STATE OF UTAH
DEPARTMENT OF HEALTH

SCOTT M. MATHESON, GOVERN

MICHAEL J STAPLEY, M P A , ACTING EXECUTIVE DIRECTOR

FEB 05 1985

533-6108

Frank L. McFarland
Department of the Air Force
Hill Air Force Base Headquarters
2849 Air Group
Hill Air Force Base, Utah 84056

Single chamber forced air propane fired

RE: Approval Order for Hydrazine Exhaust Incinerator - Davis County CDS A1
adjacent to Bldg. 2015

Dear Mr. McFarland:

On December 24, 1984, the Executive Secretary published a notice of intent to approve a hydrazine exhaust incinerator. The 30 day public comment period has expired, and no comments were received.

This air quality approval order authorizes the incinerator as proposed in your notice of intent dated November 21, 1984, with the following operating conditions:

1. All emission control equipment shall be properly installed, maintained, and operated as proposed in the notice of intent dated Nov. 21, 1984. Combustion temp. maintained at 1800°F with a residence time of 0.6 s

2. No visible emissions from the incinerator stack shall exceed 20% opacity as measured by EPA Reference Method 9.

3. If a stack test is performed, the results of the test shall be submitted to the Executive Secretary.

4. The Executive Secretary shall be notified when startup occurs as an initial compliance inspection is required.

The fee for issuing this approval order is $138.34. The amount (see enclosures for breakdown of costs) is payable to the Utah Department of Health, sent to the Executive Secretary, Utah Air Conservation Committee, and is due within 30 days after receipt of the approval order.

Sincerely,

Brent C. Bradford
Executive Secretary
Utah Air Conservation Committee

DK
DK:wml
Enclosures
cc: EPA Region VIII (N. Huey)
Davis County Health Department
6709

4.2.4-980

Hill AFB

12-24-84

NOTICE

The following notices of intent to construct, submitted in accordance with Section 3.1, Utah Air Conservation Regulations, have been received for consideration by the Executive Secretary, Utah Air Conservation Committee:

1. Hill Air Force Base, hydrazine incinerator, Davis Co.

2. Deseret Medical, catheter heparin coating, Sandy

3. Intermountain Products, vermiculite plant, Salt Lake City

4. Salt Lake Airport, parking lot, Salt Lake City

5. Geneva Rock Products, cement batch plant, Snowbird Salt Lake Co.

The engineering evaluations and air quality impacts have been completed, and no adverse air quality impacts are expected. It is the intent of the Executive Secretary to approve these construction projects.

The construction proposals and estimates of the effect on local air quality are available for public inspection and comment at the Bureau of Air Quality, Utah State Department of Health, Room 426, 150 West North Temple, Salt Lake City, Utah. Written comments received by the Bureau, P.O. Box 45500, Salt Lake City, Utah 84145, on or before January 23, 1985, will be considered in making the final decision on the approval or disapproval of the proposed construction.

If anyone so requests, within 15 days of publication of notice, a hearing will be held in the area of the proposed construction, installation, modification, relocation, or establishment.

Date of Notice: December 24, 1984

12/5/84 Minor (New)
Major
ID#

BUREAU OF AIR QUALITY
ENGINEERING REVIEW - SUMMARY (NOI Dated 11/21/84)
ENGINEER/DATE - Don Robinson 12/4/84 DR

Owner/Operator: Hill Air Force Base

Source: Emergency Power Unit Firings on F-16s

Applicant/Official: Frank L. McFarland

Applicant/Official Address: Dept. of Air Force, HDQRS 2849 Air Base Group (AFLC), Hill AFB, UT 84056

Telephone Number of Contact: 801-777-2065 (Bill Taylor)

Plant/Activity Location and Address: Hill AFB (Weber Co.)

Type of Operation: Hydrazine Exhaust Incinerator

I. Background

The F-16 is a new single-engine tactical aircraft. Since the F-16 is an electronically controlled configuration aircraft, an emergency power unit is used to provide short-term electric and hydraulic power for aircraft control. The emergency power unit (EPU) is fueled with a monopropellant hydrazine mixture, H-70, which contains 70% hydrazine and 30% water.

During EPU testing, the hydrazine fuel will be passed through the normally used catalyst, which is actually part of the EPU. The emissions of concern are the exhausts that will leave the EPU after the hydrazine passes through the catalyst.

Under no-load conditions, the EPU operates in a pulsed manner at approximately two pulses/second. Because water in the fuel does not enter into the decomposition reactions, the exhaust gas has a very high water vapor content and hence a high dew point. The exhaust gas is discharged from the F-16 aircraft through a three inch duct opening, flush with the aircraft skin near the wing root and directed vertically downward.

II. Proposal

Hill Air Force Base is proposing to install a hydrazine exhaust incinerator to control the emissions from planned EPU test firings. The incinerator is single-chambered, forced air, and propane-fired. The combustion chamber is cylindrical with a three foot inside diameter and is ten feet tall. The specified performance characteristic is that it emits hydrazine at levels which do not exceed 1 ppm. It accomplishes this by creating a combustion chamber with a temperature of 1800 degrees F. and a residence time of 0.6 seconds.

The following numbers describe the operation:

1. Two test firings per day.
2. 260 days per year.
3. One minute per test firing.
4. Hydrazine - N_2H_4.
5. One ppm N_2H_4 emitted to atmosphere.
6. Propane fired, 1.1 X 10^6 BTU/hr.
7. 45 minutes per EPU firing.
8. 4630 ft MSL
9. Stack height 15 ft.
10. Stack Temp. 1800 degrees F.
11. Residence time - 0.6 seconds.

The incinerator will be installed adjacent to Building 2005 at HAFB. This is in Weber County.

A contract has been let to AeroVironment to devise a sampling train. Samples will be taken before and after incineration in order to calculate efficiencies. Construction is already underway and startup is planned for March 1985.

III. Regulation Applicability

This source is subject to the following regulations:

1. Section 3.1, UACR - NOI requirement.
2. Section 4.1, UACR - 20% opacity.
3. Section 4.7, UACR - Unavoidable breakdown.

This source is not subject to PSD, NSPS, or NESHAPS. The area is nonattainment for particulate. Ogden is nonattainment for CO.

IV. BACT Analysis

The incinerator constitutes BACT for this source. A temperature of 1800 degrees F. and a residence time of 0.6 seconds will oxidize any VOC or hydrazine.

V. Modeling - None. Small source.

VI. Emission Summary

N_2H_4 - .48 lb/yr
NOx - 2.125 ton/yr

VII. Recommendations

Recommend approval with the following conditions:

1. All emission control equipment shall be properly installed, maintained, and operated as proposed in the notice of intent dated Nov. 21, 1984.

2. No visible emissions from the incinerator stack shall exceed 20% opacity as measured by EPA Reference Method 9.

3. If a stack test is performed, the results of the test shall be submitted to the Executive Secretary.

4. The Executive Secretary shall be notified when startup occurs as an initial compliance inspection is required.

DR/ads
6235

VIII. Emission Calculations

given (1) 520 test firings/yr
(2) 45 minutes each
(3) propane fueled
(4) STP 1 atm
68°F = 293.16°K
(5) 100% excess air
(6) 1.1×10^6 BTU/HR

products entering incinerator

POLLUTANT	LB/FIRING	LB/YR	GRAM-MOLES/YR
N_2H_4	.053	27.56	390.09
NH_3	2.956	1537.12	40,940.82
H_2	.522	271.44	61,072.65
N_2	4.869	2531.88	81,949.15
H_2O	3.6	1872	47,131.46

propane C_3H_8 2590 BTU/SCF

$$\text{Total BTU/YR} = 1.1 \times 10^6 \times 520 \times \frac{45}{60} = 4.29 \times 10^8$$

$$\therefore \#\text{SCF propane} = \frac{4.29 \times 10^8 \text{ BTU/YR}}{2590 \text{ BTU/SCF}}$$

$$= 165,637.06 \text{ SCF/YR}$$

$$n = \frac{PV}{RT} = \frac{1 \times 165,637.06 \times 28.316}{.0821 \times 293.16} = 194,868.46 \text{ gram moles}$$

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

$N_2H_4 + 3O_2 \rightarrow 2NO_2 + 2H_2O$

$NH_3 + \frac{7}{4}O_2 \rightarrow NO_2 + \frac{3}{2}H_2O$

$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

194,868.46 C_3H_8 + 974,342.30 O_2

→ (1) 584,605.38 CO_2

(2) 779,473.84 H_2O

380.09 N_2H_4 + 1170.27 O_2 →

(3) 780.18 NO_2

(4) 780.18 H_2O

40,940.82 NH_3 + 71,646.44 O_2 →

(5) 40,940.82 NO_2

(6) 61,411.23 H_2O

61,072.65 H_2 + 30,536.32 O_2 →

(7) 61,072.65 H_2O

N_2 → (8) 81,949.15 N_2

H_2O → (9) 47,131.46 H_2O

100% excess air → (10) 1,077,695.33 O_2

(11) 4,054,187.19 N_2

TOTAL GRAM-MOLES

EXHAUST = 6,790,027.41 gram moles/YR

$$VOL = \frac{nRT}{P} = \frac{6{,}790{,}022.41 \times .0821 \times 1255.28}{.8453}$$

1800°F = 1255.28°K

P = .8453 atm $= 8.27836 \times 10^8$ l/YR

$$= \frac{8.27836 \times 10^8}{28.316 \times 520 \times 45} \text{ ACFM}$$

$= \boxed{1249.38 \text{ ACFM}}$

N_2H_4 emissions at 1ppm

6.79 gram moles/YR = $\boxed{.48 \text{ lb/YR } N_2H_4}$

NO_2

41,721 gram moles/YR = $\boxed{2.115 \text{ ton/yr}}$

TSP

10 lb/10^6 SCF × 165,637.06 / 2000 = NEG

SO_2

.60 lb/10^6 SCF NEG

NOx

120 lb/10^6 SCF = $\boxed{.01 \text{ ton/yr}}$

HC

8 lb/10^6 SCF $\boxed{\text{NEG}}$

CO

20 lb/10^6 SCF NEG

summary

TSP — NEG

SO_2 — NEG

NO_x — 2.125 tons/yr

HC — NEG

CO — NEG

N_2H_4 — .48 lb/yr

STATE OF UTAH
DEPARTMENT OF HEALTH

SCOTT M. MATHESON, GOVERNOR

MICHAEL J STAPLEY, M.P.A., ACTING EXECUTIVE DIREC

November 28, 1984
533-6108

Frank L. McFarland
Dept. of the Air Force
Hill Air Force Base, Utah 84056

RE: Receipt of Notice of Intent

Dear Mr. McFarland:

This letter acknowledges receipt of your application for an air quality approval order dated November 21, 1984. We have begun our evaluation and if any additional information is necessary, you can expect to hear from us within 30 days.

Sincerely,

David Kopta
Manager, Engineering Section
Bureau of Air Quality

DK
DK/ads
6190(c)

KENNETH L. ALKEMA, DIRECTOR • DIVISION OF ENVIRONMENTAL HEALTH

150 WEST NORTH TEMPLE • P.O. BOX 2500 • SALT LAKE CITY, UTAH 84110-2500 • (801) 533-6121
AN EQUAL OPPORTUNITY EMPLOYER

RECEIVED

NOV 26 1984

Utah State Div. Of Environmental Health

D 'ARTMENT OF THE AIR FORCE
HEADQUARTERS 2849TH AIR BASE GROUP (AFLC)
HILL AIR FORCE BASE, UTAH 84056

REPLY TO ATTN OF: DE

21 NOV 1984

SUBJECT: Notice of Intent to Construct - Hydrazine Exhaust Incinerator, Hill Air Force Base

TO: Utah Air Conservation Committee
Bureau of Air Quality
PO Box 2500
Salt Lake City UT 84110-2500

1. Attached is a Notice of Intent to construct for a new Hydrazine Exhaust incinerator submitted in compliance with section 3.1 of the State Air Conservation Regulations. This is the same submittal we mailed on 12 September which has not been received by your office. We would appreciate your timely review of this submittal because the original was lost.

2. If you have any questions, please feel free to call Bill Taylor at 777-2065.

Frank L McFarland

FRANK L McFARLAND
Deputy Base Civil Engineer
Civil Engineering Division

1 Atch
Notice of Intent

Additional Plans Filed in the Engineering Section Plans File.

RECEIVED
NOV 26 1984
Utah State Div. Of
Environmental Health

NOTICE OF INTENT TO CONSTRUCT

HYDRAZINE EXHAUST INCINERATOR

HILL AIR FORCE BASE, UTAH

1. The following information is provided in accordance with the outline in section 3.1.6 of the State Air Conservation Regulations:

a. Project Description:

(1) The proposed incinerator will be installed to burn unreacted hydrazine (N_2H_4) emitted during Emergency Power Unit (EPU) test firing. The EPU is utilized in the F-16 to provide emergency electrical power in the event of generator failure. Basically, it works on the principle of passing the hydrazine fuel through an oxidizing catalyst, generating gas (ammonia and decomposition products) and turning a turbine wheel with the resulting gas.

(2) Each EPU test firing will last one minute during which time a maximum of 12 pounds of the 70% hydrazine solution are burned. This is according to an Air Force study "Exhaust Gas Composition for the F-16 Emergency Power Unit" (Report SAM-TR-79-2), which is provided as an attachment. Under a maximum loading condition, as many as two EPUs may be test fired each day, 260 days per year. This accounts for a total of 520 test firings during a year, consuming a total of 6,240 pounds of the H-70 hydrazine fuel which is 30 percent water, 70 percent hydrazine.

(3) During the EPU testing, the hydrazine fuel will be passed through the normally used catalyst which is actually part of the EPU. The finished product will only be the verification that the EPU is operating correctly. The emissions of concern are the exhausts that will leave the EPU after the hydrazine passes through the catalyst.

b. Expected Emissions:

(1) Prior to Treatment: The decomposition of hydrazine in the EPU is basically as shown in the following reaction:

$$3\ N_2H_4 \rightarrow 2\ NH_3 + 3\ H_2 + 2\ N_2$$

This shows a 50 percent dissociation of ammonia (NH_3) which corresponds to what was seen in tests. Tests have also shown that a maximum of 0.053 pounds of unreacted hydrazine may pass through the catalyst. Thus, of the 8.4 pounds of hydrazine (70% of 12 pounds) consumed in each test firing, 8.347 is reacted according to the above reaction. This gives:

$$\underset{(8.347)}{3\ N_2H_4} \rightarrow \underset{(2.956)}{2\ NH_3} + \underset{(.522)}{3\ H_2} + \underset{(4.869)}{2\ N_2}$$

The anticipated emissions before treatment can then be listed as follows:

Pollutant	Lbs/1 Min Test Fire	Lbs/Year
Hydrazine (N_2H_4) — 32.046	0.053	27.56
Ammonia (NH_3) — 17.03	2.956	1,537.12
Hydrogen (H_2) — 2.016	0.522	271.44
Nitrogen (N_2) — 14.014	4.869	2,531.88
Water & Dissociation Products — 18.016	3.6	1,872.00
	12 Lbs Fuel	

(2) After Treatment: The Air Force is requiring the exhaust treatment supplier to meet the specification of no more than one part per million of unreacted hydrazine in the treated exhaust. At a flow rate of 1333 SCFM, one ppm equates to approximately 0.0001 pounds per minute or pounds per test firing (since they are for one minute).

Pollutant	Lbs/1 Min Test Fire	Lbs/Year
Hydrazine (N_2H_4)	0.0001	0.052
Combustion Products of Hydrazine	0.0529	27.51
Combustion Products of Ammonia	2.956	1,537.12
Hydrogen (H_2)	0.522	271.44
Nitrogen (N_2)	4.869	2,531.88
Water & Dissociation Products	3.6	1,872.00
	12 Lbs Fuel	

(3) The incinerator treatment will also involve the production of emissions from the burning of propane fuel. It is estimated that 1.1 MBTU will be used per hour of operation and that the incinerator will be fired a maximum of 45 minutes per test firing. Assuming a heating value of 90,500 BTU per gallon of propane, consumption of propane per test firing can be obtained from the following:

$$\frac{(0.75 \text{ hrs/test})(1{,}100{,}000 \text{ BTU/hr})}{90{,}500 \text{ BTU/gallon}} = 9.12 \text{ gallons/test}$$

Using AP-42, "Compilation of Air Pollutant Emission Factors," and anticipating 520 test firings per year, the emissions from the propane burning is as follows:

Pollutant	Lbs/Year
Particulates	1.28
Sulfur Oxides	0.07
Nitrogen Oxides	58.81
Carbon Monoxide	14.70
Volatile Organics	
Nonmethane	1.19
Methane	1.28

(4) The volume of air/combustion products emitted from the incinerator will be approximately 1333 SCFM and they will be emitted at a temperature of 1800° F.

c. Characteristics: The proposed air cleaning device is a single chambered, forced air, propane-fired incinerator. The combustion chamber is cylindrical with a three-foot inside diameter and is ten feet tall. The specified performance characteristic is that it emits hydrazine at levels no greater than one part per million. It accomplishes this by creating a combustion chamber with a temperature of 1800° F and residence time of 0.6 seconds.

d. Location: The incinerator is to be installed adjacent to Building 2005 at Hill Air Force Base shown in Figure 1.0, which is in Weber County. The incinerator, located on a concrete pad on the east side of the building, will have its stack terminate at about 15 feet above ground level (ground level is about 4630 MSL at this location). The facility is located in a fairly remote area of the base. Building 2004 is immediately adjacent, but like 2005, will only be manned on occasions. The closest building routinely occupied is approximately 500 feet to the northeast. However, at one part per million hydrazine, the stack effluent will meet the OSHA standard for eight-hour time weighted exposure; even with no dispersion, no hazards exist.

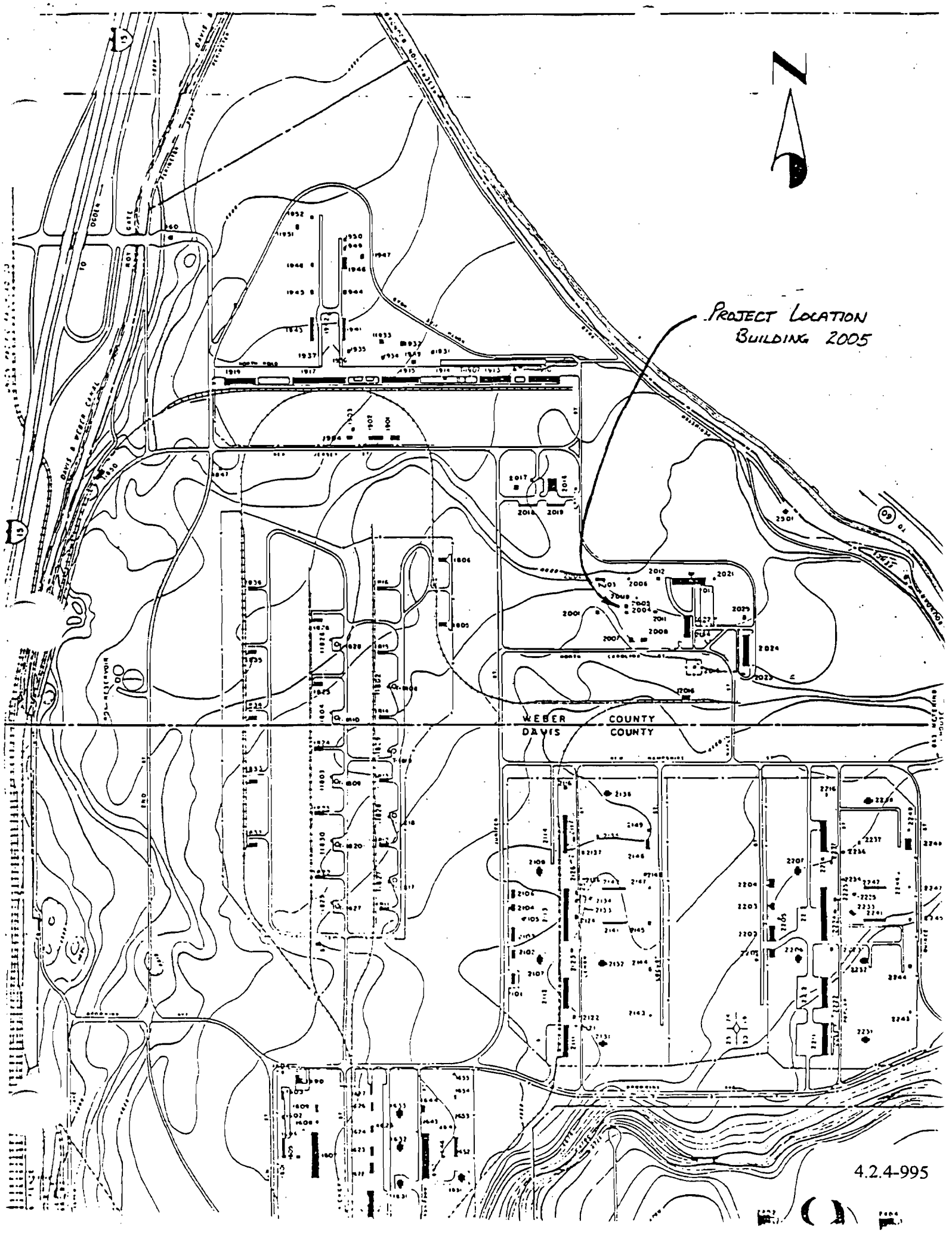
e. Sampling: The Air Force proposes to sample the incinerator both at Airesearch Los Angeles, where the incinerator will be constructed, and at Hill Air Force Base after delivery. A contract has been let to AeroVironment to devise a sampling train. It has not yet been determined whether Airesearch or AeroVironment will actually conduct the sampling. Samples will be taken before and after incineration so that efficiencies can be calculated. The exhaust sampling port is shown in the incinerator drawings. Also during sampling, a worst-case situation will be simulated where two seconds (at 0.2 Lbs/sec) of hydrazine by-passes the catalyst and goes straight to the incinerator. In actual operation, the EPU will automatically shut down after two seconds if the catalyst is not working.

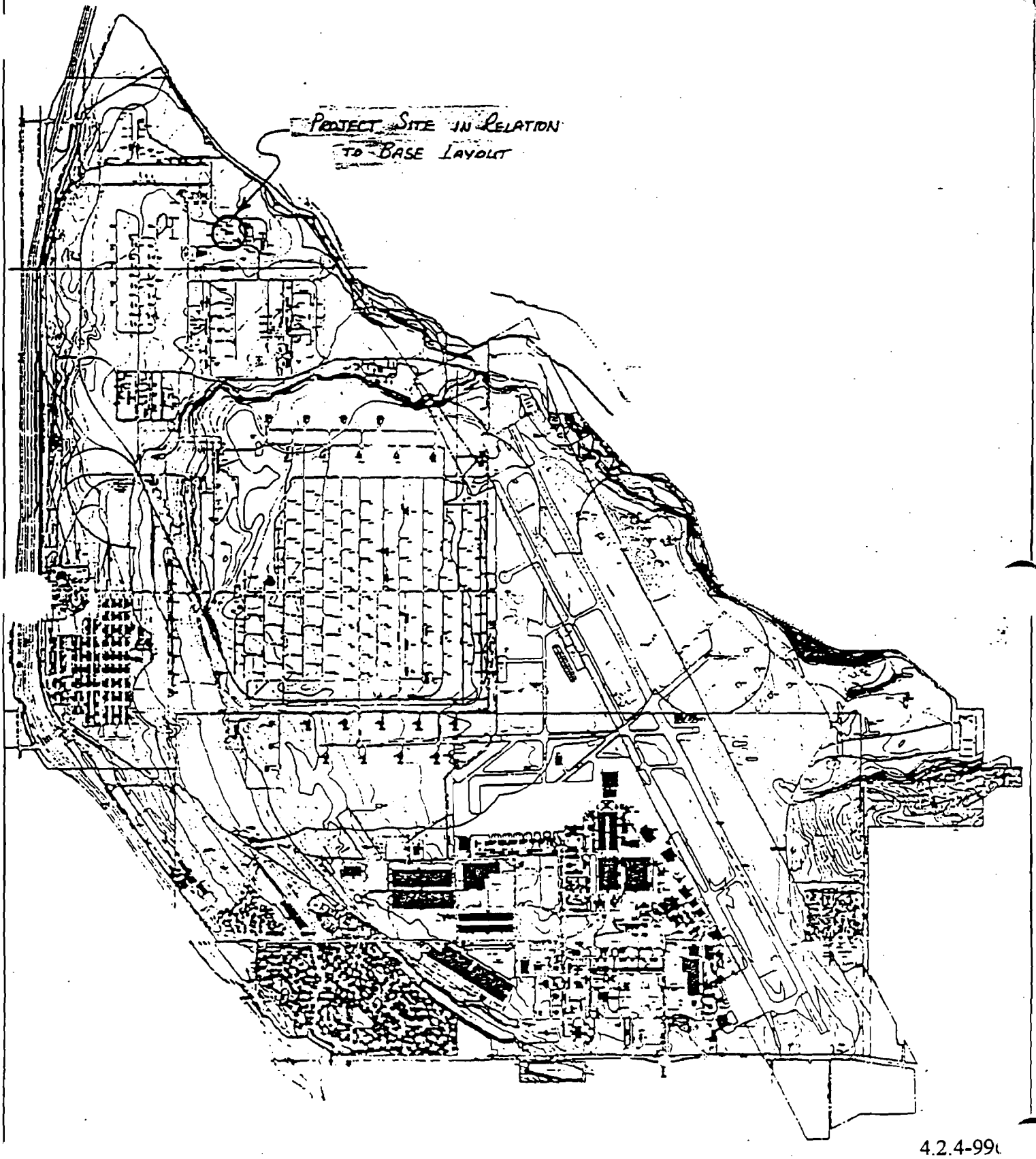
f. Operating Schedule: The heaviest usage now anticipated calls for two EPU test firings per day, 260 days per year.

g. Construction Schedule: Facility modifications are already underway to accommodate the test stand and incinerator. It is currently proposed to have the incinerator in place for sampling in March 1985.

h. Plans and Specifications: Incinerator drawings and Air Force Report SAM-TR-79-2 are attached.

3 Atch
1. Map
2. Air Force Report SAM-TR-79-2
3. Incinerator Drawings


PROJECT LOCATION
BUILDING 2005
WEBER COUNTY
DAVIS COUNTY



4.2.4-99(

HILL AIR FORCE BASE
BASIC LAYOUT PLAN
TAB C-2
30 SEP 81

Report SAM-TR-79-2

EXHAUST GAS COMPOSITION OF THE F-16 EMERGENCY POWER UNIT

Harry J. Suggs, Lieutenant Colonel, USAF, BSC
Leonard J. Luskus, Ph.D.
Herman J. Kilian, B.S.
Joseph W. Mokry, Staff Sergeant, USAF

February 1979

Interim Report for Period 1 October 1977 - 31 March 1978

Approved for public release; distribution unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

4.2.4-997

EXHAUST GAS COMPOSITION OF THE F-16 EMERGENCY POWER UNIT

INTRODUCTION

The F-16 is a new single-engine tactical aircraft scheduled to become Air Force operational in early 1979. Since the F-16 is an electronically controlled configuration (fly-by-wire) aircraft, an emergency power unit (EPU) is used to provide short-term electric and hydraulic power for aircraft control. The EPU is fueled with a monopropellant hydrazine mixture, H-70, which contains 70% hydrazine (N_2H_4), 30% water, by weight.

The introduction of hydrazine to the aircraft flight line scenario has raised numerous questions on environmental and occupational health support requirements. Early discussions with the F-16 Systems Program Office (ASD/YP), Wright-Patterson Air Force Base, Ohio, identified a need to determine the chemical composition of the EPU exhaust gas, to verify theoretical analyses. Specific questions were raised on the quantity of unreacted hydrazine and ammonia in the EPU exhaust gases. Answers to these questions were necessary to develop controls and protective actions to prevent excessive exposure to either of these toxic constituents.

During the week of 23 to 27 January 1978, an analytical team from the Crew Environments Branch, USAF School of Aerospace Medicine, collected a series of exhaust samples during ground-test firings of an installed F-16 EPU. This report describes the test procedures and details the EPU exhaust hydrazine and ammonia emissions.

DESIGN OF THE STUDY

Planned test firings or inadvertent ground firings were known to be largely cold-start runs of short duration under no-load conditions. Inadvertent firings typically have resulted in engine shut-down when the EPU mode selector switch was in the automatic position. The study therefore was designed to collect the exhaust samples following cold-start firings under no-load conditions.

Theoretical reactions of the catalytic decomposition of hydrazine are shown in Table 1. Theoretical gas composition for H-70 is shown in Figure 1 as a function of X, the fraction of ammonia dissociated in reaction 2. The value of X for the F-16 EPU was unknown at the start of the investigation, but was determined to be approximately 0.5 (50% ammonia dissociation).

4.2.4-998

TABLE 1. REACTIONS OF THE CATALYTIC DECOMPOSITION OF HYDRAZINE

$$3\ N_2H_4 \longrightarrow 4\ NH_3 + N_2 \qquad (1)$$

$$4\ NH_3 \longrightarrow 2\ N_2 + 6\ H_2 \qquad (2)$$

$$3\ N_2H_4 \longrightarrow 4(1-X)\ NH_3 + 6X\ H_2 + (2X + 1)\ N_2 \qquad (3)$$

Where X = fraction of NH_3 dissociated.

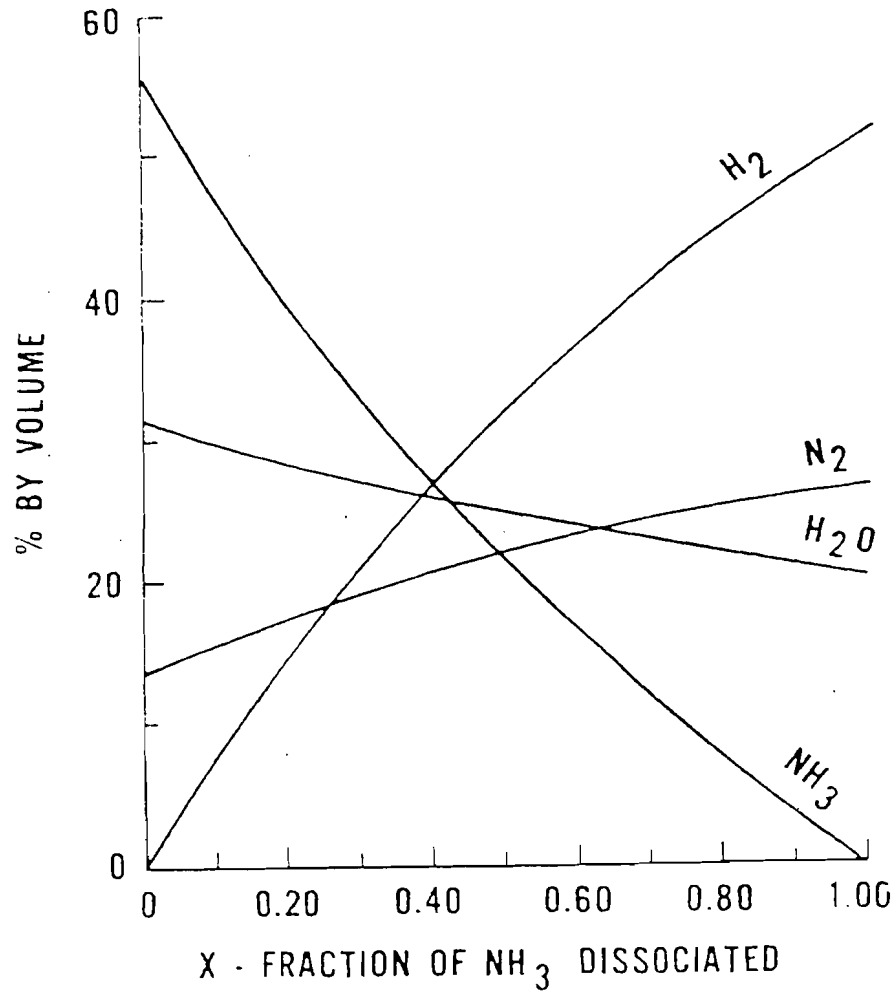


Figure 1. Theoretical exhaust products from catalytic decomposition of H-70.

Under no-load conditions, the EPU operates in a pulsed manner at approximately two pulses per second. Because water in the fuel does not enter into the decomposition reactions, the exhaust gas has a very high water vapor content and hence a high dew point. The exhaust gas is discharged from the F-16 aircraft through a 3-in (7.62 cm) duct opening, flush with the aircraft skin near the wing root and directed vertically downward. Maximum gas temperature was expected to be about 800°F (430°C). These combined factors created somewhat adverse conditions for extractive sampling. However, since in situ measurement techniques were not available within the required time frame, an extractive sampling method was devised and briefly laboratory tested before the study was undertaken.

The extractive sampling train, shown schematically in Figure 2, employed an evacuated tank (approximately 7½ liters) to draw sample through the train, to collect noncondensible gases in the sample, and to contain that gas sample for subsequent analysis. The tanks were alternatively replaced with a vacuum pump, in which case the noncondensible gases were not collected. A limiting orifice was used to maintain a known sampling rate of approximately 1 l/min. Two impingers, in series, each containing 100 ml of 2N sulfuric acid were placed in an ice bath and used to trap ammonia, hydrazine, and water. Solenoid valves before and after the impingers were remotely actuated to start and stop sample flow at predetermined times. An electrically heated sample line and nozzle, preheated to 100°C, was used to deliver the sample to the impingers. The sample line led to a manifold that allowed independent operation of five identical sampling trains, in parallel. Samples were collected from each of the five trains concurrently or sequentially as desired. Exhaust gas temperature was measured with a type J, iron-constantan thermocouple located alongside and flush with the sample nozzle.

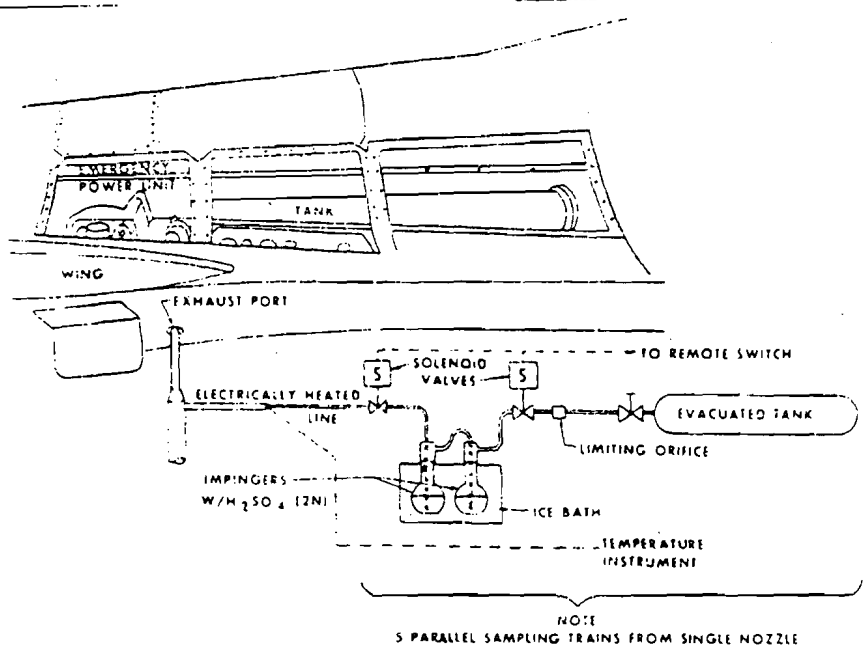


Figure 2. Schematic diagram of exhaust gas sampling train.

The sampling time interval for each sampling train for the six EPU tests is shown in Figure 3. Lines, in the figure, indicate the time of on-stream sample collection for each of the five samples in each test. Only four samples were collected in test 1. Sets A and B indicate tests with two different emergency power units installed in the aircraft. Set A was run on 24 Jan 1978 with EPU S/N 76-103, and Set B on 26 Jan 1978 with EPU S/N 76-107. The first test in each set was run after the EPU had stood overnight at ambient temperature (about 5°C). Between the two subsequent tests in each set, the catalyst bed was purged with gaseous nitrogen and cooled to touch. However, neither EPU was instrumented to measure catalyst temperature, making actual bed temperature unknown at the beginning of subsequent restarts.

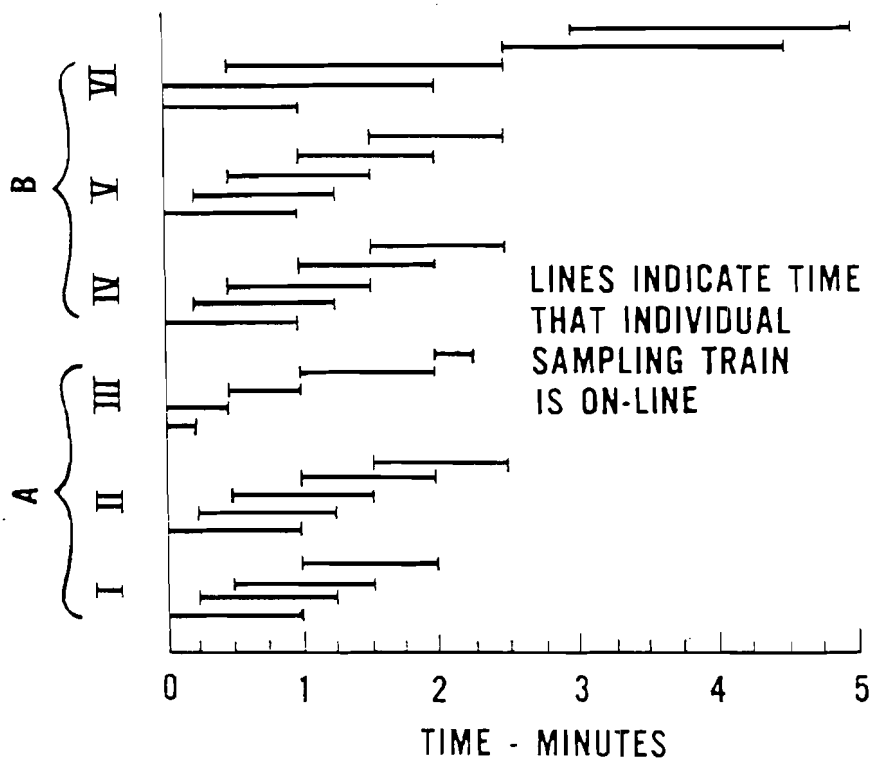


Figure 3. Sampling sequence.

Impingers were weighed before and after each test to determine total condensibles collected. Impinger samples were spot analyzed in the field to verify sample collection, but all samples were returned to the laboratory at Brooks AFB for final analysis. The p-dimethylaminobenzaldehyde (PDAB) colorimetric method (1) was used for hydrazine. Preliminary testing showed that ammonia did not interfere in the hydrazine method. Assay for ammonia was done with Nessler's reagent (2).

RESULTS

Exhaust Gas Temperature

The temperature profiles for two typical EPU tests are shown in Figure 4, as a function of time. Before the completion of the first run, it was apparent that EPU operation was not as had been expected. During run I the exhaust temperature rose rather gradually to around 500°F (260°C) then, at about 1-3/4 min into the run, the temperature increased rapidly to approximately 1200°F (650°C) just as the planned 2-min run was terminated. Run II resulted in the same phenomenon (Fig. 4) except that the rapid temperature rise started 1-1/2 min into the run and leveled off at around 1300-1400°F (700-760°C), the upper range of the type J thermocouple. Prior to run III, contractor engineers installed a 0-2000°F (-20-1100°C) thermocouple on the sample probe, taping the bare wire junction at the exhaust exit plane. During run III the contractor-installed thermocouple indicated a maximum temperature of nearly 1600°F (870°C). Run III was terminated before the planned 2-1/2 min time when flame (afterburning) was seen in the exhaust gas.

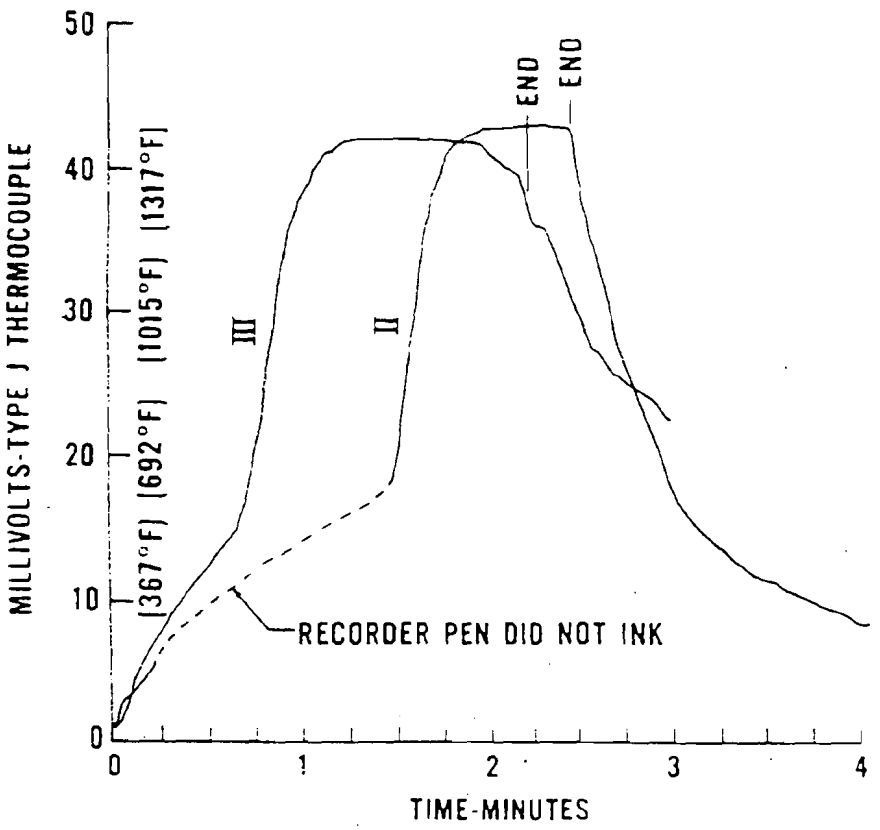


Figure 4. Exhaust gas temperature profile.

After considerable discussion of the findings from the first three tests, the contractor made the decision to exchange EPU S/N 76-103 with one taken from another aircraft. However, runs IV-VI with EPU S/N 76-107 gave essentially the same exhaust gas temperature characteristics. Afterburning was again observed, but usually only after more than 2 min operation.

Hydrazine

Results of hydrazine sampling are shown in Table 2. These results indicated some variability, but there was a clear indication that the hydrazine decreased rapidly with time into the run. Impinger collection efficiency was determined from the ratio of hydrazine in the first and second impingers. All hydrazine samples had a collection efficiency of 95.2% with a standard deviation (σ) of 8.7%.

Significantly greater amounts of unreacted hydrazine were found in runs I and IV. In both cases, these were the first runs made with each of the two different EPU's. Since there had been prolonged cold weather at the time of the test, the catalyst bed temperature was initially between $0^{\circ}C$ and $10^{\circ}C$. Between runs, the catalyst bed was purged with gaseous nitrogen; however, in the absence of instrumentation to measure catalyst bed temperature, it is probable that the bed was not cooled to initial run temperatures. This could account for the variability of the hydrazine values and suggests greater hydrazine hazard potential at colder catalyst temperatures.

Ammonia

Results of ammonia sampling are shown in Table 2. These results show little suggestion of either increases or decreases of ammonia with time into the run. Impinger collection efficiency for ammonia was calculated and found to be 88.67% with σ = 15.9%.

Gravimetric Determination of Condensibles

The 15-s to 2-min samples gave only a small mass of condensibles, which was a result of measuring a small weight difference (less than 0.5 g) between two rather large weights (about 450 g). This inherently high error determination, coupled with the extremely adverse environmental conditions under which weighings were made, rendered these results of marginal usefulness. They are not included in this report.

Noncondensible Gases

The noncondensible sample gases were collected in evacuated tanks for later laboratory gas chromatographic analysis. The tanks were initially evacuated to 1 Torr. After sampling, pressures were determined with a low volume absolute pressure gauge. Analysis of the tank

TABLE 2. HYDRAZINE AND AMMONIA IN EPU EXHAUST GAS

Run No.	Impinger set No.	Sample time (min)	Hydrazine (μg)	Ammonia (mg)
I	1	1	10,778	199
	2	1	9,100	231
	3	1	572	180
	4	1	35	164
II	1	1	1,725	152
	2	1	1,350	194
	3	1	690	191
	4	1	51	182
	5	1	14	249
III	1	0.25	1,560	58
	2	0.50	2,650	14[illegible]
	3	0.50	358	8[illegible]
	4	1	0	249
	5	0.28	0	58
IV	1	1	3,670	79
	2	1	2,380	232
	3	1	374	135
	4	1	0	94
	5	1	0	68
V	1	1	630	170
	2	1	430	145
	3	1	0	11[illegible]
	4	1	0	247
	5	1	0	160
VI	1	1	0	177
	2	2	255	244
	3	2	0	281
	4	2	0	283
	5	2	0	372

samples was delayed for several weeks due to laboratory equipment failure. At that time remeasurement of tank pressures suggested some leakage had occurred. Analysis confirmed the presence of oxygen and also suggested hydrogen had been lost. Accordingly, these results are considered suspect and are not reported herein.

Noncondensible Gas Flow Rates

Based on the initial post-sampling pressure measurements of the tanks and the sampling times, flow rates for each sample in runs V and VI were calculated. The average for the ten samples was 0.890 l/min with a σ of 0.218. The limiting orifices had initially been calibrated with air at 1.1 l/min. This value was corrected for molecular weight and temperature, according to:

$$q_2 = q_1 \sqrt{\frac{M_2 T_1}{M_1 T_2}}$$

where q_2 = Actual flow rate, l/min

q_1 = Calibration flow rate (air at 1.1 l/min)

M_2 = Molecular weight of actual gas

M_1 = Molecular weight of calibration gas (air = 29)

T_2 = Actual temperature ^{o}K

T_1 = Calibration temperature ($293^{o}K$)

By assuming that 50% of the ammonia was dissociated, the average molecular weight of the product gas was calculated to be 12. Substitution of this value for M_2 and the average sampling temperature of $278^{o}K$ for T_2, the corrected sample gas flow rate was calculated to be 0.726 l/min, in reasonable agreement with the measured value (based on average post-sampling pressure measurements).

Fuel Consumption

The EPU was not instrumented to determine fuel consumption rate. This value was approximated by determining the weight of fuel consumed during each set of runs and assuming a uniform fuel flow rate over the total lapsed run time. Fuel consumption for the first EPU (Set A) was 4.1 lb/min and for the second EPU (Set B) was 3.5 lb/min.

Determining Emissions and Emission Rates

Since both the weights of condensibles and analyses of noncondensible gases were unreliable, it is impossible to make an overall material balance. Manipulation of real data and theoretically expected values

was necessary to arrive at emission figures. The following procedure was employed.

First, the theoretical ratio of ammonia to noncondensible gas formed (mg/liter) was calculated using equation 3 (Table 1) and plotted against X, the fraction of ammonia dissociated (Fig. 5). The noncondensible gas was assumed to consist only of hydrogen and nitrogen.

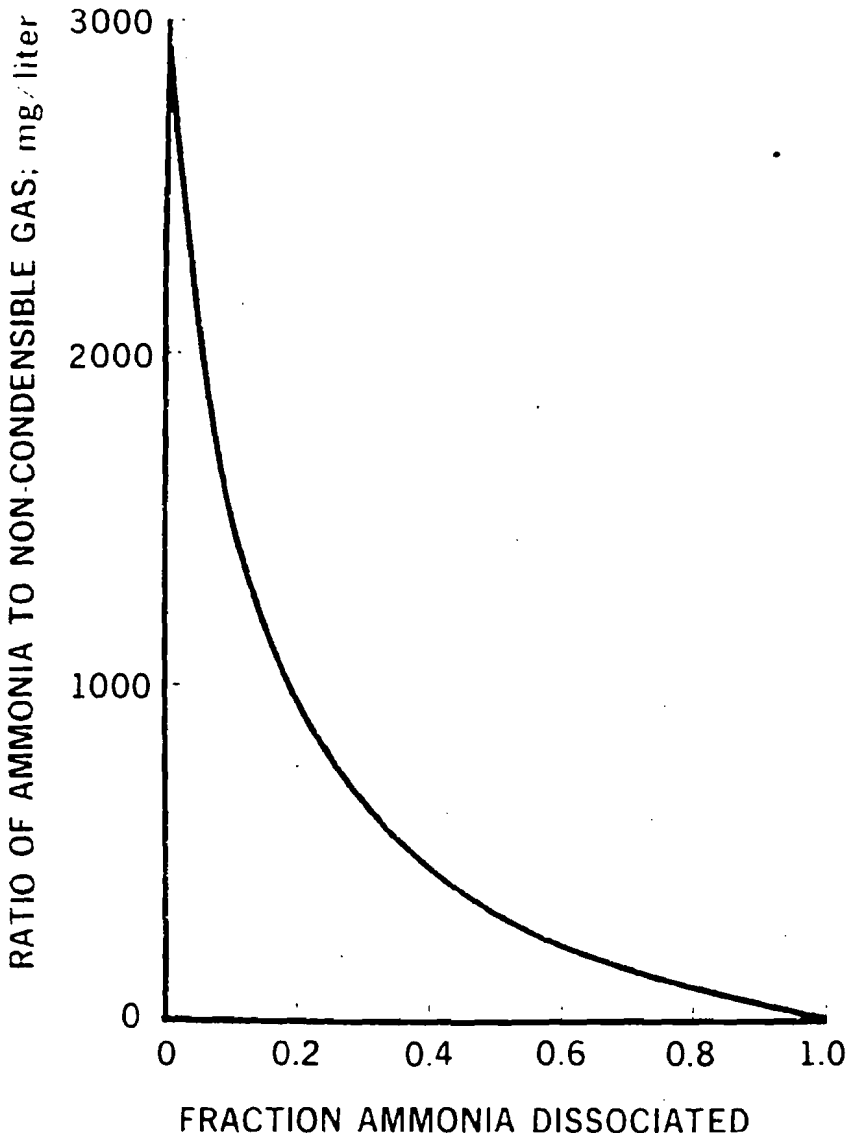


Figure 5. Theoretical ratio of ammonia to noncondensible gas ($N_2 + H_2$) as a function of fraction ammonia dissociated. (Based on equation 3, Table 1:

$$3\ N_2H_4 \rightarrow 4(1-X)\ NH_3 + 6X\ H_2 + (2X+1)\ N_2)$$

For each sample, the amount of ammonia trapped (mg) per liter of non-condensible gas sampled (0.726 l/min) was determined. These values were averaged for sample sets A and B, and the results are shown in Table 3. Using Figure 5, the corresponding value of X was determined as indicated in Table 4.

TABLE 3. TOTAL HYDRAZINE AND AMMONIA IN EPU EXHAUST

Set	Run No.	Hydrazine sampling time interval (g) 0-30 s	30-60 s	60-120 s	Total	Ammonia Average (l/min)[a]
A	I	22.55	1.50	0.08	24.13	603
	II	2.38	1.43	0.11	3.92	604
	III	5.83	0.84	0	6.67	706
B	IV	8.00	0.44	0.37	8.81	376
	V	1.37	0	0	1.37	515
	VI	0	0	0.56	0.56	475

[a]Measured at 21°C, 1 ATA

TABLE 4. RATIO OF AMMONIA TO NONCONDENSIBLE GASES AND ESTIMATED FRACTION OF AMMONIA DISSOCIATED

Set	mg NH_3/liter noncondensible	X, (Fraction NH_3 dissociated)
A	274, σ = 44	0.52
B	192, σ = 60	0.62

Once a value of X was determined, the theoretical flow rate of noncondensible gas could be determined from the fuel consumption rate and reaction 3 of Table 1, as follows:

Sample Set A: $X = 0.52$

Fuel flow rate = 4.1 lb/min (70% hydrazine)

Hydrazine flow rate = (4.1)(0.7)(454)/32

= 40.7 g-moles/min

From Equation 3:

$$3\ N_2H_4 = 4(0.48)\ NH_3 + 6(0.52)H_2 + (1.04+1)N_2$$

Noncondensible gas ratio = (3.12 + 2.04)/3

= 1.72 g-moles/g-mole hydrazine

Noncondensible gas flow rate = (1.72)(40.7)

= 70.0 g-moles/min

= 1596 l/min at 5°C

Sample ratio = 1596/0.726

= 2198 or 2200

A similar calculation for sample Set B gave a sample ratio of 2180. By means of these ratios, the hydrazine and ammonia found in the samples could be extrapolated to the total gas stream, as indicated in Table 3.

DISCUSSION OF RESULTS

The higher-than-expected exhaust gas temperatures experienced in the A set of runs led to speculation that the EPU was not operating properly. When the same temperature patterns were observed in the B set with a different EPU, it became more likely that the operation was in fact normal even if unexpected. The temperature and exhaust composition data indicated only minor difference between the two EPU units.

The variability in the results was not altogether unexpected for a field extractive sampling method, considering the adverse sampling parameters. Additional sampling by this method is considered unlikely to refine the results to any great extent. If additional refinement is needed, in situ optical methods should be explored. Laser Raman spectroscopy would appear to be a promising technique, but our laboratory is not equipped to do such work.

EVALUATION OF POTENTIAL EXPOSURES

The EPU exhaust gas presents potential exposure to both ammonia and hydrazine. By all realistic scenarios, there is little likelihood of multiple firings at any one location and on a given day, except in test programs such as the one described in this report. For either planned or inadvertent outdoor ground firings, the duration would probably be of no more than 30 s. Under normal meteorological conditions, one might expect elevated concentrations of ammonia and hydrazine to persist for a matter of 3 to 5 min. For this condition, consideration of 8-hour time-weighted average (TWA) standards are inappropriate since relatively massive exposures during this short period of time--assuming no exposure for the remainder of the day--would result in average exposure well below standards. For this reason short-term or excursion limits must be used to evaluate exposures.

Table 5 shows appropriate standards currently applicable in the Air Force. Note that the last column of Table 5 shows odor threshold values, which for both materials, are higher than even the short-term limits. Hence, odor cannot be used to give warning of overexposure.

The ratio of ammonia to hydrazine short-term limits is approximately 70:1, whereas the ratio of ammonia to hydrazine in the actual exhaust varied from 20:1 to 49:1 at 30-s duration. Hydrazine therefore appears to be the controlling material. This is unfortunate since ammonia can be measured in air easier than hydrazine, and at the higher ratio would be an indicator of potentially unsafe hydrazine concentrations.

Concentrations of ammonia in the immediate vicinity of the exhaust, while not measured directly, were probably greater than 1000 ppm. Concentrations this high are so irritating to man that he will not remain in the area of exposure unless he is physically restrained. Hence, massive worker exposures to ammonia are unlikely. Of concern, however, are those areas where the ammonia is present but cannot be detected by odor, or those areas where the ammonia is not in high enough concentration to cause great discomfort. Meteorological conditions are extremely important in determining the extent of these potential exposure zones. For unfavorable conditions, the exposure zone can extend to beyond 50-100 m downwind.

TABLE 5. AMMONIA AND HYDRAZINE EXPOSURE LIMITS

Contaminant	8-h TWA	Short-term or excursion limit	Odor threshold
Ammonia	25 ppm (18 mg/l)	35 ppm (27 mg/l)	50 ppm
Hydrazine	0.1 ppm (0.13 mg/l)	0.3 ppm (0.39 mg/l)	3-4 ppm

If the EPU were accidentally fired in a closed hangar, even of moderate size, the concentration of ammonia and/or hydrazine could quickly build up to unacceptable levels throughout the structure. In this case, high concentrations could persist for much more than 3 to 5 min, depending on the ventilation rate for the hangar. The experience to be gained in the climatic test at Eglin (April-May 1978), where the EPU exhaust will be ducted outside the hangar, will be valuable in determining if venting is a permissible procedure for indoor firings.

RECOMMENDATIONS

To arrive at realistic recommendations, we must consider both deliberate planned firings and inadvertent firings. Planned firings may be defined as routinely occurring events (tests) which require planned actions to preclude excessive exposure. Inadvertent firings, by contrast, may be defined as accidents which require general cognizance of their probability as well as preplanned actions both to prevent the accident and to minimize injury if the accident should occur.

For routine, planned ground hot firings:

1. Minimize or eliminate requirements for such firings.

2. Do not conduct planned ground firings inside closed hangars unless ducting the exhaust gas outside the building is feasible and effective.

3. Develop outdoor siting/meteorological criteria to govern outdoor firings.

4. For area monitoring, use ammonia detection techniques as an indicator of hydrazine. With the hydrazine-ammonia ratios formed, a concentration of over 10 ppm (7.2 μg/l) ammonia would indicate excessive hydrazine exposures. MSA (Mine Safety Appliance Co.) sampling tubes (FSN 6665-00-406-9450) would be appropriate for ammonia detection.

5. Use respiratory protective equipment for any tasks occurring immediately around the aircraft during firing and exclude all other personnel from the potential exposure zone.

For inadvertent ground firings:

1. Develop actions to reduce probability of inadvertent firings--safety devices, checklists, etc.

2. Conduct training for those individuals potentially exposed, to recognize sound of EPU, odor of ammonia, need to avoid the area, etc.

REFERENCES

1. Reynold, B. A., and A. A. Thomas. Determination of hydrazine and monomethylhydrazine in blood serum. AMRL-TRD-64-24, Apr 1964.

2. Standard Methods of Test for Ammonia. ASTM Designation: D1426-58 (1965), Manual on Industrial Water and Industrial Waste Water, 2d ed. American Society for Testing and Materials, Philadelphia, Pa., 1966.