SUPPLEMENTAL REPORT

ENVIRONMENTAL EFFECTS OF TRAINING WITH DEFENSIVE COUNTERMEASURES

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ACRONYMS AND ABBREVIATIONS

ACC	Air Combat Command
ACC Study	*Environmental Effects of Self-Protection Chaff and Flares*
AFB	Air Force Base
AFI	Air Force Instruction
AFSOC	Air Force Special Operations Command
AGL	Above Ground Level
AGS	Air Guard Station
Al_2O_3	Aluminum oxide
Air Force	United States Air Force
AL_{EX}	Exchangeable Aluminum
ATCAA	Air Traffic Control Assigned Airspace
C	Carbon
CFR	Code of Federal Regulations
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CONUS	Continental United States
DoD	Department of Defense
DRI	Desert Research Institute
EA	Environmental Assessment
ECR	Electronic Combat Ranges
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EPMA	Electron Probe Microanalysis
FAA	Federal Aviation Administration
°F	degree Fahrenheit
FOD	Foreign Object Debris
ft	feet
g	grams
g/cm^3	gram per centimeter cubed
GAO	General Accounting Office
IR	Infra-Red
lbs	pounds
mg	milligram
MgCl	Magnesium Chloride
MgF	Magnesium Fluoride
MgO	Magnesium Oxide
MJU	Mobile Jettison Unit
mL	milliliters
mm	millimeter
MOA	Military Operations Area
MSL	Mean Sea Level
NEPA	National Environmental Policy Act
NEXRAD	Next Generation Weather Radar
NM	Nautical Miles
NMTRI	New Mexico Training Range Initiative
NRHP	National Register of Historic Properties
NRL	National Research Laboratory
NTTR	Nevada Test and Training Range
NWS	National Weather Service
OF_2	Difluorine Oxide
PACAF	Pacific Air Forces
PM_{10}	Particulate Matter Less Than or Equal to 10 Micrometers in Diameter
ppm	parts per million
PSD	Particle Size Distribution
psi	pounds per square inch
RDX	Research Department Explosive
Re	Reynolds numbers
RF	Radio Frequency
RTV615	High strength transparent silicone rubber compound
S&I	Safe and Initiation
TVA	Tennessee Valley Authority
µm	micrometers
U.S.	United States
USACE	United States Army Corps of Engineers
UTTR	Utah Test and Training Range
UXO	Unexploded Ordnance
VT	Terminal Velocity

Nearly all military aircraft, including the F-22 pictured here, train with defensive chaff and flares.

Cover Sheet

FINAL SUPPLEMENTAL REPORT

ENVIRONMENTAL EFFECTS OF TRAINING WITH DEFENSIVE COUNTERMEASURES

a. Prepared For: United States Air Force (Air Force) Air Combat Command (ACC)

b. USACE Delivery Order W91238-07-F-0063

c. Prepared By: Science Applications International Corporation (SAIC), Hampton, Virginia

d. Date: October 2011

e. Report Purpose: This report supplements information in the ACC report entitled *Environmental Effects of Self-Protection Chaff and Flares* dated August 1997.

f. Abstract: The *Supplemental Report Environmental Effects of Training with Defensive Countermeasures* provides information on technological advancements in chaff and flares defensive countermeasures and considers the potential effects these changes could have on environmental analyses for Air Force training. This report updates chaff and flare characteristics and environmental effects of training with chaff and defensive flares.

Modern chaff is thinner than a very fine human hair and rapidly breaks down in the environment. Although large numbers of chaff bundles are deployed in training, modern chaff particles are extremely difficult to identify in the environment unless the chaff bundle fails to deploy properly and a clump of chaff is deposited on the surface. Chaff is primarily composed of silica and aluminum, two of the most common elements in Earth's crust and chaff rapidly fragments on the surface to become indistinguishable from ambient soil materials. Chaff particles are difficult to identify even in an environment subject to training chaff use for decades. No biological effects to terrestrial or marine organisms have been observed even when such organisms are subject to substantially higher concentrations than could be expected to occur from chaff release during training. Residual plastic and chaff wrapping materials are inert and are not projected to result in discernible impacts to land surface areas, offshore waters, sensitive biological species transiting or occupying those waters or land surface areas, humans, or human economic activities, such as agriculture.

Defensive flares are used by Air Force pilots regularly or intermittently in approved training airspace. This update describes different flare details so that the environmental effects of flares can be reviewed. Residual materials are deposited on the surface following flare deployment. This update describes the materials and addresses the environmental effects of deposited materials. Flare reliability and flare risks are evaluated. Fire risk from flares can be greatly reduced by enforcing a minimum altitude for deployment. There is no discernible air or soils pollution from flare ash. Dud flares are very infrequent with today's technology, but can occur. Base communications to the public instructing them not to touch a located dud flare would reduce potential risk. Safety risks from falling residual materials are calculated and explained. Residual materials on the ground from flares used in training have not been found to affect terrestrial or marine species. Residual materials could be an annoyance to persons if plastic or other pieces are found and identified.

Representative public and agency concerns regarding chaff and flare use are listed and addressed. This *Environmental Effects of Training with Defensive Countermeasures Supplemental Report* provides study-based responses to the representative concerns.

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1.0 INTRODUCTION

This report presents an update of environmental effects of training with defensive countermeasures by United States Air Force (Air Force) military aircraft. In 1997, the Air Force Air Combat Command (ACC) prepared a report titled *Environmental Effects of Self-Protection Chaff and Flares* (*ACC Study*) (Air Force 1997). A series of technical and environmental studies were conducted over a two-year period to provide information on the environmental effects of ACC aircraft training with defensive chaff and flares. This *Supplemental Report* for *Environmental Effects of Training with Defensive Countermeasures* provides an update on types of defensive chaff and flares as well as an update on relevant technical studies conducted and papers prepared subsequent to the Air Force 1997 report.

2.0 PURPOSE OF THIS SUPPLEMENTAL REPORT

The purpose of this supplemental report is to update the *ACC Study* (Air Force 1997) with subsequent studies on the environmental effects of chaff and flares. This update includes additional information on defensive countermeasures used by bomber and fighter aircraft. This study describes Air Force current usage and management actions for training with chaff and flares over military, public, and/or private lands. During environmental analyses conducted as part of the National Environmental Policy Act (NEPA), the public and agencies raised a variety of issues and concerns associated with Air Force training with defensive countermeasures. This supplemental report describes the use of chaff and flares, summarizes public and agency concerns, considers studies addressing those concerns, and identifies management actions to training with chaff and flares to reduce effects to public, private, and sensitive land uses. Policy implications, potential mission, and training impacts are discussed.

This *Supplemental Report* explains chaff characteristics and describes the environmental effects of chaff in Sections 4.0 and 5.0. Conclusions regarding chaff are summarized in Section 6.0. Flare characteristics are explained in Section 7.0 and flare environmental effects are described in Section 8.0. Conclusions regarding the use of defensive flares in training are presented in Section 9.0. Section 10.0 summarizes policies and regulations on use of chaff and flares as well as considering mitigation measures designed to reduce concerns and potential for impacts. Section 11.0 discusses potential mission impacts from management measures applied to chaff and flare training.

3.0 TRAINING WITH DEFENSIVE COUNTERMEASURES

Defensive countermeasures are used by military aircraft during training in response to simulated threats. Chaff is a self-protection device that permits an aircraft threatened by enemy radar-directed munitions to distract and/or avoid the threat. Flares are defensive countermeasures used by an aircraft to reduce the threat of heat seeking munitions. Low observability features of fifth generation fighter aircraft, such as the F-22 and F-35, reduce the aircraft's radar signature and thereby reduce the ability of an enemy to target the aircraft at a distance. However, when an engagement places such aircraft where it can be tracked by an enemy, the low observability aircraft still relies on defensive countermeasures to succeed in combat.

Defensive countermeasures are used in training to replicate combat conditions. In the 1980s, military pilots often trained using their radio buttons as a proxy for a release of defensive countermeasures. For example, during training, when threatened by a simulated radar-guided or heat-seeking missile, the pilot would train by pushing the radio call button and saying, “Chaff, chaff, chaff” or “Flare, flare, flare”.

Fast forward to a combat situation in which the pilot is maneuvering to hit a specific target with his munitions while trying to avoid collateral damage. Real enemy radar locks onto his aircraft and real missiles are fired at the aircraft. Under the combat stress of real threats, pilots were reacting exactly the way they had been trained. Pilots instinctively pushed the radio button and shouted, “Chaff, chaff, chaff”. Training experience did not replicate how a pilot would fight and did not train the pilot to react appropriately to a real threat under the stress of combat. Pilots needed to train with real defensive countermeasures to provide realistic training that carried over to combat situations. Initially, this training occurred within restricted airspace and in offshore Warning Areas. In the 1990s, ACC realistic training with defensive countermeasures was expanded to include environmentally assessed Military Operations Areas (MOAs) and Air Traffic Control Assigned Airspace (ATCAAs) over public lands (Air Force 1998). By 2001, the use of defensive countermeasures was further expanded to include training in specific environmentally assessed MOAs and ATCAAs over private lands (ACC 2001).

Figure 3–1 shows an A-10 aircraft deploying flares during training. If a heat-seeking missile were targeting the aircraft, it would be attracted away from the aircraft toward one of the flare heat sources.

Figure 3–1. A-10 Dispensing Flares

Figure 3–2 describes the life cycle of training with chaff and flare defensive countermeasures. The chaff and flares are typically contained in magazines with a capacity of 30 units per magazine. The magazines are removed from a storage structure on the base and loaded onto a training aircraft. During flight training, the pilot deploys chaff or flares in response to simulated threats that could include a ground-based threat or another aircraft participating in the training. During deployment, the chaff is dispersed and most of the flare pellet burns up. Residual materials fall to the ground, as depicted in the figure. The characteristics and environmental effects resulting from deploying defensive countermeasures are discussed in this paper, starting with chaff.

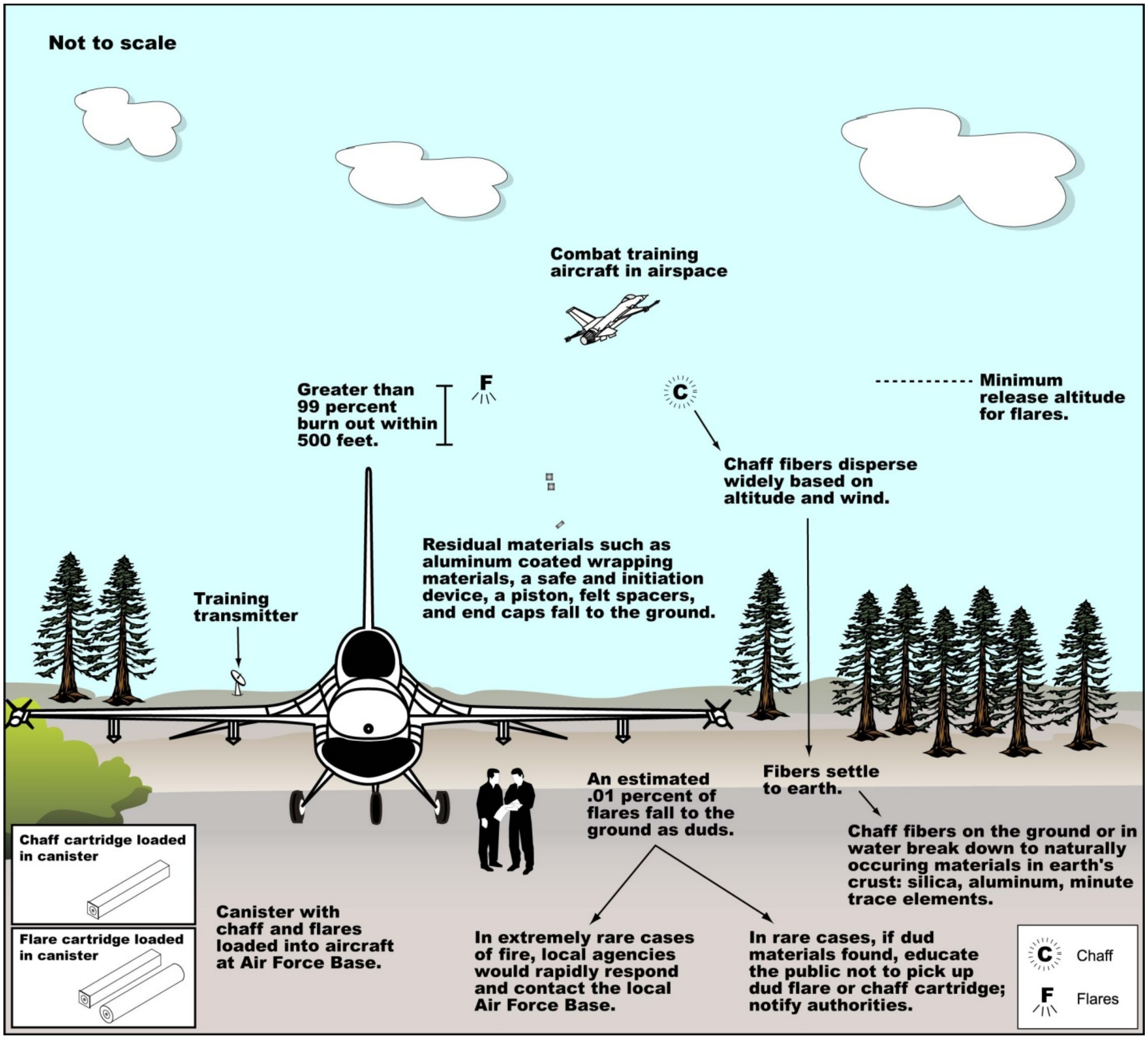


Figure 3–2. Life Cycle of Training Defensive Chaff and Flares

4.0 CHARACTERISTICS AND COMPOSITION OF SELF PROTECTION CHAFF

This section describes a variety of chaff types used by Air Force training aircraft. The chaff types explained in this section are listed on Table 4-1 lists the chaff types where a "yes" means that the aircraft uses that specific chaff type.

Table 4-1. Chaff Type by Aircraft

Chaff Type	Air Force Aircraft									
	B-1	B-52	C-130	C-5	C-17	A-10	F-15	F-16	F-22	F-35A [1]
RR-188/AL	Yes		Yes	Yes	Yes	Yes	Yes	Yes		
RR-170A/AL [2]	Yes		Yes	Yes	Yes	Yes	Yes	Yes		
RR-180A/AL[2]			Yes			Yes	Yes	Yes		
RR-196/AL									Yes	
RR-122AC		Yes								

Notes:

[1] The F-35A does not currently use defensive chaff.

[2] Delayed opening RR-170B/AL and RR-180B/AL described in this section are developmental chaff.

The basic chaff characteristics and composition described in this section are comparable for other military aircraft. The delivery systems of chaff may be different as, for example, some foreign military aircraft use a roll cutting mechanism, and the B-52 uses boxes containing chaff as opposed to the cartridges on fighter aircraft. U.S. Marine Corps and U.S. Navy aircraft have different cartridges for chaff since greater sealing requirements are needed to protect the chaff cartridges from the harsh marine environment. In general, the chaff types and materials described in Section 4.1 are representative of chaff used by military aircraft for training in U.S. airspace.

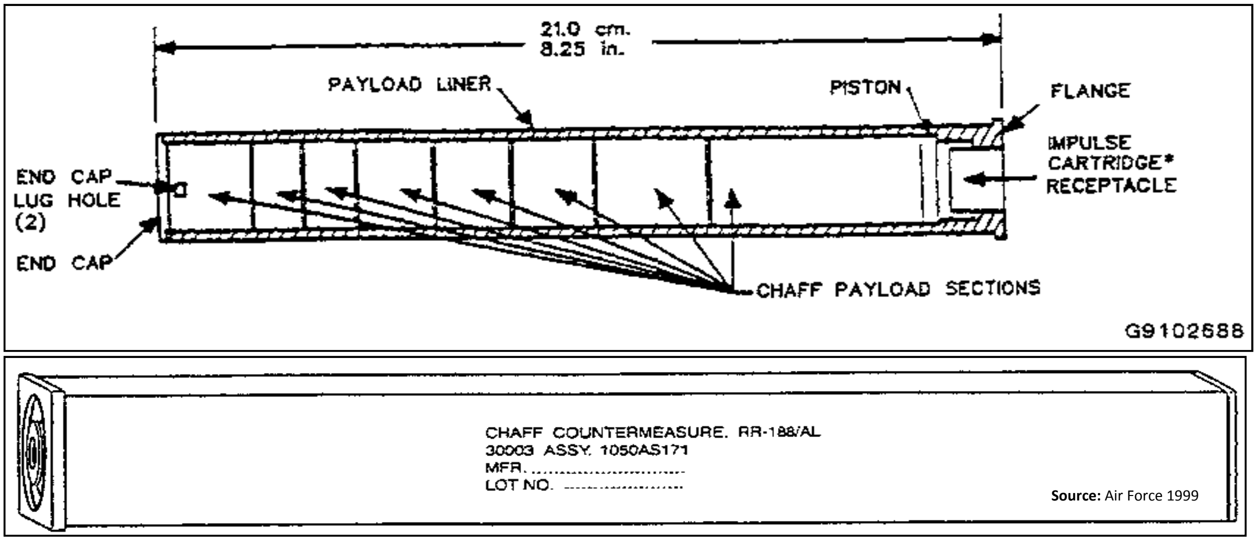
4.1 Chaff Characteristics and Composition

Modern chaff used during training consists of extremely small strands (or dipoles) of aluminum-coated, crystalline silica core fibers. Modern chaff is often called "angel hair" chaff since it is very fine and is cut to lengths that effectively counter specific radars. Modern chaff is not to be confused with the thin aluminum foil strips of chaff used from World War II through the Vietnam War. Some of this older chaff was used into the 1980s, although foil chaff was no longer manufactured by the mid-1980s. The older chaff reflected a signature to deter early radars. As radars became more sophisticated, so has chaff.

When deployed by an aircraft, modern chaff forms an electronic cloud for a moment that reflects radar signals in various bands, depending on the length of the chaff fibers. Dispersed chaff forms an image of reflected signals on an enemy radar screen. If the pilot maneuvers the aircraft while it is momentarily obscured or masked from precise radar detection by the electronic cloud, the aircraft can avoid or break the radar guided threat. Chaff is made as small and light as possible so that it will remain in the air long enough to confuse enemy radar. Individual chaff fibers are approximately one-thousandth of an inch in diameter, or one-half as thick as a very fine human hair. To put one strand of chaff in perspective, if a one-inch long strand of chaff were laid on this page, most readers would not be able to see the strand, but most readers could feel it with their fingers.

The chaff strands are primarily silica and aluminum with a Neofat coating. Silica (silicon dioxide) belongs to the most common mineral group, silicate minerals. A chaff fiber is comprised of 60 percent silica and 40 percent aluminum. Trace amounts of iron, copper, magnesium, and zinc have also been detected in the controlled combustion of chaff (Air Force 1997). Silica is inert in the environment and does not present an environmental concern with respect to soil chemistry. Aluminum is the third most abundant element in Earth's crust, forming some of the most common minerals, such as feldspars, micas, and clays. Natural background soil concentrations of aluminum ranging from 10,000 to 300,000 parts per million (ppm) have been documented. These levels vary depending on a number of environmental factors including climate, parent rock materials from which the soils were formed, vegetation, and soil moisture alkalinity/acidity as measured by the pH factor (Lindsay 1979). The solubility of aluminum is greater in acidic and highly alkaline soils than in neutral pH conditions. Aluminum eventually oxidizes to Al_2O_3 (aluminum oxide) over time, depending on its size and form and the environmental conditions. The chaff fibers' anti-clumping agent, Neofat (90 percent stearic acid and 10 percent palmitic acid), assists with rapid dispersal of the fibers during deployment (Air Force 1997). Stearic acid is a natural material that degrades when exposed to light and air.

Typical chaff used in CONUS fighter training is RR-188/AL chaff (Figure 4–1). About 5 million chaff strands (that total 3.35 ounces of chaff) are dispensed in each bundle of RR-188/AL chaff. Chaff is ejected from an aircraft by a small pyrotechnic charge and three to five chaff bundles may be ejected in rapid succession. Each chaff bundle forms a cloud that can join, obscure the aircraft, and confuse radar-guided weapons. The light chaff continues to disperse and drift with prevailing winds. The chaff fibers eventually settle to the surface. A dispersing wind-borne electronic radar reflection can persist over 100 miles, depending on the altitude of chaff release (Arfsten *et al.* 2002).



Source: Air Force 1999

Figure 4–1. RR-188/AL or RR-170A/AL Chaff Cartridge

The length of the chaff determines the frequency range of the radio wave most effectively reflected by that particular chaff dipole or length. Chaff fibers are cut to varying lengths to make them effective against the wide range of enemy radar systems that may be encountered. Since chaff can obstruct radar, its use is coordinated with the Federal Aviation Administration (FAA). Training chaff used by Air Force fighter pilots during training in the Continental United States (CONUS) has D and E band dipoles removed to reduce interference with FAA radar (ACC 1997). FAA Next Generation Weather Radar (NEXRAD) has increased sensitivity and can detect training chaff as the released chaff continues to disperse.

4.1.1 RR-188/AL Chaff

RR-188/AL chaff cartridge and components are depicted on Figure 4–1. RR-188/AL chaff is packed inside a 1 inch x 1 inch x 8 inch long rectangular tube or cartridge. The rectangular tube or chaff dispenser remains in the aircraft. Inside the plastic tube are the chaff payload, a plastic piston 1 inch x 1 inch x 1/4 inch thick, and a cushioned felt spacer the same size. A plastic end cap 1 inch x 1 inch and 1/8 inch thick seals the cartridge. The piston weighs approximately 0.0043 pounds (0.0688 ounce) and the end cap weighs approximately 0.0061 pounds (0.0976 ounce). Chaff itself is not explosive; however, it is ejected from the aircraft pyrotechnically using a small explosive charge that is part of the ejection system. The plastic end cap, plastic (or nylon) piston, and felt spacer are ejected with the chaff. The chaff fibers are generally 25.4 microns (1/1,000 of an inch) in diameter and range in length from 0.3 to somewhat over 1.0 inch (0.76 centimeter to 2.5 centimeters). For comparison, human hair varies from 50 to 120 microns in diameter. The combined weight of chaff material in an RR-188/AL cartridge is 3.35 ounces (95 grams) (Air Force 1997). Table 4-2 lists the components of the silica core and the aluminum coating.

Table 4-2. Components of RR-188/AL Chaff

Silica Core	**Chemical Symbol**	**Percent (by weight)**
Silicon dioxide	SiO_2	52-56
Alumina	Al_2O_3	12-16
Calcium Oxide and Magnesium Oxide	CaO and MgO	16-25
Boron Oxide	B_2O_3	8-13
Sodium Oxide and Potassium Oxide	Na_2O and K_2O	1-4
Iron Oxide	Fe_2O_3	1 or less
Aluminum Coating (Typically Alloy 1145)	**Chemical Symbol**	**Percent (by weight)**
Aluminum	Al	99.45 minimum
Silicon and Iron	Si and Fe	0.55 maximum
Copper	Cu	0.05 maximum
Manganese	Mn	0.05 maximum
Magnesium	Mg	0.05 maximum
Zinc	Zn	0.05 maximum
Vanadium	V	0.05 maximum
Titanium	Ti	0.03 maximum
Others		0.03 maximum

Source: Air Force 1997

Table 4-3 presents the characteristics of RR-188/AL chaff.

Table 4-3. Characteristics of RR-188/AL Chaff

Attribute	RR-188/AL
Composition	Aluminum coated silica
Ejection Mode	Pyrotechnic
Configuration	Rectangular tube cartridge
Size	8 x 1 x 1 inches (8 cubic inches)
Number of Dipoles	5.46 million
Dipole Size (cross-section)	1 millimeter (diameter)
Impulse Cartridge	BBU-35/B
Other Comments	Cartridge stays in aircraft; less interference with FAA radar (no D and E bands)

Source: Air Force 1997

4.1.2 RR-170 A/AL Chaff

RR-170 A/AL chaff looks and is the same as RR-188/AL chaff except that the dipoles in RR-170 A/AL are cut for combat to reflect different types of tracking radar. RR-170 A/AL has approximately 400,000 dipoles, each in eight cuts. Other than the cut of the dipoles, RR-170 A/AL chaff is the same as RR-188/AL chaff in materials and cartridge design. The RR-188/AL components listed in Table 4-2 and the characteristics listed in Table 4-3 are the same for RR-170A/AL chaff. Figure 4–2 is a photograph of the plastic cartridge, felt spacer, 1 inch x 1 inch x 1/8 inch end cap, a 1 inch x 1 inch x 1/4 inch piston, and the chaff fibers.

Current RR-170A/AL is a single cartridge containing 400,000 dipoles, each in eight cuts.
A plastic end cap, piston, and felt pad are discharged when the chaff is deployed.

Figure 4–2. RR-170 A/AL Chaff

4.1.3 RR-180 /AL Chaff

RR-180/AL chaff is similar to the RR-170 A/AL chaff cartridge with the primary exception that RR-180/AL chaff is contained in a dual chaff cartridge, which can be fired in sequence. The dual chaff cartridge is a 1 inch x 1 inch x 8 inch cartridge with a plastic separator, or I-beam, dividing two hyperfine (0.7 millimeter diameter) chaff cartridges. The I-beam separator uses some space and the RR-180/AL chaff has approximately 340,000 dipoles. Figure 4–3 presents the plastic cartridge, two pistons, two felt spacers, and two end caps for RR-180/AL chaff. Each of the two end caps and pistons is an approximately 1/2 inch x 1/4 inch x 1 inch plastic or nylon piece that falls to the surface when each chaff bundle deploys.

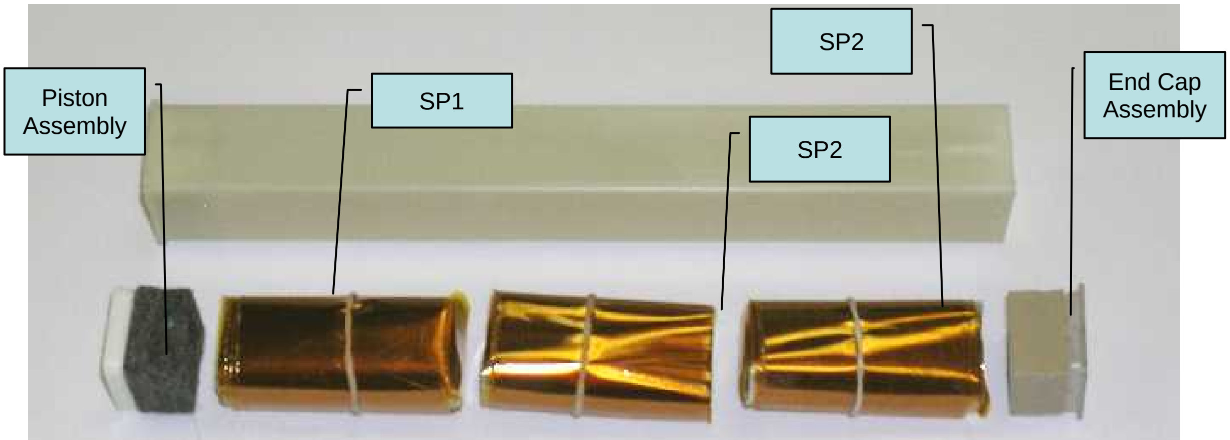
RR-180/AL is a dual chaff cartridge with unconstrained hyperfine (.7 millimeter diameter) chaff, 340,000 dipoles per cut, in an I-beam reinforced cartridge.

Figure 4–3. RR-180/AL Chaff

4.1.4 Delayed Opening Chaff: RR-170 B/AL, RR-180 A/AL, and RR-196/AL

The F-22 is a low-observability air superiority weapons system. A variety of factors contribute to the low observability nature of the aircraft including panel shapes, engine exhaust, intake treatment, and paint with low observability coating. The F-22 is designed with chaff deployment capabilities in the event that the low observability features of the aircraft are penetrated by opposing radar. During F-22 weapons test and evaluation, chaff discharge from an RR-170A/AL or RR-180/AL chaff cartridge was found to migrate into the open bay door during deployment of the chaff. Other chaff parts, specifically pistons, also did not always appropriately separate from the aircraft (refer to Figure 4–3 for chaff cartridge elements). This resulted in chaff materials increasing the aircraft visibility to opposing radar. Essentially, the chaff did not achieve the purpose of masking the aircraft but instead “lit up” the low visibility aircraft to radars.

Delayed opening chaff was developed to correct the inadequate deployment of chaff from the F-22. Figure 4–4 presents the RR-170B/AL chaff wrapped in three Mylar soft packs. Tests with RR-170B/AL chaff did not completely resolve the F-22 chaff deployment problem. Further tests were conducted using the dual cartridge RR-180/AL chaff configuration comprised of six loose chaff packs wrapped in Mylar (Figure 4–5). The rubber bands in the picture are to stabilize the chaff bundles and are removed for loading and the piston assembly and felt spacer are glued together. During deployment, the piston assembly forces the wrapped chaff and end cap out and away from the low-observability aircraft (Brune and Finnegan n.d.). The piston, wrapping, and end caps fall to the surface, and the delayed opening chaff is dispersed away from the aircraft.



RR-170B/AL has chaff packaged in “soft packs” with the same number of dipoles per cut (400,000). The piston and felt tab are glued together and the rubber bands removed before loading.

Figure 4–4. RR-170B/AL Chaff

RR-180A/AL chaff has the piston and felt spacer glued together and two sets of soft packs separated by a nylon I-beam. The chaff is standard 1 millimeter chaff with approximately 340,000 dipoles per cut.

Figure 4–5. RR-180A/AL Chaff

The soft pack Mylar wrapping was comprised of multiple layers. The first layer is a Mylar base over-wrapped by two different Dupont Kapton wraps to hold the smaller cuts together and prevent chaff from being deployed too close to the aircraft. Test results demonstrated that the RR-180A/AL chaff deployed at an adequate distance from the low-observability aircraft to prevent chaff particles or any other pieces of the deployed chaff from compromising the aircraft (Air Force 2007).

ACC continued to review the wrapping material for RR-180 A/AL chaff. The Mylar-based Kapton is a plastic polyimide film that exhibits durability under a wide range of temperature and other conditions and has no known solvents. Of particular interest to ACC was the possibility that Mylar-based wrapping in a marine environment could be perceived by marine predators, such as a jellyfish, as a food. Mylar has a density of 1.370 gram per centimeter cubed (g/cm^3) and seawater is typically about 1.025 g/cm^3, so Mylar wrapping would not be expected to remain on the surface for an extended period. Although

Mylar wrapping would not be expected to result in a significant environmental impact, ACC initiated studies of chaff wrapping materials to ascertain the possibility of reducing Mylar deposition in a marine environment (PACAF 2008).

Alternative wrapping materials were investigated to determine if the Mylar-Kapton wrapping could be replaced. A parchment paper-based wrapping was identified and tested as a viable alternative to a Mylar-Kapton-based wrapping. Parchment wrapped RR-196/AL chaff looks the same as the RR-180A/AL chaff cartridge presented in Figure 4–5, except that the wrapping material is paper rather than plastic-based. The parchment paper wrapping is coated with Quilon, a material used in greaseproof pan liners and in packing. Quilon is made from biodegradable cellulose fibers that are odorless and tasteless. Quilon paper has been approved as suitable for some kosher foods. Questions have been asked regarding Quilon since it contains trace amounts of Chromium-3, which must not to be confused with Chromium-6, which is the heavy metal form of chromium. Chromium-3 is a nontoxic trace metal found naturally in soil, water, and many foods. Trace quantities of Chromium-3 are involved in the body’s regulation of blood sugar, muscle formation, stamina, and helps lower cholesterol. Quilon-treated products containing Chromium-3 have been safely land filled, burned, and bio-treated for half a century. Quilon-treated parchment paper was tested as a replacement for Mylar-wrapped delayed-deployment chaff (Dupont Kapton 2000). The tests demonstrated successful use of parchment paper wrapping for delayed opening chaff. The RR-196/AL chaff cartridge design with parchment paper wrapping does not leave material of any kind in the F-22 dispenser bay while providing robust chaff deployment.

4.1.5 RR-112A/AL Chaff

The B-52 uses RR-112A/AL chaff, which is not deployed from a cartridge but from a paper box. The B-52 chaff is ejected mechanically as the 2.8 inch x 4.8 inch x 0.8 inch paper box (recycled paper is specified) is torn open and the chaff is ejected (Global Security 2011). The ejected chaff characteristics are the same as described for RR-188/AL (Table 4-3). The RR-112A/AL chaff residual materials consist of the paper box and two 2.75 inch x 4.75 inch x 0.06 inch pieces of plastic that supports the box. B-52 aircraft also use RR-149 chaff, which has different dipole cuts when compared to RR-112A/AL chaff. Pre-1980 B-52 chaff was aluminum foil laminated chaff with traces of lead that was not manufactured after the mid-1980s. Only the silica fiber based chaff has been purchased for B-52 use since the mid-1980s.

4.1.6 Developmental Chaff

Chaff development continues in response to threats and different aircraft requirements. The RR-170B/AL, RR-180A/AL, and RR-196/AL chaff cartridges were developed to respond to specific requirements. A new type of superfine silica fiber chaff is being manufactured that is 17.8 microns in diameter as compared with the RR-188A/AL chaff, which is 25.4 microns in diameter. Although no details on the superfine chaff are available, the components and characteristics are expected to be very similar to the chaff described in Table 4-2 and Table 4-3.

4.1.7 Chaff Comparison

Table 4-4 presents residual materials for several types of chaff. The plastic end caps, plastic pistons, and paper pieces fall to the surface with each chaff cartridge deployed.

Table 4-4. Comparison of Chaff Residual Materials

Chaff Type	Primary Use	Plastic or Mylar End Cap	Felt Spacer	Plastic Piston	Wrapping Materials
RR-188/AL	Training and combat	(1) 1 inch x 1 inch x 1/8 inch	(1 or 2) 1 inch x 1 inch x 1/8 inch	(1) 1 inch x 1 inch x 1/4 inch	None
RR-170A/AL	Combat	(1) 1 inch x 1 inch x 1/8 inch	(1 or 2) 1 inch x 1 inch x 1/8 inch	(1) 1 inch x 1 inch x 1/4 inch	None
RR-180/AL	Combat	(2) 1 inch x 1/2 inch x 1/2 inch	Glued to end cap or piston	(2) 1 inch x 1/2 inch x 1/2 inch	None
RR-170B/AL	Combat	(1) 1 inch x 1 inch x 1/2 inch	Glued to end cap or piston	(1) 1 inch x 1 inch x 1/2 inch	(3) approximately 2 inch x 4 inch Mylar
RR-180A/AL	Combat	(2) 1 inch x 1/2 inch x 1/2 inch	Glued to end cap or piston	(2) 1 inch x 1/2 inch x 1/2 inch	(6) approximately 2 inch x 4 inch Mylar
RR-196/AL	Training and Combat	(2) 1 inch x 1/2 inch x 1/2 inch	Glued to end cap and piston	(2) 1 inch x 1/2 inch x 1/2 inch	(6) approximately 2 inch x 4 inch parchment paper
RR-112AL	Training and Combat	(2) 2.75 inch x 4.75 inch x 0.06 inch	None	None	(2) 5.6 inch x 4.6 inch x 0.8 inch recycled paper strips

4.2 Chaff Ejection and Reliability

Chaff is ejected from the cartridge pyrotechnically using a BBU-35/B impulse cartridge. Pyrotechnic ejection uses hot gases generated by an explosive impulse charge. The gases push the piston down the chaff-filled cartridge and the plastic end cap is ejected, followed by the chaff fibers. The plastic tube remains within the aircraft. Residual materials, which fall to the surface following deployment, include the chaff fibers, the piston, the end cap, and the felt spacer (Table 4-4). Table 4-5 lists the characteristics of BBU-35/B impulse cartridges used to eject chaff pyrotechnically.

Table 4-5. BBU-35/B Impulse Charges Used to Eject Chaff

Component	BBU-35/B
Overall Size	0.625 inches x 0.530 inches
Overall Volume	0.163 cubic inches
Total Explosive Volume	0.034 cubic inches
Bridgewire	Trophet A
	0.0025 inches x 0.15 inches
Initiation Charge	0.008 cubic inches
	130 milligrams (mg)
	7,650 pounds per square inch (psi)
	Boron 20 percent
	Potassium Perchlorate 80 percent
Booster Charge	0.008 cubic inches
	105 mg
	7030 psi
	Boron 18 percent
	Potassium Nitrate 82 percent
Main Charge	0.017 cubic inches
	250 mg
	loose fill
	Cyclotrimethylenetrinitramine (RDX) pellets 38.2 percent
	Potassium Perchlorate 30.5 percent
	Boron 3.9 percent
	Potassium Nitrate 15.3 percent
	Super Floss 4.6 percent
	Viton A 7.6 percent

Source: ACC 1997

On release from an aircraft, chaff forms an electronic cloud, approximately 30 meters in diameter, in less than one second under normal conditions. Quality standards for chaff cartridges require that they demonstrate ejection of 98 percent of the chaff in undamaged condition, with a reliability of 95 percent at a 95 percent confidence level. They must also be able to withstand a variety of environmental conditions that might be encountered during storage, shipment, and operation. Table 4-6 lists performance requirements for chaff. Samples are tested from a manufactured lot. To achieve the performance standards and not have an entire lot rejected, manufacturers typically set mandatory standards of 99 percent reliability. Chaff performance failure could occur if the impulse charge did not fire, if the impulse charge did not discharge the chaff, or if the chaff did not disperse after deployment. There is no specific proportion of such failures associated with the manufacturing reliability rate.

Table 4-6. Performance Requirements for Chaff

Condition	**Performance Requirement**	
High Temperature	Up to +165 degrees Fahrenheit (°F)	
Low Temperature	Down to –65 °F	
Temperature Shock	Shock from –70 °F to +165 °F	
Temperature Altitude	Combined temperature altitude conditions up to 70,000 feet	
Humidity	Up to 95 percent relative humidity	
Sand and Dust	Sand and dust encountered in desert regions subject to high sand dust conditions and blowing sand and dust particles	
Accelerations/Axis	G-Level	Time (minute)
Transverse-Left (X)	9.0	1
Transverse-Right (-X)	3.0	1
Transverse (Z)	4.5	1
Transverse (-Z)	13.5	1
Lateral-Aft (-Y)	6.0	1
Lateral-Forward (Y)	6.0	1
Shock (Transmit)	Shock encountered during aircraft flight	
Vibration	Vibration encountered during aircraft flight	
Free Fall Drop	Shock encountered during unpackaged item drop	
Vibration (Repetitive)	Vibration encountered during rough handling of packaged item	
Three Foot Drop	Shock encountered during rough handling of packaged item	

Note: Cartridge must be capable of total ejection of chaff from the cartridge liner under these conditions.
Source: ACC 1997

The diagram in Figure 4–1 (Section 4.1) shows the eight different dipole cuts required to respond to the different types of radar. Figure 4–2 is a picture showing the eight actual dipole cuts in a chaff bundle. A clump of chaff would have the appearance of one or more of the dipole cuts pictured in Figure 4–2. Clumps of non-deployed chaff have found on the ground at training ranges and on public or private property under airspaces where chaff is used for training. Assuming a 99 percent reliability rate and that one-half the chaff failures represent discharged chaff that fails to deploy, and assuming a maximum of 20,000 chaff bundles were deployed annually over a 2,000 square mile area, results in an estimated average of one clump, or a maximum of 3.35 ounces, of undeployed chaff fibers per 20 square miles per year. Such bundles have been found by researchers on ranges where chaff is deployed or by ranchers on lands under training airspace evaluated for chaff use (Air Force 1997).

The average weight of chaff fibers (3.35 ounces per bundle) released in the deployment of 20,000 chaff bundles over a 2,000 square mile area would be approximately 1/20 of an ounce of chaff per acre per year. The number of residual 1 x 1 inch plastic pieces (two pieces per bundle) would be an average of three to four pieces per 100 acres per year, or an average of 20 pieces of plastic per square mile per year.

5.0 CHAFF ENVIRONMENTAL ISSUES RAISED BY THE PUBLIC AND AGENCIES

Issues have been raised by the public and agencies regarding the use of defensive countermeasures. This section presents and discusses representative issues and concerns raised regarding chaff. Section 8.0 presents and discusses representative issues and concerns raised regarding flares.

The potential for effects of chaff deposition and fragmentation in the environment has been of interest to the public and land management agencies for several years. This interest has been largely driven by concern that the fragmentation of chaff fibers was not documented. Does chaff begin breaking down almost immediately following ejection? Do chaff fibers fragment and become small enough in the atmosphere to be inhaled by man or by wildlife? If the chaff does not fragment, could chaff particles be ingested by livestock or wildlife? Would chaff particles affect the economic value of ranch or farm products? Would chaff fragment on the surface and become re-suspended in the air from wind action? What would be the environmental effects of chaff particles?

A variety of studies on the effects of chaff has been conducted over the past 40 years for the Army, Navy, Air Force, National Guard Bureau, and Canadian Forces Headquarters (GAO 1998). The focus of these studies ranged from the effects on livestock due to ingestion of chaff (Barrett and MacKay 1972) to environmental impacts from the deposition of chaff fibers on marine and terrestrial ecosystems (Air Force 1997). In the early 1990s, ACC prepared a study on the known environmental consequences of chaff and other defensive measures (ACC 1993). None of the studies demonstrated significant environmental effects from chaff.

In response to continuing concern from private citizens concerning the military's use of chaff, Senator Harry Reid (Nevada) requested that the General Accounting Office (GAO) conduct an independent evaluation of chaff use. The subsequent report, *Environmental Effects of RF Chaff* (Spargo 1999), acknowledged that citizens and various public interest groups continued to express concerns of potentially harmful or undesirable effects of chaff on the environment. The report recommended that the Secretaries of the Air Force, Army, and Navy determine the merits of open questions made in previous chaff reports to determine whether additional actions were needed to address them.

Arfsten *et al.* prepared a 2002 literature review of radar frequency chaff to document the environment effects of its use. The following five categories of issues have been raised by the public and agencies:

1. The persistence and fate of chaff particles in the environment.
2. Chaff effects on human, livestock, and wildlife health and animal products.
3. Chaff effects on natural and cultural resources.
4. Radio frequency reflective effects on air traffic and/or air traffic control.
5. Potential for injury from falling chaff residual pieces of plastic or nylon.

Arfsten *et al.* noted that the first three categories of concern were especially considered in the GAO's independent *Select Panel Report* (Arfsten *et. al.* 2002). The following sections address each of the five broad categories of issues and provide information on published and unpublished reports addressing the environmental issues raised by the public and agencies.

5.1 Persistence and Fate of Chaff Particles in the Environment

The Department of Defense (DoD) engaged a Select Blue Ribbon Panel of independent, non-government scientists to review the environmental effects of radio frequency chaff used by the U.S. military and to make recommendations to decrease scientific uncertainty where significant environmental effects of chaff are possible. The report of the Blue Ribbon Panel (Spargo 1999) identified a variety of issues of interest, presented resolutions to some issues, and included specific recommendations for the further evaluation of chaff use.

The fate of chaff fibers after release was of particular interest to the Blue Ribbon Panel so they requested additional data on two issues: 1) The degree of chaff fragmentation in the air and 2) The potential for re-suspension of chaff or chaff fragments in the natural environment (Spargo 1999).

- Atmospheric Effects - What fraction of emitted chaff breaks up from mid-air turbulence into respirable particles?
- Ground Effects - What fraction of chaff reaching the ground is subsequently abraded, re-suspended, and reduced to respirable sized particles?

An independent study on chaff fragmentation and re-suspension rates was initiated to evaluate these issues. This study resulted in the report: *The Fate and Distribution of Radio-Frequency Chaff* by the Desert Research Institute (DRI 2002). A parallel independent study by Cook also addressed chaff fragmentation and resuspension (Cook 2002). Both studies used atmospheric chaff fragmentation tests and a fluidized bed to simulate chaff fragmentation in the atmosphere. The fragmentation tests for ground chaff in both studies used wind generation in a portable environmental chamber to simulate chaff fragmentation after it falls to the ground.

5.2 Mid-Air Turbulence Effects

Chaff in the military training environment is typically released at altitudes below 30,000 feet (ft) Above Ground Level (AGL) and is typically deposited on the ground within ten hours of formation (DRI 2002). Atmospheric fragmentation, which appears to occur, takes place within the first two hours of release, likely immediately after release, when the density of fibers within the cloud is at its greatest. The DRI findings suggest that, in the simulated mid-air column, relatively little fragmentation occurs between two and eight hours after release (DRI 2002).

Both the DRI and Cook studies were designed to gather information on the potential for chaff fragmentation between the time of its release and its deposition on the ground (Appendix A) (DRI 2002; Cook 2002). A fluidized bed arrangement was used to simulate turbulence likely to be encountered by chaff fibers in the mid-air column following release during training missions. A quantity of chaff fibers was placed into a fluidized bed and agitated for 2, 4, 8, and 24 hours. Data were collected on particle size distribution of chaff fragment in a coarse range (greater than 2.5 millimeters) and fine range Particulate Matter Less Than or Equal to 10 Micrometers in Diameter (PM_{10}) or fragments less than 10 microns).

Visual observation of the chaff fibers following treatment in the fluidized bed suggests that most fibers were unaffected or only marginally fragmented by the treatment. Though not extensive, some fragmentation occurred in both size ranges studied (greater than 2.5 millimeters and less than 10 microns). With regard to coarse fragments, the number of fragments in the 2.5 to 6.1 millimeter size class remained relatively constant over the first eight hours of testing, but increased substantially after 24 hours of testing. This increase coincided with a decrease in the contribution of fragments >12.8 millimeters. A similar pattern was noted in the PM_{10} data. The fraction of fragments in the coarsest size class (>4.5 micrograms) was relatively constant over the first eight hours of testing, but decreased substantially in the 24-hour tests. At the same time, the fraction of fibers in the finest size category (< 1 microgram) was relatively constant over the first eight hours of testing, but increased substantially after 24 hours.

These findings suggest that, in the simulated mid-air column, relatively little fragmentation occurs between two and eight hours. Chaff clouds in the military training environment released at altitudes below 30,000 ft AGL are deposited on the ground within ten hours of formation (DRI 2002). It seems likely that whatever fragmentation occurs takes place within the first two hours of release and it seems likely that most fragmentation occurs immediately after release when the density of fibers within the cloud is at its greatest. Anecdotal observations made during the course of fluidized bed tests suggest that mid-air turbulence plays a minor role in fragmentation of military training chaff (Cook 2002).

The experimental data obtained from tests are not sufficiently robust to conclude definitively when most chaff fragmentation occurs. Most fragmentation could occur immediately on ejection or within the first two hours after ejection. While chaff fragmentation in these tests appears to be minor, some mid-air fragmentation does occur and there is some degree of formation of particles sufficiently small as to be considered respirable. Abrasion tests suggested that approximately 1/10,000,000 of the chaff mass may be abraded to PM_{10} or smaller (DRI 2002). Although the data sampling and testing of the fraction of chaff converted to respirable particles could be enhanced with replication, the data suggest that this is not a significant factor in the fate of training chaff in the mid-air column. Cook found no PM_{10} or $PM_{2.5}$ particles in the soil matrix samples and DRI concluded that virtually none of the chaff was degraded to respirable size particles of PM_{10} or less. Based on these tests, there is little or no environmental risk from airborne chaff abrading to respirable particles prior to the chaff being deposited on the ground.

5.3 Ground Effects - Evaluation of Chaff Fragmentation Following Deposition

The primary constituents of chaff are silica and aluminum, which are the most common elements in Earth's crust and soils. The component of chaff that has the potential to affect soil or water chemistry is aluminum, which tends to break down in acidic and highly alkaline environments. Aluminum is the most abundant metallic element in Earth's crust and is a common constituent of soils. Modern chaff is composed primarily of very fine silica fibers coated with aluminum to achieve its radar-reflective properties (Arfsten *et al.* 2002). Chaff also contains trace amounts of iron, copper, magnesium, and zinc. Chaff fibers are coated with stearic acid to prevent clumping during deployment. Stearic acid (octadecanoic acid) is a saturated fatty acid derived from animal and vegetable fats and oils (Heryanto *et al.* 2007). Stearic acid has been used in the development of drug delivery systems because it is considered to be inert, inexpensive, and biocompatible, as well as of a low toxicity.

Laboratory and field analyses (Air Force 1997) indicate that the pH of water in the soil or in a water body is the primary factor that determines the stability of the aluminum coating of chaff. The coating is the most soluble and is therefore likely to release aluminum if the soil or water pH is less than 5.0 (extremely acidic) or greater than 8.5 (strongly alkaline). In semi-arid conditions such as those found in much of the western U.S., soil pH tends to be neutral to alkaline and there is usually not enough water in the soils of this region to react with the aluminum (Air Force 1997). Typically, 99 percent of the soils in the western U.S. have a pH between 5.0 and 8.5, outside the normal range for chaff coating to release aluminum into the soil. The low percentage of soils with a pH within the range to react with the chaff coating of aluminum, in combination with the low soil water content, results in conditions that would be extremely improbable for detectable aluminum concentrations to be produced from chaff particles that weather on the ground. Local eastern areas can have pH levels below 4.5 and could be extremely acidic. Under such circumstances, the chaff coating of aluminum could break down. As explained in Section 5.4 studies in eastern aquatic environments were not able to detect significant differences in the aluminum concentrations between control and heavy chaff use areas (Wilson *et al.* 2002). Analysis to detect chaff concentration in aquatic and soil environments, where chaff has been deployed for decades, was unable to detect any but a few chaff particles. This is because chaff on the ground rapidly breaks down to silica and aluminum, the two most common elements of Earth's crust, and becomes indistinguishable from native soils (Air Force 1997; Cook 2002).

Following deposition on the ground, chaff is subjected to various physical processes that may break the individual fibers into fragments. Appendix B describes field studies and preliminary results from these studies to determine the fragmentation of chaff once it had settled from the atmosphere. Processes that may induce fragmentation include wind-driven re-suspension and deposition, wind-driven interaction with soils, wind-driven interaction with plants, disturbance by animals, and vehicular traffic. Processes that may induce fragmentation in water includes both wind and wave action. Field studies were conducted to gain information on the relative importance of these processes and to address different test approaches to evaluate post-deposition fragmentation (DRI 2002; Cook 2002).

Weighed samples of chaff were released into an in-situ environmental chamber and subjected to simulated wind driven re-suspension re-circulation for a period of two hours. Air samples from within the chamber were collected at 30-minute intervals and analyzed for Particle Size Distribution (PSD). Soil samples, taken before and after each test, were also analyzed for chaff PSD. Additional tests were conducted in which weighed chaff samples were placed on test plots and exposed to accelerated weathering through trampling by either livestock or vehicular traffic. In these tests, the environmental chamber was then placed over the plot and samples were collected, as was done for the previous tests with the environmental chamber alone.

Results of these studies indicate that, once deposited on the ground, chaff undergoes rapid fragmentation. Typically between 5 and 10 percent of the chaff in these tests was reduced to particles less than 10 microns in length over a two-hour period. In nature, assuming similar processes are at work, it seems likely that most chaff would be reduced to fragments less than 10 microns within a matter of days of deposition. Chaff fragmentation is primarily wind driven. While livestock trampling and vehicle-use probably contribute to chaff fragmentation, rapid fragmentation occurs in their absence. Moreover, increasing airflow in these studies resulted in increasing fragmentation suggesting that higher wind levels in the ambient environment would lead to increased fragmentation (DRI 2002).

Baseline sampling results from the 2002 DRI study indicated minimal chaff concentrations (1 micrograms/square ft) in the soil of an area heavily utilized for military aircraft training using chaff. This may indicate extensive fragmentation and dispersal of chaff used for training purposes on the range. The naturally occurring materials that comprise chaff, wind driven turbulence, fragmentation, and dispersal of PM_{10} size particles provide a sufficient basis to explain this finding. In essence, chaff particles, once on the ground, appear to rapidly fragment and become indiscernible from ambient silica and aluminum soil materials (DRI 2002; Cook 2002).

5.3.1 Aquatic Surface and Substrate Effects

Potential aquatic and marine effects of chaff have been of interest to both the Air Force and the Navy. Aquatic environments are sensitive to any chemicals released from any sources. The questions asked regarding chaff in an aquatic environment deal with the dissolution of the chaff in the water or marine environment, the potential resulting release of chemicals, which could be mobile within the aquatic ecosystems, and the potential sensitivity of aquatic organisms to released chemicals (Farrell and Siciliano 2004).

Confined aquatic habitats could be affected if there were a potential for significant accumulation and decomposition of chaff fibers. Since chaff would be broadly distributed with a low density in any one area, it is unlikely that chaff would be detectable or significantly accumulate within confined water bodies. Water bodies in the western U.S. are neutral to slightly alkaline in pH (similar to soils) and are outside the pH range necessary to degrade the aluminum coating. The low pH of some eastern areas could increase the solubility of aluminum from chaff. Chaff particles that fell on surface water would be chemically stable and subject to mechanical fragmentation. No impact to water bodies would be anticipated, even in a highly unlikely event such as a clump of undispersed chaff falling into a small, confined water body.

Chaff that lands on the surface of the water breaks down quickly into silica and aluminum. Under normal pH, the decomposition of aluminum in chaff is extremely slow. Only under very high or low pH could the aluminum in an undispersed clump of chaff become soluble and potentially toxic (Air Force 1997) and few organisms would be present in water bodies with such extreme pH levels. Given the small amount of diffuse or aggregate chaff material that could possibly reach water bodies and the moderate pH of western regional water bodies, it is not expected that water chemistry could be affected by chaff.

Chaff deposition on marine water surfaces would be subject to physical factors and would be expected to become part of the underlying sediment. The Navy sponsored a series of studies to address the potential for chaff materials to concentrate in the sediment. A series of studies were performed in the Chesapeake Bay to address whether chaff release was contributing to aluminum levels in the Chesapeake Bay (Wilson *et al.* 2002). An estimated 500 tons of chaff had been deposited over the bay during Navy ship and aircraft maneuvers for both research and training purposes from the mid-1970s to 1995. As part of the Wilson study, a series of sediment sampling locations were tested at various sampling depths to determine whether increased aluminum could be detected. A background sampling location at approximately the same depths was sampled in an area not subject to chaff deposition.

The studies found no significant difference in mean aluminum concentrations between the sediments that were from the control site and those taken from areas of heavy chaff use. The results did however, demonstrate some variation in the types of aluminum at the test and control locations. Inorganic monometric aluminum concentrations were significantly lower under the chaff use areas than in the background conditions. Mean concentrations of organic monometric aluminum were significantly higher in the sediment under the high chaff use area than in the control area. Exchangeable aluminum (AL_{EX}) represents aluminum bound to the soil by an electrostatic charge. AL_{EX} is a good indicator of soil acidity and of the concentration of potential toxic aluminum present. AL_{EX} concentrations under the heavy chaff use area were numerically lower but not significantly different from those of the control area (Wilson *et al.* 2002). Sediment sampling in the Chesapeake Bay area did not indicate that aluminum concentrations below military training areas were significantly increased due to chaff use. Aluminum concentrations in fish, plants, or other biota were not assessed in the sediment survey.

Aluminum is not known to accumulate to any great extent in most invertebrates under non-acidic conditions. It is unlikely that much, if any, of the aluminum present due to chaff use would be available for uptake by aquatic plants, fish, or other biota. The conclusions suggested that deployment of chaff resulted in minimal increases that were statistically significant in nontoxic aluminum in sediment under the flight path or in ship training areas. Concentrations of aluminum of toxicological interest were significantly lower under the heavy chaff use area than in background sediment samples (Wilson *et al.* 2002). Chaff plastic residual materials are typically inert and not expected to impact soils or water bodies.

5.3.2 Review and Comparison of Test Results

The DRI and Cook studies of chaff fragmentation used a similar fluidized bed apparatus. Fragmentation rates were estimated in both the Cook and DRI study at about 0.0001 percent (DRI 2002; Cook 2002). While the fluidized bed tests did not allow direct quantification of fragmentation rates, the Cook results were consistent with those obtained by DRI. These data support the conclusion that mid-air turbulence generated in fluidized bed tests results in a minimal degree of fragmentation. To the extent that these tests reflect conditions encountered by chaff in the mid-air environment, relatively little fragmentation would be expected to occur as chaff descends to Earth. These results suggest that individual chaff fibers approximately 0.3 to 1 inch long by 1/1,000 inch in diameter remain mostly intact during their descent.

Both the DRI study and the Cook study examined chaff fragmentation over a period more or less representative of the expected maximum duration that the chaff cloud would persist in the atmosphere (i.e., roughly ten hours). The Cook study provided fragmentation data at various time intervals (i.e., 2, 4, 8, and 24 hours). Looking at the data for the period most closely corresponding to the life expectancy of the chaff cloud (two to eight hours) showed that fragmentation levels appeared to be more or less constant. That is, whatever fragmentation occurred, it took place prior to the initial measurement at two hours. It may be that fragmentation was relatively constant over this two-hour period but had essentially ceased to occur when the 2-hour measurement was made. It is also possible the observed fragmentation took place at test start up and immediately dropped off after the first few seconds of testing. This would be equivalent to nearly all fragmentation occurring during deployment or within the first few seconds after deployment from an aircraft. Under this interpretation, the fact that some fragmentation occurred during the tests (albeit at very low levels) may be seen as resulting from forces at work during the initial start up of the fluidized bed.

During the first few seconds of operation, conditions within the chamber are quite turbulent and this momentary turbulence could lead to fragmentation. After a few moments, conditions within the chamber may stabilize, turbulence may be greatly reduced, and fragmentation could all but cease. This scenario would produce the same experimental results observed in both the DRI and Cook tests, which would be consistent with the turbulence acting on chaff in the first few seconds following deployment from an aircraft.

If the fluidized bed does indeed mimic conditions within the chaff cloud, the results of the DRI and Cook studies suggest that the individual chaff fibers are resistant to fragmentation due to air turbulence alone. Observations performed in the DRI study that tracked chaff clouds for distances of up to 200 miles suggest that the conclusions derived from the fluidized bed tests have validity. Chaff particles do not appear to fragment significantly prior to reaching ground level.

In contrast, when chaff is deposited on the ground and subject to wind-driven turbulence, substantial fragmentation occurs (up to 25 percent or more over the course of a two-hour period) (DRI 2002). The observed airspeeds leaving the environmental chamber in these tests were similar to ambient wind speeds measured by the anemometer. It would seem that turbulence and interaction with soils and other objects inside an environmental chamber would be similar to that which chaff fibers normally encounter once they reach ground level. Apparently, in this case, the experimental turbulence not only simulates the naturally occurring turbulence but also simulates the interaction between chaff and soil that results in chaff fragmentation. This implies that the turbulence encountered within the fluidized bed replicating the mid-air conditions was likely to produce substantially less fragmentation than encountered in the environmental chamber, which replicated contact with the surface.

The experimental data obtained from tests were not sufficiently robust to conclude definitively when most chaff fragmentation occurs. Most fragmentation could occur immediately on ejection or within the first two hours after ejection. While chaff fragmentation in the DRI tests appeared to be minor, some fragmentation did occur and there was some degree of formation of particles sufficiently small as to be considered respirable. Abrasion tests suggested that approximately 1:10,000,000 may be abraded to PM_{10} or smaller. The data sampling and testing resulted in this small fraction of chaff being converted to respirable particles. The data suggest that this fraction is not a significant factor in the fate of airborne training chaff. DRI concluded that virtually none of the airborne chaff was degraded to respirable size particles of PM_{10} or less. Based on tests conducted in these two studies, there would be little, if any, risk from airborne chaff abrading to respirable particles prior to the chaff being deposited on the surface where chaff fragments quickly become essentially indistinguishable from native soils (ACC 2006).

5.4 Chaff Effects on Humans, Wildlife, Livestock, and Ranches

Public and agency reviewers of environmental documents have questioned the effects of chaff on humans, wildlife, livestock, other agricultural operations, and economic activities. Representative questions that have been asked include:

- What would be the visual effects from chaff residual materials?
- Would chaff affect water and soil where the pH is high to very high in alkaline?
- What are the health risks from ingesting chaff residual materials?
- What are the health risks from airborne chaff?
- What are the frequency and amount of chaff drops over Tribal lands?
- Could chaff use create airborne Foreign Object Debris (FOD) hazards?
- Could chaff materials impact the economic value of wool?
- Would chaff materials affect birthing animals?
- What are the near-term and long-term impacts from chaff use?
- Will the Air Force provide chaff education to fire investigators?
- Why is chaff use limited to 60 Nautical Miles (NM) from airfield radar?
- Will chaff be distributed evenly throughout the airspace or will it be concentrated within routine training areas?
- Can the amount of chaff deployed be quantified?
- How does the use of chaff affect air quality?

- Will chaff use impact important species, such as the sage grouse?
- Can chaff use be limited to winter months to avoid the peak fire season?

The following sections consider the results from Section 5.1 and apply that and other information to respond to the list of representative questions above. Section 6.0 provides conclusions and specific responses to the representative questions.

5.4.1 Chaff Effects on Humans

Arfsten *et al.* reviewed scientific data, both published and unpublished, and concluded that there are no data indicating that inhalation or ingestion of chaff or dermal contact with chaff causes any adverse health effects in humans (Arfsten *et al.* 2002). This conclusion is consistent with the studies considered in Sections 5.2 and 5.3.

Chaff fiber diameters are too large to be inhaled into the lung. If inhaled, most chaff fibers would be deposited in the nose, mouth, or trachea and would either be swallowed or expelled. The amount of chaff silica fibers coated with aluminum that could be inhaled would be infinitesimal as compared to exposure of workers at fibrous glass and mineral wool manufacturing plants. Studies at these plants did not find an association between silica or glass fiber exposure and increased incidence of death from various cancers (Enterline *et al.* 1983; McDonald *et al.* 1990). Arfsten reported that deaths from nonmalignant respiratory diseases were significantly increased among these workers but were not correlated with exposure to glass fibers. No evidence was found that respiratory disease rates were significantly increased among workers from seven production plants that manufactured man made vitreous fiberglass (Arfsten *et al.* 2002; Hughes *et al.* 1993). No increased risk of mesothelioma has been demonstrated in workers exposed to glass wool, slag wool, or rock wool (De Vuyst *et al.* 1995). In 1998, Gibbs *et al.* 1998 concluded that exposure to fibrous glass is not associated with increased risk of death from nonmalignant or malignant respiratory diseases. The exposure of humans to aluminum-coated chaff under any postulated conditions would be infinitesimal compared to exposure in the Hughes, Enterline, and McDonald studies.

There are reports that occupational exposure to aluminum may increase the risk of asthma (Vandenplas *et al.* 1998) and pulmonary fibrosis (Nemery and Leuven 2007). Arfsten *et al.* reviewed the literature and could not find any cases of occupationally induced asthma or pulmonary fibrosis among workers involved in the manufacture or handling of chaff. Even in a manufacturing location where workers would be exposed to orders of magnitude greater quantities of chaff than could be feasible from deployed training chaff, intact chaff dipoles would not be expected to penetrate the lungs and would not be expected to increase human risk of either asthma or pulmonary fibrosis. As explained in Section 5.2, the breakdown of chaff fibers in the air results in a very small percentage (1/10,000,000) of respirable particles. On the ground, these particles rapidly become indistinguishable from ambient soils, which are comprised primarily of silica and aluminum (Section 5.3). Arfsten could find no instances in which military or personnel exposed to deployed chaff reported adverse health effects or skin irritation associated with possible chaff exposure. Any dust particles or chaff could irritate the nasal and oral mucus membranes or the eyes. Direct breathing of quantities of chaff fibers or finding and applying chaff fibers to the eyes should be avoided.

Could chaff be a potential source of aluminum if a piece of chaff from an open water area were swallowed? Arfsten cites several studies and notes that absorption of aluminum by the human gastrointestinal tract is minimal (1%), with most being passed out of the body in the feces. Absorbing aluminum from ingested chaff would be considerably less than absorbing aluminum through antacids. An adult would need to ingest about 3 g of chaff, or approximately 150,000 chaff fibers, to achieve an aluminum dose level that is equivalent to one dose of antacid (Arfsten *et al.* 2002). Some researchers believe that aluminum may be associated with Alzheimer's and dementia diseases. As explained regarding ingestion, the aluminum associated with chaff would not be taken into or, in the remote chance a chaff fiber were ingested, would not be absorbed by the body to contribute to such diseases.

5.4.2 Chaff Effects on Wildlife and Other Animals

Chaff and pieces of plastic falls to Earth with each bundle of chaff deployed. The plastic residual materials are inert and not likely to be seen by species as food, but some species of bird and rodents (e.g., pack rats) often select shiny material for their nests or burrows. Studies conducted at Nevada Test and Training Range (NTTR) in 1997 reported finding no difference in animal abundance and nesting activity in areas where chaff residual materials were present. Residual materials were not found in rodent burrows, pack rat nests, or in nesting materials for bird nests (Air Force 1997). As described in Section 5.3, chaff on the surface rapidly becomes indistinguishable from ambient soils. Chaff residual materials, such as a small end cap, could be seen as prey by fish. There is no record of a fish consuming a plastic piece. Should such a piece be approached, it is postulated that a predator fish would treat the plastic piece as a shiny pebble. No studies have been performed and no impacts have been identified. Behavioral responses from wildlife from the presence of chaff or chaff residual materials are not expected to be significant.

The 1977 Systems Consultants survey for the U.S. Navy found no evidence that chaff was acutely toxic to six species of aquatic organisms found in the Chesapeake Bay. Studies conducted by the U.S. Army found that very little aluminum was present in water after 200 milligrams (mg) of chaff was placed in 200 milliliters (mL) of water for 21 days (Haley and Kurnas 1993). Mortality was not significantly increased in Mysid shrimp (*Mysidopsis bahia*) or small, planktonic crustaceans (*Daphnia magna*) placed in the 100% water fraction for 48 hours. Mortality was not increased in sheepshead minnows (*Cyprinodon variegates*) placed in the 100% water fraction for 96 hours (Arfsten *et al.* 2002).

Foot surveys were conducted at NTTR and Townsend Range to evaluate the effects of chaff release on wildlife (DRI 2002). The surveys identified visible chaff residual materials that were present, the number and species of wildlife that were present, and whether chaff materials were used by animals in burrows or birds in nests. Chaff plastic end caps and clumps of chaff that had not deployed correctly were identified during the surveys. Animal abundance and nesting activities were considered normal and chaff was not found in the nesting material of 12 bird nests. No visible chaff or residual materials were found on the surface of a small spring at NTTR. One of four sediment samples taken from the NTTR spring contained chaff fibers. At Townsend Range, chaff that had not deployed correctly was identified along with two plastic end caps. No chaff materials were found in animal burrows excavated at Townsend. The NTTR and Townsend surveys concluded that chaff interference with wildlife activities is expected to be negligible.

Waterfowl in ponds or lakes under airspace where chaff is deployed have the potential to ingest chaff fibers, which would be comparable to sand or other soil materials. Such objects are handled by the gizzard and incidental chaff fibers would be of no consequence to the health of the bird. If a bird ingested a large amount of chaff, the chaff could interfere with the functioning of the gizzard. Although such an event could be postulated as feasible, the unnatural appearance and texture of a clump of chaff would not be expected to result in it being consumed by waterfowl. There is no documented case of waterfowl ingesting a clump of chaff (Air Force 1997). No data on ingestion of chaff by waterfowl are available and no known deaths of waterfowl have occurred from ingesting chaff (Air Force 1997).

The 1997 Air Force study addressed whether airborne chaff could potentially affect the process of echolocation used by bats for navigation and hunting. Although no studies have ever been published on the potential effects of chaff on bats, chaff rapidly disperses in the atmosphere so the concentration of chaff near ground level (where bats hunt) is expected to be very low. Chaff fibers are so small that it is extremely unlikely that the fibers could distort sound waves or interfere with bat echolocation. Chaff is not anticipated to hinder or impede bat navigation or hunting.

Once chaff reaches the ground, the primary potential effects on wildlife include ingestion or inhalation of fibers and direct body contact. Dispersed chaff, described in Section 4.0, consists of very fine strands of aluminum-coated silica fibers that are thinner than human hair. In general, chaff is released at high altitudes, drifts over very large areas, and is greatly dispersed before falling to Earth's surface. The average deposition of chaff fibers, under the assumptions in Section 4.2, is estimated to average 1/20th of an ounce of chaff per acre per year. Winds at the deployment altitude for chaff would affect drift and deposition.

Training with chaff would not result in a measurable increase in elemental aluminum in the soils. There is no evidence of chaff affecting vegetation and increased vegetation uptake of aluminum is not expected to occur because of chaff distribution (Air Force 2000). Aluminum is one of the most abundant materials in Earth's crust and the minute addition of aluminum from chaff would not have a discernible effect on the abundance or availability of aluminum in soils or vegetation.

The chemical components of chaff indicate that it would take large amounts of chaff and unique conditions for the chaff to be toxic. As used in Air Force training, these chemicals would be deposited in the environment at rates that are non-toxic and undetectable (Air Force 1997). Arfsten *et al.* reports that a study completed in 1977 for the U.S. Navy found no evidence that chaff was acutely toxic to six species of aquatic organisms within the Chesapeake Bay. Chaff fibers are not expected to dissolve in fresh water bodies unless they fall into acidic waters, and even then, concentrations of aluminum would not be expected to become toxic. Since chaff is broadly distributed with low density, it is unlikely that chaff would be detectable or accumulate within any particular wetland. Given this and the mild pH (neither excessively acid nor excessively alkaline) in most water bodies, it is not expected that the water quality for biological resources would be adversely affected by the use of defensive chaff by Air Force pilots during training.

Ingestion of chaff by either ranch animals or wildlife would be negligible as described in Section 5.2.3. Several studies have been conducted on cattle and goats that showed they would avoid eating clumps of chaff placed directly into their food. Calves consumed chaff only when the chaff was coated with molasses and thoroughly mixed with food. Those animals that did ingest the chaff showed no signs of health effects (Barrett and MacKay 1972). The wide distribution of chaff fibers would not be expected to result in concentrations of chaff. In addition, if a chaff bundle failed to deploy, neither ranch animals nor wildlife have been found to ingest chaff material, which is essentially soil. Ranch animals or wildlife has not been found to ingest chaff willingly and no case of such ingestion has ever been documented.

Inhalation of chaff fibers is not expected to have negative effects on terrestrial wildlife. Studies have demonstrated that chaff fibers are too large for inhalation and are expelled through the nose or swallowed (Air Force 1997). The probability of an individual animal (livestock or wildlife) or person encountering a single chaff fiber or clumps of fibers is extremely low. During environmental studies, public commenters have suggested that species such as bison, with their larger nostrils, could inhale greater amounts of chaff. As has been demonstrated in the tests described in Section 5.1, chaff does not break down in the air into inhalable particles. In the remote chance that a chaff fiber was inhaled, it would be expelled through the nose or swallowed.

External contact with chaff is not expected to be significant due to the flexible nature of the chaff fibers. Studies conducted at NTTR in 1997 reported finding no difference in animal abundance and nesting activity in areas where chaff were present. Chaff was not found in rodent burrows or in nesting material of bird nests (Air Force 1997).

5.4.3 Chaff Effects on Livestock and Ranches

Concerns have been expressed by ranchers and others that chaff fibers or residual materials could harm cattle, affect sheep's wool, or otherwise be detrimental to agricultural operations.

A 1972 study by the Canadian Department of Agriculture found no evidence of toxicity in calves fed chaff. The study was unsuccessful in getting calves to eat chaff until the chaff was soaked in molasses (Barrett and MacKay 1972). Six calves were fed molasses-soaked chaff each day for 14 days. No significant differences were found in the weight gain of calves given chaff versus the weight gain of animals not given chaff. Pathological examination of brains and digestive tracts of chaff-fed animals did not find any evidence of toxicity or mechanical injury. Blood parameter measurements taken at the end of the 14-day period were not significantly different from those taken at the beginning of the test. Fragments of chaff were found in the reticulum, but no evidence was found that the particles invoked a cellular response. Similar studies were conducted in cattle and goats at the University of Wisconsin by contract for the Air Force and these studies found no evidence that chaff ingestion posed a health hazard for farm animals (Air Force 1997).

Ingestion of chaff by either ranch animals or wildlife is expected to be negligible. Studies demonstrated that livestock would avoid eating clumps of chaff placed directly into their food and would only consume chaff when coated with molasses and thoroughly mixed with food. Those animals that were reported to ingest the chaff showed no signs of health effects (Barrett and MacKay 1972). Since deposition of chaff is expected to be minute from training operations, adverse effects from the highly unlikely ingestion by ranch animals would not be expected.

Once chaff reaches the ground, the primary potential effects on wildlife include ingestion or inhalation of fibers and direct body contact. Chaff released at altitude would drift over a very large area and mostly disperse before falling to Earth's surface. Winds at the deployment altitude of chaff would affect drift and deposition. An estimated one bundle of chaff per 20 square miles per year may fall to the ground without being dispersed (Section 4.2). Such clumps of undispersed chaff have been identified on military and private lands (AFSOC 2007). No instance of livestock ingesting a chaff bundle under military training airspace, where chaff has been deployed for decades, has been reported.

Public commenters have raised questions about the possibility of chaff or chaff residual materials becoming trapped in sheep's wool or in some way damaging crops. As described in Section 5.3, chaff fibers have been found to mechanically fragment and become indistinguishable from soil materials. Sheep's wool is normally processed to remove burrs, soil, or any other foreign materials so the normal process to remove impurities prior to marketing the wool would remove dust particles and any chaff particles in the unlikely event that such particles had fallen on and remained on a sheep. Studies performed with electron microscopes to distinguish chaff particles from representative background soils found it nearly impossible to differentiate a chaff particle from a dust particle (Cook 2002). In the extremely unlikely event that a plastic piece of chaff residual fell on a sheep and became enmeshed in their wool, the piece would be removed as a pebble in the normal wool cleaning process.

Chaff particles or chaff residual materials in agricultural crops or animal feed would be comparable to naturally occurring soil particles. Any steps to clean soil from the agricultural products would remove any chaff that could be present. Should a plastic residual piece of chaff fall in an agricultural field, it would be with a force equivalent to a small hailstone and be an inert object in the field. It is not expected that the piece of plastic would be processed with food any more than a small stone would become part of the processed food. Normal steps to remove a stone or other foreign material during the processing of the agricultural products for market would remove any chaff residual piece. In the unlikely event that a piece of plastic were somehow baled with animal feed, the piece of plastic would no more be expected to be ingested any more than a stone would be.

In the extremely unlikely event that a piece of chaff residual material was to be ingested by an animal in a feedlot, the plastic piece would not contribute to bovine hardware disease. Bovine hardware disease, or traumatic reticuloperitonitis, is caused when a bovine ingests a relatively heavy and sharp object such as a nail or piece of wire. The metal object falls to the bottom of the rumen and then pushed forward into the reticulum. The reticulum is one of the compartments in the bovine stomach, and its function is not well understood. However, the contractions of the reticulum force the object into the peritoneal cavity where it initiates inflammation. Since this is a relatively common disease in adult cattle, magnets are marketed for insertion into the rumen to keep the metal object from causing serious injury. Approximately nine out of 10 affected cattle are dairy cattle older than two years of age. It is believed that dairy cattle are affected because they are fed hay or silage, which contains the metal object (Cavedo *et al.* 2004). Any residual piece of plastic from chaff would not puncture or otherwise contribute to bovine hardware disease. The piece of plastic does not have sharp edges so it would pass through the digestive tract. Range cattle, including cows and calves, have been grazing on active military ranges for approximately 50 years. These ranges have been under airspaces where chaff has been regularly deployed at least for the last 30 years. There is no case of an animal contracting bovine hardware disease from a piece of chaff residual material. As described in Section 5.1, chaff is inert, does not fragment to respirable dimensions in the atmosphere, and rapidly fragments on the surface to become effectively indistinguishable from naturally occurring components of soil. Chaff is not consumed by ranch animals, it is inert, and would not harm animals including, birthing animals.

5.4.4 Chaff Effects on Marine Resources

Marine resources include aquatic resources that would be exposed to chaff deposition. Studies were conducted to evaluate the potential for chaff concentrations to be harmful to aquatic organisms in the Chesapeake Bay. The study by Systems Consultants for the U.S. Navy found no evidence that chaff was acutely toxic to six species of aquatic organisms. Concentration of chaff at between 10 to 100 times the exposure levels expected to be found in the Chesapeake Bay were placed in tanks containing a variety of aquatic organisms. American oysters (*Crassostrea virginica*), blue mussels (*Mytilus edulis*), blue crab (*Callinectes sapidus*), and killifish were among the species tested. There was no significance in mortality from exposure to concentrations of chaff of one to two orders of magnitude greater than expected chaff concentrations (Arfsten *et al.* 2002).

Chaff was not found to result in concentrations of aluminum that would produce environmental impacts in the Chesapeake Bay environment. Part of the reason for this may be that chaff is comprised of nearly entirely aluminum and silicate with some trace elements. Aluminum and silicate are the most common minerals in Earth's crust. Ocean waters are in constant exposure to crust materials and there would be little reason to believe that the addition of small amounts of aluminum and silica from chaff would have any effect on either the marine environment or sediment.

Before becoming part of the sediment, could chaff particles have environmental consequences? Chaff particles in the aquatic environment are similar to natural particles produced by sponges. The most abundant ocean shallow water sponges have siliceous spicules (small spikes) that are very similar to chaff. All fresh water sponges also contain spicules. Sponge spicules are simple, straight, needle-like silicon dioxide spikes, often with sharp pointed ends. Sponge spicules range from 1 to 30 micrometers (µm) in diameter and from 40 to 850 µm in length. Chaff fibers are approximately 25 µm in diameter and can break down to different lengths. Thus, naturally occurring sponge spicules are approximately the same diameter and can be the same length as chaff fibers. Both marine and fresh water sponges are abundant in the environment and aquatic animals regularly encounter spicules. A variety of species feed on sponges including ring-necked ducks, crayfish, sea urchins, clams, shrimp, larval king crabs, and hawks-bill turtles. These species do not purposefully consume spicules but they encounter spicules from consuming sponges. Aquatic organisms are regularly exposed to and consume materials that are the same size and are of similar composition to chaff fibers (Spargo 1999). This contact and consumption would reduce the likelihood that free-floating chaff particles would result in environmental consequences.

Chaff for low visibility aircraft has wrappers as described in Section 4.1.4. A comparison of Quilon-coated parchment paper and Mylar with Kapton suggests that Kapton is a long-lasting plastic material and parchment paper breaks down in a marine environment. The small amount of Mylar-based Kapton materials released during training would not be sufficient to produce concentrations at levels that would be expected to affect biological resources significantly. Even the small risk to species is avoided using parchment-based wrapping materials in RR-196/AL chaff as opposed to RR-180A/AL chaff. Using the Quilon-treated parchment paper means that the wrapping is a cellulose-based material coated with nontoxic Chromium-3. Quilon-treated parchment paper is also used as liners for baking pans. The result is that low observability aircraft, such as the F-22, training with parchment-wrapped delayed opening chaff would have a very low potential for environmental consequences. The change from Mylar to parchment paper (cellulose) wrapping for use in the delayed opening chaff would result in fewer plastic or Mylar pieces being deposited on the surface. Redesigning the wrapping material for delayed opening chaff (described in Section 4.1.4) reduces the potential for environmental effects associated with training by low observability aircraft.

Chaff in an aquatic environment has not been found to significantly increase the concentration of any toxic aluminum constituents in sediments under airspace that has undergone 25 years of chaff operations. Concentrations of chaff in test environments were not found to result in a significant change in mortality to a variety of marine organisms in the Chesapeake Bay area. No effect was seen in marine organisms exposed to concentrations of 10 times and 100 times the expected environmental exposure. Marine and fresh water sponges normally create chaff-like spicules. Foraging species are exposed to and consume these spicules on a regular basis with no detrimental effect. Chaff release in airspace above an aquatic environment is not expected to affect the environment and likely is not discernible within the environment.

5.4.5 Chaff Effects on Cultural Resources

Cultural or historic resources could be impacted if chaff or chaff residual materials altered the visual quality or had physical chemical impacts, which would alter the aesthetic setting or cultural resources. Chaff fibers rapidly degrade and are therefore not expected to be visible on cultural resources. Chaff residual materials fall to the ground or could land on structures or at sacred sites. Studies have shown that chaff does not pose a significant threat to the visual integrity of archaeological and architectural resources (DRI 2002). Chaff does not accumulate to any great degree and the fibers, if found, may be mistaken for natural elements such as animal fur or plant material. The fibers generally dissipate within a few days due to mechanical breakdown from wind, sediment erosion, and rain or snow.

Chaff residual plastic materials are typically 1 inch x 1 inch. The residual materials from chaff fall to the ground in a dispersed fashion and would not be expected to collect in quantities great enough to adversely affect the National Register of Historic Properties (NRHP) status of archaeological or architectural resources. Impacts to traditional cultural resources are more difficult to assess and no studies have been conducted on traditional cultural resources with regard to chaff residual materials. Chaff residual materials and clumps of undispersed chaff have been identified by ranchers on their property. If a plastic chaff piece or a clump of chaff were found and identified in conjunction with a cultural resource or at a traditional resource site, the individual finding the piece may be annoyed.

5.5 Radio Frequency Reflective Effects on Air Traffic

Chaff is designed to interfere with radar so that a maneuvering aircraft can escape a radar lock from opposing radar. The use of chaff in training could affect FAA or commercial radars such as aircraft tracking or weather monitoring radar. Weather radar has become increasingly important to predicting both flight and ground weather effects.

The primary weather surveillance radar operated by the National Weather Service (NWS), FAA, and the DoD is the Weather Surveillance Radar-1988 Doppler (WSR-88D system) (NRC 2002). Within CONUS, the Air Force uses RR-188/AL chaff to reduce, but not eliminate, chaff caused echoes to weather and other radars. In certain regions of CONUS, including near DoD training areas in the west and southwest, RR-188/AL chaff can be seen as a major radar echo contaminant (Elmore *et al.* 2004). Chaff particles suspended in weather systems could give inaccurate information regarding precipitation or severe weather conditions. Chaff may create electron interference and interfere with lightning strikes to the ground. This could affect the projection of storm severity (GAO 1998).

The NEXRAD system provides Doppler radar coverage to most of the U.S. Designed in the mid-1980s, NEXRAD continues to be upgraded to meet air traffic and weather prediction requirements (NRC 2002). As part of the ongoing NEXRAD modernization, NWS is adding polarimetric capability to existing operational radars to improve the radar's ability to identify and classify hydrometeor types such as rain, hail, and ice crystals and to distinguish non-meteorological types such as chaff (Ryzhkov *et al.* 2003). Several radar images have distinctive properties that can be differentiated using radar classification algorithms. Ongoing improvements in NEXRAD enhance the ability of radar systems to detect RR-188/AL chaff.

Could chaff be deployed at a low enough altitude and under specific meteorological conditions such that chaff particles could be predicted to stay within the surface area under the training airspace? If chaff use could be localized, potential interference with NEXRAD could be reduced. Investigations have been conducted to see whether RR-188/AL training chaff could be deployed and remain within the defined boundaries of a training airspace. By its very nature, chaff is light and designed to remain airborne to permit the evading aircraft to maneuver while the chaff's electronic cloud breaks radar contact. In most cases, both the meteorological conditions and the chaff fall rate are unpredictable. The chaff plume migrates with the prevailing wind at altitude such that it has not been possible to determine where chaff particles would fall. In a series of case studies designed to track chaff plumes under moderate wind and stable atmospheric conditions, a chaff plume from a release at altitudes between 15,000 to 22,000 ft above Mean Sea Level (MSL) traveled over 100 miles in two hours and could be expected to stay aloft for approximately another three hours. The total expected distance traveled by the deployed chaff prior to being deposited on the surface could be between 120 and 300 miles (DRI 2002).

The nature of chaff and the diversity of meteorological conditions mean that deployed chaff would continue to be a radar echo contaminant. This echo effect can be partially addressed through military communication with Air Traffic Control and weather radar operators to identify when and where chaff is deployed. Additional software or hardware refinement would improve the ability of NEXRAD to distinguish and differentiate the chaff echo from a weather echo. The Air Force has included distance setbacks from airport control radars for specific proposals to deploy defensive chaff. The distance of 60 NM has been identified by the FAA and the Air Force as sufficient distance to safely separate airport radar from training aircraft deploying chaff (Air Force 2010).

5.6 Potential for Injury from Chaff Residual Materials

Once on the ground, chaff residual plastic pieces are inert and do not have sharp edges that could cause injury. This section addresses whether a falling piece of residual chaff material would pose a safety risk from its weight and geometry.

5.6.1 Assumptions for Risk Calculations

Chaff residual materials typically consist of a 1 inch x 1 inch x 1/4 inch plastic or nylon piston and a 1 inch x 1 inch x 1/8 inch plastic or nylon end cap. A similarly sized piece of felt may also be used as a cushion within the chaff cartridge (Table 4-4). The pieces of plastic residual materials have different rates of descent and different impacts when they reach the ground. The likelihood of a strike to a person or object from a plastic piece from chaff would depend on the number of chaff bundles deployed, the area under the airspace, the population density under the airspace, and the proportion of time a person would be expected to be outdoors. This section calculates the likelihood of a piece of chaff residual material striking a person, assuming a remote, rural area with a population density of ten persons per square mile and 20,000 bundles of chaff deployed per year over a 2,000 square mile area. The assumptions in Table 5-1 do not reflect a specific location.

Table 5-1. Assumptions for Calculating Safety Risks

Area under training airspace authorized for flares	2,000 square miles [1]
Number of RR-188/AL chaff bundles used annually	20,000
Population density per square mile	10 persons
Amount of time person is exposed	10 percent of day out-of-doors and unprotected [2]

Notes:

[1] Assumes a training Military Operations Area (MOA) over a 2,000 square mile ground surface.

[2] Sources: McBride 2005; TVA 2003.

Aircraft training flights are generally distributed randomly and uniformly within a training airspace (ACC 2010). Chaff is released at altitudes and angles of release that are sufficiently random so surface locations of chaff residual materials would be distributed uniformly under training airspace where chaff use is authorized. For any residual chaff component, the conditional probability that it strikes a particular object is equal to the ratio of the object area to the total area of the airspace. For multiple objects (i.e. people), the probability of striking any one object is the ratio of the sum of the size of the objects or the sum of object areas to the MOA airspace. The frequency of a residual component striking one of many objects is the frequency of releasing residual components times the conditional probability of striking one of the many objects per given release. In equation form, this relationship is:

$$\text{Strike frequency} = \text{chaff drop frequency in MOA} \times \frac{\text{area of object} \times \text{number of objects in MOA}}{\text{MOA (area)}}$$

5.6.2 Risk/Frequency Estimation

The frequency of each of the strike consequences is computed as the product of the frequency of releasing residual components and the conditional probability of striking people, structures, vehicles, or other objects. These estimates are developed in the following paragraphs for RR-188/AL chaff. The effect of the impact of a residual chaff component is judged by computing the plastic chaff component's Terminal Velocity (V_T) and momentum. In equation form, V_T is calculated as follows:

$$V_T = \left[\frac{2}{\rho}\left(\frac{W}{A \times C_d}\right)\right]^{0.5} = 29 \times \left(\frac{W}{A}\right)^{0.5}$$

Where: V_T = Terminal Velocity (in Feet/Second)
W = Weight (in Pounds)
A = Surface Area Facing the Air stream (in ft^2)
C_d = Drag Coefficient = 1.0
Nominal Air Density = 2.378×10^{-3} $lbs\text{-}sec^2/ft^4$

Drag coefficients are approximately 1.0 over a wide range of velocities and Reynolds numbers (Re) for irregular objects (e.g. non-spherical). Using this drag coefficient, the computed terminal velocities produce Re values within this range (Re < 2×105), which justifies the use of the drag coefficient. The approximate weights and dimensions of chaff components are listed in Table 5-2.

Table 5-2. RR-188/AL Chaff Residual Component Properties

Component	Dimensions (inches)	Weight* (Pounds)
Piston	1 × 1 × 0.250	0.0043
End Cap	1 × 1 × 0.125	0.0061

Note: * Estimated weights.

Terminal velocity momentums of the chaff components are computed based on maximum and minimum areas depending on the component's orientation. Actual values of momentum when striking the surface would typically be between the maximum and minimum terminal velocities in Table 5-3. The momentum values are the product of mass (in slugs) and velocity. A slug is defined as the mass which, when acted on by a one pound force, is given an acceleration of 1.0 feet/sec^2.

Table 5-3. RR-188/AL Chaff Component Momentum

Component	Maximum Surface Area			Minimum Surface Area		
	Area (square inches)	Terminal Velocity (feet/second)	Momentum (pounds/second)	Area (square inches)	Terminal Velocity (feet/second)	Momentum (pound/second)
Piston	1.0	22.8	0.003	0.250	45.6	0.006

End Cap	1.0	27.2	0.005	0.125	76.9	0.015

5.6.2.1 Estimated Area of People

It is assumed that people who are at risk of being struck by a chaff residual plastic component are outdoors under a MOA or special use airspace. People in structures or vehicles are assumed protected. The dimensions of an average person are assumed to be approximately 5 feet 6 inches high x 2 feet wide x 1 foot deep (men, 5 feet 10 inches; women, 5 feet 4 inches; children, less than 5 feet 4 inches). The residual plastic piece would be expected to strike ground objects at an angle of 80 degrees or greater to the ground, assuming 80 degrees to the ground allows for possible wind or other drift effects. With the chaff component falling at 80 degrees to the ground, a person's body (5.5 × 2 × 1 feet) projects an area of 3.9 square feet normal to the path of the falling component. For this assessment, it is assumed that a person would be outdoors and unprotected 10 percent of the time. This assumption is based on Department of Energy and Environmental Protection Agency national studies (TVA 2003; Klepeis *et al.* 2001).

5.6.2.2 Potential Person Strikes

The frequencies of strikes can be computed based on the data and assumptions discussed above. It is assumed that flight maneuvers to deploy chaff are randomly distributed throughout the training airspace. The equation for the frequency of striking a person is:

$$Injury\ frequency = comp\,drop\ freq \times \frac{body\,area \times pop.density \times Fract\,unprot \times MOA(areainsqmi)}{MOA(areainsqft)}$$

For the assumptions in Table 5-1, this calculates for either a plastic piston or a plastic end cap to:

$$Strike\ frequency = 20{,}000/\,year \times 3.9\ ft^2 / pers \times 10\ pers/mi^2 \times 0.1 \times 3.59 \times 10^{-8}\ mi^2 / ft^2$$

= 0.003 strikes/year for either plastic piece or 0.0056 strikes/year for both plastic pieces of residual material (numbers are rounded).

This means that in a representative rural area beneath a MOA used for pilot training, the annual expected person strike frequency would be approximately six persons in every 1,000 years for a piece of plastic. The maximum momentum of the piece of plastic would vary between 0.003 and 0.015 pound-seconds depending on orientation of the falling piece. In this momentum range, there would be no injuries, but a person could feel the equivalent effect of a small hailstone. As a basis of comparison, laboratory experimentation in accident pathology indicates that, there is a less than a 1 percent probability of a brain concussion from an impulse of less than 0.10 pound-seconds to the head and a 90 percent probability that brain concussions would result from an impulse of 0.70 pound-seconds to the head (Air Force 1997). There is essentially no risk of injury from a falling residual piece of plastic from deployed chaff. There is a very remote possibility of an individual feeling a small hailstone-type effect in the unlikely event of a piece of plastic striking a person. There has been no recorded case of an individual being struck by a plastic piece of a defensive countermeasure of residual material.

The relatively slight force of a small hailstone type piece of plastic striking any object such as a structure, vehicle, domestic animal, or wildlife would not be expected to have any effect on the structure, vehicle, domestic animal, or wildlife. With an estimated average of one piece of plastic being deposited annually on an area of 30 acres, there would be little likelihood of an animal being struck.

6.0 CHAFF CONCLUSIONS

Chaff has changed from the initial aluminum strips used during World War II and through the Vietnam era to the angel hair chaff used today. As opposing electronic tracking systems improve, chaff technology has been improving. Angel hair chaff fibers are each approximately 0.3 to 1.0 inch long and 1/1,000 inch in diameter. The chaff fibers are 60 percent silica and 40 percent aluminum with trace amounts of other chemicals. Silica and aluminum are abundant elements in Earth's crust. The chaff fibers are coated with Neofat, a natural material that degrades when exposed to light or air. Chaff residual materials are two small 1 inch x 1 inch pieces of plastic, paper, Mylar, or felt pieces depending on the type of chaff in use.

6.1 Results of Chaff Studies

Although large numbers of chaff bundles are deployed by Air Force aircraft, modern chaff is typically not easy to identify in the environment unless the chaff bundle fails to deploy properly and a clump of chaff is deposited on the surface. Chaff particles have been found to be difficult to identify in an environment subject to modern chaff use for decades. The reasons for the difficulty in identifying chaff or chaff particles is because chaff is found to rapidly fragment on the surface and is composed primarily of silica and aluminum, two of the most common elements in Earth's crust. Multiple studies to identify chaff particles or to locate elevated concentrations on the ground or in substrate have had limited success, primarily because chaff rapidly fragments in the environment and becomes indiscernible from ambient soil particles. No biological effects to terrestrial or marine organisms have been observed even when such organisms are subject to substantially higher concentrations of chaff than could be expected to occur from training. The use of parchment paper in place of Mylar for delayed opening chaff is a recent measure to reduce the deposition of residual plastic pieces to the environment.

The chaff projected for use by aircraft is not expected to result in noticeable quantities of material deposited on the surface. Chaff materials are not projected to result in a discernible impact to ground surface or water areas or to sensitive biological species transiting or occupying ground surface or water areas.

Chaff radar reflectivity produces echoes on upgraded NEXRAD radar used for weather and air traffic in CONUS. Chaff is designed to interfere with electronic monitoring by radar through a mechanized interference with the radar. As systems and technology advance, software and hardware upgrades are expected to reduce chaff interference with radar echoes.

Chaff residual materials do not result in impacts on land use, economic activity, or cultural or traditional sites. An individual finding a piece of plastic or a clump of chaff that did not correctly deploy in an unexpected location could be annoyed. There is no health or safety risk from use of chaff.

6.2 Responses to Representative Questions

The representative questions from Section 5.4 have been addressed in this discussion of chaff. Wherever possible, sections are cited where specific issues have been addressed. In other cases, the detailed explanation of chaff and flare materials provides an explanation or response to public or agency concerns. The representative questions from Section 5.4 are repeated below with summary responses to the questions.

- What would be the visual effects from chaff residual materials? The chaff residual materials are described in Section 4.1. The potential for any concentration of chaff particles on the surface is very small. The average weight of chaff fibers, at 3.35 ounces of chaff per bundle, released by 20,000 bundles of chaff deployed during training over a 2,000 square mile area would be approximately 1/20 of an ounce per acre per year. Clumps of chaff that did not deploy correctly can and do occur. Chaff has a 99 percent manufacturing reliability standard. If 20,000 bundles of chaff were deployed annually over a 2,000 square mile area under a training airspace and half the chaff failures represented a failure of chaff to deploy, there would be an estimated 100 undeployed clumps of chaff per year. This would average one clump of chaff fibers or an estimated averaged of 3.35 ounces of undeployed chaff per 20 square miles per year. If a 1 inch x 1 inch piece of plastic or a clump of chaff were found and identified, the finder could be annoyed.
- Would chaff affect water and soil where the pH is high to very high in alkaline? The only feasible soils or water consequences could be from minute particles of chaff. Chaff concentrations are calculated to be approximately 1/20 of an ounce per acre per year. The soil pH is normally outside the range to react with chaff coatings (Sections 5.3 and 5.4.2). In highly acidic soil or water, aluminum could separate from the silica core. The chaff particles rapidly become indistinguishable from silica and aluminum soil elements. No soils or water impacts would be anticipated.
- What are the health risks from ingesting chaff residual materials? Chaff in the air does not fragment into respirable particles. Chaff deployment would result in an estimated average of 1/20 of an ounce per acre per year. Section 5.4.1 explains that chaff poses no human health risks. Chaff plastic or paper pieces have never been recorded as ingested by animals (Sections 5.4.2 and 5.4.3). During controlled tests, animals rejected eating chaff.
- What are the health risks from airborne chaff? Airborne chaff does not abrade to respirable particles. Chaff fibers are dispersed in the air where they rapidly break down on the surface to become silica and aluminum particles indistinguishable from the composition of soil. The animal fat micro coating of chaff fibers breaks down when exposed to sunlight. Chaff does not pose a health or other risk (Sections 5.3.2 and 5.4.2).
- What are the frequency and amount of chaff drops over Tribal lands? Chaff and flare deployment as defensive countermeasures typically results in an estimated 1/20 of an ounce of chaff fibers per acre per year. Chaff plastic residual materials of approximately one piece per 30 acres per year could be randomly distributed anywhere under a training airspace including on Tribal lands. This assumes 20,000 bundles of chaff annually deployed over a 2,000 square mile area (Section 5.6.1).
- Could chaff use create airborne FOD hazards? There has not been a recorded instance of chaff plastic or other residual materials striking or damaging an aircraft, even in extensively used training ranges such as NTTR or the Utah Test and Training Range (UTTR). Chaff fibers, which are thinner than a human hair, disperse in the air and drift to the ground. Plastic and other residual pieces from deployment of chaff fall to the ground. The heaviest piece of chaff residual materials is a plastic piece that falls with the force of a small hailstone (Section 5.6). There has been no recorded case of such piece striking another aircraft.
- Could chaff materials impact the economic value of wool? Chaff fibers rapidly break down on the surface and become indiscernible from soil. Wool processing procedures include methods for cleaning the wool for soil, burrs, or other materials. In the unlikely event that a chaff particle alighted on a sheep, such a particle would be removed along with other materials in the wool

cleaning process. There is no basis for believing that chaff or flare inert plastic or other pieces would become attached to sheep or to any other animal. The normal procedures for cleaning the wool would clean out any extremely unlikely pieces of chaff residual materials (Section 5.6.2.1).

- Would chaff materials affect birthing animals? Chaff dispersion is projected to be approximately 1/20 of an ounce of chaff per acre per year, assuming 20,000 bundles of chaff deployed over a 2,000 square mile area. Chaff rapidly breaks down and becomes indistinguishable from soil. Any contact with chaff or flare residual materials would be highly unlikely. Chaff plastic and other residual materials can be deposited anywhere on the ground. These residual materials could annoy people finding and identifying them, but there would be no physical effect on any animals (Section 5.4.3). As described in Section 5.1, chaff and chaff residual materials are inert. Chaff does not fragment to respirable dimensions in the atmosphere and rapidly fragments to become effectively indistinguishable from naturally occurring components of soil. Chaff materials are inert and would not harm birthing or other animals.
- What are the near-term and long-term impacts from chaff use? Section 5.0 describes the chaff and flare effects including the effects of residual materials that fall to the ground. Long-term studies to identify chaff have demonstrated that chaff breaks down quickly on the surface to particles of aluminum and silica, which are the most common elements in the soil (Section 5.5). The degraded chaff particles are effectively indistinguishable from existing soil particles.
- Why is chaff use limited to 60 NM from airfield radar? Chaff would not be deployed within 60 NM of airport approach radars to reduce the risk of aircraft approach radar not being able to see an aircraft. Deployed chaff could give a false positive image of clouds or rain to some weather radars and could reduce lightning strikes (Section 5.5).
- Will chaff be distributed evenly throughout the airspace or will it be concentrated within routine training routes? Chaff use in training is not limited to any specific area. It is used in response to air- and/or ground-based threats, which can occur anywhere within a training airspace. Winds at deployment altitude would disperse chaff fibers that are thinner and lighter than human hair. Aircraft training flights and chaff distribution would be random and not only on specific training routes.
- Can the amount of chaff deployed be quantified? Chaff amounts can be quantified for specific training aircraft and specific training airspace. This paper has used the example of 20,000 bundles of chaff deployed over a 2,000 square mile area, which results in 1/20 of an ounce of chaff per acre per year.
- How does the use of chaff affect air quality? Chaff filaments, thinner than a human hair, are effectively invisible in the air and break down rapidly on the surface into particles indistinguishable from existing soil. Chaff would not affect regional air quality.
- Will chaff use impact important species, such as the sage grouse? Chaff distribution would be approximately 1/20 of an ounce per acre per year. Such a concentration would not be expected to impact species such as the greater sage grouse. Even where chaff and flares were used regularly, no animal or bird nests were found to contain chaff or flare materials (Section 5.2.2). No chaff effects would be expected to sensitive species.
- Can chaff use be limited to winter months to avoid the peak fire season? Chaff is inert and does not burn or pose any fire risk.

7.0 FLARE CHARACTERISTICS AND COMPOSITION OF SELF PROTECTION FLARES

This section describes a variety of defensive flares used by Air Force training aircraft. Section 3.0 briefly describes training with defensive countermeasures. Figure 3–1 is a photograph of an A-10 aircraft deploying M-206 flares. Figure 3–2 presents the life cycle of training with defensive chaff and flares. Table 7-1 lists typical self-protection flares currently in use, the types of aircraft that use the different flares, and characteristics of the flares. The flares listed in Table 7-1 and other flare types are described in the following sections, which explain the different flare attributes and the residual materials associated with the different flares.

Table 7-1. Typical Self-Protection Flares Used for Training in ACC-Scheduled Airspace

Attribute	ALA-17/C	M-206	MJU-7A/B	MJU-10/B	MJU-23/B and A/B
Aircraft	B-52, AC-130	A-10, F-16, C-130, C-17	F-16, F-15, C-130	F-15, F-22	B-1B
Mode	Parasitic	Parasitic	Semi-parasitic	Semi-parasitic	Non-parasitic
Configuration	2 cylindrical cartridges in series	Rectangular	Rectangular	Rectangular	Cylindrical
Approximate Size	Each cylinder 4.75x2.25 inches (diameter)	1x1x8 inches (8 cubic inches)	1x2x8 inches (16 cubic inches)	2x2x8 inches (32 cubic inches)	10.5x2.75 inches (diameter) (90.7 cubic inches)
Impulse Cartridge	None; electrically activated M-2 squib	M-796	BBU-36/B	BBU-36/B	BBU-46/B
Safe and Initiation (S&I) Device	(2) Slider assembly	None	Slider assembly	Slider assembly	Slider assembly
Felt Spacers	(2) 2.25 inches diameter	(1 or 2) 1x1 inch	(1 or 2) 1x2 inches	(1 or 2) 2x2 inches	(2) 2.75 inches diameter
Piston	(2) 1/4x2.25 inches diameter	1x1x1/4 inch	1x2x1/4 inches	2x2x1/4 inches	1/4x2.75 inches diameter
End Cap	(2) 1/8x2.25 inches diameter	1x1x1/8 inch	1x2x1/8 inches	2x2x1/8 inches	1/8x2.75 inches diameter
Weight (nominal)	Pellet: 18 oz Canister: 10 oz	6.9 ounces	13 ounces	40 ounces	43 ounces
Other Comments	Canister ejected with first unit	None	None	None	End cap includes ½ inch rubber shock absorber

7.1 Flare Characteristics and Composition

Self-protection flares are primarily mixtures of magnesium and Teflon (polytetrafluoroethylene) molded into rectangular shapes (Air Force 1997). Longitudinal grooves provide space for materials that aid in ignition. Typically, flares are wrapped with an aluminum-coated Mylar or filament-reinforced tape (wrapping) and inserted into an aluminum (0.03 inches thick) case that is closed with a felt spacer and a small plastic end cap (Air Force 1997). The top of the case has a pyrotechnic impulse cartridge that is activated electrically to produce hot gases that push a piston, the flare pellet, and the end cap out of the aircraft into the airstream. A countermeasures flare may be compared to a muzzle-loading rifle. The flare case is the barrel. The flare contains a firing cap, a powder charge, wadding between the charge and the flare pellet (or bullet), and a wad or cap at the end that keeps everything in place. The electrical firing creates a gas that ejects the plastic or nylon slider, two felt spacers that hold everything in place, and the end cap. The "bullet" is a magnesium/Teflon flare pellet that is ejected and is designed to burn up in 3.5 to 5 seconds.

There are three types of ignition mechanisms for self-protection flares: non-parasitic, parasitic, and semi-parasitic. The non-parasitic flare is discharged from the aircraft before ignition. The parasitic flare ignites inside the tube within the aircraft and is discharged already burning. The semi-parasitic flare is thrust out of the case by a firing mechanism and the Safe and Initiation (S&I) device permits the hot gases to ignite the flare pellet.

7.1.1 M-206 Flare

Figure 7–1 is a drawing of an M-206 flare, which is 1 inch wide x 1 inch high x 8 inches long. The M-206 flare pellet is approximately seven inches long. When the M-796 impulse cartridge is electronically triggered, gas pressure pushes the small nylon or plastic piston. A hole extends through the piston and permits igniter gases to contact the first fire mixture on the flare pellet. This ignition of the flare pellet in the cartridge means that the M-206 is a parasitic flare. The piston pushes the flare pellet in the casing, pops off the plastic end cap, splits the wrapping material, and deploys the burning magnesium flare pellet.

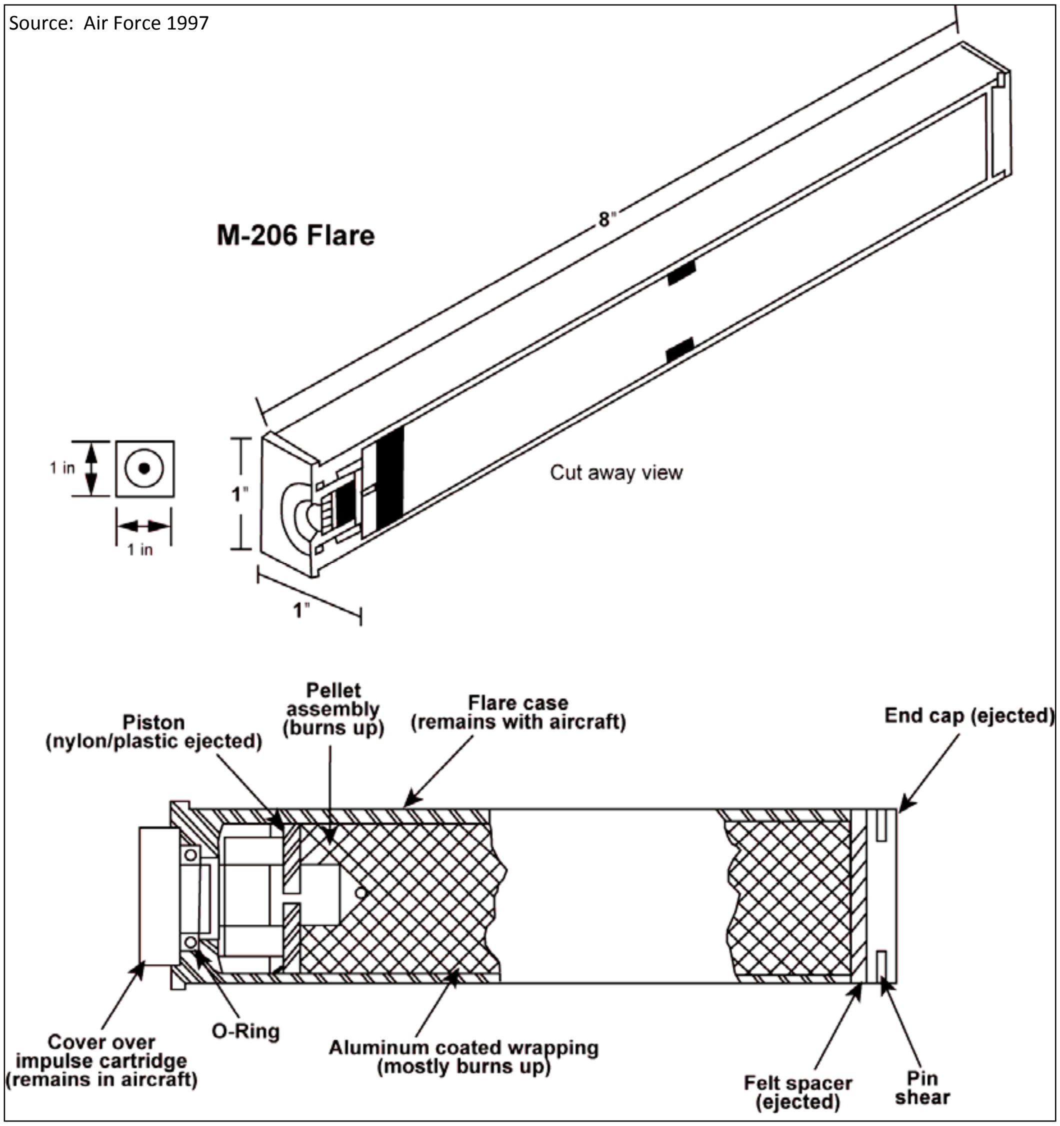

Source: Air Force 1997

Figure 7–1. M-206 Flare Dimensions and Details

Figure 7–2 presents an M-206 countermeasure flare and the aluminum case, which stays in the aircraft.

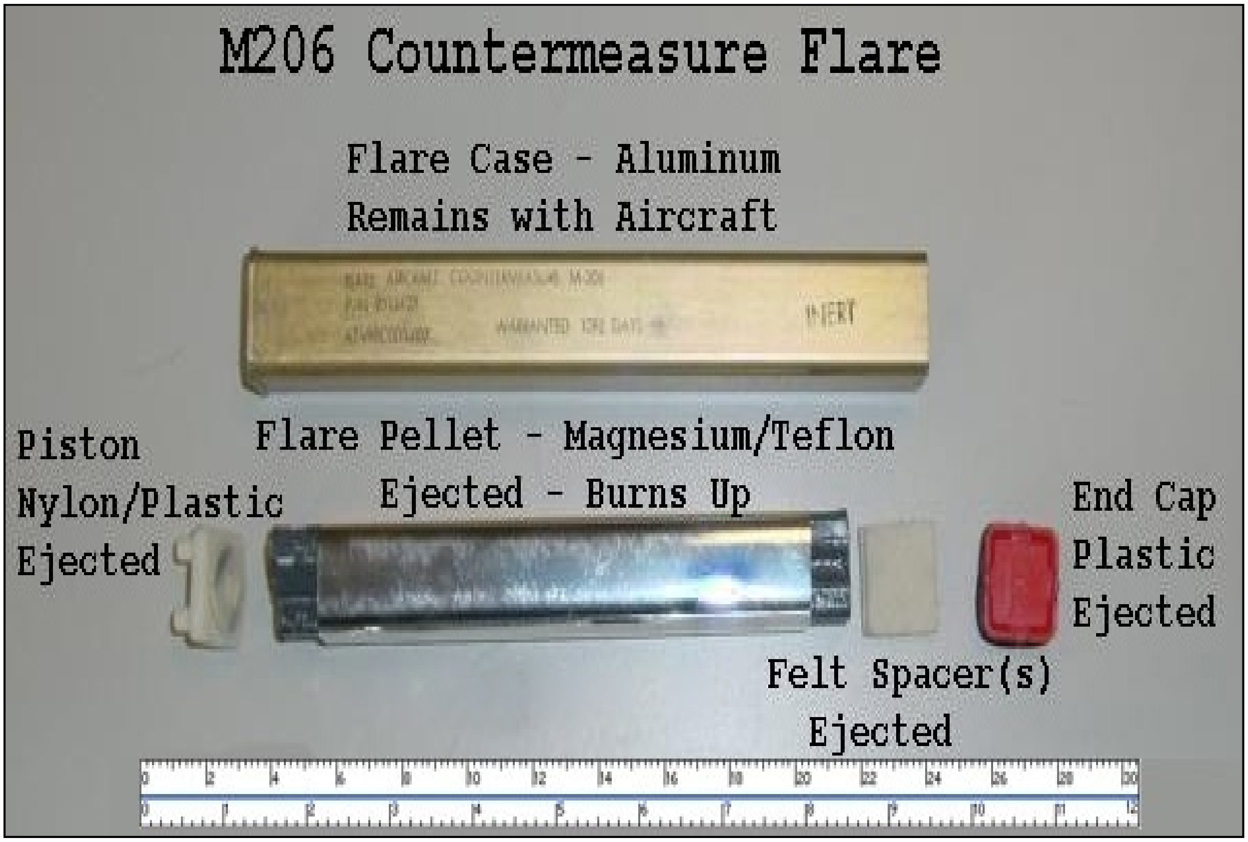
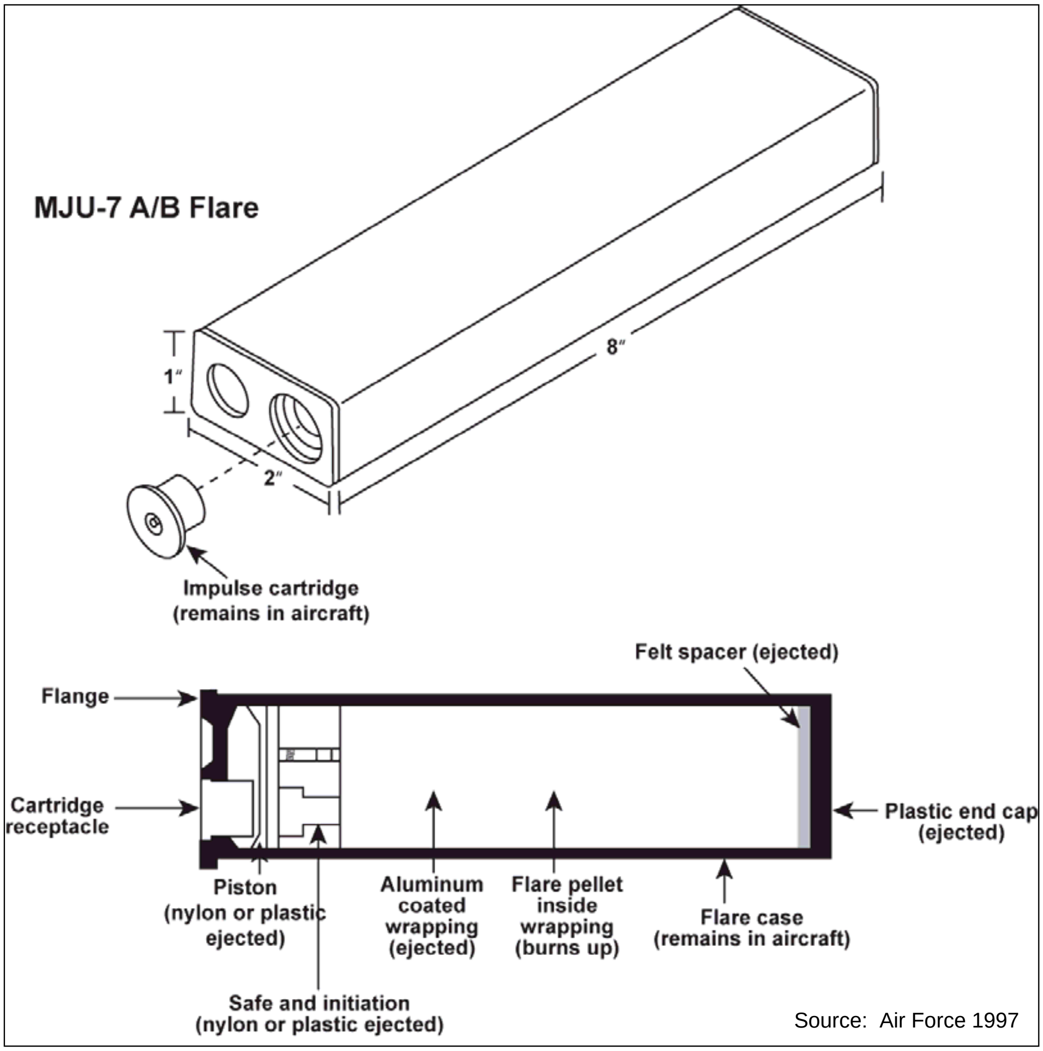


Figure 7–2. Photograph of M-206 Flare Components

7.1.2 MJU-7A/B Flare

Figure 7–3 is a drawing of an MJU-7A/B flare, which is a semi-parasitic flare that contains a charge that is ignited as the flare is ejected from the aircraft. The MJU-7A/B is approximately 2 inches wide x 1 inch high x 8 inches long. The MJU-7A/B flare pellet is approximately 14 cubic inches. The MJU-7A/B is similar to the M-206, with a flare pellet, a nylon piston, felt spacers, and an end cap. The MJU-7A/B uses the BBU-36/B impulse cartridge and contains an S&I device, which has a spring mechanism to prevent the ignition gases from igniting the flare pellet until the pellet is exiting the aluminum case. This makes the MJU-7A/B a semi-parasitic flare. The S&I device incorporates an initiation pellet (640 milligrams of magnesium, Teflon, and Viton A or Fluorel binder) that is ignited by the impulse cartridge. Hot gases reach the flare as the slider exits the case, exposing a fire passage from the initiation pellet to the first fire mixture on the flare pellet.



Source: Air Force 1997

Figure 7–3. MJU-7A/B Flare

Figure 7–4 presents a cutaway view of all parts of the MJU-7A/B flare.

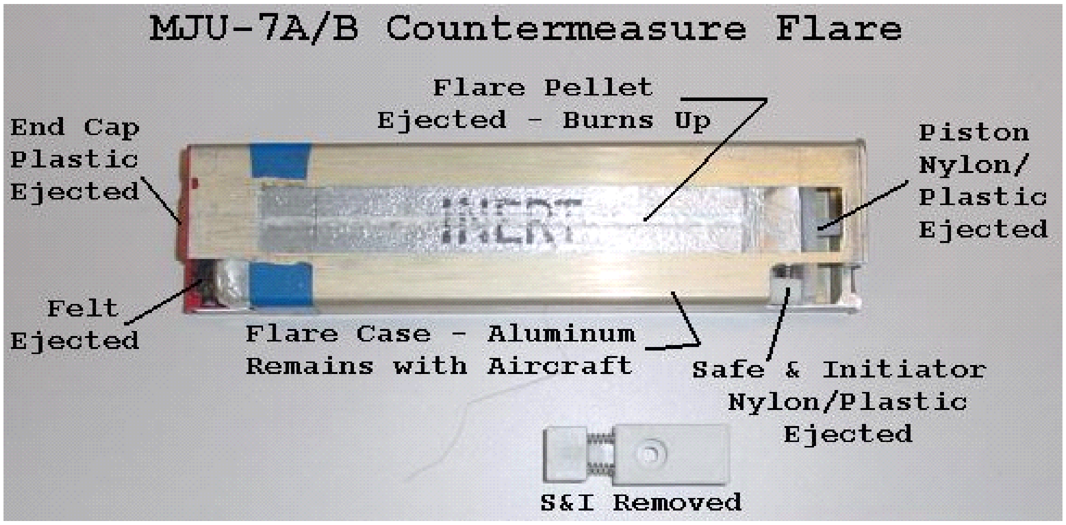


Figure 7–4. MJU-7A/B Countermeasure Flare (cutaway view)

7.1.3 MJU-10/B Flare

The flare used by the F-22 and the F-15 is the MJU-10/B. Figure 7–5 is a drawing of the MJU-10/B flare. Table 7-1 provides a summary description of the M-206, MJU-7A/B, and MJU-10/B flares. The primary difference between the MJU-7A/B and the MJU-10/B flare is that the MJU-10/B flare is twice as wide as the MJU-7A/B. The MJU-10/B is approximately 2 inches wide x 2 inches high x 8 inches long, and the flare pellet is approximately 28 cubic inches.

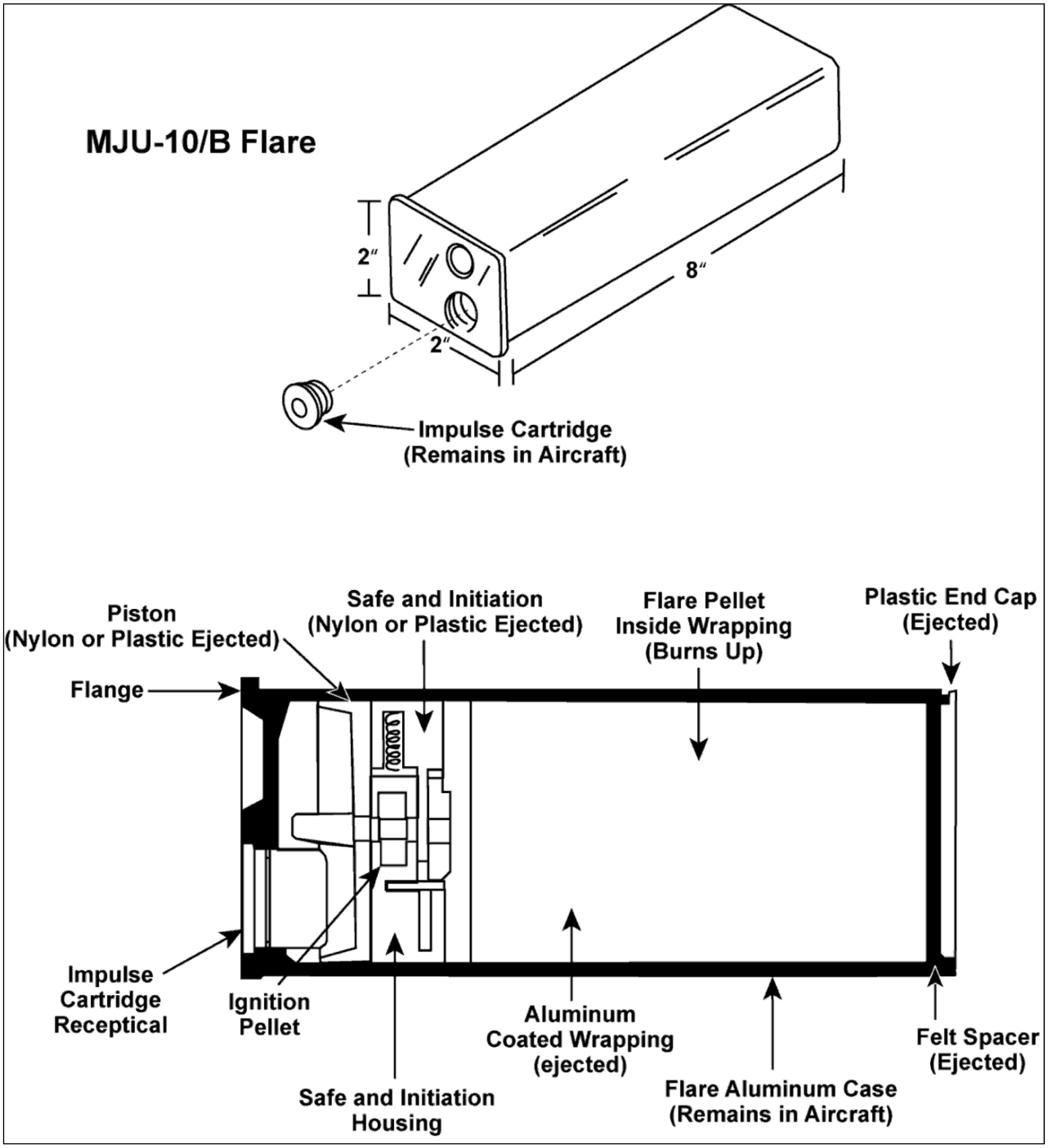


Figure 7–5. MJU-10/B Flare

Table 7-2 presents the typical composition of the MJU-10/B flare. This composition is comparable to the MJU-7A/B flare discussed in Section 7.1.2. The MJU-10/B flare is expelled from the flare cartridges with the same BBU-36/B impulse charge as is used by the MJU-7A/B flare.

Table 7-2. Composition of MJU-10/B Self-Protection Flares

Combustible	**Components**
Flare Pellet	Polytetrafluoroethylene (Teflon) (-$[C_2F_4]_n$ – n=20,000 units) Magnesium (Mg) Fluoroelastomer (Viton, Fluorel, Hytemp)
First Fire Mixture	Boron (B) Magnesium (Mg) Potassium perchlorate ($KClO_4$) Barium chromate ($BaCrO_4$) Fluoroelastomer
Immediate Fire/Dip Coat	Polytetrafluoroethylene (Teflon) (-$[C_2F_4]_n$ – n=20,000 units) Magnesium (Mg) Fluoroelastomer
Assemblage (Residual Components)	**Components**
Wrap	Mylar or filament tape bonded to aluminum tape
End Cap	Plastic (nylon)
Felt Spacers	Felt pads (0.25 inches by cross section of flare)
Safe & Initiation (S&I) Device	Plastic (nylon)
Piston	Plastic (nylon)

Source: Air Force 1997

Table 7-3 presents the components of the BBU-36/B and M-796 impulse charges used in the M-206 flare.

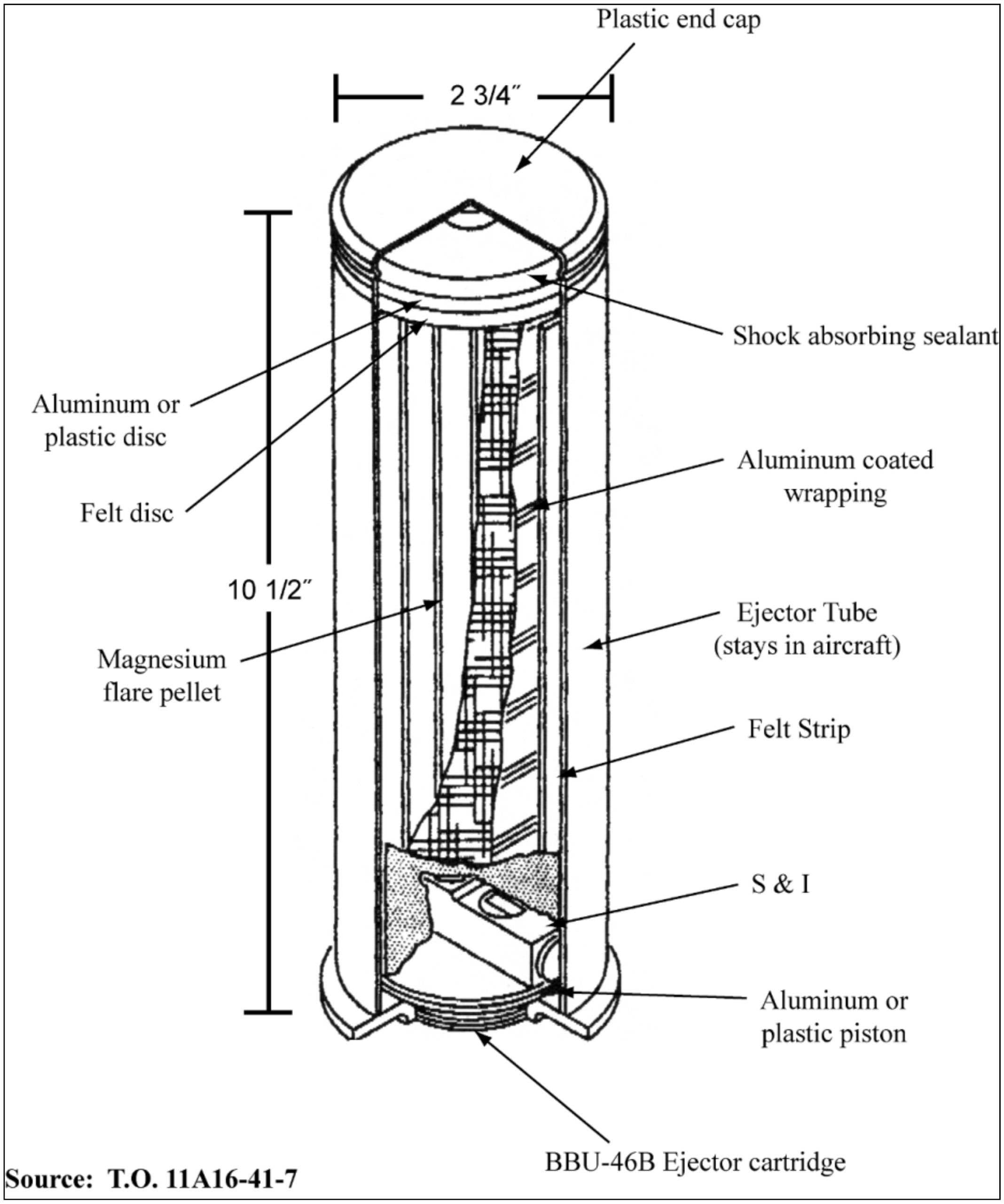
Table 7-3. Components of M-796 and BBU-36/B Impulse Charges

Component	**M-796**	**BBU-36/B**
Overall Size	0.449 x 0.530 inches	0.740 x 0.550 inches
Overall Volume	0.104 cubic inches	0.236 cubic inches
Total Explosive Volume	0.033 cubic inches	0.081 cubic inches
Bridgewire	Trophet A - 0.0025 inches (diameter)	Trophet A
Closure Disk	Scribed disc, washer	Scribed disc, washer
Initiation Charge	**M-796**	**BBU-36/B**
Volume	0.011 cubic inches	0.01 cubic inches
Weight	100 mg	100 mg
Compaction	5,500 psi	6,200 psi
Composition	20% boron and 80% calcium chromate	42.5% boron, 52.5 % potassium perchlorate, and 5.0% Viton A
Booster Charge	**M-796**	**BBU-36/B**
Volume	0.011 cubic inches	0.01 cubic inches
Weight	70 mg	150 mg
Compaction	5,500 psi	5,100 psi
Composition	18% boron and 82% potassium nitrate	20% boron and 80% potassium nitrate
Main Charge	**M-796**	**BBU-36/B**
Volume	0.011 cubic inches	0.061 cubic inches
Weight	185 mg	655 mg
Compaction	Loose fill	Loose fill
Composition	Hercules HPC-1 (~40% nitrocellulose)	Hercules #2400 smokeless powder (50-77% nitrocellulose, 15-43% nitroglycerine)

Source: Air Force 1997

7.1.4 MJU-23/B Flare

The MJU-23/B, shown in Figure 7–6, is a non-parasitic cylindrical flare used only on the B-1B aircraft. It is 10.5 inches long and 2.75 inches in diameter. The MJU-23/B flare includes the same S&I device as the semi-parasitic MJU-7A/B flare. The MJU-23/B has a plastic end cap with 0.5 inches of black rubber potting compound designed to absorb the shock of hitting spring-loaded doors on the aircraft. Earlier versions of the MJU-23 used an aluminum piston and included strips of felt spacers on the side and circular felt spacers in the cylinder. The newer MJU-23/B replaced the aluminum with a plastic piston, retained circular felt spacers, and reduced the side felt spacer strips. The MJU-23/B uses the BBU-46/B impulse charge, which is comparable to but somewhat larger than the BBU-36/B impulse charge.



Source: T.O. 11A16-41-7

Figure 7–6. MJU-23/B Flare

The MJU-23A/B in Figure 7–7 is an updated version of the MJU-23/B. The MJU-23A/B flare expels residual materials along with the magnesium/Teflon flare pellet. Residual materials for the MJU-23A/B include two felt pads in a disk shape, a plastic disk, a plastic/nylon end cap, and a piston with an S&I system attached. The aluminum wrap around the magnesium pellet is usually burned when the flare ignites on exiting the flare's case.

Figure 7–7. Photograph of MJU-23A/B Flare Components

7.1.5 ALA-17A/B Flare and ALA-17/C Flare

The B-52 uses the ALA-17 A/B flare or the newer ALA-17C flare as noted in Table 7-1. A drawing of the ALA-17A/B flare is presented in Figure 7–8. The flare consist of two independently fired aluminum cylinders, each 4.75 inches long and 2.25 inches in diameter, crimped together end-to end. The ALA-17 A/B flare with the two cylinders is 9.5 inches long, 2.25 inches in diameter, and from the outside, looks similar to the MJU-23/B flare (Figure 7–7). When the top cylinder is fired, the flare pellet is ejected from the aircraft along with the entire bottom cylinder. Impulse cartridges are not used and the flares are fired directly with an electrically activated squib set in potting compound. The M-2 squib weights about 0.0022 ounces and is composed of 40 percent potassium chlorate, 32 percent lead thiocyanate, 18 percent charcoal, and 10 percent Egyptian lacquer (Global Security 2008). Both the upper and lower flare case expels an aluminum end cap and plastic piston. Both the upper and lower flare are deployed and ignited by the impulse cartridge. The older ALA-17A/B flare has no S&I device in either the upper or lower flare cartridge case.

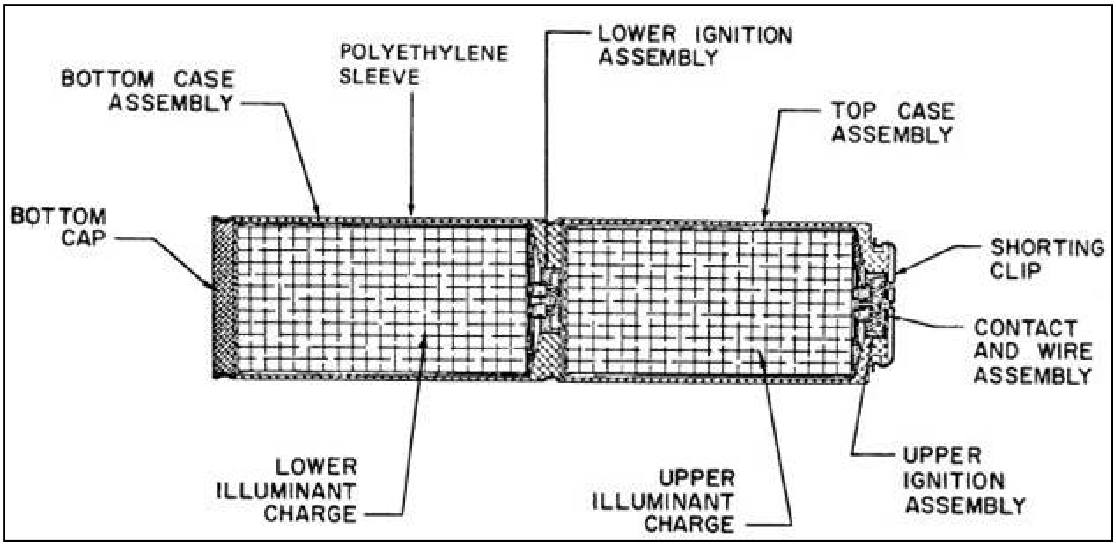


Figure 7–8. ALA-17A/B Flare Cartridge

The newer ALA-17 C flare has both upper and lower flare cylinders that are contained inside single aluminum housing as depicted in the cutaway Figure 7–9. The upper and lower flare cylinders are both wrapped in aluminum tape as well as possessing individual deployment and ignition systems. A plastic end cap and S&I system are deployed with the individual flare pellets. The lower flare's expended impulse cartridge and aluminum housing/mid-spacer are expelled by deployment of the upper flare. The ALA-17C aluminum housing, comparable to the MJU-23A/B aluminum housing pictured in Figure 7–8, remains in the B-52 dispenser rack.

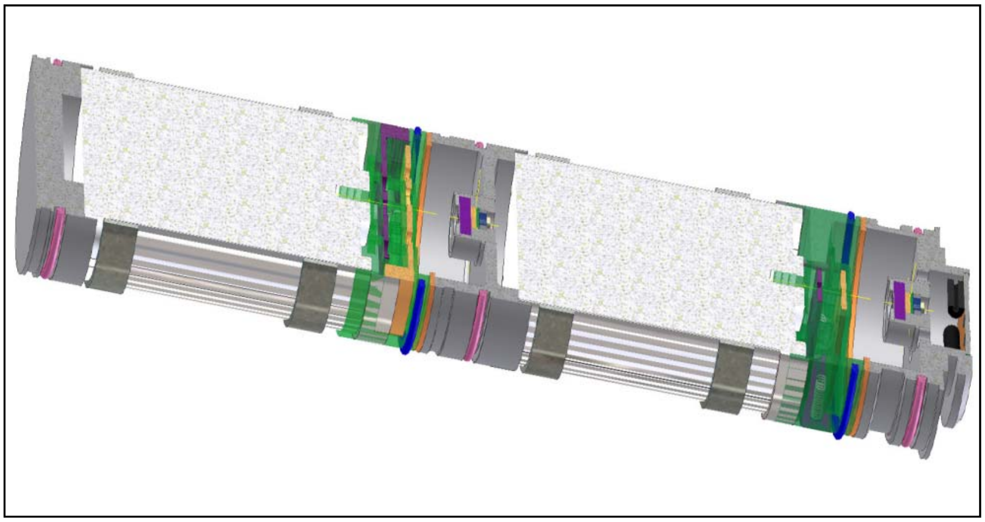


Figure 7–9. Cutaway View of the ALA-17/C Flare

7.1.6 MJU-61/B and MJU-62/B Flares

The MJU-61/B and MJU-62/B flares are the same sizes as the M-206 and MJU-7A/B flares. The length of the chaff dipoles is different for the MJU-61/B and MJU-62/B flares. The MJU-61/B flare is approximately 1 inch x 1 inch x 8 inches long (Figure 7–10). The difference between the M-206 and MJU-61/B flares is that the MJU-61/B flare has an igniter device that allows the hot gases propelling the flare from the aluminum cartridge to ignite the flare magnesium pellet as the flare exits the cartridge.

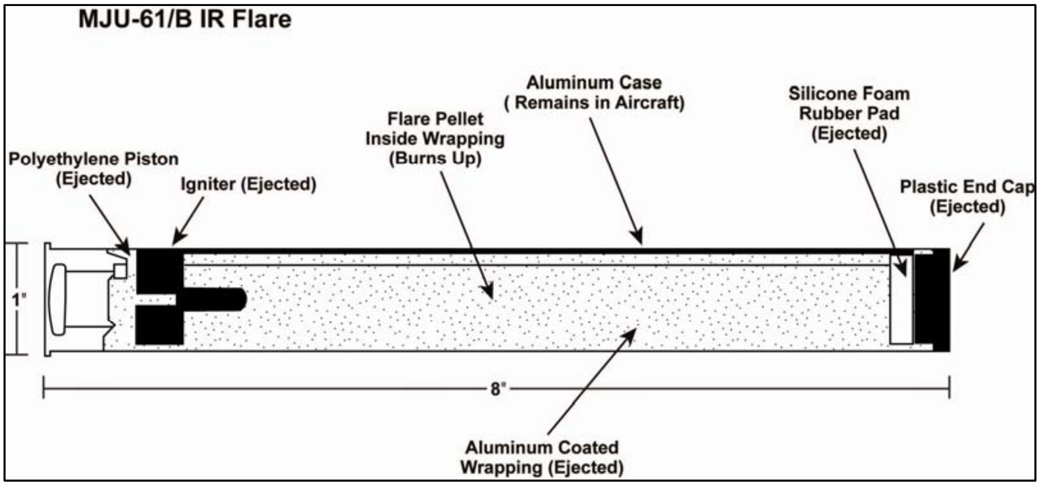


Figure 7–10. MJ61/B Flare

The MJU-62/B flare is approximately 2 inches x 1 inch x 8 inches long (Figure 7–11). The MJU-62/B flare has the same features as the MJU-7A/AB flare. After a flare is deployed, residual materials fall to the ground.

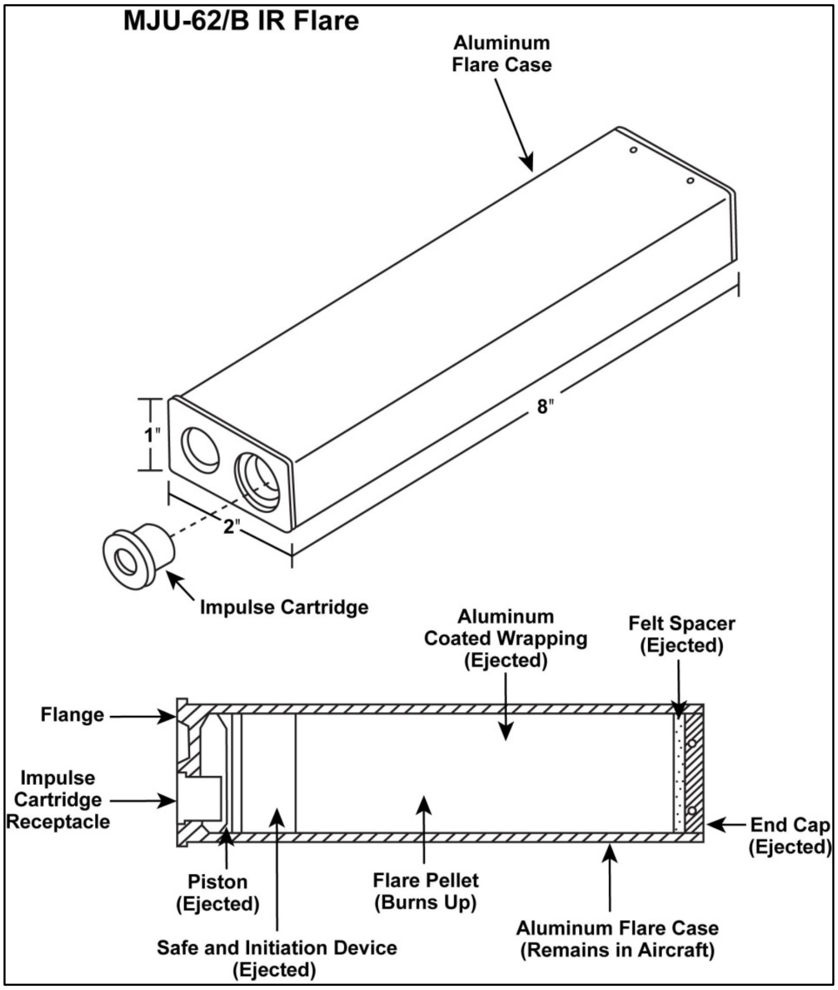


Figure 7–11. MJ62/B Flare

Table 7-4 compares the residual materials deposited on the ground following deployment of each MJU-61/B, MJU-62/B, M-206, and MJU-7A/AB flare.

Table 7-4. Residual Material Deposited on the Ground Following Deployment of One Flare

Material	Disposition	Flare Type			
		M-206	MJU-61/B	MJU-7A/B	MJU-62/B
Flare Case	Aluminum, remains in aircraft	1 inch x 1 inch x 8 inches	1 inch x 1 inch x 8 inches	2 inches x 1 inch x 8 inches	2 inches x 1 inch x 8 inches
Flare Insert	Burns when deployed	Magnesium, Teflon	Magnesium, Teflon	Magnesium, Teflon	Magnesium, Teflon
End Cap/Pad	Deposited on the ground	One 1 inch x 1 inch x 1/8 inch plastic or nylon; one same sized silicone foam pad	One 1 inch x 1 inch x 1/8 inch plastic or nylon; one same sized silicone foam pad	One 2 inches x 1 inch x 1/8 inch plastic or nylon; one same sized silicone foam pad	One 2 inches x 1 inch x 1/8 inch plastic or nylon; one same sized silicone foam pad
Piston	Deposited on the ground	One 1 inch x 1 inch x 1/2 inch nylon/plastic	One 1 inch x 1 inch x 1/2 inch nylon/plastic	One 2 inches x 1 inch x 1/2 inch nylon/plastic	One 2 inches x 1 inch x 1/2 inch nylon/plastic
Flare/Body Wrapping	Deposited on the ground	One up to 2 inches x 17 inches piece of graphite fabric stiff duct-tape type material	One up to 2 inches x 17 inches piece of graphite fabric stiff duct-tape type material	One up to 3 inches x 17 inches piece of graphite fabric stiff duct-tape type material	One up to 3 inches x 17 inches piece of graphite fabric stiff duct-tape type material
S&I Device	Deposited on the ground	None	One 1 inch x 1 inch x 1/2 inch plastic/spring device	One 2 inches x 1 inch x 1/2 inch plastic/spring device	One 2 inches x 1 inch x 1/2 inch plastic/spring device

7.1.7 MJU-68/B and MJU-69/B Flares

The MJU-68/B and MJU-69/B flares are similar to the MJU-10/B flares presented in Section 7.1.3. Each of the MJU-68/B and MJU-69/B flares has a cross-section approximately 1.5 inches x 1.5 inches x 10.5 inches long. Each flare is enclosed in an aluminum case that remains in the aircraft. The exit end of the MJU-68/B or MJU-69/B flare is closed with a sealed aluminum end cap followed by a copper tungsten nose. The internal flare assembly is a graphite fabric/phenolic resin flare wrapper around the magnesium flare that is comparable to the MJU-10/B flare. The components of the MJU-68/B and MJU-69/B flares and the flare ignition device are presented in Table 7-5. The MJU-68/B and MJU-69/B flares have a sequencer assembly (comparable to an S&I device) with an ignition pellet behind the flare assembly and a piston/backerplate assembly located behind the S&I device. The MJU-69/B has all the components of the MJU-68/B flare with the addition of a stainless steel shim positioned between the S&I device and the piston. The impulse cartridge is inserted into the backerplate for the flares.

Table 7-5. Components of F-35A Flares and Flare Ignition Devices

Pyrotechnic Components	MJU-68/B		MJU-69/B	
	Ingredient	Weight	Ingredient	Weight
1) Flare Insert	Magnesium Powder	210.6 g/0.46 lbs	Magnesium Powder	177.6 g/0.39 lbs
	Teflon Resin		Teflon Resin	
	Viton		RTV615	
			Ammonium Perchlorate	
			Potassium Perchlorate	
			Atomized Aluminum Powder	
			RDX	
2) Ignition & Intermediate Compositions	Magnesium Powder	3.0 g/0.0066 lbs	Magnesium Powder	3.0 g/0.0066 lbs
	Teflon Resin		Teflon Resin	
	Viton		Viton	
3) Sequencer Pellet	Magnesium Powder	0.31 g/0.00068 lbs	Magnesium Powder	0.31 g/0.00068 lbs
	Teflon Resin		Teflon Resin	
	Viton		Viton	
Totals		**214 g/0.472 lbs**		**181 g/0.40 lbs**

Key:

g = grams	lbs = pounds

7.1.8 Other Flares

Navy defensive flares are also used (where approved) for training in Air Force-managed training airspace. The MJU-8A/B is an example of a Navy flare. The MJU-8A/B is 5.8 inches long and 1.42 inches in diameter. It looks like a 1/2 scale MJU-23/B flare. MJU-8A/B materials are similar to Air Force flares, except the end cap is aluminum instead of plastic. A small aluminum cap (less than 1.5 inches in diameter) is used to contain the igniter composition and the inside diameter of the case forms a positive piston stop. This results in the piston not being ejected. Residual materials include the nearly 1 1/2-inch diameter aluminum end cap, one felt spacer of the same size, a S&I device, and an up to 12 inches x 2 1/4 inch piece of aluminum-coated duct tape-type wrapping material.

Other Navy flares and flares of other participating aircraft have comparable components to the flare types described for Air Force use. Other flares produce a similar number of residual pieces, which settle on the surface following deployment during training.

Flare technology is continuing to advance. Figure 7–12 compares developing approaches to new flares with the M-206 flare. The M-211 is the same size as an M-206 flare and uses silicon wafer-type materials to create an infrared signature without a visual signature. This is especially useful for night combat. Another new flare, also the size of an M-206 flare, is the M-212 flare. The M-212 flare is being developed to respond to increasingly sophisticated targeting devices on missiles. Next generation heat-seeking missiles may be programmed to the signature of the aircraft the missile is targeting. Flares that do not present the programmed signature could be ignored by the missile. The M-212 flare could be programmed to replicate the signature of the aircraft using the flare and this defensive signature could successfully deter the attack of sophisticated missiles. Residual materials and potential environmental effects of these and other new flares have not yet been identified.

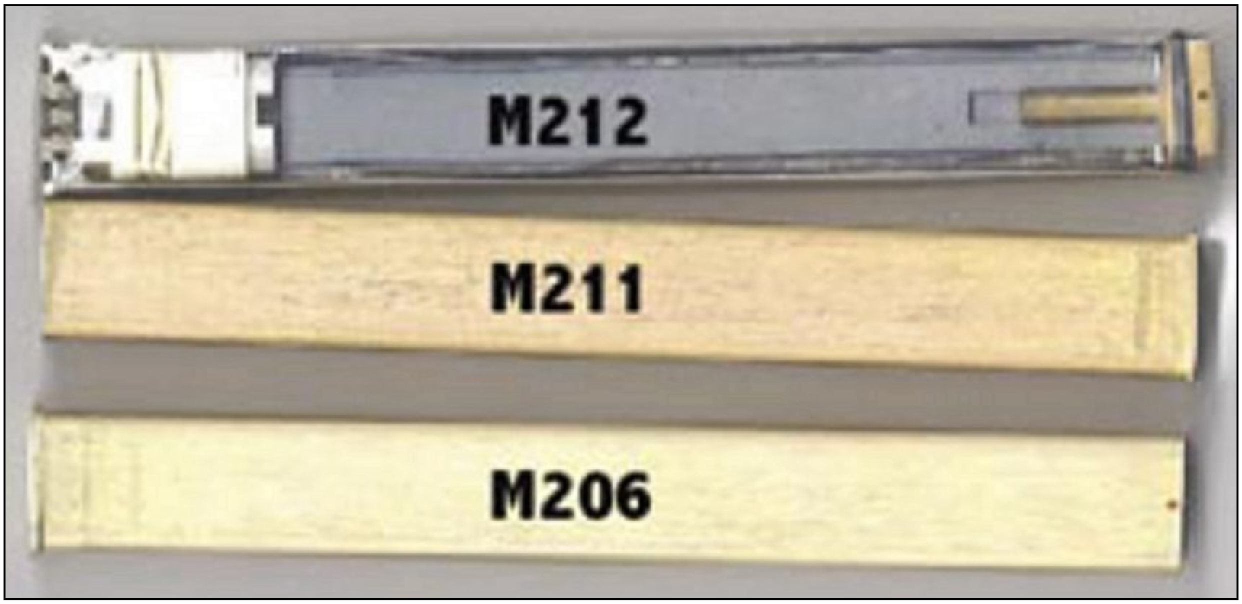


Figure 7–12. M-211 and M-212 Flares Developed to Respond to New Threats with M-206 Flare for Reference

7.2 Flare Ejection and Reliability

Flares are loaded into the aircraft at the base. When a flare is deployed, an electrical charge ignites the impulse cartridge. Hot gas from the impulse cartridge ignites the ignition pellet, pushes the piston, and ejects the end cap, flare assembly, and S&I device. As the flare assembly slides out the aluminum case, the S&I device prevents hot gasses from the ignition pellet from reaching the flare until the flare assembly exits the case. As the flare assembly exits the case, the S&I sliders spring out to allow hot gasses from the ignition pellet to ignite the ejecting flare pellet to produce the required infrared decoy image. All of this, from the electrical charge to the deployed burning flare, happens in less than one second. The flare is safe during all normal handling operations since the ignition pellet requires movement of the S&I sliders before flare ignition can occur.

7.2.1 Flare Reliability

Flare reliability is critical since a flare failure could have a catastrophic effect on a targeted aircraft. Reliability is determined by testing the flares after manufacture. The reliability test examines the success of ignition and burn, pellet breakup, and indication of dispenser damage.

The flare procurement specifications require that a flare-manufactured lot of several thousand flares pass the ignition and ejection test where a random sample of 80 flares is drawn from the manufactured lot of several thousand flares. The 80 flares are tested, and a failure of one or two flares would be acceptable, but three malfunctioning flares out of the 80 would result in the entire flare manufactured lot being rejected (Air Force 1997). To ensure that good lots are not erroneously rejected in these tests, the flares would have to be designed and manufactured to a reliability of 99 percent (assuming a confidence level of 95 percent). Therefore, the reliability of the flares is expected to be approximately 99 percent to avoid rejection of the entire lot. Lot acceptance testing for flares is the same for flares discussed in Section 7.1. This 99 percent level of reliability is reasonable when the purpose of the flare is taken into consideration. A flare is designed to protect life and a multi-million dollar investment.

7.2.2 Improper Flare Functioning

Improper flare functioning could occur in approximately one percent of the flares. Improper flare functioning is defined in one of four ways.

1. A flare was electrically triggered but did not release and did not burn. Such a flare would be treated as Unexploded Ordnance (UXO) when the aircraft returned to the base and the unused flare would be removed for disposal.
2. A flare burned, but did not release from the aircraft. This would be an extremely dangerous situation for the pilot. There is only one recorded case of this occurring. In 1980, an F-102 fighter aircraft was destroyed and the pilot ejected. Reliability of flare ignition and deployment has been substantially improved since 1980.
3. A flare that is released at too low an altitude or that did not burn correctly. If a burning flare struck the ground, it could result in a fire, with potential environmental consequences. The design, manufacturing, and testing process makes it extremely unlikely that a flare would burn for a period of time substantially longer than required for the decoy purpose. Pilots have been known to release a flare accidentally at too low an altitude when training during simulated combat conditions. A still burning flare has the potential to start a fire under the airspace.
4. A dud flare where the flare was released from the aircraft but did not burn, either in whole or in part, and became a dud flare on the ground. If an unburned broken or whole flare struck the ground, it would not burn unless subject to temperatures or friction generating temperatures in the one to two thousand degree range. A dud flare could potentially land either on or off military-controlled land. Military-controlled land includes the base airfield where, at times, an unburned flare (the first type of failure) is jolted out of its container during a landing and becomes a dud flare (the fourth type of failure) on or adjacent to the runway. Military-controlled land also includes training ranges over which flares are deployed. Non-military controlled land includes lands managed by other governmental agencies and private lands.

The first two cases of an improperly functioning flare would be a base UXO or a safety issue. The third and fourth cases of an improperly functioning flare would be environmental issues, with effects on non-military controlled lands potentially affecting the public or managing agencies.

7.2.3 Fire Risk

Effective use of flares in combat requires frequent training by aircrews to master the timing of deployment and the capabilities of the defensive countermeasure and by ground crews to ensure safe and efficient handling of flares. Defensive countermeasures deployment in authorized airspace is governed by a series of regulations based on safety, environmental considerations, and defensive countermeasures limitations. These regulations establish procedures governing the use of flares over ranges, other government-owned and -controlled lands, and nongovernment-owned or -controlled areas. Flares are used only in approved airspace at altitudes designated for the airspace. Flares burn out within approximately 500 feet, so altitude restrictions in special use airspace are established to ensure flare burnout before a flare reaches the surface under the training airspace.

Fire risk associated with flares stems from an unlikely, but possible, scenario of a flare reaching the ground or vegetation while still burning. If a flare struck the ground while still burning, it could ignite surface material and cause a fire. This has occurred at active military training ranges where flare- or munitions-caused fires are documented. In all known cases, the flares burning when they struck the ground were released at a very low altitude due to pilot error. On active military ranges, firebreaks are established to reduce the risk of fires spreading off the range. The approved altitude from which flares are dropped is regulated by the airspace manager and is based on a number of factors including flare burnout rate. The vertical flare burn out rate is calculated as follows:

$$D = (Vo * T) + [0.5 * (A * T^2)]$$

Where:

D = Distance
Vo = Initial Velocity = 0
T = Time (in Seconds)
A = Acceleration

Table 7-6 presents theoretical burnout rates assuming no aerodynamic drag. Defensive flares typically burn out in 3.5 to 5 seconds, during which time the flare will fall between 200 and 400 feet. Specific defensive flare burnout rates are classified. Table 7-6 for flare burn-out rates is based on conditions that assume zero aerodynamic drag and a constant acceleration rate of 32.2 ft per second (ACC 2010).

Table 7-6. Flare Burn-Out Rate and Distance

Time (in seconds)	Acceleration	Distance (in feet)
0.5	32.2	4.025
1.0	32.2	16.100
1.5	32.2	36.225
2.0	32.2	64.400
2.5	32.2	100.625
3.0	32.2	144.900
3.5	32.2	197.225
4.0	32.2	257.600
4.5	32.2	326.025
5.0	32.2	402.500
5.5	32.2	487.025
6.0	32.2	579.600
6.5	32.2	680.225
7.0	32.2	788.900
7.5	32.2	905.625
8.0	32.2	1030.400
8.5	32.2	1163.225
9.0	32.2	1304.100
9.5	32.2	1453.025
10.0	32.2	1610.000

The best way to reduce the risk of flare-caused fires is to establish and enforce minimum altitudes for flare release. In eight seconds, a flare would fall approximately 1,000 feet, assuming there was no wind resistance. Since there is wind resistance, the 1,000-foot fall distance is greater than would actually be expected. A defensive flare is designed to burn out within approximately 500 ft of deployment. If flares were deployed at a minimum altitude of 1,000 ft above the ground, the likelihood of a flare-caused fire would be low. In areas where flares are used within training airspace over public or private lands, the minimum altitude for flare deployment is typically designated above 2,000 ft AGL. Restrictions on flare use based on fire conditions may be established by MAJCOM policy or be based on airspace conditions.

7.2.4 Dud Flares

The fourth type of flare failure is a dud flare on the ground. A dud flare on nonmilitary land, either public or private, has the potential to produce environmental consequences. U.S. military training ranges where flares are used were contacted to estimate the potential for locating a dud flare on the ground. The military has personnel experienced with UXO who survey military ranges to identify and remove live ordnance or dud flares. Experience from the Goldwater Range in Arizona and the UTTR identified very few dud flares on the ground. The surveys were not scientific studies that evaluated the entire military training ranges, but did survey areas within which 95 to 99 percent of the UXO would be expected. In areas where approximately 200,000 flares had been deployed, an estimated 18 duds were found on the ground. This calculates to a ratio of approximately 1 in 10,000.

There is no instance of a dud flare or any flare residual materials striking an individual. A dud M-206 flare, the small flare in this report, would be an approximately 3/4 pound piece of material falling at a speed of over 100 miles per hour. It is extremely unlikely that an individual could be struck by such a falling object, but if someone were, it could cause severe injury or death. Dud flares are extremely rare, but they are dangerous.

Very few dud flares would be expected on the ground so it is likely that very few would actually be found. Any located dud flare should be treated as UXO. Figure 7–13 shows approximately 40 percent of an M-206 flare and wrapping that did not burn. Apparently, during deployment, the M-206 flare pellet broke before it was completely ignited and the unburned portion was deposited on the military training range. A dud flare would probably not ignite even in a campfire unless it was on a very hot bed of coals. If a dud flare were shot with a bullet or cut with a power saw, the friction could cause it to ignite. If a dud flare were struck by an ax, it is unlikely, but possible, that an ignition could occur. Should a flare be ignited, it would burn at a temperature of 2,000 °F and could result in severe injury or death.

In rare cases, if a dud flare or some of the materials from a burned flare reach the ground, the components that have any potential to affect soil and water chemistry are minute quantities of chromium, magnesium, aluminum, boron, and barium.

Magnesium and boron showed levels in sufficient concentrations for further evaluation in field and laboratory tests on flares (Air Force 1997). Magnesium is an essential nutrient often found in nuts, seafood, and cereals and is a principal component of chlorophyll. Only in extremely large quantities can magnesium affect water properties. Given the number, dispersal, and reliability of flares, accumulations of such levels would be impossible. Boron is both an essential and toxic element for plants. While large quantities of boron can be toxic under certain conditions, the quantities from flare combustion (less than 0.5 gram) are too small to have a toxic effect (Air Force 1997).

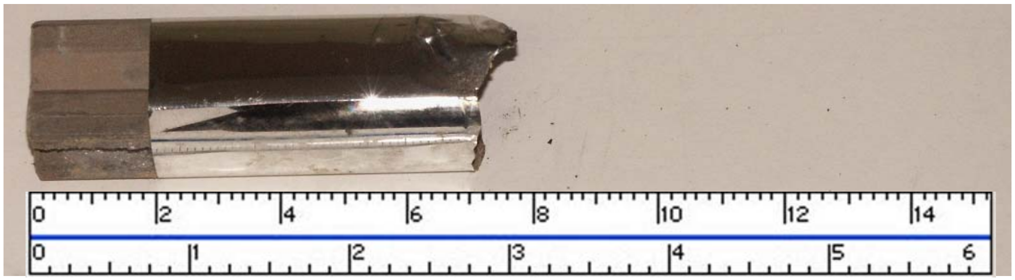


Figure 7–13. Approximately 40 Percent of an M-206 Dud Flare

The primary environmental message for anyone finding a dud flare (an extremely unlikely event) is to mark its location and notify the local fire department or the base Public Affairs Office. The likelihood of finding a dud flare is extremely remote and the likelihood of a dud flare igniting is even more remote, but since there could be dud flares on the ground under a training airspace, someone has the potential to find one.

The number of dud flares on the ground is few. If a dud flare fell in a water body, it would deteriorate over time. The chemicals released during deterioration would not be expected to be of sufficient quantity to cause a noticeable reduction in the water quality or impact on marine resources.

8.0 FLARE ENVIRONMENTAL ISSUES RAISED BY THE PUBLIC AND AGENCIES

Public and agency reviewers of environmental documents have questioned the effects of flares on humans, wildlife, livestock, other agricultural operations, or economic activities. Representative questions, which have been asked include:

- What would be the visual effects from flare residual materials?
- What are the effects of flares on ranching and other economic activities?
- Would flares affect water and soil?
- What are the risks to animals from ingesting flare residual materials?
- What are the frequency and amount of flare drops over Tribal lands?
- Could flare use create airborne FOD hazards?
- Could flare residual materials impact the economic value of wool?
- Would flare residual materials affect birthing animals?
- Will flare use be distributed evenly throughout airspace, or will it be concentrated within routine training routes?
- Can the number of flares deployed be quantified?
- How does the use of flares affect air quality?
- Will flare use impact important species, such as the sage grouse?
- Can flare use be limited to winter months to avoid the peak fire season?
- What are the near-term and long-term impacts from flare use?
- What are the fire risks from flares?
- Will the Air Force provide flare education to fire investigators?
- What is the safety risk from a dud flare igniting due to ground disturbing activity such as plowing or construction excavation?

This section incorporates the results from Section 7.0 and applies the information to respond to the representative questions. Section 9.0 provides conclusions and specific responses to the representative questions listed above.

8.1 Fire

Wildfires from any cause can impact human investments, animals, and wildlife and fire of any cause is a serious concern. Flare initiated fires would not be expected to occur although the use of flares can minimally increase fire risk. Any fires of a natural or non-natural source may adversely affect vegetation, injure wildlife or livestock, and destroy property such as fences or buildings.

A wildland fire would result in a loss of canopy and/or understory vegetation, depending on the severity of the fire, land condition at the time, and if and how soon fire control can respond. Recovery of the vegetation would depend on the plant species burned, season, and severity. Vegetation types such as grasslands naturally have a frequent fire regime, and therefore are composed of species that can recover quickly from fires. Woodlands and shrubland communities recover over longer periods depending on severity of the fire and climatic conditions (especially precipitation and temperature regimes) available following a fire. Fires also create a loss of plant cover and could increase erosion and sedimentation downslope in some areas. Bare ground resulting from fires can allow the spread of invasive non-native plant species such as annual grasses (e.g., cheatgrass) depending on the nature of the vegetation burned and the presence of invasive species in surrounding areas. Post-fire conditions of erosion, sedimentation, or invasion of non-native species are generally unfavorable for wildlife and reduce productively of habitats to support species.

A wildland fire may result in direct effects on wildlife and livestock including displacement from important habitat or range. The degree of effect varies by the severity of the fire, the season of the fire, and the type of habitat that was burned. Fires temporarily decrease available cover and foraging habitat and fires started during breeding season could adversely affect ground nesting birds and interrupt breeding rituals for resident species.

One public ranching concern is any potential for flare-caused fires. Fire damages crops, rangelands, timber, and/or ranch infrastructure. National grasslands, forests, and agricultural areas under the airspace are vulnerable to fire. Altitude restrictions on flare release are designed to ensuree flares burn out well above the ground surface (AFRC 1999; Air Force 2006). Flare use could be discontinued in specified fire danger conditions. The possibility of a flare-caused fire is remote although there are cases of pilot error where flares were deployed at too low an altitude. Any potential loss of forage, livestock, or infrastructure due to fire could result in economic impacts to affected landowners. The Air Force follows established procedures for claims in the unlikely event that an Air Force-caused fire should occur and subsequently damage livestock or infrastructure.

8.2 Dud Flares

The probability of an intact dud flare falling to the ground during training is estimated to be 1/10,000, or extremely low as described in Section 7.2.4. The probability of an intact flare falling into an aquatic system is much smaller. If this event did occur, there would be minimal to no effects of the metallic magnesium from the flare on the wetland. Magnesium is already a significant natural component of Earth and the amount from a flare would be comparably insignificant (Air Force 1997). Due to the low concentrations of flare residue and the extremely low probability of flare residue coming in contact with wildlife, flare releases are expected to have minimal and less than significant effects on wildlife. No effect of flares on water quality would be expected.

A dud flare requires a 1,000 to 2,000 °F heat source to cause it to ignite. If a dud flare were on the ground and a grass fire swept over the flare, the temperature likely would not be sufficient to ignite the flare. Friction, such as from a power saw, could ignite a flare and cause a serious potential for injury or death to the individual sawing the flare. A bullet could have similar effect to the friction from a power saw. It is unlikely that agricultural equipment would be able to create either the temperature required or the level of friction comparable to that of a power saw. The likelihood of a dud flare being located on the ground is extremely remote. An estimated two dud flares per year over a 2,000 square mile area would be expected using the assumptions in Section 8.4. A dud flare should not be handled and safety personnel should be notified in the extremely unlikely event that a dud flare found.

8.3 Flare Residual Materials

Questions have been raised regarding flare materials that are not consumed during the flare burn and are deposited on the surface following flare deployment. Unlike a dud flare, which is projected to be approximately a 1 in 10,000 event, residual flare materials are deposited on the surface after each flare deployment. Table 8-1 presents the residual materials from representative flares. These residual materials have been located on military ranges and public or private property beneath training airspace.

Table 8-1. Residual Material Deposited on the Surface Following Deployment of One Flare

Material/Geometry	Flare Type			
	M-206	MJU-7/B	MJU-10/B	MJU-23/B
End Cap/ Rectangular Plate	One 1 inch x 1 inch x 1/4 inch plastic or nylon	One 2 inch x 1 inch x 1/4 inch plastic or nylon	One 2 inch x 2 inch x 1/4 inch plastic or nylon	One 2 3/4 inch diameter x 1/4 inch thick round plastic disc
Piston/ Rectangular Open	One 1 inch x 1 inch x 1/2 inch plastic or nylon	One 2 inch x 1 inch x 1/2 inch plastic or nylon	One 2 inch x 2 inch x 1/2 inch plastic or nylon	One approximately 2 3/4 inch diameter x 1/2 inch aluminum (or plastic) piston
Spacer/ Rectangular Piece	One or two 1 inch x 1 inch felt	One or two 2 inch x 1 inch felt	One or two 2 inch x 2 inch felt	One 1/2 inch thick x 2 3/4 inch diameter rubber shock absorber sealant, two (1/8 inch x 2 3/4 inch diameter) felt discs, up to four 1 inch x 10 inch felt strips
Wrapping/ Rectangular Open	One up to 2 inch x 17 inch piece of aluminum-coated stiff duct-tape type material	One up to 3 inch x 17 inch piece of aluminum-coated stiff duct-tape type material	One up to 4 inch x 17 inch piece of aluminum-coated stiff duct-tape type material	One up to 4 1/2 inch x 20 inch piece of aluminum-coated stiff duct-tape type material
S&I Device/ Rectangular Solid	N/A	One 2 inch x 1 inch x 1/2 inch nylon and plastic spring device	One 2 inch x 1 inch x 1/2 inch nylon and plastic spring device	One 2 inch x 1 inch x 1/2 inch nylon and plastic spring device

Figure 8–1 presents two residual wrappings from MJU-7A/B flares with a pen for scale.

Figure 8–1. MJU-7 Residual Flare Wrapping Materials

Figure 8–2 includes wrapping material with burned wrapping fiber and four end caps from MJU-7A/B flares deployed over private ranch property. On military training ranges where large numbers of flares were deployed in a relatively small area, there were parts of munitions and flare residual materials on the ground, but the inert materials had not been identified as coming from flares (ACC 2006). Flare materials were identified to range workers to locate flare residual materials.

Figure 8–2. MJU-7 End Caps (Red) and Wrapping Material

The workers located a variety of residual materials including the materials pictured in Figure 8–3 and Figure 8–4. Figure 8–3 is the piston or nylon slider assembly from an M-206 flare. The burn occurs very quickly and parts, such as portion of the wrapping material in Figure 8–4, may not be consumed. Plastic pieces and wrapping material are not a risk, but they can be viewed as an annoyance by anyone finding a piece on public or private land under airspace assessed for flare use (ACC 2007).

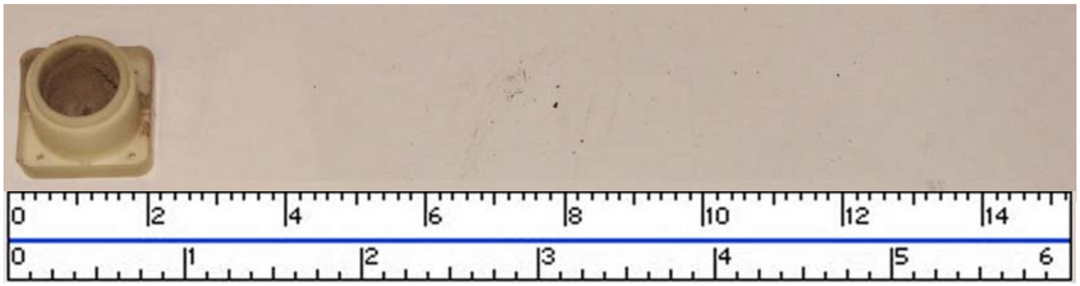


Figure 8–3. M-206 Piston

Figure 8–4. An M-206 Flare Wrapper Partially Covered by Pine Needles

Flare residual materials observed during field surveys conducted on two Air Force ranges included plastic end caps; foil wrappers, and plastic parts. No dud flares were found although they are known to occur (Air Force 1997). The field studies were on Air Force ranges where flares had been used for decades. An additional survey at Poinsett Electronic Combat Ranges (ECR) identified end caps, foil wrappers, and two S&I devices(Figure 8–5) with some melted fibers from the wrapping material attached, and a piston (Figure 8–3).

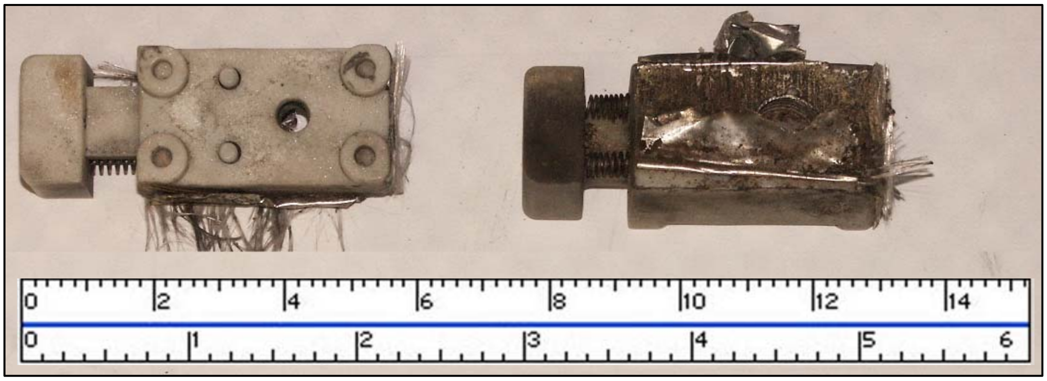


Figure 8–5. Two Safe and Initiation (S&I) Devices Used in MJU-7/B, MJU-10/B, and Other Flare Types

Residual materials from flares have only recently become a factor in environmental analysis since the materials are inert and the concern about potential impacts from fire overshadowed the residual materials. In addition, the different entities responsible for flares did not have responsibility for such residual materials that resulted from flare use. The manufacturer produced the flare, and, if the flare ejected properly and burned the prescribed time, it was a successful burn. The manufacturer was not responsible for residual materials that fell to the ground when the flare was deployed. The UXO personnel who surveyed the land on military ranges for UXO were looking for flares that had not burned or for dud flares, not for any inert residual materials that came from the flares.

Table 8-1 presents residual materials for several flares considered in this report. Table 8-2 compares residual materials from the MJU-10/B, MJU-68/B, and MJU-69/B flares. For each flare type, the wrapper may be partially consumed during ignition so the wrapping residual material could range in size from the smallest size, 1 inch x 1 inch, to the largest size, 4 inches x 13 inches. The size of the residual wrapping material depends on the amount of combustion that occurred as the flare was deployed. Even a parasitic M-206 flare may not consume the aluminum-coated Mylar wrapping around the flare pellet.

Table 8-2. Residual Material Following Deployment of One MJU-10/B, MJU-68/B, or MJU-69/B Flare

Material	Disposition	Flare Type		
		MJU-10/B	MJU-68/B	MJU-69/B
Flare Case	Aluminum, remains in aircraft	2 inch by 2 inch by 8 inch	1.55 inch by 1.55 inch by 10.5 inch	1.55 inch by 1.55 inch by 10.5 inch
Flare Insert	Burns when deployed	Magnesium, Teflon	Magnesium, Teflon	Magnesium, Teflon
End Cap/Nose	Deposited on the surface	One 2 inch x 2 inch x 0.25 inch plastic or nylon	One 1.5 inch x 1.5 inch x 0.25 inch copper; one 1.5 inch x 1.5 inch x 0.05 inch aluminum	One 1.5 inch x 1.5 inch x 0.25 inch copper; one 1.5 inch x 1.5 inch x 0.05 inch aluminum
Piston/ Backerplate	Deposited on the surface	One 2 inch x 2 inch x 0.5 inch nylon/plastic	One 1.5 inch x 1.5 inch x 0.25 inch nylon/plastic	One 1.5 inch x 1.5 inch x 0.25 inch nylon/plastic
Spacer/Mount/ Shim Housing Adapter	Deposited on the surface	One or two 2 inch x 2 inch felt	One 1.5 inch x 1.5 inch felt; one 1.5 inch by 1.5 inch stainless steel housing adapter	One 1.5 inch x 1.5 inch felt; one 1.5 inch by 1.5 inch stainless steel shim; one 1.5 inch by 1.5 inch stainless steel housing adapter
Flare/Body Wrapping	Deposited on the surface	One up to 4 inch x 17 inch piece of aluminum-coated stiff duct-tape type material	One up to 3 inch x 17 inch piece of graphite fabric stiff duct-tape type material	One up to 3 inch x 17 inch piece of graphite fabric stiff duct-tape type material
Sequencer/ Initiation (S&I) Device	Deposited on the surface	One 2 inch x 1 inch x 0.5 inch plastic and steel spring device	One 1.5 inch x 1.5 inch x 0.5 inch plastic and steel spring device	One 1.5 inch x 1.5 inch x 0.5 inch plastic and steel spring device

Figure 8–4 is an example of an M-206 flare wrapper on the ground. To the untrained eye, as the wrapping material weathers, the wrapper may have the appearance of a natural object, such as the stick in the foreground of Figure 8–4. These dropped objects are extremely unlikely to pose a risk of injury or environmental damage, but the materials would fall to the ground under airspace where such flares are used in training. The effects of these residual pieces on ranch or agricultural operations would be as described in Section 5.4.3 for chaff residual plastic pieces. The residual flare wrapper would be expected to be seen as an undesirable object in the environment. The effects of these residual pieces on cultural or Native American resources would be a described in Section 5.4.5 for chaff residual materials. No significant impacts would be anticipated, although individuals finding and identifying these pieces could express annoyance with the residual flare materials.

The plastic pistons, end caps, and S&I devices are inert and are not expected to decompose. They would not be expected to impact soil resources, but the visual effect of such manmade objects could affect recreational areas or waters. The felt spacers would decompose over time. The aluminum wrapping materials would also decompose over a much longer period. Flare residual materials would not be expected to discernibly or measurably affect water or soil resources.

Most of the residual flare materials shown in Table 8-2 have surface area to weight ratios that would not produce an impact when the residual flare material struck the surface. For example, the end caps and pistons of an M-206 flare have the same dimensions and a similar weight to the piston and end cap of RR-188/AL chaff described in Section 5.6. The end caps and pistons fall with the force of a small hailstone. The items that could fall with enough force to impact an object on the ground are the plastic and steel spring S&I device found in most flares and the copper nose in the MJU-68/B and MJU-69/B flares.

The weight of flare residual materials is of interest to assess whether the materials represent a safety risk. Weights of residual components for representative flares are presented in Table 8-3. The flare wrapping materials have a high surface-to-weight ratio and do not fall with much force. The MJU-68/B and MJU-69/B flares have the heaviest residual piece of material in the 1.4-ounce copper nose. The heaviest residual component of most other flares is the S&I device, which weighs approximately .08 ounces.

Table 8-3. M-206, MJU-7A/B, MJU-10/B, and MJU-68/B Component Weights

Component	Estimated Weight			
	M-206	MJU-7A/B	MJU-10/B	MJU-68/B
End cap (plastic)	0.0061 lbs	0.0072 lbs	0.0144 lbs	0.0144 lbs
Piston and cushion assembly (plastic of nylon)	0.0043 lbs	N/A	N/A	N/A
S&I device	N/A	0.0453 lbs	0.0453 lbs	0.0525 lbs
Piston (plastic or nylon)	N/A	0.0072 lbs	0.0144 lbs	0.0144 lbs
Felt spacer	0.0007 lbs	0.0011 lbs	0.0025 lbs	N/A
Wrapper	0.0215 lbs (2 in x 13 in)	0.0322 lbs (3 in x 13 in)	0.0430 lbs (4 in x 13 in)	0.0430 lbs (3 in x 17 in)
Nose	N/A	N/A	N/A	0.09 lbs

Key: in = inch lbs = pounds N/A = Not Applicable.

8.4 Safety Risks

When an object separates from an aircraft in flight, numerous physical factors act on the object and influence the force that the object strikes the ground. These factors include the size, shape, and weight of the object, as well as other aerodynamic forces that act on the object as it falls through the air.

When an object is dropped, it is subjected to the force of gravity where it enters free-fall toward the ground, which creates an acceleration of approximately 32.2 feet/sec^2. The object's shape influences the effect of aerodynamic drag forces exerted on it, which reduces the rate of acceleration to varying degrees such that after a period, the object is no longer accelerating and has reached a state referred to as *terminal velocity*. When terminal velocity is reached, the object would continue to fall at that velocity indefinitely. Once terminal velocity is known, the momentum (in pound-seconds) can be calculated. Momentum is the metric used to quantify the relative hazard associated with a falling object striking a person or property on the ground.

The likelihood of a strike to a person or object from a piece of flare residual material would depend on the number of flares deployed, the area under the airspace, the population density under the airspace, and the proportion of time a person would be expected to be outside.

This section calculates the likelihoods of a piece of flare residual material striking a person, a private structure, a vehicle, or range cattle under the set of assumptions in Table 8-4. The assumptions in Table 8-4 do not reflect a specific location. They were designed to reflect differences in training airspace, numbers of flares, and underlying population characteristics.

Table 8-4. Assumptions for Calculating Safety Risks

Area under training airspace authorized for flares	2,000 square miles [1]
Number of flares used annually	20,000
Population density per square mile	10 persons
Person exposure	10 percent of day out-of-doors and unprotected [2]
Persons per family	2.65
Structures per family [3]	2 (each surface area = 1500 square feet)
Vehicles per family	2 (each surface area = 100 square feet)
Range cattle per square mile	10 beef cattle

Notes:

[1] Assumes a Military Operations Area (MOA) over 2,000 square mile ground surface.
[2] McBride 2005; TVA 2003.
[3] The 3,000 square feet could include a house, garage, or other structure.

The potential risk of a residual component striking a particular object uses the same calculations as described in Section 5.6.2. The potential risks are postulated for the following:

- Striking the body of an unprotected individual: potential injury
- Striking private structures: potential damage
- Striking private vehicles: potential damage (potential injury if vehicle is moving)
- Striking range cattle: potential injury

Aircraft training flights are generally distributed randomly and uniformly within a training airspace (ACC 2010). Flare component release altitudes and angles of release are sufficiently random that ground impact locations of flare materials would be distributed uniformly under training airspace where flare use is authorized. For any particular residual component of a released flare, the conditional probability that it strikes a particular object is equal to the ratio of the object area to the total area of the airspace. For multiple objects (i.e. people, structures, vehicles, cattle), the probability of striking any one object is the ratio of the sum of object areas to the airspace. In this example, a 2,000 square mile MOA is used. The frequency of a residual component striking one of many objects is the frequency of releasing residual components times the conditional probability of striking one of the many objects per given release. In equation form, this relationship is:

$$\textit{Strike frequency} = \textit{component drop frequency in MOA x } \frac{\textit{area of object x number of objects in MOA}}{\textit{MOA (area)}}$$

8.4.1 Risk/Frequency Estimation

The frequency of each of the strike consequences is computed as the product of the frequency of releasing residual components with high momentum and the conditional probability of striking people, structures, vehicles, or other objects. These estimates are developed in the following paragraphs for the flare, piston, S&I device, and copper nose. The effect of the impact of a residual component from Table 8-3 is judged by computing the flare component's terminal velocity and momentum. Terminal Velocity (V_T) is calculated by the equation:

$$V_T = \left[\frac{2}{\rho}\left(\frac{W}{A \times C_d}\right)\right]^{0.5} = 29 \times \left(\frac{W}{A}\right)^{0.5}$$

Where: V_T = Terminal Velocity (in Feet/Second)
ρ = Nominal Air Density (2.378×10^{-3} lbs-sec^2/ft^4)
W = Weight (in Pounds)
A = Surface Area Facing the Air stream (in ft^2)
C_d = Drag Coefficient = 1.0

Drag coefficients are approximately 1.0 over a wide range of velocities and Reynolds numbers (Re) for irregular objects (e.g. non-spherical). Using this drag coefficient, the computed terminal velocities produce Re values within this range (Re < 2×105), which justifies the use of the drag coefficient.

The approximate weights and geometries of flare components with a surface to weight ratio that could potentially result in impact are presented in Table 8-3. The piston is included to represent components, including the end cap, which has high surface to weight ratios and would not be expected to fall to the ground with enough force to cause an impact greater than that of a small hailstone. The S&I device and the nose are components with surface to weight ratios that could result in an impact.

Terminal velocity momentums for the Table 8-3 components are computed based on maximum and minimum areas depending on the component's orientation. The component momentum is listed in Table 8-5. Actual values of momentum when striking the surface would typically be between the maximum and minimum terminal velocities. The momentum values are the product of mass (in slugs) and velocity. A slug is defined as the mass which, when acted on by a 1-pound force, is given an acceleration of 1.0 feet/sec^2.

Table 8-5. Flare Component Momentum

Component	Maximum Surface Area			Minimum Surface Area		
	Area (in^2)	Terminal Velocity (ft/sec)	Momentum (lb-sec)	Area (in^2)	Terminal Velocity (ft/sec)	Momentum (lb-sec)
Piston	1.65	23.0	0.005	0.413	46.0	0.02
End Cap	2.00	21.0	0.005	0.125	84.0	0.02
S&I device	1.65	58.0	0.087	0.413	115.0	0.15
Nose *	2.25	69.6	0.195	0.375	170.5	0.48

Note: Only on MJU-68/B or MJU-69/B.

Key:

ft/sec = feet per second

in^2 = square inches

lb/sec = pounds per second

Flare components, such as the piston, have weight to surface area characteristics that are not calculated to achieve a momentum, which could cause injury or damage. The piston and end cap would fall with the impact of a small hailstone (Section 5.6). The S&I device and especially the copper nose each has a calculated momentum that could cause injury or damage.

8.4.2 Estimated Areas of People, Structures, Vehicles, and Cattle

As explained in Section 5.6, people who are at risk of being struck by a flare residual component would be standing outdoors under a MOA (people in structures or vehicles are assumed protected). The dimensions of an average person are assumed to be approximately 5 feet 6 in high x 2 feet wide x 1 foot deep (men, 5 feet 10 inches; women, 5 feet 4 inches; children, less than 5 feet 4 inches). The residual flare device would be expected to strike ground objects at an angle of 80 degrees or greater to the ground, assuming 80 degrees to the ground allows for possible wind or other drift effects. With the flare component falling at 80 degrees to the ground, a person's body (5.5 × 2 × 1 feet) projects an area of 3.9 square feet normal to the path of the falling component. For this assessment, it is assumed that a person would be outdoors and unprotected 10 percent of the time. This assumption is based on Department of Energy and Environmental Protection Agency national studies (TVA 2003; Klepeis *et al.* 2001).

Structure and vehicle densities are estimated from the 2000 Bureau of the Census data. Based on these data, average family size in rural areas is 2.65 persons (Census 2000). The assumed ten persons per square mile equates to approximately 3.8 families per square mile. It is assumed that each family would have, or otherwise use, the equivalent of two structures associated with their property and own two vehicles, which would be outside the structures. Thus, it was assumed that there would be the equivalent of eight structures/mi^2 and eight vehicles/mi^2 under the training airspace.

It is assumed that range cattle density is ten cattle per square mile. In the arid west, the annual carrying capacity is more typically four to five range cattle per square mile. A cow-calf combination or range cattle is projected to have a surface area of 3 feet by 6 feet (18 square feet) and be unprotected 100 percent of the time (Bullock 2007).

8.4.3 Potential Person Strikes

The frequencies of strikes can be computed based on the data and assumptions discussed above. It is assumed that flight maneuvers to deploy flares are randomly distributed throughout the training airspace. Injury to a person could occur if an S&I or nose device struck an unprotected person. The frequency of striking a person is:

$$Injury\ frequency = comp\, drop\ freq \times \frac{body\, area \times pop.density \times Fract\, unprot \times MOA(areainsqmi)}{MOA(areainsqft)}$$

For the assumptions in Table 8-4, this calculates for either an S&I or a nose device to:

$$Strike\, frequency = 20{,}000/\,year \times 3.9\ ft^2\,/\,pers \times 10\, pers/mi^2 \times 0.1 \times 3.59 \times 10^{-8}\, mi^2\,/\,ft^2$$

= 0.003 strikes/year for an S&I or 0.003 strikes/year for a nose device (numbers are rounded).

In a representative rural area beneath a MOA used for pilot training, the annual expected person strike frequency would be three persons every 1,000 years for either device. The maximum momentum of the S&I device would vary between 0.087 and 0.16 pound-seconds depending on orientation of the falling S&I device. It is postulated that in this momentum range, an injury could be equivalent to a bruise from a large hailstone. Approximately 20 percent of strikes could be to the head, which could potentially be a more serious injury.

The maximum momentum of the nose device would vary between 0.195 and 0.477 pound-seconds, depending on orientation of the falling nose device. It is postulated that in this momentum range, an injury could be equivalent to being struck by a stack of five U.S. dollar coins. Such a strike could result in severe injury.

As a basis of comparison, laboratory experimentation in accident pathology indicates that, there is a less than a one percent probability of a brain concussion from an impulse of less than 0.10 pound-seconds to the head, and a 90 percent probability that brain concussions would result from an impulse of 0.70 pound-seconds to the head (Air Force 1997). A strike of an S&I device to the head has approximately a 1 percent probability of causing a concussion, but would not be expected to damage a structure. An S&I impact could cause a cosmetic dent to a vehicle and a strike to the windshield of a moving vehicle could result in an impact comparable to a stone kicked up by a truck tire.

The nose device with a potential impulse between 0.195 and 0.477 would have a 5 to 80 percent probability of causing a concussion. Cost and safety elements associated with the MJU-68/B and MJU-69/B flares restrict their use to test and validation over unmanned restricted areas or Warning Areas (HQ ACC/A3T0; 22 August 2011).

8.4.4 Potential Structure Strikes

The expected annual number of an S&I device striking structures is calculated as follows:

$$Sructure\, strike\ frequency = comp\, drop\ freq \times \frac{struct.area \times struct.density \times MOA(area)}{MOA(area)}$$

For the assumptions in Table 8-4, this calculates for an S&I device:

$$Structurestrike\, frequency = 20{,}000/\,year \times 1500\ ft^2\,/unit \times 8\, struct/mi^2 \times 3.59 \times 10^{-8}\, mi^2\,/\,ft^2$$

= 8.12 strikes to structures/year

The S&I device would be comparable to a large hailstone and would not be expected to damage a structure. If an S&I device struck a window at an angle, it would have the same effect as a large hailstone.

8.4.5 Potential Vehicle Strikes

The expected annual number of S&I devices that strikes a vehicle is calculated as follows:

$$Vehicle\ \ strike\ \ frequency\ = comp\ \ drop\ \ freq \times \frac{veh.area \times veh.density \ \times MOA\left(area\right)}{MOA\left(area\right)}$$

For the assumptions in Table 8-4, this calculates for an S&I device to the following:

$$Vehiclestrike\ frequency = 20{,}000 / year \times 100\ ft^2 / veh \times 8 veh / mi^2 \times 3.59 \times 10^{-8}\ mi^2 / ft^2$$

= 0.54 impacted vehicles/year (approximately one strike every two years, numbers are rounded).

A strike of an S&I device to a vehicle could cause a cosmetic dent or a chip in a windshield similar to a hailstone impact. Although not numerically estimated, a strike to a moving vehicle could result in a vehicle accident.

8.4.6 Potential Range Cattle Strikes

The expected annual number of S&I devices striking range cattle in a rural area are calculated as follows:

$$Rangecattle\ strike\ \ frequency = comp\ drop\ \ freq \times \frac{body\ area \times cattle\ density \times Fractunprot \times MOA\left(areainsqmi\right)}{MOA\left(areainsqft\right)}$$

For the assumptions in Table 8-4, this calculates for either an S&I or nose device striking a range cattle:

Range cattle strike frequency = 20,000/year x 18 ft^2*/individual x 10 individuals/*mi^2 *x 100 percent exposed x 3.59 x* 10^{-8} mi^2/ft^2 *= 0.129 per year (approximately 1 to 2 strikes in 10 years, numbers are rounded).*

A strike of an S&I device to range cattle would not be expected to cause an injury. It is important to note that the range cattle density in rural western areas over a year's time is approximately four to six cattle (or cow-calf combinations) per square mile (Bullock 2007). Range cattle potential strikes can be calculated for any number of individuals per mile by selecting an appropriate cattle density while specifying the airspace.

8.4.7 Potential Aircraft Strikes

Concern has been expressed during public meetings on for the environmental documents whether flare or chaff residual materials could impact a civilian aircraft during flight or on the ground. It would be extremely unlikely for an aircraft to somehow intersect or otherwise be struck by a falling piece of residual material from chaff or flare use. The density of civilian aircraft in and flying through an area would be estimated to be below one aircraft per 50 square miles, with an area of 200 square feet exposed not more than 10 percent of the time. The likelihood of an aircraft being struck by a piece the size of a hailstone of flare residual material would be approximately the same as the likelihood of an unprotected person being struck by a large hailstone sized piece of residual material, or three in 1,000 years. There has never been a recorded case of any aircraft being struck by a residual piece of a defensive countermeasure, even where extensive numbers of chaff and flares are deployed over military ranges during exercises involving multiple aircraft.

8.4.8 Summary of Impact Frequency

This risk assessment was performed to estimate the likelihood of a flare S&I device, piston, or end cap striking an unprotected person or property assuming 20,000 flares are deployed annually in airspace over a 2,000 square mile rural area. The results of the assessment are summarized in Table 8-6.

Table 8-6. Example Estimated Flare Residual Material Safe and Initiation (S&I) Strikes

Consequence Type	Expected Value Events/Year [1]		
	Piston or End Cap	S&I Device	Average Flare Piece
Persons Struck	0.006	0.003	0.009
Structures Struck	16.24	8.12	24.36
Vehicles Struck	1.082	0.541	1.633
Range Cattle Struck [2]	0.338	0.129	0.467

Notes:

[1] 20,000 flares deployed over 2,000 square mile Military Operations Area (MOA) with ten persons per square mile.

[2] Ten cattle per square mile.

The expected value or frequency presented in Table 8-6 is based on the same mathematics that occurs when a fair coin is flipped. The expected frequency of tails in ten coin flips per year is ten flips per year x 0.5 probability of tails per coin flip equals five expected tails per year. The conditional probability of one dropped flare component striking an object or a body is included in the Table 8-6 calculation. In our example, the probability of one S&I residual component striking a person is 0.00000015. The product of this probability and the drop frequency of 20,000 flares per year give the expected value of 0.003 strikes per residual S&I component per year. The expected strike values take into consideration the population density, area under the airspace, and the number of flares deployed.

The strike of flare end caps or pistons would be comparable to a small hailstone. An estimated six persons in 1,000 years are calculated to experience an end cap or piston strike. This type of strike would be noticed and would not result in injury, but could result in annoyance. The strike of an S&I device would be comparable to a large hailstone and could result in a bruise or, if it hit the head, there is approximately a 1 to 5 percent chance of a concussion. An estimated three persons in 1,000 years are calculated to experience an S&I device strike.

Other population densities and flare numbers could be used for an analysis. For example, if there were 10,000 flares deployed in a comparable rural area to that in Table 8-6, it would produce one-half the frequency of an S&I strike. If all the individuals under the airspace were in the open and unprotected 100 percent of the year (ten times the results from U.S. studies), there would be an annual ten times increase in the frequency of an S&I strike in Table 8-6, from six persons in 1,000 years to six persons in 100 years. This same approach can be used to calculate the potential for a strike to a sheep, assuming sheep have approximately one-third the surface area of range cattle. The strike probability would be one-third the cattle strike numbers in Table 8-6. So if there were 50 sheep per square mile (five times the number of range cattle) for the same flare and area assumptions, there would be approximately 0.215 expected S&I strikes to sheep per year.

Table 8-7 provides expected annual strikes for densities of 1, 10, and 40 persons per square mile under the same flare and area assumptions as used for Table 8-6. These various population densities demonstrate that the likelihood of an individual under training airspace being struck by a large hailstone potential injury-causing residual S&I device would range from fewer than two in 100 years to approximately three in 10,000 years, depending on density and other variables.

Table 8-7. Likelihood of Safe and Initiation (S&I) Annual Strike Value [1]

Persons Per Square Mile	Persons	Structure	Vehicle	Cattle [2]
1.0	0.0003	0.81	0.054	0.013
10.0	0.0030	8.12	0.541	0.129
40.0	0.0120	32.36	2.164	0.516

Note:

[1] Assumes 20,000 flares over 2,000 square miles per year, 2.65 family size, 10 percent exposure, two vehicles and two structures per family; range cattle density same as persons.

[2] Assumes same number of cattle per square mile as people

These estimated expected values have been computed as nominal values; they are not statistically biased in either a conservative or a non-conservative direction. These risk values are computed to support evaluations of the risks of annually using a specified number of flares with S&I devices in approved military training airspace of a specified area.

Residual components of the M-206 flare do not include an S&I device. The effects of 20,000 M-206 flares would be comparable to the piston and end cap column in Table 8-6. Some of the flare materials that fall to the surface after deployment are larger than an S&I device. Table 8-3 lists larger pieces from the MJU-10/B flare, including the end caps and wrapping. The surface to mass ratio of most of these pieces would not be expected to permit the pieces to achieve a terminal velocity as great as the S&I device. Some parts, such as the ALA-17A/B flare residual materials include the entire bottom cylinder assembly, as well as the end cap and felt spacers from the top flare. The residual materials from an ALA-17A/B flare could fall in an orientation where terminal velocity could produce a momentum in the 0.10 to 0.20 range. The relative low use of these flares reduces potential risk from the bottom cylinder assembly. ACC units are estimated to use fewer than 4,000 of these flares annually worldwide.

The expected frequency of an S&I device from an MJU-7A/B flare striking an exposed person is approximately three in 1,000 years. In rural areas, birds, small mammals, or reptiles would be more populous, be exposed ten times as much, but have 1/100th of the surface area as a human. Although a strike by an S&I device could have a comparable probability to the case of a human, a strike to a small bird or other small wildlife could produce a mortality. The relatively small likelihood, estimated at three to six in 1,000 years of such a strike, would not be expected to have any effect on populations of small species. If an S&I device struck a larger species, such as wild ungulates or farm animals, it could produce a bruise and a startle reaction. Such a strike from an S&I device would not be expected to seriously injure or otherwise significantly affect wildlife or domestic species.

8.5 Flare Emissions

Questions have been raised regarding flare emissions, including flare ash. Studies on ash components were performed by measuring residual materials after flares were ignited in a furnace (Air Force 1997). Constituents from combustion were identified and calculations were performed to determine under what conditions flare emissions or flare ash could result in an environmental impact.

The M-206 and MJU-7A/B flares do not contain lead although some earlier flares had lead in the firing mechanism and some flares still contain chromium in the firing mechanism. A statistical model was used to calculate emission concentrations of lead and chromium with the goal of learning what level of flare emissions or ash would be required to achieve toxic levels of lead or chromium. The model calculated that 1.5 million MJU-7A/B flares would have to be released below an altitude of 400 ft AGL over a 10,000-acre training range before the level of chromium emissions would become a health risk. Approximately 400,000 flares are deployed annually by ACC aircraft in all ACC training airspace approved for defensive flare training (Air Force 1997) No location has such a combination of flare numbers, altitude, and range area to produce any health risk. The number of flares is smaller, the minimum release altitude is higher, and the training area is substantially larger.

There are also trace elements of boron in the flare pellet. To achieve a toxic level of boron, flare ash from approximately 4,000 flares would need to fall on an acre of land annually. It would be impossible to deposit 4,000 flares on one acre of land. In fact, it would not be possible for a high performance military aircraft to purposefully deposit even one flare on a specific acre of land. Flare ash and flare emissions are not able to result in measurable air quality or physical effects to the environment.

The magnesium pellet of an MJU-10/B flare burns at approximately 2,000 °F. The combustion products from an MJU-10/B flare were analyzed in a report by the Tracor Company to the Aeronautical Systems Division (12 July 1978) as follows:

- Magnesium Oxide (MgO) - 51 grams (19.43 oz) - MgO is a naturally occurring mineral used for relief of heartburn and in industrial applications.
- Magnesium Chloride (MgCl) – 91 grams (3.2 oz.) - MgCl is used as a de-icer on highways and airports as well as multiple medical and industrial uses. The burning magnesium flare produces magnesium oxide (a naturally occurring mineral).
- Carbon (C) – 41 grams (1.4 oz.) - C is a naturally occurring mineral.
- Magnesium Fluoride (MgF) – 319 grams (11.3 oz.) - MgF is a transparent inorganic compound used extensively in optics, windows, and anti-reflective coatings. The burning magnesium flare produces magnesium oxide (a naturally occurring mineral).
- Trace quantities (less than 1 gram) of carbon dioxide (CO_2), carbon monoxide (CO), and difluorine oxide (OF_2) were also found following the flare burn.

Studies on flare ash components were performed by measuring remaining materials after magnesium flare pellets were ignited in a furnace (Air Force 1997). Constituents from combustion were identified and the amount of flare emissions or flare ash was measured. The chemical constituents in older flares (lead or chromium) had a very remote potential for impact to the environment. Flares described in Section 4.1 do not contain lead and the trace amounts of chromium are not sufficient to result in an environmental impact.

Most flare ignition devices are comprised of magnesium, Teflon resin (similar to that used in cooking pans), and viton (a synthetic rubber used as a seal in scuba tanks). The burning magnesium flare produces magnesium oxide (a naturally occurring mineral). The burning flare components do not emit measurable toxic constituents. No surface concentration of flare ash would be detected on the ground under areas where flares were deployed. Flare emissions are not now, nor is it feasible that they could become, a health hazard (Air Force 1997).

8.6 Biological Effects

Effects of residual flare materials would be comparable to the effects described in Sections 5.4.2, 5.4.3, and 5.4.4 for chaff residual materials. Toxicological studies on flare residual materials indicate that no chemical effects to biological resources would be expected. The amount of magnesium dispersed from flares (as the combustion product magnesium oxide) is too small to result in levels that would be associated with acute exposure (Air Force 1997). The concentration of flare ash residue at any location would be undetectable under normal circumstances due to dispersal of the minimal amount of residue produced by a burning flare deployed in the airspace.

At night, a flare would create a brief (not more than five seconds) bright light in the air at deployment altitudes typically above 2,000 ft AGL. This light would not be expected to interfere with nocturnal species. It would not be bright enough, nor last long enough, to light a portion of the ground. Depending on the flare altitude and duration, the light could result in a momentary freezing behavior on the part of an individual, which would not be expected to occur frequently nor have any long-term effects on either an individual or a population.

8.7 Visual Intrusions

The release of flares could have a visual effect from residual materials, which remain on the ground or land on structures or at sacred sites. Flare residual materials do not pose a significant threat to the visual integrity of archaeological and architectural resources. Flare residual plastic materials are typically 1 inch x 1 inch or 1 inch x 2 inches and are usually red or blue. The flare residual materials fall to the ground in a dispersed fashion and do not collect in quantities great enough to affect the NRHP status of archaeological or architectural resources adversely. Impacts to traditional cultural resources are more difficult to assess and no studies have been conducted on them with regard to flare residual materials. Flare residual materials have been identified by ranchers on their property. When a plastic flare piece is found and identified on private property, in an unexpected public location, or in conjunction with a cultural resource, the individual finding the piece may be annoyed.

One or more burning flares produce a brief visual intrusion as a light that lasts for a few seconds. If a pilot repeatedly releases two or three flares in succession, the flares may appear as blinking lights in the sky as one set burns out and other flares are deployed. Although this would not be noticed by most individuals, someone staring up into the sky, such as a tribal member participating in a vision quest, a camper in an isolated location, or a rural rancher, could observe a brief light, or what appears to be blinking lights. If such an experience occurred, the observer may or may not perceive the brief lights as deployed flares from a training aircraft.

9.0 FLARE CONCLUSIONS

Effective use of flares in combat requires frequent training by aircrews to master the timing of deployment and the capabilities of the defensive countermeasure as well as by ground crews to ensure safe and efficient handling of the flares. Defensive countermeasures deployment in authorized airspace is governed by a series of policies and regulations based on safety, environmental considerations, and defensive countermeasures limitations. These policies, regulations, and guidance are included in Section 10.0. Procedures govern the use of flares over ranges, other government-owned and -controlled lands, and nongovernment-owned or -controlled areas.

9.1 Results of Flare Studies

Flare manufacturing reliability standards result in an estimated 99 percent flare reliability rate. The numbers of dud flares located under training airspace are in the range of one dud flare for 10,000 flares deployed. Different flares have different residual materials with different rates of descent and different impacts when they reach the ground. Most residual flare materials that fall have surface area to weight ratios that would not produce any substantial impact when the residual flare material struck the ground. The largest item on most flares is the approximately 2 inch × 1 inch × 0.5 inch plastic and spring S&I device with a weight of approximately 0.72 ounces. The S&I device could strike the ground with a momentum of 0.16 pounds per second or approximately the same force as a large hailstone. If an S&I device were to strike an unprotected individual, it could cause a bruise or more serious injury. The likelihood of a strike would depend on the number of flares deployed, the area under the airspace, the population density under the airspace, and the proportion of time a person would be expected to be outside. Assuming a rural area with a population density of ten persons per square mile and 20,000 flares deployed per year in a MOA over a 2,000 square mile area, the potential strike from a large hailstone sized S&I residual piece has been calculated as 0.003 strikes per year, or approximately three strikes in 1,000 years of training.

Training flare residual pieces of plastic or wrappers would not be likely to strike a person and most pieces fall with a force that would not be expected to result in a serious injury even if a person were struck. An S&I device could result in a bruise or other injury. If a nylon/plastic or other piece of flare residual material were found on the ground and identified, the finding individual could be annoyed.

On extremely rare occasions (estimated at approximately one in 10,000 flares dispensed), a flare may not ignite and would fall to Earth as a dud flare. In an extremely rare occasion, where a dud flare is found, it should not be moved, the location should be identified, and the local fire department or base Public Affairs Office should be contacted and provided with the location of the dud flare. The environmental consequences of realistic military training with flares can be summarized as:

- The risk of a fire can be greatly reduced through establishing the minimum altitude for deployment of self-protection flares. There is still the possibility of a mistake where a flare could be deployed at too low an altitude, but enforcing an established minimum altitude substantially reduces the potential for that mistake or for a flare-caused fire in the environment.
- Dud flares are infrequent with today's technology and manufacturing requirements. Analyses demonstrate that the risk from a falling dud flare striking anything is so low as to be inconsequential. The important environmental piece of information for dud flares is that, if one is found, it should be left where it is, its location should be marked, and authorities should be notified.
- There is almost no discernible trace from flare ash. A burning flare can be seen, but air pollution or ash on the surface is undetectable from the number of flares burned within a training airspace.
- Residual materials from the chaff cartridges and the M-206 flare, as well as most pieces from the MJU-7A/B, MJU-10/B, ALA-17/C, or MJU-23 A/B flares, fall with the force of a small hailstone and have very little safety risk. The S&I device in all but the M-206 falls with the force of a large hailstone and could cause a bruise or other injury. The likelihood of an S&I strike to a human is calculated to be three in 1,000 years of training. As noted in Section 8.4.3, the MJU 68/B and

MJU 69/B flares would be deployed only over unmanned ranges or Warning Areas. There has never been a case of an individual being struck by any residual flare piece.

- Flare residual materials would have little environmental effect and would not result in impacts on land use, economic activity, or cultural or traditional sites.
- An individual finding residual plastic or wrapping materials could be annoyed.

9.2 Responses to Representative Questions

The representative questions from Section 8.0 have been addressed in this discussion of flares. Wherever possible, studies have cited where specific issues have been addressed. In other cases, the detailed explanation of flare materials provides a response to public or agency concerns. The representative questions from Section 8.0 are repeated below with summary responses to the questions.

- What would be the visual effects from flare residual materials? The flare residual materials are described in Section 8.3. Figure 8–1 through Figure 8–5 represents residual materials that result from flare use. If a piece of plastic or wrapper material were found and identified, such material could be an annoyance.
- What are the effects of flares on ranching and other economic activities? Section 8.0 describes the effects of flares, including fire and residual materials effects. Fire can result in loss of animals and infrastructure. The potential for a flare caused fire is discussed in Section 7.2.3. The primary reason for a flare caused fire is human error and that risk is typically avoided through altitude restrictions on flare use. Infrequent dud flares would be extremely unlikely to disrupt agricultural activities. The flare and chaff residual plastics pieces or wrapper would result in approximately one piece per eight acres per year based on the assumptions is Table 8-4. The pieces would be inert and would be removed from animal or farm products in the normal processing steps to market the products. The risk from a strike from a piece of residual materials is calculated for range cattle and discussed for sheep. There would be no discernible effect to range animals. Section 8.4.6 describes the potential for an S&I (large hailstone size) strike to cattle. An estimated one to two range cattle could be struck by a large hailstone sized piece of plastic every ten years. Animals have not been found to ingest a plastic flare piece. If inadvertently ingested, the plastic pieces do not have sharp edges so no animal health or other ranching issues would be expected. The primary effect from a flare residual piece, which was located and identified on a ranch or other property, would be human annoyance.
- Would flares affect water and soil? The only feasible soil or water consequences could be from a dud flare deteriorating. Large quantities of dud flares falling at the same place would be necessary to create sufficient chemicals to affect soil or water properties. As noted in Section 7.2.4, there would be very few dud flares. It would be nearly impossible for multiple dud flares to accumulate in one small area.
- What are the risks to animals from ingesting flare residual materials? Livestock have grazed on military ranges for decades where chaff and flares are deployed. Flare plastic or wrapping pieces, as with chaff residual pieces, have never been recorded as ingested by animals (Sections 5.4.2 and 5.4.3). If a plastic piece were inadvertently consumed by an animal, it would pass through the digestive tract as with any inert material.

- What is the frequency and amount of flare use over Tribal lands? Defensive flare deployment would be random over lands underlying the airspace. Flare and chaff residual materials of approximately one piece per eight acres per year could be randomly distributed anywhere under a training airspace, including on Tribal lands. This assumes there would be two plastic pieces from 20,000 bundles of chaff and three plastic pieces and one wrapper from 20,000 flares over a 2,000 square mile area.
- Could flare use create airborne FOD hazards? There has never been a recorded instance of a flare plastic piece or wrapper striking or damaging an aircraft, even in extensively used training ranges such as NTTR or UTTR. Plastic and paper residual pieces from deployment of flares falls to the ground. The heaviest piece of flare residual materials outside a test range is a plastic piece, which falls with the force of a large hailstone (Section 8.4). There has never been a recorded case of such a piece striking another aircraft in the air or on the ground.
- Would flare residual materials affect birthing animals? Any contact with flare residual materials would be highly unlikely. Flare plastic and wrapper residual materials are inert. These residual materials would have no physical effect on any animals, including birthing animals.
- Will flare use be distributed evenly throughout the airspace or will it be concentrated within routine training routes? Flare use in training is not limited to any specific area. Flares are deployed in response to air- and/or ground-based threats, which can occur anywhere within a training airspace. Aircraft training flights and distribution of flare residual materials would be random and not on any specific training routes.
- Can the number of flares deployed be quantified? Flare use can be quantified for specific training aircraft and specific training airspace. This report has used the example of 20,000 flares deployed over a 2,000 square mile area.
- How does the use of flares affect air quality? Flare emissions are infrequent and distributed over a large area. Emissions are not concentrated in an area where they could be even quantified. No air quality or visibility impacts would occur from burning flares. Section 8.3 explains that flare ash is dispersed over a large area. Flares would not affect regional air quality.
- Will flare use impact important species, such as the sage grouse? Flare residual pieces would not be expected to impact species such as the greater sage grouse. Even where flares are used regularly, no animal or bird nests were found to contain flare materials (Section 5.4.2). No flare effects would be expected to sensitive species.
- Can flare use be limited to winter months to avoid the peak fire season? As explained in Section 7.2.3, seasonal and altitude restrictions for flare use are determined by ACC policy and then by the Base Commander in consultation with the base Airspace Manager.
- What are the near-term and long-term impacts from flare use? Section 8.0 describes the flare effects including the effects of residual materials that fall to the ground, which are inert and would be expected to remain on the ground unless disturbed. Figure 8–4 demonstrates that natural actions such as pine needles can over time, reduce the visual effects of residual materials.
- What are the fire risks from flares? The potential for fires is directly related to the release altitude of the flares (Section 7.2.3). Flares burn out within 500 feet. If flare deployment always occurred above 2,000 ft AGL, there would be very little likelihood of a flare-caused fire. The ACC minimum flare release altitude of 2,000 ft AGL should effectively preclude any flare caused fire. The primary flare fire risk is from a pilot in an engagement deploying a flare or flares at too low an altitude. Such human error has occurred, notably over training ranges, and resulted in fires that migrated off the ranges and damaged public and private property. Although it is not

possible to remove risk from human error, altitude and seasonal restrictions can be established which greatly reduce the possibility of a pilot being substantially below the minimum release altitude.

- Will the Air Force provide fire education to fire investigators? The base Fire Department is party to mutual aid support agreements with the nearby communities and government land managers such as the Bureau of Land Management. In addition, Air Force personnel will continue to cooperate with communities and government land managers.
- What is the safety risk from a dud flare igniting due to ground disturbing activity such as plowing or construction excavation? As described in Section 7.2.3, a temperature of approximately 1,000 to 2,000 °F is required to ignite a flare. Friction from a power saw or, possibly, a bullet, could ignite a dud flare. Farm equipment would not be expected to create the level of friction or heat required to ignite a dud flare. In the unlikely event of fire damage from a dud flare, the base Public Affairs Office should be contacted to determine how to file a damage claim.

10.0 POLICIES AND REGULATIONS ON FLARE USE

This section identifies policies and regulations on flare use and discusses potential management actions to reduce the potential for impacts from training with defensive flares.

10.1 Policies and Regulations

Current Air Force policy on use of chaff was established by the Airspace Subgroup of Headquarter Air Force Flight Standards Agency in 1993. The following regulations are also applicable.

- **Air Force Instruction (AFI) 13-201 -** U.S. Air Force Airspace Management, September 2001. This guidance establishes practices to decrease disturbance from flight operations that might cause adverse public reaction. It emphasizes the Air Force's responsibility to ensure that the public is protected to the maximum extent practicable from hazards and effects associated with flight operations.
- **AFI 11-214 -** Aircrew and Weapons Director and Terminal Attack Controller Procedures for Air Operations, July 1994. This instruction delineates procedures for flare use. It prohibits use unless in an approved area.
- **40 Code of Federal Regulations (CFR)** - Classifies flares as munitions under the military munitions rule.

10.2 Examples Management Actions to Reduce the Potential for Flare Environmental Impacts

Several actions have been taken to minimize effects of flare use including implementing management practices such as the following:

- All aircrew/units planning flare employment in the airspace would contact the base Operations Office for current flare restrictions.
- Current flare restrictions would be briefed to all aircrew planning to employ flares, the day of the sortie, and prior to flight operations in the airspace.

- When not further restricted, minimum altitude for flare release within the airspace boundaries in training areas other than government-owned or controlled property would not be below 2,000 ft AGL (ACC supplement to AFI 11-214, 22 December 2005).
- Flare use would be evaluated by the base Operations Officer. Decisions regarding altitude for flare release when fire danger ratings achieve very high or extreme levels (via National Fire Danger Reporting System).
- Base-level public affairs offices would work with on base and local fire departments underlying the airspace to educate them on flare deployment and handling techniques. This education would include distributing flyers to fire departments describing flare residual materials and dud flares.
- Current flare restrictions would be checked no earlier than 24 hours prior to training. When mission planning is done well in advance, an additional call would be required within 24 hours of airspace entry to ensure the most recent restrictions are attained. The Air Force would continue to cooperate with local fire agencies for mutual aid response to wildland fires.
- Although the risk of combustion of a dud on the ground is low, it could be ignited by a hot fire or by friction from a strike with something like a power saw or, possibly, a bullet. On a military range, a dud flare is treated as UXO. The basic rule for the public to follow if a dud flare were found is to identify its location, not experiment with it, and notify a local safety authority of its location. The authority, in turn, would notify the base, which has the personnel and facilities to handle dud flares in the unlikely event one should be found.
- The base Fire Department is party to mutual aid support agreements with the nearby communities and government land managers such as the Bureau of Land Management.
- Air Force personnel would cooperate with local agencies for mutual aid response to fires and develop an education program for fire departments beneath the airspace, including information on flares.
- Chaff deployment setback distances from airport radars have been agreed to between ACC and FAA to ensure adequate FAA tracking of aircraft and weather systems.

11.0 POTENTIAL EFFECTS OF POLICIES, REGULATIONS, AND MANAGEMENT ACTIONS ON MISSION TRAINING

Military defensive countermeasures are used by the Air Force to protect aircraft from heat-seeking weapons and from radar-guided weapons targeting aircraft. This report has addressed chaff and flares used in training by Air Force fighter pilots within the CONUS. Post-Cold War tactics have dictated the need for pilots to react nearly instinctively with the correct response to heat-seeking or radar-guided threats. This need has required pilots to "train as they will fight" using chaff and flares as defensive countermeasures in response to realistic threats during training. The need for training with such defensive countermeasures has expanded the need for pilots to use chaff and flares in airspace where realistic training is conducted. The use of chaff and flares in training extends from active military training ranges to other special use airspace that overlies government and private lands.

Under combat conditions, pilots and aircrews deploy chaff and flares at any altitude and over any terrain in response to threats to their aircraft, which would be ideal for training. Training in airspace over military, public, and private land in the CONUS faces certain restrictions that effects training as follows:

- Altitude and seasonal limitation on flare deployment
  - Restriction - Deployment of defensive countermeasures, specifically flares, is restricted by altitude to reduce the potential for flare caused fires. These restrictions may apply to specific sections of a training airspace and may apply to seasons and specific fire danger levels.
  - Training Effect - In combat, pilots and aircrews are required to respond immediately to a threat using defensive countermeasures. They are not sensitive to the altitude but rather to the time-critical response to ensure aircraft safety. Application of altitude and seasonal limitations somewhat reduces the realism of combat training. Since much of the combat activity as of 2011 is above 5,000 ft AGL and frequently above 20,000 ft AGL, the current effect of the limitations does not substantially hamper training. Low altitude penetration or other low altitude training flights would not be able to use defensive flares. Agreed-to altitude and seasonal limitations reduce the realism of low altitude training below 2,000 ft AGL.
- Limitations on the types of chaff and flares deployed during training
  - Restriction - Chaff radar echoes to FAA radars require training chaff rather than combat chaff. Improved FAA radars incur radar echoes from training chaff. Setback distances from airport radars somewhat address the radar echo contaminant issue. Training chaff permits pilots and aircrews to experience the use of chaff as a defensive tool but does not permit realistic engagements since opposing forces have the ability to “see through” the training chaff. New types of flares, which include metallic Infra-Red (IR) signatures rather than a magnesium pellet and flares such as the MJU-68/B with more realistic signatures cannot be used in any but restricted airspaces and ranges. The environmental and safety aspects of these types of flares have not been evaluated for use in military training airspace.
  - Training Effect - Combat realism involves both aggressive and defensive maneuvers. The inability to deploy combat chaff and the restrictions on chaff deployment within specified distances of FAA radar reduce the area in which training could occur and reduces the effectiveness of the training. Training with the newest types of flares cannot be accomplished where the potential environmental or safety impacts are not fully understood or have not been assessed. These limitations restrict the amounts and types of chaff and flares that can be used for realistic combat training.
- Area limitations on chaff and flare use
  - Restriction - Not all training airspace can be used by pilots to train with chaff and flares. Only airspaces where the environmental effects have been thoroughly addressed and mitigation measures, where applicable, have been employed can be used for chaff and flare training. This places limitation on the airspaces that can be used for realistic combat training.
  - Training Effect - This restriction requires that chaff and flare training for some pilots and aircrews can be performed only in offshore Warning Areas or after long commutes to airspace that permits chaff and flare use.
- Public annoyance with chaff and flare residual materials
  - Restriction - The public and some organizations have expressed frustration with inert residual materials and have exerted pressure to identify biodegradable chaff or flare residual materials. The chaff itself rapidly fragments on the surface into particles that are effectively indistinguishable from naturally occurring soils. This means that chaff, by its very nature, degrades to ambient soil conditions. Steps have been taken to reduce potential

chaff or flare residual materials deposited on the surface due to training. The change to paper wrapping for RR-196 chaff is a specific step to reduce the long-term effect of plastic or Mylar pieces on the surface. Continuing efforts in design and materials testing are underway to identify new end caps or pistons that could be made from more easily degradable material.

- Training Effect - The introduction of new materials must be thoroughly tested to ensure that the impacts of the new materials are not greater than the current materials. For example, the replacement of Mylar wrappings in RR-196 chaff with parchment paper could be accomplished only after it was demonstrated that the parchment paper facilitated chaff deployment. Introduction of biodegradable end caps or pistons rather than existing plastic end caps or pistons could convert what is currently an inert object to an object with potential uptake by biological systems. The ramifications of such introduced material would need to be assessed prior to wholesale adoption of a biodegradable solution to correct a possibly nonexistent problem. In addition, it is important that the introduction of new types of end caps or pistons do not contribute to chaff or flare failures. The plastic end caps are sealed so they can withstand extreme weather and temperature conditions. Introduction of a biodegradable end cap or piston could result in the end cap or piston not functioning as required under extreme weather or temperature conditions. Any action to resolve public annoyance with chaff and flare residual materials would need to be sure that the resultant solution does not create greater environmental problems in terms of increases in chaff failures, clumps of chaff, flare failures, or dud flares.

- Misinformation on training with modern chaff and flares
    - Restriction - Many of the agency and public concerns regarding chaff and flare use are related to chaff or flares that were in use 20 to 30 years ago. In the mid-1980s, foil chaff resulted in a variety of public issues including shorting out power transformers, having strips of foil covering the landscape, and visible foil strips descending from aircraft. Flare concerns are frequently related to fires on ranges. There are cases of fires beginning on military ranges, which have migrated off the range and resulted in infrastructure damage, such as in New Mexico and New Jersey. These fires may or may not be initiated by a flare. In some cases, the fires resulted from sparks from munitions fired at targets and hitting rocks or from the use of rockets on military targets. Public and agency concerns resulted in tightening restrictions on chaff and flare use.
    - Training Effect - Restrictions on chaff and flare use, whether they are based on valid information or incorrect information, reduce the effectiveness of military pilot and aircrew training. The pursuit of restrictions can exceed any valid information about the risks of training with chaff or flares.

12.0 SUMMARY – REVIEW OF MILITARY TRAINING WITH DEFENSIVE COUNTERMEASURES

This report provides information learned from the 1997 Chaff and Flares Study and adds information available over the succeeding decade. Included are explanations of the types of chaff and flares used, studies on chaff in the environment, explanations of the potential types of flare failures, and environmental risks of chaff and flares.

If 20,000 bundles of chaff and 20,000 MJU-7/B flares were deployed annually over a 2,000 square mile area, there would be an estimated 100,000 pieces of plastic, 40,000 pieces of felt, and 20,000 wrappers distributed over the 2,000 square mile area annually. There would also be an expected two dud flares and 100 clumps of undeployed chaff per year in the 2,000 square mile area. It is assumed that the materials would be distributed evenly under the airspace resulting in approximately one piece of residual material per eight acres per year under the airspace. Residual materials do not appear to accumulate in quantities that would result in a significant visual effect, although such materials could be intrusive and unwanted to private landowners or public land users under the airspace. Chaff or flare residual materials could be undesirable in areas specifically protected to preserve naturalness and pristine qualities. These areas include Wilderness Areas, Wild and Scenic Rivers, wildlife and habitat project areas, and areas designated to have outstanding visual quality, where any human-made object would be incongruous and unexpected, and where people walking, camping, and hiking would not expect to see residual plastic or wrapper materials on the ground.

12.1 Discussion of Chaff

Although large numbers of chaff bundles are deployed in training, modern chaff is typically not easy to identify in the environment unless the chaff bundle fails to deploy properly and a clump of chaff is deposited on the ground. The reasons for the difficulty in identifying chaff or chaff particles is because chaff rapidly fragments on the surface and is nearly entirely composed of silica and aluminum, two of the most abundant elements in soils. Studies to identify chaff particles and the chaff fragments on the ground have had limited success, primarily because chaff rapidly fragments in the environment and becomes indiscernible from ambient soil particles.

Assuming the observed fluidized bed tests fragmentation rates correctly reflect what would occur as chaff descends to the ground, the majority of chaff fibers would reach the surface largely intact, with minimal formation of PM_{10} or smaller particles. Winds could result in the extensive dispersion of chaff fibers, which could be deposited relatively distant from the release point. Both the DRI and Cook studies demonstrated that once the chaff fibers reach ground level, considerable fragmentation occurs (DRI 2002; Cook 2002). Given the rapid fragmentation suggested by these studies, it is likely that chaff fiber fragmentation becomes relatively complete within days of deposition. A clump of undeployed chaff undergoes the same fragmentation over a longer period. Animals have not been shown to willingly ingest or otherwise use chaff or chaff materials. No chemical risk to water or soil could occur from the amount of chaff deposited in a specific location.

12.2 Discussion of Flares

This report discusses the constituents and potential environmental consequences associated with Air Force pilot training using self-protection flares. Flares are described and potential environmental effects from flare use are explained.

Flares in common use on Air Force fighter and other aircraft are manufactured to achieve a high level of reliability. Potential flare failures could occur in four cases. One failure would be the result of a flare failing to ignite and remaining in the aircraft (treated at the base after the aircraft's return as UXO). A second failure would be if the flare ignited but did not deploy from the aircraft. One case of this occurring is documented and resulted in the loss of the aircraft. A third type of failure is if the flare was deployed, but did not burn in the designated period. A comparable result would occur if a training aircraft deployed a flare at too low an altitude. A fourth failure would occur if a flare were deployed but failed to ignite, which would result in a dud flare on the ground.

Flares undergo rigorous testing prior to acceptance of an entire lot because flares must perform in a combat situation where a pilot's life and an aircraft depend on the successful deployment of the flares. The test sampling process requires that better than 97 percent of the flares can be successfully deployed or the entire manufactured lot is rejected. This has resulted in flares being designed and manufactured to a high performance standard. Typically, less than one percent of flares fail in any of the four types of failures noted above. The number of dud flares found during regular range cleanup of UXO on military training ranges where flares were regularly deployed represents approximately one dud in 10,000 flares used over the range. Although dud flares are very infrequent with today's technology, there has not been a thorough survey or study to validate the estimated frequency of dud flares. The important environmental information for dud flares is that, if one is found, it should be left where it is, its location should be marked, and authorities should be notified.

Methods that could be used to reduce environmental risks were also identified. The risk of a fire can be greatly reduced through adjusting the minimum altitude for deployment of self-protection flares. There is still the possibility of a human error where a flare would be deployed at too low an altitude, but establishing minimum altitudes substantially reduces the potential for that error or for a flare-caused fire in the environment. There is almost no discernible trace from flare ash. A burning flare can be seen, but there is almost no detectable air or soil pollution from the number of flares potentially deployed within a training airspace.

Flare residual materials have become more completely understood and addressed in environmental documentation. Residual flare materials from flares used in training over the CONUS fall with the force of a small hailstone (end cap or piston) or large hailstone (S&I device). Such inert flare residual materials have little environmental effect except that a piece of plastic or wrapper could be viewed as an annoyance if found on the ground.

12.3 Other and Developing Defensive Countermeasures

Other defensive countermeasures are in use for different aircraft and by different services. In addition, there is continuing development of defensive countermeasures to enable them to defeat threats during combat. This section briefly notes the other and developing countermeasures.

12.3.1 Other Chaff

This paper has addressed a variety of training and combat chaff used in training airspace. The RR-188/AL chaff has not historically interfered with FAA radars, although radars that are more recent receive an echo from RR-188/AL chaff. Potential interference with tracking and weather radars has led to chaff release setbacks from airport radars and communications to reduce radar contaminants.

Technological advances in targeting systems continually change the requirements for combat chaff. These changes in chaff length and dispersion are expected to be coordinated in training within FAA-controlled airspace.

12.3.2 Other Flares

This paper has focused on flares used regularly during training with Air Force aircraft. Other types of flares are used as defensive countermeasures by different aircraft such as cargo aircraft, helicopters, or aircraft from other services. In general, the flare structure and use of these other flare types are comparable to the flares addressed in this report. Flare failure rates are typically low for other flares for the same reason that they are low for the flares described in this report: Survival of the pilot and the aircraft depends on reliable flares that are successfully deployed. The differences between the flares addressed in this report and other flares can include the duration of burn and the shape and weight of flare residual materials after deployment.

As targeting munitions become technologically advanced, defensive countermeasures have advanced to continue to provide pilots and aircraft protection during combat conditions. Representative advancements in flare technology are the M-211, M-212, MJU-68/B, and MJU-69/B flares. Each provides different defense capabilities for aircraft against technologically advancing threat systems. Residual materials and potential environmental effects of these flares have not yet been identified or environmentally evaluated.

12.3.3 Other Countermeasures

Chaff and flares are defensive countermeasures designed to defeat specific targeting devices. Other types of defensive countermeasures are being considered as methods to defeat the radar or heat-seeking threats. Such countermeasures include lasers to defeat heat-seeking missiles and directed energy pulses to defeat the electronics of radio transmitters or trackers to render the radar-guided weapon systems unusable. Although such systems could become operational on developing and future aircraft, conventional radar guided and heat-seeking weapons continue to threaten aircraft for the foreseeable future and the need for training to accurately deploy chaff and flare countermeasures to defeat these weapons will be required for Air Force pilots.

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Appendix A

EFFECTS OF MID-AIR TURBULENCE ON CHAFF PARTICLE SIZE

APPENDIX A EFFECTS OF MID-AIR TURBULENCE ON CHAFF PARTICLE SIZE

A.1 Mid-Air Turbulence Problem Statement

The ultimate fate of chaff fibers was identified as an unresolved problem in the Naval Research Laboratory Report (NRL). At issue was the extent to which individual fibers break up into smaller fragments, particularly in the period between release and the time the chaff cloud reaches the ground. The size distribution of the fragments is a key measure in evaluating the potential for environmental effects. The diameter of chaff fragments, more so than the length, was identified as a factor in settlement rates conducted by the Desert Research Institute (DRI).

The degree of fragmentation has implications for the potential effects on biota. It has been postulated that if large, unfragmented fibers accumulated on the ground, they could be subject to ingestion by wildlife or livestock or be otherwise utilized by wildlife (e.g., as nesting material). Reduction of the chaff to very small particles could increase dispersion, and make it unlikely that they could be deliberately ingested in substantial amounts, or otherwise deliberately utilized by wildlife. However, very small particles (e.g., less than 10 micrograms), of chaff fragments could theoretically affect Particulate Matter Less Than or Equal to 10 Micrometers in Diameter (PM_{10}) concentrations in the air. Such small particles might be inhalable and could have physiological effects on wildlife, livestock, or human beings. In addition, such particles could be ingested by wildlife or livestock if deposited on food materials or entrained in soil and water.

These pathways have different consequences for the health of wildlife, livestock, and human beings. The exact (or even approximate) consequences of each pathway are the subject of considerable debate. This section contributes information needed to evaluate which pathways can realistically be expected to occur in the natural environment. In particular, the objective of the section is to determine whether chaff fibers fragment into respirable size particles (<10 microns) due to exposure to mid-air turbulence.

A.2 Mid-Air Turbulence Study Design

When chaff is ejected from an aircraft during a training mission, it “blooms” to form a chaff cloud. The cloud quickly expands to a size sufficient to hide the aircraft from opposition radar, thereby improving aircraft and pilot survivability. At jet aircraft speeds, the formation of the cloud must occur rapidly to serve any useful purpose. In practice, this means the cloud must reach a size sufficient to confuse the opposition radar within seconds of ejection. Following bloom formation, individual fibers begin to settle earthward where they are gradually dispersed by atmospheric turbulence. NRL concluded that chaff released at an altitude of 10,000 feet would reach ground level in about 10 hours (DRI 2002). This is consistent with DRI chaff fall tests (DRI 2002). During the descent, individual fibers are exposed to a variety of forces that might contribute to fragmentation. The individual fibers are designed to break up immediately into smaller fibers during ejection (roughly 1.0, 1.5, and 2.0 centimeters[1]). Additional fragmentation may occur during the early stages of the bloom as individual fibers strike each other in the close confines of the chaff cloud. As the cloud expands, fiber-to-fiber contact would decrease quickly, and would probably become uncommon after a few minutes or less. Thereafter, the only fragmentation forces likely to be acting on the fibers are mid-air atmospheric turbulence and interaction

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[1] These lengths correspond to specific frequency bands that do not conflict to the maximum extent possible, with frequency bands used by certain weather radar, Air Traffic Control transponders, cell phones, and UHF broadcasts.

with other particles in the atmosphere. A study was designed and performed to assess the effects of mid-air turbulence on chaff fragmentation.

A fluidized bed was used to simulate the effect of turbulent air on chaff fragmentation. Fluidized beds are designed to maintain small particles suspended within an air stream for an indefinite period. This is achieved by the continuous introduction of gas (in this case compressed air) into the fluidized-bed chamber at sufficient velocity to maintain the particles suspended within the column. Such an arrangement simulates the natural atmospheric turbulence that chaff fibers would experience following release at height. There is a variety of fluidized bed designs available. Most fluidized beds include features that increase the contact between the particles and the apparatus such as a feedstock delivery system, cyclone chambers offset from the main settling chamber, and feed stock removal or recycling systems. These features increase the potential for fragmentation due to mechanical contact with the fluidized bed, and unrelated to what the chaff fibers would normally encounter in the atmosphere. To overcome this limitation, a modified fluidized bed was used to minimize fiber fragmentation from these sources. Modification included a) direct placement of chaff within the settling chamber, b) removal of the attached cyclone system, and c) positioning the exhaust outlet above the settling chambers filter[2].

To test the effect of atmospheric turbulence on chaff fragmentation, chaff samples were introduced into the fluidized bed apparatus. Samples for each test were removed directly from the first dipole cut of a single intact chaff cartridge and measured 1.52 centimeters in length. The average sample loaded into the fluidized-bed chamber ranged from 0.09 gram to 0.38 grams, averaging 0.27 g[3]. The concentration of chaff fibers within the test chamber is estimated as ranging between 6 and 26 fibers per cubic inch, averaging 18 fibers per cubic inch. These densities correspond to a chaff cloud with a diameter roughly between 30 and 120 feet.

Before being introduced into the fluidized bed, the samples were placed on a screen, washed with acetone to remove the fatty acid slip coat (to preclude adhesion or bird nesting), and air-dried. Individual samples were introduced into the system through the top of the modified fluidized bed and circulated with air in the apparatus to keep the chaff suspended inside the cylinder for the duration of the individual test runs. Air was blown through the test apparatus at a rate that kept the fibers suspended inside the test section. This simulated prolonged exposure to atmospheric turbulence[4]. Individual samples were suspended within the apparatus for 2, 4, 8, or 24 hour periods. Three replicate tests were performed for each period.

At the conclusion of each test run, the chaff cylinder was washed down with water to remove any lodged particles. The aggregate fibers, consisting of the bulk of the fragmented chaff, were collected in a plastic transfer bag for further analysis. The bottom fluidized bed filters were set aside for separate processing[5].

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[2] The chamber of the fluidized bed was six feet in length, and three inches in diameter. A 0.3 micron Nucleopore filter was set in the exhaust port to prevent loss of chaff fibers. A 0.5 micron Nucleopore filter was placed at the air inlet.

[3] These weights were taken post-treatment.

[4] The Naval Research Laboratory Report indicated that atmospheric residence time for chaff to reach ground level ranges from about ten minutes (chaff released at 100 m) to ten hours (chaff released at 10,000 m). Their data indicate that 60% of chaff released at an altitude of 10,000 meters would settle at an average rate of about 1 foot per second.

[5] Particle size distribution analysis was performed by the University of Wyoming Materials Characterization Laboratory, Department of Geology and Geophysics, in Laramie, Wyoming.

A.3 Results

Recovered materials were processed for Particle Size Distribution (PSD) analysis. Three distinct categories of chaff were recognized:

- Bulk Chaff - Most of the recovered material consisted of bulk, largely unfragmented chaff fibers.
- This material was removed from the bag, weighed, and then set aside. No further analysis was performed on these materials.
- Adherent Chaff - Coarse chaff fibers and fiber fragments adhered to the plastic collection bag. PSD data for these samples were obtained by microscopic examination of a portion of the entire bag. The area examined comprised approximately 16 percent of the total surface area of the bag. Data were collected for three size classes: 6.1 – 2.5 millimeters, 12.7 – 6.2 millimeters, and >1.52 – 12.8 millimeters. Table A 1 provides the coarse PSD data for this study.
- Filtered Particulate Chaff - Fine chaff fiber particles, were captured on the fluidized bed filters during each test run. PSD data for these samples were obtained using Electron Probe Microanalysis (EPMA). Data were collected for six size classes: <0.52, 1.0 – 0.51, 2.5 – 1.01, 3.5 – 2.51, 4.5- 3.51, and >4.5 micron. Table A 2 shows the fine PSD results for this study.

Table A 1. Number of Chaff Fiber Fragments Adhering to Sample Bag by Length Category as a Function of Test Duration (Raw Data)

Hours	Replicate	Weight (grams)	Number of Chaff Fibers by Length (millimeter)			Total
			12.8+	12.7-6.2	6.1-2.5	
2	1	0.38	113	25	138	**276**
	2	0.38	112	20	360	**492**
	3	0.22	86	69	158	**313**
	Average	**0.33**	**104**	**38**	**219**	**360**
4	1	0.36	54	32	367	**453**
	2	0.32	58	25	179	**262**
	3	0.2	68	13	70	**151**
	Average	**0.29**	**60**	**23**	**205**	**289**
8	1	0.21	35	11	101	**147**
	2	0.12	116	46	218	**380**
	3	0.09	151	25	171	**347**
	Average	**0.14**	**101**	**27**	**163**	**291**
24	1	0.32	27	45	615	**687**
	2	0.39	42	7	274	**323**
	3	0.25	50	33	184	**267**
	Average	**0.32**	**40**	**28**	**358**	**426**

Table A 2. Fine Particle Size Distribution Data from EPMA Analysis of Fluidized Bed Test Runs

Sample	Hours	Total Particle Surface Area (sq microns)	Longest Fiber (microns)	Average Fiber Length (microns)	Percent of Particle Surface Area in Sample by Fragment Length class (microns)					
					<0.51	0.51-1.0	1.01-2.5	2.51-3.5	3.51-4.5	>4.5
1	2	762.6	14.64	2.15	9.2	25.8	37.3	12.4	4.6	10.6
2	2	685.3	14.51	2.92	3.8	22.1	26	19.8	9.9	18.3
3	2	317.2	12.8	2	15.4	23.1	30.8	15.4	7.7	7.7
Average	**2**	**588.4**	**14.0**	**2.4**	**9.5**	**23.7**	**31.4**	**15.9**	**7.4**	**12.2**
1	4	537.7	20.95	4.48	5.3	13.2	15.8	18.4	7.9	39.5
2	4	182.9	10.01	2.6	4.5	25	31.8	13.6	11.4	13.6
3	4	77.1	8.55	1.91	7.1	42.9	25	10.7	7.1	7.1
Average	**4**	**265.9**	**13.2**	**3**	**5.6**	**27**	**24.2**	**14.2**	**8.8**	**20.1**
1	8	55.3	4.6	1.71	0	50	27.3	9.1	4.5	9.1
2	8	487.0	19.98	5.13	4	16	12	4	24	40
3	8	120.1	6.79	3.07	0	21.1	26.3	21.1	5.3	26.3
Average	**8**	**220.8**	**10.5**	**3.3**	**1.3**	**29**	**21.9**	**11.4**	**11.3**	**25.1**
1	24	208.5	1.71	2.21	5.7	37.7	30.2	9.4	5.7	11.3
2	24	49.7	4.49	1.31	31.3	28.1	18.8	15.6	6.3	0
3	24	-	-	-	-	-	-	-	-	-
Average	**24**	**129.1**	**3.1**	**1.8**	**18.5**	**32.9**	**24.5**	**12.5**	**6**	**5.7**

A.4 Bulk Chaff Discussion

Other than final weight data, no objective measures of bulk chaff fragmentation were obtained for the bulk chaff fibers. Visual observation of the recovered chaff samples indicated that most of the chaff remained intact, or largely intact. Most recovered chaff fibers were indistinguishable from those initially placed within the chamber. Nonetheless some fragmentation did occur, as described for the adherent chaff recovered from the sides of the plastic transfer bag, and from the fine particulate material recovered from the fluidized bed filters. These results are consistent with those reported by DRI using a similar fluidized bed apparatus showing fragmentation rates of less than 0.0001 percent during tests lasting up to 15 hours.

A.5 Adherent Chaff Discussion

PSDs were obtained for the chaff particulate matter adhering to the walls of the plastic transfer bag. Table A 3 shows normalized results for the adherent chaff particle PSD. The data in each size class have been expressed as a percent of the total number of particles counted for any given test duration. Overall, the contribution of each size class is similar for the two, four, and eight-hour tests (roughly 30, 10, and 60 percent for coarse, mid, and fine size classes). However, at the end of 24 hours of testing, the contribution of the coarse chaff decreased to about 10 percent, while the contribution of fine chaff increased to about 85 percent of the fibers. At a minimum, these data demonstrate that fragmentation does occur under the test condition. These data apply only to the subsample of chaff adhering to the walls of the collection bag. It is not known if the observed degree of fragmentation in the adherent particles reflects that for the chaff samples as a whole. We can conclude that some degree of fragmentation does occur under conditions intended to mimic mid-air turbulence. Based on the calculation that chaff released at an altitude of 30,000 feet would reach ground level in about ten hours, the eight-hour test results would appear to be representative of training activity up to 30,000 feet. The 24-hour test was conducted to evaluate an extreme case that is not expected to be representative of natural conditions.

Table A 3. Average Particle Size Distribution of Adherent Chaff as a Function of Test Duration

Duration (hours)	Average Percent of Particles by Size Class (millimeters)		
	12.8+	12.7-6.2	6.1-2.5
2	30%	12%	58%
4	26%	8%	66%
8	33%	9%	58%
24	9%	7%	84%

A.6 Filtered Particulate Chaff Discussion

PSDs were obtained for chaff particles collected on the fluidized bed filters. Table A 4 and Figure A 1 and Figure A 2 summarize these results[6]. The data show a bimodal distribution with peaks at around 1 microgram and at 4.5+ micrograms. Inspection of the data suggests that the amount of chaff in various size categories varied with test duration, though no clear-cut systematic pattern emerges. There is some indication that the results of the two to eight hour tests are relatively similar to each other but differ markedly from the 24-hour test. From the perspective of Figure A 2, it would seem that chaff in the relative coarse fraction is being converted into finer fragments as the tests progress. Some support for this view is obtained from Figure A 3. These data show a progressive decrease in the length of the longest fiber with increasing duration of the test. This is consistent with increasing chaff fragmentation through time. Figure A 4 shows the effect of increasing test duration on the total particle surface area. The results are somewhat counter intuitive. It would be expected that the total surface area of particles recovered on the filter would increase with increasing fragmentation. The data, however, show a reduction in total surface area. This may indicate that at long test durations, some portion of the chaff was being reduced to sizes that were small enough to pass through the filter. Alternatively, some particles may have been reduced to sizes small enough to remain in suspension in the air column at the conclusion of the test. In either case, recovery of such small particles may not have been complete.

Table A 4. Fine Particle Size Distribution for Filtered Particulate Chaff

Hours	*Average Particle Surface Area (sq. microns)*	*Longest Fiber (microns)*	*Avg. Length (microns)*	Average Percent of Sample by Fragment Length (micron) Categories					
				<0.51	*0.51-1.0*	*1.01-2.5*	*2.51-3.5*	*3.51-4.5*	*>4.5*
2	588.4	13.8	2.4	9.5	23.7	31.4	15.9	7.4	12.2
4	265.9	13.2	3	5.6	27	24.2	14.2	8.8	20.1
8	220.8	10.5	3.3	1.3	29	21.9	11.4	11.3	25.1
24	129.1	8.1	1.8	18.5	32.9	24.5	12.5	6	5.7

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[6] The results in Table 2-4 show retention of particles smaller than the filter size (0.3 microns). From this it appears that the filters did not provide a sharp cut-off for retention of particles larger than 0.3 microns.

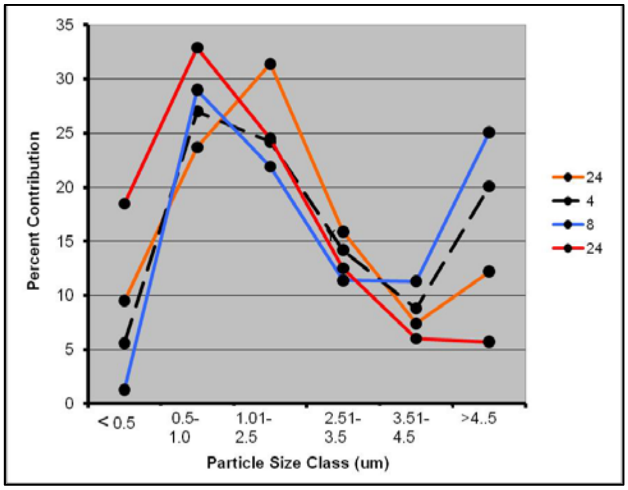

Figure A 1. Filter PSD as a Function of Test Duration

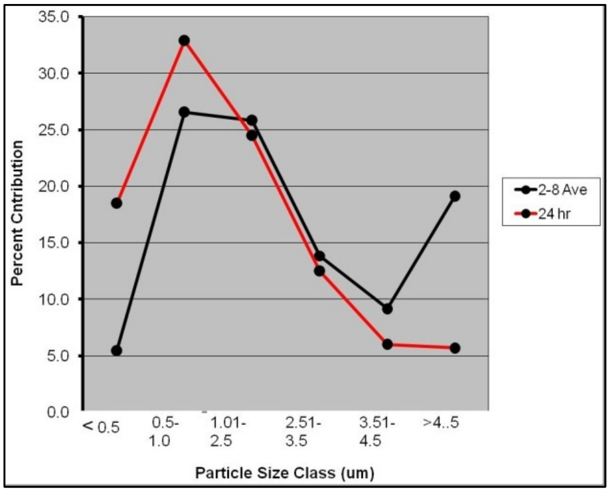

Figure A 2. Simplified Filter PSD as a Function of Test Duration

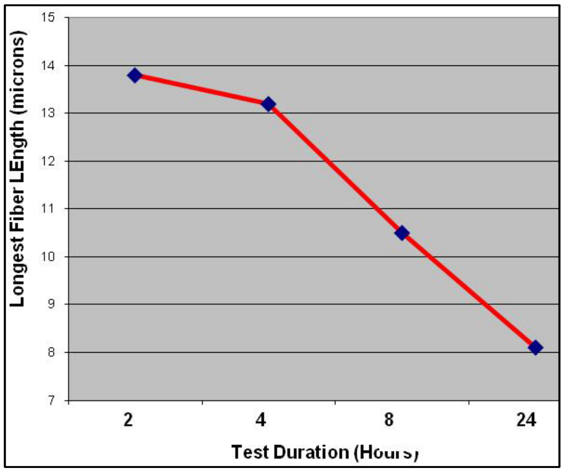

Figure A 3. Change in Length of Longest Fiber as a Function of Test Duration

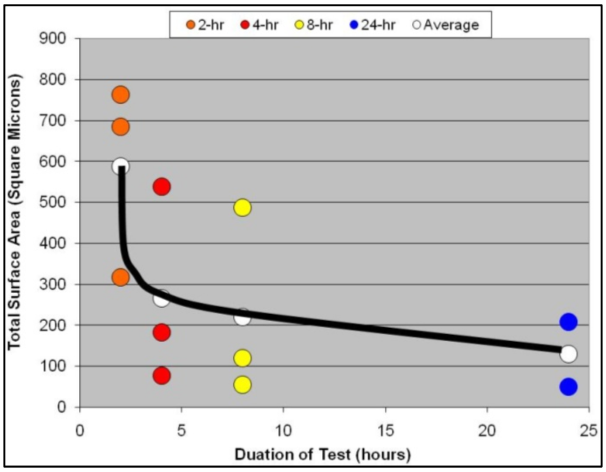

Figure A 4. Particle Area as a Function of Test Duration

A.7 Summary of Effects of Mid-Air Turbulence on Chaff Particle Size

Visual observations for the recovered chaff indicate that most fibers remained unfragmented, or largely unfragmented, in the fluidized-bed tests. Nonetheless, some fragmentation does occur. Both the adherent chaff and PM_{10} data show the formation of small chaff fragments. In the case of the adherent chaff data, the results show the formation of chaff particles down to 2.5 millimeters. The PM_{10} data show the formation of very fine chaff particles (under 10 micron) including respirable chaff particles (less than 2.5 microns) at sizes down to 0.5 microns or less.

The extent of chaff fragmentation was not found to be large. The total fragmentation rates from the DRI study were less than 0.0001 percent for tests lasting up to 15 hours (DRI 2002). Test data sets show that the contribution of different size classes is relatively constant over the first eight hours of testing, but changes markedly at 24 hours of testing. Surprisingly, the PM_{10} data shows that the total surface area for PM_{10} size particles recovered on the filter decreases with time. This suggests that material is being lost from the test chamber over time. The most plausible explanation for this finding is that prolonged abrasion of the chaff reduces individual chaff particles to sizes less than the cut-off point for the filter (0.3 microns). While some of the sub-0.3 micron material appears to have been retained on the filter, the reduction in total surface area suggests that most of the material below 0.3 microns was lost during the course of the test.

A.8 Fluidized-Bed Test – Lessons Learned

This study program began with a goal to identify the extent of chaff fragmentation prior to deposition on the ground and fragmentation post-deposition. A series of tests to identify chaff fragmentation were proposed for this study. The results of these tests demonstrated several lines of study that could be used should future investigations be desired to evaluate chaff fragmentation.

1. Test Duration - Given the minimal apparent fragmentation during the tests, restriction of future tests to two-hours would probably be cost effective. Time-series testing within this two-hour period might yield useful information that would help answer the question as to whether the observed fragmentation occurred during initial start up of the fluidized bed.
2. Utilize Larger Chaff Loads - Chaff loads utilized in these tests resulted in concentrations within the fluidized-bed chamber similar to those that would be expected in a fully formed chaff cloud. Use of higher concentrations of chaff would simulate conditions during earlier stages of cloud formation when chaff densities are higher. Such conditions present greater potential for fiber-to-fiber contact. Results of fluidized bed tests utilizing larger chaff loads may give some insight as to whether fiber-to-fiber contact contributes to chaff fragmentation.

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APPENDIX B

POST-DEPOSITION FRAGMENTATION OF CHAFF

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B.1 Post-Deposition Fragmentation Problem Statement

The 1998 Government Accounting Organization (GAO 1998) report recommended that the Secretaries of the Air Force, Army, and Navy determine the merits of open questions made in previous chaff reports and if additional actions are needed to address them. The Select Blue-Ribbon Panel of independent, non-government scientists (DRI 2002) identified a need for further investigation of the re-suspension of chaff and chaff fragments once deposited on the ground. This study was designed to evaluate the effect of certain physical processes thought to be potentially important in chaff fragmentation and re-suspension. Specifically, the tests were designed to determine the extent to which the following factors contribute to chaff fragmentation:

- Wind driven re-suspension and re-circulation.
- Accelerated livestock trampling to replicate extended grazing.
- Accelerated vehicular traffic to replicate extensive traffic.

B.2 Post-Deposition Fragmentation Technical Approach

Three series of tests were carried out to evaluate the effects of wind, livestock, and vehicle operation on the re-suspension, fragmentation, and re-deposition of chaff.

B.3 Wind-Driven Fragmentation of Chaff

A series of tests were conducted at various locations on Melrose Air Force Range, New Mexico to test the effect of simulated wind on chaff fragmentation. These tests employed an open-bottom rectangular[7] "environmental chamber" equipped with a 36-inch fan (Figure B 1). Air was delivered from the fan to the chamber via a flexible cowling attached to the fan and passing through a 2-foot diameter hole in the plywood board sealing the fan-end of the chamber. During testing, the fan drew air into the chamber and exhausted it through an exhaust vent at the rear. The exhaust vent was covered with a 1-millimeter mesh screen to minimize loss of chaff fragments. The resulting wind currents within the chamber were estimated at about 15 miles per hour. Chaff samples, with a uniform fiber length of 1.52 centimeters, were introduced into the chamber using a "paint-ball gun"[8]. Separate tests were conducted using high (0.16 grams) and low (0.03 grams) amounts of chaff[9].

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[7] The dimensions of the chamber were 8 feet x 4 feet x 4 feet.

[8] The chaff was placed inside a "paper wad" that was, in turn, placed down the barrel of the paintball gun. The chaff was fired into the chamber from the access door on the side of the chamber and directed towards the fan (which had been activated).

[9] These chaff levels were based on levels of chaff deposition at Nellis Air Force Range, Nevada (Spargo 1999).

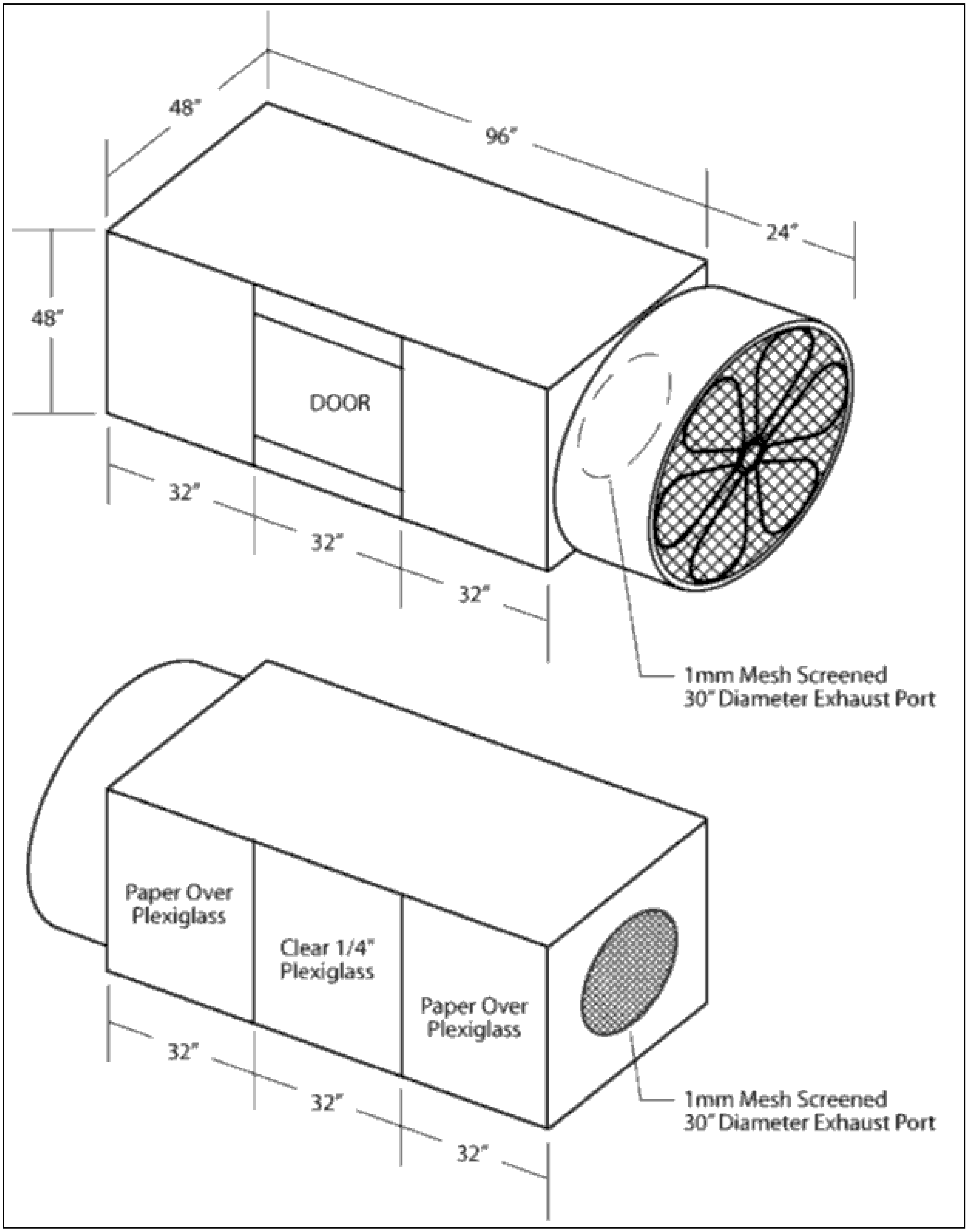

Figure B 1. Portable Environmental Chamber

An air-stream was continuously drawn from the chamber throughout the test using a Particulate Matter Less Than or Equal to 10 Micrometers in Diameter (PM_{10}) cyclone inlet attached to a Gilair 5-L/minute air pump (Figure B 2). Chaff particles in the air stream were collected on 0.1 micron Nucleopore filters. Particle Size Distribution (PSD) for the material on the filters was obtained. Chaff PSDs were also obtained for pre-test and post-test soil samples[10] collected for each study site.

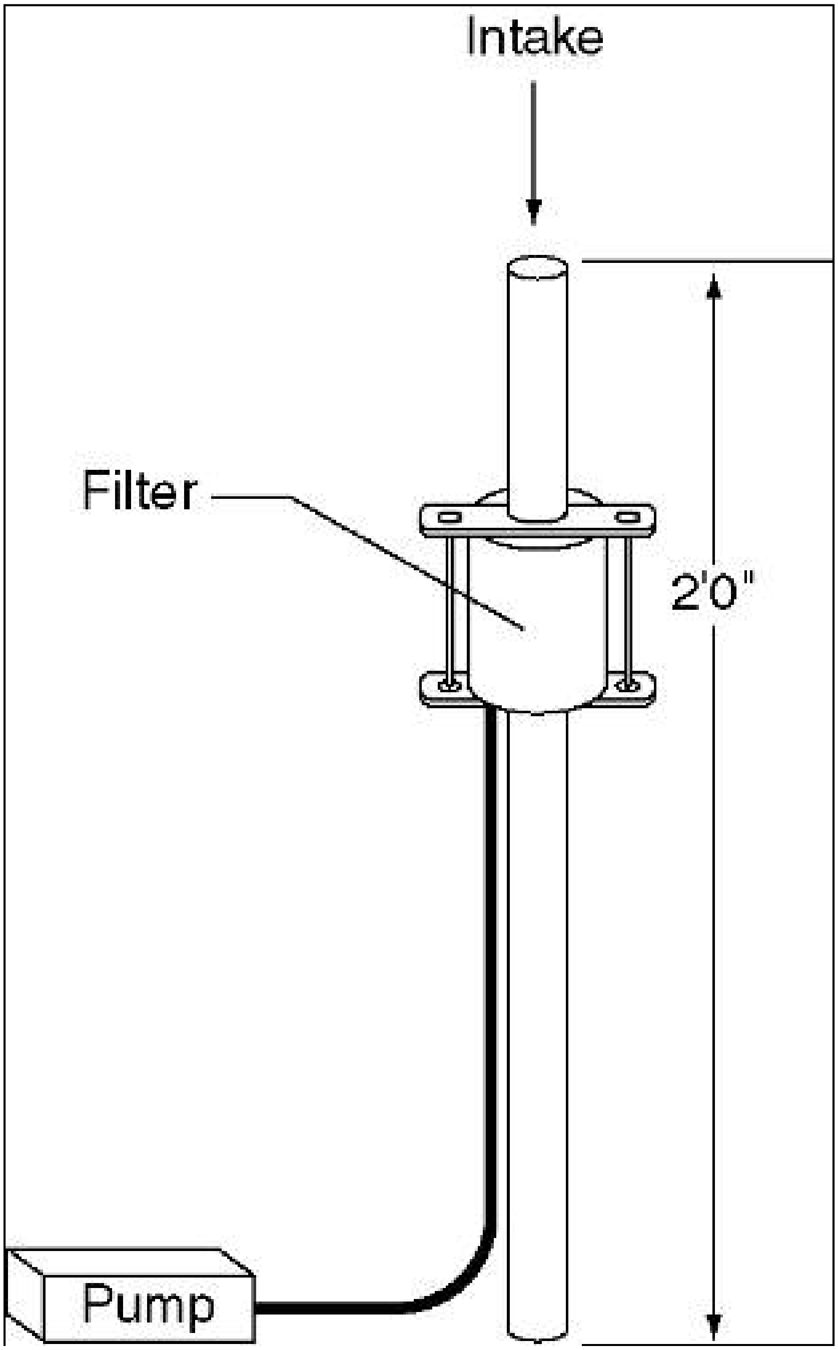

Figure B 2. Schematic of Air Sample Collector

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[10] Soil samples were collected near the fan end of the chamber and near the exhaust end of the chamber. Each sample consisted of three composited subsamples recovered from a 100 cm^2 area. Total composite collection area for each sample was 300 cm^2 or 0.323 square feet.

B.4 Vehicle Driven Fragmentation of Chaff

The tests of accelerated vehicular traffic were conducted on dirt roads on Melrose Air Force Range, New Mexico. Half of the environmental chamber was placed on a test site and chaff samples were released using a paintball gun. The environmental chamber was removed and a pickup truck was driven over the experimental area for ten passes. Chaff and dust were allowed to settle for approximately 30 minutes. The environmental chamber was then positioned over the test site. Re-suspension tests were then carried out comparable to those described for the wind-driven fragmentation tests.

B.5 Livestock Driven Fragmentation of Chaff

Tests designed to evaluate the effect of accelerated livestock grazing on chaff fragmentation were similar to those used to evaluate wind driven chaff fragmentation. The tests were conducted at random sites in sagebrush/mixed grass vegetation community on a ranch north of Dwyer, Wyoming. In this case, chaff samples were released at a test site using a paintball gun prior to the placement of the environmental chamber. Livestock (500 head) were then herded over the site for four passes. Chaff and dust was allowed to settle for approximately 30 minutes. The environmental chamber was then positioned over the test site. A 48-inch fan was operated to re-suspend the chaff fibers. The use of the 48-inch fan (as opposed to the 36-inch fan in the other tests) left a substantial (3.4 square feet) open area at the fan-end of the chamber. During operation, air was able to leave the chamber both through the exhaust port at the other end of the chamber, and through the “Fan-Gap”. Air samples were collected at one-half hour intervals, as was done for the wind-driven fragmentation studies. Soil samples were collected at the test sites prior to initial chaff and chamber placement, and again at the conclusion of the test. These samples were used to determine PSD for any chaff already present in the soil prior to, and following the test.

B.6 Particle Analysis

Soil and air filter samples were analyzed for the presence, particle size, and number of chaff fibers present. All samples were submitted to the University of Wyoming’s Materials Characterization Laboratory, Department of Geology and Geophysics located in Laramie, Wyoming for particle analysis. Particle counting was performed using visible light microscopic techniques for particles 1-millimeter and larger and X-ray diffraction for particles 10 micrograms and smaller.

B.7 Soil Samples

Coarse (larger than 1-millimeter) particle counts were obtained using visible light counting techniques. Three random sub-samples were removed from each soil sample and placed in a 10-centimeter Petri dish. The Petri dish was placed above 0.5-centimeter grid paper on a movable viewing stand and illuminated with dual high intensity lights. The samples were viewed through an Olympus SZ-CTV microscope with an SZ-40 objective lens to detect particles 1 millimeter or larger. Samples were scanned with overlapping passes at 4x power. Detected particles were recorded into three size categories.

X-ray diffraction techniques were applied to obtain fine (less than 10 micrograms) particle data. Samples used for the coarse particle analysis were passed through a 2.36-millimeter brass sieve (U.S.A. Standard Sieve Series No. 8) to remove coarse material. The remaining material was examined using X-ray diffraction with a JEOL-8900 Electron Probe Microanalyzer (EPMA). Samples were mounted on carbon tape and carbon coated to enable examination with an electron beam. A representative area measuring 1.74 x 106 square micrograms was selected for each sample. The backscattered electron and secondary electron imaging capabilities of the EPMA was used on the initial examination to locate a minimum of 100 discrete particles per sample. The location of these particles within the field was stored in the EPMA memory.

Each particle was then examined in detail using the wavelength dispersive spectrometer and compared to a compositional standard for chaff. Prior to sample analysis, element mapping of chaff fibers based on their composition was completed to establish an identification protocol. The EPMA was used to focus an electron beam on the material and compare the resulting image with set crystal spectrometers to detect characteristic X-rays. The element map for chaff was based on the aluminum (Al) coating of the fibers that is retained by the fibers and conspicuous due to the high intensity of characteristic Al X-rays. X-ray intensity maps for the silicon and trace elements that are found in chaff and in naturally occurring soils (magnesium, calcium, iron, sodium, and potassium) were also acquired for differentiation. All maps were collected at an accelerating voltage of 15 kilovolts and reported measured intensities were normalized to counts/second/nanoamp (c/s/nA). Each particle was categorized as either “chaff” or “other”. A particle was identified as chaff if it:

1. Was a single grain as opposed to a composite of smaller grains,
2. Had a recognizable metallic Al coating, and
3. If the intensity ratios of the trace elements in the silica (Ca, Al, Mg, and Na) fell within 20 percent of the ratios documented for coated or uncoated chaff particles in pure samples.

B.8 Air Sample Particle Analysis

The air filters were quartered, approximately 200 square millimeters in size, mounted to a glass slide and carbon coated. Samples were examined using the JEOL-8900 EPMA protocol described above for identification and size characterization.

B.9 Methodologies Used for Determination of Particle Size Distribution

This study applied various methodologies to discriminate between chaff particles and naturally occurring materials. This discrimination was made difficult because the components of chaff, once fragmented, essentially become the same as the ambient materials. This section describes the methodologies attempted to distinguish chaff particles in both air filter and soil samples.

B.10 Air Filter Samples

Approximately one quarter of each filter (approximately 200 square millimeters) was mounted on a glass slide with double-sided tape. Care was taken that the center point of the filter was included in the examined area because the highest concentration of particles occurred there. The sample was then carbon-coated and examined using a JEOL-8900 EPMA. Initial examination utilized the backscattered electron and secondary electron imaging capabilities of the instrument to locate at least 100 particles on the filters. The position of these individual particles was stored in memory and each particle was then examined for composition using the wavelength dispersive spectrometers on the EPMA.

Detailed examination of chaff particles from the air filters demonstrated that compositional data obtained can be used to categorize unambiguously a particle as “chaff” or “other”. A particle was identified as chaff if it:

1. Is a single grain and not a composite of smaller grains, and
2. Has a recognizable metallic aluminum coating, or
3. If the intensity ratios of calcium, aluminum, magnesium, and sodium relative to silicon fell within 20 percent of the ratios documented for coated or uncoated chaff particles in pure chaff samples.

Approximately 100 particles per sample were examined. If the total number of chaff particles found in the initial sample was less than five, more particles were located and examined. However, the time spent on each sample did not exceed 1.5 hours. The actual filter area examined depended on the number of particles per unit area (which varied significantly), but which was found to be approximately 0.4 square millimeter particles/200 square millimeters filter area in preliminary analyses. The documented results for each sample consisted of a tally for chaff and non-chaff particles in each of the size classes. Spectra and images were recorded for several representative particles in each size class.

A back-up sampling of air-borne chaff particles was attempted using double-sided tape strips fastened to the inside of the test chamber. Materials did collect on the tape, but any attempts to separate the materials from the tape for sampling to determine whether any chaff particles were present and to size any such particles was unsuccessful. All treatments to remove the materials from the tape resulted in stripping the aluminum from any chaff particles present. The resulting materials could not be differentiated from ambient soil materials.

B.10.1 Soil Samples

Due to the difficulty in separating chaff particles from ambient soil collected during the portable chamber and systematic sampling grid sections of the project, a two-phased approached was used to estimate the number of chaff particles in soil samples. The first (coarse scale phase) consisted of viewing soil samples under a binocular microscope (Olympus SZ-CTV with an SZ-40 objective lens) to detect chaff particles larger than 1 millimeter. The second phase consisted of placing soil samples from the coarse phase onto carbon tape and analyzing with an EPMA for chaff particles less than 1 millimeter. The methods used for the EPMA were the same as used with the EPMA for the air filter samples.

Coarse Scale Analysis for Soil Chaff Particles - For analysis of each soil sample, three (3) random teaspoons of material were extracted from the container and pooled in a plastic Petri dish (3.4 inches or 8.7 centimeters diameter). The Petri dish and contents were then viewed with a binocular microscope at 4x power to detect chaff particles greater than 1 millimeter in length. The Petri dish was placed on a movable viewing table and illuminated with dual high intensity lights. The Petri dish was placed on top of grid paper (0.2 inches [0.5 centimeter] square grid blocks) to facilitate overlapping passes. The viewing table was moved via threaded shafts and the field of view in the Petri dish was approximately 0.40 inches (1.0 centimeter). The contents of the Petri dish were scanned using the binocular microscope in overlapping passes. Approximately eight passes were required to scan the entire surface of the material in the Petri dish. For each pass, the Petri dish was moved horizontally from one edge (such as the bottom) to the other (such as the top). The Petri dish was moved laterally four grid blocks and the next pass was performed. The number of chaff particles detected was categorized into three size classes: 1.0 to 6.3 millimeters, 6.4 to 12.9 millimeters, and 13 to 25 millimeters.

Fine Scale Analysis for Soil Chaff Particles - After the visual scan using the binocular microscope, the soil material from the Petri dish was passed through a 2.36 millimeter brass sieve (U.S.A. Standard Sieve Series No. 8) and put on carbon tape for analysis using the EPMA. The EPMA was used to detect and estimate the number of chaff particles in the soil samples. The EPMA protocol used to analyze the air filter samples was used to analyze the soil samples for chaff particles less than 10 microns in size.

Preliminary examination of soil samples produced rough calculations of the expected abundance of chaff particles in the soil samples that indicated that the chance of finding chaff particles in unaltered soil samples was far too low to justify direct examination. Statistically meaningful determination of the abundance of chaff particles in soil samples was dependant on finding a method for enriching the ratio of chaff particles per volume of soil.

Chaff was separated from soil minerals by processing in sodium hypochlorite, pH 11, and then immersed in a boiling water bath for three hours to remove the organics. Particle analyses then followed the protocol set for the air filters. The wetting characteristics of chaff (aluminum coating), the behavior/recovery of small chaff fragments (<10 micrograms) and the interference of organic material in the soil were points of concern.

The examination procedure used differed from the initial proposed mapping technique of using an electron microscope. After extensive testing and method evaluation, the mapping technique proved to be inadequate for chaff fragments smaller than 20 micrograms. Element maps easily identify larger chaff fragments, namely intact portions of the original fibers. Due to the characteristic aluminum coating, they were easily identifiable visually when examining the sample under the electron microscope. The main reason why element mapping techniques failed in this case was that maps acquired in a reasonable timeframe (1 hour per sample) did not allow the observer to differentiate reliably between chaff fragments and alumino-silicate mineral particles. The main issues were intensity variations depending on the angle at which a sample was being hit by the electron beam, obscuring of smaller particles by “large chunks”, and relatively poor counting statistics even on maps with a 1-hour acquisition time.

Examining the samples in the manner proposed above involved more operator time but had the advantage that the elemental composition could be examined at the same time as the visual appearance of the particle. It is very common that soil particles are made up of an agglomerate of two or more smaller grains. The “average” elemental fingerprint can be very similar to what a chaff fragment was expected to look like. An automated routine would most likely identify such a particle as “chaff,” while an experienced operator can recognize potential “problem” particles and verify the homogeneity of the particle by probing it in two or different locations.

Tests with Heavy Liquid Separation (Water Soluble Salt) - A first set of tests was performed using sodium polytungstate. Chaff particles appeared to have very bad wetting characteristics, particularly if they still had the aluminum coating around the core. The particles did not settle according to their specific gravity but tended to float and stick to the walls. Therefore, this procedure was eliminated from consideration for analyzing soil samples for chaff particles.

Tests with Heavy Liquid Separation (Organic Solvents) - Tests using bromoform (sp. gr. 2.9), dibromomethane (sp. gr. 2.49), and mixtures of the two were conducted next. The specific gravity of the chaff particles was estimated to be approximately 2.65. Wetting characteristics were satisfactory and particles settled/floated according to their density. Unfortunately, the aluminum coating reacted vigorously with the solvents causing the chaff particles to be stripped of their aluminum coating in the processing. Consequently, this procedure was eliminated from consideration.

Problems Associated with the Specific Gravity of Chaff of 2.65 - The observed specific gravity for chaff fell right in the middle of the range of specific gravity for feldspars and quartz, the bulk of the soil minerals likely to be encountered in the collected soil samples. An easy one-step enrichment of chaff particles was therefore seriously hampered. In a preliminary fractionation attempt, preparations of ground-up chaff and soil heavily dosed with ground-up chaff were introduced into a solvent mixture with a specific gravity of 2.65. Chaff particles were observed to float in the center of the liquid phase, with some soil particle floating on top, some sinking to the bottom. The sample was sonicated, swirled, and a liquid sample was withdrawn from the center of the vial. The solvent in this sub-sample was replaced with acetone. The sample was then air-dried, re-suspended in water, and then collected on a 0.2 microgram filter for examination on the Microprobe.

Microprobe Analyses - The Microprobe is in some sense a specialized scanning electron microscope with improved capabilities to quantify the elemental composition of a sample. Typically, microprobe analyses require a flat, polished, and horizontal surface. Examining loose grains, as was needed for these analyses, is not normally done on this instrument. However, since the chaff particles appeared to have a unique chemical composition, it was hypothesized that a determination of the ratios of certain key elements would allow the identification of individual chaff particles. Microprobe analyses on samples containing chaff only as well as samples with presumably high concentrations of chaff in soil were performed. Samples were examined directly on the 0.2 microgram filters, and sampling points were spaced in either a two-dimensional grid (distance between points 3-5 micrograms) or a straight line (similar distance between points). Pure chaff samples were used to establish windows for element ratios used to identify chaff particles. Indicator elements used were silicon, aluminum, calcium, magnesium, and sodium. Potassium (K) and iron (Fe) were also measured as counter-indicators.

Problem of Aluminum Reactivity - The reaction between the organic solvents and the aluminum coating was a potential problem. On particles with the aluminum coating intact, the aluminum signature was obviously very strong. However, if the particle had both Al-coated areas and partially exposed silica core, the signal was mixed and therefore less distinct. In addition, the particles tended to be small so they may have only been partially hit by the electron beam, which would further add to the deterioration of the distinct signature of the chaff particles. In short, large particles completely covered in aluminum and small particles completely stripped of the aluminum were easily identified by their chemical signature, everything in between was not.

B.11 Observations from Application of Methodology

These different methodologies applied to determine chaff concentrations suggest future applications and identify approaches that are not expected to produce differentiation of chaff particles from ambient soil conditions.

- Examinations of air filter samples using an EPMA permits categorizing of sample particles chaff or other.
- Sampling of particles using a tape captive method does not permit differentiation of samples of chaff from other samples.
- Tests using water-soluble salt or organic solvents to identify chaff particles were unsuccessful due to the easy stripping of aluminum from chaff particles.

- The specific gravity of chaff does not permit easy separation of chaff from ambient soil samples although a multi-step process can achieve some separation.
- Enhanced electron microscope (microprobe) techniques have the potential to separate chaff from ambient soil particles using indicator elemental ratios.
- Since chaff is aluminum-coated silica, fragments of silica with aluminum coating intact did not have a unique signature that could be used to differentiate chaff particles from ambient soils.

In general, once chaff begins to fragment in soils, the chaff becomes nearly indistinguishable from other materials in the soils.

B.12 Results

This section summarizes of field test data and evaluates the factors that affect post-deposition chaff fragmentation. Factors considered include wind speed, airflow, air sampling, and soils sampling.

B.13 Wind Speed

In these tests, the environmental chamber served as a miniature "wind tunnel". Data on airspeed at the inlet and outlet (exhaust) of the chamber, as well as ambient wind speed were collected. These data are summarized in Table B 1. Additional wind-speed readings were taken on the leeward side of the native vegetation present within the chamber in the Chamber-Only tests. Ambient wind conditions during the tests averaged about 9 mph and ranged between 1 and 28 miles per hour.

Table B 1. Wind Speed Data for Environmental Chamber Tests

Treatment	Replicate	Wind Speed Data (MPH)							
		High Chaff Load				Low Chaff Load			
		Ambient	Inlet	Exhaust	Lee Side of Vegetation	Ambient	Inlet	Exhaust	Lee Side of Vegetation
Chamber Only	1	0.6	15.4	3.9		1.2	20.5	6.8	
	2	<28.0	17.0	12.2	0.4	7.7	14.5	4.5	0.5
	3	<11.4	20.5	9.1	1.8	19.9	15.7	8.9	3.4
Livestock	1	1.0		12.9		4.1		7.3	
	2	4.0		12.7		1.4		13.3	
	3	11.9		12.1		11.5		11.1	
Vehicle	1	3.4	14.2	7.4			21.0	11.1	
	2	17.6	15.9	5.4		14.8	11.4	5.7	
	3	2.2	17.4	5.9		7.4	16.5	7.0	
Minimum		0.6	14.2	3.9	0.4	1.2	11.4	4.5	0.5
Average		8.9	16.7	9.1	1.1	8.5	16.6	8.4	2.0
Maximum		28.0	20.5	12.9	1.8	19.9	21.0	13.3	3.4

Air Samples - Table B 2 shows chaff particle size distribution[11] for PM_{10} air samples taken from the environmental chamber for each of the treatment types: chamber-only, livestock, and vehicle.

Table B 2. Chaff Particle Size Distribution for Air Samples

Treatment	Replicate	Time	High Chaff Load					Low Chaff Load				
			Number Particles Examined	Chaff particles by Size Class (1)		Percent of Total Particles by Size Class (1)		Number Particles Examined	Chaff particles by Size Class (1)		Percent of Total Particles by Size Class (1)	
				10-2.5 µm	<2.5 µm	10-2.5 µm	<2.5 µm		10-2.5 µm	<2.5 µm	10-2.5 µm	<2.5 µm
Chamber Only	1	1	153	4	1	2.6%	0.7%	178	6	2	3.4%	1.1%
		2	157	1	1	0.6%	0.6%	182	5	4	2.7%	2.2%
		3	149	1	2	0.7%	1.3%	159	7	5	4.4%	3.1%
		4	146	1	3	0.7%	2.1%	153	3	4	2.0%	2.6%
	2	1	154	9	3	5.8%	19%	165	6	0	3.6%	0.0%
		2	164	6	4	3.7%	2.4%	175	4	7	2.3%	4.0%
		3	152	3	2	2.0%	1.3%	149	5	8	3.4%	5.4%
		4	152	4	3	2.6%	2.0%	149	5	5	3.4%	3.4%
	3	1	149	5	3	3.4%	2.0%	148	0	1	0.0%	0.7%
		2	135	0	7	0.0%	5.2%	146	0	0	0.0%	0.0%
		3	151	4	2	2.6%	1.3%	154	2	0	1.3%	0.0%
		4	145	1	3	0.7%	2.1%	154	0	1	0.0%	0.6%
Livestock	1	1	176	2	2	1.1%	1.1%	176	2	1	1.1%	0.6%
		2	159	2	3	1.3%	1.9%	163	0	0	0.0%	0.0%
		3	150	3	3	2.0%	2.0%	155	1	1	0.6%	0.6%
		4	143	0	3	0.0%	2.1%	167	0	0	0.0%	0.0%
	2	1	144	3	2	2.1%	1.4%	139	5	3	3.6%	2.2%
		2	142	2	2	1.4%	1.4%	154	3	3	1.9%	1.9%
		3	160	1	2	0.6%	1.3%	167	3	1	1.8%	0.6%
		4	154	1	7	0.6%	4.5%	158	1	2	0.6%	1.3%
	3	1	141	8	2	5.7%	1.4%	166	1	0	0.6%	0.0%
		2	130	2	3	1.5%	2.3%	138	1	0	0.7%	0.0%
		3	168	0	0	0.0%	0.0%	159	0	0	0.0%	0.0%
		4	135	2	0	1.5%	0.0%	140	0	1	0.0%	0.7%
Vehicle	1	1	169	7	1	4.1%	0.6%	144	0	0	0.0%	0.0%
		2	149	5	1	3.4%	0.7%	166	0	0	0.0%	0.0%
		3	167	2	2	1.2%	1.2%	150	2	2	1.3%	1.3%
		4	162	1	4	0.6%	2.5%	163	0	1	0.0%	0.6%
	2	1	157	2	0	1.3%	0.0%	142	1	0	0.7%	0.0%
		2	150	3	2	2.0%	1.3%	154	0	0	0.0%	0.0%
		3	156	3	3	1.9%	1.9%	148	0	1	0.0%	0.7%
		4	154	1	7	0.6%	4.5%	150	1	0	0.7%	0.0%
	3	1	137	4	0	2.9%	0.0%	158	1	0	0.6%	0.0%
		2	155	4	3	2.6%	1.9%	145	1	1	0.7%	0.7%
		3	133	3	4	2.3%	3.0%	163	0	1	0.0%	0.6%
		4	166	0	0	0.0%	0.0%	165	2	0	1.2%	0.0%

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[11] These data are reorganized compared to the raw data presented in Appendix B

Soil Samples - Table B 3 shows the results of coarse PSD analysis for soil samples taken from the bottom of the environmental chamber prior to and following various treatments.

Table B 3. Coarse Chaff Particle Size Distribution Data for Soil Samples

Treatment	Replicate	Location	Pre-Test Chaff Counts						Post-Test Chaff Counts					
			High Chaff Load			Low Chaff Load			High Chaff Load			Low Chaff Load		
			25-13 mm	12.9-6.4 mm	6.3-1.0 mm	25-13 mm	12.9-6.4 mm	6.3-1.0 mm	25-13 mm	12.9-6.4 mm	6.3-1.0 mm	25-13 mm	12.9-6.4 mm	6.3-1.0 mm
Chamber Only	1	Exhaust	0	0	0	0	0	0	1	0	0	0	0	2
		Fan	0	1	0	0	0	0	0	0	0	0	1	2
	2	Exhaust	0	0	0	0	0	1	0	0	2	0	0	0
		Fan	0	0	0	0	0	0	0	0	1	0	0	0
	3	Exhaust	0	0	0	0	0	0	0	0	0	0	0	0
		Fan	0	0	0	0	0	0	0	0	0	0	0	0
Livestock	1	Exhaust	0	0	0	0	0	0	0	0	0	1	0	1
		Fan	0	0	0	0	0	0	0	0	0	0	0	0
	2	Exhaust	0	0	0	0	0	0	0	2	1	0	0	0
		Fan	0	0	0	0	0	0	0	0	0	0	0	0
	3	Exhaust	0	0	0	0	0	0	0	0	0	0	0	0
		Fan	0	0	0	0	0	0	0	0	0	0	0	1
Vehicle	1	Exhaust	0	0	0	0	0	0	0	1	8	0	1	4
		Fan	0	0	0	0	0	0	0	0	0	0	0	2
	2	Exhaust	0	0	0	0	0	0	3	597	348	0	0	5
		Fan	0	0	0	0	0	0	0	0	0	0	0	0
	3	Exhaust	0	0	0	0	0	0	1	3	11	0	0	9
		Fan	0	0	0	0	0	0	0	2	0	0	1	0

Table B 4 shows the results obtained from X-ray diffraction analysis of soil samples spiked and unspiked with chaff.

Table B 4. Elemental X-Ray Diffraction Intensities for "Spiked" and "Unspiked" Soil Samples

	Al (Aluminum)	Si (Silicon)	K (Potassium)	Ca (Calcium)	Fe (Iron)	Mg (Magnesium)	Na (Sodium)
Spiked	1822	848	84	500	43.8	103.4	55.7
	1559	862	83	516	49.6	92.5	57.6
	1202	711	72	119	90.9	107	64.2
	1179	705	86	251	89.6	77.5	58.8
	1489	725	90	349	49.5	97.6	76.2
	1792	798	84	378	118	95.1	65.6
Unspiked	197	735	50	473	27.4	83.5	72.8
	209	789	81	373	56	53.5	63.4
	297	776	82	70	102	142.9	80.2
	106	270	31	70	19.9	16.9	21.7
	206	832	70	270	32.2	80	51.3
	248	842	90	396	113	79.1	64.9
Spiked/Unspiked	9.3	1.2	1.7	1.1	1.6	1.2	0.8
	7.5	1.1	1.0	1.4	0.9	1.7	0.9
	4.0	0.9	0.9	1.7	0.9	0.7	0.8
	11.2	2.16	2.8	3.6	4.5	4.6	2.7
	7.2	0.9	1.3	1.3	1.5	1.2	1.5
	7.2	0.9	0.9	1.0	1.1	1.2	1.0
Average	**7.7**	**1.2**	**1.4**	**1.7**	**1.8**	**1.8**	**1.3**

Table B 5 shows the similar elemental intensities under various test conditions.

Table B 5. Elemental Intensities from EPMA Analysis of Soil Samples

Treatment	*Chaff Load*	*Replicate*	*Chamber Location*	Pre-Test							Post-Test						
				Al	*Si*	*K*	*Ca*	*Fe*	*Mg*	*Na*	*Al*	*Si*	*K*	*Ca*	*Fe*	*Mg*	*Na*
Chamber	High	1	1	317	652	81	533	93	159	60	276	758	87	423	75	115	64
			2	239	600	77	402	87	117	54	121	546	26	156	25	26	45
		2	1	275	774	95	215	113	104	71	258	570	48	37	53	19	45
			2	292	782	88	204	82	139	68	243	671	88	196	90	106	57
		3	1	161	450	42	42	19	20	14	243	755	76	238	77	97	61
			2	189	571	36	101	26	25	37	177	532	35	37	21	21	40
	Low	1	1	262	693	81	258	90	90	69	233	512	78	172	78	54	65
			2	286	789	94	118	101	141	79	266	719	97	111	88	79	67
		2	1	117	352	37	26	27	15	27	70	180	27	17	12	16	20
			2	260	766	84	117	74	88	64	177	574	42	46	27	29	21
		3	1	293	763	87	399	87	117	70	252	678	69	388	94	126	60
			2	275	677	89	261	107	121	73	280	717	80	384	98	115	68
Livestock	High	1	1	219	643	69	135	60	84	54	299	818	88	210	90	154	77
			2	259	736	86	145	61	88	57	312	842	79	213	80	85	73
		2	1	249	642	85	197	86	128	48	277	741	83	157	64	98	59
			2	227	657	85	209	66	109	65	224	699	77	144	96	130	66
		3	1	253	728	98	366	70	70	65	268	730	82	361	113	100	68
			2	251	657	89	323	112	108	56	285	766	86	129	123	104	81
	Low	1	1	340	787	92	308	109	145	72	293	751	88	201	67	113	75
			2	283	728	92	286	129	105	64	297	772	84	213	117	118	86
		2	1	268	751	91	257	84	134	85	271	723	84	449	87	114	55
			2	282	764	87	320	104	123	68	301	810	98	182	107	162	71
		3	1	244	716	99	247	106	111	94	282	787	90	281	110	118	67
			2	311	873	95	249	110	116	78	224	673	85	144	53	109	60
Vehicle	High	1	1	197	735	50	473	27	84	73	198	775	80	467	47	99	56
			2	197	811	79	498	60	117	77	261	815	68	452	59	75	59
		2	1	188	437	73	162	68	36	42	300	777	93	481	110	74	84
			2	213	636	80	56	39	32	47	360	923	98	256	65	76	81
		3	1								226	675	34	401	32	27	46
			2	209	789	81	373	56	54	63	156	551	95	305	118	22	47
	Low	1	1	297	776	82	70	102	143	80	261	688	86	70	115	71	149
			2	276	647	89	128	100	228	80	308	753	94	314	89	125	75
		2	1	291	658	74	233	47	50	49	229	605	65	311	58	92	61
			2	106	270	31	70	20	17	22	246	765	76	284	70	53	65
		3	1	206	832	70	270	32	80	51	252	721	70	503	88	105	81
			2	248	842	90	396	113	79	65	242	848	82	445	73	154	72

Key:

Al = Aluminum

Ca = Calcium

Fe = Iron

K = Potassium

Mg = Magnesium

Na = Sodium

Si = Silicon

Table B 6 compares Pre-test (baseline) and Post-Test intensities for high and low chaff loads, and varying treatment types.

Table B 6. Post-Test/Pre-Test Intensity Ratio Compared for Different Treatment Types High and Low Chaff Loads

Treatment	Chaff Load	Post Test/Pretest						
		Al	Si	K	Ca	Fe	Mg	Na
Chamber	**High**	0.89	1.00	0.86	0.73	0.81	0.68	1.03
	Low	0.86	0.84	0.83	0.95	0.82	0.73	0.79
	High/Low	1.05	1.20	1.03	0.77	0.99	0.93	1.30
Livestock	**High**	1.14	1.13	0.98	0.98	1.28	1.19	1.24
	Low	0.98	0.98	0.95	0.90	0.85	1.01	0.93
	High/Low	1.17	1.15	1.03	1.09	1.51	1.18	1.33
Vehicle	**High**	1.27	1.20	1.23	2.06	1.61	1.35	1.20
	Low	1.22	1.28	1.22	1.97	1.69	1.54	1.62
	High/Low	1.04	0.94	1.00	1.04	0.95	0.87	0.74
Overall	**High**	1.09	1.07	1.02	0.98	1.1	0.98	1.04
	Low	0.94	0.94	0.98	1.32	0.97	1.1	0.99
	High/Low	1.16	1.14	1.04	0.75	1.14	0.89	1.05

Key:

Al = Aluminum
Ca = Calcium
Fe = Iron
K = Potassium
Mg = Magnesium
Na = Sodium
Si = Silicon

B.14 Airflow

Knowledge of the amount of air flowing through the chamber during a test is essential for interpreting PM_{10} air sample data collected in these studies. Airflow estimates can be developed from air speed data collected during the course of the tests.

The average measured inlet airspeed for these tests was 16.7 miles per hour, while the measured exhaust airspeed was 8.7 miles per hour. The discrepancy between these two airspeeds is due to imprecision in the inlet airspeed data. Air flowing through the exhaust port is well mixed, and relatively homogenous; airspeeds taken anywhere within the air flow at this location should be representative of airflow through the exhaust port as a whole. Airspeeds measured in the area in front of a fan vary depending on where the measurement is taken. Airflow is relatively slight towards the center of the fan, and at a maximum near the tip of the fan blade. In these tests, the airspeed data was taken at a position near the tips of the fan blades where airspeeds would be highest. As a result, the measured inlet airspeed data are not representative of the inlet airflow as a whole. For this reason, airflow calculated for these tests is based solely on the airspeed of the exhaust.

In the case of the Livestock tests where air could have escaped the chamber through the Fan-Gap, airspeed in the Fan-Gap is assumed equal to that at the exhaust port. Airspeed at the exhaust port varied from test to test, so the estimated airflow through the chamber also varied. Table B 7 summarizes airflow estimates for the various tests. Overall, total airflow through the chamber in these tests averaged about 10 acre-feet. Given a chamber volume of 128 cubic feet, this suggests that the air within the chamber was completely replaced on the average of once every two seconds during the course of each test. This relatively high flushing rate suggests that any fine particulate chaff being created (e.g., PM_{10}) would have been quickly winnowed from the chamber. As a result, the amount of chaff available to be captured by the PM_{10} sampler would have been relatively slight at any given moment.

Table B 7. Airflow Through the Environmental Chamber Under Test Conditions

Chaff Load	Treatment	Replicate	Exhaust Air Speed (MPH)	Estimated Air Flow (Acre-Feet)		
				Exhaust	Fan-Gap	Total
High	**Chamber**	1	3.9	2.9	0.0	**2.9**
		2	12.2	9.1	0.0	**9.1**
		3	9.1	6.8	0.0	**6.8**
	Livestock	1	12.9	9.7	10.6	**20.3**
		2	12.7	9.5	10.4	**19.9**
		3	12.1	9.1	10.0	**19.1**
	Vehicle	1	7.4	5.6	0.0	**5.6**
		2	5.4	4.1	0.0	**4.1**
		3	5.9	4.4	0.0	**4.4**
Low	**Chamber**	1	6.8	5.1	0.0	**5.1**
		2	4.5	3.4	0.0	**3.4**
		3	8.9	6.7	0.0	**6.7**
	Livestock	1	7.3	5.5	6.0	**11.5**
		2	13.3	10.0	11.0	**21.0**
		3	11.1	8.4	9.2	**17.6**
	Vehicle	1	11.1	8.3	0.0	**8.3**
		2	5.7	4.3	0.0	**4.3**
		3	7.0	5.3	0.0	**5.3**

B.15 Air Samples

PSD data for air sample data taken from the environmental chamber can be used to evaluate the effects of three major variables on the production of fine chaff particles in the range of under 10 micrograms. The variables that can be considered include a) chaff load level, b) duration of the tests, and c) treatment types.

B.15.2 Chaff Load Level

Table B 8 summarizes the results for different treatments under high and low chaff loadings. Assuming a constant PM_{10} background, the data suggest that the total number of chaff particles identified was dependent on chaff loading. That is, high levels of PM_{10} chaff were recovered for tests conducted with high chaff loads, and lower levels of PM_{10} chaff were recovered for lower chaff loads. Overall, chaff particles accounted for 3.5 percent of the total particles in the high chaff load tests, and 2.2 percent in the low chaff load tests, for an average of 2.8 percent. This effect was most apparent in the Livestock and Vehicle tests. The Chamber-Only tests showed similar concentrations for high and low chaff loads. These findings may reflect differences in ambient PM_{10} concentration between some of the tests. Alternatively, the data may reflect inherent differences between the treatment types. Differences in test design unrelated to treatment type may also account for some of the difference. For example, in the Chamber-Only treatment tests, chaff was introduced directly into the chamber. In tests involving other treatments, part of the chamber was constructed around the study site, the chaff was placed on the study site, the chamber parts were removed, treatments carried out, and the chamber assembled over the study site. The chaff was re-suspended by fan-driven circulation. Ambient wind conditions during the chamber construction may have affected dispersal of the chaff within the chamber and resulted in different patterns of chaff recovery.

Table B 8. Effect of Chaff Load Level on Chaff PM_{10} Levels

Treatment	Chamber Only		Livestock		Vehicle	
Replicate	High Chaff Load	Low Chaff Load	High Chaff Load	Low Chaff Load	High Chaff Load	Low Chaff Load
1	2.3%	5.4%	2.9%	0.8%	3.6%	0.8%
2	5.5%	6.3%	3.3%	3.4%	3.4%	0.5%
3	4.3%	0.7%	3.0%	0.5%	3.0%	1.0%
Average	**4.0%**	**4.1%**	**3.1%**	**1.6%**	**3.3%**	**0.8%**

B.15.3 Test Duration

Filters from the PM_{10} sampler were removed at 30-minute intervals during the course of each test. Figure B 3 summarizes the results of these tests, compositing the results for all treatment types and chaff load levels. In general, the data indicate that the amount of chaff recovered from the test chamber decreased through time.[12] It appears that as the tests progressed chaff was progressively fragmented into finer size fraction, and then removed from the chamber either through the exhaust port and/or through the Fan-Gap.

With less chaff available to form PM_{10} sized particles, the amount of chaff recovered in the PM_{10} filters would be expected to decrease, a conclusion supported by these data.

In addition, there appears to be a progressive decrease in the larger size chaff fragments through time, coupled with a corresponding increase in the sub 2.5 microgram particle class. This suggests that the abrasion processes that the chaff was exposed to (impact on the ground, walls of the chamber, mesh screening, vegetation, as well as the vehicular and livestock treatments) favored the formation of very fine chaff particles.

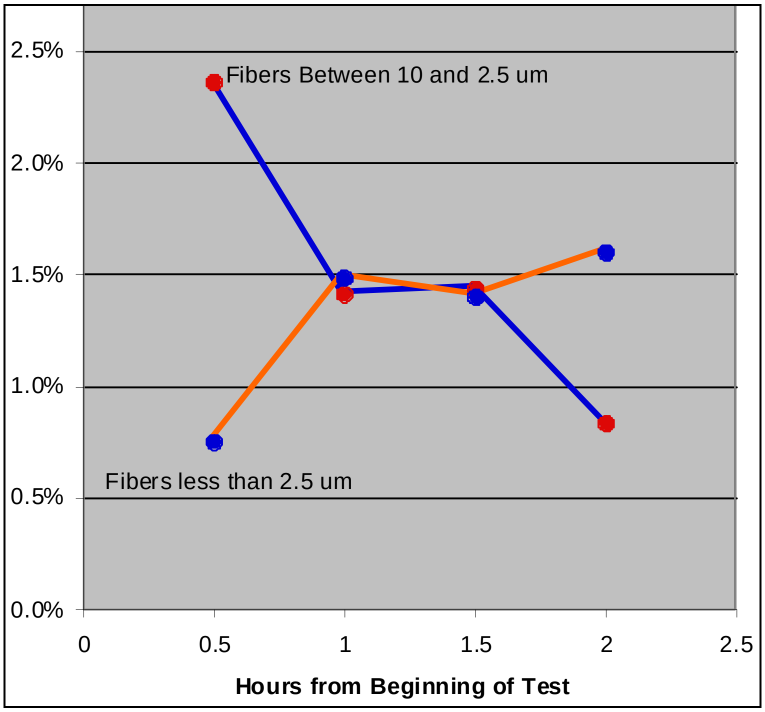

Figure B 3. Air Sample PM_{10} Chaff with Time

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[12] This assumes that the total particle counts reflect a constant ambient PSD level across all tests.

B.15.4 Treatment Type

Table B 9 summarizes data on the contribution of chaff by treatment type to total PM_{10} in the air sample data. These data show a substantial (almost twofold) increase in chaff recovered on the PM_{10} filters for the Chamber-Only treatment. This may not reflect an intrinsic difference between treatment types. The nature of the Livestock and Vehicle tests required that the chamber be erected over the test plot following the test-treatment. As a result, some of the chaff may have been lost from the plot prior to erection of the chamber. This could not have occurred in the Chamber-Only test since the chaff was inserted into the test chamber after the chamber had been set up. Given the similarity in the amount of chaff recovered in the Livestock and Vehicle Treatment tests (2.3 and 2.2 percent, respectively), it would appear that these treatment types did not have a noticeable effect on chaff fragmentation.

Table B 9. Proportion of PM_{10} Appearing as Chaff in Air Samples by Treatment

Treatment	Total Particles	PM_{10} Chaff			
		Coarse	Fine	Total Chaff	Percent Total
Chamber	3,719	82	71	153	4.1%
Livestock	3,684	43	41	84	2.3%
Vehicle	3,703	43	33	76	2.1%

B.15.5 Chaff Fragmentation and Loss

The rate at which chaff breaks up into fine particles (i.e., PM_{10}) is of considerable interest for the purposes of this study. The technique employed in developing these data involved counting a more or less fixed number of particles; as a result, the data can be used directly to compare the relative contribution of chaff particles to the total PM_{10} particle concentration. This does not permit a direct assessment of the amount of chaff reduced to the PM_{10} level of fragmentation. However, if it is assumed that the natural background (ambient) PM_{10} levels are constant between studies, an indirect assessment of chaff fragmentation can be obtained by proportioning the data against a representative ambient PM_{10} level.

Ambient PM_{10} data are not available for the study sites. The 24-hour standard for PM_{10} is 150-micrograms/cubic meter, while the annual standard is 50-micrograms/cubic meter. These standards place a crude upper bound on the likely PM_{10} concentrations that might have been present during the various tests. The Environmental Protection Agency’s (EPA) AIRS database shows that in 2001 the average PM_{10} level for New Mexico was 22 micrograms/cubic meter, with a peak concentration of 136-micrograms/cubic meter, and no exceedances of either the 24-hour or annual standard. Peak PM_{10} measurements occurred primarily in urban settings. In most locations, the PM_{10} concentration given in the EPA data never exceeded 67-micrograms/cubic meter. The following analysis assumes an ambient PM_{10} concentration corresponding to the statewide average of 22-micrograms/cubic meter. It is likely that PM_{10} values in the rural environment of the study area would be lower than this.

Assuming a constant background PM_{10} level of 22-micrograms/cubic meter, estimated airflow through the chamber can be combined with the relative amount of PM_{10} chaff in the air samples, and the absolute amount of chaff introduced into the chamber in each test, to estimate the fragmentation rate. This analysis is shown in Table B 10.

Table B 10. Chaff Fragmentation Based on Air Sampling PM_{10} Data

Treatment	Replicate	Chaff Load	Airflow (Acre-Feet)	Total PM_{10} in Airflow (µg)	% PM_{10} Appearing as Chaff in Airflow	Weight Chaff PM_{10} in Airflow (µg)	% Load Converted to PM_{10}
Chamber	1	H	2.9	79,535	0.023	1,829.3	1.1%
		L	5.1	139,047	0.054	7,508.5	25.0%
	2	H	9.1	247,967	0.055	13,638.2	8.5%
		L	3.4	92,698	0.063	5,840.0	19.5%
	3	H	6.8	185,396	0.043	7,972.0	5.0%
		L	6.7	180,761	0.007	1,265.3	4.2%
		Average	**5.7**	**154,234**	**0.04**	**6,342.2**	**11%**
Livestock	1	H	20.4	552,487	0.029	16,022.1	10.0%
		L	11.5	311,472	0.008	2,491.8	8.3%
	2	H	19.9	541,311	0.033	17,863.3	11.2%
		L	21.0	569,494	0.034	19,362.8	64.5%
	3	H	19.1	517,987	0.030	15,539.6	9.7%
		L	17.5	476,198	0.005	2,381.0	7.9%
		Average	**18.2**	**494,825**	**0.023**	**12,276.8**	**19%**
Vehicle	1	H	5.6	151,965	0.036	5,470.7	3.4%
		L	8.3	225,233	0.008	1,801.9	6.0%
	2	H	4.1	111,260	0.034	3,782.8	2.4%
		L	4.3	116,687	0.005	583.41	1.9%
	3	H	4.4	119,401	0.030	3,582.0	2.2%
		L	5.3	143,824	0.010	1,438.2	4.8%
		Average	**5.3**	**144,728**	**0.021**	**2,776.5**	**3%**

Figure B 4 displays these data in terms of airflow through the chamber, and chaff loading. The data are not entirely consistent but generally show that fragmentation increases with increasing airflow. Examination of Figure B 4 also suggests that chaff fragmentation is unrelated to chaff load.

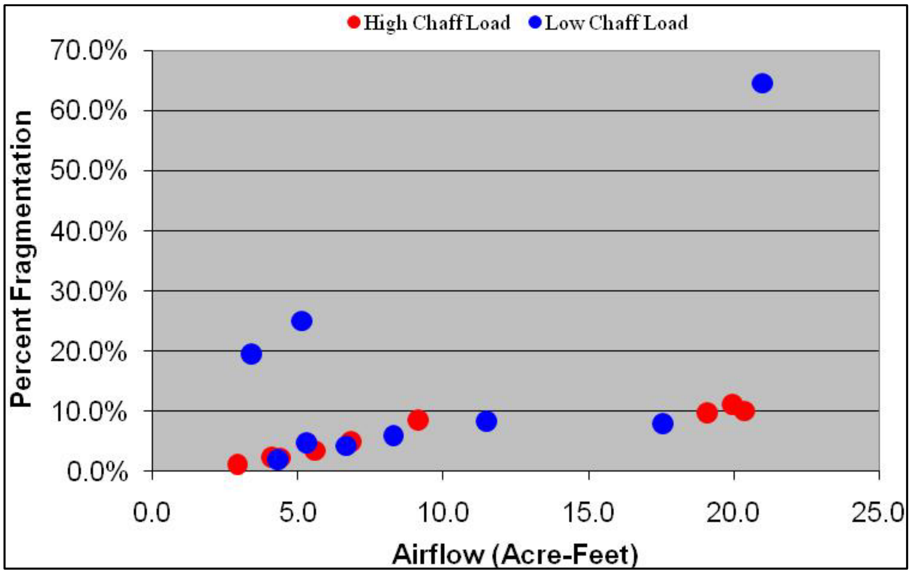

Figure B 4. Chaff Fragmentation as Function of Airflow and Chaff Load

The possible effects of treatment type are seen in Figure B 5. Inspection of these results may suggest some treatment specific difference. While fragmentation rates for the Chamber-Only and Vehicle treatments are indistinguishable from each other, data for the Livestock treatment are well separated from that of the other treatments (Table B 7).

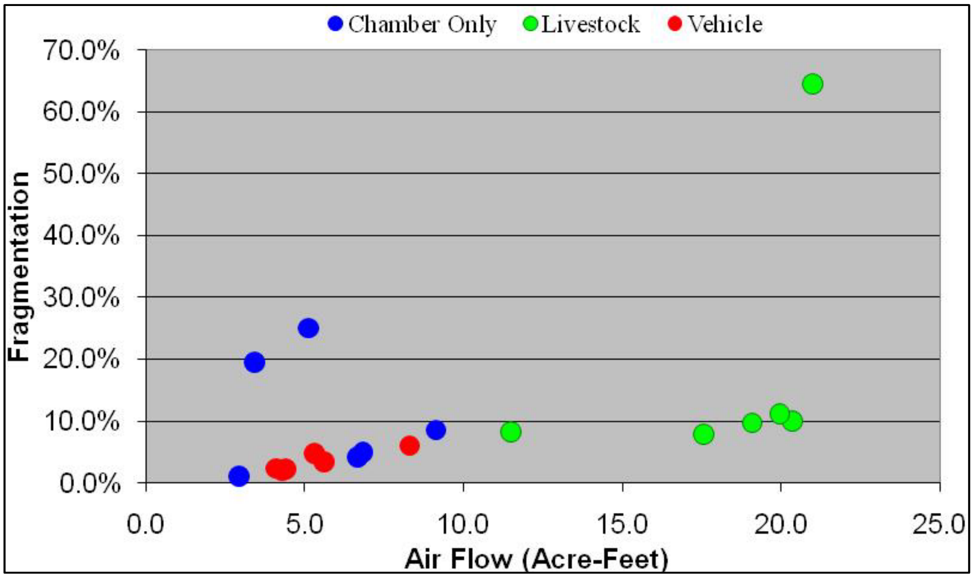

Figure B 5. Chaff Fragmentation as a Function of Air Flow and Treatment Type

The separation of the Livestock treatment data from that of the other treatments appears to be an artifact of the study design (Figure B 6). Specifically, the separation seems to be due to the fact that the Livestock treatment involved higher airflows than were found for the other treatments. This higher airflow is likely related to use of a larger fan for the Livestock treatment than for other samples. Overall, the data do not support a conclusion that treatment type had any substantive effect on chaff fragmentation.

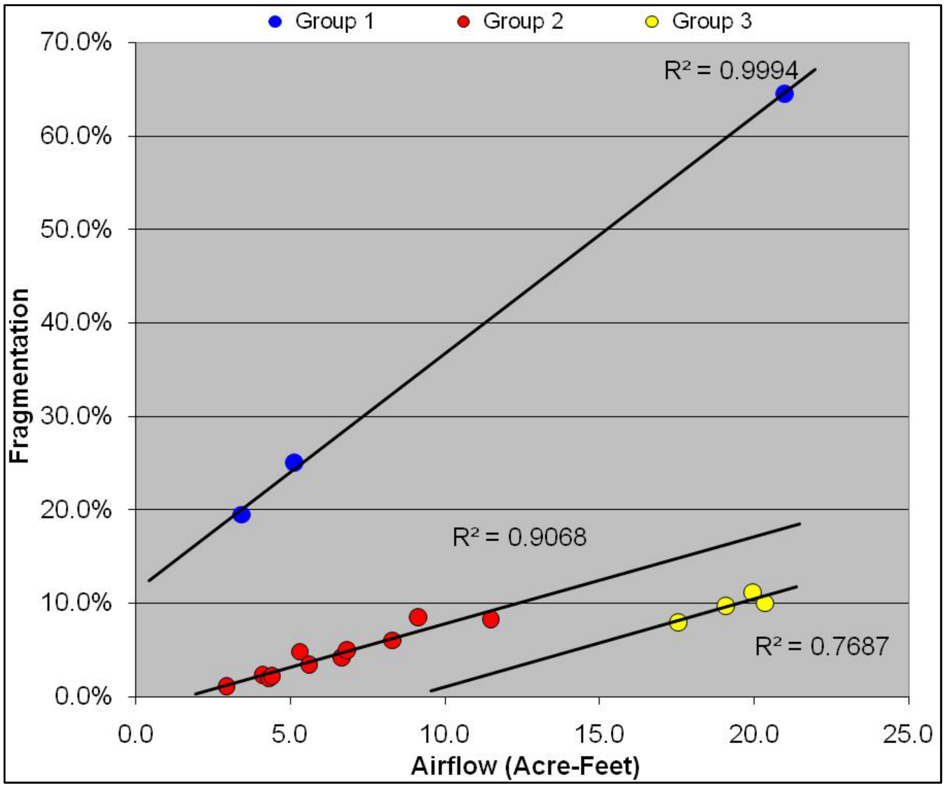

Figure B 6. Chaff Fragmentation as a Function of Airflow

These data are consistent with the conclusions drawn from examining the data on the fraction of the PM_{10} samples appearing as chaff. In these tests, chaff fragmentation on the ground is primarily driven by wind and the livestock and vehicle treatments probably had little effect on the rate of fragmentation[13]. The results are also consistent with the finding that higher fragmentation occurred in the tests using lower chaff loads. It is not intuitively obvious why this should be the case. The results, however, are relatively consistent across all three treatments (Chamber-Only, Vehicle, or Livestock). One possible explanation is that clumping of chaff fibers might occur at a higher rate with high chaff loads. Clumped chaff (known as "bird-nesting") is a common problem in the use of training chaff (DRI 2001). If it occurred in these tests, the effect would probably have been to reduce the extent of chaff "lofting" into the air stream. This would have reduced the amount of chaff available for collection by the PM_{10} sampler. One of the high chaff load tests did show evidence of such clumping.

Overall, these data indicate that approximately 5 to 10 percent of the chaff introduced into the chamber is fragmented into PM_{10}. In some cases, under low chaff loading, substantially larger amounts of chaff (30 to 40 percent of the total load) appear to be converted into PM_{10}. These data support the idea that wind driven fragmentation of chaff fibers that have contacted the ground occurs quite rapidly. Presumably, if controlled tests were carried out for longer periods, additional chaff would have been converted into PM_{10}. The observed fragmentation rates are sufficiently high that it seems likely that nearly complete conversion would be expected over the course of a few days.

It should be emphasized that these estimates are based on the assumption that ambient PM_{10} concentration was 22 micrograms/cubic meter. It is unlikely that the PM_{10} concentration would be much higher than this in a rural environment where these tests were conducted. It seems unlikely that the PM_{10} concentration would have been substantially less than the 22 micrograms/cubic meter assumed. Even so, a concentration of 10 micrograms/cubic meter would still have corresponded to a fractionation rate of between roughly 3 and 5 percent. It is also worth noting that in the case of the Livestock Treatment tests un-fragmented or partially fragmented fibers may have been winnowed from the chamber through the unscreened Fan-Gap. Such chaff would not have been converted into PM_{10}. This would have resulted in a low estimate of PM_{10} conversion.

B.16 Soil Samples

There were 72 soil samples recovered from tests in the three treatment types[14]. The data was analyzed in terms of baseline conditions, treatment type, chaff load level, and sample location within the chamber. PSD data was collected in two broad size classes, coarse particles greater than 1-millimeter and fine particles less than 10 micrograms. Table B 10 summarizes coarse (>1 millimeter) particle counts by size class aggregated for all post-treatment test results. Coarse chaff fibers were found in roughly one-half (48 percent) of test samples. Most of the samples showed one to fifteen chaff fragments. One sample[15] contained an unusually large number (948) of particles. Field observations indicate that this sample contained a cluster of semi-intact fibers that had become buried under the dirt on the floor of the chamber and is considered an anomaly that was removed from the analysis except as noted[16]. Data

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[13] The reduction in chaff fragmentation rates in the Livestock and Vehicle Treatment tests is probably due to winnowing of chaff during the course of the treatment itself, and prior to wind driven fragmentation when the fan was operated.

[14] Three treatment types, three replicates per treatment type, two samples (fan-end, exhaust-end) per replicate, and two chaff load levels, plus pre- and post-test samples; i.e., 3x3x2x2x2=72 soil samples.

[15] In one of the "High Chaff Load, Vehicle Treatment" replicates.

[16] In the following tables an * indicates where these data have been removed in the following tables.

on PSD for fine particles was collected using X-ray diffraction techniques, which should have been able to detect the presence of particles in this size class. However, no such particles were in fact detected so it is assumed that particles in this size class were not retained in the soil samples. The following discussion focuses on results of the coarse PSD analysis.

B.16.6 Baseline Conditions

One-half of the soil samples were obtained prior to testing. Coarse chaff fragments were found only in some pre-treatment samples in the Chamber-Only tests. The Vehicle treatment tests were conducted on unpaved roads on Melrose Air Force Range, New Mexico, where it would be plausible that chaff retention would be low due to ambient wind conditions. Livestock tests were conducted in Wyoming, where chaff was not in routine use. Thus, it is not surprising that pre-treatment chaff fragments were recovered only from the Chamber-Only tests.

Pre-treatment data suggest a chaff density of 1 microgram/square feet[17] in the soils of Melrose Range. The sparseness of these data[18] limits the confidence that can be placed in this estimate. It is useful to recognize that the amount of chaff used in the treatment tests (0.16 grams and 0.03 grams), if dispersed evenly over the area covered by the environmental chamber, would have resulted in much higher densities (5,000 micrograms/square feet and 938 micrograms/square feet, respectively) than that observed in the pre-treatment soil samples. On this basis, it is clear that baseline chaff concentrations in the test areas are sufficiently low that they can be safely ignored in interpreting test results.

B.16.7 Chaff Load Level

Post-Treatment soil samples show differences in the number of chaff particles recovered for high chaff loads and low chaff load tests. Table B 11 summarizes these differences for raw particle numbers.

Table B 11. Coarse Chaff Particles Recovered from Soil Samples

Chaff Load	Treatment	Size Class Mean Particle Length (millimeter)			Total All Lengths
		19	**9.65**	**3.65**	
		Estimated Weight (micrograms) of Chaff Recovered by Size Class			
High	Chamber Only	1	0	3	**4**
	Vehicle*	1	6	19	**26**
	Livestock	0	2	1	**3**
	Total	**2**	**8**	**23**	**33**
Low	Chamber Only	0	1	4	**5**
	Vehicle	0	2	20	**22**
	Livestock	1	0	2	**3**
	Total	**1**	**3**	**26**	**30**

Note: *One of five samples discarded as anomalous.

Table B 12 shows the differences in terms of total chaff weight recovered[19]. Overall, data shows that high chaff loads resulted in greater chaff deposition on the soil of the chamber. These results, though

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[17] This estimate is based on a linear-density of 0.2µg/mm. This, in turn, is based on DRI 2002, which specifies that a representative chaff bundle weighs about 150 g, and consists of about 5 million fibers, each fiber being between 1 and 2 cm in length,

[18] While chaff was recovered from some of the pre-treatment soil samples in the Chamber-Only tests, only two out of 24 samples contained chaff, and the amount of chaff recovered was sparse (a single chaff fragment in each test).

[19] Based on a chaff length-density of 1.5152µg/mm, assuming that the chaff fragments within a given size class are of a uniform size corresponding to the mid-point of the size class.

not entirely consistent, are generally as expected. That is, it would be expected that the use of larger amounts of chaff in any given test would result in larger amounts of chaff being recovered from the soil.

Table B 12. Weight of Chaff Recovered from Soil Samples

Chaff Load	Treatment	Size Class Mean Particle Length (millimeter)			Total All Lengths
		19	**9.65**	**3.65**	
		Estimated Weight (micrograms) of Chaff Recovered by Size Class			
High	Chamber Only	380	0	219	**599**
	Vehicle*	380	1,158	1,387	**2,925**
	Livestock	0	386	73	**459**
	Total	**760**	**1,544**	**1,679**	**3,983**
Low	Chamber Only	0	193	292	**485**
	Vehicle	0	386	1,460	**1,846**
	Livestock	380	0	146	**526**
	Total	**380**	**579**	**1,898**	**2,857**

Note: *One of five samples discarded as anomalous.

B.16.8 Longitudinal Distribution

Paired soil samples were taken for each test, with one sample taken from the inlet (fan) side of the chamber, and one sample taken from the exhaust side of the chamber. These data (Table B 13 and Table B 14) can be used to evaluate longitudinal differences in chaff distribution within the chamber. Overall, these data show that most of the chaff (roughly 80 percent by weight) was deposited at the exhaust-end of the chamber. These results are consistent for both high and low chaff loads.

Table B 13. Comparison of Particle Numbers by Position within Chamber

Chaff Load	Chamber Location	Size Class Mean Particle Length (millimeter)			Total All Lengths
		19	**9.65**	**3.65**	
		Number of Particles Recovered by Size Class			
High	Exhaust Side	2	6	22	**30**
	Fan Side	0	2	1	**3**
	Total	**2**	**8**	**23**	**33**
Low	Exhaust Side	1	1	16	**18**
	Fan Side	0	2	5	**7**
	Total	**1**	**3**	**21**	**25**

Note: *One of five samples discarded as anomalous.

Table B 14. Comparison of Chaff Weight by Position within Chamber

Chaff Load	Chamber Location	Size Class Mean Particle Length (millimeter)			Total All Lengths
		19	**9.65**	**3.65**	
		Number of Particles Recovered by Size Class			
High	Exhaust Side	43.8	66.7	92.5	**202.9**
	Fan Side	0.0	22.2	4.2	**26.427**
	Total	**43.8**	**88.9**	**96.7**	**229.32**
Low	Exhaust Side	21.9	11.1	67.2	**100.2**
	Fan Side	0.0	22.2	21.0	**43.2**
	Total	**21.9**	**33.3**	**88.3**	**143.5**

Note: *One of five samples discarded as anomalous.

B.16.9 Particle Size Distribution

The data in Table B 12 also provides information on aggregate particle size distribution for chaff recovered from soil samples. Table B 15 summarizes the data by count and by estimated weight for all tests. The data show an increase in recovered particles in the smallest size class. These data are consistent with progressive fractionation of the chaff fibers into smaller particles.

Table B 15. Chaff Particles Recovered from Soil Samples

	Chaff Particles by Median Size Class (millimeter)		
	19	9.65	3.65
Count	3	11	49
Weight (micrograms)	1,140	2,123	3,577

B.16.10 Treatment Type

Table B 16 provides data on the estimated amount of chaff remaining on the chamber floor following treatment. In the case of the chamber only and livestock tests, about 2 percent of the chaff was retained on the soil as particles larger than 1 mm. Substantially higher retention levels (18 percent for high chaff loads, and 6 percent for low chaff loads) were obtained for the Vehicle treatment tests. This difference in retention between the chamber only and Livestock treatment on the one hand, and the vehicle treatment on the other appears to be an innate difference associated with treatment type.

Table B 16. Effect of Treatment Type on Chaff Deposition

Chaff Load	Treatment	Number of Samples [1]	Total Weight Introduced to Chamber (micrograms)	Total Weight Recovered (micrograms)	Average Weight Recovered per Sample (micrograms)	Chaff Density (micrograms/ square feet) [2]	Total Deposition [3]	Percent of Load Deposited on Chamber Floor
High	Chamber Only	6	480,000	599	100	310	9,907	2.1%
	Vehicle (4)	5	320,000	2,925	585	1,811	57,957	18.1%
	Livestock	6	480,000	459	77	238	7,628	1.6%
	Total	**17**	**1,280,000**	**3,983**	**762**	**2,359**	**75,492**	**4.5%**
Low	Chamber Only	6	480,000	485	81	25	8,025	1.7%
	Vehicle	6	480,000	1,846	308	954	30,514	6.4%
	Livestock	6	480,000	526	88	272	8,718	1.8%
	Total	**18**	**1,440,000**	**2,857**	**477**	**1,251**	**47,257**	**2.1%**

Notes:

[1] Three replicate tests, each with a composite sample taken at front and rear of chamber, for six samples.
[2] Sample area = 0.323 square feet.
[3] Chamber area = 32 square feet.
[4] One of six original samples discarded as anomalous.

It is unlikely that these results can be explained by differences in chamber design. Chamber design in the livestock treatment was substantially different from that in the chamber only tests; nonetheless, chaff retention levels shown in these treatments were virtually identical. Chamber design for the vehicle treatment tests was identical to that used in the chamber-only tests; yet in this case, chaff retention between the treatments was much different. Thus, the elevated deposition of chaff observed in the soil data for the Vehicle Treatment tests appears to be innately related to the treatment itself.

Several treatment-related explanations for these data present themselves. First, the nature of the livestock and vehicle treatments required that the treatment be performed prior to complete erection of the environmental chamber. It is possible that some chaff was lost from the study site prior to the erection of the chamber, and hence, could not contribute to the recovery of chaff from the chamber floor at the conclusion of the test. While it is likely that some “pre-chamber wastage” occurred in the livestock and vehicle tests, it is unlikely that wastage contributed significantly to the higher retention rates for the vehicle tests. If wastage were a significant factor, it would be expected that the Chamber-Only tests (where wastage could not occur) would have the highest retention. Yet in that case, retention was virtually identical to the livestock test, and substantially lower than that found in the Vehicle tests. While effects from wastage should not be ignored, this factor does not appear to be related to the higher retention rate for the vehicle tests.

It is possible that some of the differences in retention are related to the formation of particles less than 1 millimeter. Particles less than 1 millimeter would not have been captured in the soil PSD data, creating the impression of wastage. It is very likely that these treatments did result in the formation of substantial amounts of particles less than 1 millimeter. However, all treatments involved the use of the environmental chamber. As a result, the vehicle and livestock treatments could only have resulted in greater fragmentation, and hence greater formation of particles less than 1 millimeter. Under these circumstances, it would again be expected that retention would be reduced in the vehicle tests. Since retention is highest in the vehicle tests it would not seem that wastage from this source is an important factor in explaining the results.

A final possibility that may be considered is that the vehicle tests uniquely resulted in less fragmentation than the other tests. In this view, operation of the vehicles may have been sufficiently rigorous to force some of the chaff fibers into the dirt in such a way that they could not be “lofted” when the environmental chamber was put over the study site. This would have removed these fibers from the fragmentation process, resulting in greater retention in the soil sampling data. While this seems a likely explanation for the experimental results, additional testing would be required to assess this possibility.

B.16.11 Elemental Intensity Data

X-ray diffraction represents a potentially useful approach for rapidly assessing changes in chaff concentration in soils under varying conditions. Comparison of results for spiked and un-spiked soil samples in Table B 5 shows that differences in chaff level can be detected in bulk soil samples; at least where the amount of chaff involved is substantial. Element intensities for silicon, potassium calcium iron, magnesium, and sodium were higher by a factor of 1.3 to 1.8 in the spiked soil samples. In the case of aluminum, intensities were substantially higher in the spiked samples (by a factor if 4.0 to 11.2); this presumably represents the high aluminum content of chaff.

Data for elemental intensities in experimental samples suggests that this approach is less useful for samples with trace contamination of chaff. The data in Table B 6 show that overall element intensities were higher for post-test chaff samples. That indicates that chaff was being retained in the soils resulting from the various treatments employed. This is consistent with the coarse particle data evaluated above. However, with an overall Post-Test/Pre-Test ratio of 1.14, the increase in elemental intensity was not great. Indeed, in many cases (23 instances out of 56, or 50 percent of the time), the element intensities were higher in the pre-test (baseline) samples. This suggests that the differences in element intensities were unrelated to test conditions. It is likely that natural variability in the abundance of these elements simply overwhelmed any effect due to chaff loading, and that any overall difference in element intensity reflects random sample variation.

X-ray diffraction techniques were also used to examine test samples for the presence of individual chaff particles in the range of 10 micrograms or less. No such particles were detected in the soil using this technique. If such fragments were present, they proved to be indistinguishable from other soil particles. However, coarse particles in the spiked samples were readily detected in X-ray diffraction microphotographs. Overall, it seems likely that 10 micrograms or fewer particles were simply not present in the soil samples, despite the fact that we know from the air sampling PM_{10} data that such particles were created. It appears that while PM_{10} particles were being created during the test via chaff fragmentation, they were not retained in the soil.

A likely explanation for the absence of PM_{10} chaff particles in the soil lies with the rapid flushing rate of the chamber. The airflow analysis suggests that the chamber was being emptied about once every two seconds during the course of each test. While PM_{10} particles were being created under the test conditions in sufficient quantities to be captured by the PM_{10} sampler, those particles were apparently flushed from the chamber as rapidly as they were being created. Only the chaff "in the air" at the end of the test would have been available for resettling onto the soil of the chamber.

The amount of chaff potentially available for re-deposition can be estimated. If the entire chaff load used in these tests was converted into PM_{10} size fragments, the amount of PM_{10} being created each second would have been about 22 micrograms[20]. If re-deposited on the soil, the resulting chaff density would have been about 0.7 micrograms/square feet, or slightly less than baseline levels of 1 microgram/square feet. Two factors make this an overestimate of the amount of PM_{10} chaff that could be present on the chamber floor at the end of the test. First, we know from the coarse soil samples that not all chaff was converted to PM_{10} size fractions. Observed coarse chaff concentrations in the soil were 3 to 4 orders of magnitude larger than the maximum fine chaff concentration that could be expected. Second, the data on from the PM_{10} samplers indicates that the amount of fine chaff being created dropped off towards the end of the test period; as a result, less chaff would have been present in the air and available to settle out on the ground at the conclusion of the test. Thus, even under optimal conditions we would expect the PM_{10} concentration in the soil to be slight, and well below observed baseline levels.

B.16.12 Chaff Retention and Fragmentation

It is useful to compare the chaff retention data (Table B 17) obtained from the soil samples, with the fragmentation rates obtained from the air sampling data. As a generalization, it would be expected that chaff retention would be inversely related to fragmentation. This is because reduced fragmentation implies more of the chaff would be in size ranges larger than 1 millimeter, and larger particles are more likely to be retained within the chamber, to be ultimately deposited on the chamber floor. This interpretation is borne out in the data in Table B 17, and illustrated in Figure B 7.

Table B 17. Chaff Fragmentation and Retention

Chaff Load	Treatment	Fragmentation	Retention	Air flow
High	Chamber Only	4.9%	2.1%	6.3
	Livestock	10.3%	1.6%	19.8
	Vehicle	2.7%	18.1%	4.7
Low	Chamber Only	16.2%	1.7%	5.1
	Livestock	26.9%	1.8%	16.7
	Vehicle	4.2%	6.4%	6

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[20] In high chaff load tests 0.16 gram of chaff was placed in the chamber. The test duration was two hours. This is equivalent to 22.2 micrograms chaff being created per second. Spread evenly over the area of the chamber, this would have been equivalent to a density of 0.69 micrograms/square feet. As was previously noted, background PM_{10} concentrations are probably on the order of 1 microgram/square feet, at least at the study sites on Melrose Range.

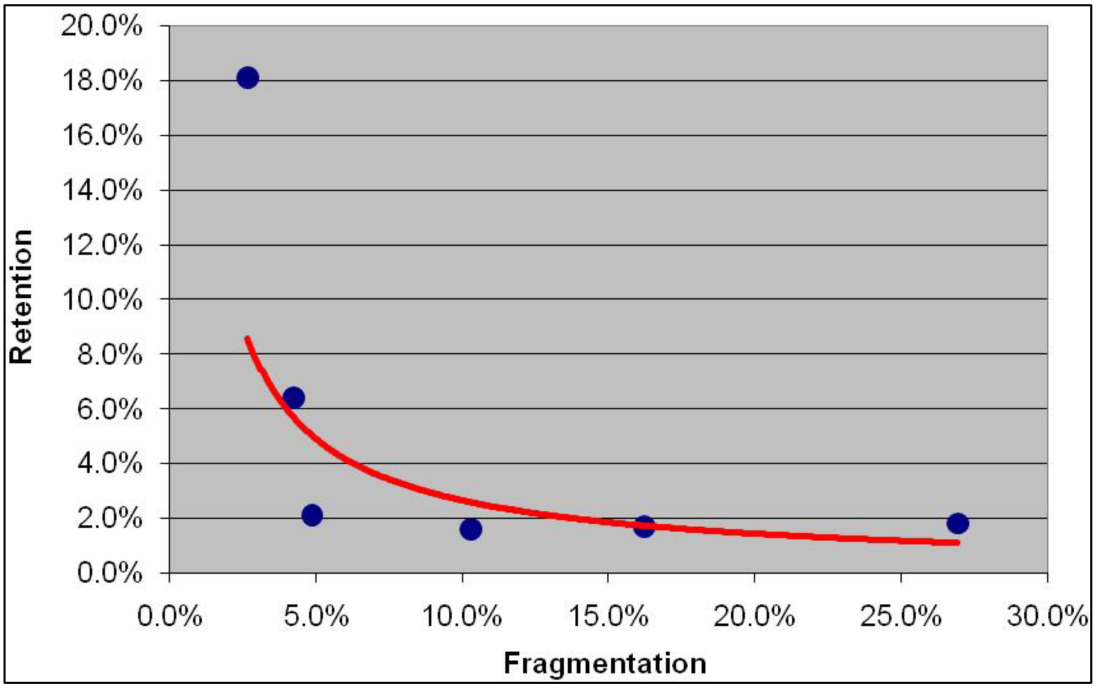

Figure B 7. Chaff Retention as a Function of Fragmentation

Overall, chaff retention appears to be relatively slight (about 2 percent) over the observed range of chaff fragmentation except at very low levels of fragmentation. This may be because fragmentation is directly related to wind speed. At low air flow, less fragmentation occurs, and particles available for deposition are larger, a circumstance favoring retention. This interpretation may be overly simplistic. While it is true that high retention was observed only in tests with low air flows, it is also true that high retention was only observed in the Vehicle treatment tests. It is thus difficult to determine whether high retention was related to low air flow, or to the nature of the treatment. The correlation between retention and fragmentation may be purely coincidental. Expanded sampling could determine the relationship between retention and air flow.

B.17 Environmental Chamber Test Lessons Learned

Use of an environmental chamber offers considerable potential for understanding the fate of chaff in the environment. The following recommendations are made.

B.17.13 Employ a Standardized Chamber Design

The Chamber-Only and Vehicle tests utilized a 36-inch fan connected to the chamber by a cowling system venting into the chamber through a plywood end panel. The Livestock tests employed a 48-inch fan butting directly to the end of the chamber. This created a “fan-gap” at the corners of the chamber that allowed air to escape. This design difference affected the interpretation test results. In particular, airspeed measurements in the Livestock tests were not directly comparable to those obtained in the Chamber-Only and Vehicle tests. This affected estimated airflow through the chamber, a measure of considerable importance for estimation of chaff fragmentation, and deposition within the chamber. In addition, the presence of the unscreened fan-gap allowed the escape of large chaff fragments, thereby further distorting fragmentation data.

B.17.14 Employ a Standardized Test Design

In the Chamber-Only tests, chaff was introduced into the chamber after the fan was turned on; as a result, the chaff was immediately entrained into the air stream. The nature of the Vehicle and Livestock tests required that the chaff be placed on the ground prior to test treatments; the chamber was erected over the chaff after the treatment was completed. This difference in test design affected test results in several ways:

1. Unfragmented chaff may have been lost from the Vehicle and Livestock tests sites prior to erection of the environmental chamber; this would have reduced the amount of chaff available for recovery from the test chamber during the operation of the chamber, exaggerating the estimates of fragmentation.
2. In the Livestock and vehicle tests, the test chaff was lofted from the ground when the fan was started. It is possible that the treatment prevented some of the chaff from being entrained into the air stream. Such chaff embedded in the soils would not be subject to fragmentation driven by wind turbulence. This, again, would have resulted in an underestimation of chaff fragmentation, at least in the PSD sampler results. It could have also resulted in exaggerated recovery of large fibers from the soil samples.
3. The tests included a number of uncontrolled or only partially controlled environmental variables. These variables included ambient wind conditions, substrate type, and natural vegetation present within the chamber.
    a. Ambient wind conditions varied considerably from test to test, and there is some evidence that the airspeed at the exhaust vent varied to some extent with ambient wind conditions.
    b. Substrate type may have affected the amount of chaff retained on the soil, particularly in the Vehicle and Livestock tests where the chaff was lofted from the soil as airspeed increased. It is likely that the airspeed needed to loft the chaff fibers varied with substrate type. Thus, substrate type may have affected the amount of chaff exposed to wind turbulence within the chamber, affecting both chaff fragmentation measurements.
    c. The presence of native vegetation within the test chamber may have created ‘sanctuaries’ on which chaff fibers may have been protected from wind turbulence, thereby reducing estimated fragmentation rates. Alternatively, fragmentation may have increased due to increased surface area against which the fibers could have come in contact. In either case, the amount and kind of vegetation within the chamber was not considered in the test design, and represents an uncontrolled variable.
    d. Elemental intensities of the soil, as measured in EPMA analysis, varied widely, even within a single test location. This natural variation is thought to be large compared to any potential variation due to the accumulation of chaff within the soil resulting from test conditions. As a result, it was not possible to estimate the extent of chaff retention in the soils through changes in elemental intensity.

Elimination of sources of natural environmental variation is essential if future tests of this sort are conducted. Elimination of these sources of variability could be accomplished by conducting studies within a laboratory environment, where ambient wind conditions and substrate type could be controlled.

In this study, the fraction of chaff converted to PM_{10} was based on estimating the ratio of chaff/non-chaff PM_{10} collected in the PM_{10} sampler. Multiplying this ratio by the estimated ambient PM_{10}

background provided a crude estimate of the amount of chaff PM_{10} collected in the sampler. That crude estimate was then used to estimate the fraction of chaff fragmented into PM_{10} during the test. Obtaining a direct measurement of ambient PM_{10} and weighing sampling filters could improve the sampling results.

B.18 Summary

Taking into consideration the combined data for air and soil sampling, results of the environmental chamber tests suggest that chaff fibers, once deposited on the ground, are readily re-suspended at air speeds representative of ambient wind conditions. Once suspended, the chaff fibers are subjected to various abrasive forces (fiber-to-ground, fiber-to-fiber, impingement on the walls of the chamber, etc.) which act to fragment individual fibers. Overall, the data show that at the conclusion of the tests, about 10 percent of the chaff had been converted to PM_{10} size particles, and about 2 percent remained at particle sizes larger than 1 millimeter. While there is substantial variation in these data, it appears that generally, most of the chaff is reduced to particles between 1 millimeter and 10 microns. Particles in this size range are too large to be picked up in the PM_{10} sampler, yet small enough to be winnowed through the screening of the exhaust port. As a result, only largely unfragmented chaff fibers remained within the chamber at the end of a test where they were deposited on the floor of the chamber. While some PM_{10} chaff is undoubtedly present within the chamber and settles onto the chamber floor at the end of a test, the absolute amount of such chaff is negligible (less than 1 microgram/square feet). It is not surprising that chaff in the PM_{10} size range, at this concentration, would not be detected in the soil samples.

While there are some differences in chaff fragmentation and retention related to treatment type, by and large, it appears that wind related turbulence is the major factor in determining the fate of training chaff. Results are generally constant between the DRI and Cook studies (DRI 2002; Cook 2002). There is a relatively rapid fragmentation of the chaff fibers in these tests, at wind speeds approximating ambient wind conditions. The conclusion is that most chaff fibers would fragment into particles 1 mm or less within a few days of deposition. Some of those particles are within the range of respirable particle sizes. At these particle sizes, chaff becomes indistinguishable from ambient soil particles. The data at hand are not sufficient to gauge whether prolonged exposure to environmental conditions would result in greater formation of PM_{10} size particles. It is possible that prolonged exposure would convert virtually all of the chaff fibers into PM_{10}. It is also possible that further formation of PM_{10} would be negligible.

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APPENDIX C

SAMPLES

APPENDIX C SAMPLES

Table C-1. Intensity Maps for Pre-Test Soil Samples

Test	Replicate	Load	Pre-Post	Sub Sample	Element Intensity (c/s/nA)	Sample	Al-norm	Si-norm	K-norm	Ca-norm	Fe-norm	Mg-norm	Na-norm
C-1L	PC1	C	1	L	P	C1	262.1	693	81.1	257.l7	89.9	89.9	69.1
C-1L	PC2	C	1	L	P	C2	285.9	789.4	94.1	117.6	101.2	141.2	78.8
C-1H	PC1	C	1	H	P	C1	204.5	549.9	68.6	83.5	27.4	39.9	26.2
C-1H	PC2	C	1	H	P	C2	352.3	687.7	86	240.9	90.8	93.2	64.2
C-2L	PC1	C	2	L	P	C1	116.9	352	37.3	26.1	27.4	14.9	27.4
C-2L	PC2	C	2	L	P	C2	260	765.8	84.3	117.1	73.8	87.8	64.4
C-2H	PC1	C	2	H	P	C1	275.1	773.9	94.7	214.9	112.5	103.6	71.3
C-2H	PC2	C	2	H	P	C2	291.8	781.7	88	203.8	82.4	139.2	67.9
C-3L	PC1	C	9	L	P	C1	292.5	763	87.3	398.6	87.3	116.7	69.6
C-3L	PC2	C	3	L	P	C2	275.3	676.5	89.4	261.2	107.1	121.2	72.9
C-3H	PC1	C	9	H	P	C1	160.8	450.1	42.4	42.4	18.7	20	13.7
C-3H	PC2	C	3	H	P	C2	188.6	570.7	36	100.5	26.1	24.8	37.2
C-4H	PC1	C	4	H	P	C1	316.7	651.7	81.3	532.8	93.4	159	59.5
C-4H	PC2	C	4	H	P	C2	238.9	600.2	76.9	402.1	87.4	116.6	53.6
L/S-1L	PC1	L/S	1	L	P	C1	268.4	750.6	91.3	257.2	83.5	133.6	84.6
L/S-1L	PC2	L/S	1	L	P	C2	282.4	763.7	86.8	319.8	104.4	123.1	68.1
L/S-1H	PC1	L/S	1	H	P	C1	218.5	642.7	69.4	135	60.4	83.5	54
L/S-1H	PC2	L/S	1	H	P	C2	258.9	736	86.3	144.7	60.9	87.6	57.1
L/S-2L	PC1	L/S	2	L	P	C1	244.4	716	98.8	246.9	106.2	111.1	93.8
L/S-2L	PC2	L/S	2	L	P	C2	311.1	872.8	95.1	249.4	109.9	116	77.8
L/S-2H	PC1	L/S	2	H	P	C1	249.4	642.2	85.1	197	86.2	128.2	47.8
L/S-2H	PC2	L/S	2	H	P	C2	227.1	656.5	84.7	209.4	65.9	109.4	64.7
L/S-3L	PC1	L/S	3	L	P	C1	339.7	787.2	92.3	307.7	109	144.9	71.8
L/S-3L	PC2	L/S	3	L	P	C2	282.6	727.6	92.1	286.4	129.2	104.9	63.9
L/S-3H	PC1	L/S	3	H	P	C1	252.5	728.1	97.8	365.6	70.3	70.3	65.2
L/S-3H	PC2	L/S	3	H	P	C2	251.2	657.4	89.1	322.9	112.3	107.6	55.6
V-1L	PC1	V	1	L	P	C1	297	775.7	81.5	70.2	101.5	142.9	80.2
V-1L	PC1S	V	1	L	P	C1S	1201.9	711.2	72.2	119	90.9	107	64.2
V-1L	PC2	V	1	L	P	C2	276	646.7	89.3	128	100	228	80
V-1H	PC1	V	1	H	P	C1	196.9	735.1	50.1	472.6	27.4	83.5	72.8
V-1H	PC1S	V	1	H	P	C1S	1822.3	847.5	83.6	500	43.8	103.4	55.7
V-1H	PC2	V	1	H	P	C2	197.2	810.8	78.7	498	59.8	116.5	76.7
V-2L	PC1	V	2	L	P	C1	291.3	657.8	74	233	47.3	49.8	48.5
V-2L	PC2	V	2	L	P	C2	105.7	269.9	30.8	70	19.9	16.9	21.7
V-2L	PC2S	V	2	L	P	C2S	1179.1	704.5	85.6	251.3	89.6	77.5	58.8
V-2H	PC1	V	2	H	P	C1	187.8	436.6	73.1	161.8	68.2	35.6	41.7
V-2H	PC2	V	2	H	P	C2	212.5	636.2	79.9	55.7	39.3	31.5	46.6
V-3L	PC1	V	3	L	P	C1	206.4	831.7	70.4	269.7	32.2	80	51.3
V-3L	PC1S	V	3	L	P	C1S	1489.3	724.6	89.6	348.9	49.5	97.6	76.2
V-3L	PC2	V	3	L	P	C2	247.5	841.8	90.3	395.5	112.6	79.1	64.9
V-3L	PC2S	V	3	L	P	C2S	1791.8	798.2	83.5	377.9	118.3	95.1	65.6
V-3H	PC2	V	3	H	P	C2	209	788.6	80.8	373.1	56	53.5	63.4
V-3H	PC2S	V	3	H	P	C2S	1559	861.9	83.1	516.1	49.6	92.5	57.6

Key:

L = low chaff treatment H = high chaff treatment PC = pre-treatment

Table C-2. Intensity Maps for Post-test Soil Samples

Test	Replicate	Load	Pre-Post	Sub Sample	Element Intensity (c/s/nA)	Sample	Al-norm	Si-norm	K-norm	Ca-norm	Fe-norm	Mg-norm	Na-norm
C-1L	POC1	C	1	L	PO	C1	232.5	511.7	78.3	171.7	78.3	53.7	65.4
C-1L	POC2	C	1	L	PO	C2	266.3	719.1	96.9	111.4	88.4	78.7	66.6
C-1H	POC1	C	1	H	PO	C1	289.4	705.9	96.5	148.2	84.7	109.4	76.5
C-1H	POC2	C	1	H	PO	CW	248.1	564.5	74.4	130.3	42.2	36	47.1
C-2L	POC1	C	2	L	PO	C1	69.7	180.3	27.4	17.4	12.4	16.2	19.9
C-2L	POC2	C	2	L	PO	C2	177.1	573.6	42.4	46.1	27.4	28.7	21.2
C-2H	POC1	C	2	H	PO	C1	258.1	569.5	48.4	37.2	53.3	18.6	44.7
C-2H	POC2	C	2	H	PO	C2	243	670.6	87.6	196.3	90	106.3	57.2
C-3L	POC1	C	3	L	PO	C1	251.8	677.6	69.4	388.2	94.1	125.9	60
C-3L	POC2	C	3	L	PO	C2	279.7	717	80.4	384.4	98	114.5	68.3
C-3H	POC1	C	3	H	PO	C1	242.6	755	75.5	237.6	76.7	96.5	60.6
C-3H	POC2	C	3	H	PO	C2	176.6	532.3	34.8	37.3	21.1	21.1	39.8
C-4H	POC1	C	4	H	PO	C1	276.3	757.6	86.7	422.7	74.9	114.8	64.4
C-4H	POC2	C	4	H	PO	C2	120.9	546.1	26.2	155.9	24.9	26.2	44.9
L/S-1L	POC1	L/S	1	L	PO	C1	292.7	751.3	87.9	201	66.6	113.1	75.4
L/S-1L	POC2	L/S	1	L	PO	C2	296.7	771.5	83.7	212.9	117.2	118.4	86.1
L/S-1H	POC1	L/S	1	H	PO	C1	298.6	817.7	87.5	209.8	89.9	153.5	76.7
L/S-1H	POC2	L/S	1	H	PO	C2	312	842.1	78.9	213	80.2	85.2	72.7
L/S-2L	POC1	L/S	2	L	PO	C1	270.7	722.6	83.9	448.5	87.2	114.1	54.8
L/S-2L	POC2	L/S	2	L	PO	C2	301.2	809.5	97.6	182.1	107.1	161.9	71.4
L/S-2H	POC1	L/S	2	H	PO	C1	276.5	740.7	82.7	156.8	64.2	97.5	59.3
L/S-2H	POC2	L/S	2	H	PO	C2	223.7	698.6	76.6	143.5	95.7	130.4	65.8
L/S-3L	POC1	L/S	3	L	PO	C1	282.1	787.2	89.7	280.8	110.3	117.9	66.7
L/S-3L	POC2	L/S	3	L	PO	C2	224.4	673.1	84.6	143.6	52.6	109	60.3
L/S-3H	POC1	L/S	3	H	PO	C1	267.7	730.3	81.8	360.6	113.1	100	67.7
L/S-3H	POC2	L/S	3	H	PO	C2	285.2	766.1	85.9	128.9	122.9	103.8	81.1
V-1L	POC2	V	1	L	PO	C2	308	753.1	93.5	314.2	88.5	124.7	74.8
V-1H	POC1	V	1	H	PO	C1	198.1	774.5	80	466.6	46.5	99	56.1
V-1H	POC2	V	1	H	PO	C2	261.3	815	68	452.3	58.5	75.2	58.5
V-2L	POC1	V	2	L	PO	C1	229.4	605.3	65.4	311.1	57.5	92	60.5
V-2L	POC2	V	2	L	PO	C2	245.8	765.1	75.7	283.9	69.6	52.7	64.8
V-2H	POC1	V	2	H	PO	C1	299.5	776.8	93.1	480.9	109.8	74	83.5
V-2H-	POC2	V	2	H	PO	C2	359.8	922.7	98.2	256.1	65.1	76.2	80.6
V-3L	POC1	V	3	L	PO	C1	252	720.5	70.1	503	88.4	104.7	81.3
V-3L	POC2	V	3	L	PO	C2	242.4	848.3	81.5	445	73.3	153.8	72.3
V-3H-	POC1	V	3	H	PO	C1	225.8	674.9	33.5	400.7	32.3	27.3	45.9
V-3H	POC2	V	3	H	PO	C2	155.5	551	94.5	304.7	118.2	22.4	47.3

Key:

L = low chaff treatment H = high chaff treatment PC = pre-treatment

Table C-3. Results for Chamber-Only Tests

Sample	Time	Number Particles Examined	microns (µm)		Total Core	Al-Chaff	Total Core	Al-Chaff
			Chaff Particles Recognized: 10-2.5	Chaff Particles Recognized: <2.5				
BG/Y-1H	1	173	10	1	9	1	1	0
BG/Y-1L	1	178	6	1	5	2	2	0
BG/Y-1L	2	182	5	2	3	4	3	1
BG/Y-1L	3	159	7	2	5	5	4	1
BG/Y-1L	4	153	3	1	2	4	2	2
BG/Y-2H	1	154	9	1	8	3	3	0
BG/Y-2H	2	164	6	3	3	4	4	0
BG/Y-2H	3	152	3	1	2	2	2	0
BG/Y-2H	4	152	4	1	3	3	3	0
BG/Y-2L	1	165	6	0	6	0	0	0
BG/Y-2l	2	175	4	0	4	7	5	2
BG/Y-2L	3	149	5	1	4	8	6	2
BG/Y-2L	4	149	5	2	3	5	5	0
BG/Y-3 low	1	148	0	0	0	1	1	0
BG/Y-3 low	2	146	0	0	0	0	0	0
BG/Y-3 low	3	154	2	1	1	0	0	0
BG/Y-3 low	4	154	0	0	0	1	0	1
BG/Y-EH	1	149	5	1	4	3	2	1
BG/Y-3H	2	135	0	0	0	7	7	0
BG/Y-3H	3	151	4	2	2	2	2	0
BG/Y-3H	4	145	1	0	1	3	1	2
BG/Y-4 high	1	153	4	0	4	1	0	1
BG/Y-4 high	2	157	1	0	1	1	0	1
BG/Y-4 high	3	149	1	1	0	2	1	1
BG/Y-4 high	4	146	1	0	1	3	1	2

Table C-4. Results for Livestock Tests

Sample	Time	Number Particles Examined	microns (µm)		Total Core	Al-Chaff	Total Core	Al-Chaff
			Chaff Particles Recognized: 10-2.5	Chaff Particles Recognized: <2.5				
CAT-1H	1	176	2	0	2	2	1	1
CAT-1H	2	159	2	1	1	3	3	0
CAT-1H	3	150	3	1	2	3	2	1
CAT-1H	4	143	0	0	0	3	3	0
CAT-1L	1	176	2	1	1	1	0	1
CAT-1L	2	163	0	0	0	0	0	0
CAT-1L	3	155	1	0	1	1	0	1
CAT-1L	4	167	0	0	0	0	0	0
CAT-2H	1	144	3	0	3	2	1	1
CAT-2H	2	142	2	0	2	2	2	0
CAT-2H	3	160	1	0	1	2	1	1
CAT-2H	4	154	1	0	1	7	3	4
CAT-2L	1	139	5	0	5	3	2	1
CAT-2L	2	154	3	1	2	3	3	0
CAT-2L	3	167	3	0	3	1	1	0
CAT-2L	4	158	1	0	1	2	2	0
CAT-3H	1	141	8	1	7	2	1	1
CAT-3H	2	130	2	0	2	3	1	1
CAT-3H	3	168	0	0	0	0	0	0
CAT-3H	4	135	2	1	1	0	0	0
CAT-3L	1	166	1	0	1	0	0	0
CAT-3L	2	138	1	0	1	0	0	0
CAT-3L	3	159	0	0	0	0	0	0
CAT-3L	4	140	0	0	0	1	1	0

Table C-5. Results for Vehicle Tests

Sample	Time	Number Particles Examined	microns (µm)		Total Core	Al-Chaff	Total Core	Al-Chaff
			Chaff Particles Recognized: 10-2.5	Chaff Particles Recognized: <2.5				
RD-1L	1	144	0	0	0	0	0	0
RD-1L	2	166	0	0	0	0	0	0
RD-1L	3	150	2	0	2	2	2	0
RD-1L	4	163	0	0	0	1	0	1
Road 1 High	1	169	7	2	5	1	1	0
Road 1 High	2	149	5	2	3	1	0	1
Road 1 High	3	167	2	0	2	2	0	2
Road 1 High	4	162	1	1	0	4	2	2
Road 2 High	1	157	2	0	2	0	0	0
Road 2 High	2	150	3	0	3	2	0	2
Road 2 High	3	156	3	1	2	3	1	2
Road 2 High	4	154	1	0	1	7	3	4
Road 2 Low	1	142	1	0	1	0	0	0
Road 2 Low	2	154	0	0	0	0	0	0
Road 2 Low	3	148	0	0	0	1	0	1
Road 2 Low	4	150	1	1	0	0	0	0
Road 3 High	1	137	4	1	3	0	0	0
Road 3 High	2	155	4	0	4	3	0	3
Road 3 High	3	133	3	2	1	4	1	3
Road 3 High	4	166	0	0	0	0	0	0
Road 3 Low	1	158	1	0	1	0	0	0
Road 3 Low	2	145	1	0	1	1	1	0
Road 3 Low	3	163	0	0	0	1	0	1
Road 3 Low	4	165	2	1	1	0	0	0