Naval Research Laboratory

Washington, DC 20375-5320

Select Panel

Theodore L. Hullar, Ph.D., Chair
Cornell University

Steven L. Fales, Ph.D.
Pennsylvania State University

Harold F. Hemond, Ph.D.
Massachusetts Institute of Technology

Petros Koutrakis, Ph.D.
Harvard University

William H. Schlesinger, Ph.D.
Duke University

Richard R. Sobonya, M.D.
University of Arizona

John M. Teal, Ph.D.
Woods Hole Oceanographic Institution

John G. Watson, Ph.D.
Desert Research Institute

NRL/PU/6110- -99-389

ENVIRONMENTAL EFFECTS OF RF CHAFF

A Select Panel Report to the
Undersecretary of Defense for Environmental Security

Transmitted via:

Barry J. Spargo, Ph.D.
Chemistry Division

and the

Assistant Secretary of the Air Force
Assistant Secretary of the Army
Assistant Secretary of the Navy

August 31, 1999

Table of Contents

List of Figures

Select Panel

Theodore L. Hullar, Ph.D, **Chair**
Center for the Environment
Cornell University
Ithaca, NY

Steven L. Fales, Ph.D.
Department of Agronomy
Pennsylvania State University
State College, PA

Harold F. Hemond, Ph.D.
Department of Civil/ Environmental Engineering
Massachusetts Institute of Technology
Cambridge, MA

Petros Koutrakis, Ph.D.
School of Public Health
Harvard University
Cambridge, MA

William H. Schlesinger, Ph.D.
Department of Botany
Duke University
Durham, NC

Richard R. Sobonya, M.D.
Department of Pathology
School of Medicine, University of Arizona
Tucson, AZ

John M. Teal, Ph.D.
Scientist Emeritus
Woods Hole Oceanographic Institution
Woods Hole, MA

John G. Watson, Ph.D.
Energy and Environmental Engineering Center
Desert Research Institute
Reno, NV

A biographical sketch of each panel member can be found in Appendix A.

Disclosures

The opinions and assertions contained herein are those of the Select Panel on the Environmental Effects of RF Chaff and are not to be construed as official or reflecting the views of the Departments of Defense or other agencies of the U.S. government. The use of trademark or brand names is incidental and not intended to endorse their use or exclusion.

Acknowledgements

The panel would like to thank the following individuals for their time and expertise in informing and educating the panel members on the military's research and development and use of RF chaff in training and operational settings.

J. Kevin Roll, Lt Col, USAF
Air Combat Command, Langley AFB

Mr. William R. Rock
PMA272J3

Cody L.Wilson, LT, USNR
Naval Medical Research Laboratory

Mr. Victor L. Kutsch
Naval Research Laboratory

Ms. Rebecca VanHooser
Naval Air Systems Command

Dr. Jo Ann Ratto
U.S. Army Soldier Systems Command

Mr. Robert L. Ritchie
Picatinny Army Arsenal

Dr. Kurt W. Riegel
Office of the Assistant Secretary of the Navy

Joseph Reeves, LT, USN
Naval Strike and Air Warfare Center

Brad Goetsch, CAPT, USN
Naval Strike and Air Warfare Center

In addition, the panel would like to thank the following commands and government agencies for hosting site visits, responding to requests for information and providing documents.

National Security and International Affairs Division
General Accounting Office

Naval Research Laboratory

Naval Strike and Warfare Center
Naval Air Station Fallon

Picatinny Army Arsenal

National Oceanographic and Atmospheric
Administration, National Weather Service

Air Combat Command
Langley Air Force Base

U.S. Department of Agriculture

International Affairs Division
Royal Canadian Military Forces

The Honorable Robert L. Pirie Jr.
Assistant Secretary of the Navy for Installations and Environment
1000 Navy Pentagon
Washington, DC

Subj: Environmental Effects of RF Chaff: A Select Panel Report to the Undersecretary of Defense for Environmental Security

Dear Mr. Pirie:

We are pleased to submit to you our Select Panel Report on "Environmental Effects of RF Chaff." It has been a privilege to serve on this panel and prepare this report.

We find that current use of RF chaff for training purposes provides no negative environmental effects that can be identified or postulated. We come to this conclusion using "upper bounds" (or worst-case) estimates based on the amounts and areas of chaff use, analysis of known literature data related to the effects of RF chaff, and reasonable, prudent extrapolations and derivations from these data.

In our work, we have operated wholly independent from the military services in terms of analysis of data and reaching our conclusions. At the same time, we are grateful for the support, information, and courtesies provided to us from each of the services and their staff. We particularly acknowledge the very professional, continuous, and helpful support provided us by Barry J. Spargo, Ph.D., Naval Research Laboratory, Washington, D.C.

We will be pleased to discuss the report with you and your colleagues in the Department of Defense. Thank you for the opportunity to serve in this way and we trust the report will be useful.

Respectfully,

Theodore L. Hullar, Ph.D., Chair
Cornell University

William H. Schlesinger, Ph.D.
Duke University

Steven L. Fales, Ph.D.
Pennsylvania State University

Richard R. Sobonya, M.D.
University of Arizona

Harold F. Hemond, Ph.D.
Massachusetts Institute of Technology

John M. Teal, Ph.D.
Woods Hole Oceanographic Institute

Petros Koutrakis, Ph.D.
Harvard University

John G. Watson, Ph.D.
Desert Research Institute

Executive Summary

This report presents the assessment of the environmental effects of radio-frequency (RF) chaff as determined by a select panel of university-based research scientists, each with published expertise in a relevant field of study. The analytical approach was to use paradigms from environmental toxicology and related disciplines, "upper bounds" (or worst-case) estimates based on the amounts and areas of chaff use, analysis of known literature data related to the effects of RF chaff, and reasonable, prudent extrapolations and derivations from these data.

The Panel concludes that widespread environmental, human, and agricultural impacts of RF chaff as currently used in training are negligible, and far less than those from other man-made emissions, based on available data, analyses, estimations, and related information. Empirical information is lacking concerning the extent to which chaff abrades and is resuspended to the atmosphere and actual exposure in populated areas near release. However, upper limit calculations suggest that those impacts are also negligible.

Prior studies and the analysis provided here do not warrant modification of current DOD RF chaff training practices based on environmental concerns. However, significant increases in RF chaff use in training beyond its use in the recent past or the use of degradable chaff as a replacement would require further consideration of environmental impact.

Up to 2.3 million bundles of RF chaff are released annually by the military services worldwide for operational and training purposes. This is about 500 tons per year (tpy), approximately the same as emissions from a single coal-powered generating station. Of this amount 5 tpy and 0.12 tpy were released respectively at NAS Fallon and Patuxent River NAS, the two case-study sites.

Virtually all RF chaff is 10-100 times larger than PM_{10} and $PM_{2.5}$, the air particulates of concern for public health. If, however, all RF chaff were of those sizes, it would only be 0.006-0.0016% of those particulates emitted annually in the U.S. Based on the MOA (military operating area) for use of RF chaff, and using accepted air transport models and conservative estimates for settling and areal distribution, average rates of deposition were estimated to be 8.7 and 12 g ha^{-1} yr^{-1}; a direct weight estimate was 2.8 g ha^{-1} yr^{-1}. Therefore, RF chaff (which is comprised of 40% aluminum and 60% silicon, the two most common elements in the Earth's crust) introduces only 1/50,000 and 1/5,000 the amounts of silicon dioxide and aluminum oxide in the top 2 cm of soil in the areas where it is deposited. Based on available data and analysis, the environmental fate of released chaff is likely to be deposition of whole fibers directly on the soil surface. It is possible fibers could be broken or abraded; even so, most of the fragments would be too large to be respired into the lungs.

Respirable air particles are those which lodge in the lungs and, if toxic or hazardous, cause lung damage. Ambient air concentrations of RF chaff are calculated as 0.036 and 0.0061 $\mu g\ m^{-3}$ for NAS Fallon and Patuxent River NAS, respectively. For example, if chaff were actually PM_{10} or $PM_{2.5}$, it would contribute 0.5% and 1.2% of the PM_{10} and $PM_{2.5}$ background concentrations of 7 and 3 $\mu g\ m^{-3}$ for Nevada, respectively. Epidemiological studies of workers in glass fiber production show no evidence of glass fibers of the size and type used for RF chaff causing lung

damage. Aluminum toxicity is possible, but epidemiological studies among workers are equivocal.

The maximum amount of aluminum ingested by cows from chaff would be only 1/100,000 of the maximum tolerable level of soluble Al in the diet (based on the areal depositions above). No toxic effects were found in feeding massive doses of chaff to calves. Toxic effects are unlikely through the rumen due to pH effects. Negative pulmonary effects are unlikely for the same reasons as they are unlikely in humans.

Deleterious effects on marine and freshwater organisms are unlikely because siliceous spicules (similar to chaff particles) are already part of marine and freshwater sponges that are natural parts of those ecosystems. Furthermore, toxicity tests using marine organisms show no deleterious effects at appropriate exposure levels.

Of the several open questions noted in the 1998 GAO report on RF chaff, only the extent of break-up and abrasion of chaff, and the resulting shapes and resuspension chaff particles, are considered significant. It is recommended that these studies be done. Because degradable chaff is being developed for environmental and operation reasons, it is recommended that its environmental effects be evaluated in a systematic, integrated research program conducted consistent with approaches in this report and through the leadership of a qualified scientific program manager.

Summary Findings and Recommendations

- Chaff particle concentrations in air of chaff-affected areas are 1/100th of allowable limits set by EPA and less than 1/10th of the natural background concentration for suspended soil particles.

- Deposition of chaff, even under areas of intensive use, is hundreds of times less than the annual deposition of dust in the southwestern U.S. The chemical composition of chaff is very similar to the chemical composition of desert dust.

- Estimated U.S. chaff emissions are several orders of magnitude less than the U.S. mass emissions estimated by the U.S. EPA for dust, vehicle exhaust, power generation and industrial emitters.

- Deposition of chaff does not result in the accumulation of toxic or otherwise undesirable substances in soils.

- The risk of exposure for humans through inhalation or ingestion is considered negligible because chaff fibers are too large pass through the nose or mouth or do not exceed known toxic thresholds.

- Inhalation and ingestion exposure to domestic livestock and non-domestic grazers is considered minimal to nil. Nutritional values of chaff are low and comparable in composition to soil.

- Marine and freshwater organisms exposed to relevant levels of chaff are unlikely to exhibit effects in their growth or development.

- Previous studies on the environmental effects of chaff failed to consider realistic chaff exposure levels. Extremely high, non-relevant exposures were used to predict an effect.

- Of the open questions identified by the GAO, only resuspension, abrasion and exposure of chaff were identified as requiring additional research efforts by the DOD.

- The panel recommends that the DOD address the following questions related to the resuspension and fate of chaff:

  1. What fraction of emitted chaff breaks up in atmospheric turbulence into respirable particles?
  2. How much chaff is abraded and resuspended after it is deposited on a surface?
  3. What are the shapes of chaff particles after abrasion?
  4. What is the empirical terminal deposition velocity of chaff?
  5. What is the spatial distribution of chaff under different release and meteorological conditions?
  6. How do chaff emissions and expected concentrations compare to emissions and concentrations from other particle emitters over the time and areas where chaff is released?
  7. What quantities of inhalable chaff are found in communities near training facilities where chaff is released?

- Degradable chaff is under development. However, the environmental effects of this material are unknown, and current DOD efforts fall short of demonstrating degradability, ultimate fate, and environmental effects.

- Further, the panel recommends an organized program addressing the environmental effects of degradable chaff.

Introduction

In 1998, the U.S. General Accounting Office (GAO), the investigative arm of the U.S. Congress, prepared a report for the Honorable Harry S. Reid, Senator, Nevada on the environmental effects of chaff. The GAO report entitled, "Environmental Protection: DOD Management Issues Related to Chaff (GAO Report, GAO/NSAID-98-219, September 1998)" is incorporated in full in this report (Appendix B). In that report the GAO concluded, "[the] DOD and the services have developed ongoing initiatives to address certain concerns raised by the military's use of chaff. These initiatives include plans for increased liaison with agencies such as [Bureau of Land Management] BLM, [Fish and Wildlife Service] FWS, and [National Weather Service] NWS. Nevertheless, the public, DOD studies, and other federal agencies continue to raise questions about the potential adverse effects of chaff. DOD has not systematically followed up to determine whether these questions merit further action. Further, the Navy has initiated a degradable chaff research and development program but has not yet completely analyzed the operational and environmental benefits it expects to achieve."

Furthermore, the GAO recommended that the Secretary of Defense direct "the Secretaries of the Army, the Navy, and the Air Force to determine the merits of open questions made in previous chaff reports and whether additional actions are needed to address them…"

The Assistant Secretary of the Navy for Installations and Environment (ASN I&E), in consultation with his counterparts in the Air Force and Army, recommended that a Blue Ribbon Panel of non-government scientists be established. The Panel was asked to review the environmental effects of radio frequency (RF) chaff used by the U.S. military in training exercises in and around the continental United States (CONUS) and to make recommendations to decrease scientific uncertainty where significant environmental effects of RF chaff are possible. And to address, where appropriate, open questions raised by the GAO report as follows:

- long-term and chronic exposure to inhaled chaff fibers;
- resuspension rates of coated and uncoated chaff fibers;
- weathering rates and chemical fate of metal coatings in soil, fresh and marine waters;
- review of threshold metal toxicity values in humans, animals, and fresh and marine organisms;
- evaluation of potential impacts of fibers;
- respirability of fibrous particles in avian species;
- aquatic and marine studies to establish the impact of fibers;
- pathology of inhaled fibers;
- chaff accumulation on water bodies and its affect on animals;
- bioassay tests to assess toxicity of chaff to aquatic organisms, and;
- the potential for impacts on highly sensitive aquatic habitats.

Panel Charge. The panel was charged with the following:

- Review available reports on the environmental effects of RF chaff released during military training.
- Assess chaff reports using the following criteria:
  - appropriateness of the scientific questions being asked;
  - soundness of methodology and approach;
  - completeness of the study and;
  - consistency of results with comparable studies.
- Identify information shortfalls preventing adequate assessment of significant chaff impact in an environmental context.
- Prepare a report that assesses the present scientific certainty and uncertainty of the environmental effects of RF chaff and recommend additional actions to decrease scientific uncertainty where significant environmental effects of RF chaff are possible. Specifically, "determine the merits of open questions made in previous chaff reports and whether additional actions are needed to address them.[1]"

Panel Composition. The panel members were selected from a pool of candidates with expertise in areas that could address the open questions identified by the GAO report. The panel was composed of academicians with expertise in of disciplines, which include: environmental engineering, soil biogeochemistry, toxicology, medical pathology, agronomy, public health, air quality management and marine biology. Specifically, each panel member was selected because the research they conducted had direct bearing on or applicability to the questions raised by the GAO.

Panel Review Process. The GAO report was a primary reference document and provided the panel context. The panel also reviewed numerous available studies conducted related to the use and environmental effects of chaff (see Appendix C). Briefings on the current research and development efforts being conducted by the DOD and private sector as well as site visits provided the panel with additional information.

The panel used a two-phased approach to complete the charge. The first phase was a review of the studies to date, focussing on the soundness of the study, and data gaps. The second phase of the review was to assess the potential environmental impact of RF chaff based on its use in training in specified regions of the U.S., which included a visit to one of the major training sites, NAS Fallon, NV. Finally, in light of phase two results, the panel assessed whether reanalysis of existing studies or additional studies should be conducted.

[1] Environmental Protection: DOD Management Issues Related to Chaff, GAO Report, GAO/NSAID-98-219, September 1998

Analysis

To address the issues cited in the GAO report and make conclusions regarding the potential effects of RF chaff on plants, animals and humans, an understanding of the amount or mass of RF chaff released, deposited, or remaining in the atmosphere in a given area is required. These quantitative parameters cannot be precisely estimated or measured. A number of unknown factors determine the deposition of chaff and its distribution in air and on the Earth's surface (e.g. soil, sediment, and water). These factors include, but are not limited to: the altitude and location, prevailing winds, and meteorological conditions where chaff is released.

Owing to the inability to obtain detailed information on these factors, upper bounds are estimated for the extent to which released chaff might contribute to adverse air quality, dry land deposition and aquatic deposition. These estimates are made for the entire U.S. and for two case study areas where chaff is released, the Naval Air Station (NAS) Fallon in Churchill County, Nevada and the Patuxent River NAS in St. Mary's County, Maryland near the Chesapeake Bay. These upper limits are compared to contributions from similar emitters with allowable levels defined by environmental standards, and with current knowledge of effects of chaff and chaff-like materials on human, animal and aquatic life.

Chaff Emissions

A typical bundle of training chaff contains ~5 million fibers, each of 1-mil (25 µm) diameter and typically 1 to 2 cm length and composed of glass silicate with an aluminum coating (trace elements include B, Ca, Mg, Na, Ti, Fe, and F). Each bundle contains ~150 g of chaff and an example of typical RF chaff bundles is shown in Appendix D. U.S GAO (1998) estimates that ~2.3 million of these bundles are released annually by all services in operational and training settings worldwide.

Approximately 30,000 bundles of RR-144 (Navy training round) chaff are released per year at the NAS Fallon. Most of the chaff is released at 15,000 to 20,000 ft. above ground level (agl) over an area of ~10,000 mi^2. Less than 5 % is released below 5,000 ft agl, and less than 1% is released below 1,000 ft agl (Goetsch, 1999). Low-level tactics are no longer favored as a rule, due to increased threats, such as shoulder-launched missiles at low altitudes. Actual usage was 38,000 bundles in FY 1997[2], and 21,000 bundles in FY 1998 (Goetsch, 1999). At the Patuxent River NAS, 683 bundles were released during 1998 over an area of 2400 mi^2 (Rock, 1999).

The amount of chaff released worldwide by all services is approximately 500 tons per year (tpy); the amount released at NAS Fallon is equivalent to ~5 tpy, and the amount released at Patuxent River NAS is ~0.12 tpy. The 500 tpy release is comparable to primary particle emissions from some individual U.S. point sources, such as a coal-fired power station.

On a national basis, the total chaff emissions constitute an extremely small fraction of directly-emitted particle emission. The significance of chaff release in the atmosphere over the U.S. is provided by comparison to total particle emissions of PM_{10} and $PM_{2.5}$, which are estimated by the U.S. EPA. PM_{10} and $PM_{2.5}$ emissions are estimated and their concentrations are monitored

[2] The GAO report (p24) states 13,212 bundles used at NAS Fallon in 1997.

because they are inhalable[3] and thus have a potential negative human health effect. Particles in the PM_{10} and $PM_{2.5}$ ranges are 10 to 100 times smaller than chaff. Going further, ***if*** all chaff released nationwide were PM_{10} it would constitute 0.0016% of the national releases. If it were all in$PM_{2.5}$ this fraction would rise to 0.006%. These levels are much lower than releases from any other category.

To provide a perspective on the amount of chaff released into the atmosphere over the U.S., Figures 1 and 2 summarize U.S. particle emissions from different source categories estimated by the U.S. Environmental Protection Agency (U.S. EPA, 1998) for 1997. Particle emissions are estimated for PM_{10} and $PM_{2.5}$ (particles with aerodynamic diameters less than 10 µm and 2.5 µm, respectively) because these are regulated by National Ambient Air Quality Standards (NAAQS; U.S. EPA, 1997) to protect public health. Of these particle emissions, fugitive dust from paved and unpaved roads, construction, agriculture, and wind erosion make up the majority of the inventory and have compositions most similar to chaff.

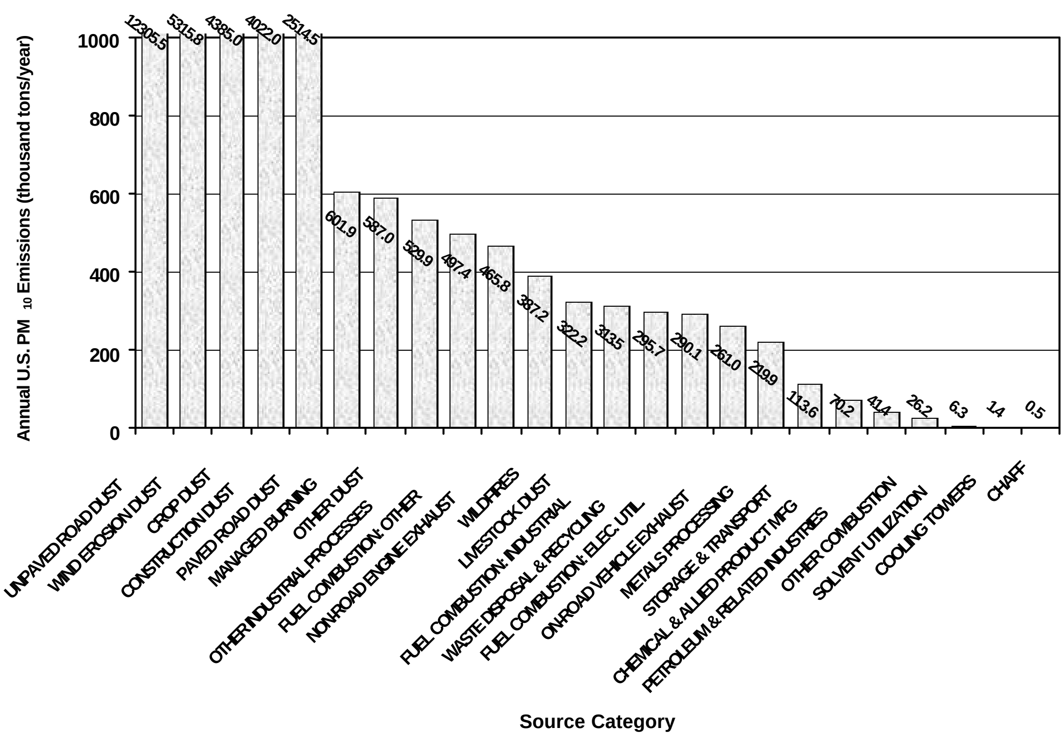


Figure 1. U.S. National Emission in 1997 for PM_{10}. Source: U.S. EPA, 1998. The chaff category is included as an upper limit assuming all chaff abrades to the PM_{10} size fraction.

[3] In this context an inhalable particle is of dimensions capable of being transported through the upper respiratory tract into the alveolar tissues of the lung. In this document the terms respirable and inhalable have similar meanings, excepted where noted.

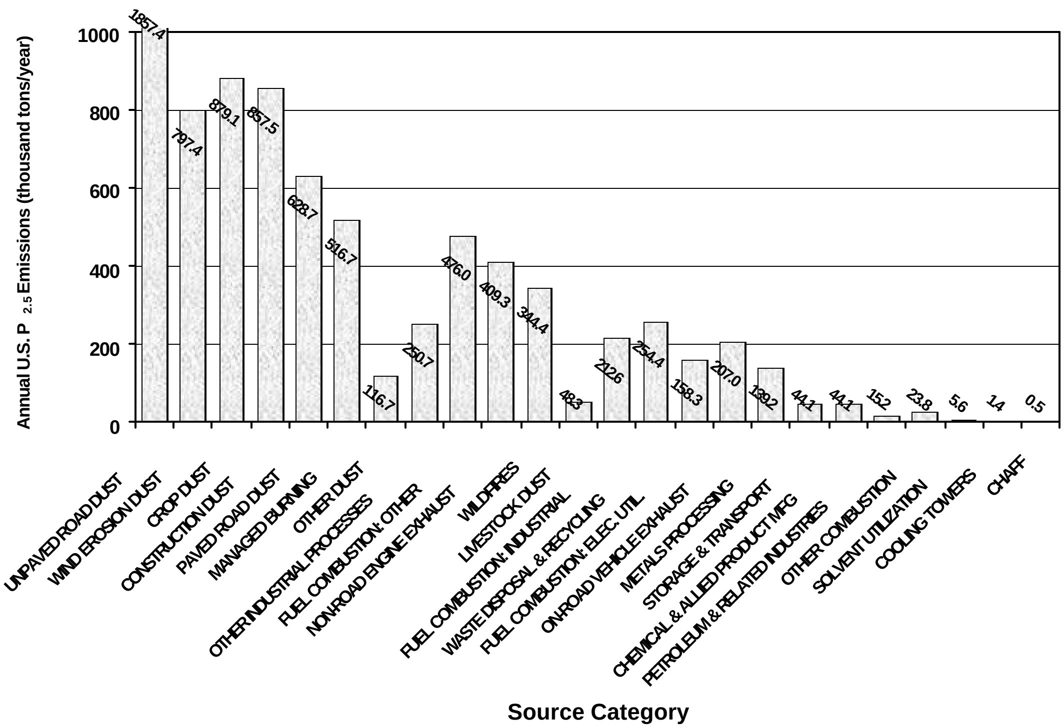


Figure 2. U.S. National Emission in 1997 for $PM_{2.5}$. Source: U.S. EPA, 1998. The chaff category is included as an upper limit assuming all chaff abrades to the $PM_{2.5}$ size fraction.

The values reflected in Figures 1 and 2 are upper limits for chaff emission calculated as PM_{10} and $PM_{2.5}$. A U.S. Air Force study[4] found that chaff particles entering a PM_{10} sampler retained their original dimensions. Their analysis of soil samples in chaff release areas also found that most dipoles detected in soil retained their original dimensions (no quantitative data available). Actual equivalent emissions in the PM_{10} or $PM_{2.5}$ size ranges would be much smaller than these estimates because it appears that only a small fraction of dipoles will degrade into particles sizes less than 2.5 or 10 µm.

Further reduction in particle size may occur after deposition, however, when deposited dipoles are abraded by soils and possibly resuspended. There is insufficient information about the extent to which chaff particles are broken up by abrasion. The amounts and times of resuspension from surfaces depends on wind speeds over the surfaces of test ranges, but the total amount cannot exceed the 500 tpy total if all deposited chaff were reduced to smaller particles.

For Fallon and Patuxent River Naval Air Stations, comparable PM_{10} and $PM_{2.5}$ emissions for Churchill County, NV and St. Mary's County, MD, where these stations are located are given in Figures 3 through 6.

[4] Environmental Effects of Self-Protection Chaff and Flares, August 1997, USAF, Air Combat Command

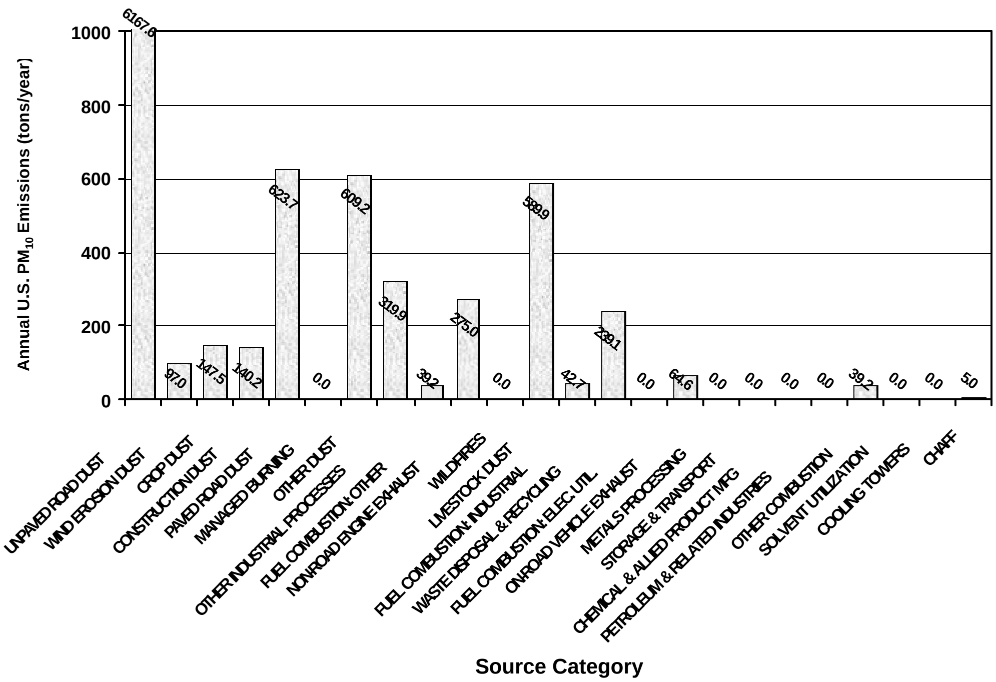


Figure 3. Churchill County, NV, PM_{10} Emissions estimates for 1997. Source: U.S. EPA, 1998.

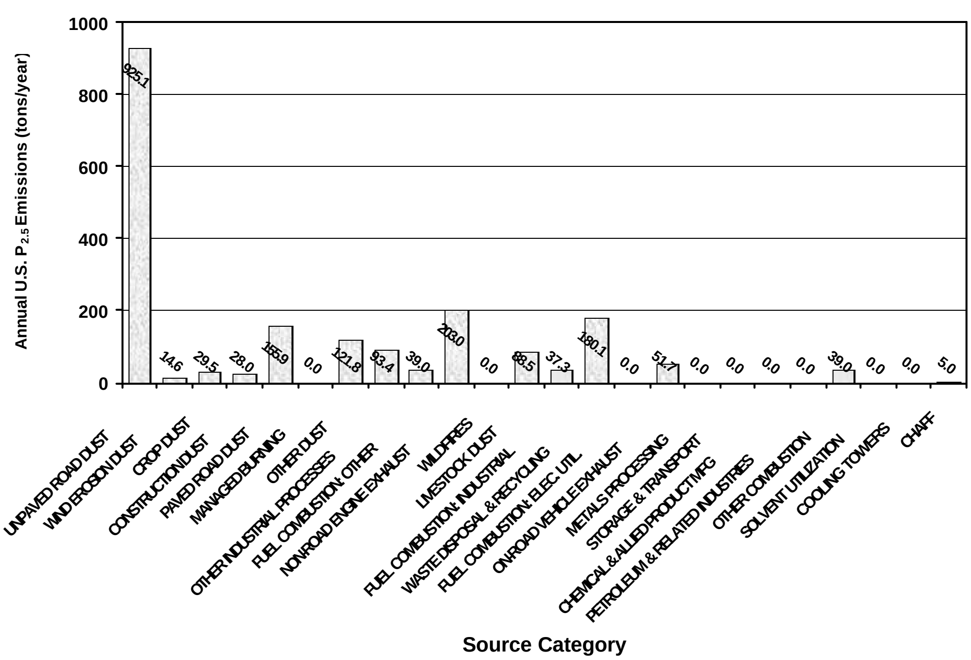


Figure 4. Churchill County, NV, $PM_{2.5}$ Emissions estimates for 1997. Source: U.S. EPA, 1998.

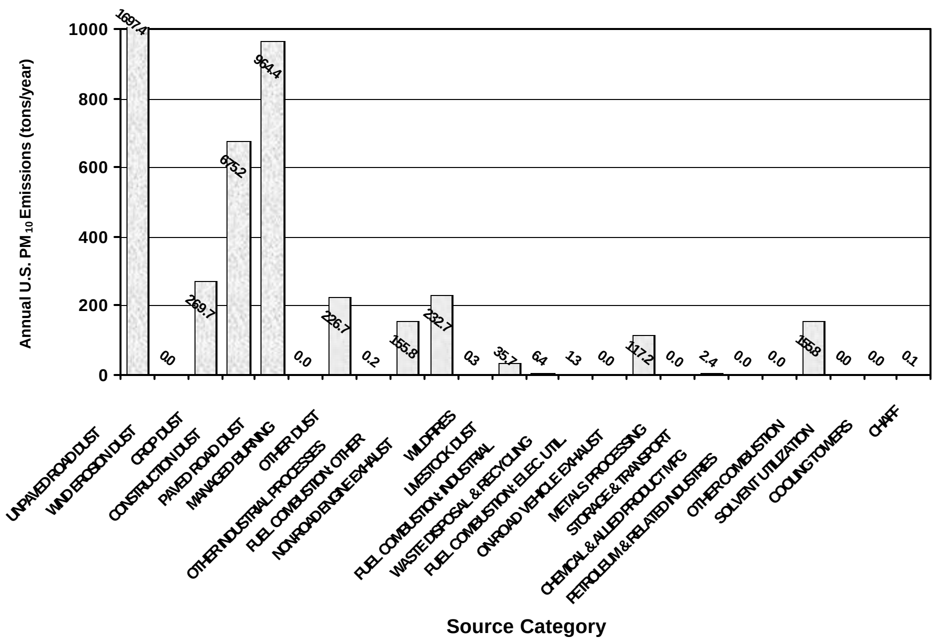


Figure 5. St. Mary's County, MD, PM_{10} Emissions estimates for 1997. Source: U.S. EPA, 1998.

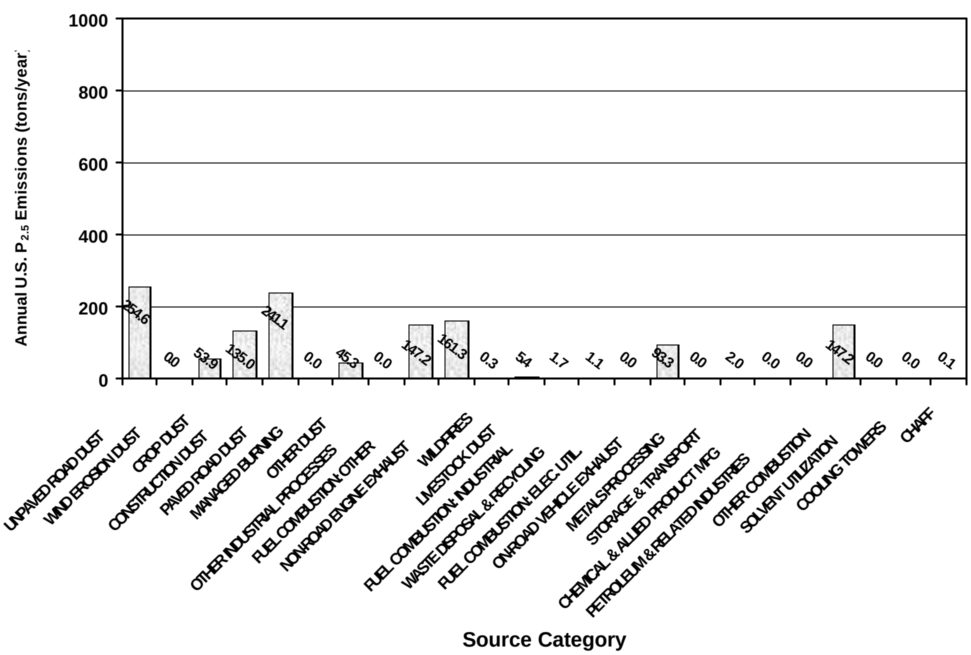


Figure 6. St. Mary's County, MD, $PM_{2.5}$ Emissions estimates for 1997. Source: U.S. EPA, 1998.

These figures show that if chaff released in these counties was completely abraded to the PM_{10} or $PM_{2.5}$ size fraction, its emissions would still be very small compared to other emissions within the county. At most, chaff would constitute 0.05% of PM_{10} and 0.25% of $PM_{2.5}$ emissions in Churchill County and 0.003% of PM_{10} and 0.009% of $PM_{2.5}$ emissions in St. Mary's County.

Chaff Deposition and Environmental Fate

Figure 7 shows the extent to which chaff is removed from the atmosphere assuming gravitational settling velocities[5] of 30 cm s^{-1}, a lower estimate for chaff deposition rates (Cataido et al., 1992). Estimates are made for release heights of 100 m, 500 m, 1000 m, 5000 m and 10,000 m agl. Two models are used to estimate residence time (Hinds, 1982): 1) a "stilled chamber" model, in which particles fall in the absence of atmospheric mixing; and 2) a "stirred chamber" model in which particles are instantaneously mixed uniformly throughout the depth between release height and ground level. These extreme models bound the actual atmospheric situation in which a fraction of particles falls directly to the surface and another fraction is mixed aloft by atmospheric turbulence. These extreme estimates show atmospheric residence times ranging from ~10 min for the majority of chaff dipoles released at 100 m to ~10 hr for most of the dipoles released at 10,000 m. Observations indicate that chaff dipoles that retain their original sizes do not stay suspended for long periods. These calculated residence times are longer than those observed on radar traces of chaff releases.

Deposition in desert ecosystems of the southwestern U.S. The panel was provided with estimates of chaff deposition in the vicinity of NAS Fallon—for instance, an estimate of 0.04 ounces per acre per year, equivalent to 2.8 g ha^{-1} yr^{-1}, was cited (Goetsch, 1999).

For comparison, the panel made two additional, independent estimates, each using a different approach. Approach 1: It was assumed that 30,000 bundles yr^{-1}, each with a mass of 150 g, are dispersed over the area of operations (MOA), which comprises 6.4 million acres at NAS Fallon. NAS Fallon personnel indicated that the chaff is released over approximately 20% of the MOA, so it is assumed in this approach that the chaff falls only on this area of intensive use—518,000 ha. The average rate of deposition would then be 8.7 g ha^{-1} yr^{-1}, or (0.00087 g m^{-2} yr^{-1}). Note that this calculation provides an upper-bound on the rate of chaff deposition at NAS Fallon; the actual deposition rate will probably be much less because chaff is likely to be dispersed over a much larger area as a result of prevailing winds and atmospheric turbulence. Similar calculations for Nellis AFB indicate deposition ranging from 9 to 30 g ha^{-1} yr^{-1}.

Approach 2: This approach was based on estimated atmospheric dispersion rates and chaff settling rates to calculate an order-of-magnitude rate of chaff deposition on the ground. It was assumed that 1-mil glass fiber chaff is employed, with a settling velocity[6] of 30 cm s^{-1}. A typical

[5] Jiusto, JE and WJ Eadie. 1963 Terminal fall velocity of radar chaff. Journal of Geophysical Research 68:2858-2861. Provides theoretical estimates and empirical measurements of the fall velocity at altitudes ranging from 0 to 20 km. Values range from 62 cm s^{-1} to 139 cm s^{-1}. Faster velocities at higher altitudes is associated with lower air viscosity.

[6] Environmental Effects of Self-Protection Chaff and Flares, August 1997, USAF, Air Combat Command

scenario is based on wind speeds[7] of 30 ft s^{-1} at 10,000 ft agl, 15 ft s^{-1} at 5000 ft agl, so the mean horizontal travel is 250,000 ft for chaff released at 10,000 ft agl. The reasonableness of this number can be confirmed by multiplying an average wind speed of 15 ft s^{-1} (neglecting the shape of the wind velocity profile) by calculated chaff fall time.

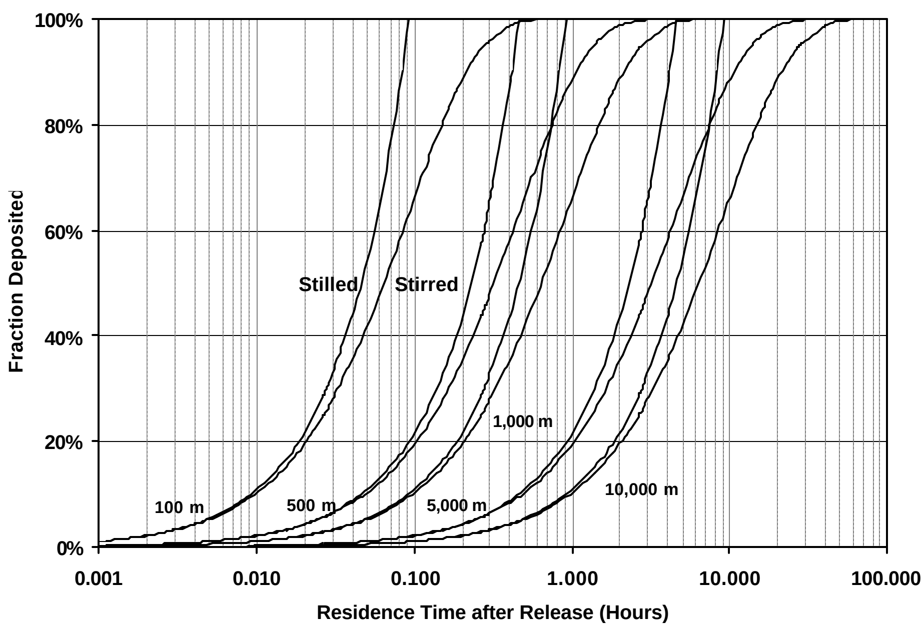


Figure 7. Fractions of chaff particles deposited after different release times and elevations above ground level. Mixed and stirred chamber models (Hinds, 1982) are used to bound atmospheric mixing conditions assuming a deposition velocity of 30 cm s^{-1}.

Dispersion of chaff was estimated using the Pasquill-Gifford model (e.g., Seinfeld, 1986) with a neutral stability category (a conservative approach, because most chaff is released during the day). The expected patch of chaff on the ground resulting from the release of one round is an area 8,000 m wide by 12,000 m long (1 std dev.). Release of 30,000 bundles of chaff per year in a pattern that would distribute such chaff patches along two sides of the roughly square MOA would result in deposition of ca. 40 fibers m^{-2} yr^{-1} on the ground. In actuality, the variability in release point and atmospheric transport are likely to result in more dispersion. Under certain meteorological conditions, large fibers or particles can be transported over surprisingly long (hundreds of miles) distances. For example, particles from the Sahara desert can be transported across the Atlantic Ocean and deposited in the southeastern region of the U.S. (Prospero, 1999). Similarly, media reports indicate that chaff released during the Kosovo air campaigns has been transported over several hundred miles to areas in the Southeastern Balkans.

[7] *ibid.*

The estimate resulting from Approach 2 corresponds to a positively biased chaff deposition of approximately 12 g ha^{-1} yr^{-1}, within range of the value estimated in Approach 1. Both estimates are close to the value of 0.04 oz $acre^{-1}$ yr^{-1} (= 2.8 g ha^{-1} yr^{-1}) cited for NAS Fallon (Goetsch, 1999). The similarity of the three estimates is probably coincidental, given the many approximations and assumptions that were necessary; however, it builds confidence that the correct general magnitudes are known.

These estimates of chaff deposition are consistent with reports of the identification of chaff in soil samples gathered at Nellis AFB[8]. Soil samples were 10 x 10 cm in area and 2 cm in depth. Concentrations of chaff ranged between 0.02 and 251 mg kg^{-1} of soil, with most samples having < 0.5 mg kg^{-1}. Assuming 1.4 g cm^{-3} soil density, the maximum amount of chaff that was observed in any soil was about 7 g m^{-2}, with most samples having < 0.014 g m^{-2}. It would take about 9.3 yr to accumulate > 0.014 g m^{-2}, if chaff is deposited at the rate of 15 g ha^{-1} yr^{-1}, a middle value among the rates calculated for Nellis AFB. Assuming little fiber degradation in soils, this calculation suggests that the amount of chaff that has accumulated on the ground is consistent with deposition rates that are less than 15 g ha^{-1} yr^{-1}, during the past 50 years of chaff usage at Nellis AFB.

The calculation of Approach 2 implies an atmospheric concentration of one fiber per 10,000 m^3 of air for release of one bundle of chaff at 10,000 ft agl. This is equivalent to an airborne concentration of 0.003 μg m^{-3}.

Deposition of chaff at Patuxent River NAS. Using Approach 1, the maximum rate of deposition of chaff at Patuxent River NAS was 0.16 g ha^{-1} yr^{-1}. As of the writing of this report, chaff usage over Patuxent River NAS was 919 bundles in 1999, resulting in the deposition of 0.20 g ha^{-1} yr^{-1}. These estimates are more than 10 times lower than the deposition calculated at NAS Fallon.

For chaff dispersed by mortar rounds from naval vessels[9], the estimated deposition is 53 dipoles ft^{-2} for the area of deposition under a single round that disperses chaff at a height of 300 ft. This deposition corresponds to 170 g chaff ha^{-1}. This estimate is much higher than deposition calculated for the southwestern U.S., where the altitude of chaff release is much higher and the calculations are long-term averages for the entire MOA, rather than for the area directly beneath a single release. The estimate of 170 g ha^{-1} yr^{-1} represents an upper-limit of chaff deposition to be expected from normal operations over land and at sea and is a rare event.

Environmental fate of chaff in air, soils, and aquatic systems. The environmental fate of chaff includes alterations that may occur between its release and its deposition on the ground, and the long-term degradation and burial processes that it experiences after hitting the ground.

Chaff fibers experience little breakup before reaching the ground based on the fact that breakup of fibers would degrade the effectiveness of chaff. Chaff ejection systems subject chaff to minimal breakup. Because ejection of chaff appears to subject the fibers to much larger forces

---

[8] *ibid*., p.3-39

[9] Rapid Bloom Offboard Chaff System Evaluation and Naval Air Systems Command Multi-Frequency Chaff Evaluation.

than would atmospheric turbulence, it is unlikely that fibers that survive ejection intact subsequently break up during their fall to earth.

Although breakup of fibers during ejection is probably not a significant process, this can be confirmed from radar cross-section data. Because breakup of fibers will significantly affect the radar cross section of the chaff cloud, radar echoes should be examined for both loss of reflectivity (relative to modeled data or control studies) at the frequencies for which the chaff is designed and for appearance of larger-than-predicted reflectance at higher frequencies, due to the presence of short fragments. It is possible that such a study could be conducted at minimal cost using existing data. The panel recommends that this be considered by those having the appropriate radar expertise as well as access to classified radar cross section data, as a part of the additional studies recommended.

Geochemical significance of chaff deposition. Chaff is approximately 60% glass fibers and 40% aluminum by weight (Rock, 1999). To put this in a geochemical perspective, the deposition of chaff can be compared with airborne dusts found in the high desert environment. The comparison to desert dust is relevant because the composition of dust is dominated by silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3), which are the most common minerals in the Earth's crust (Pye, l987).

Reheis and Kihl (1995) measured the mean total deposition of silt and clay ranges from 4.3 to 15.7 g m^{-2} yr^{-1} in the Mojave Desert of California and southern Nevada. From 1984-1989 these values are 10,000 times higher than the rate of chaff deposition in this region. However, much of the dust that is deposited in arid lands may be derived from local sources. Chadwick et al. (1995) estimate that the *net* input of silt + clay to soils in northern Nevada ranges from 0.2 to 0.4 g m^{-2} yr^{-1}, which is 375X higher than the annual deposition of chaff that was calculated for NAS Fallon.

Windblown dusts typically contain between 50 and 60% SiO_2 (Pye, 1987), which is similar to the content of Si in the glass fibers of chaff. Using the reported chemical composition of each fraction[10], then each gram of chaff deposited at NAS Fallon carries 0.32 g of SiO_2 (or 0.15 g of elemental Si) to the soil surface. The glass fibers in chaff contain a small amount of Al, but the coating on chaff is nearly pure aluminum. Each gram of chaff deposited adds about 0.44 g of Al to the soil surface. Compared to these inputs, the average soil contains >50,000 times more Si and 5000 times more Al in the upper 2 cm. The remaining constituents in chaff, dominated by Ca, Mg, and B, are also common in airborne dusts. The deposition of Ca in chaff is about 5600 times lower than the background rate Ca deposition from the atmosphere in the southwestern U.S., where the atmospheric deposition of Ca leads to the formation massive deposits of caliche in desert soils (Schlesinger, 1985).

Ambient Concentrations

Particle size and mass concentration have both been determined to affect the public health significance of airborne particles (U.S. EPA, 1996, Vedal, 1997). Small particles also have lower deposition velocities and can remain suspended for much longer time periods than those

[10] Environmental Effects of Self-protection Chaff and Flares, August 1997, USAF, Air Combat Command , Table 3.2-1, see Appendix C

indicated by Figure 7. National Ambient Air Quality Standards (NAAQS) for particulate matter (PM; U.S. Environmental Protection Agency, 1997) specify:

1. Twenty-four hour average $PM_{2.5}$ not to exceed 65 $\mu g\ m^{-3}$ for a three-year average of annual 98th percentile at any population-oriented monitoring site in a Metropolitan Planning Area (MPA).
2. Three-year annual average $PM_{2.5}$ not to exceed 15 $\mu g\ m^{-3}$ concentrations from a single community-oriented monitoring site or the spatial average of eligible community exposure sites in a MPA.
3. Twenty-four hour average PM_{10} not to exceed 150 $\mu g\ m^{-3}$ for a three-year average of annual 99th percentiles at any monitoring site in a monitoring area.
4. Three-year average PM_{10} not to exceed 50 $\mu g\ m^{-3}$ for three annual average concentrations at any monitoring site in a monitoring area.

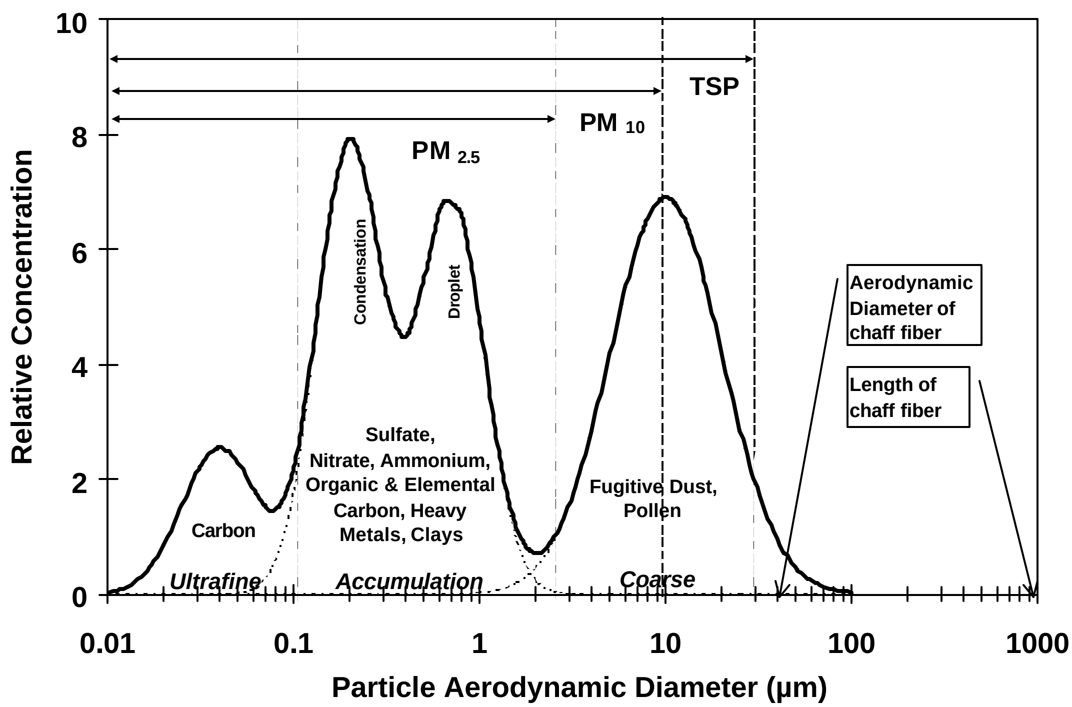


Figure 8. Typical distribution of particle sizes in the atmosphere. Concentrations at larger particle sizes are limited by gravitational settling.

How particles of different sizes are typically distributed in the atmosphere, the size fractions occupied by $PM_{2.5}$, PM_{10}, and a prior NAAQS for Total Suspended Particulate (TSP) is shown in Figure 8.

Particles larger than 30 µm deposit to the surface within less than an hour after suspension unless they are injected to or released from high altitudes. This deposition effectively limits atmospheric concentrations for very large particles. Without substantial decomposition, chaff particles deposit rapidly to surfaces, as shown in Figure 7.

The “ultrafine particles” (Oberdörster et al., 1995; Fitzgerald et al., 1997; Kotzick et al., 1997) in Figure 8 have diameters less than ~0.08 µm that are emitted directly from combustion sources or that condense from cooled gases soon after emission. Ultrafine particle lifetimes are usually less than one hour because they rapidly coagulate with larger particles or serve as nuclei for cloud or fog droplets. The nucleation range is detected only when fresh emissions are close to a measurement site or when new particles have been recently formed in the atmosphere (Lundgren and Burton, 1995).

The “accumulation” range consists of particles with diameters between 0.08 and ~2 µm. These particles result from the coagulation of smaller particles emitted from combustion sources, from gas-to-particle conversion, from condensation of volatile species, and from finely ground dust particles. Chemical-specific size distributions show that these sub-modes exist in several different environments (Hering and Friedlander, 1982; Hoppel et al., 1990; Sloane et al., 1991). John et al. (1990) interpreted the peak centered at ~0.2 µm as a “condensation” mode containing gas-phase reaction products, and the ~0.7 µm peak as a “droplet” mode resulting from growth by nucleation of particles in the smaller size ranges and by reactions that take place in water droplets. The liquid water content of ammonium nitrate, ammonium sulfate, sodium chloride, and other soluble species increases with relative humidity, and this is especially important when relative humidity exceeds 70% (Tang, 1976). When these modes contain soluble particles, their peaks shift toward larger diameters as humidity increases (Tang, 1976, 1980, 1993; Tang et al., 1977; McMurry et al., 1987; Zhang, 1989). The ultrafine and accumulation ranges constitute the “fine” particle size fraction, and the majority of sulfuric acid, ammonium bisulfate, ammonium sulfate, ammonium nitrate, organic carbon, and elemental carbon is found in this size range.

The $PM_{2.5}$, PM_{10}, and TSP size fractions commonly measured by air quality monitors are identified in Figure 8 by the portion of the size spectrum that they occupy. The mass collected is proportional to the area under the distribution within each size range. The TSP size fraction ranges from 0 to ~30 µm, the PM_{10} fraction ranges from 0 to 10 µm, and the $PM_{2.5}$ size fraction ranges from 0 to 2.5 µm in aerodynamic diameter. No sampling device operates as a step function, passing 100% of all particles below a certain size and excluding 100% of the particles larger than that size. When sampled, each of these size ranges contains a certain abundance of particles above the upper size designation of each range (Watson et al., 1983; Wedding and Carney, 1983). As a result, it is possible for a small fraction of chaff particles to pass through the size-selective inlets that are used to separate PM_{10} from other particle sizes.

The following are reasonable to worst case assumptions to estimate the largest increments in ambient PM_{10} and $PM_{2.5}$ concentrations that might be contributed by chaff emissions:

1. All released chaff abrades to sizes less than 2.5 or 10 µm. As noted above, it is probable that only a small fraction of released chaff achieves sizes <10 µm and that an even smaller fraction (<<1%) achieves sizes <2.5 µm.
2. All chaff released during a year remains suspended within the borders of the continental United States or of a specific air station practice range. As shown in Figure 7, it is probable that most of the dipoles settle to the surface within less than a day after release; remaining chaff would be transported beyond U.S. borders within a few weeks.

3. Chaff is released at 5,000 m above ground level and mixes evenly throughout that altitude. Higher concentrations at lower altitudes imply deposition to the surface that would quickly reduce ambient concentrations. This is within the range of altitudes estimated for most naval chaff releases and an elevation at which particles can remain aloft long enough to be transported long distances from the release point. Non-depositing chaff particles released at lower altitudes would eventually be mixed within the troposphere over a yearlong period, as evidenced by the penetration of long-lived halocarbons to the stratosphere.

With these assumptions, a 500 tpy chaff release would result in an annual average concentration of PM_{10} or $PM_{2.5}$ over the continental United States (area 3,539,341 mi^2) of .01 µg m^{-3}. If one-tenth of these emissions were dispersed over the state of Nevada (area 109,895 mi^2), the annual average concentration would be 0.032 µg m^{-3}. For NAS Fallon, a 5 tpy release over 10,000 mi^2 would result in an annual average concentration of 0.036 µg m^{-3}. For Patuxent River NAS, a 0.12 tpy release over 2400 mi^2 would yield an annual average concentration of 0.0061 µg m^{-3}.

The same upper limit concentration estimates would apply if all chaff were released and mixed through the specified volume in a day or even within an hour, since no deposition losses are assumed. In reality there are higher concentrations just after release before the chaff plume disperses in the atmosphere. If operations are confined to the designated test areas, however, off-site concentrations should not exceed these upper limits. These are far below the annual average NAAQS of 50 µg m^{-3} for PM_{10} and 15 µg m^{-3} for $PM_{2.5}$ that have been set to protect public health.

These levels are compared with spatial distributions of background PM_{10} and $PM_{2.5}$ concentrations in Figures 9 and 10 (courtesy J. Sisler, National Parks Service, Ft. Collins, CO). These isopleths include data from monitors in populated areas at Lake Tahoe, CA and Washington, D.C. that do not represent background levels, but most of the monitors are distant from nearby emitters.

Within the continental United States, annual average background PM_{10} concentrations range from a minimum of 6.4 µg m^{-3} in northern California and western Nevada to 20 µg m^{-3} along the eastern seaboard. For $PM_{2.5}$, concentrations are lowest at 2.9 to 3.3 µg m^{-3}, in the inland west, including Nevada, Utah, Wyoming, northern Arizona, and western Colorado.

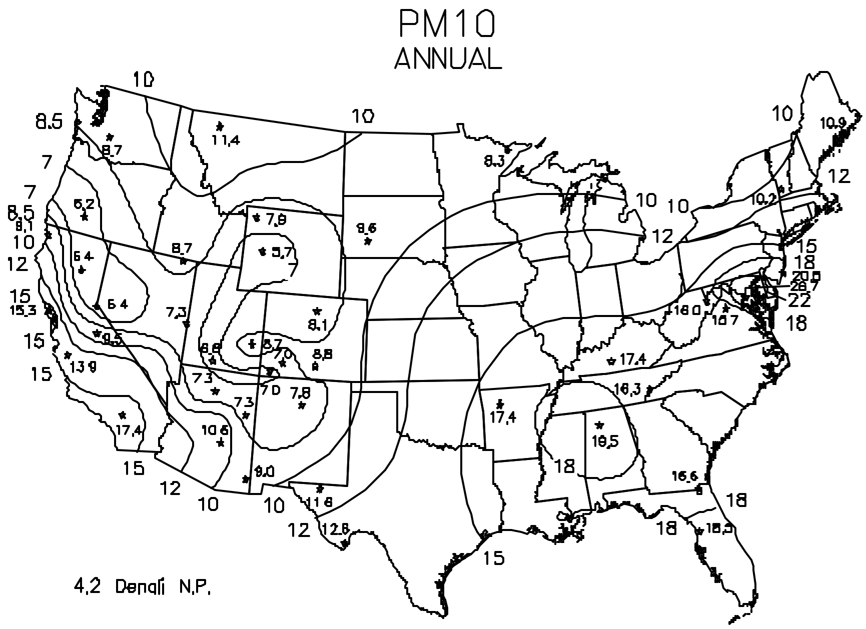


Figure 9. Annual average PM_{10} concentrations (µg m^{-3}) from 1988-95 at IMPROVE regional background sites in the continental United States (James Sisler, National Parks Service).

The $PM_{2.5}$ fraction is chemically characterized in the IMPROVE network and soil-related elements are used to estimate the geological contribution to $PM_{2.5}$. Chaff would be perceived by this network as part of this fraction. Figure 11 shows that these soil levels range from 0.2 µg m^{-3} near the west coast to 1.0 µg m^{-3} near the east coast. Soil concentrations in the inland western states are ~0.5 µg m^{-3}. These background levels are more than ten times the highest levels that chaff might contribute with extremely conservative assumptions about particle size and deposition rates.

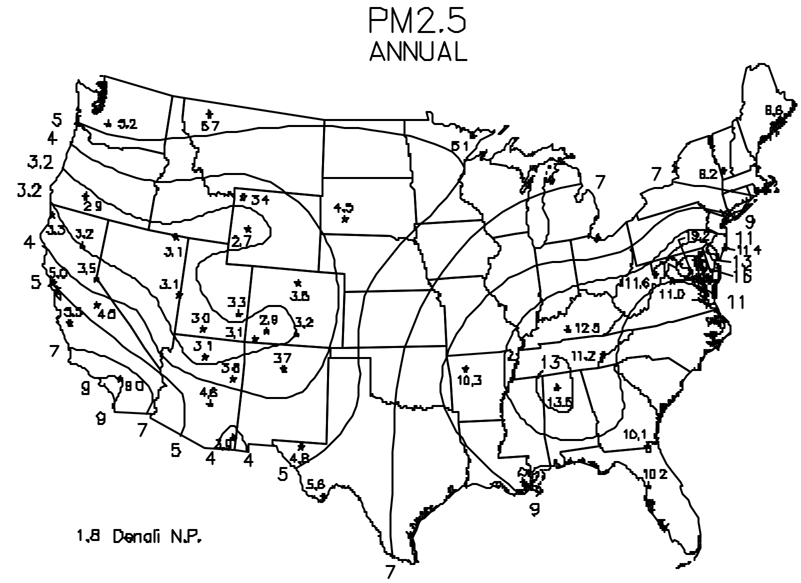


Figure 10. Annual average $PM_{2.5}$ concentrations ($\mu g\ m^{-3}$) from 1988-95 at IMPROVE regional background sites in the continental United States (James Sisler, National Parks Service).

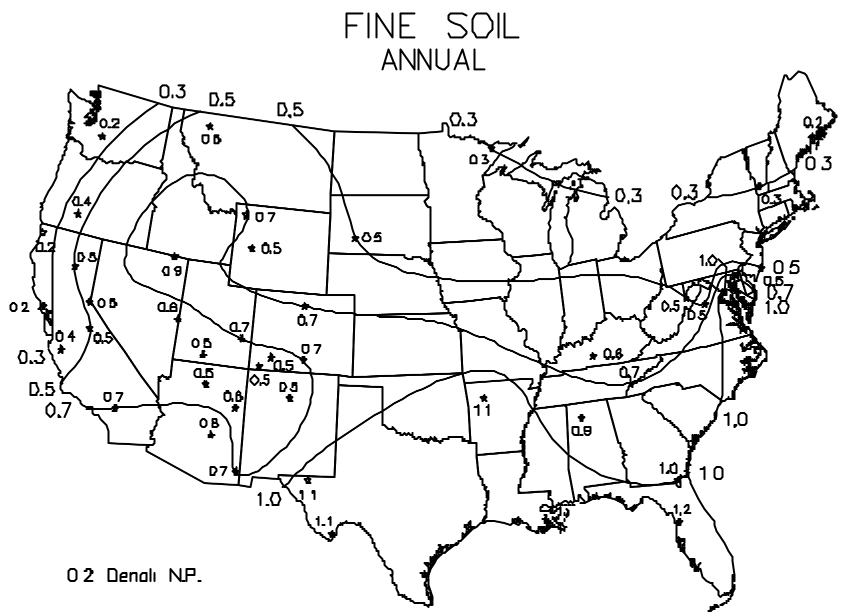


Figure 11. Annual average geological contributions ($\mu g\ m^{-3}$) to $PM_{2.5}$ from 1988-95 at IMPROVE regional background sites in the continental United States (James Sisler, National Parks Service).

Effects of Chaff on Humans

The size of chaff dipoles is too large to be easily inhaled by humans. Figure 12 (Phalen et al., 1991; ACGIH, 1993; Heyder et al., 1986; Swift and Proctor, 1982) shows the fraction of particles with different sizes that deposit in different parts of the human body when particle-laden air is breathed. The aerodynamic diameter of a chaff dipole cross section (~40 µm) is also shown. Most particles larger than 10 µm are removed in the mouth or nose prior to entering the body. Ten to 60% of the particles passing the trachea with aerodynamic diameters less than 10 µm may deposit in the lung where they might cause harm. The lung deposition curve is bimodal, peaking at 20% for ~3 µm particles and at 60% for ~0.03 µm particles. These curves show that the amount of particles larger than 2 or 3 µm transmitted through mouth-breathing is significantly larger than the amount transmitted when breathing takes place through the nose.

Extreme abrasion would be needed to reduce chaff to these size ranges. The most probable breakup of a dipole would be perpendicular to its length, with remaining particles having a diameter similar to the dipole radius, with an aerodynamic diameter of ~40 µm. Figure 12 shows that only a very small number of these particles pass through the upper respiratory system into the lung.

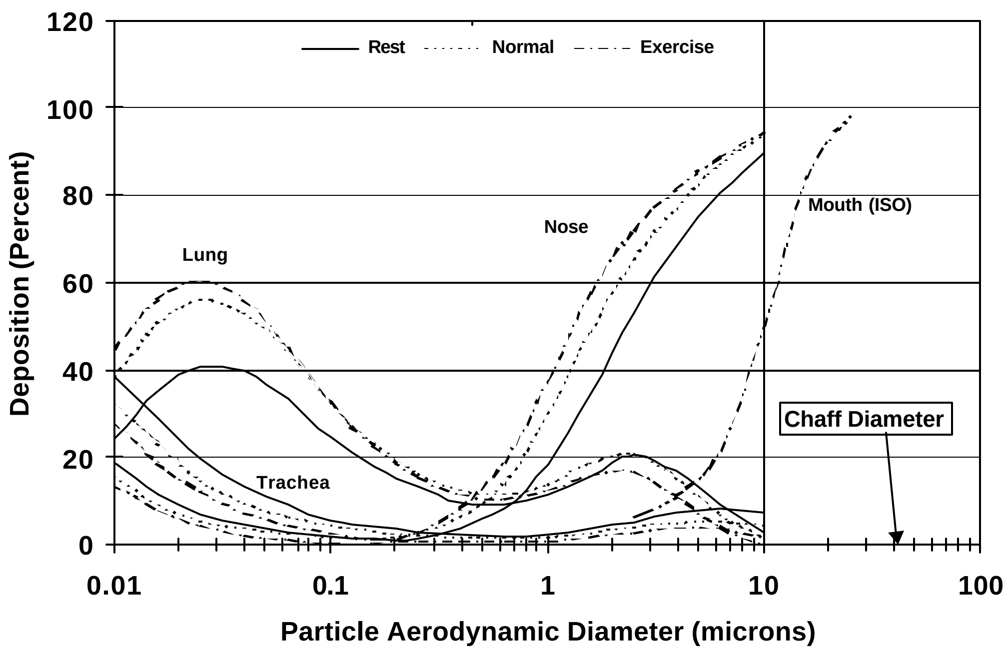


Figure 12. Human deposition of particles in the mouth, nose, trachea. Deposition varies with breathing rate, as indicated by curves measured at rest, normal, and exercise breathing rates.

A relevant analogy is that of the Bedouins of the Sahara desert, who live in a sea of sand, which is composed of silica (silicon dioxide). Silica is a common, well-known cause of nodular fibrosis of the lungs. However, the Bedouins do not get silicosis (nodular fibrosis of the lungs due to silica) because the sand particles are not of a respirable size. They are too large to inhale into the alveolated portion of the lungs and produce disease.

Human lungs at autopsy contain a mixture of respired dusts, some of which are capable of producing disease. These include carbon (anthracotic pigment), silica, silicates, iron, and asbestos. In most cases however, no disease attributable to these dusts is seen, because their concentrations are too low. Even if abraded chaff particles reached the depths of the human lung, the fraction would be small compared to inhaled dust from other sources any disease would not likely result. Since fibrous glass and aluminum oxide in chaff are relatively nontoxic, disease would be unlikely. A much more toxic substance such as asbestos can produce serious lung disease, but even asbestos has a threshold level, below which no disease is produced.

Airborne chaff fibers have not been epidemiologically associated with human disease. Nonetheless, concern for possible ill effects on humans has been voiced by the public and echoed in newspapers (Mullen, 1998; Ropp, 1999) from areas near chaff dispersal. Though no human data on chaff toxicity exist, its possible toxicity can be assessed with studies on fibrous glass and aluminum. The National Institute for Occupational Safety and Health (NIOSH) published a recommended standard for occupational exposure to fibrous glass, including a review of previous studies on fibrous glass and health risks (US Department of Health, Education and Welfare, 1977). These studies investigated the health of those primarily involved in the manufacture of fibrous glass products. Effects on skin and mucous membranes and respiratory effects were reviewed, including epidemiological studies. Smaller lengths of glass fibers were irritating to the skin, but sensitization, an immune response, did not occur. Similar mechanical irritation could also occur with exposure to the eye or nasal or oral mucous membranes. These problems were self-limited and avoidable.

A few individuals had lung disease due to aspiration of plugs or masses of glass fibers, but in several case series, no chronic disease was detected. Most studies are epidemiological, and often the degree to which the subjects being studied smoked was not investigated. Two diseases would be primarily found in such studies: fibrosis (scarring) of the lungs, an irreversible disabling chronic disease, and primary cancer of the lung proper (carcinoma) or the pleura (malignant mesothelioma). The majority of these studies showed no significant differences between glass workers and non-exposed controls, and no difference between mildly and severely exposed glass workers.

In one study, an excess of cases of glass workers dying of “nonmalignant respiratory disease” was noted (Bayliss et al., 1976). The precise nature of the diseases was not stated, and exposure to other dusts in other occupations was not excluded, nor was the role of cigarette use. A more recent publication states that fibrous glass is not associated with an excess of death from nonmalignant lung disease (Ameille et al., 1998). The workers in the above study (Bayliss et al., 1976) were exposed to 80,000 glass fibers m^{-3} of air; fibers had a median diameter of 1.8 μm and length of 28 μm. Thus, these fibers are much smaller than chaff and were more likely to have been inhaled. The atmospheric concentration of the fibers also was very much higher than any concentration, which could be achieved in open air.

Enterline et al. (1983) and McDonald et al. (1990) studied workers in 17 plants that had produced most of the fibrous glass and mineral wool from 1940-1952. The authors concluded that: "Respiratory cancer deaths were not excessive for the fibrous glass workers…" and "This study provided no consistent evidence of a respiratory disease hazard related to exposure to man-made fibers among the workers who produce these fibers." There was again an excess of nonmalignant respiratory disease deaths, but the increase was not related to amount of exposure to glass.

Weill et al. (1983) studied workers in seven plants that produced man-made vitreous fibers (MMVF), which includes fibrous glass. No abnormalities in lung function were found in the workers, and chest film showed only very mild abnormalities in a minority. The authors concluded: "In general, however, the minimal evidence of respiratory effects detected in this investigation, which cannot, at present, be considered clinically significant, is encouraging concerning the question of potential health effects of exposure to MMVF." A review of MMVF in 1998 came to a similar conclusion: "At the present time there is no evidence of a pneumoconiosis risk in workers exposed in either glass, rock or slag wool production plants. This is probably due to the low respirability and low persistence of these fibers when compared to asbestos"(Ameille, 1998). No increased risk for cancer was found as well.

A study of autopsy lung tissue from 112 workers employed in plants where MMVF's, including fibrous glass, were manufactured was carried out to search for the burden of these fibers (Weill, 1983). Nearly three-fourths of the lung samples contained no MMVF's. The remaining 26% contained MMVF's in very low levels. The fibers appeared to be partially degraded. Fiber concentrations did not correlate with years of occupational exposure. Thus, glass fibers do not appear to accumulate in the lungs of those most heavily exposed to such fibers.

The above studies were in humans exposed to glass fibers of respirable size over long periods of time at concentrations far exceeding those possible in the open air. Still, the effects of this intense exposure were trivial; in most comparisons of glass workers with non-exposed controls, there were no significant differences. No excess cases of cancer or lung fibrosis were detected (Gibbs, 1998). A Committee on Environmental Health of the American Collage of Chest Physicians put it this way: "Fiberglass inhalation seems to produce a minimal tissue response in the lungs…There is no evidence to indicate that inhaling fiber glass is associated with either permanent respiratory impairment or carcinogenesis…."(Gross, 1976).

Aluminum is a very common metal in the earth's crust and thus is a part of the natural soil layer. This light, durable metal has many uses and manufacturing involving aluminum is widespread. It is estimated that nearly two million people in the United States are exposed to aluminum as part of their occupation (Nemery, 1998). However, lung disease due to aluminum is a controversial topic. Some say aluminum does not cause any lung disease (fibrosis), while others claim to have seen rare examples of lung disease due to aluminum. All agree that "parenchymal lung disease…appears to be very uncommon." (Nemery, 1998). The few cases reported appear to have been heavy exposures to respirable-sized particles during manufacturing, an exposure that should not have occurred. Other cases of disease may involve exposure to silica as well, as well as other chemical bound to the aluminum. Thus the aluminum itself may not be at fault.

Various authors conclude that aluminum exposure is not associated with an increased risk of cancer. Rarely, it may cause pulmonary fibrosis if large numbers of respirable particles are inhaled (Nemery, 1998; Chip et al., 1998). Considering the large number of workers exposed to aluminum, the likelihood of harmful exposure appears extremely small. Exposure in the open air, as from chaff, would not result in disease because the concentration of aluminum/glass particles is so low and the particles are too large to be respired.

As discussed in other sections, nearly all chaff fibers are too large a size to be respired. The tiny number of fibers that could be inhaled because they are of respirable size or have degraded to such a size are insufficient to produce disease. Persons occupationally, that is, heavily exposed to the components of chaff fibers are at no increased risk for lung fibrosis or cancer. The components of chaff, that is, glass and aluminum, do not have any proven fibrogenic or carcinogenic potential. This is very different from certain types of asbestos fibers, which are both fibrogenic and carcinogenic. In summary, available human data on chaff and its components fail to show an increased incidence of lung disease.

Effect of Chaff on Domestic Livestock

Nutritional effects due to chaff ingestion. Given the chemical composition of chaff and the limited potential for exposure of grazing animals to chaff fibers, it is highly unlikely that any harmful effects are to be expected due to chaff ingestion by livestock. Chemically, chaff fibers are very similar in composition to predominant minerals in the earth's crust, Al_2O_3 and SiO_2.

Although the aluminum in chaff exists as relatively inert metallic aluminum coated on the glass fibers, it could be postulated that after ingestion some of the aluminum could be leached during passage through the gut. While there is no information in the literature to document toxic effects due to metallic aluminum ingestion (Sorenson et al., 1974), conditions do exist in the gut that (theoretically at least) could give rise to some aluminum solublization. Salts of aluminum can interfere with animal nutrition. As Al^{+3}, aluminum can interfere with phosphorus absorption and cause secondary phosphorus deficiency in both ruminants and non-ruminants (NRC, 1980). The primary factors that affect the severity of aluminum toxicity are the amount of aluminum, the solubility of the aluminum, and the level of phosphorus in the diet. Bailey (1977) and Valdivia et al. (1978) found no adverse effects of feeding soluble salts of aluminum to calves at rates of up to 1200 mg kg^{-1} aluminum in the diet. Similar investigations with sheep showed no adverse effects up to 1215 mg kg^{-1} aluminum. Based on these studies, the National Research Council (NRC) recommends that the maximum tolerable level of soluble aluminum (Al^{+3}) for cattle and sheep is approximately 1000 mg kg^{-1} in the diet. Research on the effects of aluminum on non-ruminant animals has been confined mainly to turkeys and chicks (Cakir et al. 1978; Storer and Nelson, 1968). The NRC recommendation is that dietary aluminum from soluble salts for non-ruminants should be limited to approximately 200 mg kg^{-1}. It also should be noted, however, that although the NRC recommendations limit Al ingestion at the high end, there is some evidence that feeding limited amounts of Al salts can actually improve animal performance (Dishington, 1975; McManus and Bigham, 1978).

The degree to which any given amount of aluminum metal leaches from chaff in the gut will be determined by two factors: the ambient pH, and the residence time of the chaff particle. In general, conversion of aluminum metal to Al^{+3} requires a pH of 5.0 or lower. Rumen pH rarely drops below 5.4 and is normally closer to 6.0, depending on the nature of the diet. Again, depending on diet, the mean residence time for a particle in the rumen is about 24 hours. The pH of the abomasum drops to 4.5 and the remainder of the hindgut is somewhat lower. Rate of passage at this stage is variable but usually rapid, ranging from several minutes to several hours (G. Varga, personal communication). Because of the fine fibrous nature of chaff, it is possible that some of the material could collect over time and form "hairballs" in the rumen that could remain for a considerable period of time. Indeed, actual hairballs have been found in cows during post-mortem examination of rumen contents. It is also possible that chaff fibers could collect in the villi of the omasum, which is a filtering organ between the rumen and abomasum. Like the rumen, however, the omasum is usually well-buffered and non-acidic. It is also relatively dry. Thus it is unlikely that any significant amount of aluminum in ingested chaff would be exposed to internal conditions long enough to render it toxic to the animal.

Nevertheless, a "worst possible case" can be calculated, based on estimated daily dry matter intake and potential for chaff ingestion by cows in the NAS Fallon area. Beef cattle consume somewhere around 2% of their body weight daily as plant dry matter. For a typical 550 kg beef cow, the daily feed intake would be approximately 11 kg dry matter. If all the aluminum in ingested chaff became the soluble (Al^{+3}) form, 11 g of Al^{+3} (11,000 mg Al^{+3} per 11 kg feed) would need to be nutritionally available daily to reach the 1000 mg kg^{-1} dietary threshold for toxicity determined by the NRC. This is highly unlikely given that the conversion of Al to Al^{+3} is very slow in the dry, non-oxidizing environment in Nevada and the annual loading rate for chaff (at least for NAS Fallon). Mass balance calculations (See "Chaff Distribution", above) showed that ≤ 20 g ha^{-1} are deposited per year over the test site. The highest expected stocking density for livestock on good rangeland is one animal unit (cow or cow-calf pair) per 2 ha. Thus, one animal unit would have access to 40 g (40,000 mg) annually, not daily, of which only 16 g (40%) would be aluminum metal.

Finally, when all of this information is put in proper perspective, it is clear how minuscule a threat chaff presents to livestock, at least nutritionally. Coming back to the soil, aluminum in soil can range from 4 to 30% of the dry matter (Allen, 1984), and is present in various forms, including silicate clays, hydrated oxides, phosphates, and in ionic form. Grazing animals are known to consume considerable amounts of soil, with soil intakes inversely related to the amount of available plant material. Soil intakes as high as 400 g day^{-1} have been observed for grazing ewes (Healy, 1967), and 1.3 kg day^{-1} for cattle (Mayland et al., 1973) with no negative effects. Clearly, the contribution of chaff aluminum to the large mass of native aluminum potentially ingested is very small indeed and poses no conceivable threat to livestock.

Physical effects due to chaff ingestion. Because of its fibrous glass composition, chaff does have the potential to cause physical harm to gut mucosa if ingested. Very little research has examined this potential. One unpublished study, a report to the Director of Canadian Electronic

Warfare[11] fed aluminum coated fiberglass chaff to beef calves (approximately 180 kg live weight) at up to 7 g day^{-1}. It is instructive that a preliminary investigation found that the animals rejected the chaff outright, and that the material had to be evenly scattered over the grain ration and thoroughly mixed with molasses before the calves would eat it. The feeding treatments were applied for up to 39 consecutive days, during which time no differences were shown between chaff-fed and control animals in terms of weight gain or blood chemistry. Post-mortem examination, including a detailed histological examination of sections of the entire gut showed no lesions. Small chaff fragments found trapped in between the villi of the reticulum did not appear to have provoked any cellular reaction. Based on these results, MacKay[12] concluded that long-term tests for chronic toxicity were unwarranted. In another unpublished study at the Pennsylvania State University (R. Adams, personal communication), 1.8 kg of chaff was fed daily to dairy calves. "No adverse effects were found in the several animals receiving such over an appreciable period of feeding." Both of these sources of information indicate that ingested chaff poses no threat to animal health.

Inhalation hazards to livestock. Most of the research addressing inhalation hazards of glass fibers has been conducted either on humans or laboratory animals (CDC, 1977; Lee et al. 1979). Results of this work (reported in a section above entitled, "Chaff and Other Atmospheric Particulates") should apply to domestic livestock as well. Suffice it to say that because of their size (15-25 µm diameter) the primary fibers are not considered to be capable of being inhaled. After they deposit on the ground, however, they can be fragmented to smaller sizes through abrasion and erosion. The degree to which this occurs is unknown, and warrants an experimental approach as suggested in the section below entitled, "Remaining Questions and Experimental Approaches."

Chaff and Its Effects on Marine and Freshwater Ecosystems.

There are three possible ways chaff could affect aquatic systems: 1) by the addition of aluminum and glass to these systems, and/or; 2) by the particles themselves on the ecology of aquatic organisms, and/or; 3) by transmission through the food chain, such as to ducks that feed on aquatic organisms.

As has been pointed out in previous sections, Al_2O_3 and SiO_2 are the most common minerals in the earth's crust. Since ocean waters are in constant exposure to crustal materials, there is little reason to believe that the addition of small amounts of chaff will have any effect on either water or sediment composition.

We can consider estimates of amounts of glass and aluminum added to the ocean by human activities in forms other than chaff. As an example, Clean Ocean Action gives data for beverage cans and glass bottles picked up on New Jersey beaches in 1994. About 5 kg km^{-1} of bottles and 450 g km^{-1} of beverage cans (assumed to be aluminum) were collected. The total beach shore of New Jersey is about 200 km in the counties that participated in the cleanup. If we assume the debris came from the shore to 1 km offshore we would have about 0.45 g ha^{-1} yr^{-1} of aluminum

[11] The Ingestion of Fiberglass Chaff by Cattle, Canada Department of Agriculture for the Director of Electronic Warfare, Canadian Forces Headquarters, 1972.
[12] *ibid*.

from beverage cans. This is of the same order of magnitude as the estimated chaff deposition over the Chesapeake Bay. Of course, there are other sources of aluminum metal in both fresh and ocean waters.

Studies of the effects of water exposed to 1000 mg L^{-1} chaff on freshwater water fleas (*Daphnia magna*) showed no effect, although the animals were not exposed directly to the fibers[13]. In another series of tests, Chesapeake Bay animals were exposed directly to the chaff fibers. Blue crabs, menhaden and killifish were force fed whole and broken fibers for several weeks at concentrations up to 1000 times that to which they would be exposed in the Bay. No effects were observed. There was no significant effect at 10 times the environmental exposure (the most concentrated level used) in one-day-old oyster larvae. Nor were there significant effects at 100 times the environmental exposure in 10-day-old oyster larvae; at 1000 times the environmental exposure, there was a small effect on larval size. Polychaetes were tested at 10 times the environmental exposure with no effect, although some of the worms used the chaff in their burrows. In summary, these experiments indicate that aquatic organisms exposed to chaff levels that occur in Chesapeake Bay do not show any effects from the chaff[14].

When considering the possible effects of chaff particles themselves on aquatic systems, we can ask whether or not there are natural particles of a similar nature to which these systems and their inhabitants are already adapted. The siliceous spicules of some sponges are similar to chaff.

The most abundant shallow water sponges in the oceans are in the subclass *Monaxonida* of the *Demospongiae* (Hyman, 1940). All of these sponges have siliceous spicules, composed of opal glass. All freshwater sponges also contain siliceous spicules. Freshwater sponges are common in clean ponds, lakes, streams, and rivers. They occur throughout North America. Barton and Addis (1997) described them in six drainage basins in western Montana. Sponge spicules come in different shapes but many are simple, straight, needle-like objects, made of SiO_2, often with sharp pointed ends. Some representative spicule sizes from the marine sponges of British Columbia are from 1-30 µm in diameter and from 40-8500 µm long (Smecher, 1999). Chaff fibers are about 25 µm in diameter up to centimeters long. Sponge spicules are therefore about the same diameter as chaff whether it be whole or split longitudinally (if that happens). Unbroken chaff fibers are much longer than spicules, but it is highly likely that interactions between chaff and animals will occur with fibers that have been broken and therefore more like spicules.

Sponge spicules are present in sediments from both geological and recent times in freshwater and marine sediments (Cohen and Davies 1989, Harrison et al., 1979). Freshwater sponges are abundant in Okefenokee Swamp in southern Georgia, a wilderness area over which chaff is dispersed during air training. Some samples of peat from Okefenokee swamp contain up to 3% siliceous spicules from freshwater sponges (Cohen 1973). In Florida lake sediments, sponge silica averaged 31.5 mg g^{-1} (Conley and Schelske, 1993). To put this in context, 30 mg g^{-1} would be about 6 mg g^{-1} of wet sediment assuming 80% water content. The chaff deposition at

[13] Aquatic Toxicity and Fate of Iron and Aluminum Coated Glass Fibers, Haley, M.V. and Kurnas, C.W., US Army Chemical Research, Development, and Engineering Center, ERDEC-TR-422, 1992.
[14] Effects of Aluminized Fiberglass on Representative Chesapeake Bay Marine Organisms, Systems Consultants, Inc under contract to the US Naval Research Laboratory, 1977.

Patuxent River NAS was a little over 0.2 g ha^{-1} yr^{-1}. If we assume sediment deposition on the average keeps up with sea level rise of about 2 mm yr^{-1} and sediment density is about 1, the chaff concentration at Patuxent River NAS over the long term would be 10 ug g^{-1}, over three orders of magnitude lower than the sponge silica in Florida lake sediments.

Aquatic animals contact spicules in the ordinary course of their lives. There is also evidence that animals that feed on sponges ingest the spicules without damage. Freshwater sponges are the most important invertebrate food for juvenile ring-neck ducks (Mcauley and Longcore 1988). Crayfish feed on them (Williamson 1979) and a Brazilian fish eats them so regularly that it is used as a collecting mechanism by sponge experts (Volkmer-Ribeiro and Grosser, 1981). In the sea, sponges are eaten and their spicules found in sea urchins (Birenheide et al., 1992), euphausid shrimp (Ritz et al. 1990), clams (Osorio et al., 1987), larval king crabs (Feder at al., 1980), and hawksbill turtles (Ernst et al., 1994). It is clear from these examples that aquatic organisms get along with sponge spicules. They do not eat sponges to get the spicules, but they ingest the spicules in the course of eating the sponges. They handle the spicules without harm. Since chaff fibers are of similar composition and size once the aluminum chips off and the fibers break up, aquatic organisms should have no difficulty dealing with those they may encounter.

While sponge spicules provide a reasonable analog to the RF chaff, they are extremely rare compared to diatoms, the frustrules (cell covers) of which are composed of silica. Diatoms are an important component of both marine and freshwater food webs and are routinely ingested by many types of zooplankton and fish larvae. The bulk of the silica passes through the digestive system and is packaged into fecal pellets. Silicoflagellates and radiolaria are other groups of aquatic organisms that incorporate silica into their structures. It should also be noted that silicon dioxide is soluble in water, the actual solubility is dependent on the specific form.

Open Questions and Degradable Chaff

Open Questions. A number of open questions were identified in the GAO report with respect to the environmental effects of RF chaff. Those questions were:

- long-term and chronic exposure to inhaled chaff fibers;
- resuspension rates of coated and uncoated chaff fibers;
- weathering rates and chemical fate of metal coatings in soil, fresh and marine waters;
- review of threshold metal toxicity values in humans, animals, and fresh and marine organisms;
- evaluation of potential impacts of fibers;
- respirability of fibrous particles in avian species;
- aquatic and marine studies to establish the impact of fibers;
- pathology of inhaled fibers;
- chaff accumulation on water bodies and its affect on animals;
- bioassay tests to assess toxicity of chaff to aquatic organisms, and;
- the potential for impacts on highly sensitive aquatic habitats.

In light of the analysis described in the body of this report and the scientific studies to date, the panel concludes that only two significant questions remain regarding the environmental effects of the current RF chaff used in training and should be considered for further study. Specifically, the resuspension rates of chaff fibers and their physical fate (considered above as weathering rates) should be addressed. Guidance as to the scientific questions that should be asked in such studies and suggested experimental approaches are provided in the Panel Recommendations section below.

The current data and "upper bounds" estimates significantly reduce the uncertainty of environmental effect to the remaining open questions identified by the GAO. While some of those questions may be important in scientific pursuit, there is just not enough evidence to suggest, given the current use of chaff, that addressing these questions will yield significant results or further our understanding of environmental effects in general.

Degradable Chaff. The DOD is currently developing degradable chaff, which is driven by both environmental and operational needs. There is not a strong sense by the panel that a well-planned programmatic approach to addressing non-engineering issues has been developed. Two studies are known that address ecotoxicity of degradable chaff. But a cohesive program to address environmental concerns, such as those that resulted in a request for a GAO investigation of standard chaff (RF chaff used to date), has not been identified. This leads the panel to conclude that as degradable chaff moves from the R&D stages to use in training that the research addressing environmental issues will be spotty and result only in response to pressure placed on the DOD. The panel recommends that a small to modest program with a scientific program manager be established. The program manager, in consultation with a scientific advisory group, should develop a cohesive realistic set of projects to address real environmental issues that may result with the use of degradable chaff.

Panel Findings

- *Chaff emissions.* Although chaff particles are much larger than the PM_{10} and $PM_{2.5}$ particle emissions estimated by EPA, total U.S. emissions are orders of magnitude less than those from suspended dust, vehicle exhaust, power generation, and industrial processes. This is true for the United States as a whole and for counties surrounding test areas where chaff is released.

- *Chaff concentrations*. Under worst case conditions that assume no deposition and complete breakup to respirable PM_{10} and $PM_{2.5}$, chaff releases will not provide more than a 0.05 µg m^{-3} over current ambient concentrations. This is less than one-hundredth of the particle levels set by U.S. EPA to protect public health. It is less than one-tenth of the $PM_{2.5}$ geological concentrations found at U.S. background monitoring sites.

- *Possible nutritional effects due to chaff ingestion*: Risk is minimal to nil for both humans and livestock, considering the chemical composition of chaff (essentially identical to soil) and low chaff loading to the environment.

- *Possible physical effects due to chaff ingestion:* Ingestion of glass fibers conceivably could induce lesions and other harmful responses in either humans or livestock. The limited studies conducted on ruminants, however, have shown no harmful effects in feeding trials lasting several weeks. A definitive answer to the question of long-term exposure would require further research.

- *Possible inhalation hazards to livestock:* Primary chaff fibers are too large to be inhaled by livestock. Secondary fibers, resulting from the break-up in the environment to smaller fibers, possibly could be small enough to be inhaled. To be a significant inhalation hazard these secondary fibers must be resuspended in the air and transported in sufficient quantities to a location where they can be inhaled. As above, a definitive answer will require further research.

- Aquatic animals are exposed to siliceous sponge spicules at sizes similar to chaff often at much higher concentrations than chaff and have been through geological time without damage.

Panel Recommendations

- The panel recommends that the DOD address the following questions related to the resuspension and fate of chaff (guidance is provided in the following section):

    1. What fraction of emitted chaff breaks up in atmospheric turbulence into inhalable particles?
    2. How much chaff is abraded and resuspended after it is deposited on a surface?
    3. What are the shapes of chaff particles after abrasion?
    4. What is the empirical terminal deposition velocity of chaff?
    5. What is the spatial distribution of chaff clouds under different release and meteorological conditions?
    6. How do chaff emissions and expected concentrations compare to emissions and concentrations from other particle emitters over the time periods and areas where chaff is released?
    7. What quantities of inhalable chaff are found in communities near training facilities where chaff is released?

- Further, the panel recommends an organized program addressing the environmental effects of degradable chaff

Remaining Questions and Experimental Approaches

After examining the available information, the following questions remain to be answered by experiment. The experiments outlined for the questions below can be conducted for the different types of chaff used in the U.S. using existing expertise and facilities.

What fraction of emitted chaff breaks up in atmospheric turbulence into inhalable particles?
Simulate worst-case chaff breakup in the laboratory by placing a known quantity of chaff into a fluidized bed and agitating it for 24-hours (or longer) while sampling the atmosphere above the bed through PM_{10} and $PM_{2.5}$ inlets onto filters. The fluidized bed agitation and the accompanying abrasion of adjacent fibers should exceed expected turbulent movements found in the atmosphere. Weigh the filters to estimate the quantities of PM_{10} and $PM_{2.5}$ produced per unit weight of chaff. Weight the chaff before and after agitation to determine the total amount lost to the atmosphere. Sieve the chaff before and after agitation to determine changes in large particle size distribution (presumably none of the long fibers will penetrate the >100 mesh sieves, but broken up portions of fibers will penetrate).

How much chaff is abraded and resuspended after it is deposited on a surface?
Simulate chaff suspension in a laboratory wind tunnel by depositing a thin layer on soil surfaces similar to those over which chaff is released. Worst-case abrasion could be simulated by using a loose surface with maximum abrasion potential. Chaff would be evenly mixed within this reservoir to maximize abrasion by the loose soil particles. Sample onto Nucleopore filters that can be examined microscopically to determine the quantity of chaff in different size ranges.

What are the shapes of chaff particles after abrasion?
Obtain samples on Nucleopore filters and examine them under an electron microscope. Determine the fraction of abraded particles that are amorphous and those that form respirable fibers. Apply x-ray analysis to individual particles to determine the extent to which the aluminum coating separates from the glass fibers.

What is the empirical terminal deposition velocity of chaff?
Release a known quantity of chaff from atop a fall tower onto a continuously recording microbalance. Determine the equivalent velocity for 10%, 50%, and 90% of the falling fibers to reach the surface. Infer the orientation of chaff falling in still air from this distribution. Cataido et al. (1992) used the theoretical approach of Liu et al. (1993) to determine an equivalent Stokes diameter that is the basis for estimating terminal velocities. This theory is based on the prolate spheroid model of Fuchs (1964). While Liu et al. (1993) experimentally showed that this aerodynamic diameter could be used to estimate PM_{10} inlet properties, they did not address gravitational deposition of large chaff particles. The degree to which the oblate spheroid model represents actual deposition of these dipoles is unknown.

What is the spatial distribution of chaff clouds under different release and meteorological conditions?
Record NEXRAD images of chaff releases in areas where test ranges are in the proximity of sensors. Analyze these images for duration and intensity of chaff distributions after release. Map zones of influence and superimpose these on population density and land use maps.

Determine the extent to which flight operations can be coordinated with meteorological conditions to minimize the impact of chaff deposition on sensitive areas.

How do chaff emissions and expected concentrations compare to emissions and concentrations from other particle emitters over the time periods and areas where chaff is released?
Repeat emissions comparisons and worst-case concentration calculations for specific counties over which chaff is expected to have an influence. Use more specific information about quantities released at different altitudes within and around county boundaries, fractions abraded to PM_{10} or $PM_{2.5}$, size and spatial extent of the chaff cloud, and other emissions within affected counties.

What quantities of inhalable chaff are found in communities near training facilities where chaff is released?
Acquire samples of particles on filter media over long time periods and examine them chemically and microscopically for the quantity of intact and abraded chaff. Daily and weekly average samples are taken throughout an entire year in representative communities. Radar and wind measurements are examined to determine when nearby communities are most likely receive chaff particles. These samples are submitted to appropriate analyses to determine the relative contributions from chaff and other PM_{10} and $PM_{2.5}$ sources. Properties to be sought are determined from the same analysis applied to chaff that has been subjected to abrasion.

References

Allen, VG Influence of dietary aluminum on nutrient utilization in ruminants. J. Anim. Sci. 59:836, 1984.

Ameille J, De Vuyst Pairon, CJ and De Vuyst P Man-made vitreous fibers and respiratory health effects, in: Occupational Lung Disease, Banks DE and Parker JE, eds.; Chapman and Hall, London, pgs. 263-75, 1998

American Conference of Governmental Industrial Hygienists Threshold Limit Values. ACGIH, Cincinnati, OH, 1993.

Bailey, CB Influence of aluminum hydroxide on the solubility of silicic acid in rumen fluid and the absorption of silicic acid from the digestive tract of ruminants. Can. J. Anim. Sci. 57:239, 1977.

Barton, SH and Addis, JS Freshwater sponges (Porifera: Spongillidae) of western Montana. Great Basin Nat 57: 93-103, 1997.

Bayliss D, Dement J, Wagoner JK, and Blejer HP Mortality patterns among fibrous glass production workers. Ann NY Acad Sci 271:324-35, 1976.

Bender and Hadley Glass-fiber Manufacturing and Fiber Safety: The Producers Perspective; Environmental Health Perspectives, 102: 37-40, Supplement 5, 1994.

Birenheide, R, Motokawa, T, and Amemiya, S Sponge spicules in the body of spongivorous sea urchins. Zool. Sci. 9: 1251, 1992.

Brochard P., et al. The Occupational Physicians Point-of View: The Model of Man-Made Vitreous Fibers, Environmental Health Perspectives, 102: 31-36, Supplement 5, 1994.

Cakir, AT, Sullivan, W and Mather FB Alleviation of fluorine toxicity in starting turkeys and chicks with aluminum. Poultry Sci. 57:498, 1978.

Centers for Disease Control, Occupational exposure to fibrous glass. CDC, Public Health Service. U.S. Department of Health, Education, and Welfare. Washington, D.C., 1977.

Chadwick, OA, Nettleton, WD and Staidl GJ Soil polygenesis as a function of Quaternary climate change, northern Great Basin, USA. Geoderma 68: 1-16, 1995.

Chip S, Churg A, and Colby TV. Disease caused by metals and related compounds, in: Pathology of Occupational Lung Disease, Churg A and Green FHY, eds; Williams and Wilkins, Baltimore, pgs. 92-96, 1998.

Clean Ocean Action. http://www.CleanOceanAction.org, 1999.

Cohen, AD Petrology of some Holocene peat sediments from the Okefenokee swamp-marsh complex of southern Georgia. Geological Society of America Bulletin 84: 3867-3678, 1973.

Cohen, AD and Davies, TD Petrographic/botanical composition and significance of the peat deposits of Florida Bay. Bull. Mar. Sci., 44:515-516, 1989.

Conely, DJ and Schelske, CL Potential role of sponge spicules in influencing the silicon biogeochemistry of Florida lakes. Canadian J. Fisheries and Aquatic Sci. 50:296-302, 1993.

Criteria for a Recommended Standard, Occupational Exposure to Fibrous Glass: U.S. Department of HEW, National Institute for Occupational Safety and Health, U.S. Government Printing Office, Wash D.C., 1977.

Dishington, IW Prevention of milk fever (*Hypeocalcemic paresis puerperalis*) by dietary salt supplements. Acta Vet. Scand. 16:503, 1975.

Enterline PE, Marsh GM, and Esmen NA Respiratory disease among workers exposed to man-made mineral fibers. Am Rev Respir Dis 128:1-7, 1983.

Ernst, CH, Lovich, JE, and Barbour, RW Turtles of the United States and Canada. Smithsonian Inst. Press 578 pp., 1994.

Feder,H.M, McCumby, K, and Paul, AJ The food of post-larval king crab, *Paralithodes camtschatica* , in Kachemak Bay, Alaska (Decapoda, Lithodidae) Crustaceana, 39: 315-318, 1980.

Fuchs, NA Mechanics of Aerosols. Pergamon Press, New York, NY, 1964.

Gibbs AR, Wagner JC, and Churg, A Disease due to synthetic fibers, in: Pathology of of Occupational Lung Disease, Chrug A and Green FHY, eds. Williams and Wilkens, Baltimore, 1998, pp. 398-400.

Goetsch, B, Naval Air and Strike Warfare Center, NAS Fallon, NV, Personal communication to the select panel, May 1999.

Gross P The pulmonary response to fiberglass dust: Report of the Committee on Environmental Health, American College of Chest Physicians. Chest 69:216-9, 1976.

Harrison, FW Gleason, PJ, and Stone, PA Paleolimnology of Lake Okeechobee, Florida: an analysis utilizing spicular components of freshwater sponges (Porifera: Spongillidae) Not. Nat., Acad. Nat. Sci., Phila., (no. 453), 1-5, 1979.

Healy, WB Ingestion of soil by sheep. Proc. New Zealand Soc. Anim. Prod. 27:109, 1967.

Hering, SV and Friedlander, SK Origins of aerosol sulfur size distributions in the Los Angeles basin. Atmos. Environ. 16, 2647-2656, 1982.

Heyder, J, Gebhart, J, Rudolf, G, Schiller, CF and Stahlhofen, W Deposition of particles in the human respiratory tract in the size range 0.005 - 15 µm. J. Aerosol Sci. 17, 811-825, 1986.

Hinds, WC Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles. John Wiley & Sons, New York, NY, 1982.

Hoppel, WA, Fitzgerald, JW, Frick, GM, and Larson, RE Aerosol size distributions and optical properties found in the marine boundary layer over the Atlantic Ocean. J. Geophys. Res. 95, 3659-3686, 1990.

Hyman, LH The Invertebrates: Protozoa through Ctenophora. McGraw-Hill, New York 725pp., 1940.

John, W, Wall, SM, Ondo, JL, and Winklmayr, W Modes in the size distributions of atmospheric inorganic aerosol. Atmos. Environ. 24A, 2349-2359, 1990.

Lee. KP, Barras, CE, Griffith, FD and Waritz, RS Pulmonary response to glass fiber by inhalation exposure. Lab. Investig. 40:123, 1979.

Liu, BYH, Pui, DYH, Wang, XQ, and Lewis, CW Sampling of carbon fiber aerosols. Aerosol Sci. Technol. 2, 499-511, 1999.

Lundgren, DA and Burton, RM Effect of particle size distribution on the cut point between fine and coarse ambient mass fractions. Inhalation Toxicology 7, 131-148, 1995.

Mayland, HF, Florence, AR Rosenau, RC. Lazar, VA and Turner. HA Soil ingestion by cattle on semiarid range as reflected by titanium analysis of feces. J. Range Manage. 28:448, 1975.

Mcauley, DG and Longcore, JR Foods of juvenile ring-necked ducks: Relationship to wetland pH. J. Wildl. Manage. 52:177-185, 1988.

McDonald JC, Case BW, Enterline PE, et al. Lung dust analysis in the assessment of past exposure of man-made mineral fiber workers. Ann Occup Hyg 34:427-41, 1990.

McManus, WR, and Bigham, ML Effects of mineral buffers on the rumen flora of sheep fed grain diets. Res. Vet. Sci. 24:129, 1978.

Mullen JR F Many in State See Dangers, Reno Gazette-Journal, Dec. 16, 1998.

National Research Council, Mineral tolerance of domestic animals. National Academy of Sciences. Washington, D.C., 1980.

Nemery B. Lung disease from metal exposure, in: Occupational Lung Disease, Banks DE and Parker JE, eds. Chapman and Hall, London , 1998.

Oberdörster, G, Gelein, R, Ferin, J, and Weiss, B Association of particulate air pollution and acute mortality: involvement of ultrafine particles? Inhalation Toxicology 7, 111-124, 1995. Occupational Lung Disease, Churg A and Green FHY, eds; Williams and Wilkins, Baltimore, pgs. 398-400, 1998.

Osorio, RC, Bustos, PV and Bustos, RE   Gastric contents of the calm (*Venus antigua* King and Broderip, 1835) in Ancud, Chile (Mollusca: Veneridae). Invest. Pesq. (Santiago) 34:139-147, 1987.

Phalen, RF and Bates, DV Proceedings of the Colloquium on Particulate Air Pollution and Human Mortality and Morbidity. Inhalation Toxicology 7, 1-163, 1995.

Prospero, J Long-range transport of mineral dust in the global atmosphere: Impact of African dust on the environment of the southeastern United States. Proceedings of the National Academy of Sciences USA 96: 3396-3403, 1999.

Pye, K Aeolian dust and dust deposits. Academic Press, San Diego, CA., 1987.

Reheis, MC, and Kihl, R. Dust deposition in southern Nevada and California, 1984-1989: Relations to climate, source areas and source lithology. Journal of Geophysical Research 100: 8893-8918, 1995.

Ritz, DA, Hosie, GW and Kirkwood, RJ   Diet of *Nyctiphanes australis* Sars (Crustacea: *Euphausiacea*). Aust. J. Mar. Freshwat. Res. 41:365-374, 1990.

Rock, W, PMA272J3, Naval Air Systems Command, Jacksonville, FL, Personal communication to the select panel, June 1999.

Rogers, CF and Watson, JG Progress in evaluating particulate liquid water measurement methods and in developing a benchmark generator. In Transactions, Visibility and Fine Particles, Mathai, C.V., Ed. Air & Waste Management Association, Pittsburgh, PA, pp. 222-231, 1990.

Ropp T, Military chaff may be killing valley lightning (pg. 1); Complaints go beyond weather effect (pg. 18); Arizona Republic (Phoenix), July 4, 1999.

Schlesinger, WH The formation of caliche in soils of the Mojave Desert, California. Geochimica et Cosmochimica Acta 49:57-66, 1985.

Sloane, CS, Watson, JG, Chow, JC, Pritchett, LC, and Richards, LW Size-segregated fine particle measurements by chemical species and their impact on visibility impairment in Denver. Atmos. Environ. 25A, 1013-1024, 1991.

Seinfeld, JH Atmospheric chemistry and physics of air pollution. Wiley and Sons, NY, 1986.

Smecher, Curt   http://www.interchg.ubc.ca/csmecher/, 1999.

Sorenson, JR, Campbell, IR Tepper, LB and Lingg, RD Aluminum in the environment and human health. Environ. Health Perspect. 8:3, 1974.

Storer, NL and Nelson, TS The effect of various aluminum compounds on chick performance. Poult. Sci. 47:244, 1968

Swift, DL and Proctor, DF Human respiratory deposition of particles during breathing. Atmos. Environ. 16, 2279-2282, 1982.

Tang, IN Phase transformation and growth of aerosol particles composed of mixed salts. J. Aerosol Sci. 7, 361-371, 1976.

Tang, IN Deliquescence properties and particle size change of hygroscopic aerosols. In Generation of Aerosols and Facilities for Exposure Experiments, Willeke, K., Ed. Ann Arbor Science Publishers, Inc., Ann Arbor, MI, 1980.

Tang, IN and Munkelwitz, HR Composition and temperature dependence of the deliquescence properties of hygrosopic aerosols. *Atmos. Environ.* 27A, 467-473, 1993.

U.S.EPA   Air quality criteria for particulate matter. Report No. EPA/600/P-95/001abcF,   U.S. EPA, Research Triangle Park, NC, 1996.

U.S.EPA National ambient air quality standards for particulate matter: Final rule. Federal Register 62, 38651-38760, 1997.

U.S.EPA National air pollutant emission trends, 1900-1996. Report No. EPA-454/R-98-008, U.S. EPA, 1998.

Valdivia, R, Ammerman, CB Wilcox, CJ and Henry, PR Effect of dietary aluminum on animal performance and tissue mineral levels of growing steers. J. Anim. Sci. 47:1351, 1978.

Vedal, S Critical review - Ambient particles and health: lines that divide. *JAWMA* 47, 551-581, 1997.

Voisin C, et al. Mineralogical Analysis of the Respiratory Tract in Aluminum Oxide-Exposed Workers, Eur. Respiratory Journal, 9, pp 1874-1879, 1996.

Volkmer-Ribeiro, C, Grosser, KM Gut Contents of *Leporinus obtusidens* "Sensu" von Ihering (Pisces, Characoidei) Used in a Survey for Freshwater Sponges. Rev. Brasil. Biol. 41:175-183, 1981.

Watson, JG, Chow, JC, Shah, JJ, and Pace, TG The effect of sampling inlets on the PM_{10} and PM_{15} to TSP concentration ratios. *JAPCA* 33, 114-119, 1983.

Wedding, JB and Carney, TC A quantitative technique for determining the impact of non-ideal ambient sampler inlets on the collected mass. Atmos. Environ. 17, 873-882, 1983.

Weill H, Hughes JM, Hammad YY, Glindmeyer III HW, et al. Respiratory health in workers exposed to man-made vitreous fibers. Am Rev Respir. Dis. 128:104-12, 1983.

Williamson, CE Crayfish predation on freshwater sponges Am. Midl. Nat., 101: 245-246, 1979.

Abbreviations

AFB, Air Force Base

ASN (I&E), Assistant Secretary of the Navy for Installations and Environment

BLM, Bureau of Land Management

CONUS, Continental United States

DOD, Department of Defense

FWS, Fish and Wildlife Service

GAO, General Accounting Office

MMVF, man-made vitreous fibers

MOA, Military Operating Area

MPA, Metropolitan Planning Area

NAAQS, National Ambient Air Quality Standards

NAS, Naval Air Station

NEXRAD, Next Generation Weather Radar

NRC, National Research Council

NWS, National Weather Service

$PM_{2.5}$, Particulate Matter less than 2.5 microns

PM_{10}, Particulate Matter less than 10 microns

R&D, Research and Development

RF, Radio Frequency

TSP, Total Suspended Particles

USAF, United States Air Force

US EPA, Environmental Protection Agency

<u>Units of Measure</u>

cm, centimeter

ft. agl, feet above ground level

ft, feet

g, gram

ha, hectare

hr, hour

kg, kilogram

m, meter

mg, milligram

mi, mile

min, minute

s, second

std dev, standard deviation

tpy, tons per year

um, micrometer

ug, microgram

yr, year

Appendices

A. Panel Member Profiles

B. Environmental Protection: DOD Management Issues Related to Chaff, GAO Report, GAO/NSAID-98-219, September 1998

C. Bibliography. Chaff Environmental R&D

Appendix A

Biographical Sketch: Panel Members

Steven L. Fales
Professor of Agronomy
Pennsylvania State University

Dr. Steven Fales is a Professor and Department Head of Agronomy in the College of Agricultural Sciences, Penn State University. Dr Fales is also the Director of the Grazing Research and Education Center, which focuses on environmental sustainability and profitability of animal agriculture through better use of grassland resources. Dr. Fales' research focuses on crop management, forage crop quality, physiology, and utilization; plant-plant and plant-animal interactions in pastoral environments; pasture management; ecology of intensive grazing systems. He is a member or officer of a number of research councils. Dr Fales is the author or co-author of over 30 refereed journal articles, several book chapters, and numerous bulletins and other publications.

Harold F. Hemond
Professor, Civil and Environmental Engineering
Massachusetts Institute of Technology

Dr. Harold Hemond is William E. Leonhard Professor of Civil and Environmental Engineering and Director of the R.M. Parsons Laboratory at the Massachusetts Institute of Technology. Dr Hemond's research focuses on biogeochemistry, groundwater quality; and environmental instrumentation. Currently, he and his colleagues are studying major reservoirs and human exposure pathways of chemical contamination on the Aberjona Watershed. They have developed techniques for in-situ measurement of the disappearance rates of environmental contaminants in streams, and have characterized specific microorganisms within a microbial community involved in biodegradation in order to determine the predominant organisms either directly involved or indirectly involved in degrading toluene, a model environmental contaminant. Much ongoing work focuses on the transport of arsenic in the waters of the Aberjona, sediment processes that govern mobility of arsenic, and plant uptake processes of this toxic metal. Prof. Hemond is an author of *Chemical Fate and Transport in the Environment*, a widely used university textbook.

Theodore L. Hullar
Director, Cornell Center for the Environment
Cornell University

Dr. Ted Hullar is the Director of Cornell's Center for the Environment at Cornell University. Dr. Hullar is the former Chancellor of the University of California at Riverside and at Davis and is a Professor Emeritus in the Environmental Toxicology Department at UC Davis. As Director of the Center for the Environment, he is responsible for establishing major grants, one or more new undergraduate environmental degrees at Cornell, and new program initiatives such as for watersheds, environmental informatics, and integrated natural and social science programs. Other objectives include assisting and providing leadership for development of a new public policy and public affairs program, multi-college programs for environment, and new forms of state- and federal-Cornell relationships.

Petros Koutrakis
Professor, Environmental Sciences
Harvard University

Dr. Petros Koutarkis is a professor in the Environmental Sciences Department, School of Public Health, Harvard University. Dr. Koutrakis' research activities focus on the development of human exposure measurement techniques and the investigation of sources, transport, and the fate of air pollutants. In collaboration with his colleagues in the Environmental Chemistry Laboratory, he has developed an ambient particle concentrator that can be used to conduct human and animal inhalation studies. He has also developed a personal ozone monitor, a continuous fine particle measurement technique and several other sampling methods for a variety of gaseous and particulate air pollutants. These novel techniques have been used extensively by air pollution scientists and human exposure assessors in United States and worldwide. Dr. Koutrakis has conducted a number of comprehensive air pollution studies in the United States, Canada, Spain, Chile, and Greece that investigate the extent of human exposures to acid and oxidant air pollutants that may effect respiratory health. Recent research interests include the development and evaluation of new technologies that can be used to characterize human exposure to and health effects of air pollutants such as particle filters and diffusion denuders. Dr. Koutrakis is Technical Editor-in-Chief for the Journal of the Air & Waste Management Association.

William H. Schlesinger
Professor of Botany and Geology
Duke University

Dr. William H. Schlesinger is James B. Duke Professor in the Department of Botany at Duke University, where he holds a joint appointment in the Division of Earth and Ocean Sciences of the Nicholas School of the Environment. Completing his A.B. at Dartmouth (1972), and Ph.D. at Cornell (1976), he joined the faculty at Duke in 1980. He is the author or coauthor of over 125 scientific papers and the widely-adopted textbook Biogeochemistry: An analysis of global change (Academic Press, 2nd ed. 1997). He was elected a member of the American Academy of Arts and Sciences in 1995.

Currently, Dr. Schlesinger focuses his research on the role of soils in the global carbon cycle. He has worked extensively in desert ecosystems and their response to global change-often leading to the degradation of soils and regional desertification. Currently, he serves as Principal Investigator for the NSF-sponsored program of Long Term Ecological Research (LTER) at the Jornada Basin in southern New Mexico, where he examines changes in soil chemistry and soil erosion that accompany the desertification of semiarid grasslands. Past work includes studies of the formation of caliche in soils of the Mojave desert of California, the contribution of wind erosion to the chemistry of rainfall in the southwestern U.S., and studies that link the distribution of overland flow to the distribution and abundance of desert shrubs.

Richard E. Sobonya
Professor of Pathology
University of Arizona

Dr. Richard Sobonya is the Director of the Residency Program and the Division Chief of Anatomic Pathology at the University of Arizona College of Medicine. Following a fellowship in pulmonary pathology, Dr. Sobonya spent two years at the Armed Forces Institute of Pathology in the Pulmonary-Mediastinal Branch. He then joined the faculty at Kansas University Medical Center. He became a faculty member at the University of Arizona College of Medicine in 1977, and was a participating investigator in a multidisciplinary NIH grant on the epidemiology of obstructive lung diseases for 15 years. His special interests, besides lung pathology, include directing the Autopsy Service and participating in electron microscopy, muscle pathology, and cardiac pathology. Publications include over 80 original articles and chapters in several texts on pulmonary pathology. He is a Fellow of the American College of Chest Physicians and the College of American Pathologists.

John M. Teal
Professor Emeritus
Woods Hole Oceanographic Institution

Dr. John Teal is a Professor Emeritus at the Woods Hole Oceanographic Institute and Director of Teal, Ltd. Environmental Consultants. His research over the years has focused in the following areas: wetland and coastal ecology, especially salt and brackish marsh ecosystem structure and function; fish nursery value, nutrient cycling, hydrology, productivity, eutrophication, marsh restoration, pollution effects and environmental risk; groundwater influences on water bodies, groundwater contamination with nutrients; wastewater treatment by natural and artificial wetlands; petroleum pollution and hydrocarbon biogeochemistry; coastal marine ecology including dune and beach ecology; and aquaculture and fisheries. Dr. Teal is the author of more than 140 peer-reviewed scientific papers, ten articles in popular publications, four encyclopedia articles, six children's articles on oceanography, and four trade books. Dr Teal is a member of several editorial boards, scientific panels, and scientific advisory boards.

John G. Watson
Research Professor
Desert Research Institute

Dr. Watson is a Research Professor at the Desert Research Institute of the University and Community College System of Nevada. His research includes the development and evaluation of measurement processes, receptor models, and the effects of measurement uncertainty on model results. Major projects that Dr. Watson has participated in include the development of receptor modeling and data analysis software and its integration with source and receptor databases. Dr. Watson is principal investigator for the California Regional $PM_{10}/PM_{2.5}$ Air Quality Study, the Mexico City Particulate Study, the Southern Nevada Air Quality Study, and the Fresno $PM_{2.5}$ Supersite. Dr. Watson was previously principal investigator, or a major participant in the Project MOHAVE study of regional contribution to haze in the Grand Canyon, the Mt. Zirkel Visibility Study to determine haze contributions in the Mt. Zirkel Wilderness in northern Colorado, and the Northern Front Range Air Quality Study to determine contributions to $PM_{2.5}$ near Denver, CO. Dr. Watson has more than twenty years of experience in the study of suspended particles and is the author or co-author of more than 100 peer-reviewed publications and more than 150 technical reports.

Appendix B

Environmental Protection: DOD Management Issues Related to Chaff, GAO Report, GAO/NSAID-98-219, September 1998

United States General Accounting Office

GAO

Report to the Honorable
Harry Reid, U.S. Senate

September 1998

ENVIRONMENTAL PROTECTION

DOD Management Issues Related to Chaff

GAO/NSIAD-98-219

GAO

United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

B-279055

September 22, 1998

The Honorable Harry Reid
United States Senate

Dear Senator Reid:

This report responds to your request regarding the use of chaff by the Department of Defense (DOD) and the effects of chaff. Chaff is composed of aluminum-coated silica glass fibers that can be spread by aircraft in flight, ships at sea, and vehicles on the ground to help them evade enemy radar. You expressed concern about DOD's continued use of chaff for decades without sufficient knowledge of its long-term effects on the environment. As agreed with your office, this report addresses (1) the extent and locations of chaff use, (2) its reported known and potential effects, and (3) the initiatives being taken or considered to address chaff's unintended effects.

Background

Chaff works like a decoy by presenting a false target to enemy radar systems. It has been used by the military for more than 50 years. It was used during World War II and more recently during Operation Desert Storm. Chaff is also used in the peacetime training and testing of weapons. Chaff may be dispersed in bundles weighing from a few ounces to 24 pounds or from rolls in a continuous stream of over 30 pounds per minute.[1]

DOD updated controls over the use of chaff in an October 1997 interim draft of section 3212.02 of the Chairman of the Joint Chiefs of Staff manual. The manual sets the procedures for controlling the types of chaff to be used, the areas where it can be used, and altitudes at which it can be released. Each military facility has the authority to set local procedures that govern the use of chaff at training ranges and other locations near the facility.

Concern about the potential effects of chaff continues to be an issue and has been expressed mainly by citizens and various public interest groups. In addition, some DOD research on the effects of chaff has expressed concerns and recommended further research. Most of the public concerns center around its effects on human health and the environment, including

[1] A bundle is any precut chaff load in containers such as plastic tubes or cardboard boxes. Chaff rolls consist of either about 3,000 continuous strands that are dispensed by a cutter or of precut fibers placed between mylar sheets that are dispensed when the sheets are separated.

the potential for chaff particles to be inhaled or ingested and chaff's effects on land, water, plants, and animals.

Results in Brief

Chaff is used worldwide in conjunction with military training, testing, and other assigned missions. In fiscal year 1997, the Air Force reported using about 1.8 million bundles worldwide, Navy and Marine Corps aircraft used more than 354,000 bundles and 593 rolls, and Navy combat ships used about 10,000 large bundles. DOD records indicate that fiscal year 1998 inventories include more than 37 million bundles and more than 141,000 rolls of chaff. The Air Force holds about 77 percent of the bundles, while the Navy and the Marine Corps hold all the rolls. The Army has some mission needs but possesses and uses little chaff in peacetime training or testing.

While DOD components report that chaff is an effective means of defense for aircraft, ships, and related weapon systems, DOD and other agencies have identified some unintended and potential side effects of chaff. Chaff can affect safety by interfering with air traffic control radar. Chaff can also affect weather radar observations and the operation of friendly radar systems, especially when vehicles stir up chaff that has settled on the ground. It has been reported that chaff has also caused power outages and damaged electrical equipment. Potential effects cited by Defense and other organizations include those on health and the environment. For example, the Air Force reported that chaff has a potential but remote chance of collecting in reservoirs and causing chemical changes that may affect water and the species that use it.

The services have a number of ongoing initiatives to address concerns about the unintended and potential effects of chaff. For example, DOD has entered into or is negotiating agreements with other federal agencies to address issues related to commercial air safety, weather forecasting, and environmental impacts on public lands. Also, the Navy has started a program to develop degradable chaff that is estimated to cost about 40 percent more than the current chaff. While intended as beneficial, the Navy has not yet defined the operational and environmental benefits that could result from this program.

Notwithstanding DOD's actions, some concerns continue to be raised by the public and federal agencies about the potentially harmful or undesirable effects of chaff on the environment. Also, some of DOD's studies cite additional areas where questions have been raised about the unintended effects of chaff. DOD has not systematically followed up on these questions or on the recommendations in these reports to determine whether they merit additional review. Lastly, DOD continues to retain lead-based chaff in its inventory even though this type of chaff has not been manufactured since 1987 and is reportedly no longer in use.

Extent and Location of Chaff Use

The first recorded large-scale use of chaff by American forces in combat was on December 20, 1943, in an air raid by 8th Air Force bombers over Bremen, Germany. Today, the services use chaff on combat ranges and at other locations worldwide for peacetime training and testing.

Aluminum, because of its electrical conductivity,[2] low cost, low weight, and durability, has been a consistent ingredient in chaff. In the 1980s, the cost of chaff was further reduced by replacing solid aluminum with hair-like silica glass fibers with a thin aluminum coating. Chaff was once produced using lead, and the Air Force still has some chaff containing lead in its inventory. According to the manufacturer, chaff containing lead was last manufactured in 1987.[3] The proportion of lead in chaff dropped from about 1.2 ounces (7.5 percent) per pound in the 1950s to 0.16 ounces (1 percent) by 1987.

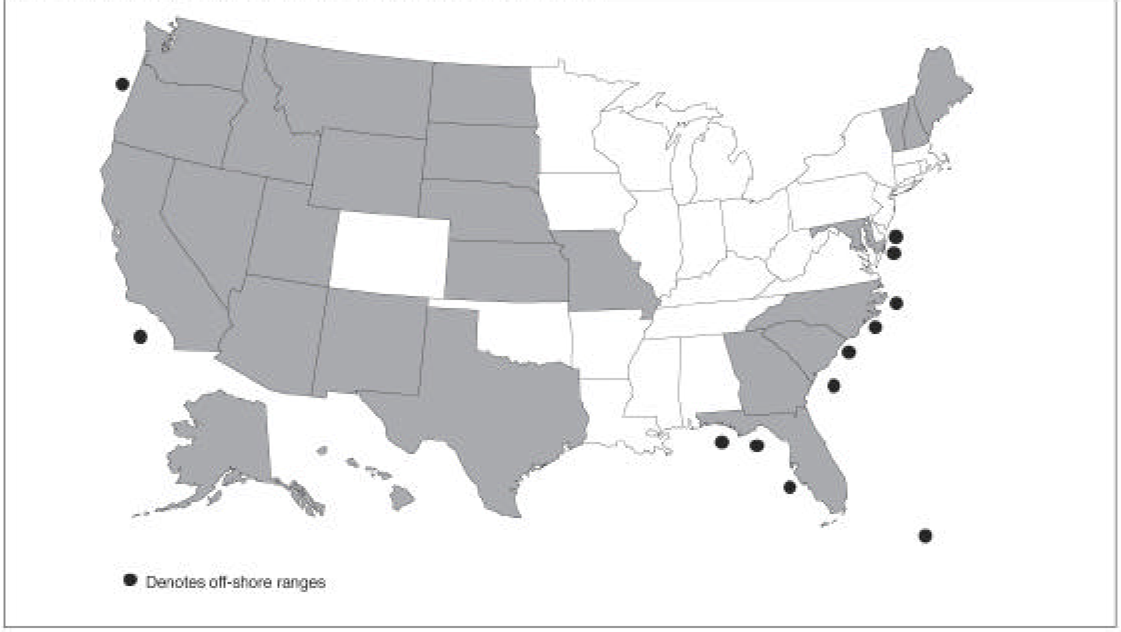
The Air Force, the Navy, and the Marine Corps are the leading users of chaff. Air Force records indicate they used nearly 2 million 6- to 7-ounce bundles worldwide in fiscal year 1996 and about 1.8 million bundles in fiscal year 1997. Navy and Marine Corps aircraft together expended more than 340,000 and 354,000 similarly sized bundles in fiscal years 1996 and 1997, respectively. They also reported using 158 rolls in fiscal year 1996 and 593 rolls in fiscal year 1997. The Army currently uses very little chaff but has the capability to use it from some of its helicopters. The Army used a total of only 2,700 bundles of chaff from fiscal year 1991 to 1997. Army officials reported they plan to increase training with chaff and are developing chaff and dispensing equipment to be used on land-based vehicles. (See app. I for the various types of chaff used and app. II for data on reported chaff use by service and by selected location.)

[2]Electrical conductivity is important because chaff absorbs and reflects electromagnetic energy to create a radar echo.

[3]Only one U.S. manufacturer supplies chaff to the military. However, at least one additional manufacturer performs research and development into chaff materials. According to DOD, chaff with lead was last produced in 1983.

The services use chaff on training ranges around the world. The Air Force uses about 39 ranges in the United States and off its coast; the Navy and the Marine Corps use 14 ranges. The Air Force uses 14 ranges in 1 African and 7 European countries and 2 ranges in Korea, while the Navy and the Marine Corps have 1 range in Italy. According to Army officials, the Army does not use chaff on any of its ranges, but the other services do. For example, the Air Force uses chaff at White Sands Missile Range, and the Navy uses Dugway Proving Grounds for Navy ship chaff acceptance testing. Navy ships train with chaff in most of the world's international waters. Navy officials stated that naval ships perform chaff tests and evaluations at two ranges off the U.S. east and west coasts. Figure 1 shows the states and offshore locations near the United States where chaff is used.

Figure 1: States (shaded) and Off-shore Ranges Where Chaff Is Used



The methods used to disperse chaff have evolved over the years, from simply tossing it out of airplane windows to launching it with spring-loaded or pneumatic machines. Currently, the services use pyrotechnic charges, rockets, mortars, air flows, or motors to disperse chaff. Many aircraft employ pyrotechnic charges that eject chaff in bursts from small bundles weighing about 6 ounces, while others use air flows to disperse ejected chaff. The Navy uses small rockets to launch airborne charges containing 8.5 pounds of chaff and shipborne charges containing 16.8 pounds of chaff. Navy ships can also launch mortar-like charges of chaff weighing between 16 and 24 pounds. Motors feed chaff from rolls of about 40 pounds through cutters[4] carried on some aircraft to produce either bursts or a continuous stream.

The continuous stream technique, called saturation chaff, may be used by aircraft to cover a large area. By 2005 or 2006, the Army also plans to use saturation chaff to mask vehicle and troop movements. Using a cutter, 360 pounds of chaff from nine 40-pound rolls can be deployed in 10 minutes. Depending on the method and the number of aircraft, such releases could disperse billions of fibers. The B-52 can carry about 750 seven-ounce boxes of chaff; each box contains up to 11 million fibers that can be expelled continuously or in bursts.

Most chaff bundles contain millions of fibers. For example, the chaff bundles used most by the Air Force (RR-188) and the Navy (RR-144) contain more than 5 million individual fibers each, and the Navy's Zuni rocket warhead (RR-182) contains more than 100 million fibers.

Questions Continue to Be Raised Concerning Known and Potential Effects of Chaff

Studies addressing the effects of chaff cite a number of known and potential effects. Furthermore, our discussions with officials from DOD, other federal agencies, and the private sector indicate that there are additional questions about the effects of chaff. Among these are the known effects of chaff on various types of radar and its potential effects on health and the environment.

Air Force 1997 Report Summarizes Past Chaff Research

Ten studies (see app. III) on the effects of chaff have been carried out over the past 45 years on request by the Army, Navy, Air Force, National Guard Bureau, and Canadian Forces Headquarters.[5] An August 1997 report for

[4] A cutter is used to cut a group of continuous strands of chaff to the desired length.

[5] Although this was the only non-U.S. military sponsor, we chose to include it in our review because its report is a key animal study cited in many of the other studies we reviewed.

the U.S. Air Force Air Combat Command was the most recent and comprehensive review of the effects of chaff. The report includes original study as well as reviews of most of the previous reports. It cited the following categories that can be affected by the use of chaff: safety, air quality, physical resources (soil and water), biological resources, and land and cultural resources. Most known chaff effects fall into the safety category, while potential effects fall into the other categories. The following sections summarize the known and potential effects described in the Air Force report.

Safety

The report noted that while chaff is effective at confusing enemy radar, it also interferes with air traffic control radar. The report said that chaff had interfered at least twice with Federal Aviation Administration (FAA) radar but added that such events could be effectively avoided or managed. According to the report, safety risks from the use of chaff are extremely low and impacts on aircrews, aircraft, or the public are not anticipated. For example, the report found (1) no incidents of chaff interfering with satellite tracking; (2) two recorded incidents of military fighter aircraft interfering with FAA radar, but details were unavailable; (3) no documentation that chaff had caused aircraft radar systems to falsely identify nearby traffic; (4) no evidence of an aircraft engine failing after ingesting chaff; and (5) no reported accidents in which pilots were distracted by chaff.

The report states that the primary safety concern is the potential for interference with FAA's air traffic control radar but notes that DOD and FAA have agreed to restrict locations, altitudes, and times at which chaff can be used. The report states that a newer type of chaff that does not interfere with FAA radar is readily available.

Air Quality

Air quality issues addressed in the report include the potential for (1) noncompliance with national air quality standards due to the release of significant quantities of particulates, (2) release of hazardous air pollutant emissions, and (3) visibility impairment. The report takes into consideration the Clean Air Act[6] and its amendments and includes a literature review of chaff dispersion and air quality effects as well as its own April 1994 technical report on chaff particulate testing.

The report's literature review shows that none of the previous studies had addressed the possible formation of inhalable particulates or issues related to compliance with the Clean Air Act. But the report indicates

[6] The Clean Air Act requires the Environmental Protection Agency to set national air quality standards.

some inconsistencies in the reported size, use, and manufacture of chaff. The report cited a particulate test showing that potential effects would not exceed air quality standards, even though explosive charges on impulse cartridges may result in minimal releases of particulates. The report says that further study may be needed on the potential for short-term visibility impairment near training areas where large quantities of chaff are used. However, it says that chaff dispersed over a wide area and settled quickly in particulate testing. Its conclusions assume chaff containing lead is no longer being used. According to DOD, there have been no reports of short-term visibility impairments caused by chaff.

Soil and Water

The report says that the chemical or physical effects of chaff on soil and water would be very limited because chaff falls only in small quantities in any one location. It cites potential effects on wildlife through ingestion, inhalation, or skin contact; on species, habitat conditions, and aesthetics through settling in the water; and on water quality. The report includes a literature review, a laboratory analysis, and field studies at two locations where chaff is frequently used. One location is arid desert (Nellis Range Complex, Nevada) and the other humid woodlands (Townsend Air to Ground Gunnery Range, Georgia).

The report notes that the literature addressing the effects of chaff on water quality and aquatic habitats is limited and that there has been no systematic analysis of chemical changes in soils exposed to various concentrations of chaff. It cites a 1977 Navy report that found no increase in aluminum or trace metals from chaff placed in water. The Air Force report notes that chaff's potential to adversely affect the environment depends on the quantity deposited in a particular area, the fibers' stability, the specific conditions of the soil and water, and the sensitivity of the environment to contaminants. It states that the likelihood of chaff falling into a particular pond, stream, or estuary in sufficient quantity to measurably affect the water's chemical makeup is remote.

Biological Resources

The report addresses the potential biological effects of chaff on wildlife due to inhalation, ingestion, and direct contact as well as the effects of chaff on vegetation and aquatic life of chaff decomposing in soil or water. The Air Force reported no adverse impacts from chaff and said that chaff is generally nontoxic. However, few studies of the effects of chaff on wildlife have been conducted, and the report found no data on chaff's decomposition process under different environmental conditions (arid, alkaline, wet, acidic) or inside the digestive systems of animals. The study includes a literature review, field studies, and laboratory analyses of soil samples taken at Nellis and Townsend, the two military range areas studied. The report cites a 1972 Canada Department of Agriculture study that found no health hazards to farm animals. The Air Force study also cited a previous report on the Chesapeake Bay ecosystem that found no impacts on the six marine organisms studied.[7]

The Air Force study reports the following:

- Animals can inhale chaff particles, but the particles do not penetrate far into the respiratory system and can be easily cleared out.
- Chaff disperses over a large area of land, limiting exposure of grazing animals. Little chaff accumulated on the surface of standing water bodies. Surface-feeding or bottom-feeding animals and fish may ingest chaff, but this only affects a few individual animals and has a low impact on species populations except in the case of protected species.
- The numbers of chaff particles are negligible because chaff disperses over a large land area. Low concentrations of chaff limit the likelihood that birds would use chaff for nests and expose the young.
- Chaff disintegrates on land. It decomposes slowly in arid areas and has no adverse effects on soil chemistry and plant growth. Chaff interference with wildlife is expected to be negligible based on chaff use, characteristics, and observed accumulations.
- Chaff decomposing in water has no adverse impacts on water chemistry and aquatic life. In wet areas, chaff is covered by plant growth and dead leaves. Chaff decomposes more rapidly in wet acidic environments, but when doing so it releases only minute amounts of chemicals.
- Lead has not been used in the manufacture of chaff since 1983.[8]

Land and Cultural Resources

Land resource issues addressed in the report concerned the accumulation of chaff and its potential to alter the land's use and visual quality, while cultural resource issues related to the potential for physical or chemical impacts to alter the aesthetic setting and cultural context. The Air Force reviewed applicable laws and other related information and produced the field studies' technical report. It did not identify any studies that assessed the impacts of chaff on either land use or its visual quality, or on cultural resources. Nevertheless, according to the Air Force, while chaff debris may be perceived as annoying or intrusive, it does not accumulate in quantities likely to have such impacts. The report states that, overall, chaff

[7] Two universities, working with the prime contractor, reported effects on some of the Chesapeake Bay organisms studied, but the prime contractor concluded these effects were not significant and reported no short- or long-term adverse environmental effects in its summary (see app. III).

[8] The manufacturer's representative told us the business had last manufactured chaff with lead in 1987. As discussed in this report, chaff with lead was still in Air Force inventories at the time of our review.

debris has low visibility and little effect on the aesthetic quality of the environment. While noting that little data existed, the study reports that common nondestructive materials such as chaff have little potential for effects. The Air Force report states that the primary potential is for chaff debris to affect the aesthetic setting but that cultural resources are not generally located beneath airspace where heavy chaff use is concentrated and examinations could be done on a site-specific basis. It noted that no research exists on Native American concerns about the aesthetic effects of chaff deposits.

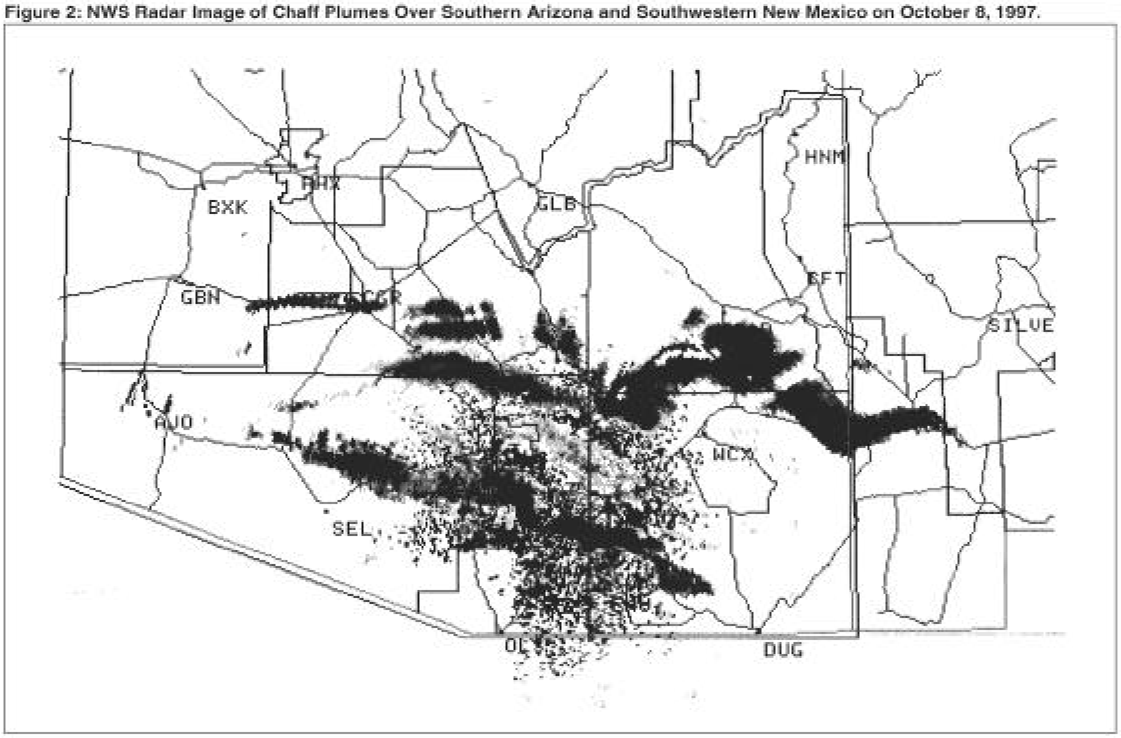
Other Known Chaff Effects

Our discussions with officials from federal agencies and the private sector brought out other known effects that are discussed in the following three sections.

Effects on Weather

Chaff can show up on radar as a false weather phenomenon and may affect lightning within storms. The National Weather Service (NWS) began to observe the widespread and frequent use of chaff in the late 1980s, when it started using new and more sensitive weather radar. Radar observations show that chaff can spread over several hundreds of miles and stay in the air for up to a day. A scientist formerly with the National Oceanic and Atmospheric Administration (NOAA), who now performs weather research at the University of Oklahoma, estimated it would have taken more than 200 billion chaff particles to create a radar picture taken in Arizona in 1997. DOD officials stated that it is improbable that such a large chaff deployment occurred outside of combat and is unlikely to occur in any future DOD training events. Figure 2 shows a 1997 NWS weather radar image of chaff over Southern Arizona. NOAA also provided pictures taken since 1993 in many other parts of the country and showing radar images of chaff.

Figure 2: NWS Radar Image of Chaff Plumes Over Southern Arizona and Southwestern New Mexico on October 8, 1997.



According to NOAA officials and scientists, chaff can be easily identified under clear skies, but it can give false readings under other weather conditions and can thus impair the ability to make accurate forecasts. Chaff may be interpreted as precipitation and in some cases could result in inaccurate warnings of severe weather. Chaff could therefore interfere with missions that rely on accurate weather forecasts. One NOAA technical report describes chaff's interference with normal weather observation data in at least two space-shuttle launch attempts.[9]

[9]Chaff Observations with WSR-88D: Examples and Operational Impacts, NOAA / NWS /Spaceflight Meteorology Group, Johnson Space Center (July 1, 1994).

NOAA scientists are also concerned that chaff may cause inaccurate weather data to be archived for long-term climate research studies. Meteorologists can usually correctly identify chaff on radar, but automated systems cannot now distinguish chaff from rainfall. The automated systems record chaff as precipitation and overstate the amount of rain archived in the database. Researchers may therefore get inaccurate results from their studies.

NOAA scientists are also trying to determine whether chaff suppresses lightning because this may also make it more difficult to assess the weather accurately.[10] Large storms will usually produce frequent lightning strikes to the ground, and there is a direct correlation between the severity of a storm and the number of such strikes. However, it has been observed that some large storms inside chaff clouds had little or no lightning. If chaff reduces lightning, it could cause forecasters to underestimate the severity of storms. NOAA scientists and a University of Oklahoma weather researcher said they would like to further study the effects of chaff on thunderstorms if they could obtain funding. DOD officials stated that the U.S. Forest Service has used chaff for a number of years to suppress lightning and prevent forest fires, and NOAA issued an environmental impact statement on lightning suppression in October 1972. DOD believes the findings of this project should be reviewed to determine the need for additional analysis of this recognized phenomenon prior to expending additional funds.

Friendly Forces Radar Systems

Just as it can confuse enemy and FAA radar and produce false precipitation echos on NWS radar, chaff can also affect other friendly radar systems and thus hinder military air traffic controllers' and meteorologists' support for missions and operations. It can also affect friendly warning and targeting systems. According to Army chaff program officials, chaff on the ground can be stirred up by vehicles and can thus interfere with friendly airborne radar systems. Although the Army stated this as an area of potential concern, we found little documentation of these potential effects. To help alleviate the problem, the Army is developing chaff that will reduce interference with friendly forces' radar systems. It hopes to have this chaff in the inventory by 2005-06.

Power Outages

Chaff can disrupt electrical power and directly affect electrical equipment. San Diego Gas and Electric Company and Navy officials have identified two instances in which chaff caused power outages in 1985. In the first

[10]Intense Convective Storms With Little or No Lightning Over Central Arizona: A Case of Inadvertent Weather Modification?, NOAA, Environmental Research Laboratories, National Severe Storms Laboratory (July 22, 1996).

case, chaff accidently blown over San Diego, California, during a Navy exercise 75 to 200 miles from the coast affected power to 65,000 customers and disrupted air traffic control. The Navy reimbursed the power company between $50,000 and $60,000 for damage. The second incident occurred 5 days later, again in San Diego, when a Navy jet inadvertently showered power lines with chaff on takeoff, causing interruptions in power service.

Current DOD Initiatives and Related Chaff Management Issues

In an effort to address the unintended effects of chaff, DOD and the services have ongoing initiatives related to air traffic control, chaff use on public lands, chaff effects on weather, and degradable chaff. However, the initiative to develop degradable chaff is not supported by an operational or environmental requirement. According to DOD, the need to develop degradable chaff is supported by its obligation to protect the environment and its sensitivity to concerns expressed by some members of the public over the use and degradability of chaff. Notwithstanding these actions, questions about the potential adverse effects of chaff on health and the environment continue to be raised by various public interest groups and some federal and state officials.[11] DOD's own studies discuss some of the same questions. Our work shows that DOD has not systematically followed up on the questions being raised to determine whether they merit any further action. Also, DOD continues to retain lead-based chaff in its inventory, even though it is reportedly no longer being used.

DOD Initiatives for Civilian Air Traffic Control

To address concerns that chaff interferes with civilian air traffic control radar, FAA and DOD components have agreed to restrict the use of chaff and now require military installations to obtain clearance when using chaff in training and testing. DOD components also use training chaff, which is designed not to interfere with FAA radar frequencies. FAA has established procedures for coordinating all DOD electronic countermeasure missions and issues annual clearance letters to military facilities that use chaff, outlining restrictions that include controls over what kind of chaff can be used, where it can be used, and the altitudes at which it can be released.

The Air Force, the Navy, and the Army have coordinated electronic countermeasures with FAA under a multiservice instruction that was first issued in 1964. According to DOD officials, an interim draft section 3212.02

[11] Public interest groups include the Rural Alliance for Military Accountability, People for the West, the Wilderness Society, Citizen Alert, and the Sierra Club. Federal officials include those at the Department of Interior's Bureau of Land Management and Fish and Wildlife Service. State officials include those at Nevada's Department of Environmental Protection.

of the Chairman of the Joint Chiefs of Staff manual replaced the multiservice instruction in October 1997 and is expected to be finalized in October 1998. In commenting on a draft of this report, DOD said it has voluntarily restricted chaff use over concerns about public safety.

DOD Initiatives for Chaff Use on Public Lands

Initiatives between DOD and Department of Interior agencies are helping to identify and minimize the effects of chaff on public lands. The Fish and Wildlife Service (FWS) and the Bureau of Land Management (BLM) have signed agreements with individual military services to control chaff use over wildlife refuges, Native Americans' reservations, and public lands near military training grounds. Examples include agreements signed November 21, 1994, for the Cabeza Prieta National Wildlife Refuge near Luke Air Force Base, Arizona; signed December 22, 1997, for the Desert National Wildlife Refuge near Nellis Air Force Base, Nevada; and signed June 11, 1998, for the public lands near Mountain Home Air Force Base, Idaho. Many military installations have local procedures to restrict the use of chaff near environmentally sensitive areas or population centers. In 1997, BLM set up a committee composed of representatives from the military services and civilian agencies to explore, among other issues, establishing a policy on dropping chaff over public lands, where it may be considered litter. The Navy said it has entered into three limited agreements to restrict chaff use over wildlife refuges and public lands because of concern over possible impacts on sensitive species.

DOD Initiatives for Chaff Effects on Weather

DOD and components of NOAA have recently begun to identify and address concerns that chaff interferes with weather radar data and forecasting. These initiatives have been aided by the placement of new weather radar monitors at major military range weather stations.[12] DOD frequency managers must now alert range operations officials to halt high-altitude chaff drops within a specified distance from the Kennedy Space Center prior to scheduled space-shuttle launches. Since February 1998, the Navy and NWS have been conducting coordinated chaff drops to allow NWS radar to record known quantities, areas, and times of chaff use. They anticipate a preliminary report by September 1998.

NOAA officials suggested additional recommendations to address chaff's effects on the weather, including improving NWS and DOD liaison and interaction, having DOD alert NWS of planned unusual chaff use, and having

[12]In a cooperative effort with DOD and FAA, NWS has deployed a total of about 160 new weather surveillance radars.

DOD limiting chaff use when significant weather is reported over or near the ranges. NOAA officials stated that their computer programs could be modified to address chaff effects on current forecasting and data archiving systems but said these modifications would be costly.

Navy's Initiative for Degradable Chaff

The Navy is developing a new type of chaff that will break up more quickly in the environment. It says the new chaff is needed to alleviate public concerns about the health and environmental effects of chaff, particularly the perceived threat that chaff can be inhaled. However, DOD has not demonstrated how it will address these public concerns. The new chaff is also more expensive.

Some Navy program officials told us there is no operational or environmental requirement to develop a new type of chaff and that the Navy believes the chaff currently in use is not harmful to the environment or a threat to health or public safety. However, they acknowledged that fiberglass chaff persists in the environment and that some members of the public perceive chaff as environmentally harmful or undesirable. They are taking action to develop a new degradable chaff, saying they thus hope to head off any possible restrictions on chaff use that may result in reductions in military training. DOD officials stressed its obligation to protect the environment and DOD's sensitivity to concerns expressed by some members of the public. It noted that the effort includes the development of environmentally degradable parts to replace plastic pieces presently used in systems that dispense chaff.

Unlike fiberglass chaff, the new chaff's base material and its aluminum coating can take a few weeks to a few months to break up, depending on conditions. Development of the new chaff began in September 1993, and total development costs are estimated at about $3.6 million. Navy officials anticipate the new chaff will be available beginning in fiscal year 2001 and expect to buy only degradable chaff in the future. They plan to buy about 474,000 bundles a year through fiscal year 2003. A Navy program official estimated that a bundle of the new chaff will cost about 40 percent more than it does currently.

No Systematic Follow-Up on Open Questions

Studies by DOD and others, including some carried out years ago, continue to create questions in the public's mind about the health and environmental effects of chaff. Department records indicate that DOD has not systematically followed up on these reports to determine the merits of any outstanding question or the costs and benefits of addressing them.

While none of the studies we reviewed demonstrated significant operational or environmental effects of chaff, 9 of the 10 reports cited gaps in information on potential effects. Six of the nine made no recommendations but cited missing data, suggested additional studies or long-term monitoring, or cited possible long-term chronic effects. Three reports recommended additional studies covering chaff toxicity, long-term exposure, weathering, or other study areas. However, DOD has not reviewed the recommendations and information gaps cited in the reports in a comprehensive and systematic way to assess their merits for further actions. For example, the Army's January 1992 report cites data gaps and recommends that the long-term risk and chronic exposure of inhaled fibers be evaluated. Specifically, it recommends

- future research on the resuspension rates of uncoated and coated fibers;
- studies to establish the weathering rates and chemical fate of metal coatings in soils, fresh water, and marine waters;
- a comprehensive review of threshold metal toxicity values for humans, animals, and important fresh water and marine organisms;
- a series of experiments to evaluate the potential impacts of fibers;
- an examination of the respirability of fibrous particles in avian species;
- aquatic and marine studies to establish the potential impacts of fibers; and
- future research on the pathology of inhaled fibers.

The second and third of the above recommendations were partially addressed in the Army's September 1992 report. Two other reports also partially addressed the second recommendation.[13] We found limited evidence of follow-up on the other five recommendations.

The 1997 Air Force study and its technical reports also cite the need for data and further research, including long-term studies. Two of the three technical reports recommend further research. One suggests long-term studies to monitor chaff accumulation on water bodies in high-use areas and the effects on animals using those water bodies. Another states that consideration could be given to monitoring programs for highly sensitive environments subjected to repeated chaff releases and conducting bioassay tests to further assess the toxicity of chaff to aquatic organisms. The final report noted that in some cases it might be appropriate to

[13] Technical Report No. 4, Field Studies, October 1994, and Technical Report No. 5, Laboratory Analysis of Chaff and Flare Materials, November 1994, from the 1997 Air Force report.

analyze the potential for impacts to highly sensitive aquatic habitats that support threatened and endangered species in areas underlying airspace where chaff is proposed for use. But it does not recommend any follow-up work.

Open questions similar to those in these reports have been cited by public interest groups such as those identified earlier. In discussing these questions in May and June 1998, DOD and service officials stated that additional actions were warranted on items such as follow-ups to previous studies and chaff's weather-related effects. These officials said they are meeting to develop strategies to address the use and effects of chaff. They said these strategies, which have yet to be defined, could include a systematic follow-up of key study findings and recommendations and screening environmental assessments and impact statements to ensure consistent citation of study results. They said efforts will need to be coordinated among DOD components and could include interim controls over chaff use in sensitive environments.

Unneeded Lead-Based Chaff Inventories Are Being Retained

During the course of our work, we noted that some lead-based chaff was still being held in DOD's active inventory. Older productions of foil chaff contained lead and lead is known to be toxic and can result in a number of health problems. As a result, DOD stopped purchasing chaff with lead. The Air Force reported it does not expect to use any chaff containing lead and the 1997 Air Force report stated that it is highly unlikely that any chaff containing lead is still in use. However, we found that the Air Force still does have chaff containing lead in its inventory and has no plans to eliminate it.

We were provided a sample of chaff containing lead at one of the Air Force bases we visited during our review. The sample we obtained was of an aluminum-foil type used primarily by B-52s. In addition, Air Force records show that it still has in its inventory almost 40,000 bundles of chaff containing lead. These records came from Air Force and Defense Logistics Agency central inventory control points.

Conclusions

DOD and the services have developed ongoing initiatives to address certain concerns raised by the military's use of chaff. These initiatives include plans for increased liaison with agencies such as BLM, FWS, and NWS. Nevertheless, the public, DOD studies, and other federal agencies continue to raise questions about the potential adverse effects of chaff. DOD has not systematically followed up to determine whether these questions merit further action. Further, the Navy has initiated a degradable chaff research and development program but has not yet completely analyzed the operational and environmental benefits it expects to achieve. Lastly, although lead-based chaff has not been produced since 1987 and is no longer reported used, it is still retained in DOD's inventory.

Recommendations

We recommend that the Secretary of Defense direct

- the Secretary of the Navy to study the costs and benefits of the degradable chaff program before making a production procurement decision;
- the Secretaries of the Army, the Navy, and the Air Force to determine the merits of open questions made in previous chaff reports and whether additional actions are needed to address them; and
- the Secretary of the Air Force to prepare a specific plan to ensure that chaff containing lead at inventory control points and military installations is located and eliminated.

Agency Comments

In written comments on a draft of this report, DOD concurred with our findings and recommendations. (See app. IV.) DOD stated that the Navy is developing information on the costs and benefits of degradable chaff for use in a procurement decision. It stated that the services will assess whether additional actions are needed to address open questions from previous chaff reports. DOD also said that any training chaff with lead would be eliminated and that operational chaff would be clearly marked so that it could only be used to meet combat requirements. DOD also provided technical comments which we incorporated where appropriate.

Scope and Methodology

To address the extent and location of DOD's chaff use, the known and potential effects of chaff, and initiatives to mitigate these effects, we interviewed and obtained documents from officials at the Department of Defense, the military services, components of the National Oceanic and Atmospheric Administration (including the Office of Oceanic and Atmospheric Research and the National Weather Service), the Federal Aviation Administration, the Bureau of Land Management, the Fish and Wildlife Service, the Environmental Protection Agency, the Defense Logistics Agency, and the Federal Communications Commission. In addition, we spoke with state officials and other parties from the states of Nevada, Florida, Oklahoma, and Arizona, including Native Americans, public interest groups, and interested citizens, to determine whether they had concerns about chaff use or were aware of any health or environmental effects. We also visited chaff manufacturers' representatives to discuss the production of chaff and the development of degradable chaff.

To obtain information on the extent and locations of chaff use, we performed work at the following military installations: Fallon Naval Air Station and Nellis Air Force Base, Nevada; Eglin Air Force Base, Florida; and Luke Air Force Base and Yuma Marine Corps Air Station, Arizona. These installations conduct operations using chaff as part of their electronic countermeasure training. At these locations we discussed the use of chaff, the studies that have been performed on chaff, and public perceptions about the use and effects of chaff from military operations.

We reviewed environmental reports and research studies, environmental impact statements and assessments, and other related information dealing with the effects of chaff to determine the environmental effects of chaff that have been documented. Our review of these reports was limited to an analysis of their recommendations, issues, and questions they raised. We grouped these into generally related categories to assess the extent to which DOD actions related to the categories. We did not attempt to analyze the content of each report. We did note that many of these studies were carried out a number of years ago and that research records were not readily available.

We conducted our review from December 1997 to July 1998 in accordance with generally accepted government auditing standards.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 15 days after its issue date. At that time, we will make copies available to appropriate Senate and House committees; the Secretaries of Defense, the Army, the Navy, and the Air Force; the Commandant of the Marine Corps; and the Director, Defense Logistics Agency.

B-279055

Please contact me on (202) 512-8412 if you or your staff have any questions concerning this report. Major contributors to this report are listed in appendix V.

Sincerely,

David R. Warren, Director
Defense Management Issues

Contents

Contents

Abbreviations

BLM	Bureau of Land Management
DOD	Department of Defense
FAA	Federal Aviation Administration
FWS	Fish and Wildlife Service
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service

Appendix I

Types of Chaff

Chaff type	Service	Weight	Composition[a]	Inventory[b]
RR-170A/AL (operational)	Air Force	6.4 oz.	Fiber	23,606,750
RR-180/AL (operational)	Air Force	6.4 oz.	Fiber	830,786
RR-188/AL (training)	Air Force	6.4 oz.	Fiber	1,881,503
RR-112A/AL (B-52)	Air Force	7.0 oz.	Fiber	372,720
RR-136C/AL (RF-4)	Air Force	14.4 oz.	Fiber	939,990
RR-141E/AL (EF-111)	Air Force	6.9 oz.	Foil	207,557
RR-149/AL (B-52)	Air Force	5.9 oz.	Foil	1,440
RR-149A/AL (B-52)	Air Force	Unknown	Fiber	412
RR-72B/AL	Air Force	Unknown	Foil	37,800
RR-72C/AL	Air Force	Unknown	Fiber	210,360
RR-185/RR-ZZZ (B-52)	Air Force	Unknown	Fiber	235,767
RR-129/AL (operational)	Navy[c]	4.7 oz.	Fiber	Classified
RR-144/AL (training)	Navy[c]	4.8 oz.	Fiber	Classified
RR-171/AL (roll)	Navy[c]	41-43 lbs.	Fiber	Classified
RR-179/AL (roll)	Navy[c]	40 lbs.	Fiber	Classified
RR-181/AL (AIRBOC-ship)	Navy[c]	16 lbs.	Fiber	Classified
RR-182/AL (Zuni rocket)	Navy[c]	8.5 lbs.	Fiber	Classified
RR-184/AL (operational)	Navy[c]	1.4 oz.	Fiber	Classified
RR-189/AL (training)	Navy[c]	1.4 oz.	Fiber	Classified
MK-182 mod 1	Navy[d]	16 lbs.	Fiber	4,841
MK-182 mod 2	Navy[d]	24 lbs.	Fiber	4,909
MK-214	Navy[d]	24.3 lbs.	Fiber	50,163
MK-216	Navy[d]	16.8 lbs.	Fiber	24,118
M-1	Army	3.5 oz.	Fiber	310,000

[a]Fiber: aluminum-coated silica glass fibers; foil: aluminum foil.

[b]Air Force data as of May 8, 1998; Navy data as of March 3, 1998; and Army data as of February 23, 1998.

[c]Launched from airplanes.

[d]Dispensed from ships.

Appendix II

Services' Use of Chaff During Fiscal Years 1991-97

Table II.1: Air Force Chaff Used During Fiscal Years 1991-97 (bundles)

	Fiscal year						
Chaff type	1991	1992	1993	1994	1995	1996	1997
RR-170A/AL	1,361,216	1,689,200	1,545,715	1,412,244	1,415,496	834,827	826,669
RR-180/AL	0	0	530	0	0	0	4,565
RR-188/AL	0	103	7,105	166,447	1,285,876	1,153,439	950,655
RR-112A/AL[a]							
RR-136C/AL	0	0	0	0	0	0	0
RR-141E/AL	0	0	0	0	0	0	0
RR-149/AL[a]							
RR-149A/AL[a]							
RR-72B/AL[a]							
RR-72C/AL[a]							
RR-185 and RR-ZZZ[a]							

[a]According to Air Force logistics officials, expenditure history for these chaff types is unknown.

Table II.2: Navy Air-launched Chaff Used During Fiscal Years 1991-97 (bundles, unless otherwise indicated)

	Fiscal year						
Chaff type	1991	1992	1993	1994	1995	1996	1997
RR-129	343,117	436,219	277,665	243,219	339,087	233,662	107,469
RR-144	34,593	89,868	79,252	84,698	74,944	91,875	197,370
RR-171 (rolls)	641	179	199	115	58	47	26
RR-179 (rolls)	665	367	289	327	369	111	567
RR-181	171	189	166	148	88	279	217
RR-182 rocket	552	80	24	0	0	0	0
RR-184	0	0	0	0	352	6,637	39,712
RR-189	0	0	0	0	0	8,303	10,145

Table II.3: Navy Sea-launched Chaff Used During Fiscal Years 1991-97 (bundles)

	Fiscal year						
Chaff type	1991	1992	1993	1994	1995	1996	1997
MK-182 Mod 1	1,752	1,599	1,215	1,403	1,029	1,293	581
MK-182 Mod 2	733	661	1,218	806	263	373	175
MK-214	721	1,704	5,332	1,987	1,957	3,129	8,472
MK-216	186	453	619	574	1,232	1,214	1,026

Table II.4: Army Chaff Used During Fiscal Years 1991-97 (bundles)

	Fiscal year						
Chaff type	1991	1992	1993	1994	1995	1996	1997
M-1	0	50	0	1,251	1,161	118	120

Table II.5: Chaff Use Reported at Military Installations Reviewed (bundles)

		Fiscal year		
Installation	Chaff type	1995	1996	1997
Nellis Air Force Base (AFB), Nev.	RR-170 RR-188	122,798 271,946	98,370 186,772	58,420 194,161
Eglin AFB, Fla.	RR-170 RR-188 other	58,509 645 2,480	114,444 14,260 0	124,787 22,291 704
Luke AFB, Ariz.	RR-170 RR-188	Not available	Not available	12,667 162,053
Fallon Naval Air Station, Nev.	RR-129 RR-144	35,610 12,480	55,469 36,660	0 13,212
Yuma Marine Corps Air Station, Ariz.	RR-129 RR-144	Not available	Not available	24,169 34,086

Appendix III

GAO-Reviewed Reports on Chaff Research

The reports we reviewed on chaff research were issued between 1952 and 1997. As shown below, all but one were sponsored by DOD components.

Environmental Effects of Self-Protection Chaff and Flares, U.S. Air Force Air Combat Command (Aug. 1997).[1]

Aquatic Toxicity and Fate of Iron and Aluminum Coated Glass Fibers, U.S. Army Chemical Research, Development, and Engineering Center (Sept. 1992).[2]

Environmental and Health Effects Review for Obscurant Fibers/Filaments, prepared by the Pacific Northwest Laboratory for the U.S. Army Chemical Research, Development, and Engineering Center (Jan. 1992).

Environmental Effects of Air National Guard Chaff Training Activities, prepared by Science and Engineering Associates, Inc., for the National Guard Bureau (Dec. 1990).

Identifying and Evaluating the Effects of Dispensing Chaff From Military Aircraft, prepared by Science and Engineering Associates, Inc., for the Air Force Strategic Air Command (Dec. 5, 1989).

Environmental Effects of Chaff, U.S. Air Force Occupational and Environmental Health Laboratory (Dec. 1978).

Effects of Aluminized Fiberglass on Representative Chesapeake Bay Marine Organisms, prepared by Systems Consultants, Inc., for the U.S. Naval Research Laboratory (Nov. 23, 1977).[3]

The Ingestion of Fiberglass Chaff by Cattle, prepared by the Canada Department of Agriculture for the Director of Electronic Warfare, Canadian Forces Headquarters (Mar. 8, 1972).

Chaff, Wright Air Development Center (May 1956).

[1]Includes three technical reports on the effects of chaff dated April 1994, October 1994, and November 1994. Portions of the report, including two additional technical reports, address the effects of flares, which are not included in our scope.

[2]We also reviewed the Army Report, Aquatic Toxicity and Fate of Nickel Coated Graphite Fibers, With Comparisons to Iron and Aluminum Coated Glass Fibers, U.S. Army Chemical and Biological Defense Agency (July 1993), but because it focused mainly on infrared obscurants rather than radar-evading chaff, we did not include it in our scope.

[3]Systems Consultants, Inc., incorporated reports by two subcontractors, the University of Delaware and the University of Maryland.

Toxicity of Chaff to Livestock, U. S. Air Force Aeromedicine Laboratory (1952).

Appendix IV

Comments From the Department of Defense

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON DC 20301-3000

ACQUISITION AND TECHNOLOGY

21 SEP 1998

Mr. David R. Warren
Director, Defense Management Issues
National Security and International Affairs Division
Washington, DC 20548

Dear Mr. Warren:

This is the Department of Defense (DoD) response to the General Accounting Office (GAO) draft report, "ENVIRONMENTAL PROTECTION: DoD Management Issues Related to Chaff," dated August 6, 1998 (GAO Code 709295/OSD Case 1666).

In general, the DoD concurs with both the general findings and the specific recommendations in this draft report. We previously provided technical corrections and other suggested changes to the draft report. The GAO has satisfactorily addressed these comments.

I am also enclosing a summary of the three GAO recommendations with our responses.

If you have any questions, please contact Mr. Peter Boice at (703) 604-0524.

Very truly yours,

Sherri W. Goodman
Deputy Under Secretary of Defense
(Environmental Security)

Enclosure:
As stated

Environmental Security *Defending Our Future*

Appendix IV
Comments From the Department of Defense

GAO DRAFT REPORT - DATED AUGUST 6, 1998
(GAO CODE 709297) OSD CASE 1666

"ENVIRONMENTAL PROTECTION: DOD Management Issues Related to Chaff"

RECOMMENDATIONS

RECOMMENDATION 1: The GAO recommended that the Secretary of Defense direct the Secretary of the Navy to study the costs and benefits of the degradable chaff program before making a production procurement decision.

DOD RESPONSE: Concur. The Navy's R&D program is developing information to support the accurate identification of the costs and benefits of degradable chaff before embarking on a procurement decision. The Navy will provide a summary of the costs and benefits of degradable chaff once its research is completed.

RECOMMENDATION 2: The GAO recommended that the Secretary of Defense direct the Secretaries of the Army, the Navy, and the Air Force to determine the merits of open questions made in previous chaff reports and whether additional actions are needed to address them.

DOD RESPONSE: Concur. DoD will request that the Army, Navy, and Air Force identify open questions in previous chaff reports and provide an assessment of whether additional actions are needed to address them.

RECOMMENDATION 3: The GAO recommended that the Secretary of Defense direct the Secretary of the Air Force to prepare a specific plan to ensure that chaff containing lead at inventory control points and military installations is located and eliminated.

DOD RESPONSE: Concur. The Air Force will identify all remaining lead-based chaff in its inventory. All training chaff will be eliminated. All combat chaff will be clearly marked and will only be used to meet combat requirements.

Attachment to Memo
GAO Draft Report – OSD Case 1666
Page 1 of 1

Appendix V

Major Contributors to This Report

National Security and International Affairs Division, Washington, D.C.	Charles I. Patton, Jr. Uldis Adamsons Richard W. Meeks
Los Angeles Field Office	Lionel C. Cooper, Jr. Gary W. Kunkle
Office of the General Counsel, Washington, D.C.	Margaret L. Armen

Ordering Information

The first copy of each GAO report and testimony is free. Additional copies are $2 each. Orders should be sent to the following address, accompanied by a check or money order made out to the Superintendent of Documents, when necessary. VISA and MasterCard credit cards are accepted, also. Orders for 100 or more copies to be mailed to a single address are discounted 25 percent.

Orders by mail:

U.S. General Accounting Office
P.O. Box 37050
Washington, DC 20013

or visit:

Room 1100
700 4th St. NW (corner of 4th and G Sts. NW)
U.S. General Accounting Office
Washington, DC

Orders may also be placed by calling (202) 512-6000
or by using fax number (202) 512-6061, or TDD (202) 512-2537.

Each day, GAO issues a list of newly available reports and testimony. To receive facsimile copies of the daily list or any list from the past 30 days, please call (202) 512-6000 using a touchtone phone. A recorded menu will provide information on how to obtain these lists.

For information on how to access GAO reports on the INTERNET, send an e-mail message with "info" in the body to:

info@www.gao.gov

or visit GAO's World Wide Web Home Page at:

http://www.gao.gov

PRINTED ON RECYCLED PAPER

Appendix C

Bibliography. Chaff Environmental R&D

Environmental Degradability and Ecotoxicity of Chaff Fibers, Farrell, R.E., University of Saskatchewan, 1998.

Environmental Effects of Self-Protection Chaff and Flares, US Air Force Air Combat Command, 1997

Polypyrrole-coated Fibers as Microwave and Millimeterwave Obscurants, Buckley, L.J. and Eashoo, M., Naval Research Laboratory, 1996.

Aquatic Toxicity and Fate of Iron and Aluminum Coated Glass Fibers, Haley, M.V. and Kurnas, C.W., US Army Chemical Research, Development, and Engineering Center, ERDEC-TR-422, 1992.

Aquatic Toxicity and Fate of Nickel Coated Graphite Fibers, with Comparisons to Iron and Aluminum Coated Glass Fibers, Haley, M.V. and Kurnas, C.W., US Army Chemical Research, Development, and Engineering Center, ERDEC-TR-090, 1993.

Environmental and Health Effects Review for Obscurant Fibers/Filaments, Cataldo, D.A., et al. Pacific Northwest Laboratory under contract to US Army Chemical Research, Development, and Engineering Center, CRDEC-CR-126, 1992.

Environmental Effects of Air National Guard Chaff Training Activities, Science and Engineering Associates, Inc under contract to Air Force Strategic Air Command, 1990.

Identifying and Evaluating the Effects of Dispensing Chaff from Military Aircraft, Science and Engineering Associates, Inc under contract to Air Force Strategic Air Command, 1989.

Environmental Effects of Chaff, US Air Force Occupational and Environmental Health Laboratory, 1978.

Effects of Aluminized Fiberglass on Representative Chesapeake Bay Marine Organisms, Systems Consultants, Inc under contract to the US Naval Research Laboratory, 1977.

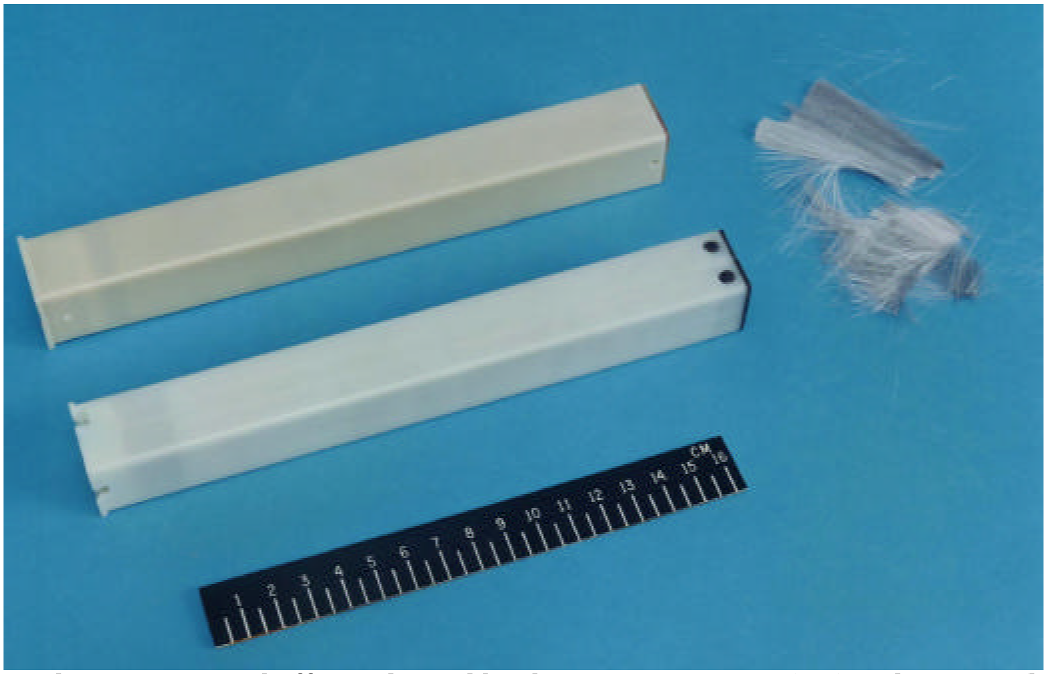
> The Biotic Response of Typical Estuarine Organisms to Aluminum Fiberglass Chaff, Keck, R.T., et al., University of Delaware, College of Marine Studies under contract to Systems Consultants, Inc., 1977.
>
> Effects of Chaff on the American Oyster, Crassostrea virginica and the Polychaete Worm, Nereis succinea, Graves, W.G., et al., University of Maryland, Center for Environmental and Estuarine Studies under contract to Systems Consultants, Inc., 1977.

The Ingestion of Fiberglass Chaff by Cattle, Canada Department of Agriculture for the Director of Electronic Warfare, Canadian Forces Headquarters, 1972.

Chaff, Wright Air Development Center, 1956.

Appendix D

Examples of RF Chaff Bundles



Training and operation RF chaff rounds used by the USAF. RR-188 (top) and RR-180 (bottom).

Training and operation RF chaff rounds used by the USN. RR-144 (top) and RR-129 (bottom).