^3) and the approximate STEL (50 mg/m^3) for both fog oil and graphite flakes were estimated. For Cases 1 and 4 (56.5-m plume height), 30-min average air concentrations are not expected to exceed either 10 or 50 mg/m^3 at any downwind location. For Cases 2, 3, 5, and 6, average air concentrations of 10 and 50 mg/m^3 are not expected to be exceeded at distances greater than about 100 m downwind of the generator. Because these results are approximate and averaged over 30 min, it is probable that local events cause short-term air concentrations exceeding 10 mg/m^3 within perhaps 1 km downwind of the generator. In addition, if the graphite flake aerosol TLV is changed to 2 mg/m^3 as is planned (Section 2.2.2), average concentrations may equal or exceed the planned TLV at center-line downwind distances within about 0.4 km of the generator, and short-term concentrations could exceed the planned TLV at distances greater than 1 km. Again, listed values are center-line (downwind) estimates; concentrations at crosswind locations will be much reduced (see below).

A.2.2 Surface Deposition

Figures A.3 and A.4 respectively show the calculated profiles of peak fog oil and graphite deposition versus downwind distance. The profiles were determined for a 120-min continuous dissemination of fog oil and graphite flakes. The fog oil deposition profiles in Figure A.3 do not consider the relatively small quantities of fog oil removed by deposition between the smoke generator and each downwind distance. Consequently, the fog oil deposition values shown for each downwind distance are the maximum values that could occur if deposition did not begin until that downwind distance. In contrast, the graphite deposition profiles in Figure A.4 do consider deposition between the smoke generator and each downwind distance. The secondary maxima in the deposition profiles in Figure A.4 are the result of the downward mixing of the particles that initially mix upward and are reflected at the top of the surface mixing layer. This phenomenon can be found in deposition measurements for releases of small drops or particles if the measurements extend far enough downwind (for example, see Dumbauld et al. 1976).

Estimated deposition loading levels are greatly influenced by atmospheric stability category and plume height. The estimated surface loadings downwind of the generator are summarized in Table A.4. These results are based on Figures A.3 and A.4. In summary (for 120 min of smoke generation), deposition level estimates for fog oil range between 0 and 80 mg/m^2 at a distance of 0.1 km, between 0.6 and 6 mg/m^2 at 1 km, and between ~ 0.007 and 0.4 mg/m^2 at 10 km. Similar summary deposition level estimates for graphite flakes range between 0 and 25 g/m^2 at

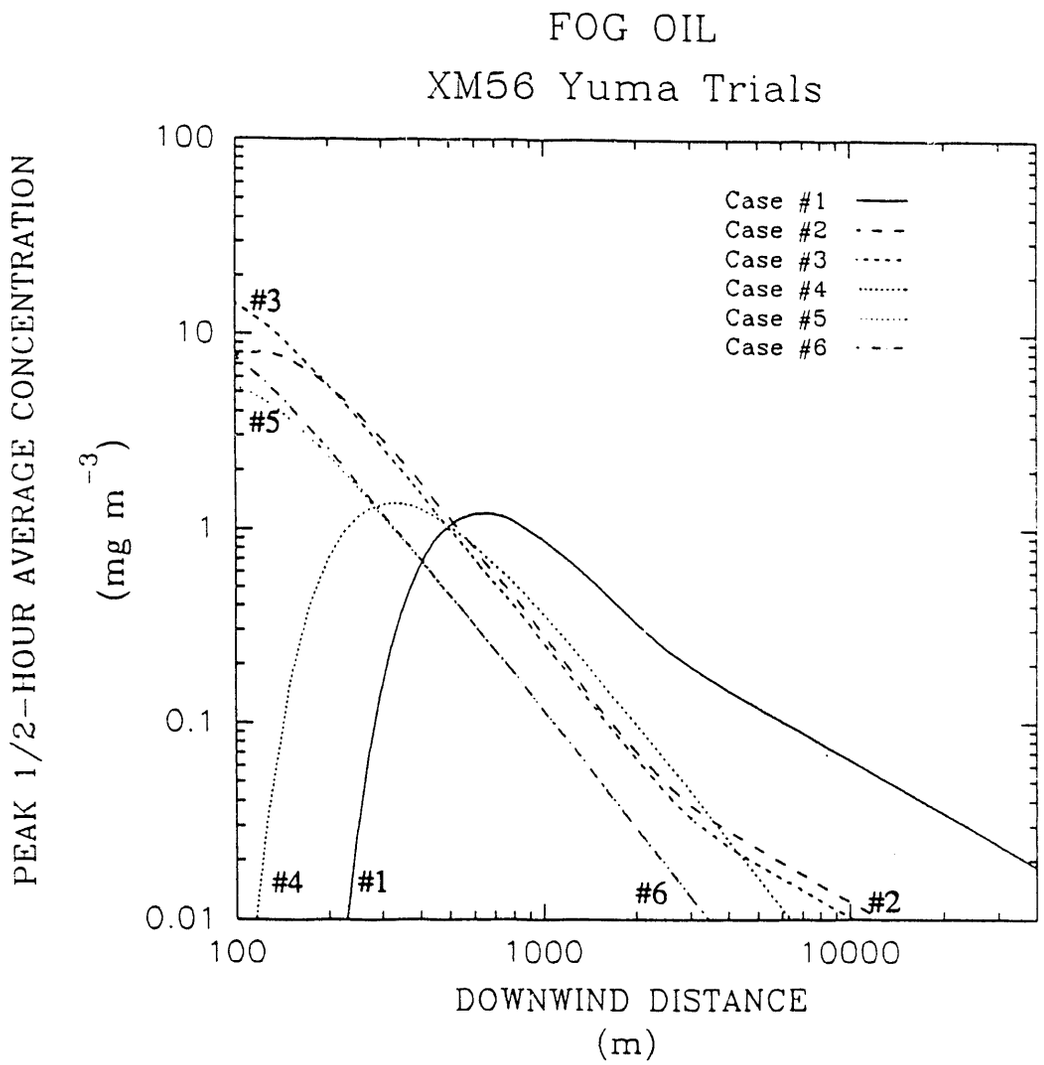

FIGURE A.1. Estimated Profiles of Peak Fog Oil 30-min Average Concentration Versus Downwind Distance for the YPG Road Test. See Table A.1 for a definition of the six meteorological cases.

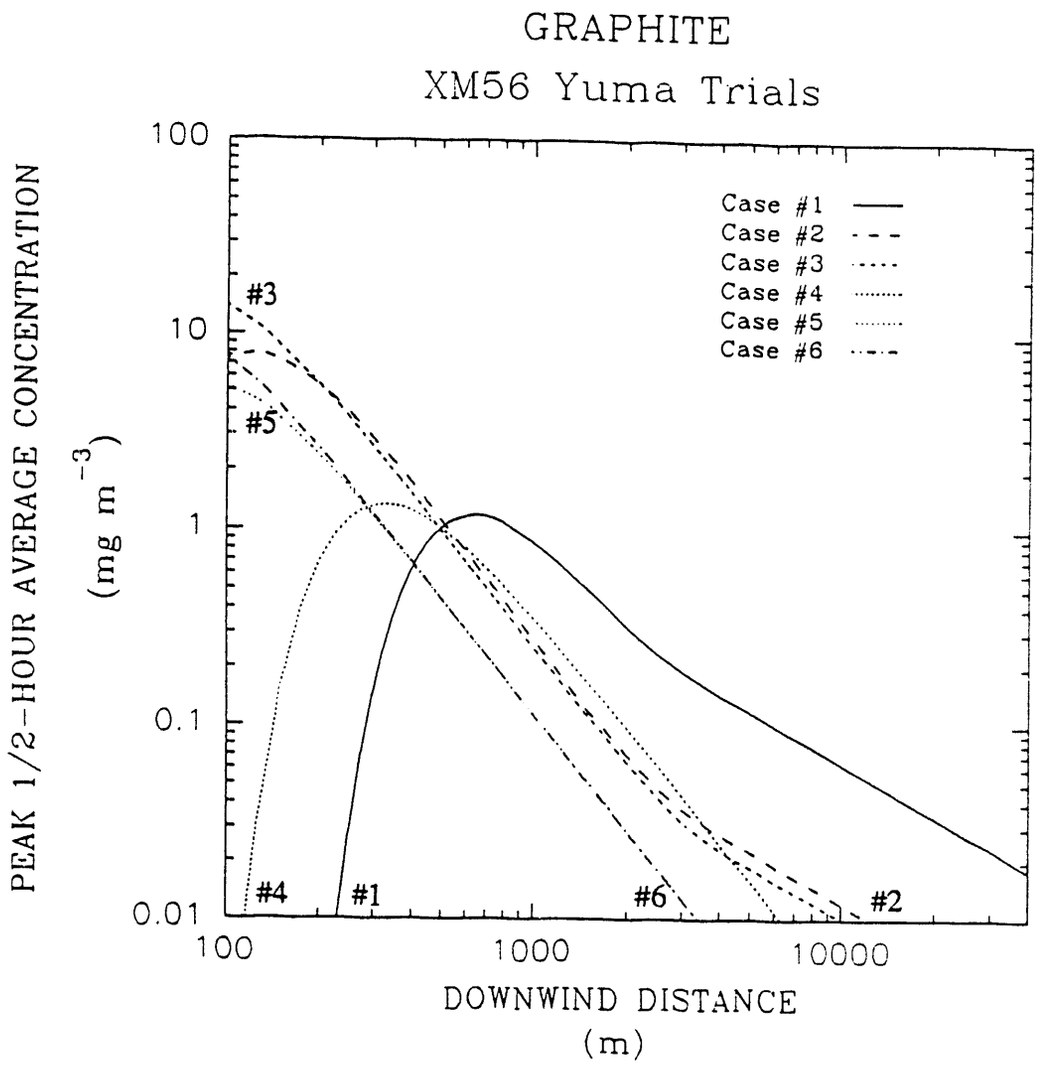

FIGURE A.2. Estimated Profiles of Peak Graphite Flake 30-min Average Concentration Versus Downwind Distance for the YPG Road Test. See Table A.1 for a definition of the six meteorological cases.

TABLE A.3. Estimated 30-min Average Air Concentration Levels (mg/m^3) for Mixed Fog Oil and Graphite Flake Aerosols During the Planned YPG M1037/XM56 Road Tests

		Downwind Distance		
Material	Atmospheric Conditions (ASC)	100 m	1,000 m	10,000 m
Fog Oil	Clear, partly cloudy (A, B, C)	0 - 8	0.1 - 0.4	~0.001 - 0.004
	Cloudy, partly clear (D)	0 - 14	0.3 - 1	0.01 - 0.07
Graphite	Clear, partly cloudy (A, B, C)	0 - 7	0.1 - 0.3	~0.002 - 0.003
	Cloudy, partly clear (D)	0 - 13	0.2 - 0.9	0.01 - 0.07

TABLE A.4. Estimated Deposition Levels (mg/m^2) for a 120-min Continuous Release of Mixed Fog Oil and Graphite Flake Aerosols During the Planned YPG M1037/XM56 Road Tests.

		Downwind Distance		
Material	Atmospheric Conditions (ASC)	100 m	1,000 m	10,000 m
Fog Oil	Clear, partly cloudy (A, B, C)	0 - 40	0.6 - 2	~0.007 - 0.02
	Cloudy, partly clear (D)	0 - 80	1.5 - 6	0.05 - 0.4
Graphite	Clear, partly cloudy (A, B, C)	3 - 14,000	25 - 80	0.1 - 0.5
	Cloudy, partly clear (D)	0 - 25,000	60 - 250	2 - 4

0.1 km, between 25 and 250 mg/m^2 at 1 km, and between 0.1 and 4 mg/m^2 at 10 km. Estimated deposition levels were generally greater for cloudy conditions and were enhanced by corresponding decreased atmospheric dispersion.

A.2.3 Area-Based Surface Loading

The maximum probable, or worst-case, surface deposition levels were estimated based on 120 min of continuous smoke generation. Maximum surface deposition will occur under the center line of the smoke plume. Peak worst-case deposition is likely to occur within a 90° arc bounded by the directions northwest and northeast as measured from the smoke generator. This conclusion is based on prevailing wind direction data for YPG in August. Plume width will be a function of wind direction uniformity and atmospheric stability; plume widths will be larger on sunny days with light unsteady winds, and smaller on cloudy days. The distance to worst-case, center-line deposition levels was determined using the information presented in Figures A.3 and A.4 and is shown in Table A.5. For fog oil, estimated maximum surface loading levels decrease from < 10 to 0.01 $\mu g/cm^2$ at downwind distances from 0.1 to 40 km. For graphite flakes, estimated maximum surface loading levels decrease from 1000 to 0.01 $\mu g/cm^2$ as downwind distance increases from 0.2 to about 45 km. Surface deposition levels of graphite flakes are expected to exceed those of fog oil within about 40 km of the generator.

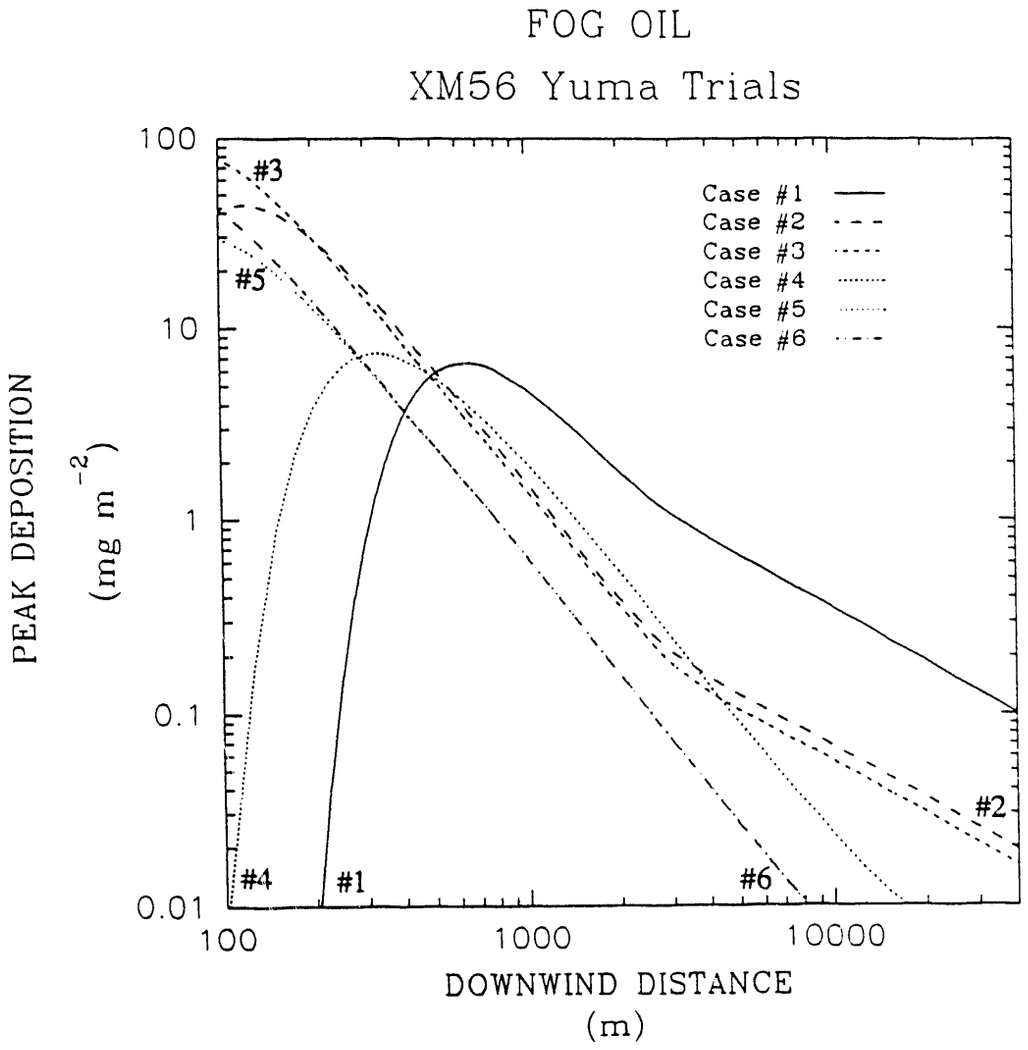

FIGURE A.3. Estimated Profiles of Peak Fog Oil Deposition Versus Downwind Distance for the YPG Road Test, Assuming a 120-min Continuous Smoke Dissemination Period. See Table A.1 for a definition of the six meteorological cases.

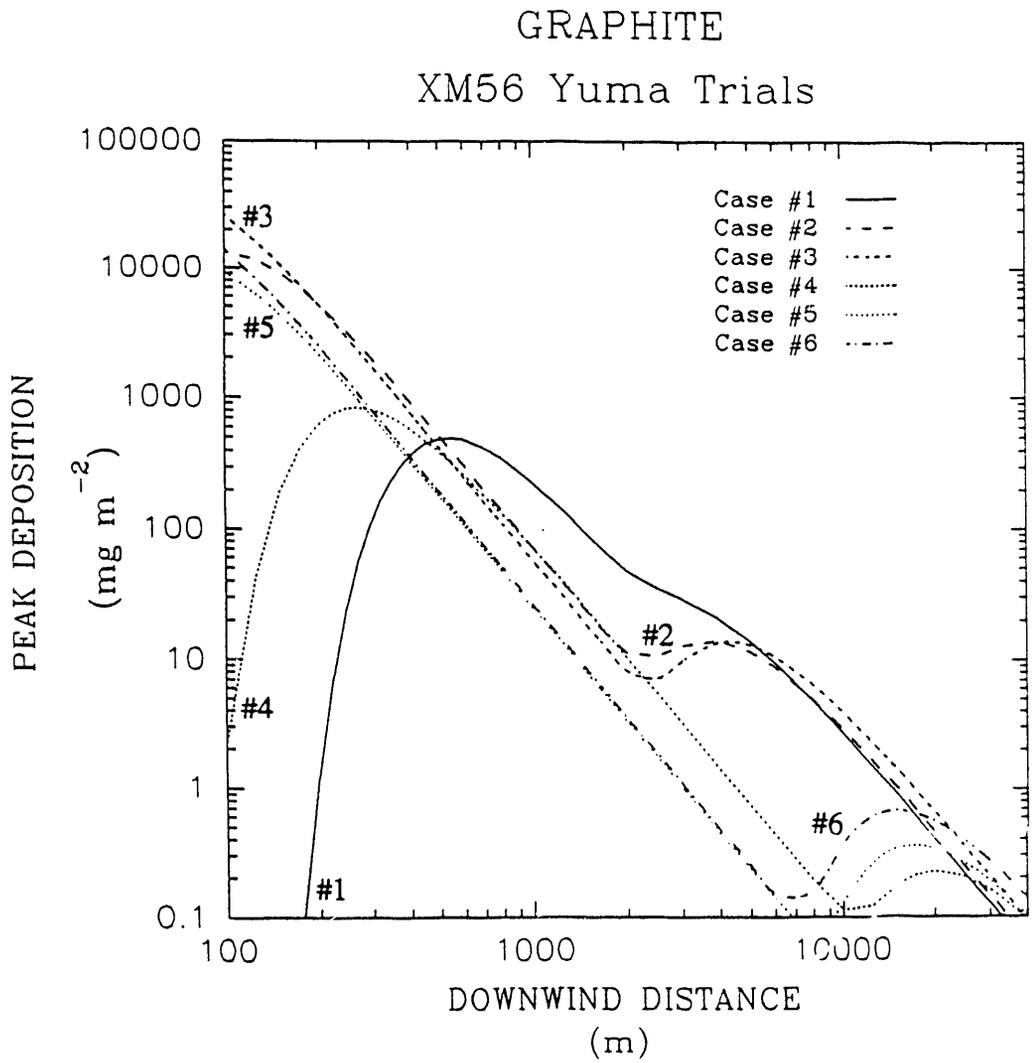

FIGURE A.4. Estimated Profiles of Peak Graphite Flake Deposition Versus Downwind Distance for the YPG Road Test, Assuming a 120-min Continuous Smoke Dissemination Period. See Table A.1 for a definition of the six meteorological cases.

TABLE A.5. Estimated Worst-Case Deposition Levels ($\mu g/cm^2$) for a 120-min Continuous Generation of Mixed Fog Oil and Graphite Flake Aerosols During the Planned YPG M1037/XM56 Road Tests. These levels may occur within a 90° arc in the area bounded to the northwest and northeast of the smoke generator.

Worst-Case Surface Mass Loading ($\mu g/cm^2$)	Downwind Distance	
	Fog Oil (km)	Graphite Flake (km)
1000	NA[a]	0.2
300	NA	0.3
100	NA	0.6
30	<< 0.1	0.8
10	< 0.1	1.5
3	0.2	2.7
1	0.4	6.3
0.3	1.5	11
0.1	3.2	17
0.03	13	30
0.01	> 40	~ 45

[a] NA = smoke plume deposition levels greater than 100 $\mu g/cm^2$ are not expected at the field site.

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APPENDIX B

AVERAGE METEOROLOGICAL CONDITIONS

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AVERAGE METEOROLOGICAL CONDITIONS

TABLE B.1. Summary of Average Meteorological Conditions at Yuma, Arizona, and the U.S. Army Yuma Proving Ground

Parameter	Spring[a]	Summer[a]	(August)[b]	Autumn[a]	Winter[a]
	City of Yuma Airport - Years of Record ~1882 to 1983[c,d]				
Wind Speed					
Mean Speed	8.2 mph	9.0 mph	(8.9 mph)	6.9 mph	7.3 mph
Prevailing Direction	W - WNW	SSE	SSE	SSE, N	N
Precipitation					
Normal	0.35 in.	0.58 in.	(0.42 in.)	0.74 in.	0.98 in.
Maximum	-	-	(2.96 in.)	-	-
Thunderstorms	-	-	-	-	-
Temperature					
Average Maximum	86 °F	105 °F	(105 °F)	90 °F	71 °F
Average Minimum	54.5 °F	77 °F	(79.5 °F)	62 °F	44 °F
	Yuma Proving Ground - Years of Record 1954 - 1990[e]				
Wind Speed					
Mean Speed[f]	~5.5 mph	~4.5 mph	(~4.5 mph)	~3.5 mph	~3.5 mph
Prevailing Direction	W	SW	(SW)	W	NNW
Precipitation					
Normal	0.42 in.	0.89 in.	(0.57 in.)	1.17 in.	1.05 in.
Maximum	-	-	-	-	-
Thunderstorms	0 days	7 days	(4 days)	3 days	0 days
Temperature					
Average Maximum	85 °F	103 °F	(104 °F)	84 ° F	68 °F
Average Minimum	57 °F	76 °F	(79 °F)	59 °F	43 °F

Notes:
(a) Spring (M, A, & M), Summer (J, J, & A), Autumn (S, O, & N), Winter (D, J, & F).
(b) August Cloudiness: 9 days (Yuma Airport), 1/10 sky cover (YPG).
(c) Years of record are approximate.
(d) Reference for City of Yuma Airport: NOAA 1983 (see Appendix A references).
(e) Reference for YPG: YPG Central Meteorological Observatory data.
(f) YPG mean wind speeds are based on 1-significant-digit data in knots.

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