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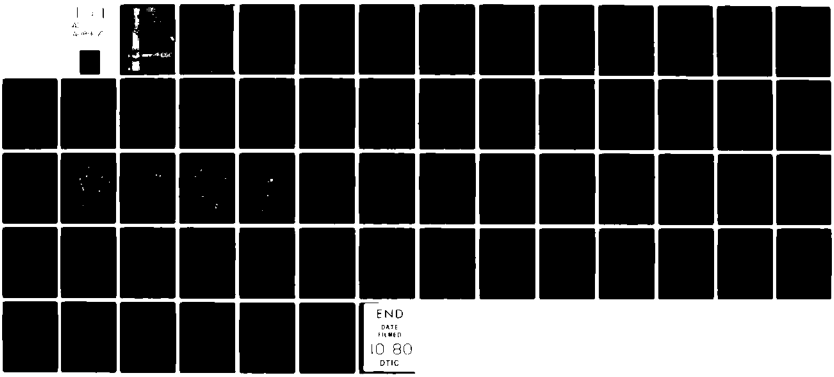

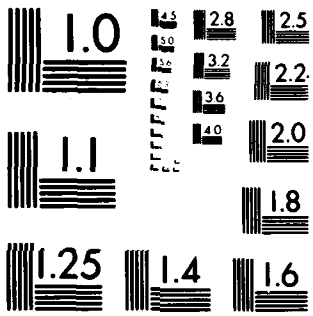

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FUEL JETTISONING BY U.S. AIR FORCE AIRCRAFT

VOLUME I : SUMMARY AND ANALYSIS

HARVEY J. CLEWELL III
ENVIRONICS DIVISION
ENVIRONMENTAL SCIENCES BRANCH

MARCH 1980

FINAL REPORT
FEBRUARY 1972 – DECEMBER 1979

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An analysis of 3½ years of data on fuel jettisoning by US Air Force aircraft was performed to provide the basis for an accurate assessment of the environmental effects associated with this practice. The nature and extent of US Air Force jettisoning was examined, and the principal commands, aircraft, locations, altitudes, and quantities were identified. The reasons for fuel jettisoning were also investigated, and the relative importance of fuel jettisoning as a source of hydrocarbon pollution was estimated, considering both the possibility

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) of ground contamination by liquid fuel, and the potential for production of photochemical oxidant pollution from the vapors.

The analysis indicates that current Air Force policies concerning fuel jettisoning are adequate to minimize any negative environmental consequences, and that Air Force operational practices are in keeping with these policies. Fuel jettisoning as carried out by Air Force aircraft does not appear to produce any serious environmental consequences.

PREFACE

This final report was prepared by HQ AFESC Engineering and Services Laboratory, Tyndall Air Force Base, Florida. The report covers Air Force fuel jettisoning during the period 1 January 1975 through 30 June 1978, but the work involved, including establishment of the fuel dump reporting system and analysis of the results, spans the interval from February 1972 to December 1979. This work was accomplished under Program Element 62601F, Project 19004C02. The author and project officer since June 1976 was Capt Harvey J. Clewell, previous project officers were Capt James T. Haney and Capt Edward R. Ricco.

This report is presented in two volumes. Volume I contains a complete summary and analysis of fuel jettisoning by Air Force aircraft. Volume II includes three appendices which contain individual listings of all reported fuel dumping incidents for the period 1 January 1975 through 30 June 1978, sorted by Air Force command and by aircraft, along with a detailed distribution of fuel jettisoning by location. This is Volume I.

The author wishes to thank Gregory A. Urda for his assistance in maintaining the fuel dump reporting system and in preparing part of the summary. The computer sorting routines were written by personnel in the AFESC data processing center.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

HARVEY J. CLEWELL III, Capt, USAF, BSC
Air Quality Research Chemist

MICHAEL G. MacNAUGHTON, Lt Col, USAF, BSC
Chief, Environmental Science Branch

EMIL C. FREIN, Lt Col, USAF
Chief, Environics Division

GEORGE BALLENTINE, Lt Col, USAF
Director, Engineering and Services
Laboratory

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SECTION I

INTRODUCTION

Fuel dumping, or fuel jettisoning, as used in this report refers to the discharge of unburned fuel directly into the atmosphere by an aircraft while airborne. The fuel is generally released through ports which are specifically designed for fuel jettisoning; these ports are usually placed in the wingtips. Tanker aircraft, however, discharge fuel through the boom normally used for refueling other aircraft. Although the reasons for fuel jettisoning will be discussed more thoroughly later, the basic purpose for jettisoning fuel is to reduce the aircraft's gross weight to facilitate a safe landing.

In 1971 the Assistant Secretary of Defense for Health and Environment sent a memorandum to the Secretaries of the Military Departments expressing the concern of the Executive Office of the President and Congress "about the extent to which aircraft fuel dumping practices contribute to the pollution of our air, threaten the public health and degrade our environment." During this same period the Air Force received several inquiries concerning its fuel dumping practices as well as two complaints, eventually shown to be without basis, of crop damage resulting from Air Force fuel dumping. As a result of the increased awareness of fuel dumping's potential for environmental degradation, the Air Force initiated a study in 1972 to determine the nature, the extent, and the environmental impact of fuel dumping by Air Force aircraft. Responsibility for this effort was given to the Environics Branch of the Air Force Weapons Laboratory, which has since been redesignated as the Environics Division of the Air Force Engineering and Services Center.

The investigation of Air Force fuel jettisoning was divided into two areas. The first, a survey of the nature and extent of Air Force fuel jettisoning, is the primary subject of this report. The second, the examination of the physical fate of the jettisoned fuel, is reported separately (References 1 and 2), but the important results of that effort are also included here for completeness. It is hoped that this report will provide the necessary information to permit an "accurate assessment of the environmental effects associated with USAF aircraft fuel jettisoning," as called for by Air Force Regulation 19-3.

Air Force Regulation 19-3, "Reporting of Aircraft Fuel Jettisoning," was published on 15 March 1973 at the request of the Environics Branch. This regulation required the reporting of all noncombat fuel jettisoning episodes using Air Force Form 161, (Figure 1). In addition to documenting the size and location of fuel dumps, the information requested on the Aircraft Fuel Jettisoning Report was designed to permit the determination of typical values of other fuel dumping parameters (e.g., altitude, airspeed, dump rate, and meteorological factors) which affect the fate of the fuel after release.

AIRCRAFT FUEL JETTISONING REPORT

REPORT CONTROL SYMBOL

TO:

FROM:

ACFT TYPE/ COMMAND A	FUEL TYPE B	DUMP LOCATION (Coordinates) C	ALTITUDE (In M/Ft) D	TRUE AIRSPEED (Knots) E	QUANTITY DUMPED (Pounds) F	DUMP RATE (Lbs/Min) G	CALENDAR DATE H	TIME (Zulu) I	OUTSIDE AMBIENT TEMP J	WIND DIRECTION (Magnetic)/ WIND SPEED K

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Figure 1. Aircraft fuel jettisoning report.

After an initial delay during which the reporting system was being implemented by the various commands, sufficient reports were received to justify an interim summary for the period October 1974 to March 1975 (Reference 3). The reporting system was continued until Air Force Regulation 19-3 was rescinded in September 1978, at which time it was felt that a sufficient data base had been collected to meet the purpose of the regulation. The 3 1/2-year period covered by this report was selected to include only those months when all commands appeared to be fully complying with the reporting requirement. However, it is impossible to verify that every fuel dump occuring during this period (particularly in the earlier years) was reported. Moreover, the combined concerns of environmental protection and fuel conservation led the individual commands to place continuing emphasis on more complete reporting, and it is likely that the apparent increase in fuel jettisoning noted in this report for some commands is due in part to increased reporting compliance rather than to an actual increase in the incidence of fuel jettisoning.

Based then on 3 1/2 years of data on fuel jettisoning by USAF aircraft, the purposes of this report are to provide a thorough description of the nature and extent of Air Force fuel jettisoning, to determine whether Air Force practice follows Air Force policy, and to investigate the impact of fuel jettisoning both on the environment and on fuel conservation. In the first section the extent of fuel jettisoning is summarized both by command and by aircraft, the distribution of fuel dumps by altitude and geographic location is described, and the reasons for fuel jettisoning are explored. The cost and relative frequency of occurrence of fuel jettisoning is then examined, and its importance as a source of hydrocarbons in an air quality control region is estimated. Finally, the physical fate of the jettisoned fuel is outlined, and the likelihood of negative environmental impact, based on current Air Force fuel jettisoning policy and practice, is discussed.

SECTION II

FUEL JETTISONING SUMMARY

During the period 1 January 1975 through 30 June 1978, Air Force aircraft jettisoned fuel an average of 938 times a year, or roughly two and one-half dumps each day, worldwide. The fuel released to the atmosphere by these aircraft averaged 7,276 metric tons (sixteen million pounds) per year -- approximately twenty six thousand liters (seven thousand gallons) per day. The level of fuel jettisoning during this time was not constant, however. Between 1975 and 1977 the amount of fuel jettisoned by the Air Force decreased by 18 percent. During this same period total Air Force jet fuel consumption dropped only 8 percent (Reference 4), indicating a real decrease in the relative amount of fuel lost through jettisoning.

The total fuel jettisoned by the Air Force each year is shown in Figure 2. Also shown are the totals for the Strategic Air Command (SAC), the Tactical Air Command (TAC), and the sum of all other commands. Note that the decrease in the amount of fuel dumped annually contrasts with a marked increase in the number of dumps, shown in Figure 3. In both of these figures, as in all similar figures and tables throughout this report, the totals for the six months from January through June 1978 have been arbitrarily multiplied by two to obtain an estimate for the year 1978. Inspection of the monthly fuel dump summaries at the end of Appendix A shows no indication of an annual cycle of fuel dumping incidents which would cause this procedure to be misleading.

2.1 SUMMARY BY COMMAND

The average level of fuel jettisoning by each command from January 1975 through June 1978 is shown in Table 1. One striking feature of this table is the predominance of SAC and TAC. Together they are responsible for 89 percent of the fuel dumped by the Air Force and 80 percent of the dumps. At the same time, an important difference between SAC and TAC is apparent. With an average dump size of 17 metric tons (37,000 pounds), SAC accounts for over two-thirds of all fuel dumped with only one-third of the total number of dumps. On the other hand, TAC accounts for nearly half of all Air Force fuel dumps, but due to an average dump size of only three metric tons (6,000 pounds) these dumps result in just one-sixth of the total fuel jettisoned. This difference, of course, is due to the different aircraft employed by each command. The third largest contributor to Air Force fuel jettisoning is the United States Air Forces in Europe (USAFE), with a relatively small average dump size similar to that of TAC.

As might be expected from the discussion of Table 1, the decrease in total Air Force fuel dumped reflects a similar trend

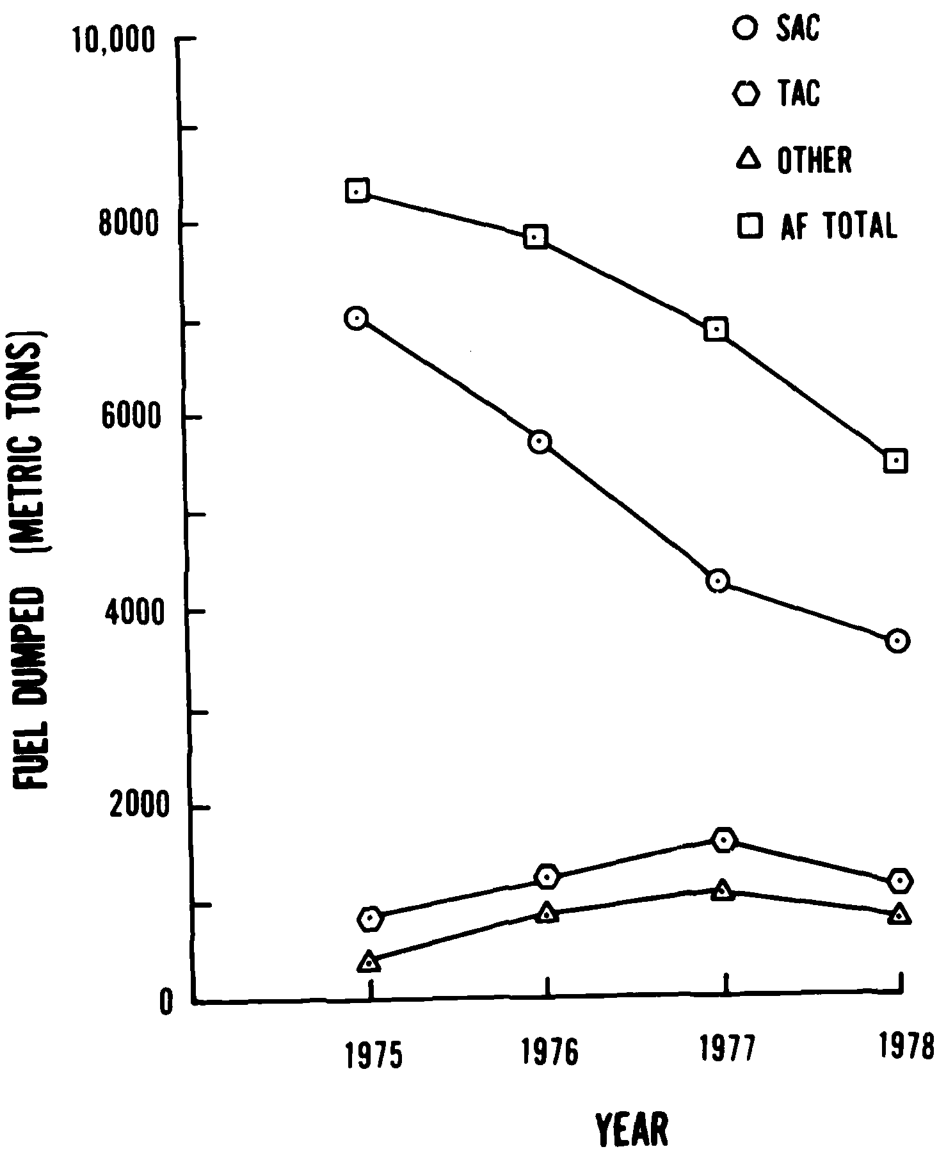

Figure 2. Quantity of fuel jettisoned per year by commands.

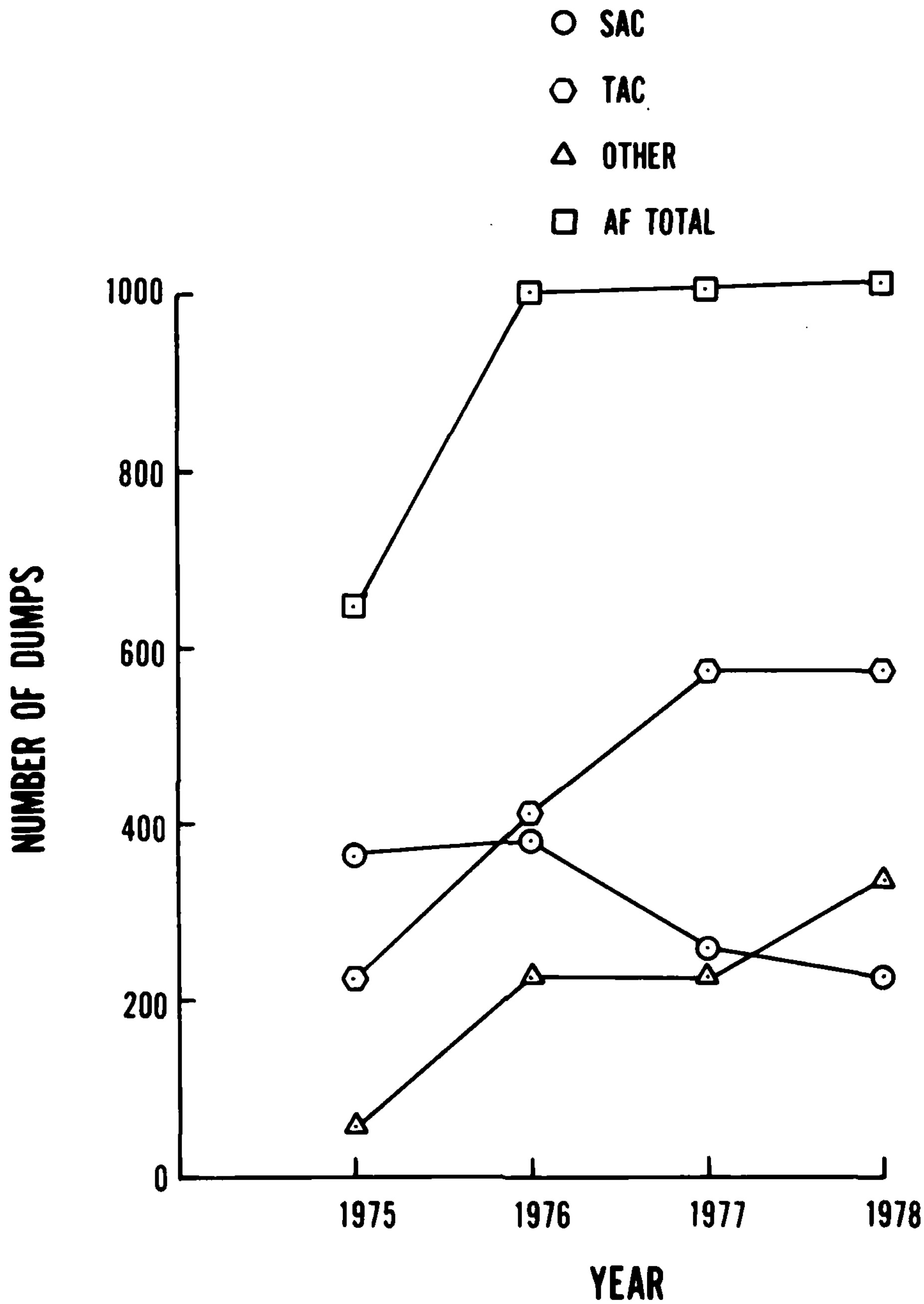

Figure 3. Number of fuel dumps per year by commands.

TABLE 1. FUEL JETTISONING BY COMMAND

Command	Dumps per Year	Percent of Air Force Total	Metric Tons per Year	Percent of Air Force Total	Metric Tons per Dump
SAC	318	34	5,316	73	17
TAC	427	46	1,182	16	3
USAFE	120	13	323	4	3
MAC	20	2	165	2	8
AFSC	23	2	156	2	7
ADC/AFRES	14	1	107	1	8
AFLC	13	1	22	-	2
PACAF	3	-	5	-	2
TOTAL	938		7,276		

in SAC (Figure 2). In fact, all other commands show a slight increase during the period. At the same time, the contrasting increase in the number of dumps Air Force wide (Figure 3) is simply a result of the decrease in the number of SAC dumps being outweighed by a larger increase in the number of dumps by the other commands. The relatively small size of these "non-SAC" dumps prevents them from similarly affecting the overall Air Force trend toward decreasing quantity noted in Figure 2. Thus the picture of Air Force fuel jettisoning appears to be slowly changing from one of large dumps by SAC aircraft to one of more frequent but smaller dumps by the othe commands. However, a note of caution must be made here. The apparent increase in the number of "non-SAC" dumps may be a by-product of increasing compliance with reporting requirements. Only SAC had a fuel dump reporting system in existence when AFR 19-3 was published. There is no way to be sure at what point the other commands reached "full" reporting status. The apparent decrease in SAC dumping cannot be explained by this reasoning, however, and is considered to represent a meaningful trend.

A complete listing organized by command of all reported fuel dumps from 1 January 1975 through 30 June 1978 is included as Appendix A in Volume II. Following this listing is a monthly summary for each command. Notes explaining the items listed are included at the end of the appendix.

2.2 SUMMARY BY AIRCRAFT

Not all Air Force aircraft have the capability to jettison fuel. The most notable example is the venerable B-52 bomber. Nevertheless, most aircraft can, and do, jettison fuel when a reduction of gross weight is required. Table 2 is a complete listing of all Air Force aircraft for which a fuel jettisoning episode was reported during the period of this study. However, just five aircraft account for 78 percent of all Air Force dumps and 88 percent of the fuel dumped: the KC-135, RC-135, FB-111, F-111, and F-4. The first three are SAC aircraft: a tanker, a reconnaissance aircraft and a bomber, respectively. The last two are fighters used primarily by TAC and USAFE. The trends for these five aircraft are shown in Figures 4 and 5. It is readily apparent that the decrease in fuel dumped by the Air Force (and SAC) is solely a result of decreased dumping by the KC-135 tanker. The amount of fuel dumped by RC-135s, and to a lesser extent the other aircraft, has actually increased in recent years. As mentioned earlier, the apparent increase in dumping by F-4s and F-111s may actually reflect more complete reporting. It is not possible to determine whether the frequency of dumping by the fighter aircraft is increasing or whether the actual level of dumping by these aircraft for the entire period of this report would be more adequately represented by the 1978 figures.

To determine whether the changes in the amount of fuel jettisoned by a given aircraft were due solely to changes in the

TABLE 2. FUEL JETTISONING BY TYPE OF AIRCRAFT

Aircraft	Dumps per Year	Percent of Air Force Total	Metric Tons per Year	Percent of Air Force Total	Metric Tons per Dump
A-37	1	0.2	0.8	-	0.6
A-7	55	5.8	52	0.7	1
B-1	7	0.7	113	1.6	16
CH-3	2	0.2	0.5	-	0.2
C-130	6	0.7	41	0.6	7
C-135	1	0.1	11	0.2	11
C-141	4	0.5	66	0.9	16
C-5	1	0.1	12	0.2	12
EC-121	12	1.2	81	1.1	7
EC-135	9	1.0	148	2.0	16
E-3	2	0.2	45	0.6	22
FB-111	28	3.0	193	2.6	7
F-105	3	0.3	6	0.1	2
F-111	269	28.7	1013	13.9	4
F-15	17	1.8	46	0.6	3
F-4	162	17.3	219	3.0	1
HC-130	1	0.1	10	0.1	10
HH-3	3	0.3	2	-	0.7
HH-53	2	0.2	1	-	0.5
KC-135	174	18.6	3427	47.1	20
KC-97	1	0.1	9	0.1	9
NC-135	0.3	-	2	-	8
NKC-135	0.3	-	3	-	10
NT-39	0.3	-	0.3	-	1
RC-135	99	10.5	1540	21.2	16

TABLE 2. FUEL JETTISONING BY TYPE OF AIRCRAFT (Concluded)

Aircraft	Dumps per Year	Percent of Air Force Total	Metric Tons per Year	Percent of Air Force Total	Metric Tons per Dump
RF-4	41	4.4	70	1.0	2
SR-71	4	0.4	42	0.6	10
T-39	4	0.4	3	-	0.8
U-2	10	1.0	25	0.3	3
WC-135	2	0.2	46	0.6	23
VC-140	0.6	0.1	1	-	2
Unknown	16	1.7	44	0.7	3
TOTAL	938		7276		

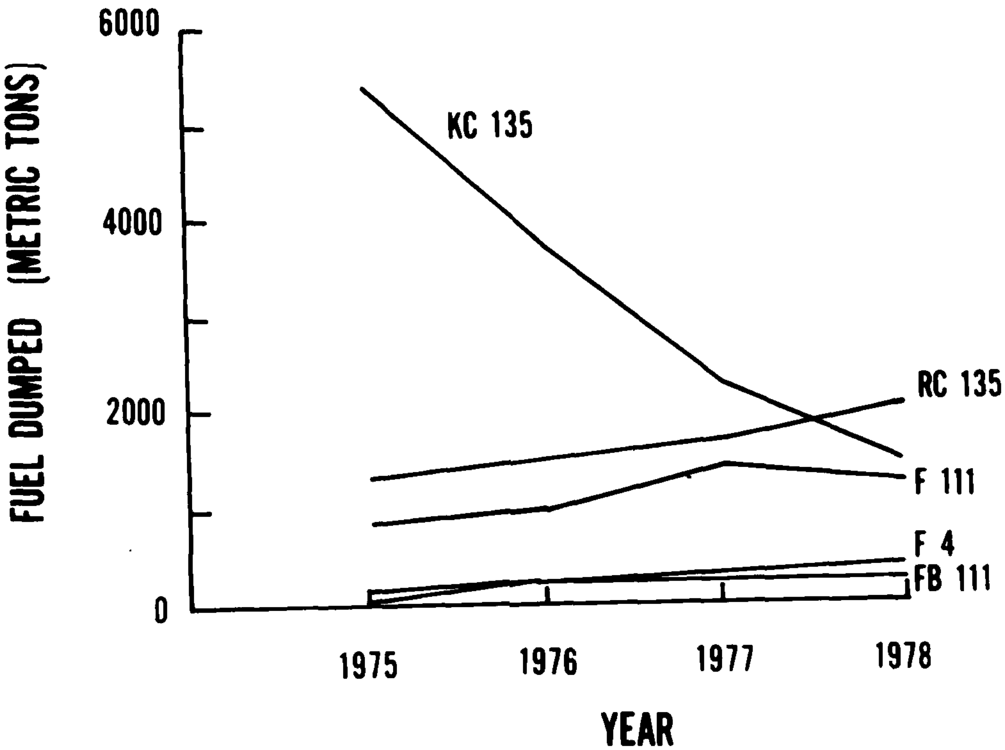

Figure 4. Quantity of fuel jettisoned per year by selected aircraft

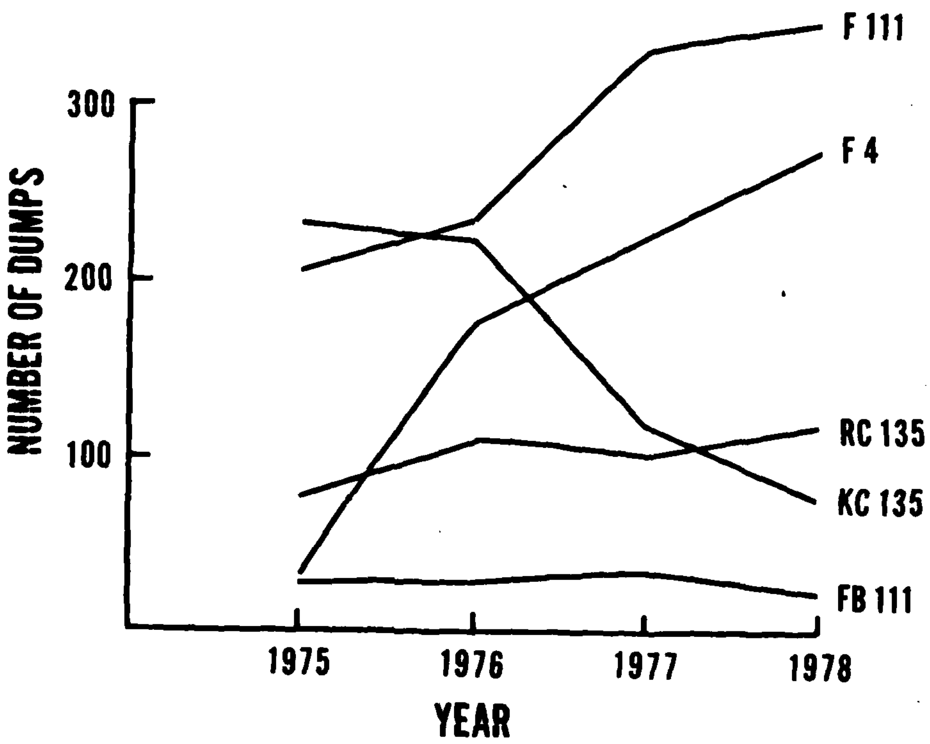

Figure 5. Number of fuel dumps per year by selected aircraft.

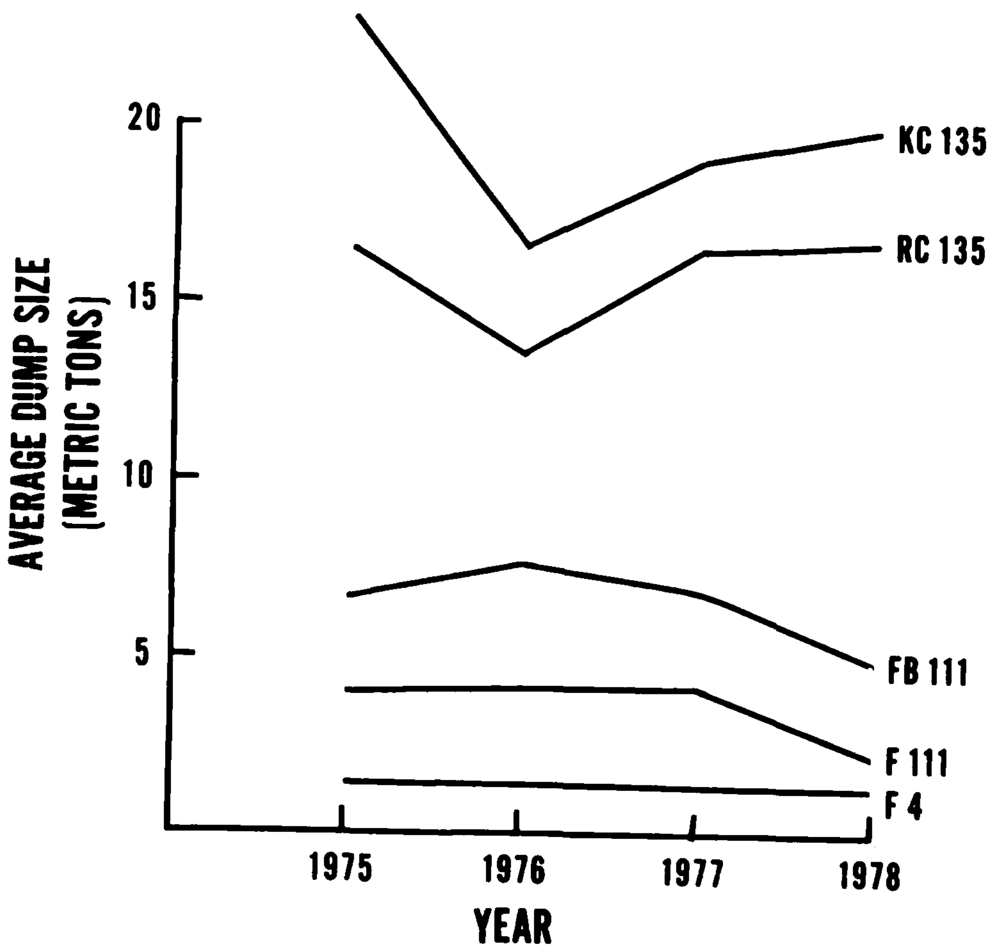

Figure 6. Average dump size for selected aircraft.

frequency of dumping, or whether they were partially reflections of changes in the average size of individual dumps, the trend of average dump size was plotted for each aircraft (Figure 6). Although fluctuating somewhat, the average dump size for each aircraft has remained fairly constant through the years. It appears that the reduction in the total amount of fuel dumped by the Air Force is solely the result of a decrease in the number of dumps per year performed by KC-135s. This decrease probably results in turn from a decreased sortie rate for KC-135s in recent years. Strangely, the size of FB-111 and F-111 dumps suddenly decreased in 1978. The cause of this change is not known, but the overall effect is small.

A second listing of all fuel dumps, sorted by the type of aircraft, is included as Appendix B in Volume II. This listing is particularly useful for determining typical fuel jettisoning parameters for a given aircraft. Notes explaining the items listed are included at the end of the appendix.

2.3 DISTRIBUTION BY ALTITUDE AND QUANTITY

Jettisoning fuel at higher altitudes is a generally recognized way to reduce the possibility of environmental degradation by providing an opportunity for the fuel to evaporate and disperse before reaching the ground. For this reason TAC and USAFE regulations (References 5, 6, and 7) specify that when circumstances permit, fuel jettisoning should be carried out more than 1,500 meters (5,000 feet) above the ground. Similarly, SAC policy (Reference 8) specifies the use of altitudes over 6,000 meters (20,000 feet) above ground level except when precluded by the nature of an emergency situation. The actual distribution of fuel jettisoning by altitude indicates that these policies are carried out in practice (Figures 7 and 8). Eighty-five percent of all Air Force fuel dumps are performed above 1,500 meters (5,000 feet), accounting for more than 92 percent of the fuel dumped by the Air Force. More than 70 percent of all SAC dumps take place above 5,800 meters (19,000 feet).

The distribution of fuel dumps by size (Figure 9) indicates the preponderance of smaller dumps. More than half of all dumps are less than five metric tons (10,000 pounds). However, while practically all dumps by TAC and USAFE are under ten metric tons (20,000 pounds), SAC dumps often range as high as fifty metric tons (100,000 pounds). On the other hand, the larger size of SAC dumps is offset by the higher altitude at which SAC typically releases the fuel, allowing greater dispersion before reaching the ground.

2.4 DISTRIBUTION BY LOCATION

To determine the areas where Air Force fuel jettisoning takes place, all fuel dumps for which the location was specified by

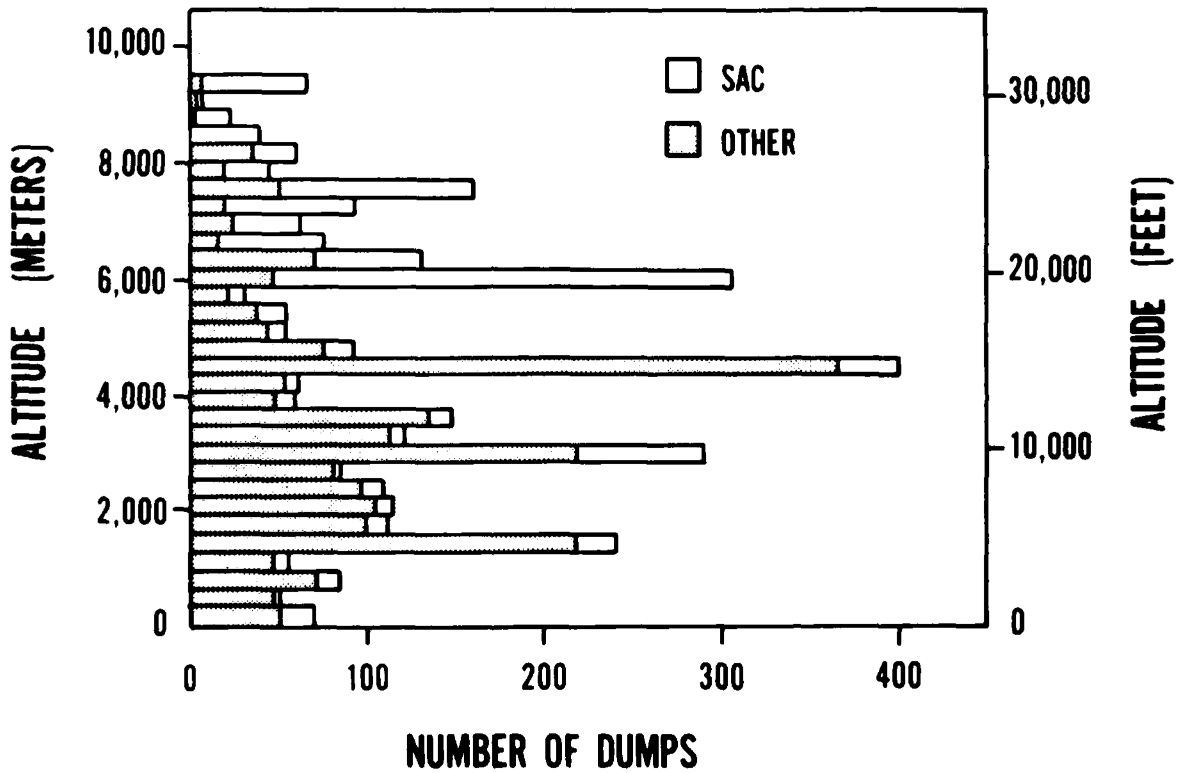

Figure 7. Distribution of fuel dumps by altitude.

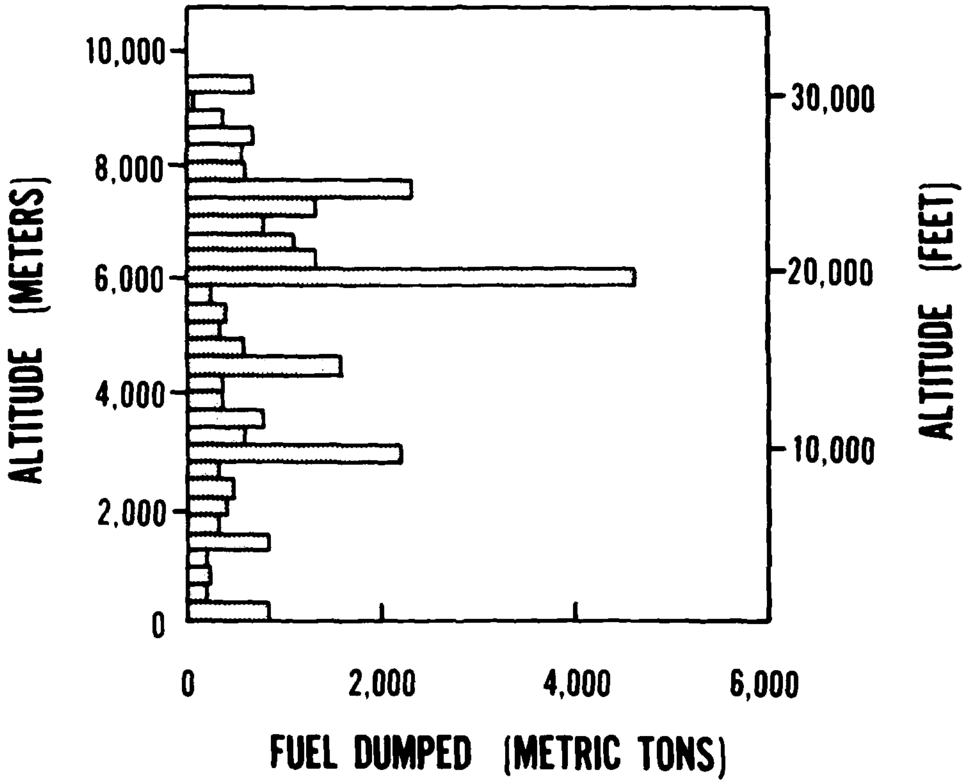

Figure 8. Amount of fuel dumped by altitude.

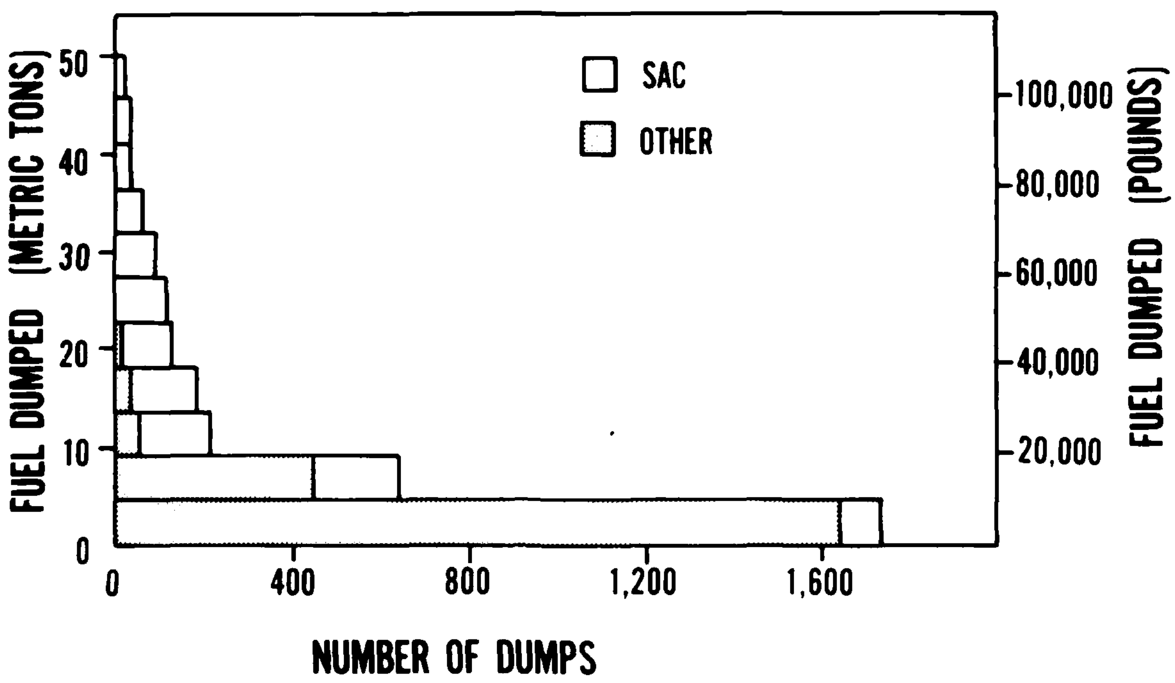

Figure 9. Distribution of fuel dumps by size.

latitude and longitude coordinates were sorted into a one-degree latitude by one-degree longitude grid. The number of fuel dumps and total quantity of fuel dumped in each grid box are listed in Appendix C in Volume II. Out of 3,282 reported fuel dumps for the period 1 January 1975 through 30 June 1978, a total of 2,726 or 83 percent could be sorted in this manner. An additional 81 dumps could be associated with two grid boxes and are added as footnotes in the appendix. In all, approximately 92 percent of the fuel dumped by Air Force aircraft during the period of this report can be accounted for by location using Appendix C. In some cases the grid box can be associated with a nearby Air Force base (AFB); in others only a state, country, or area is given.

Nineteen major fuel jettisoning regions are listed in Table 3 in order of total fuel dumped per year. Typical dumping aircraft and altitude ranges for each region are also listed. Each region encompasses a number of adjacent grid boxes and represents the jettisoning from a single base or several nearby bases. Except for Okinawa, each of these regions can be identified in Figures 10 and 11. These two figures present, for the United States and Western Europe, a pictorial display of the location of all one-degree latitude by one-degree longitude areas in which the Air Force has jettisoned more than one metric ton of fuel per year (more than 7,700 pounds during the 3 1/2-year period of this report).

It should be pointed out that rather large grid boxes had to be used in order to make the sorting by location tractable, and to provide a graphic display. A one-degree latitude by one-degree longitude area covers anywhere from 6,000 to 12,000 square kilometers (2,200 to 4,600 square miles), depending on the latitude. In some cases only one or two dumps have caused a grid box to be shaded in Figures 10 and 11. Thus the fact that the entire grid box is shaded should not be construed to imply that the entire area is subject to fuel jettisoning.

The areas in the United States with the highest incidence of fuel jettisoning are listed in Table 4. In each case they include only a single grid box and are identified in Figure 10 by solid shading. In the interest of clarity, the standard two letter abbreviations for state names have been used in Table 4 as they are in Appendix C. These abbreviations are listed in Table 5. The "typical dump coordinates" in Table 4 have been chosen to contain at least two-thirds of all the dumps in the one-degree latitude by one-degree longitude area. A description of the location circumscribed by the typical dump coordinates is also included.

The location of fuel jettisoning areas is generally not a matter of chance. Not surprisingly the vast majority of fuel jettisoning is performed in fairly close proximity to an Air Force base. The descriptions in Table 4 bring out another

TABLE 3. MAJOR FUEL JETTISONING REGIONS

	Location	Coordinates	Dumps per Year	Metric Tons per Year	Altitude (km)	Typical Aircraft
1.	England/North Sea*	N51°–55°; W4°–E4°	83	552	0–7.5	F-111
2.	Central Alaska	N63°–66°; W143°–149°	21	472	4.5–7.5	KC-135;RC-135
3.	Okinawa (300 km radius)	N24°–33°; E125°–130°	17	399	0–7.5	RC-135;KC-135
4.	Bering Sea	N50°–55°; E171°–178°	39	366	6–7.5	RC-135
5.	Eastern New Mexico	N33°–36°; W102°–106°	76	303	1.5–4.5	F-111
6.	Northern California	N38°–41°; W120°–123°	20	291	4.5–7.5	KC-135; U-2
7.	Southwestern Idaho	N41°–44°; W115°–118°	50	243	1.5–4.5	F-111
8.	Northern New York	N43°–45°; W72°–74°	21	209	1.5–7.5	FB-111;KC-135
9.	Southeastern Nebraska	N40°–43°; W94°–99°	11	193	6–7.5	RC-135
10.	Central California	N35°–37°; W118°–120°	9	181	4.5–7.5	KC-135
11.	Northern Idaho	N48°–49°; W116°–118°	7	156	4.5–7.5	KC-135
12.	South of Maine (Atlantic)	N42°–44°; W69°–71°	13	152	1.5–7.5	FB-111;KC-135
13.	Northern Maine	N46°–48°; W68°–69°	7	109	4.5–7.5	KC-135
14.	Mojave Desert	N34°–36°; W117°–118°	31	107	1.5–4.5	F-4; B-1
15.	Northern Louisiana	N31°–33°; W92°–94°	24	103	1.5–7.5	KC-135; A-7
16.	Southern California	N33°–34°; W115°–118°	5	101	4.5–7.5	KC-135
17.	Southern Nevada	N36°–39°; W113°–117°	39	83	4.5	F-4
18.	Southwestern North Dakota	N42°–44°; W102°–104°	5	83	4.5–7.5	KC-135;RC-135
19.	South Carolina	N33°–35°; W80°–81°	30	51	1.5	RF-4
	TOTAL		508	4154		
	* England Only	N51°–55°; W4°–E1°	57	293	1.5–4.5	F-111

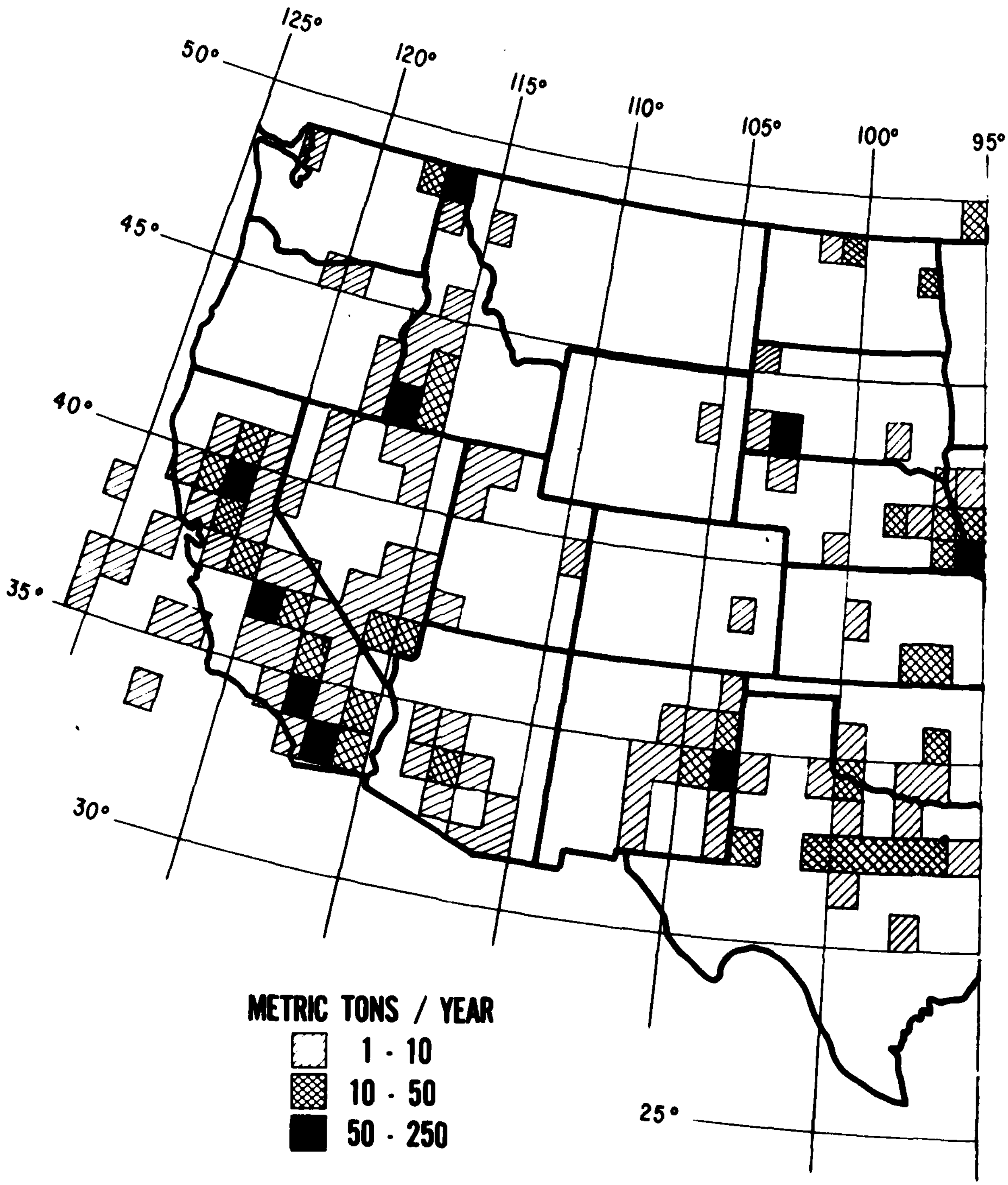

Figure 10. Distribution of fuel jettisoning in the United States.

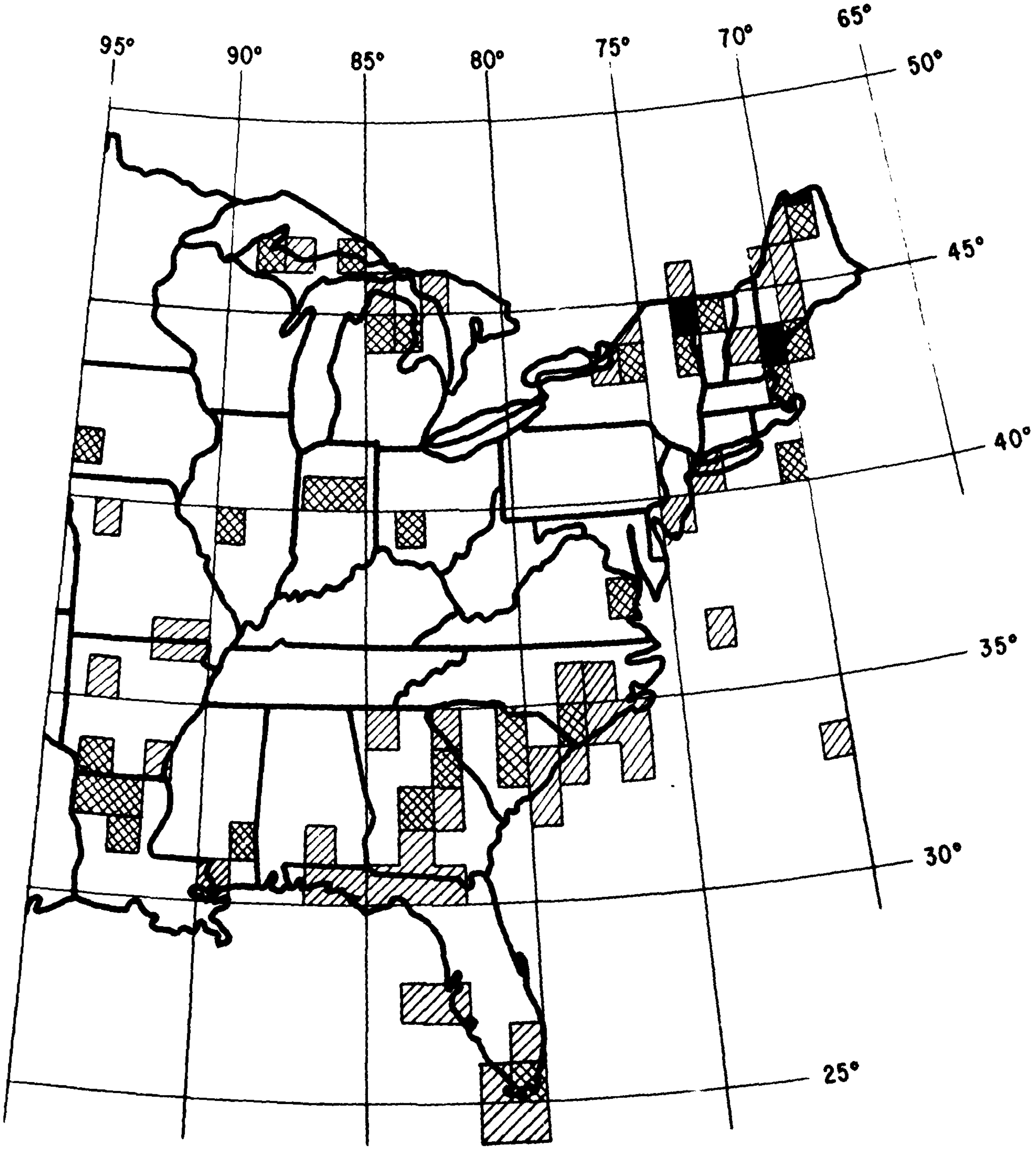

Figure 10. Distribution of fuel jettisoning in the United States. (Continued)

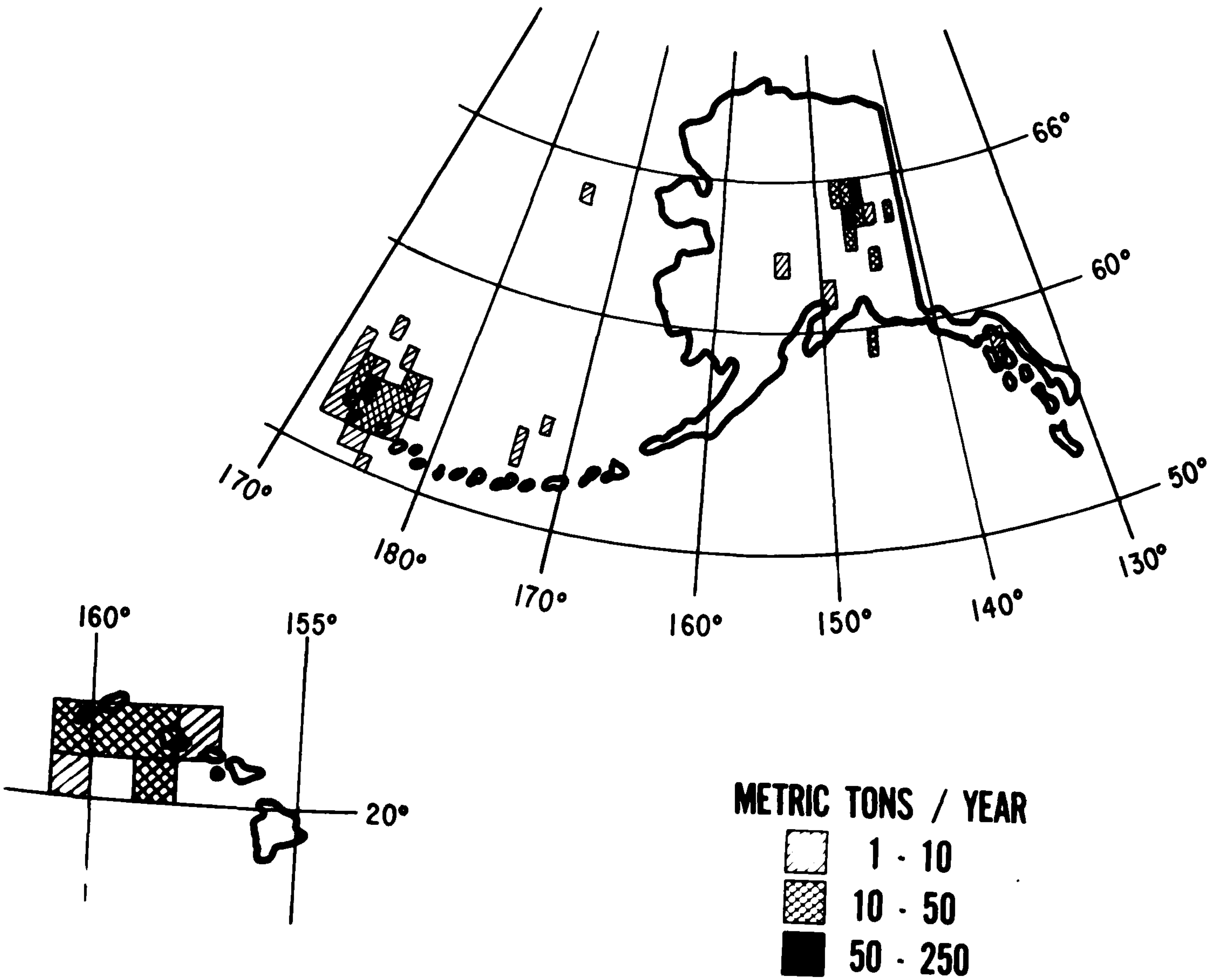

Figure 10. Distribution of fuel jettisoning in the United States. (Concluded)

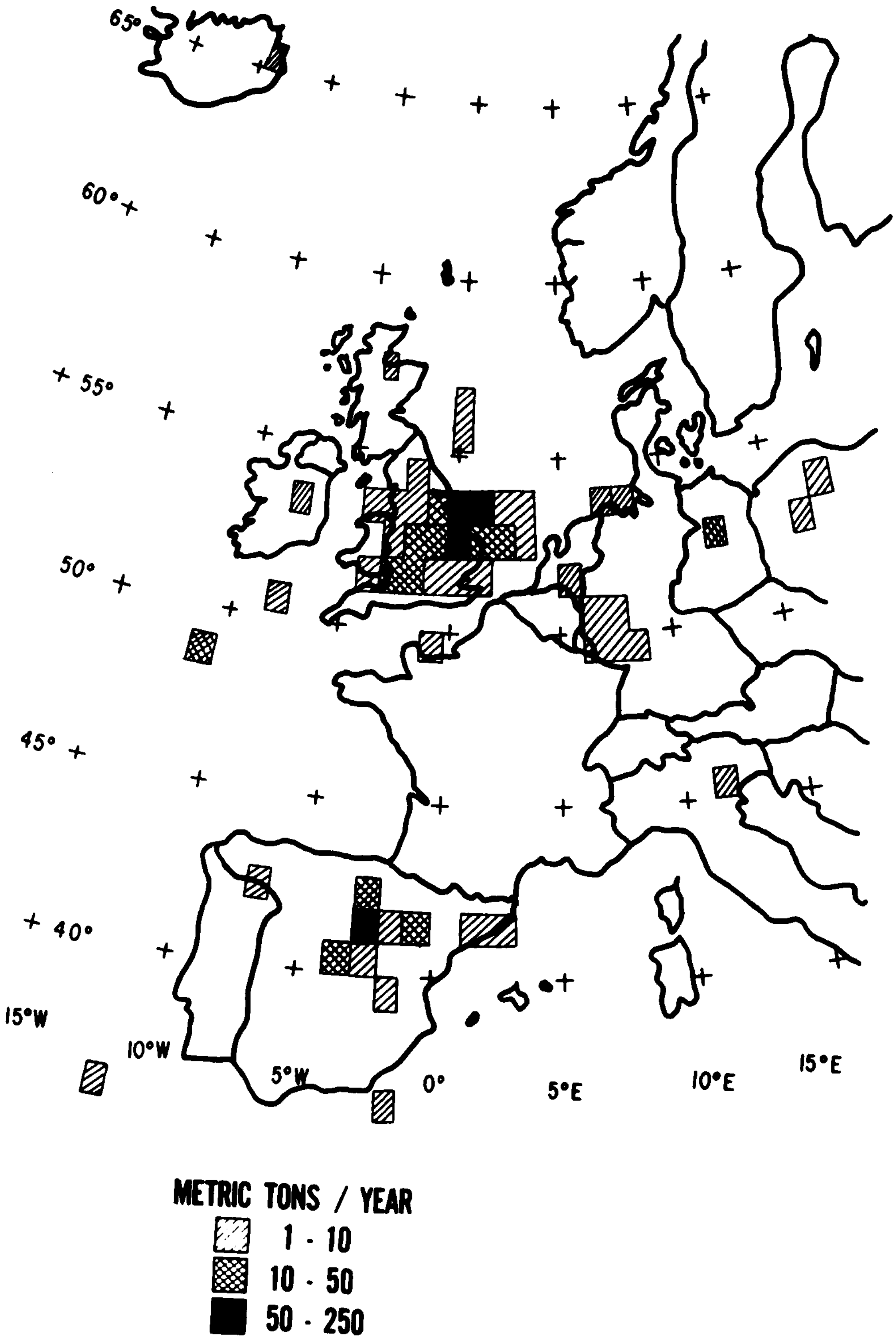

Figure 11. Distribution of fuel jettisoning in Europe.

TABLE 4. DESCRIPTION OF PRINCIPAL FUEL JETTISONING AREAS

1. N34°-35°; W103°-104°

Nearest Base:	Cannon AFB NM (TAC)
Nearest City:	Clovis NM
Dumps/Year:	59
Metric Tons/Year:	233
Metric Tons/Dump:	4
Aircraft:	F-111
Altitude (km):	1.5-4.5
Typical Dump Coordinates:	N34° 10'-34° 50'; W103° 05'-103° 35'
Description:	within thirty mile radius of Clovis NM

2. N42°-43°; W116°-117°

Nearest Base:	Mountain Home AFB ID (TAC)
Nearest City:	Boise ID
Dumps/Year:	37
Metric Tons/Year:	189
Metric Tons/Dump:	5
Aircraft:	F-111
Altitude (km):	1.5-4.5
Typical Dump Coordinates:	N42° 44'-42° 51'; W116° 06'-116° 16'
Description:	just south of the Snake River, fifty miles south of Boise ID

3. N64°-65°; W147°-148°

Nearest Base:	Eielson AFB AK (SAC)
Nearest City:	Fairbanks AK
Dumps/Year:	8
Metric Tons/Year:	187
Metric Tons/Dump:	21
Aircraft:	KC-135 and RC-135
Altitude (km):	4.5-7.5
Typical Dump Coordinates:	N64° 00'-64° 25'; W147° 15'-147° 30'
Description:	foothills of the Alaskan Range, forty miles south of Fairbanks AK and forty miles northeast of Mt. McKinley National Park

4. N65°-66°; W146°-147°

Nearest Base:	Eielson AFB AK (SAC)
Nearest City:	Fairbanks AK
Dumps/Year:	9
Metric Tons/Year:	185
Metric Tons/Dump:	21
Aircraft:	RC-135
Altitude (km):	6.0-7.5
Typical Dump Coordinates:	N65° 07'-65° 17'; W146° 15'-146° 30'
Description:	mountainous area fifty miles northeast of Fairbanks AK

TABLE 4. DESCRIPTION OF PRINCIPAL FUEL JETTISONING AREAS (Continued)

5. N44°-45°; W73°-74°

Nearest Base:	Plattsburgh AFB NY (SAC)
Nearest City:	Plattsburgh NY
Dumps/Year:	17
Metric Tons/Year:	171
Metric Tons/Dump:	10
Aircraft:	FB-111 and KC-135
Altitude (km):	1.5-7.5
Typical Dump Coordinates:	N44°16'-44°31'; W73°27'-73°52'
Description:	in the Adirondack Forest Preserve between Lake Placid and Lake Champlain, twenty-five miles south of Plattsburg NY

6. N36°-37°; W119°-120°

Nearest Base:	Castle AFB CA (SAC)
Nearest City:	Fresno CA
Dumps/Year:	8
Metric Tons/Year:	161
Metric Tons/Dump:	20
Aircraft:	KC-135
Altitude (km):	4.5-7.5
Typical Dump Coordinates:	N36°40'-36°50'; W119°05'-119°30'
Description:	foothills of the Sierra Nevada, twenty miles east of Fresno CA and ten miles west of Sequoia National Park

7. N39°-40°; W121°-122°

Nearest Base:	Beale AFB CA (SAC)
Nearest City:	Sacramento CA
Dumps/Year:	9
Metric Tons/Year:	142
Metric Tons/Dump:	16
Aircraft:	KC-135 and U-2
Altitude (km):	4.5-7.5
Typical Dump Coordinates:	N39°33'-39°53'; W121°26'-121°46'
Description:	foothills of the Sierra Nevada, eighty miles north of Sacramento CA

TABLE 4. DESCRIPTION OF PRINCIPAL FUEL JETTISONING AREAS (Continued)

8. N48°-49°; W116°-117°

Nearest Base:	Fairchild AFB WA (SAC)
Nearest City:	Spokane WA
Dumps/Year:	6
Metric Tons/Year:	129
Metric Tons/Dump:	22
Aircraft:	KC-135
Altitude (km):	4.5-7.5
Typical Dump Coordinates:	N48°30'-48°31'; W116°45'-116°50'
Description:	just southeast of Priest Lake in northern Idaho, sixty miles northeast of Spokane WA

9. N43°-44°; W70°-71°

Nearest Base:	Pease AFB NH (SAC)
Nearest City:	Portsmouth NH
Dumps/Year:	9
Metric Tons/Year:	95
Metric Tons/Dump:	11
Aircraft:	FB-111 and KC-135
Altitude (km):	1.5-7.5
Typical Dump Coordinates:	N43°00'-43°10'; W70°20'-70°30'
Description:	over the Atlantic Ocean, twenty five miles east of Portsmouth NH

10. N40°-41°; W95°-96°

Nearest Base:	Offutt AFB NE (SAC)
Nearest City:	Omaha NE
Dumps/Year:	6
Metric Tons/Year:	90
Metric Tons/Dump:	15
Aircraft:	RC-135
Altitude (km):	6.0-7.5
Typical Dump Coordinates:	N40°25'-40°55'; N95°30'-95°50'
Description:	east of the Missouri River, thirty miles southeast of Omaha NE

11. N33°-34°; W116°-117°

Nearest Base:	March AFB CA (SAC)
Nearest City:	San Diego CA
Dumps/Year:	4
Metric Tons/Year:	77
Metric Tons/Dump:	19
Aircraft:	KC-135
Altitude (km):	6.0-7.5
Typical Dump Coordinates:	N33°5'-33°20'; W116°35'-116°50'
Description:	forty miles northeast of San Diego CA

TABLE 4. DESCRIPTION OF PRINCIPAL FUEL JETTISONING AREAS (Concluded)

12. N47°-48°; W68°-69°

Nearest Base:	Loring AFB ME (SAC)
Nearest City:	Presque Isle ME
Dumps/Year:	3
Metric Tons/Year:	72
Metric Tons/Dump:	24
Aircraft:	KC-135
Altitude (km):	4.5-7.5
Typical Dump Coordinates:	N47°10'; W68°25'
Description:	ten miles south of Canadian border, forty miles north of Presque Isle ME

13. N43°-44°; W102°-103°

Nearest Base:	Ellsworth AFB SD (SAC)
Nearest City:	Rapid City SD
Dumps/Year:	4
Metric Tons/Year:	67
Metric Tons/Dump:	17
Aircraft:	KC-135 and RC-135
Altitude (km):	4.5-7.5
Typical Dump Coordinates:	N43°15'-43°35'; W102°15'-102°40'
Description:	Pine Ridge Indian Reservation, sixty miles southeast of Rapid City SD and just northwest of Wounded Knee

TABLE 5. STANDARD TWO-LETTER ABBREVIATIONS FOR STATES NAMES

ALASKA	AK	MONTANA	MT
ALABAMA	AL	NEBRASKA	NE
ARIZONA	AZ	NEVADA	NV
ARKANSAS	AR	NEW HAMPSHIRE	NH
CALIFORNIA	CA	NEW JERSEY	NJ
CANAL ZONE	CZ	NEW MEXICO	NM
COLORADO	CO	NEW YORK	NY
CONNECTICUT	CT	NORTH CAROLINA	NC
DELAWARE	DE	NORTH DAKOTA	ND
DISTRICT OF COLUMBIA	DC	OHIO	OH
FLORIDA	FL	OKLAHOMA	OK
GEORGIA	GA	OREGON	OR
HAWAII	HI	PENNSYLVANIA	PA
IDAHO	ID	PUERTO RICO	PR
ILLINOIS	IL	RHODE ISLAND	RI
INDIANA	IN	SOUTH CAROLINA	SC
IOWA	IA	SOUTH DAKOTA	SD
KANSAS	KS	TENNESSEE	TN
KENTUCKY	KY	TEXAS	TX
LOUISIANA	LA	UTAH	UT
MAINE	ME	VERMONT	VT
MARYLAND	MD	VIRGINIA	VA
MASSACHUSETTS	MA	VIRGIN ISLANDS	VI
MICHIGAN	MI	WASHINGTON	WA
MINNESOTA	MN	WEST VIRGINIA	WV
MISSISSIPPI	MS	WISCONSIN	WI
MISSOURI	MO	WYOMING	WY

characteristic of fuel jettisoning areas: they are generally located in unpopulated or sparsely populated terrain such as oceans, mountain ranges and forests. This observation is in keeping with command policies. Both TAC and USAFE direct that when circumstances permit, jettisoning should be carried out over unpopulated areas (References 5, 6, and 7). Most bases have predesignated fuel jettisoning areas which are selected to minimize any impact. All SAC units are required to have designated fuel jettisoning areas "located so that prevailing winds will not carry fuel spray to urban areas, agricultural regions, or water supply sources" (Reference 8).

2.5 REASONS FOR FUEL JETTISONING

As mentioned earlier, the basic purpose for jettisoning fuel is to reduce the aircraft's gross weight to facilitate a safe landing. To perform their mission, many aircraft are required to take off with a gross weight much higher than their maximum safe landing weight. If an emergency or change in operational plans requires the aircraft to land prematurely, fuel is jettisoned to reduce weight to a safe level. In some cases the nature of an emergency may lessen the airworthiness of the aircraft. In such instances reducing weight even below the normal landing weight may be desired to permit a slower landing speed and improve control.

The policy of TAC and USAFE (as well as other commands) is that "fuel dumping will be conducted only to reduce aircraft gross weight in an emergency" (References 5, 6, and 7). In addition to emergencies, SAC policy also authorizes fuel jettisoning to meet an "urgent operational requirement," and for several other circumstances in the case of reconnaissance aircraft (Reference 8). During the period 1 January 1976 through 30 June 1978, the fuel jettisoning reports received from SAC included the reason for jettisoning. These reports were sorted into three categories: aircraft emergency, operational requirement, and aborted mission (Figure 12). Over one-half of all dumps were precipitated by emergency situations. Table 6 lists the type of emergencies reported. Clearly, engine related malfunctions dominate. Slightly under one-third of all dumps resulted from urgent operational requirements; approximately half of these were performed by RC-135 aircraft in major fuel jettisoning region #4 (Table 3). Only 10 percent of fuel dumps resulted from aborted missions. These could actually be included in the previous category since the decision to dump fuel and land, rather than to fly in a circle until sufficient fuel has been burned, is generally made on the basis of an operational requirement. Typical causes for mission aborts include radio or compass malfunctions as well as failure of a receiver aircraft to rendezvous with a tanker. There is no difference in the average size of fuel dumps initiated for different reasons, indicating that the amount of fuel discharged is not a function of the situation.

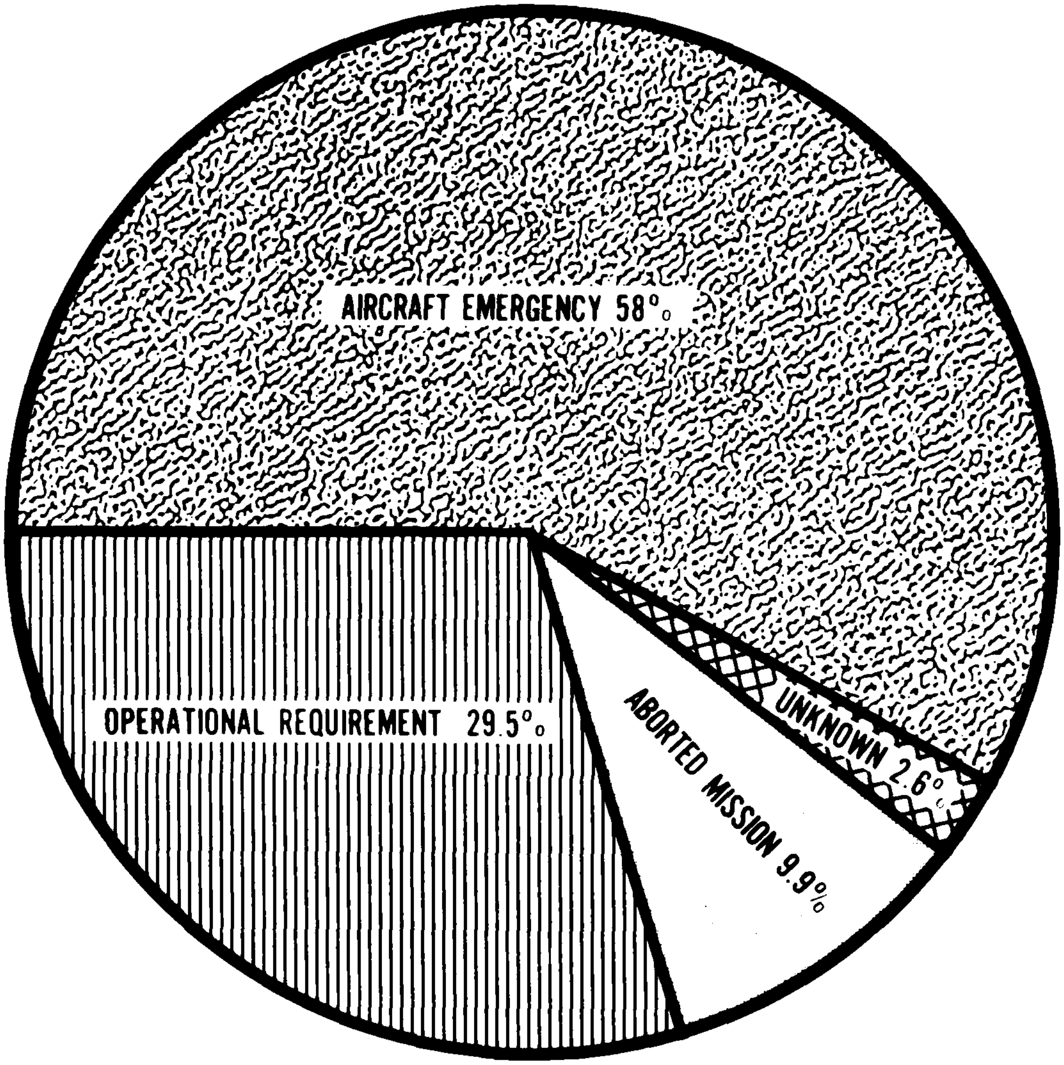

Figure 12. Situations requiring fuel jettisoning by SAC aircraft.

TABLE 6. EMERGENCY SITUATIONS REQUIRING FUEL JETTISONING BY SAC AIRCRAFT

Situation	Reports	Percent
Engine Failure	71	34
Engine Fire	28	12
Improper Oil Pressure	26	12
Engine Vibration	5	2
Total Engine-Related	130	61
Hydraulic System	16	7
Fuel Leak	14	7
Landing Gear	14	7
Medical Emergency	6	3
Generator	5	2
Control Surfaces	5	2
Other	24	11
TOTAL	214	

SECTION III

EXAMINATION OF FUEL JETTISONING IMPACT

In order to put the extent of Air Force fuel jettisoning in perspective it is necessary to examine its relative importance both economically, as a waste of fuel, and environmentally, as a source of hydrocarbon pollution. But beyond the consideration of Air Force fuel jettisoning in general, the potential of individual fuel dumps under unfavorable conditions to have more serious environmental consequences must also be addressed.

3.1 COST OF FUEL JETTISONING

During 1977 the Air Force consumed eighty million barrels of jet fuel (9.67 million metric tons) at a cost of 1.6 billion dollars, or about 6 percent of the annual budget of the Air Force (Reference 4). The jet fuel lost through fuel jettisoning in that year amounted to 6,782 metric tons, or 0.07 percent of the total Air Force fuel consumption, at a cost of 1.1 million dollars. The annual cost of fuel jettisoning has remained fairly constant at the 1.1 million dollar level because while the amount of Air Force fuel jettisoning has been decreasing, the cost of the fuel has risen.

3.2 FREQUENCY OF FUEL JETTISONING

Table 7 lists the seven aircraft which account for most of the Air Force fuel jettisoning and compares the number of fuel dumps they performed in 1977 with their sortie rate and operational strength figures for the same period (Reference 9). During 1977 these seven aircraft represented less than 25 percent of the total Air Force sorties, but performed 85 percent of the fuel dumps. It is obvious from Table 7 that some of these aircraft are required to dump fuel much more frequently than others. While the F-4 and F-15 average more than a thousand sorties between fuel dumps, the F-111 and FB-111 average less than one hundred and fifty. The KC-135 is intermediate, dumping fuel on one out of approximately every 350 sorties. The greater frequency of dumping by the 111 series aircraft probably reflects a higher incidence of mechanical problems associated with these aircraft.

3.3 IMPORTANCE AS A SOURCE OF HYDROCARBON EMISSIONS

During 1975, the total release of hydrocarbons into the atmosphere, worldwide, due to Air Force fuel jettisoning amounted to 8,246 metric tons, or slightly less than the hydrocarbons given off by evaporation during the pumping of gasoline in metropolitan Cincinnati, Ohio, over the same period (Reference 10). On a national scale, Air Force fuel jettisoning does not appear

TABLE 7. FREQUENCY OF FUEL JETTISONING FOR SELECTED AIRCRAFT

Air Force Aircraft Designation	Number of Aircraft	Number of Sorties	Number of Dumps	Dumps per Year per Aircraft	Percent of Sorties Resulting in a Fuel Dump
F-4	1,361	231,341	222	0.16	0.10
RF-4	345	56,726	69	0.20	0.12
F-15	181	30,508	22	0.12	0.07
F-111	346	28,311	330	0.95	1.16
FB-111	65	4,773	34	0.52	0.71
KC-135	623	42,761	118	0.19	0.28
RC-135	24*	2,865*	100	--#	--#
Seven Aircraft TOTAL	2,945	397,285	895	0.30	0.23
Air Force TOTAL	9,394	1,705,176	1,055	0.11	0.06

* Does not include aircraft on classified missions.

Not considered representative due to exclusion of aircraft on classified missions.

to be a significant source of hydrocarbon pollution, averaging approximately 0.03 percent of the total hydrocarbon emissions from all other sources.

Although Air Force fuel jettisoning is only a small fraction of national hydrocarbon emissions, this does not preclude the possibility that in some areas where fuel jettisoning is concentrated, its relative importance would increase. To investigate this possibility, Air Force fuel jettisoning was compared with other hydrocarbon sources in several Air Quality Control Regions (AQCR) characterized by a relatively high fuel jettisoning incidence. The significance of Air Force fuel jettisoning, expressed as the percentage of the total hydrocarbon emissions in the AQCR is compared in Table 8 with several other representative hydrocarbon emissions sources (Reference 10). In most regions, Air Force fuel jettisoning runs well behind gas handling evaporation losses and military aircraft exhaust emissions as a source of hydrocarbons. However, in northern Maine and northern Alaska, where the total hydrocarbon emissions from other sources are very low, Air Force fuel jettisoning constitues a small but significant fraction of the total.

On an even more local level there is the possibility that repetitive, relatively heavy fuel dumping over a long period, such as occurs in some of the areas listed in Table 4, might impact negatively on the area. The heaviest possible ground contamination which could be generated for such a case can be estimated by ignoring evaporation and dispersion and simply considering the geometry of the typical dumping pattern. This pattern, called a racetrack, consists of a 2-minute downwind leg, a 2-minute turn, a 2-minute upwind leg, and another 2-minute turn. This is only a rough description, and other patterns could be used, but we will use the pattern as described for our calculation. At a typical aircraft speed of 175 meters per second (350 knots), the aircraft will cover roughly 21 kilometers on one of the straight legs. Assuming all aircraft initiate their dump at the same point but in different directions (depending on wind direction), the area covered can be estimated by a circle of radius 21 kilometers, or 1,400 square kilometers. The heaviest fuel dumping in a small area from Table 4 is around 200 metric tons per year. Thus the heaviest possible concentration of fuel would be 0.14 metric tons per square kilometer per year (130 gallons per square mile per year), or roughly the equivalent of spraying a quart of gasoline each year on an area the size of a football field. By comparison, natural hydrocarbon emissions from a wooded region are probably on the order of several metric tons per square kilometer per year (Reference 11).

The importance of a source of hydrocarbons rests not only on its magnitude, but also on the reactivity of the specific hydrocarbons released; that is, their potential to participate in the atmospheric reactions which result in photochemical smog. Table 9

TABLE 8. COMPARISON OF AIR FORCE FUEL JETTISONING WITH OTHER HYDROCARBON SOURCES AS A PERCENTAGE OF THE TOTAL HYDROCARBON EMISSIONS IN AN AIR QUALITY CONTROL REGION (ACQR)

Region	Total Hydrocarbon Emissions (Metric Tons)	Fuel Jettisoning	Military Aircraft	Gas Handling Evaporation Loss	Light Vehicles
United States	24,636,894	0.03%	0.77%	4.13%	32.77%
California	2,287,719	0.03%	0.98%	4.52%	38.78%
Sacramento Valley (AQCR 28)	123,946	0.23%	3.82%	5.26%	49.64%
San Joaquin Valley (AQCR 31)	189,625	0.10%	2.14%	5.27%	42.65%
Eastern Washington/ Northern Idaho (AQCR 62)	60,293	0.26%	1.27%	4.72%	43.21%
Southwestern Idaho (AQCR 63)	71,518	0.34%	0.98%	2.15%	16.40%
Eastern New Mexico (AQCR 155)	37,606	0.81%	2.18%	1.03%	30.50%
Champlain Valley (AQCR 159)	68,000	0.31%	1.30%	3.63%	28.77%
Northeastern Maine (AQCR 108)	7,786	1.40%	--	0.41%	36.72%
Northern Alaska (AQCR 9)	14,237	3.32%	6.57%	2.40%	14.01%

compares the reactivity of jettisoned fuel with several other sources of hydrocarbons, based on a five-class reactivity categorization (Reference 12). This system assigns individual organic compounds or groups of related organic compounds to a set of reactivity classes based on an analysis of the results from smog chamber studies of photochemical oxidant production. For example, the highly reactive olefins all belong to class V (reactivity 1.4), while the relatively unreactive benzene is in class I (reactivity 0.1). The relative reactivities for each of the five classes are given in parentheses in Table 9. The overall reactivity of the hydrocarbons from a particular source is then taken to be the sum of the reactivities of each class multiplied by the fraction of hydrocarbons which belong to that class. A "source weight reactivity" is also defined in Table 9. The source weight reactivity provides a means of comparing the relative reactivity of the hydrocarbons from sources having different average molecular weights when emissions are given on a weight basis, as they are in Table 8.

It turns out that using this scheme the reactivity of jettisoned fuel depends only on its aromatic content since nearly all aromatics are in class IV, while essentially all the paraffins and cycloparaffins which make up the rest of jet fuel are in class III. Even using a fairly high aromatic content of 20 percent, the source weight reactivity of jettisoned fuel is only 0.40 -- well below the reactivity of aircraft exhaust emissions and other typical hydrocarbon sources.

In some non-emergency situations, as an alternative to jettisoning fuel, the aircraft can simply remain in the air until sufficient fuel has been burned to obtain the necessary weight reduction. The fact that the hydrocarbons released by fuel jettisoning are less reactive than those emitted in the aircraft's exhaust does not imply that jettisoning fuel is to be preferred environmentally over burning. At cruise power a gas turbine engine is highly efficient and hydrocarbon emissions generally amount to less than 0.1 percent of the fuel burned (Reference 13). Thus although the emissions are made more reactive, they are greatly reduced. One drawback of burning the fuel is the nitric oxide generated by the engines in the process. For every metric ton of fuel burned off, the aircraft will emit roughly ten kilograms of nitric oxide (Reference 13). However, this does not appear to constitute a significant source of nitric oxide. If all the fuel jettisoned during 1975 were burned instead, nitric oxide emissions from all military aircraft would have been increased by only 2.5 percent (Reference 10). The greatest difficulty with burning fuel instead of jettisoning is the time involved: a KC-135 can dump 24 metric tons of fuel in less than 8 minutes, but it would have to cruise for nearly 2 hours to burn off the same amount.

It should be noted, finally, that hydrocarbons cannot by themselves produce photochemical oxidant pollution; sunlight and

TABLE 9. RELATIVE REACTIVITY OF HYDROCARBONS RELEASED BY FUEL JETTISONING

Source:	Fuel Jettisoning	Aircraft Exhaust	Gas Handling Evaporation Loss	Automobile Exhaust	Los Angeles Average
Mole Percent in Classes:					
I (0.1)*	1	9	4	28	30
II (0.34)	-	4	-	-	-
III (0.64)	79	38	69	30	35
IV (0.95)	19	16	9	19	17
V (1.40)	1	33	18	23	18
Source Molar Reactivity:	0.70	0.88	0.78	0.72	0.66
Molecular Weight:	120	121	74	69	72
Source Weight** Reactivity:	0.40	0.50	0.73	0.72	0.64

* Class Reactivity

** Source Weight Reactivity = 69 x $\frac{\text{Source Molar Reactivity}}{\text{Molecular Weight}}$

nitric oxide are the other necessary ingredients. The jettisoned fuel is generally mixed in the aircraft wake with the engine exhaust, which contains nitric oxide. However, within minutes the wake expands to over twice the wing span of the aircraft (References 1 and 14), reducing the nitric oxide concentration to near ambient levels. Photochemical reactions require several hours to produce significant oxidant levels. Therefore, except for fuel jettisoning in an area already characterized by sufficiently high nitric oxide levels, significant photochemical activity within the fuel cloud is unlikely.

3.4 PHYSICAL FATE OF THE JETTISONED FUEL

Jet fuel, when jettisoned from an aircraft, readily breaks up into small droplets ranging from tens to hundreds of micrometers in diameter (Reference 14). These droplets quickly evaporate; after only a few minutes less than 10 percent of jettisoned JP-4 fuel typically remains in liquid form (Reference 2). The fuel vapor and droplets are subject to entrainment in the aircraft wake, atmospheric dispersion processes, and (in the case of the droplets) gravitational settling. Figure 13 shows the percent of JP-4 fuel which can be expected to reach the ground before evaporating, based on the release altitude and the temperature at ground level (References 1 and 2). These curves were generated by a computer model of fuel droplet free fall and evaporation (Reference 2), using initial droplet size distribution data from experimental studies of JP-4 fuel jettisoning from a KC-135 tanker aircraft. These studies were carried out at Edwards AFB by the Air Force Engineering and Services Center and the Air Force Geophysics Laboratory (References 1, 2, and 14). Although these studies used a KC-135, a comparison with droplet size distributions obtained in previous experimental studies (Reference 15) indicates that the curves in Figure 13 are representative for other aircraft as well. (Note, however, that the droplet evaporation calculations in Reference 15 are incorrect. A discussion of this matter is included in Reference 2).

The curves in Figure 13 indicate that except for very low altitude releases, the fraction of fuel reaching the ground as liquid droplets is primarily determined by the temperature. For JP-4 fuel jettisoned higher than 1,500 meters (5,000 feet) at ground-level temperatures above freezing (0°C), more than 98 percent of the fuel should evaporate before reaching the ground. These results confirm the wisdom of TAC and USAFE guidance to jettison fuel more than 1,500 meters above the ground. Jettisoning above 1,500 meters takes full advantage of fuel droplet evaporation to reduce the possibility of ground contamination. The adequacy of these guidelines is also supported by the previously mentioned studies at Edwards AFB. During those studies fuel was jettisoned as low as 750 meters (2,500 feet) above the ground at 11°C (50°F) and no liquid fuel could be detected by ground observers (Reference 2).

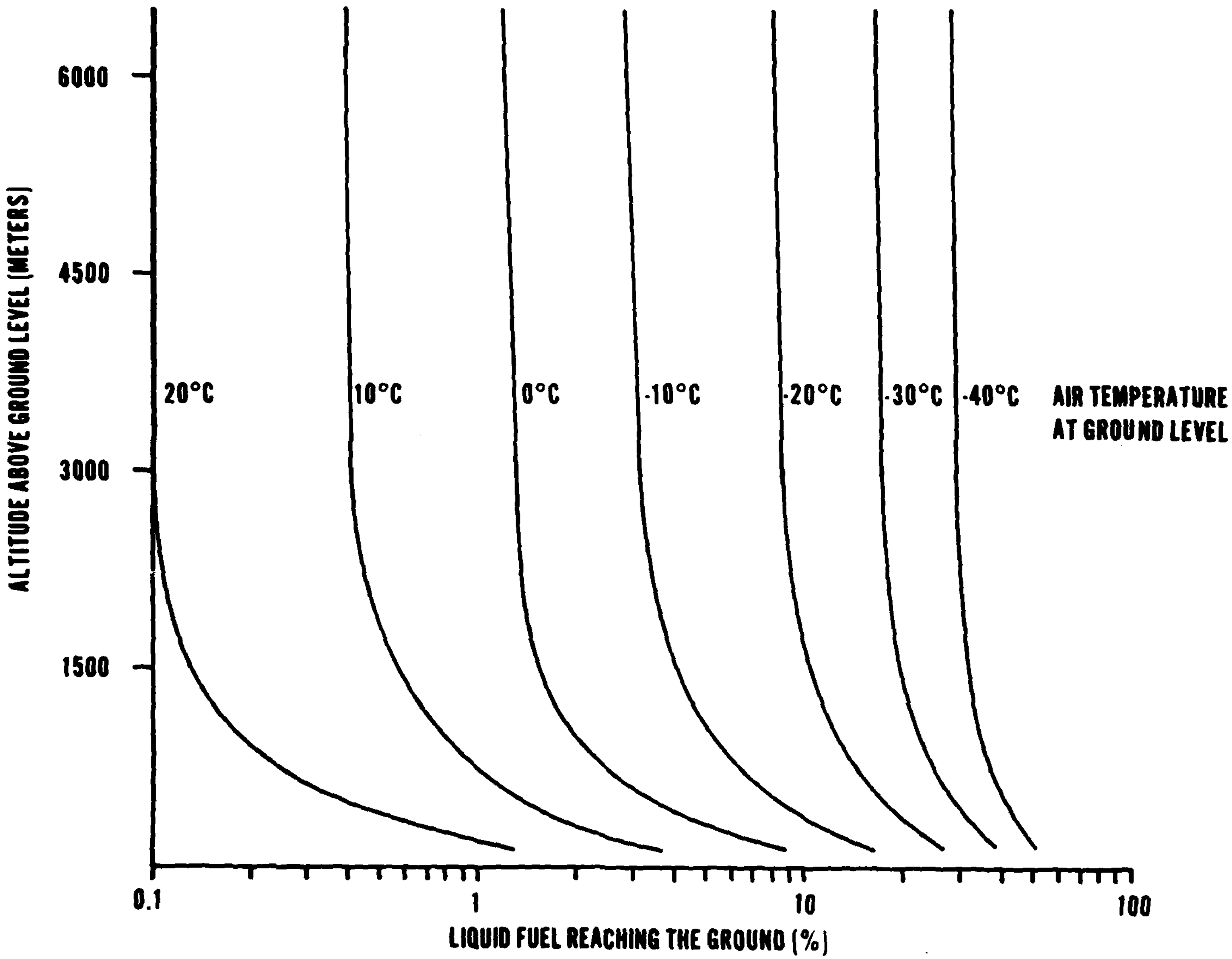

Figure 13. Percent of jettisoned fuel reaching the ground.

It should be noted that the temperatures listed for individual fuel dumps in Appendices A and B are the air temperatures at the altitude of the aircraft. The temperatures shown in Figure 13 are the air temperatures at ground level. The ground-level temperature corresponding to the temperature given in one of the fuel dump listings can be estimated under standard atmospheric conditions by adding 6.5°C per kilometer (2°C per thousand feet) to the temperature at a given altitude (Reference 16).

Inspection of Appendix A shows that practically all Air Force jettisoning involves JP-4 jet fuel. However there has recently been a trend, particularly in USAFE, toward the use of JP-8, a kersosene-based fuel similar to commercial jet fuel. Since JP-8 is much less volatile than JP-4, it can be anticipated that more JP-8 will reach the ground as liquid droplets than would be the case for JP-4 under the same conditions. Preliminary calculations suggest that the percent of JP-8 reaching the ground at, for example, 0°C would be somewhat between the curves for JP-4 at -20 and -40°C in Figure 13.

The possiblity that the airborne fuel vapor or droplets could interfere with the natural atmospheric processes relating to cloud formation, rainfall, or dissipation of fog was investigated by the Arnold Engineering Development Center (Reference 17). The results of this study, which was performed with a Wilson-type cloud chamber, indicate that JP-4 vapors have negligible effects on these processes. The evidence suggests that the JP-4 vapors are effectively scavenged and cleaned from the atmosphere by the natural process of condensation of water vapor and subsequent rainfall. The fuel droplets themselves showed an ability to act as seed nuclei to initiate condensation. Thus fuel jettisoning during atmospheric conditions favoring rainfall may increase the probability of precipitation. This in turn could increase the percent of the fuel reaching the ground as a liquid.

Most of the fuel vapor is generated within the first few minutes, before the droplets are able to fall more than a few hundred meters. Therefore the maximum possible hydrocarbon vapor concentration at ground level is determined by the ability of atmospheric diffusion processes to transport the vapors downward. The highest ground concentrations will be obtained under unstable atmospheric conditions since the vertical transport is then maximum. For an aircraft jettisoning parallel to the wind, the fuel dump can be treated as a pseudo-continuous source.

A worst-case analysis (Reference 2) indicates that fuel jettisoned parallel to the wind at an altitude H (in kilometers) will reach its maximum ground concentration after time T (in minutes), where $T = 40H^2$. At this time the crosswind width W (in kilometers) over which the vapors are spread at the ground will be greater than $W = 2.4H^2$. For example, fuel jettisoned at 1,500 meters would generate a maximum vapor concentration at the ground

90 minutes later, and would be spread out over a path more than 5.4 kilometers (3.4 miles) wide at the ground. The maximum ground concentration X (in micrograms per cubic meter) depends on the aircraft speed V (in meters per second) and the fuel jettisoning rate Q (in kilograms per second). Using a simple box model, the maximum ground concentration can be estimated by the formula $X = 1000Q/(VWH)$. To convert from micrograms per cubic meter to parts per million as methane (ppmC), divide by 667. Table 10 shows some examples of maximum ground concentrations for the principal jettisoning aircraft. Except for the last case, which represents an emergency at take-off, all of these worst-case ground concentrations are well below the 160 microgram per cubic meter ambient air quality standard for hydrocarbons. However, a KC-135 or RC-135 jettisoning fuel at 1,500 meters could produce ground concentrations approaching fifty micrograms per cubic meter. Considering the larger average size of fuel dumps by SAC aircraft and the higher jettisoning rates, the specification of a higher jettisoning altitude in SAC regulations than that called for by other commands seems warranted. The additional altitude allows greater dispersion to reduce ground concentrations.

At temperatures below freezing the fraction of fuel reaching the ground as liquid droplets could become significant. For example, from Figure 13 more than 8 percent of the JP-4 jettisoned when the surface temperature is -20°C (-4°F) would reach the ground, even from higher altitudes. As in the case of the fuel vapor, however, natural atmospheric dispersion would reduce the droplet density at the ground. For jettisoning parallel to the wind, the droplets would be spread over nearly as wide a path as the vapor. Therefore the maximum liquid fuel contamination of the ground, C (in milligrams per square meter), would be given approximately by the formula $C = 10\ PQ/(VW)$ where P is the percent of fuel reaching the ground in liquid form from Figure 13. To convert from milligrams per square meter to gallons per square mile, divide by 1.1. Some examples of liquid fuel contamination of the ground for jettisoning under extreme conditions are given in Table 11 using the same jettisoning parameters as in Table 10. The last example demonstrates that significant liquid fuel contamination can also occur for jettisoning at extremely low altitudes.

For jettisoning in any direction other than parallel to the wind, the droplets would be further separated by the process of winnowing: as the droplets are carried along by the wind the larger droplets fall faster and are deposited sooner (closer to the jettisoning location) than the smaller droplets, which tend to be transported more like the vapor. The distance L (in kilometers) that the fuel will be carried downwind before reaching the ground is given by $L = 0.06\ UT$, where U is the average wind speed between the jettisoning altitude and the surface, and T is the time of fall. As stated earlier, $T = 40H^2$ for

TABLE 10. MAXIMUM CONCENTRATION AT THE GROUND OF FUEL JETTISONED FROM SELECTED AIRCRAFT AND ALTITUDES

Aircraft	Air Speed (m/s)	Jettison Rate (kg/s)	Jettison Altitude (km)	Width at Ground (km)	Maximum Ground Concentration (ug/m^3)
F-4	175	5	1.5	5.4	3.5
F-111	175	17	1.5	5.4	12.0
FB-111	175	17	6	86.4	0.2
KC-135	175	50	6	86.4	0.6
F-111	175	17	0.3	0.2	1500

TABLE 11. EXAMPLES OF LIQUID FUEL CONTAMINATION OF THE GROUND

Aircraft	Jettison Altitude (km)	Surface Temperature (C)	Width at Ground (km)	Liquid Fuel Contamination (mg/m^2)
F-4	1.5	0	5.4	0.08
F-111	1.5	0	5.4	0.28
FB-111	6	-20	86.4	0.09
KC-135	6	-20	86.4	0.27
F-111	0.3	20	0.2	3.06

TABLE 12. EXAMPLES OF THE EFFECT OF WINNOWING ON LIQUID FUEL CONTAMINATION OF THE GROUND

Aircraft/ Base	Jettison Altitude (km)	Surface Temperature (C)	Wind Speed (m/s)	Width at Ground (km)	Liquid Fuel Contamination (mg/m^2)
F-4/Shaw	1.5	0	5	19	0.02
F-111/ Mountain Home	1.5	0	5	19	0.08
FB-111/ Plattsburg	6	-20	3	246	0.03
KC-135/Eielson	6	-20	4	328	0.07
F-111/Cannon	0.3	20	4	0.2	3.06

the vapor. This value also holds approximately for the smallest droplets. However, for the largest droplets (on the order of 200 to 400 micrometers in diameter) the time of fall based on the droplet evaporation and free fall model can be roughly estimated as T = NH, where N is 18, 12, and 10 minutes per kilometer for ambient temperatures of 0°C, -20°C, and -40°C, respectively (Reference 2). Therefore, for fuel jettisoned crosswind, the droplets will be spread by winnowing over a distance downwind W (in kilometers) given by the equation $W = 0.06\ U\ (40H^2 - NH)$. Several sample calculations are given in Table 12 using the same jettisoning parameters as Table 10. The wind speeds were chosen to represent average values between the jettisoning altitude and the ground for the locations indicated, based on Air Force Air Weather Service climatic data provided by HQ AFESC/WE. Except for the last case, the liquid fuel ground contamination is reduced by a factor of three to four when jettisoning crosswind as compared to jettisoning with the wind. At the low altitude of the last example, winnowing has no effect.

A second effect of the wind is to shift the location of ground impact considerably downwind of the jettisoning aircraft. The actual distances can be calculated with the formulas already given for L and T. As an example, for fuel jettisoning at 1,500 meters with 4 meter per second (8 knot) winds and a surface temperature of 0°C (32°F), the first droplets would reach the ground 6.5 kilometers (4 miles) downwind of the aircraft's position and the maximum vapor concentration at the ground would be reached over 20 kilometers (13 miles) away from the site of the jettisoning. For the same average wind speed and temperature, the nearest ground impact from a fuel dump at 6,000 meters occurs over 25 kilometers (15 miles) downwind, and the highest concentraion of vapor at the ground is not reached for nearly 350 kilometers (215 miles). Therefore the effect of prevailing winds must be a prime consideration in the choice of a jettisoning location.

The composition of the fuel droplets which reach the ground is no longer the same as that of the JP-4 fuel which was jettisoned. The more volatile, lower molecular weight components evaporate off preferentially, and the droplet ends up containing a residual mixture of the higher molecular weight components. A typical composition for a distribution of droplets which have evaporated to 10 percent of their original mass is shown in Table 13. This composition was determined with the fuel droplet freefall and evaporation model (Reference 2), which simulates JP-4 as a mixture of 33 representative compounds based on chemical analyses provided by the Air Force Aero Propulsion Laboratory. Each component in the synthetic mixture represents a class of similar compounds in real JP-4. It can be seen from Table 13 that the fuel droplets which reach the ground have lost essentially all of their volatile components. In fact their composition resembles kerosene, in that they are composed chiefly of hydrocarbons having a molecular weight greater than 150 grams per mole.

TABLE 13. RESIDUAL COMPOSITION OF FUEL DROPLETS AFTER NINETY PERCENT OF THE ORIGINAL MASS HAS EVAPORATED

Component	Original Percent of Droplet Mass	Percent Remaining of Component	Percent of Final Droplet Mass
iso-pentane	3.2	0	-
iso-hexane	7.1	0	-
cyclohexane	2.2	0	-
benzene	0.3	0	-
3-methylhexane	8.6	0	-
methylcyclohexane	7.3	0	-
toluene	0.8	0	-
4-methylheptane	9.4	0	-
cis-1,4-dimethyl-cyclohexane	7.7	0	-
m-xylene	1.8	0	-
4-methyloctane	8.7	0	-
isopropylcyclohexane	4.6	0.3	0.1
1-ethyl-2-methylbenzene	2.8	1.6	0.4
2,7-dimethyloctane	7.0	1.0	0.7
p-menthane (cis)	3.9	4.2	1.6
p-cymene	2.1	7.4	1.5
napthalene	0.3	46.4	1.4
undecane	4.7	26.9	12.4
3-methylbutylcyclohexane	2.7	27.0	7.1
3-methylenedecalin (trans)	4.0	31.0	12.2
1-butyl-3-methylbenzene	1.2	35.4	4.2
1-methylnapthalene	0.3	66.8	2.0
dodecane	2.8	48.3	13.3
3-ethylbutylcyclohexane	1.3	42.9	5.5
1,3,5-triethylbenzene	0.6	47.0	2.8
2,3-dimethylnapthalene	0.3	78.9	2.3
tridecane	1.1	63.2	6.8
3-isopropylbutyl-cyclohexane	0.4	55.7	2.2
3,5-diethyl-1-propyl-benzene	0.1	61.6	0.6
tetradecane	0.2	73.8	1.4
pentadecane	0.1	81.4	0.8
perhydrophenanthrene	2.2	86.7	18.7
residual	0.2	99.8	2.0

SECTION IV

SUMMARY AND CONCLUSIONS

During the period 1 January 1975 through 30 June 1978, Air Force aircraft performed approximately 80 fuel dumps each month, worldwide. The fuel released to the atmosphere by these dumps averaged 600 metric tons (well over a million pounds) per month, or roughly 800,000 liters (200,000 gallons) per month. This quantity of fuel amounts to 0.07 percent of the total Air Force jet fuel consumption at an annual cost of 1.1 million dollars.

Air Force command directives authorize fuel jettisoning when required to reduce the aircraft's gross weight in order to facilitate making a safe landing. The most frequent situation leading to fuel jettisoning is an in-flight emergency resulting from a malfunction in one of the aircraft systems, particularly engine failure. To a lesser extent, fuel jettisoning is also performed to permit a more expeditious landing in the event of an urgent operational requirement or aborted mission. Alternatives to fuel jettisoning include remaining airborne until sufficient fuel has been burned to reach the required weight, or landing with more than the recommended maximum safe landing weight.

The preponderance of Air Force fuel jettisoning is performed by aircraft belonging to the Strategic Air Command (the KC-135, RC-135 and FB-111) and the Tactical Air Command (the F-4 and F-111). The frequency with which these aircraft need to jettison fuel ranges from less than once in a thousand sorties for an F-4 to more than once in a hundred sorties (nearly once a year) for an F-111. The average size of fuel dumps also varies: from a few metric tons (less than 10,000 pounds) for an F-4 or F-111 to nearly twenty metric tons (40,000 pounds) for a KC-135 or RC-135. Overall, Air Force fuel jettisoning decreased by roughly nine percent a year during the report period. This decline was the direct result of a decreasing incidence of fuel jettisoning by KC-135 aircraft.

In accordance with command policies, practically all Air Force fuel jettisoning takes place at altitudes above 1,500 meters (5,000 feet). Jettisoning above 1,500 meters takes full advantage of the fuel's volatility, allowing it to evaporate and disperse, thus reducing ground contamination. When the temperature at the ground level is above freezing (0°C) more than 98 percent of the fuel jettisoned above 1,500 meters will evaporate before reaching the ground. Strategic Air Command policy calls for jettisoning altitudes above 6,000 meters when the situation permits, and most of the jettisoning by Strategic Air Command aircraft is indeed performed at or above this altitude. The greater dispersion afforded by these altitudes serves to offset the larger dump size and jettisoning rate typical of Strategic Air Command aircraft.

The vast majority of Air Force fuel jettisoning is performed in fairly close proximity to an Air Force base. In particular, nineteen major fuel jettisoning regions can be identified which account for over half of all Air Force fuel jettisoning. The principal fuel jettisoning areas are generally located in unpopulated or sparsely populated terrain such as mountain ranges, forests and the oceans. This observation is in keeping with command directives concerning the selection of fuel jettisoning areas to minimize any impact.

From an environmental viewpoint, fuel jettisoning is a potential source of hydrocarbon pollution. The fuel typically jettisoned (JP-4) is a petroleum distillate intermediate in properties between gasoline and kerosene and, like them, is a mixture of hundreds of different hydrocarbon species. When jettisoned the fuel is readily broken up into small droplets which then quickly evaporate as they fall. Under normal circumstances practically all of the jettisoned fuel will have been vaporized before it can reach the ground.

Atmospheric diffusion processes rapidly disperse and dilute the vapors to concentrations far below those at which they could be harmful in themselves. Therefore, the possible environmental consequences of these hydrocarbon vapors derive principally from their role in the production of photochemical oxidant pollution (ozone and smog). However, fuel jettisoning is generally not an important source of hydrocarbons when compared to automobiles, aircraft exhaust, and other sources in the same region. Moreover, the hydrocarbons released by fuel jettisoning are relatively unreactive compared to those from other sources, diminishing their importance in smog production even further. In a few remote areas characterized by frequent fuel jettisoning, the hydrocarbons released by jettisoning may consitute a significant fraction of the anthropogenic hydrocarbons in the local area. But hydrocarbons alone cannot produce photochemical oxidant pollution; nitric oxide is also required. The nitric oxide emitted in the exhaust from the engines of the jettisoning aircraft is not sufficient to raise local nitric oxide levels appreciably. Since these remote areas are generally characterized by low nitric oxide and hydrocarbon levels, and since the jettisoned fuel vapors are rapidly dispersed and diluted to low concentrations as well, no photochemical oxidant pollution is likely to occur in these areas as a result of fuel jettisoning. Similarly, the only likely effects of jettisoning fuel at very high altitudes is an insignificant temporary fluctuation in the local ozone levels.

After the bulk of the fuel has evaporated from the droplets, a small fraction roughly resembling kerosene remains. Generally, only a few percent of the fuel is represented by this residual liquid. These droplets could possibly act as seed nuclei for condensation of water, even increasing the likelihood of rainfall under favorable conditions, but the usual fate of the droplets is to settle directly to the ground. As with the vapors, natural dispersion processes act to spread the fuel droplets over a wide area, reducing the density of ground contamination to very low levels. Even for jettisoning at extremely low temperatures or close to the surface, where a significant fraction of the fuel can reach the ground before evaporating, the ground contamination only reaches the order of a few milligrams per square meter (a few gallons per square mile). It is not likely that such minimal contamination of the ground would be noticeable even on close inspection.

The hydrocarbons released by fuel jettisoning will continue to be dispersed and scrubbed from the atmosphere by natural processes until they eventually reach the level of the natural background. The fate of the hydrocarbons in ground and water environments is currently under investigation. No serious consequences are expected at the low concentrations produced by fuel jettisoning incidents.

Current Air Force policies concerning fuel jettisoning appear adequate to minimize any negative environmental consequences. Analysis of data on fuel jettisoning by Air Force aircraft for a 3 1/2-year period indicates that Air Force operational practices are in keeping with Air Force policies. Fuel jettisoning as carried out by Air Force aircraft does not appear to entail any serious environmental implications.

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