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# DEFINITION OF AVIATION TURBINE FUEL CONTAMINATION UNDER SIMULATED COMBAT CONDITIONS

FINAL REPORT

AFLRL NO. 90

by

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><br>✓ JP-4 drain samples were obtained from Army aircraft, tank trucks, and other points in the fuel supply system at six field exercises under intensive training conditions. The samples were analyzed for particulate contaminants and compared to the contaminants package for test fluids used in aviation gas turbine engine component and systems qualification testing under AV-E-8593B. Results indicate that (a) the vast majority of samples had contamination concentration levels several orders of magnitude less than the AV-E-8593B package, (b) an |                       |                                                                                   |

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20. ABSTRACT

unexpectedly high number of aircraft drain samples (roughly 7 percent) and numerous points in the refueling systems showed concentrations far exceeding this package. Both the quantities and chemical nature of these particulate contaminants indicate that the AV-E-8593B package is realistic and representative of contamination which can occasionally occur in field Army operations. The utilization of this contaminants package therefore provides suitably stringent criteria for bench test qualification of aviation gas turbine engine fuel system components.

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## FOREWORD

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## TABLE OF CONTENTS

|                                                                                | <u>Page</u> |
|--------------------------------------------------------------------------------|-------------|
| LIST OF ILLUSTRATIONS . . . . .                                                | 4           |
| LIST OF TABLES . . . . .                                                       | 5           |
| I. INTRODUCTION . . . . .                                                      | 7           |
| II. FIELD SAMPLE COLLECTION . . . . .                                          | 9           |
| III. LABORATORY ANALYSIS . . . . .                                             | 10          |
| IV. RESULTS OF ANALYSIS . . . . .                                              | 13          |
| V. DISCUSSION . . . . .                                                        | 27          |
| VI. ARIZONA ROAD DUST COMPOSITION . . . . .                                    | 28          |
| VII. CONCLUSIONS . . . . .                                                     | 31          |
| APPENDICES                                                                     |             |
| A. Filtration Photomicrographs for New Mexico ANG Training Operation . . . . . | A-1         |
| B. Filtration Photomicrographs for Operation Reforger . . . . .                | B-1         |
| C. Filtration Photomicrographs for Operation Brave Shield XIV . . . . .        | C-1         |
| D. Filtration Photomicrographs for Operation Brave Shield XV . . . . .         | D-1         |
| E. Filtration Photomicrographs for Operation Gallant Crew . . . . .            | E-1         |

## LIST OF ILLUSTRATIONS

| <u>Figure</u> |                                                                                                                     | <u>Page</u> |
|---------------|---------------------------------------------------------------------------------------------------------------------|-------------|
| 1             | Visual Inspection . . . . .                                                                                         | 10          |
| 2             | Tyndall Cone Apparatus . . . . .                                                                                    | 10          |
| 3             | Cascade Filtration Apparatus . . . . .                                                                              | 11          |
| 4             | Photomicrographic Apparatus . . . . .                                                                               | 11          |
| 5             | X-Ray Fluorescence Spectrometer . . . . .                                                                           | 11          |
| 6             | Contaminants Analysis Sequence for JP-4 Samples . . . . .                                                           | 12          |
| 7             | Scanning Electron Photomicrograph of 26- to 52- $\mu$ m Particles of A.C. Test Dust (Lot C-306, Table 15) . . . . . | 29          |

## LIST OF TABLES

| <u>Table</u> |                                                                                                         | <u>Page</u> |
|--------------|---------------------------------------------------------------------------------------------------------|-------------|
| 1            | Fuel Contaminant Package for AV-E-8593B Engine Component Qualification Testing . . . . .                | 7           |
| 2            | JP-4 Particulate Contaminant Concentrations at Ft. Hood, Texas (Hood AAF) . . . . .                     | 14          |
| 3            | JP-4 Particulate Contaminant Concentrations at Ft. Bragg, N.C. (Oak Grove AAF) . . . . .                | 15          |
| 4            | JP-4 Particulate Contaminant Concentrations at Ft. Bliss, Texas (Biggs AAF) . . . . .                   | 16          |
| 5            | Particulate Size, Mass, and Class Distribution for Biggs AAF Underground Storage Tank Samples . . . . . | 18          |
| 6            | Particulate Size, Mass, and Class Distribution for Biggs AAF—Refueled Aircraft Samples . . . . .        | 18          |
| 7            | JP-4 Particulate Contaminant Concentrations for Brave Shield XIV . . . . .                              | 19          |
| 8            | JP-4 Particulate Contaminant Concentrations for Reforger . . . . .                                      | 20          |
| 9            | JP-4 Particulate Contaminant Concentrations for Reforger . . . . .                                      | 21          |
| 10           | JP-4 Particulate Contaminant Concentrations for Brave Shield XV . . . . .                               | 23          |

### LIST OF TABLES (Cont'd)

| <u>Table</u> |                                                                                    | <u>Page</u> |
|--------------|------------------------------------------------------------------------------------|-------------|
| 11           | JP-4 Particulate Contaminant Concentrations for Brave Shield XV . . . . .          | 24          |
| 12           | JP-4 Particulate Contaminant Concentrations for Gallant Crew . . . . .             | 25          |
| 13           | JP-4 Particulate Contaminant Concentrations for Gallant Crew . . . . .             | 26          |
| 14           | X-ray Fluorescence Analysis of Various Lots of AC Test Dust . . . . .              | 28          |
| 15           | X-ray Analysis of Various Sized Particles of AC Test Dust, Lot No. C-306 . . . . . | 28          |

## I. INTRODUCTION

Aviation fuel contamination traditionally manifests itself in some form of in-flight malfunction, or, at best, in power loss or startup malfunction during ground operations. The purpose of all engine/fuel specification requirements is to minimize the likelihood of fuel-related incidents. Requirements can become more severe and less realistic with time to the extent that pass/fail criteria may be challenged by either fuel refiners or engine/component manufacturers. This process of challenge and review of requirements often proves beneficial to both industrial and military interests who share a common goal of maximum systems performance at minimum cost.

The contaminant package for test fluids used in aviation gas turbine engine component and systems qualification testing under AV-E-8593B has come under some criticism for being unrealistically severe. This in itself would not be grounds for relaxation of contaminant size/type criteria since qualification testing must be severe to provide accelerated representation of component life expectancy. A more pertinent and significant question is whether or not the AV-E-8593B contaminant package (see Table 1) is now representative of the type of contaminants encountered in field Army aviation operations, since this package has evolved over the years with ingredients being added as a result of specific military occurrences or operating environments.

Thus there is a basis for a dual argument, quantity and character, for redefinition of this contaminant test package. Such action, however, should be based upon exact

TABLE 1. FUEL CONTAMINANT PACKAGE FOR AV-E-8593B  
ENGINE COMPONENT QUALIFICATION TESTING

| Contaminant                                                                                                                                             | Particle size,<br>$\mu\text{m}$                                                                                                                                                | Quantity,<br>g/1000 gal   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Ferrous-Ferrie Iron Oxide<br>( $\text{Fe}_3\text{O}_4$ , Black color,<br>Magnetite)                                                                     | 0-5                                                                                                                                                                            | 14.0                      |
| Ferrie Iron Oxide<br>( $\text{Fe}_2\text{O}_3$ , Hematite)                                                                                              | 0-5                                                                                                                                                                            | 14.5                      |
| Ferrie Iron Oxide<br>( $\text{Fe}_2\text{O}_3$ , Hematite)                                                                                              | 5-10                                                                                                                                                                           | 1.5<br>(30)*              |
| Crushed Quartz                                                                                                                                          | 150- 300                                                                                                                                                                       | 1.0                       |
| Crushed Quartz                                                                                                                                          | 300- 420                                                                                                                                                                       | 1.0                       |
| Crushed Quartz                                                                                                                                          | 420-1000                                                                                                                                                                       | 1.75                      |
| Crushed Quartz                                                                                                                                          | 1000-1500                                                                                                                                                                      | 0.25<br>(4)*              |
| Prepared dirt conforming<br>to A.C. Spark Plug Co.<br>Part No. 1543637<br>(Coarse Arizona road dust)                                                    | Mixture as follows:<br>0-5 (12%)<br>5-10 (12%)<br>10-20 (14%)<br>20-40 (23%)<br>40-80 (30%)<br>80-200 (9%)                                                                     | (8.0)*                    |
| Cotton linters                                                                                                                                          | Prime cotton linters,<br>First Cut Staple No. 7<br>(U.S. Department of<br>Agriculture Grading<br>Standards) as ground<br>in a Wiley Mill and screened<br>through a 4 mm screen | 0.1                       |
| Crude naphthenic acid                                                                                                                                   |                                                                                                                                                                                | 0.03% by vol              |
| Salt water prepared by<br>dissolving salt in<br>distilled water or other<br>water containing not<br>more than 200 parts per<br>million of total solids. | 4 parts<br>by weight of NaCl<br><br>96 parts<br>by weight of $\text{H}_2\text{O}$                                                                                              | 0.01% by<br>vol entrained |
| *Sub-total                                                                                                                                              |                                                                                                                                                                                |                           |

knowledge of the spectrum of contaminants actually encountered by Army aircraft under realistic conditions. A reasonable approach was to collect representative fuel samples during both routine and intense operational situations. During May 1976–March 1977, representatives of the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) collected and analyzed some 219 samples from seven diverse Army aviation activities. One of these, at Ft. Hood, Texas, may be considered more-or-less routine, while the others were the sites of intense training operations. These are detailed in Tables 2 through 13 in Section IV. In addition to aircraft samples, it was considered pertinent to obtain samples at key points in the fuel supply systems (e.g., underground storage tanks, tank trucks, railcars, etc.).

## II. FIELD SAMPLE COLLECTION

In April 1976, formal permission was secured from Headquarters, Forces Command (FORSCOM), Fort McPherson, Georgia, to collect JP-4 fuel samples from aircraft and other fuel supply points participating in the following exercises held during 1976-1977:

SOLID SHIELD  
BRAVE SHIELD XIV  
BR/VE SHIELD XV  
REFORGER\*  
GALLANT CREW

In addition, coordination with cognizant authorities at Fort Hood, Texas and Fort Bliss, Texas resulted in the securing of samples from these two posts under both routine and special training exercise situations.

Prior to obtaining samples, familiarization with various helicopter fuel systems was accomplished at Corpus Christi Army Depot (CCAD), Corpus Christi, Texas where the fuel systems of the UH-1, AH-1, OH-6, and OH-58 were made available to AFLRL technical personnel, and aircraft drain system operations and mechanisms were explained. Based upon the knowledge obtained during this familiarization exercise, the following technique for sample collection was developed:

- (a) Clean around aircraft fuel sump drain to remove all foreign matter.
- (b) Open sample container (525-ml Nalgene linear polyethylene bottle) while in place under sump drain.
- (c) Activate drain as necessary to fill sample bottle.
- (d) When bottle is full, place cap on container while in place under sump drain to avoid inclusion of foreign material.
- (e) Record aircraft registration number, type, sampling point, last aircraft refueling location, type of refueling, and type of mission flown.
- (f) Return sample immediately to AFLRL for analysis.

This sampling technique was the procedure used by AFLRL personnel at all locations.

---

\*Required coordination with Headquarters USAREUR.

### III. LABORATORY ANALYSIS

Each sample was analyzed sequentially as follows:

*Step 1. Visual Inspection* (see Figure 1)--for a general estimate of the degree and type of contamination.

*Step 2. Tyndall Cone* (see Figure 2) --a light-scattering technique for qualitative evaluation of particle size distribution of suspended material. A light beam is projected into the sample through the bottom of the sample vial. Particle reflectance as seen in a darkened room permits estimation of particle size and degree of contamination. The type of filtration required can be determined.

*Step 3. Cascade Filtration* (see Figure 3) The total fuel sample is filtered vertically through a stacked column of filter elements of decreasing porosity. For those samples deemed relatively clear, only two porosities, 8 and  $0.45\text{ }\mu\text{m}$ , were used; for samples having higher particulate content, stacked filters of 1000, 500, 300, 102, 52, 26, 8, and  $0.45\text{ }\mu\text{m}$  were used. The 8- and  $0.45\text{-}\mu\text{m}$  filters were cellulose acetate and the others were nylon mesh.

*Step 4. Gravimetric Analysis* (see also Figure 3)--The filters were heptane rinsed and dried. The net weight increase of each filter was recorded. This, plus knowledge of each filter's porosity, resulted in mass distribution histogram data for the select particle size differentials.

*Step 5. Photomicrographic Analysis* (see Figure 4)--Filter elements were examined under a microscope (20-60X) and those having significant contaminant were photographed at 4X.



FIGURE 1. VISUAL INSPECTION

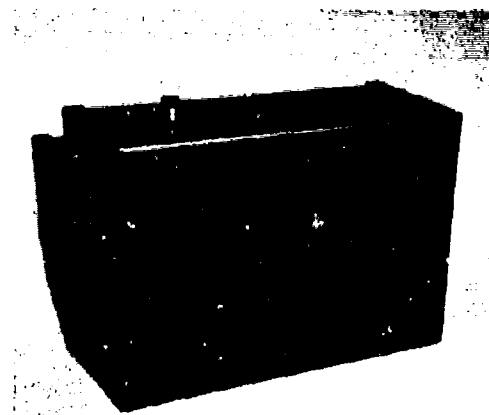


FIGURE 2. TYNDALL CONE APPARATUS

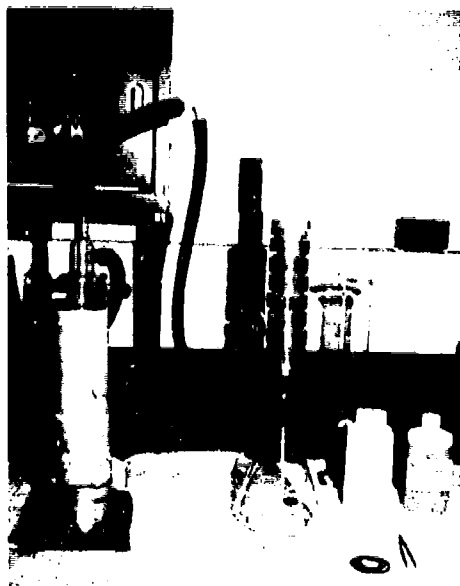


FIGURE 3. CASCADE FILTRATION APPARATUS

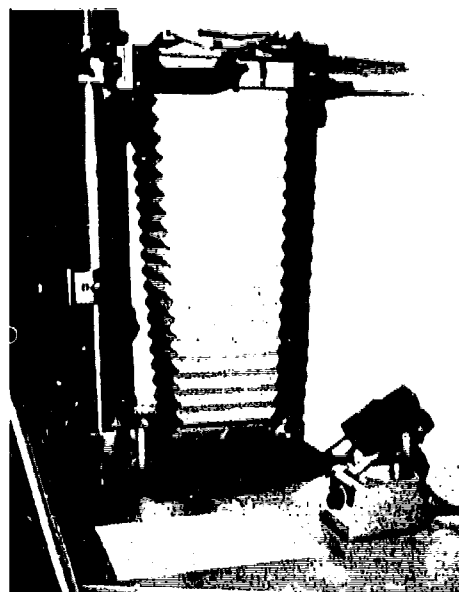


FIGURE 4. PHOTOMICROGRAPHIC APPARATUS

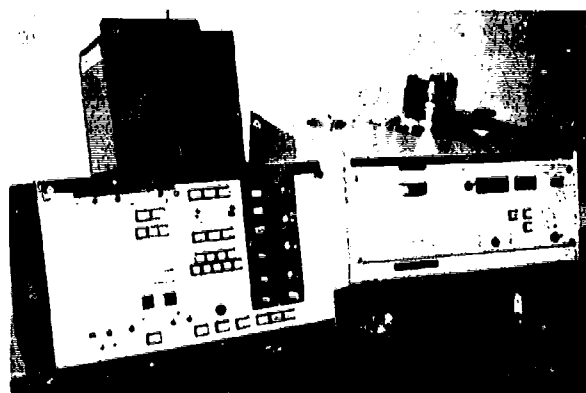
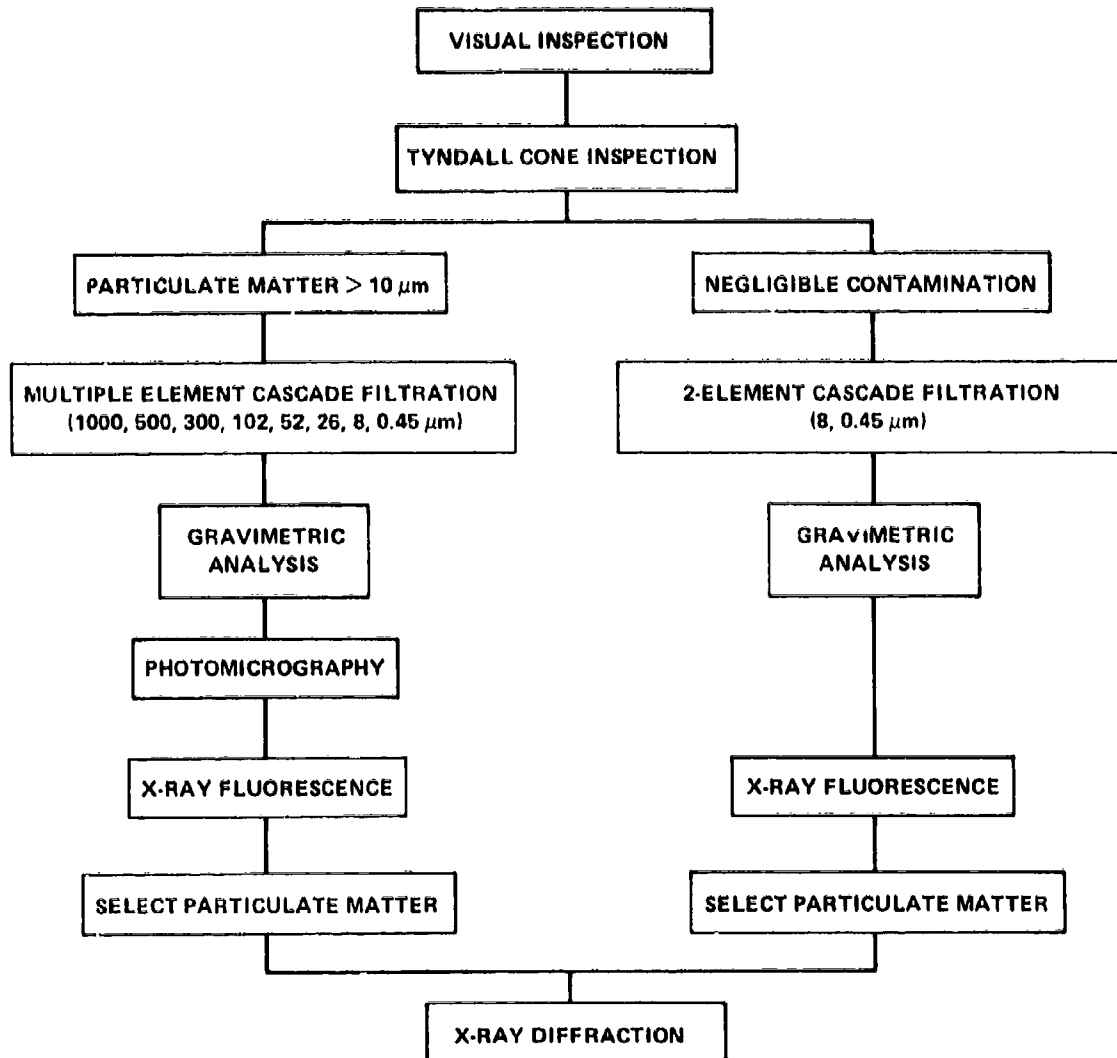


FIGURE 5. X-RAY FLUORESCENCE SPECTROMETER

*Step 6. X-Ray Fluorescence Analysis* (see Figure 5)—All filters were subjected to energy dispersive X-ray fluorescence analysis (XRF), a nondestructive technique for *elemental* assay. Virtually all elements can be quantitatively identified by XRF. The significant elements detected were iron, aluminum, silicon, phosphorus, sulfur, calcium, chromium, titanium, copper, and zinc. From the distribution of these elements, estimation of the mineralogical and metallic makeup can be made which facilitate confirmation by more sophisticated methods.

*Step 7. X-Ray Diffraction*—Selected contaminant materials were removed from some of the filters and analyzed by X-ray powder diffractometry. The diffraction patterns were compared to ASTM powder data file standards. Compound composition and crystalline structure were then determined.

Figure 6 presents a flow schematic for the above analysis sequence.



- Mass and Particle Size Distribution
- Elemental Analysis and Compound Identification

FIGURE 6. CONTAMINANTS ANALYSIS SEQUENCE FOR JP-4 SAMPLES

#### IV. RESULTS OF ANALYSIS

JP-4 particulate contaminants data for the several operational sites are summarized in Tables 2 through 13. Lab sample numbers, sample dates, and aircraft/unit identification are self-explanatory. Particulate concentrations (in grams per thousand gallons) have been calculated and reported as the oxides of the metals even though the element is determined by X-ray fluorescence. Reporting all iron as  $\text{Fe}_2\text{O}_3$ , all silicon as  $\text{SiO}_2$  (quartz), all aluminum as  $\text{Al}_2\text{O}_3$ , and all calcium as  $\text{CaO}$  is the only possible way to permit comparison of data to AV-E-8593B values.

Numbers in parentheses (30.0, 4.0, and 8.0) at the bottom of certain columns represent the AV-E-8593B levels for iron oxides, silicon dioxide, and "road dust" (see Table 1).

##### A. Hood AAF, Fort Hood, Texas (1976)

Prior to participating in scheduled Army field training exercises, AFLRL personnel took 11 drain samples from aircraft at Hood AAF. These aircraft were either used in routine training operations with Second Armored Division stationed at Fort Hood, or were transient aircraft undergoing periodic maintenance. Visual inspection and subsequent filtration and gravimetric analysis (see Section III) showed contaminant levels (see Table 2) for all samples to be lower than AV-E-8593B levels, so no cascade filtrations were performed. This was intended as a field/lab familiarization exercise as well as to provide initial data.

All aircraft samples were taken at belly sump drain points, since sampling from other points in the aircraft would have entailed disassembly of internal fuel system components and consequent interruption of the air support mission. All sump samples\* actually represent maximum particulate contamination accumulated between preflight or maintenance sump drain operations.

##### B. Oak Grove AAF, Solid Shield, Fort Bragg, North Carolina (1976)

In this first sampling from a formal exercise, relatively low contamination was found in 26 samples from active aircraft and 3 samples from nozzle and bladder/sump drains at the fixed fuel point at Oak Grove AAF (see Table 3). For this reason, no cascade filtration was performed.

##### C. New Mexico ANG Training Exercise, Biggs AAF (1976)

Three samples in Table 4 (6466, 6476, and 6486) had such high contaminant concentrations that cascade filtration was indicated. Data for this analysis are given in Table 5. These three samples were collected from the Biggs (Fort Bliss) AAF underground fuel storage complex†. Samples 6466 and 6476 were obtained with a sampling thief from tanks three and five, approximately 1 inch above each tank bottom. All tanks had been cleaned and filter elements changed February 1976, some 90 to 120 days prior to AFLRL sampling. Sample 6486 was taken immediately downstream of the filtration system serving tanks 3 and 4 jointly. Note that tanks 4 and 6 center samples (6471, 6481) had far less contaminant as compared to the other samples in Table 5, but still had quite high levels as compared to most aircraft samples. The sample taken immediately downstream of the joint tank 5/6 filtration system (6493, Table 4) showed virtually no contamination.

\*L.F. left forward; R.F. right forward; L.R. left rear; R.R. right rear; L.M. left main; R.M. right main; F. forward, A. aft.  
†Under control of Directorate of Industrial Operations, Petroleum, Oils, Lubricants (DIO-POL).

TABLE 2. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS  
AT FT. HOOD, TEXAS (HOOD AAF)

| Sample no.               | Date   | Aircraft reg no. | Aircraft type | Unit                | Particulate concentration, g/1000 gal. <sup>a</sup> |                 |                 |                 |                                       | Total Particulate Contaminants | Sump |
|--------------------------|--------|------------------|---------------|---------------------|-----------------------------------------------------|-----------------|-----------------|-----------------|---------------------------------------|--------------------------------|------|
|                          |        |                  |               |                     | Fe <sup>b</sup>                                     | Si <sup>b</sup> | Al <sup>b</sup> | Ca <sup>b</sup> | Total Non-Ferrous Oxides <sup>c</sup> |                                |      |
| 4442                     | 5-7-76 | 71-20474         | OH-58A        | 2nd Armored Div     | Nil <sup>d</sup>                                    | Nil             | Nil             | Nil             | Nil                                   | Nil                            | -    |
| 6443                     | 5-7-76 | 73-21850         | UH-1H         | 2nd Armored Div     | 0.021                                               | 0.034           | 0.028           | Nil             | 0.062                                 | 0.083                          | LF   |
| 6444                     | 5-7-76 | 73-21850         | UH-1H         | 2nd Armored Div     | Nil                                                 | 0.033           | 0.057           | Nil             | 0.090                                 | 0.090                          | RF   |
| 6445                     | 5-7-76 | 73-21850         | UH-1H         | 2nd Armored Div     | 0.025                                               | Nil             | Nil             | Nil             | Nil                                   | 0.025                          | LF   |
| 6446                     | 5-7-76 | 67-15654         | AH-1G         | 2nd Armored Div     | 0.103                                               | 1.020           | 0.363           | 0.522           | 1.905                                 | 2.008                          | F    |
| 6447                     | 5-7-76 | 68-16991         | OV-1          | 2nd Armored Div     | 0.091                                               | 0.340           | Nil             | Nil             | 0.034                                 | 0.125                          | -    |
| 6448                     | 5-7-76 | 68-13820         | UH-1H         | 2nd Armored Div     | 0.031                                               | Nil             | Nil             | Nil             | Nil                                   | 0.031                          | LF   |
| 6449                     | 5-7-76 | 70-16093         | AH-1G         | 2nd Armored Div     | Nil                                                 | Nil             | Nil             | Nil             | Nil                                   | Nil                            | A    |
| 6450                     | 5-7-76 | 67-18491         | CH-47B        | Ft. Sill. OK        | 0.031                                               | Nil             | Nil             | Nil             | Nil                                   | 0.031                          | -    |
| 6451                     | 5-7-76 | 70-16478         | UH-1H         | Ft. Sam Houston, TX | Nil                                                 | Nil             | Nil             | Nil             | Nil                                   | Nil                            | LF   |
| 6452                     | 5-7-76 | 70-16478         | UH-1H         | Ft. Sam Houston, TX | 0.014                                               | 0.069           | Nil             | Nil             | 0.069                                 | 0.083                          | RF   |
| AV-E-8593B concentration |        |                  |               |                     | (30.0)                                              | (4.0)           |                 |                 | (8.0)                                 | (42.0)                         |      |

Notes: Numbers in parentheses are designated concentrations (g/1000 gal) for specific constituents of AV-E-8593B test fluid.

<sup>b</sup>Calculated as Fe<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and CaO, respectively.

<sup>a</sup>Al particulate matter less than 10µm.

<sup>c</sup>Total Non-Ferrous Oxides = SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub> + CaO (principal constituents of A.C. 1543637 prepared dirt)

<sup>d</sup>Nil - Below lower limit of resolution by X-Ray Fluorescence (<0.001 g/1000 gal.).

Contaminant concentration for the five extreme cases (Table 5) are expressed in g/1000 gallons for consistent comparison to the preceding tables, and particle size distribution in micrometers ( $\mu\text{m}$ )\* has been determined by gravimetric and X-ray fluorescence analyses which give net particulate mass and predominant elements, respectively. Determination of compound class from element distribution was quite straightforward. For sample 6466, iron compounds comprised 99 to 100 percent of the mass down to 300  $\mu\text{m}$ , and comprised 80 to 90 percent thereafter to 8  $\mu\text{m}$ . The balance was silicon, and subsequent X-ray diffraction analysis confirmed that all iron was present as  $\text{Fe}_2\text{O}_3$ ,  $\text{Fe}_3\text{O}_4$ , or  $\text{FeO}(\text{OH})$  and all silicon as  $\text{SiO}_2$ . The same was true for sample 6486, except that more  $\text{SiO}_2$  was present in the 8- to 500- $\mu\text{m}$  range. Sample 6486 had, in addition to iron oxides and quartz, significant amounts of calcium and aluminum. Again, X-ray diffraction confirmed these elements to be present as calcium aluminum silicates ( $\text{Ca Al}_2 \text{Si}_2 \text{O}_8$ ), a claylike material indigenous to the southwest United States.

Table 6 presents particulate distribution data for the four aircraft having highest contaminant levels from the Fort Bliss (Biggs AAF) operation. No mass distribution data could be obtained for samples 6487 or 6492 since all particulate matter was captured on 8- and 0.45- $\mu\text{m}$  filters and consumed for X-ray diffraction analysis to determine compound class distribution. *It is significant that the values for these samples approached specification levels and came from aircraft having recently completed several NOE missions over desert terrain.*

#### D. BRAVE SHIELD XIV (1976)

All samples for BRAVE SHIELD XIV were taken at the single fixed refueling point at Yakima Firing Range, Washington. Data are given in Table 7. Again, contaminant levels for 23 samples from aircraft belly drains and 3 samples from refueling trucks were found to be below specification levels. For this reason, no subsequent gravimetric analysis was deemed necessary.

#### E. REFORGER, Germany (1976)

Advanced coordination with USAREUR resulted in an AFLRL staff member participating in this OCONUS exercise. Some 38 aircraft bellydrain samples (see Table 8) were taken at several aircraft deployment positions. In addition, numerous samples were taken upstream and downstream of individual bladder-filtration units and at exit nozzle points. Since one of the points of supply prior to the hardpoint refueling stations was a railroad tank car, it was possible to obtain samples from the tank car itself and after filtration through the discharge filter separator. Sample 6600 shows a total nonferrous oxide level of 16.566. Of this quantity, 15.806 was found to be composed of a silicon compound. This was attributable to a single tuft of inorganic material, and cascade filtration was therefore not required. The source of the tuft remains unknown; it was downstream of the filter separator. It is quite likely that subsequent filtration would have removed this item from the fuel flowstream.

Three aircraft samples, 6594, 6603, and 6614, were found to have sufficiently high particulate concentrations to warrant cascade filtration and subsequent X-ray diffraction analysis for compound class. These are given in Table 9. For sample 6594 (AH-1G No. 70-16045), it was found that iron oxide particulates were distributed across the total range of filter porosities. Quartz and calcium silicates took the form of rather fine particles in the 8- to 52- $\mu\text{m}$  range while zinc compounds (likely from paint) were in rather large chips of sizes in excess of 1000  $\mu\text{m}$ . For 6603 (OH-58A No. 71-20497), enormous quantities of iron oxides and zinc compounds of relatively large particle

\*Commonly referred to as microns ( $\mu$ ).

TABLE 5. PARTICULATE SIZE, MASS, AND CLASS DISTRIBUTION  
FOR BIGGS AAF UNDERGROUND STORAGE TANK SAMPLES

| Sample no. | Location                                                     | Compound class                 | Estimated particulate concentration, g/1000 gal |                |               |               |              |             |            |              | Total |
|------------|--------------------------------------------------------------|--------------------------------|-------------------------------------------------|----------------|---------------|---------------|--------------|-------------|------------|--------------|-------|
|            |                                                              |                                | >1000<br>μm                                     | 500-1000<br>μm | 300-500<br>μm | 102-300<br>μm | 52-102<br>μm | 26-52<br>μm | 8-26<br>μm | 0.45-8<br>μm |       |
| 6466       | Biggs AAF DIO-POL<br>Tank 3 Bottoms                          | Iron oxides <sup>a</sup>       | 203                                             | 100            | 58            | 96            | 97           | 85          | 70         | Nil          | 709   |
|            |                                                              | Quartz <sup>b</sup>            | Nil                                             | Nil            | Nil           | 8             | 8            | 16          | 13         | Nil          | 45    |
| 6476       | Biggs AAF DIO-POL<br>Tank 5 Bottoms                          | Iron oxides <sup>a</sup>       | 991                                             | 270            | 270           | 1890          | 1060         | 1040        | 196        | Nil          | 5717  |
|            |                                                              | Quartz <sup>b</sup>            | Nil                                             | Nil            | 23            | 354           | 199          | 195         | 37         | Nil          | 808   |
| 6486       | Biggs AAF DIO-POL<br>Nozzle Downstream<br>of Tank 3/4 Filter | Iron oxides <sup>a</sup>       | Nil                                             | Nil            | Nil           | 135           | 9            | Nil         | Nil        | Nil          | 144   |
|            |                                                              | Quartz <sup>b</sup>            | 29                                              | 142            | 287           | 203           | 13           | Nil         | Nil        | Nil          | 674   |
|            |                                                              | Calcium silicates <sup>c</sup> | 2                                               | 9              | 19            | 13            | 1            | Nil         | Nil        | Nil          | 44    |
| 6471       | Biggs AAF DIO-POL<br>Center of Tank 4                        | Iron oxides <sup>a</sup>       | d                                               | d              | d             | d             | d            | d           | 1          | d            | 1     |
|            |                                                              | Quartz <sup>b</sup>            | d                                               | d              | d             | d             | d            | d           | 2          | d            | 2     |
|            |                                                              | Calcium silicates <sup>c</sup> | d                                               | d              | d             | d             | d            | d           | 1          | d            | 1     |
| 6481       | Biggs AAF DIO-POL<br>Center of Tank 6                        | Iron oxides <sup>a</sup>       | d                                               | d              | d             | d             | d            | d           | 8          | d            | 8     |
|            |                                                              | Quartz <sup>b</sup>            | d                                               | d              | d             | d             | d            | d           | 2          | d            | 2     |
|            |                                                              | Calcium silicates <sup>c</sup> | d                                               | d              | d             | d             | d            | d           | 1          | d            | 1     |

<sup>a</sup>As Fe<sub>2</sub>O<sub>3</sub>.  
<sup>b</sup>As SiO<sub>2</sub> (α-quartz).  
<sup>c</sup>As CaAl<sub>2</sub>Si<sub>2</sub>O<sub>8</sub>.  
<sup>d</sup>All particulate matter collected on 8-μm filter and consumed during XRD analysis.

TABLE 6. PARTICULATE SIZE, MASS, AND CLASS DISTRIBUTION  
FOR BIGGS AAF-REFUELED AIRCRAFT SAMPLES

| Sample no. | Aircraft (unit)                               | Compound class                 | Estimated particulate concentration, g/1000 gal |                |               |               |              |             |            |              | Total |
|------------|-----------------------------------------------|--------------------------------|-------------------------------------------------|----------------|---------------|---------------|--------------|-------------|------------|--------------|-------|
|            |                                               |                                | >1000<br>μm                                     | 500-1000<br>μm | 300-500<br>μm | 102-300<br>μm | 52-102<br>μm | 26-52<br>μm | 8-26<br>μm | 0.45-8<br>μm |       |
| 6496       | OH-58A, 71-20667<br>(3rd Air Cav)             | Iron oxides <sup>d</sup>       | Nil                                             | Nil            | 0.18          | 0.07          | Nil          | Nil         | Nil        | Nil          | 0.25  |
|            |                                               | Quartz <sup>e</sup>            | Nil                                             | Nil            | 0.05          | 1.15          | 0.15         | Nil         | Nil        | Nil          | 1.35  |
| 6499       | AH-1G, 70-15953 <sup>a</sup><br>(3rd Air Cav) | Iron oxides <sup>d</sup>       | Nil                                             | 0.02           | 0.20          | 0.02          | Nil          | Nil         | Nil        | Nil          | 0.24  |
|            |                                               | Quartz <sup>e</sup>            | Nil                                             | 0.27           | 1.10          | 0.40          | Nil          | Nil         | Nil        | Nil          | 1.77  |
| 6487       | AH-1G, 71-20984 <sup>b</sup><br>(3rd Air Cav) | Iron oxides <sup>d</sup>       | g                                               | g              | g             | g             | g            | g           | 1.00       | g            | 1.00  |
|            |                                               | Quartz <sup>e</sup>            | g                                               | g              | g             | g             | g            | g           | 10.03      | g            | 10.03 |
|            |                                               | Calcium silicates <sup>f</sup> | g                                               | g              | g             | g             | g            | g           | 3.94       | g            | 3.94  |
| 6492       | AH-1G, 71-20984 <sup>c</sup><br>(3rd Air Cav) | Iron oxides <sup>d</sup>       | g                                               | g              | g             | g             | g            | g           | 0.57       | g            | 0.57  |
|            |                                               | Quartz <sup>e</sup>            | g                                               | g              | g             | g             | g            | g           | 2.27       | g            | 2.27  |
|            |                                               | Calcium silicates <sup>f</sup> | g                                               | g              | g             | g             | g            | g           | 0.95       | g            | 0.95  |

<sup>a</sup>Front Drain.  
<sup>b</sup>Aft Drain.  
<sup>c</sup>Front Drain.  
<sup>d</sup>As Fe<sub>2</sub>O<sub>3</sub>.  
<sup>e</sup>As SiO<sub>2</sub> (α-Quartz).  
<sup>f</sup>As CaAl<sub>2</sub>Si<sub>2</sub>O<sub>8</sub>.  
<sup>g</sup>All particulate matter collected on 8-μm filter and consumed during XRD analysis.

TABLE 7. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR BRAVE SHIELD XIV

| Sample no. | Date    | Aircraft reg no. | Aircraft type | Unit                   | Particulate Concentration, g/1000 gal. <sup>a</sup> |                 |                 |                 |                                       |                                | Sump |
|------------|---------|------------------|---------------|------------------------|-----------------------------------------------------|-----------------|-----------------|-----------------|---------------------------------------|--------------------------------|------|
|            |         |                  |               |                        | Fe <sup>b</sup>                                     | Si <sup>b</sup> | Al <sup>b</sup> | Cd <sup>b</sup> | Total Non-Ferrous Oxides <sup>c</sup> | Total Particulate Contaminants |      |
| 6545       | 8-23-76 | 74-22429         | UH-1H         | USAASL REDCOM          | 0.164                                               | Nil             | Nil             | 0.542           | 0.542                                 | 0.706                          | LF   |
| 6546       | 8-23-76 | 74-22495         | UH-1H         | USAASL REDCOM          | 0.243                                               | 0.645           | 0.518           | 0.212           | 1.378                                 | 1.621                          | LF   |
| 6558       | 8-23-76 | ---              | ---           | 5th Air Cav            | 0.144                                               | Nil             | Nil             | Nil             | Nil                                   | 0.144                          | ---  |
| 6561       | 8-23-76 | ---              | ---           | 5th Air Cav            | 0.519                                               | 0.798           | Nil             | Nil             | 0.798                                 | 1.317                          | ---  |
| 6566       | 8-23-76 | ---              | ---           | 5th Air Cav            | 0.048                                               | 1.299           | Nil             | Nil             | 1.299                                 | 1.347                          | ---  |
| 6551       | 8-23-76 | 68-15451         | UH-1H         | "B" Troop, 5th Air Cav | 0.148                                               | Nil             | Nil             | Nil             | Nil                                   | 0.148                          | LF   |
| 6547       | 8-23-76 | 71-20806         | OH-58A        | "C" Troop, 5th Air Cav | 0.199                                               | Nil             | Nil             | 0.014           | 0.014                                 | 0.213                          | ---  |
| 6549       | 8-23-76 | 71-20444         | OH-58A        | "C" Troop, 5th Air Cav | 2.018                                               | 2.266           | 2.743           | 0.236           | 5.245                                 | 7.263                          | ---  |
| 6550       | 8-23-76 | 71-21087         | OH-58A        | "C" Troop, 5th Air Cav | 1.175                                               | 1.451           | 0.663           | 0.206           | 2.300                                 | 3.475                          | ---  |
| 6548       | 8-23-76 | 68-15769         | UH-1H         | "C" Troop, 5th Air Cav | 0.113                                               | Nil             | Nil             | 0.028           | 0.028                                 | 0.141                          | LF   |
| 6553       | 8-23-76 | 69-15171         | UH-1H         | 540 Avn Co, Wash Ang   | 0.215                                               | Nil             | Nil             | 0.056           | 0.056                                 | 0.271                          | LF   |
| 6552       | 8-23-76 | 71-20215         | UH-1H         | 116th Avn Co           | 0.089                                               | Nil             | Nil             | Nil             | Nil                                   | 0.089                          | LF   |
| 6560       | 8-23-76 | 68-16239         | UH-1H         | 116th Avn Co           | 0.104                                               | Nil             | Nil             | Nil             | Nil                                   | 0.104                          | LF   |
| 6562       | 8-23-76 | 66-00856         | UH-1H         | 116th Avn Co           | 0.141                                               | Nil             | Nil             | Nil             | Nil                                   | 0.141                          | LF   |
| 6563       | 8-23-76 | 65-9987          | UH-1H         | 116th Avn Co           | 0.178                                               | Nil             | Nil             | 0.050           | 0.050                                 | 0.228                          | LF   |
| 6556       | 8-23-76 | 66-17064         | UH-1H         | 116th Avn Co           | 0.124                                               | Nil             | Nil             | Nil             | Nil                                   | 0.124                          | LF   |
| 6554       | 8-23-76 | 71-20763         | OH-58A        | 9th Div                | 0.294                                               | 0.624           | Nil             | 0.048           | 0.673                                 | 0.967                          | ---  |
| 6555       | 8-23-76 | 71-20586         | OH-58A        | 9th Div                | 0.694                                               | 0.700           | 0.401           | 0.087           | 1.188                                 | 1.882                          | ---  |
| 6557       | 8-23-76 | 69-16723         | UH-1H         | 9th Div                | 0.086                                               | Nil             | Nil             | Nil             | Nil                                   | 0.086                          | LF   |
| 6559       | 8-23-76 | 70-15254         | OH-58A        | 9th Div Atty           | 0.077                                               | Nil             | Nil             | Nil             | Nil                                   | 0.077                          | ---  |
| 6564       | 8-23-76 | 70-16384         | UH-1H         | 9th Avn Bn             | 0.066                                               | Nil             | Nil             | Nil             | Nil                                   | 0.066                          | LF   |
| 6568       | 8-23-76 | 66-16627         | UH-1H         | 9th Avn Bn             | 0.077                                               | Nil             | Nil             | Nil             | Nil                                   | 0.077                          | LF   |
| 6565       | 8-23-76 | 70-15311         | OH-58A        | "C" Troop, 9th Avn Co  | 0.165                                               | Nil             | Nil             | 0.035           | 0.035                                 | 0.200                          | ---  |
| 6569       | 8-23-76 | 66-16616         | UH-1H         | 54th Med Avn Co        | 0.127                                               | Nil             | Nil             | 0.050           | 0.050                                 | 0.177                          | LF   |
| 6570       | 8-23-76 | 70-16381         | UH-1H         | 54th Med Avn Co        | 0.101                                               | Nil             | Nil             | 0.050           | 0.050                                 | 0.151                          | LF   |
| 6567       | 8-23-76 | 73-21786         | UH-1H         | 411th Trans Co         | 0.124                                               | Nil             | Nil             | Nil             | Nil                                   | 0.124                          | LF   |
|            |         |                  |               |                        | (30.0)                                              | (4.0)           |                 |                 | (8.0)                                 | (42.0)                         |      |

Notes: Numbers in parentheses are designated concentration (g/1000 gal) for specific constituents of AV-L-8593B fluid.

<sup>a</sup> Calculated as Fe<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, + CaO.<sup>b</sup> All particulate matter less than 10  $\mu$ m.<sup>c</sup> Total Non-Ferrous Oxides = SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub> + CaO.<sup>d</sup> Nil - Below lower limit of resolution by X-Ray Fluorescence (<0.001 g/1000 gal).

TABLE 8. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR REFORGER

| Sample no.                                                                                                             | Aircraft reg. no.      | Aircraft type    | Unit                      | Particulate Concentration, g/1000 gal. <sup>a</sup> |                 |                  |                 |                                       |                                | Sump |
|------------------------------------------------------------------------------------------------------------------------|------------------------|------------------|---------------------------|-----------------------------------------------------|-----------------|------------------|-----------------|---------------------------------------|--------------------------------|------|
|                                                                                                                        |                        |                  |                           | Fe <sup>b</sup>                                     | Si <sup>b</sup> | Al <sup>b</sup>  | Cu <sup>b</sup> | Total Non-Ferrous Oxides <sup>c</sup> | Total Particulate Contaminants |      |
| 6579                                                                                                                   | 71-20142               | UH-1H            | "A" Co, 5th Trans Bn      | 0.112                                               | 0.854           | Nil <sup>d</sup> | 0.026           | 0.880                                 | 0.992                          | RF   |
| 6578                                                                                                                   | 71-20142               | UH-1H            | "A" Co, 5th Trans Bn      | 0.216                                               | 0.953           | Nil              | 0.039           | 0.992                                 | 1.208                          | LF   |
| 6613                                                                                                                   | 74-22359               | UH-1H            | "A" Co, 5th Trans Bn      | 0.049                                               | Nil             | Nil              | Nil             | Nil                                   | 0.049                          | RF   |
| 6612                                                                                                                   | 74-22359               | UH-1H            | "A" Co, 5th Trans Bn      | 0.178                                               | 0.894           | Nil              | 0.122           | 1.016                                 | 1.194                          | LF   |
| 6591                                                                                                                   | 69-15369               | UH-1H            | "A" Co, 5th Trans Bn      | 0.098                                               | Nil             | Nil              | 0.029           | 0.029                                 | 0.127                          | RF   |
| 6590                                                                                                                   | 69-15369               | UH-1H            | "A" Co, 5th Trans Bn      | 0.129                                               | 1.095           | Nil              | Nil             | 1.095                                 | 2.079                          | LF   |
| 6593                                                                                                                   | 69-15754               | UH-1H            | "A" Co, 5th Trans Bn      | 0.111                                               | Nil             | Nil              | 0.025           | 0.025                                 | 0.136                          | RF   |
| 6592                                                                                                                   | 69-15754               | UH-1H            | "A" Co, 5th Trans Bn      | 0.074                                               | Nil             | Nil              | 0.042           | 0.042                                 | 0.116                          | LF   |
| 6586                                                                                                                   | 73-21709               | UH-1H            | "A" Co, 5th Trans Bn      | 0.098                                               | Nil             | Nil              | Nil             | Nil                                   | 0.098                          | RF   |
| 6585                                                                                                                   | 73-21709               | UH-1H            | "A" Co, 5th Trans Bn      | 0.123                                               | Nil             | Nil              | 0.029           | 0.029                                 | 0.152                          | LF   |
| 6584                                                                                                                   | 70-15798               | UH-1H            | "A" Co, 5th Trans Bn      | 0.130                                               | 1.328           | Nil              | 0.050           | 1.378                                 | 1.508                          | LF   |
| 6582                                                                                                                   | 66-19135               | CH-47B           | "A" Co, 5th Trans Bn      | 0.429                                               | 1.558           | 0.466            | 0.151           | 2.175                                 | 2.604                          | R    |
| 6581                                                                                                                   | 66-19135               | CH-47B           | "A" Co, 5th Trans Bn      | 0.186                                               | 0.791           | 0.376            | 0.118           | 1.284                                 | 1.470                          | L    |
| 6580                                                                                                                   | 67-15721               | AH-1G            | "A" Co, 5th Trans Bn      | 0.297                                               | 2.945           | 0.549            | 0.151           | 3.644                                 | 3.941                          | F    |
| 6594                                                                                                                   | 70-16045               | AH-1G            | "A" Co, 5th Trans Bn      | High Particulate Concentration. See Table 9         |                 |                  |                 |                                       | 21.550                         | F    |
| 6583                                                                                                                   | 70-15238               | OH-58A           | "A" Co, 5th Trans Bn      | 0.075                                               | Nil             | Nil              | Nil             | Nil                                   | 0.075                          |      |
| 6589                                                                                                                   | 68-16977               | OH-58A           | "A" Co, 5th Trans Bn      | 0.563                                               | 0.473           | Nil              | 0.170           | 0.643                                 | 1.206                          |      |
| 6588                                                                                                                   | 67-17672               | UH-1H            | "B" Co, 5th Trans Bn      | 0.228                                               | 7.152           | Nil              | 0.113           | 7.265                                 | 7.493                          | RF   |
| 6587                                                                                                                   | 67-17672               | UH-1H            | "B" Co, 5th Trans Bn      | 0.237                                               | 1.899           | Nil              | 0.038           | 1.937                                 | 2.174                          | LF   |
| 6595                                                                                                                   | Pol-Rapid Refill Point |                  | "D" Co, 426 S&S Bn        | 0.122                                               | Nil             | Nil              | Nil             | Nil                                   | 0.122                          |      |
| 6596                                                                                                                   | Pol-Rapid Refill Point |                  | "D" Co, 426 S&S Bn        | 0.155                                               | Nil             | Nil              | 0.043           | 0.043                                 | 0.198                          |      |
| 6597                                                                                                                   | Pol-Rapid Refill Point |                  | "D" Co, 426 S&S Bn        | 0.056                                               | Nil             | Nil              | Nil             | Nil                                   | 0.056                          |      |
| 6598                                                                                                                   | 7G1216                 | Tank Truck       | "D" Co, 426 S&S Bn        | 0.068                                               | Nil             | Nil              | Nil             | Nil                                   | 0.068                          |      |
| 6599                                                                                                                   | 007-0-323-9P           | Railway tank car | 493 S&S Co, 87th Maint Bn | 0.102                                               | Nil             | Nil              | 0.037           | 0.037                                 | 0.139                          |      |
| 6600                                                                                                                   | 007-0-323-9P           | Railway tank car | 493 S&S Co, 87th Maint Bn | 0.683                                               | 15.806          | Nil              | 0.760           | 16.566                                | 17.249                         |      |
| 6601                                                                                                                   | 70-15561               | OH-58A           | 175 Av Co, 1st Arm Div    | 0.360                                               | 0.940           | 0.463            | 0.107           | 1.511                                 | 1.871                          |      |
| 6602                                                                                                                   | 72-21405               | OH-58A           | 175 Av Co, 1st Arm Div    | 0.245                                               | Nil             | 0.346            | 0.131           | 0.477                                 | 0.722                          |      |
| 6603                                                                                                                   | 71-20497               | OH-58A           | 25 Av Co, VII Corps       | High Particulate Concentration. See Table 9         |                 |                  |                 |                                       | 138.900                        |      |
| 6604                                                                                                                   | 70-15172               | OH-58A           | 25 Av Co, VII Corps       | 0.136                                               | 0.658           | 0.518            | 0.071           | 1.247                                 | 1.383                          |      |
| 6606                                                                                                                   | 70-15771               | UH-1H            | 25 Av Co, VII Corps       | 0.087                                               | Nil             | Nil              | Nil             | Nil                                   | 0.087                          | RF   |
| 6605                                                                                                                   | 70-15771               | UH-1H            | 25 Av Co, VII Corps       | 0.072                                               | Nil             | Nil              | Nil             | Nil                                   | 0.072                          | LF   |
| 6611                                                                                                                   | NK02VN                 | Tank truck       | 25 Av Co, VII Corps       | 0.097                                               | Nil             | Nil              | Nil             | Nil                                   | 0.097                          |      |
| 6610                                                                                                                   | 68-15755               | UH-1H            | HHC 2nd Support Com       | 0.114                                               | Nil             | Nil              | 0.070           | 0.070                                 | 0.184                          | RF   |
| 6609                                                                                                                   | 68-15755               | UH-1H            | HHC 2nd Support Com       | 0.095                                               | Nil             | Nil              | Nil             | Nil                                   | 0.095                          | LF   |
| 6608                                                                                                                   | 73-21770               | UH-1H            | HHC 2nd Support Com       | 0.096                                               | Nil             | Nil              | 0.022           | 0.022                                 | 0.118                          | RF   |
| 6607                                                                                                                   | 73-21770               | UH-1H            | HHC 2nd Support Com       | 0.141                                               | Nil             | Nil              | 0.124           | 0.124                                 | 0.265                          | LF   |
| 6618                                                                                                                   | 74-22329               | UH-1H            | 30th Trans Co             | 0.162                                               | 0.988           | Nil              | 0.029           | 1.017                                 | 1.179                          | RF   |
| 6617                                                                                                                   | 74-22329               | UH-1H            | 30th Trans Co             | 0.133                                               | 0.836           | 0.385            | 0.038           | 1.259                                 | 1.392                          | LF   |
| 6620                                                                                                                   | 65-12773               | UH-1H            | 30th Trans Co             | 0.099                                               | Nil             | Nil              | 0.068           | 0.068                                 | 0.167                          | RF   |
| 6619                                                                                                                   | 65-12773               | UH-1H            | 30th Trans Co             | 0.085                                               | Nil             | Nil              | Nil             | Nil                                   | 0.085                          | LF   |
| 6622                                                                                                                   | 69-17126               | CH-47C           | 30th Trans Co             | 0.332                                               | 1.153           | 0.746            | 0.364           | 2.264                                 | 2.596                          | RF   |
| 6621                                                                                                                   | 69-17126               | CH-47C           | 30th Trans Co             | 1.464                                               | 5.433           | 0.849            | 0.568           | 6.850                                 | 8.314                          | LF   |
| 6623                                                                                                                   | 70-15127               | OH-58A           | 30th Trans Co             | 0.093                                               | Nil             | Nil              | 0.054           | 0.054                                 | 0.147                          | RF   |
| 6615                                                                                                                   | 71-20838               | OH-58A           | "B" Troop 2/17 Cav        | 1.523                                               | 2.468           | 1.501            | 0.485           | 4.455                                 | 5.978                          |      |
| 6614                                                                                                                   | 71-21031               | AH-1G            | "C" Troop 2/17 Cav        | High Particulate Concentration. See Table 9         |                 |                  |                 |                                       | 54.890                         | F    |
|                                                                                                                        |                        |                  |                           | (30.0)                                              | (4.0)           |                  |                 | (8.0)                                 | (42.0)                         |      |
| Notes: Numbers in parentheses are designated concentration (g/1000 gal) for specific constituents of AV-E-8593B fluid. |                        |                  |                           |                                                     |                 |                  |                 |                                       |                                |      |
| <sup>b</sup> Calculated as Fe <sub>2</sub> O <sub>3</sub> , SiO <sub>2</sub> , Al <sub>2</sub> O <sub>3</sub> + CaO.   |                        |                  |                           |                                                     |                 |                  |                 |                                       |                                |      |
| <sup>a</sup> All particulate matter less than 10 µm.                                                                   |                        |                  |                           |                                                     |                 |                  |                 |                                       |                                |      |
| <sup>c</sup> Total Non-Ferrous Oxides = SiO <sub>2</sub> + Al <sub>2</sub> O <sub>3</sub> + CaO.                       |                        |                  |                           |                                                     |                 |                  |                 |                                       |                                |      |
| <sup>d</sup> Nil - Below lower limit of resolution by X-Ray Fluorescence (<0.001 g/1000 gal).                          |                        |                  |                           |                                                     |                 |                  |                 |                                       |                                |      |

TABLE 9. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR REFORGER

| Sample No. | Aircraft (Unit)                                        | Compound Class              | Estimated particulate concentration, g/1000 gal. |                  |                 |                 |                |               |              |                |       |
|------------|--------------------------------------------------------|-----------------------------|--------------------------------------------------|------------------|-----------------|-----------------|----------------|---------------|--------------|----------------|-------|
|            |                                                        |                             | >1000 $\mu$ m                                    | 500-1000 $\mu$ m | 300-500 $\mu$ m | 102-300 $\mu$ m | 52-102 $\mu$ m | 26-52 $\mu$ m | 8-26 $\mu$ m | 0.45-8 $\mu$ m | Total |
| 6594       | AH-1G, 70-16045 <sup>a</sup><br>(“A” Co. 5th Trans Bn) | Iron oxides <sup>b</sup>    | 0.91                                             | 0.11             | 0.23            | 0.54            | 0.30           | 1.24          | 2.08         | Nil            | 5.41  |
|            |                                                        | Quartz <sup>c</sup>         | Nil                                              | Nil              | Nil             | 1.66            | Nil            | 1.24          | 2.06         | Nil            | 4.98  |
|            |                                                        | Calcium silicates           | Nil                                              | Nil              | Nil             | Nil             | Nil            | 1.65          | 2.78         | Nil            | 4.43  |
|            |                                                        | Zinc compounds <sup>d</sup> | 6.73                                             | Nil              | Nil             | Nil             | Nil            | Nil           | Nil          | Nil            | 6.73  |
| 6603       | OH-58A, 71-20497<br>(25 AV Co., VII Corps)             | Iron oxides <sup>b</sup>    | 16.85                                            | 25.99            | 12.12           | 10.54           | 0.66           | 0.38          | Nil          | Nil            | 66.54 |
|            |                                                        | Quartz <sup>c</sup>         | 0.17                                             | Nil              | 0.55            | 0.99            | Nil            | Nil           | Nil          | Nil            | 1.71  |
|            |                                                        | Calcium silicates           | Nil                                              | Nil              | Nil             | Nil             | Nil            | Nil           | Nil          | Nil            | Nil   |
|            |                                                        | Zinc compounds <sup>d</sup> | 19.49                                            | 25.76            | 12.06           | 10.48           | 0.79           | 0.49          | 1.58         | Nil            | 70.65 |
| 6614       | AH-1G, 71-21031 <sup>a</sup><br>(“C” Troop 2/17 Cav)   | Iron oxides <sup>b</sup>    | 9.80                                             | 0.65             | Nil             | 1.97            | 0.76           | 1.38          | 2.58         | Nil            | 17.14 |
|            |                                                        | Quartz <sup>c</sup>         | 5.10                                             | Nil              | Nil             | 1.58            | 1.78           | 4.81          | 18.05        | Nil            | 31.32 |
|            |                                                        | Calcium silicates           | Nil                                              | Nil              | Nil             | Nil             | Nil            | 0.69          | 5.15         | Nil            | 5.84  |
|            |                                                        | Zinc compounds <sup>d</sup> | Nil                                              | 0.20             | Nil             | 0.39            | Nil            | Nil           | Nil          | Nil            | 0.59  |

<sup>a</sup>Front drain.  
<sup>b</sup>As Fe<sub>2</sub>O<sub>3</sub>.  
<sup>c</sup>As SiO<sub>2</sub> ( $\alpha$ -quartz).  
<sup>d</sup>ZnO and basic zinc carbonates, nonabrasive to steel.

<sup>a</sup>Front drain.<sup>b</sup>As Fe<sub>2</sub>O<sub>3</sub>.<sup>c</sup>As SiO<sub>2</sub> (α-quartz).<sup>d</sup>ZnO and basic zinc carbonates, nonabrasive to steel.

size were found. These were likely from fuel system rust and ingested paint compounds. For sample 6614 (AH-1G No. 71-21031), contamination stemmed both from iron oxides and quartz. The uniform distribution of both contaminants indicates that the source would be both fuel system rust and clay or sand-like materials ingested into the fuel system during refueling or maintenance operations.

#### **F. BRAVE SHIELD XV, Eglin AFB, Florida (1976)**

Thirty aircraft belly-drain samples were taken and two samples from tank trucks used to refuel these same aircraft (see Table 10). In this operation, four individual aircraft (samples 6664, 6665, 6666, and 6667) were found to have significant particulate contamination and were cascade filtered. Data for these four aircraft are given in Table 11. For sample 6664 (OH-58A No. 70-15613), the dominant contaminating material was quartz, the likely source being sand ingested during refueling or maintenance operations. Although contamination was somewhat less for the other three samples, the domination of quartz is still apparent and is not surprising because of the location of this exercise.

#### **G. GALLANT CREW, Fort Hood, Texas (1977)**

Two of the 32 aircraft belly-drain samples for this exercise required cascade filtration (see Table 12). At least three other samples (6897, 6898, and 6901) had total nonferrous oxide contamination at a level to warrant cascade filtration, but since no Tyndall Cone effect was observed, this could not be ascertained until after initial filtration. For sample 6895 (CH-47C No. 70-15008), principal contamination stemmed from both quartz and calcium silicates, indicating a mixture of sand and clay from outside sources (see Table 13). To a lesser degree iron oxides were present, again likely from fuel system rust. Sample 6914 (CH-47C No. 70-15019) had roughly the same relative distribution of quartz, calcium silicates, and iron oxides, although at a considerably lower level. Such clay-sand mixtures are indigenous to the Fort Hood area.

TABLE 10. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR BRAVE SHIELD XV

| Sample no. | Date     | Aircraft reg. no. | Aircraft type | Unit               | Particulate Concentration, g/1000 gal. <sup>a</sup> |                 |                  |                 |                                       |                                | Sump |
|------------|----------|-------------------|---------------|--------------------|-----------------------------------------------------|-----------------|------------------|-----------------|---------------------------------------|--------------------------------|------|
|            |          |                   |               |                    | Fe <sup>b</sup>                                     | Si <sup>b</sup> | Al <sup>b</sup>  | Cu <sup>b</sup> | Total Non-Ferrous Oxides <sup>c</sup> | Total Particulate Contaminants |      |
| 6642       | 10-13-76 | 70-16293          | UH-1H         | 119th Av Co        | 0.086                                               | 0.127           | Nil <sup>d</sup> | Nil             | 0.127                                 | 0.213                          | LF   |
| 6643       | 10-13-76 | 70-16293          | UH-1H         | 119th Av Co        | 0.082                                               | 0.082           | Nil              | Nil             | 0.082                                 | 0.164                          | RF   |
| 6644       | 10-13-76 | 70-16472          | UH-1H         | 119th Av Co        | 0.087                                               | 0.231           | Nil              | Nil             | 0.231                                 | 0.318                          | LF   |
| 6645       | 10-13-76 | 70-16472          | UH-1H         | 119th Av Co        | 0.143                                               | 0.634           | 0.070            | Nil             | 0.705                                 | 0.848                          | RF   |
| 6646       | 10-13-76 | 69-15314          | UH-1H         | 119th Av Co        | 0.073                                               | 0.131           | Nil              | Nil             | 0.131                                 | 0.204                          | LF   |
| 6647       | 10-13-76 | 69-15314          | UH-1H         | 119th Av Co        | 0.090                                               | 0.131           | 0.054            | Nil             | 0.185                                 | 0.275                          | RF   |
| 6648       | 10-13-76 | 69-15853          | UH-1H         | 119th Av Co        | 0.126                                               | 0.234           | 0.080            | Nil             | 0.314                                 | 0.440                          | LF   |
| 6649       | 10-13-76 | 69-15853          | UH-1H         | 119th Av Co        | 0.106                                               | 0.248           | 0.062            | Nil             | 0.310                                 | 0.416                          | RF   |
| 6650       | 10-13-76 | 64-13536          | UH-1H         | 119th Av Co        | 0.069                                               | 0.233           | Nil              | Nil             | 0.233                                 | 0.302                          | LF   |
| 6651       | 10-13-76 | 64-13536          | UH-1H         | 119th Av Co        | 0.066                                               | 0.157           | Nil              | Nil             | 0.157                                 | 0.223                          | RF   |
| 6652       | 10-13-76 | No. 47            | Tank truck    | 119th Av Co        | 0.054                                               | 0.092           | Nil              | Nil             | 0.092                                 | 0.146                          | Fwd  |
| 6653       | 10-13-76 | No. 47            | Tank truck    | 119th Av Co        | 0.071                                               | 0.117           | Nil              | Nil             | 0.117                                 | 0.188                          | Hose |
| 6654       | 10-13-76 | 69-16000          | UH-1H         | 119th Av Co        | 0.067                                               | 0.143           | Nil              | Nil             | 0.143                                 | 0.210                          | LF   |
| 6655       | 10-13-76 | 69-16000          | UH-1H         | 119th Av Co        | 0.080                                               | 0.154           | 0.061            | Nil             | 0.216                                 | 0.296                          | RF   |
| 6656       | 10-13-76 | 69-15315          | UH-1H         | 119th Av Co        | Nil                                                 | 0.071           | Nil              | Nil             | 0.071                                 | 0.071                          | LF   |
| 6657       | 10-13-76 | 69-15315          | UH-1H         | 119th Av Co        | 0.077                                               | 0.102           | 0.026            | Nil             | 0.128                                 | 0.205                          | RF   |
| 6658       | 10-13-76 | 65-9749           | UH-1H         | 119th Av Co        | 0.060                                               | 0.117           | Nil              | Nil             | 0.117                                 | 0.177                          | LF   |
| 6659       | 10-13-76 | 65-9749           | UH-1H         | 119th Av Co        | 0.049                                               | 0.127           | Nil              | Nil             | 0.127                                 | 0.176                          | RF   |
| 6660       | 10-13-76 | 70-16470          | UH-1H         | 119th Av Co        | 0.105                                               | 0.165           | 0.093            | Nil             | 0.258                                 | 0.363                          | LF   |
| 6661       | 10-13-76 | 70-16470          | UH-1H         | 119th Av Co        | 0.063                                               | 0.118           | 0.080            | Nil             | 0.198                                 | 0.261                          | RF   |
| 6662       | 10-13-76 | 69-15318          | UH-1H         | 119th Av Co        | 0.071                                               | 0.188           | Nil              | Nil             | 0.188                                 | 0.259                          | LF   |
| 6663       | 10-13-76 | 69-15318          | UH-1H         | 119th Av Co        | 0.105                                               | 0.170           | 0.031            | Nil             | 0.201                                 | 0.306                          | RF   |
| 6664       | 10-13-76 | 70-15613          | OH-58A        | "B" Co, 82nd Av Bn | High Particulate Concentration. See Table 11        |                 |                  |                 |                                       | 47.100                         |      |
| 6665       | 10-13-76 | 72-21194          | OH-58A        | "B" Co, 82nd Av Bn |                                                     |                 |                  |                 |                                       | 4.770                          |      |
| 6666       | 10-13-76 | 79-15150          | OH-58A        | "B" Co, 82nd Av Bn |                                                     |                 |                  |                 |                                       | 17.800                         |      |
| 6667       | 10-13-76 | 69-16096          | OH-58A        | "B" Co, 82nd Av Bn |                                                     |                 |                  |                 |                                       | 31.300                         |      |
| 6668       | 10-13-76 | 67-18430          | CH-54A        | 478 Av Bn          | Nil                                                 | 0.141           | Nil              | Nil             | 0.141                                 | 0.141                          | Fwd  |
| 6669       | 10-13-76 | 67-18430          | CH-54A        | 478 Av Bn          | 0.121                                               | 0.209           | 0.108            | Nil             | 0.416                                 | 0.537                          | Aft  |
| 6670       | 10-13-76 | 67-18420          | CH-54A        | 478 Av Bn          | 0.078                                               | 0.113           | Nil              | Nil             | 0.113                                 | 0.191                          | Fwd  |
| 6671       | 10-13-76 | 67-18420          | CH-54A        | 478 Av Bn          | 0.370                                               | 0.472           | 0.121            | Nil             | 0.593                                 | 0.963                          | Aft  |
| 6672       | 10-13-76 | 67-18424          | CH-54A        | 478 Av Bn          | 0.335                                               | 0.286           | 0.199            | Nil             | 0.385                                 | 0.720                          | Fwd  |
| 6673       | 10-13-76 | 67-18424          | CH-54A        | 478 Av Bn          | 0.123                                               | 0.118           | Nil              | Nil             | 0.118                                 | 0.241                          | Aft  |
|            |          |                   |               |                    | (30.0)                                              | (4.9)           |                  |                 | (8.0)                                 | (42.0)                         |      |

Notes. Numbers in parentheses are designated concentration (g/1000 gal) for specific constituents of AV-E-8593B fluids.

<sup>b</sup> Calculated as Fe<sub>2</sub>O<sub>3</sub> + Al<sub>2</sub>O<sub>3</sub> + CaO.<sup>c</sup> All particulate matter less than 10 µm.<sup>d</sup> Total Non-Ferrous Oxides = SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub> + CaO.<sup>e</sup> Nil - Below lower limit of resolution by X-Ray Fluorescence (<0.001 g/1000 gal).

TABLE 11. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR BRAVE SHIELD XV

| Sample no. | Aircraft (unit)                      | Compound class              | Estimated particulate concentration, g/1000 gal. |                 |                 |                 |                |               |              |                |       |
|------------|--------------------------------------|-----------------------------|--------------------------------------------------|-----------------|-----------------|-----------------|----------------|---------------|--------------|----------------|-------|
|            |                                      |                             | >1000 $\mu$ m                                    | 500-100 $\mu$ m | 300-500 $\mu$ m | 102-300 $\mu$ m | 52-102 $\mu$ m | 26-52 $\mu$ m | 8-26 $\mu$ m | 0.45-8 $\mu$ m | Total |
| 6664       | OH-58A, 70-15613 ("B" Co 82nd Av Bn) | Iron oxides <sup>a</sup>    | Nil                                              | 0.50            | 0.48            | 0.63            | 0.08           | 0.22          | 0.12         | Nil            | 2.0   |
|            |                                      | Quartz <sup>b</sup>         | 0.098                                            | 4.35            | 6.90            | 25.56           | 0.70           | 0.56          | 0.53         | 0.10           | 38.8  |
|            |                                      | Calcium silicates           | Nil                                              | 1.20            | 1.30            | 3.82            | Nil            | Nil           | Nil          | Nil            | 6.3   |
|            |                                      | Zinc compounds <sup>c</sup> | Nil                                              | Nil             | Nil             | Nil             | Nil            | Nil           | Nil          | Nil            | Nil   |
| 6665       | OH-58A, 72-21194 ("B" Co 82nd Av Bn) | Iron oxides <sup>a</sup>    |                                                  |                 |                 |                 |                |               | 0.95         |                | 0.95  |
|            |                                      | Quartz <sup>b</sup>         |                                                  |                 |                 |                 |                |               | 3.82         |                | 3.82  |
|            |                                      | Calcium silicates           |                                                  |                 |                 |                 |                |               | Nil          |                | Nil   |
|            |                                      | Zinc compounds <sup>c</sup> |                                                  |                 |                 |                 |                |               | Nil          |                | Nil   |
| 6666       | OH-58A, 70-15150 ("B" Co 82nd Av Bn) | Iron oxides <sup>a</sup>    | 0.74                                             | 0.15            | 0.26            | 0.51            | 0.46           | 0.22          | 0.16         | Nil            | 2.6   |
|            |                                      | Quartz <sup>b</sup>         | 0.55                                             | 1.39            | 1.81            | 4.98            | 2.80           | 0.73          | 0.74         | 0.05           | 13.1  |
|            |                                      | Calcium silicates           | 0.16                                             | 0.12            | 0.15            | 0.97            | 0.60           | Nil           | 0.14         | Nil            | 2.1   |
|            |                                      | Zinc compounds <sup>c</sup> | Nil                                              | Nil             | Nil             | Nil             | Nil            | Nil           | Nil          | Nil            | Nil   |
| 6667       | OH-58A, 69-16096 ("B" Co 82nd Av Bn) | Iron oxides <sup>a</sup>    | Nil                                              | 0.21            | 0.20            | 1.62            | 0.91           | 0.32          | 0.25         | Nil            | 3.5   |
|            |                                      | Quartz <sup>b</sup>         | Nil                                              | 0.52            | 1.40            | 13.44           | 3.96           | 1.04          | 1.24         | 0.07           | 21.7  |
|            |                                      | Calcium silicates           | Nil                                              | 0.45            | Nil             | 3.44            | 1.11           | 0.16          | 0.98         | Nil            | 6.1   |
|            |                                      | Zinc compounds <sup>c</sup> | Nil                                              | Nil             | Nil             | Nil             | Nil            | Nil           | Nil          | Nil            | Nil   |

<sup>a</sup>As Fe<sub>2</sub>O<sub>3</sub>.  
<sup>b</sup>As SiO<sub>2</sub> ( $\alpha$ -Quartz).  
<sup>c</sup>ZnO and basic zinc carbonates, nonabrasive to steel.

TABLE 12. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR GALLANT CREW

| Sample No | Date    | Altcraft rep. no. | Altcraft type | Unit                     | Particulate Concentration, g/1000 gal. <sup>a</sup> |                 |                 |                 |                                       |                                | Sump               |
|-----------|---------|-------------------|---------------|--------------------------|-----------------------------------------------------|-----------------|-----------------|-----------------|---------------------------------------|--------------------------------|--------------------|
|           |         |                   |               |                          | Fe <sup>b</sup>                                     | Si <sup>b</sup> | Al <sup>b</sup> | Ca <sup>b</sup> | Total Non-Ferrous Oxides <sup>c</sup> | Total Particulate Contaminants |                    |
| 6878      | 3-28-77 |                   | Bladder No. 1 | 13th COSCOM              | 0.077                                               | 0.625           | Nd <sup>d</sup> | 0.039           | 0.664                                 | 0.741                          | ---                |
| 6879      | 3-28-77 |                   | Bladder No. 2 | 13th COSCOM              | 0.058                                               | Nd              | Nd              | Nd              | Nd                                    | 0.058                          | ---                |
| 6880      | 3-28-77 |                   | Bladder No. 4 | 13th COSCOM              | 0.077                                               | Nd              | Nd              | Nd              | Nd                                    | 0.077                          | ---                |
| 6881      | 3-28-77 |                   | Bladder No. 6 | 13th COSCOM              | Nd                                                  | Nd              | Nd              | Nd              | Nd                                    | Nd                             | ---                |
| 6882      | 3-28-77 |                   | Bladder No. X | 13th COSCOM              | Nd                                                  | Nd              | Nd              | Nd              | Nd                                    | Nd                             | ---                |
| 6883      | 3-28-77 | 70-16211          | UH-1H         | HHG Troop 4-9 Cav        | 0.103                                               | 0.460           | Nd              | Nd              | 0.460                                 | 0.563                          | RI                 |
| 6884      | 3-28-77 | 70-16211          | UH-1H         | HHG Troop 4-9 Cav        | 0.077                                               | 0.333           | Nd              | Nd              | 0.333                                 | 0.390                          | LI                 |
| 6885      | 3-28-77 | 71-20553          | OH-58A        | "A" Troop 7-17 Cav       | 0.198                                               | 1.063           | 0.388           | 0.221           | 1.670                                 | 1.868                          | ---                |
| 6886      | 3-28-77 | 71-20224          | UH-1H         | HHG Troop 7-17 Cav       | 0.058                                               | 0.258           | Nd              | Nd              | 0.258                                 | 0.316                          | LI                 |
| 6887      | 3-28-77 | 71-20224          | UH-1H         | HHG Troop 7-17 Cav       | Nd                                                  | 0.263           | Nd              | Nd              | 0.263                                 | 0.263                          | RI                 |
| 6888      | 3-28-77 | 69-15010          | UH-1H         | HHG Troop 7-17 Cav       | Nd                                                  | Nd              | Nd              | Nd              | Nd                                    | Nd                             | LI                 |
| 6889      | 3-28-77 | 69-15010          | UH-1H         | HHG Troop 7-17 Cav       | 0.065                                               | Nd              | Nd              | Nd              | Nd                                    | 0.065                          | RI                 |
| 6890      | 3-28-77 | 71-20223          | UH-1H         | HHG Troop 7-17 Cav       | 0.122                                               | 0.608           | 0.188           | 0.117           | 1.013                                 | 2.035                          | LI                 |
| 6891      | 3-28-77 | 71-20223          | UH-1H         | HHG Troop 7-17 Cav       | 0.152                                               | 0.791           | 0.223           | 0.242           | 1.286                                 | 1.286                          | RI                 |
| 6892      | 3-28-77 | 70-15371          | OH-58A        | 3rd Bde 1st Cav          | 0.105                                               | 0.839           | 0.149           | 0.109           | 1.096                                 | 1.201                          | ---                |
| 6893      | 3-28-77 | 70-15010          | CH-47C        | "D" Co. 34th Spt 6ACCB   | 0.517                                               | 1.333           | 0.929           | 0.114           | 2.376                                 | 2.893                          | LI                 |
| 6894      | 3-28-77 | 70-15010          | CH-47C        | "D" Co. 34th Spt 6ACCB   | 0.084                                               | 0.278           | Nd              | Nd              | 0.278                                 | 0.362                          | RI                 |
| 6895      | 3-28-77 | 70-15008          | CH-47C        | "D" Co. 34th Spt 6ACCB   | High Particulate Concentration (see Table 13)       |                 |                 |                 |                                       | 11.780                         | LI                 |
| 6896      | 3-28-77 | 70-15008          | CH-47C        | "D" Co. 34th Spt 6ACCB   | 0.558                                               | 1.665           | Nd              | Nd              | 1.665                                 | 2.223                          | RI                 |
| 6897      | 3-28-77 | 70-15027          | CH-47C        | "D" Co. 34th Spt 6ACCB   | 1.007                                               | 5.490           | 2.242           | 0.073           | 7.805                                 | 8.812                          | LI                 |
| 6898      | 3-28-77 | 70-15027          | CH-47C        | "D" Co. 34th Spt 6ACCB   | 1.465                                               | 8.754           | 3.738           | 0.887           | 13.378                                | 14.843                         | RI                 |
| 6899      | 3-28-77 | 70-15025          | CH-47C        | "D" Co. 34th Spt 6ACCB   | 0.107                                               | Nd              | Nd              | Nd              | Nd                                    | 0.107                          | LI                 |
| 6900      | 3-28-77 | 70-15025          | CH-47C        | "D" Co. 34th Spt 6ACCB   | 0.104                                               | 0.262           | Nd              | 0.297           | 0.560                                 | 0.664                          | LI                 |
| 6901      | 3-28-77 | 70-15025          | CH-47C        | "D" Co. 34th Spt 6ACCB   | 0.638                                               | 5.466           | 1.614           | 2.741           | 9.814                                 | 10.452                         | RR                 |
| 6902      | 3-28-77 | 70-15025          | CH-47C        | "D" Co. 34th Spt 6ACCB   | 0.354                                               | 1.706           | 0.515           | 1.044           | 3.265                                 | 3.619                          | RM                 |
| 6903      | 3-29-77 | 66-00888          | UH-1H         | 5280h Trans, 13th COSCOM | 0.083                                               | Nd              | Nd              | Nd              | Nd                                    | 0.083                          | LI                 |
| 6904      | 3-29-77 | 66-00888          | UH-1H         | 5280h Trans, 13th COSCOM | 0.123                                               | 0.111           | Nd              | Nd              | 0.111                                 | 0.234                          | RI                 |
| 6905      | 3-29-77 | 73-16265          | UH-1H         | 162 Av Co (AID)          | 0.067                                               | Nd              | Nd              | Nd              | Nd                                    | 0.067                          | LI                 |
| 6906      | 3-29-77 | 70-16265          | UH-1H         | 162 Av Co (AID)          | 0.090                                               | Nd              | Nd              | Nd              | Nd                                    | 0.090                          | RI                 |
| 6907      | 3-29-77 | 68-16614          | UH-1H         | 162 Av Co (AID)          | 0.269                                               | 0.646           | Nd              | 0.546           | 1.192                                 | 1.461                          | LI                 |
| 6908      | 3-29-77 | 68-16614          | UH-1H         | 162 Av Co (AID)          | 0.127                                               | 0.246           | Nd              | Nd              | 0.246                                 | 0.373                          | RI                 |
| 6909      | 3-29-77 | 68-16627          | UH-1H         | 162 Av Co (AID)          | 0.082                                               | Nd              | Nd              | Nd              | Nd                                    | 0.082                          | LI                 |
| 6910      | 3-29-77 | 68-16627          | UH-1H         | 162 Av Co (AID)          | 0.087                                               | Nd              | Nd              | Nd              | Nd                                    | 0.087                          | RI                 |
| 6911      | 3-29-77 |                   | Bladder       | 1080h QM                 | 0.063                                               | Nd              | Nd              | Nd              | Nd                                    | 0.063                          | ---                |
| 6912      | 3-29-77 | PSI 132           | Tank Truck    | 1080h QM                 | 0.093                                               | Nd              | Nd              | Nd              | Nd                                    | 0.093                          | Nozzle Compartment |
| 6913      | 3-29-77 | PSI 132           | Tank Truck    | 1080h QM                 | 0.067                                               | Nd              | Nd              | Nd              | Nd                                    | 0.067                          | ---                |
| 6914      | 3-29-77 | 70-15019          | CH-47C        | "D" Co. 34th Spt 6ACCB   | High Particulate Concentration (see Table 13)       |                 |                 |                 |                                       | 158.920                        | RI                 |
| 6915      | 3-29-77 | 70-15019          | CH-47C        | "D" Co. 34th Spt 6ACCB   | 0.322                                               | 0.511           | 0.329           | 0.163           | 1.003                                 | 1.325                          | RR                 |
| 6916      | 3-29-77 | 70-15019          | CH-47C        | "D" Co. 34th Spt 6ACCB   | 1.663                                               | 10.828          | 3.726           | 7.376           | 21.930                                | 23.593                         | LI                 |
| 6917      | 3-29-77 | 70-15019          | CH-47C        | "D" Co. 34th Spt 6ACCB   | 0.189                                               | 0.233           | 1.223           | 0.521           | 1.977                                 | 2.166                          | LI                 |
|           |         |                   |               |                          | (30.0)                                              | (4.0)           |                 |                 | (8.0)                                 | (42.0)                         |                    |

Notes: Numbers in parentheses are designated concentration (g/1000 gal) for specific constituents of AV-1-8593B fluids.  
<sup>a</sup> Calculated as Fe, O<sub>2</sub>, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, + CaO.  
<sup>b</sup> All particulate matter less than 10 μm.  
<sup>c</sup> Total Non-Ferrous Oxides = SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub> + CaO.  
<sup>d</sup> Nd = Ref. A level limit resolution by X-Ray Fluorescence (< 0.001 g/1000 gal).

TABLE 13. JP-4 PARTICULATE CONTAMINANT CONCENTRATIONS FOR GALLANT CREW

| Sample no. | Aircraft (unit)                                                       | Compound class                 | Estimated particulate concentration, g./1000 gal. |                  |                 |                 |                |               |              |                | Total |
|------------|-----------------------------------------------------------------------|--------------------------------|---------------------------------------------------|------------------|-----------------|-----------------|----------------|---------------|--------------|----------------|-------|
|            |                                                                       |                                | >1000 $\mu$ m                                     | 500-1000 $\mu$ m | 300-500 $\mu$ m | 102-300 $\mu$ m | 52-102 $\mu$ m | 26-52 $\mu$ m | 8-26 $\mu$ m | 0.45-8 $\mu$ m |       |
| 6914       | CH-47C, 70-15019 <sup>a</sup><br>(D) Co. 34th Spt. 6AACB <sup>1</sup> | Iron oxides <sup>b</sup>       | 3.15                                              | 1.88             | 2.41            | 10.90           | 2.46           | 0.80          | 0.84         | Nil            | 22.44 |
|            |                                                                       | Quartz <sup>c</sup>            | 0.84                                              | 4.24             | 5.73            | 47.26           | 11.06          | 4.93          | 6.21         | Nil            | 80.27 |
|            |                                                                       | Calcium silicates <sup>d</sup> | 0.25                                              | 4.23             | 3.88            | 31.72           | 7.99           | 3.37          | 4.77         | Nil            | 56.21 |
|            |                                                                       | Zinc compounds <sup>d</sup>    | Nil                                               | Nil              | Nil             | Nil             | Nil            | Nil           | Nil          | Nil            | Nil   |
| 6895       | CH-47C, 70-15008 <sup>e</sup><br>(D) Co. 34th Spt. 6AACB <sup>1</sup> | Iron oxides <sup>b</sup>       | Nil                                               | Nil              | 0.34            | 0.80            | 0.10           | 0.03          | 0.36         | Nil            | 1.63  |
|            |                                                                       | Quartz <sup>c</sup>            | Nil                                               | Nil              | 0.32            | 3.17            | 0.62           | 0.27          | 1.32         | Nil            | 5.70  |
|            |                                                                       | Calcium silicates <sup>d</sup> | Nil                                               | Nil              | 0.10            | 1.80            | 0.07           | Nil           | 2.48         | Nil            | 4.45  |
|            |                                                                       | Zinc compounds <sup>d</sup>    | Nil                                               | Nil              | Nil             | Nil             | Nil            | Nil           | Nil          | Nil            | Nil   |

<sup>a</sup>Left front drain.<sup>b</sup>As Fe<sub>2</sub>O<sub>3</sub>.<sup>c</sup>As SiO<sub>2</sub> ( $\alpha$ -quartz).<sup>d</sup>ZnO and basic zinc carbonates, nonabrasive to steel.<sup>e</sup>Right front drain.

## V. DISCUSSION

From the preceding data, it can be seen that (a) the vast majority of all aircraft sump drain samples contain nowhere near the concentration of the particulates specified by AV-E-8593B, but (b) an unexpectedly high number of aircraft samples (roughly 7 percent) plus numerous points in the refueling systems showed concentrations far exceeding those specified for this package. The fact that drain samples taken from operational Army aircraft contained concentrations of the same order as a test contaminant package criticized for its severity must be placed into proper perspective. These samples were (a) taken from the lowest point in the aircraft fuel systems, (b) upstream of on-board aircraft fuel filtration elements, (c) cumulative in the sense that most residual particulate matter will settle to the drain area over a period of time, and (d) calculated as oxides of the elements identified ( $\text{Fe}_2\text{O}_3$ ,  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ) as opposed to costly quantitative analysis required for identification of clay-like compounds.

For the above reasons, the data as presented represent a *worst possible case* with respect to comparison to specification values. It can be properly argued as to whether any of the contaminants as identified by sump drain would pass through on-board filtration systems and, even if this occurred, would result in significant, cumulative damage to the powerplant system. It must be presumed that such abrasive contaminants as quartz ( $\text{SiO}_2$ ) could cause significant fuel pump wear, malfunction of close-tolerance servo-valves, and degradation/failure of miniature bearings. The effect of less abrasive calcium aluminum silicates (clays) must be assumed to be minor with respect to wear and abrasion, but would contribute to degradation of precision components. Iron oxides are relatively less abrasive than quartz but could contribute to wear and system malfunction.

Probably the most important fact uncovered by this investigation is that significant quantities of the exact elements and compounds as specified in AV-E-8593B were, in fact, found in on-board aircraft fuel systems even though this fuel had been subjected to the extensive upstream filtration prescribed for Army aviation fuel supply.

## VI. ARIZONA ROAD DUST COMPOSITION

Coarse Arizona Road Dust (A.C. Spark Plug Co. Part No. 1543637) is a component in the fuel contamination package used to meet AV-E-8593B specifications (see Table 1). This dust has traditionally been reported to be composed of:

$4 \pm 1\%$   $\text{Fe}_2\text{O}_3$   
 $68 \pm 1\%$   $\text{SiO}_2$   
 $16 \pm 1\%$   $\text{Al}_2\text{O}_3$   
 $3 \pm 1\%$   $\text{CaO}$   
 $1 \pm 1\%$   $\text{MgO}$

Since several field samples had been found to contain both the above compounds and more complex clay-like materials, a separate study on Arizona Road Dust composition was undertaken. Different batches of AC dust were obtained and analyzed by X-ray fluorescence spectroscopy. The results obtained are compiled in Table 14.

One batch (Lot No. C-306) was separated by particle size, and each particle range analyzed by X-ray fluorescence for elemental content. These results are shown in Table 15.

X-ray diffraction data for mineralogical species was also obtained on Lot C-306. The diffraction data and the X-ray fluorescence data permitted the calculation of mineralogical composition. The results showed the test dust to be composed of:

$72\%$   $\text{Ca}(\text{Mg})_{2.3} \text{Na}_{.77} \text{AlSi}_{2.77} \text{O}_8$  (a plagioclase feldspar),  
 $20\%$   $\text{SiO}_2$  ( $\alpha$ -quartz), and  
 $8\%$   $\text{Fe}_3\text{O}_4$  (magnetite).

TABLE 14. X-RAY FLUORESCENCE ANALYSIS OF VARIOUS LOTS OF AC TEST DUST

| Lot No.         | % Al       | % Si       | % Ca      | % Ti         | % Fe      | Remarks              |
|-----------------|------------|------------|-----------|--------------|-----------|----------------------|
| F-049           | 6.8        | 26.8       | 0.8       | 0.3          | 2.0       | F indicates "fine"   |
| F-138           | 7.7        | 30.1       | 0.8       | 0.2          | 2.1       |                      |
| C-306           | 6.9        | 29.4       | 1.2       | 0.3          | 2.2       | C indicates "coarse" |
| C-349           | 7.8        | 32.0       | 1.1       | 0.3          | 2.2       |                      |
| C-362           | 6.9        | 28.0       | 1.1       | 0.3          | 2.2       |                      |
| C-364           | 6.8        | 27.9       | 1.0       | 0.3          | 2.2       |                      |
| C-387           | 6.8        | 28.4       | 0.8       | 0.2          | 1.8       |                      |
| Mean            | 7.1        | 28.9       | 1.0       | 0.3          | 2.1       |                      |
| As Oxides       | 13.4       | 61.8       | 1.4       | 0.4          | 3.0       |                      |
| Reported values | $16 \pm 1$ | $68 \pm 1$ | $3 \pm 1$ | Not reported | $4 \pm 1$ |                      |

TABLE 15. X-RAY ANALYSIS OF VARIOUS SIZED PARTICLES OF AC TEST DUST, LOT NO. C-306

| Particle Size, $\mu\text{m}$ | % Sample | % Al | % Si | % Ca | % Ti | % Fe | Remarks             |
|------------------------------|----------|------|------|------|------|------|---------------------|
| >500                         | 0.3      |      |      |      |      |      | Insufficient sample |
| 500-300                      | 0.3      |      |      |      |      |      | Insufficient sample |
| 300-102                      | 18.0     | 4.4  | 18.8 | 1.0  | 0.3  | 1.8  |                     |
| 102-53                       | 40.4     | 5.2  | 21.0 | 0.3  |      | 1.6  |                     |
| 52-26                        | 26.0     | 5.7  | 25.6 | 1.1  | 0.2  | 1.5  |                     |
| <26                          | 15.0     | 3.8  | 17.9 | 0.2  | 0.2  | 1.1  |                     |
|                              | 100.0    |      |      |      |      |      |                     |



2300X

FIGURE 7. SCANNING ELECTRON PHOTOMICROGRAPH OF 26- TO 52- $\mu$ m PARTICLES OF A.C. TEST DUST (LOT C-306, TABLE 15)

To verify this compositional conclusion, a sample of the 26- to 52- $\mu$ m sized test dust from Lot No. C-306 was examined under a scanning electron microscope (SEM). The total image is shown in Figure 7. The crystallographic form of the almost rectangular particle in the upper right quadrant appears to be different from that of the other large particles. In the SEM process, X-rays are emitted from all areas of the sample. These X-rays may be analyzed for energy distribution, and the sample can be mapped for elemental content. Such element maps were obtained for silicon and aluminum. The map for silicon indicated that all particles contained silicon. However, the map for aluminum showed that the previously mentioned particle in the upper right quadrant contained far greater amounts of aluminum than do the other particles. This indicates that this particle contains both silicon and aluminum and is chemically different from the other particles in Figure 7 which are quartz. This supports the X-ray diffraction data which indicate a mixture of mineral types present in the test dust.

The conclusions drawn from this study are that:

- (1) the A.C. Test Dust is relatively uniform in composition over the various particle size ranges examined, and
- (2) that A.C. Test Dust is not a mixture of metal oxides as commonly believed but is a mixture of three mineral species.

These mineral species (quartz, plagioclase, and magnetite) have significantly different properties both from one another and from the properties of the metal oxides typically listed. These mineral species are, in two out of three cases (quartz and magnetite), redundant with other components of the fuel contaminant package for AV-15-8593B engine component qualification testing. The plagioclase component is soft and would not abrade the ferrous metals in a fuel system as would quartz. The plagioclase thus contributes no severity to the test. As a result, the A.C. Test Dust really contributes nothing to the test that the other components of the test package do not already accomplish.

It is interesting to note that X-ray diffraction studies of several selected samples obtained in the field from fuel tanks showed the material to be similar in composition to the test package in that oxides of iron, quartz, and minerals in the plagioclase feldspar family were identified (for example,

see Tables 5 and 6). Therefore, the test package does indeed resemble the types of contaminants found in the field but is redundant in some of its components and contains some material which would not stress a candidate gas turbine engine component.

## VII. CONCLUSIONS

Specific conclusions which can be derived from this program are:

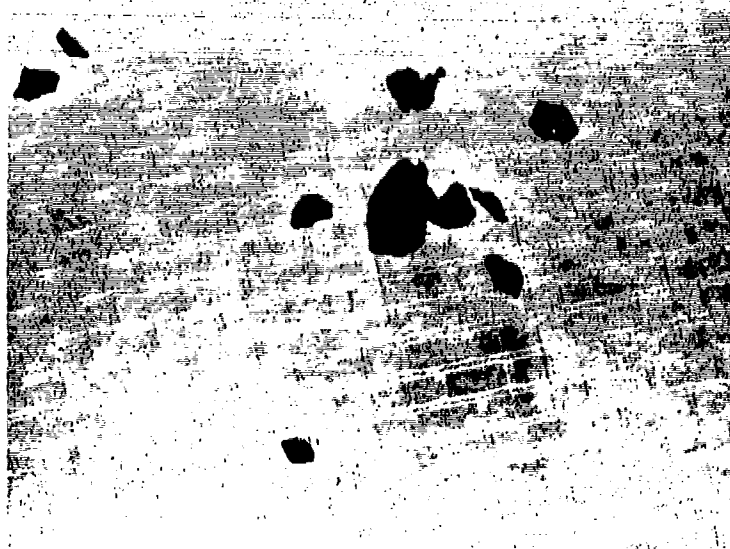
- (1) The same contaminants as specified in AV-E-8593B are encountered in field Army aviation operations.
- (2) These contaminants are encountered at levels approaching or exceeding AV-E-8593B in a disproportionately high incidence.
- (3) For the above reasons, the contaminant package in AV-E-8593B is valid for the purpose of accelerated qualification testing of fuel system components.

It should be noted and emphasized that all the aircraft included in this program had been operating satisfactorily, probably due to on-board fuel filtration systems. The utilization of this contaminant package for test fluids in AV-E-8593B has undoubtedly benefitted Army aviation flight safety and maintenance.

**APPENDIX A**  
**FILTRATION PHOTOMICROGRAPHS FOR NEW MEXICO ANG**  
**TRAINING OPERATION**

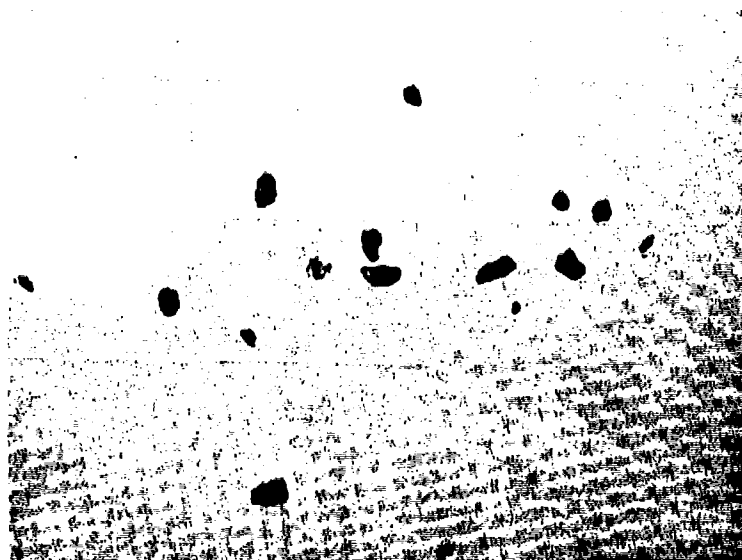
**APPENDIX A-1  
CASCADE FILTRATION PHOTOMICROGRAPHS  
SAMPLE NO. 6466**

**Biggs AAF Tank 3 Bottoms  
(See Table 5)**



1000 $\mu$ m

4X



500 $\mu$ m

4X

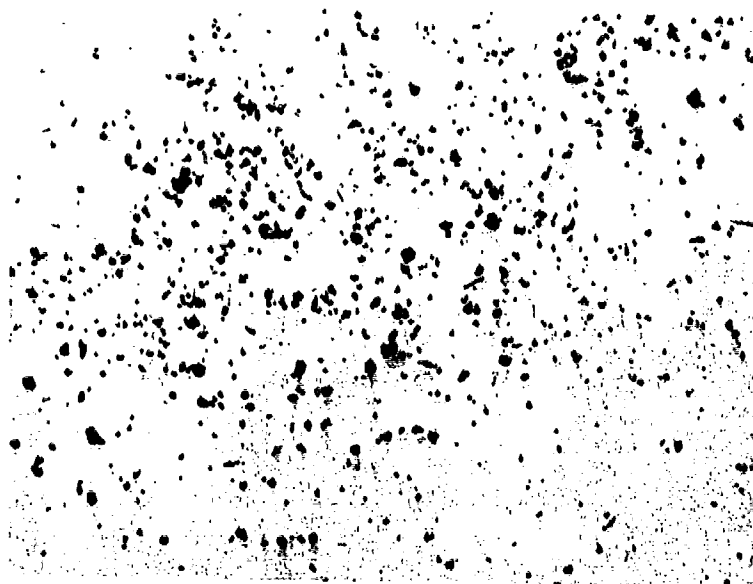
A-5

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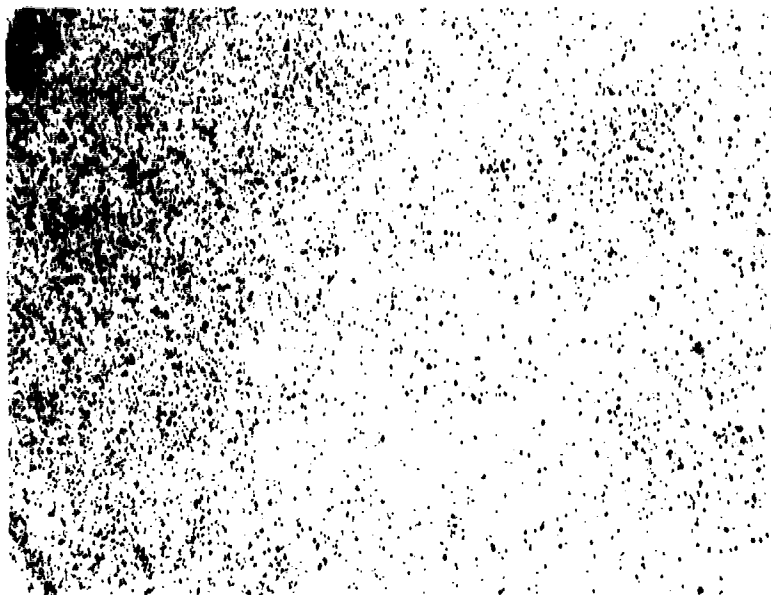
300 $\mu$ m

4X



102 $\mu$ m

4X



52 $\mu$ m

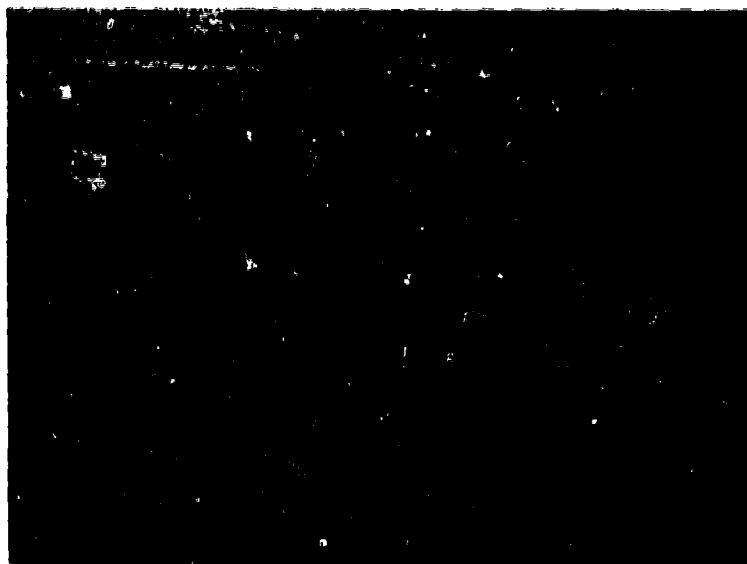
4X



26 $\mu$ m

4X

A-7



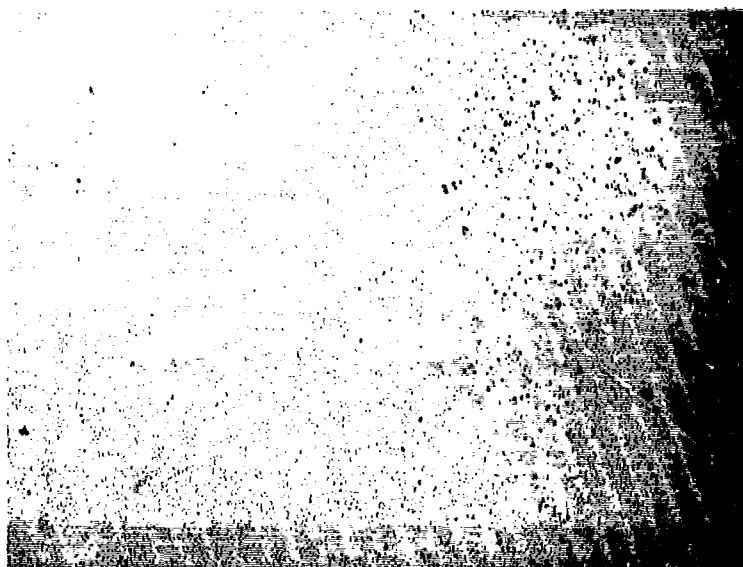
8μm

4X



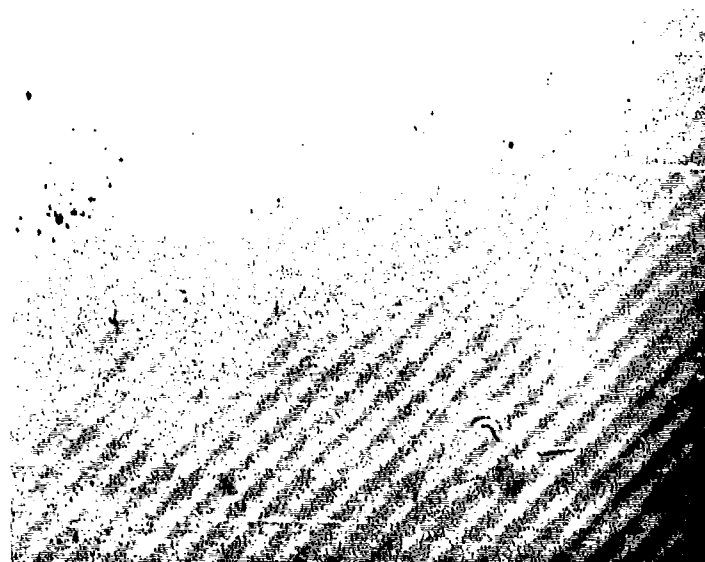
8μm

4X



0.45 $\mu$ m

4X

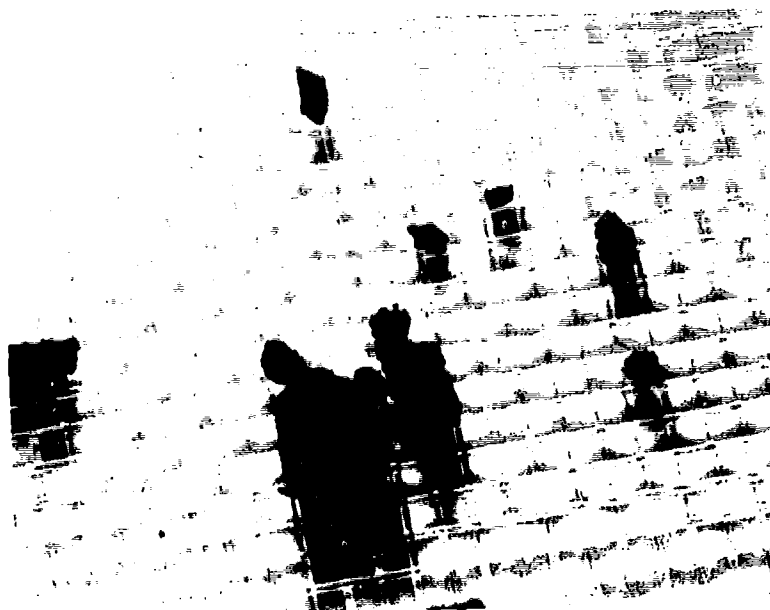


0.45 $\mu$ m

4X

**APPENDIX A-2**  
**CASCADE FILTRATION PHOTOMICROGRAPHS**  
**SAMPLE NO. 6476**

**Biggs AAF Tank 5 Bottoms**  
**(See Table 5)**



1000 $\mu$ m

4X

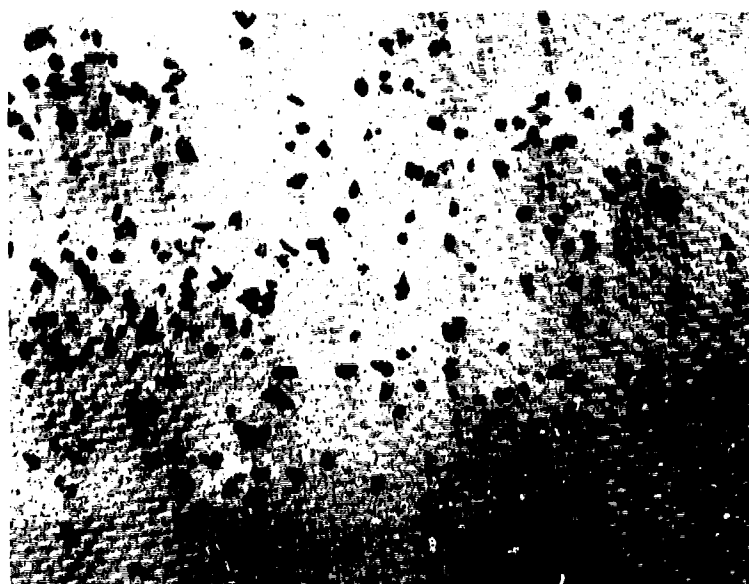


500 $\mu$ m

4X

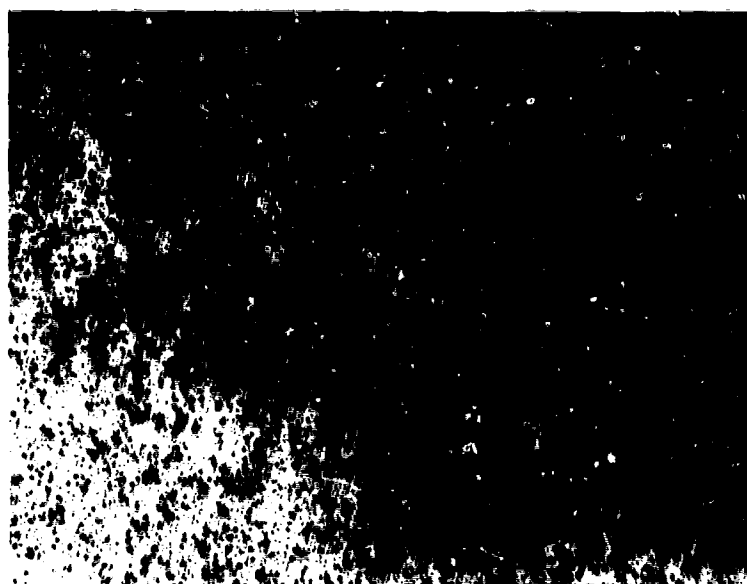
A-13

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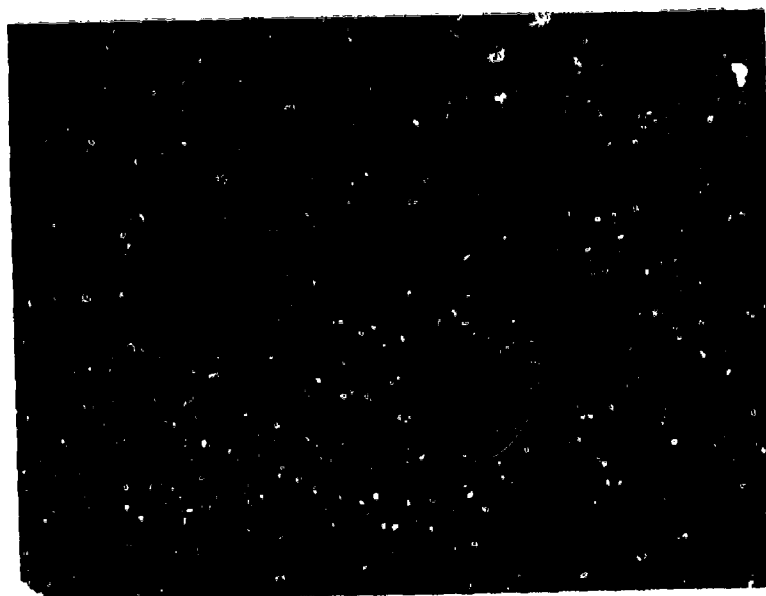
300 $\mu$ m

4X



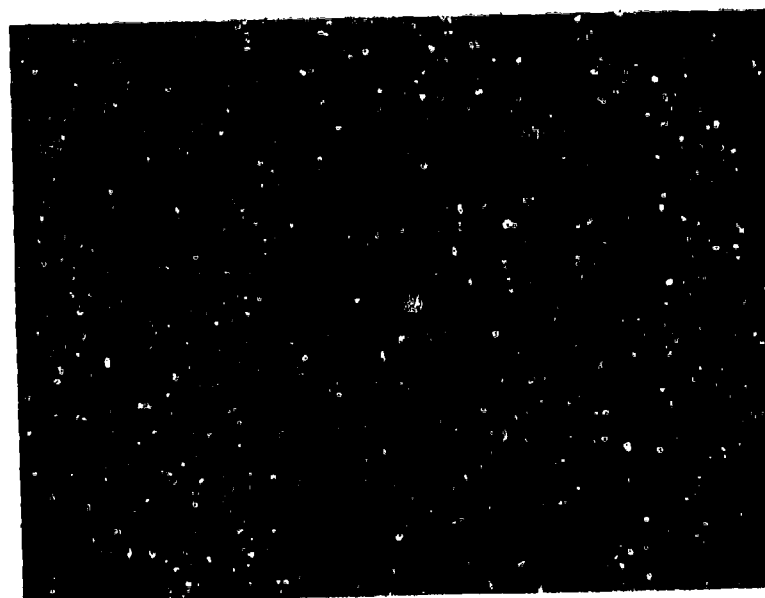
102 $\mu$ m

4X



52 $\mu$ m

4X



26 $\mu$ m

4X



8 $\mu$ m

4X

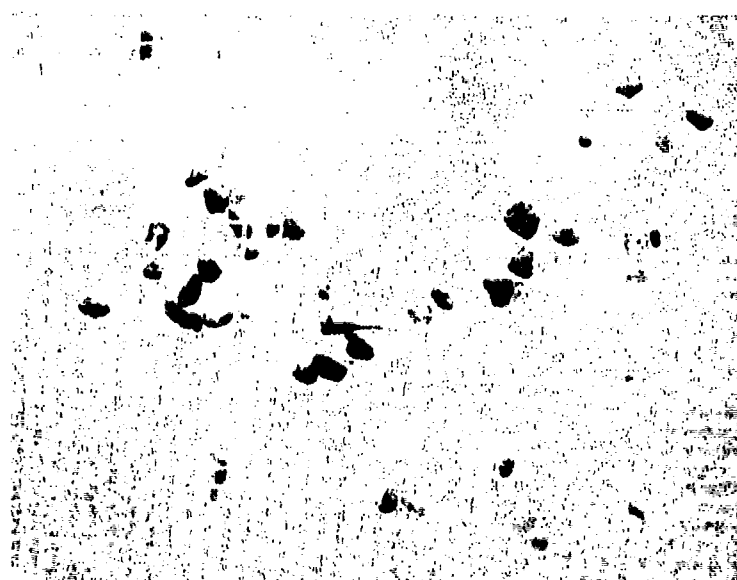
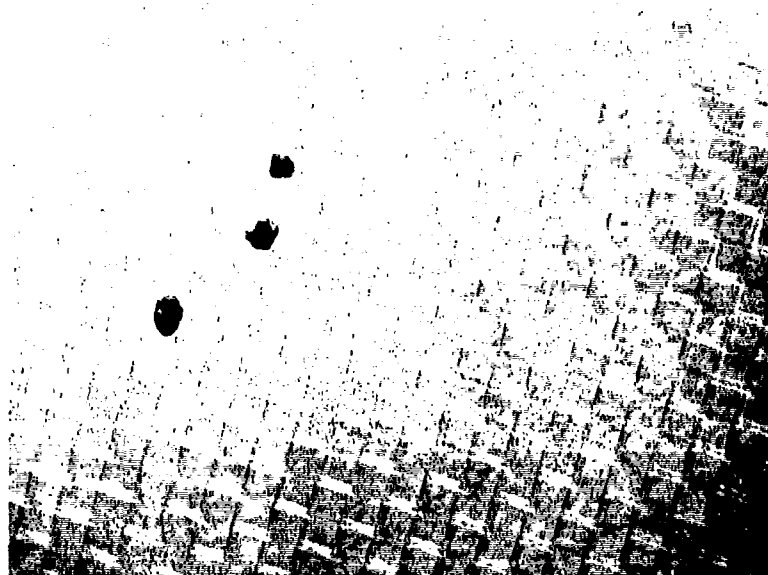


0.45 $\mu$ m

4X

**APPENDIX A-3**  
**CASCADE FILTRATION PHOTOMICROGRAPHS**  
**SAMPLE NO. 6486**

**Biggs AAF Tanks 3/4 Nozzle (After Filter)**  
**(See Table 5)**



500μm

4X

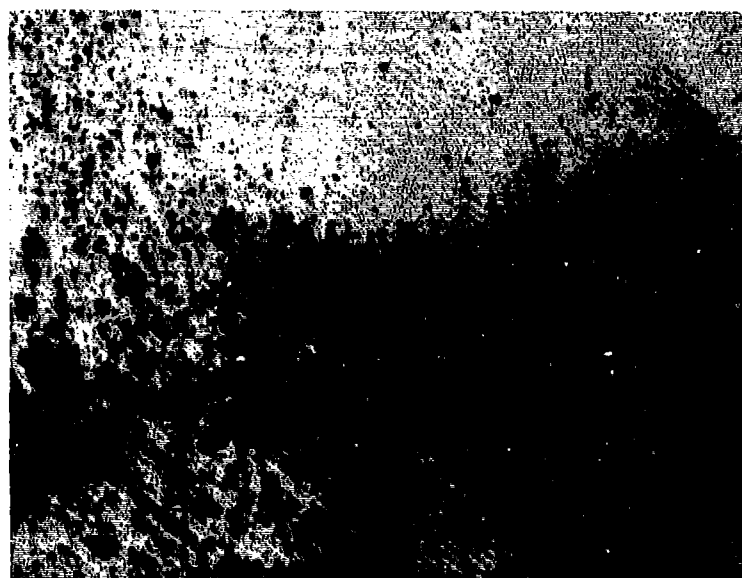
A-19

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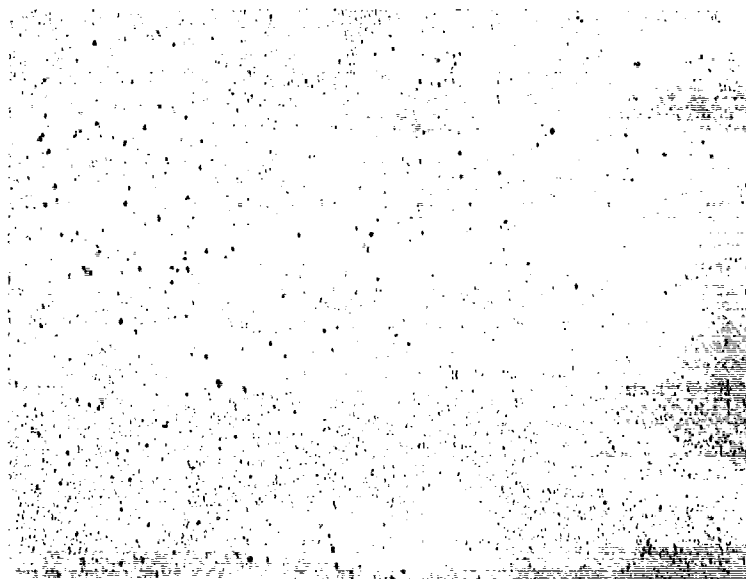
300 $\mu$ m

4X



102 $\mu$ m

4X



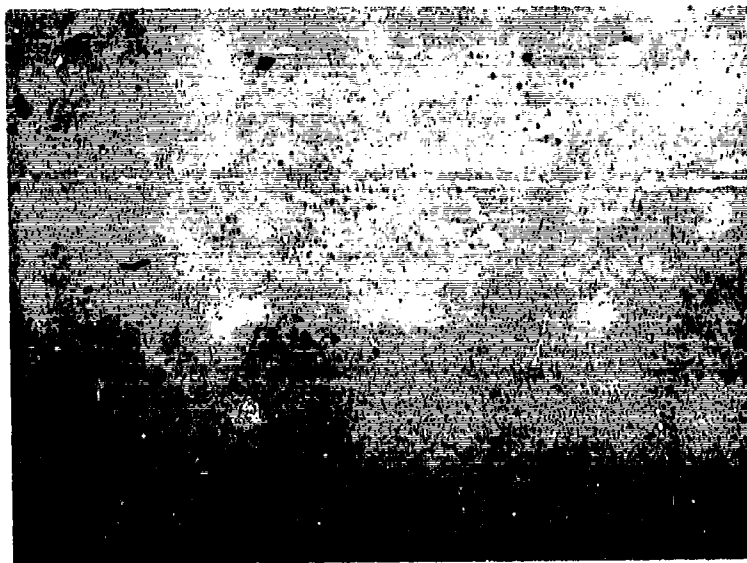
52 $\mu$ m

4X



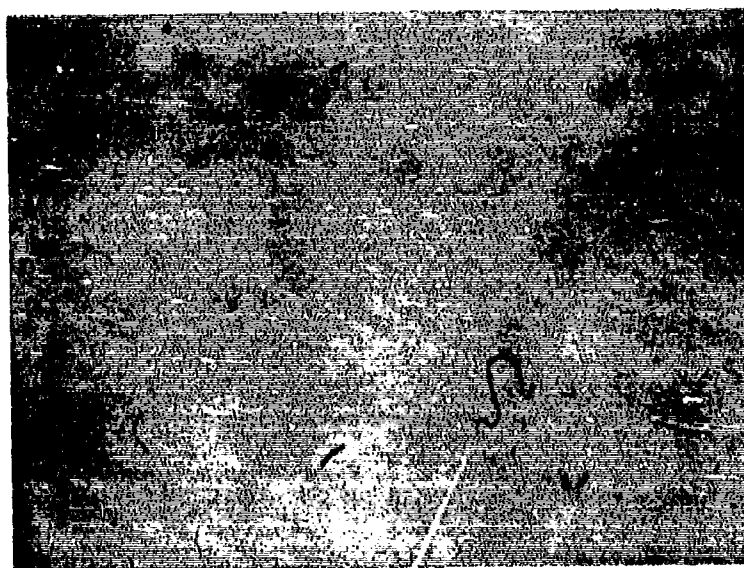
26 $\mu$ m

4X



8 $\mu$ m

4X



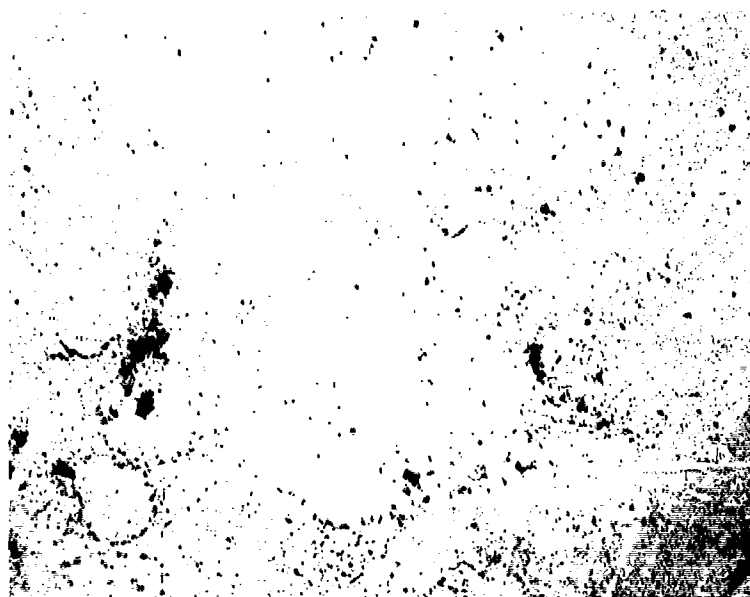
0.45 $\mu$ m

4X

A-22

**APPENDIX A-4**  
**8- $\mu$ m FILTRATION PHOTOMICROGRAPHS**  
**SAMPLE NO. 6471**  
(Center of Tank 4)  
and  
**SAMPLE NO. 6481**  
(Center of Tank 6)

Biggs AAF  
(See Table 5)



8 $\mu$ m

SAMPLE 6471

4X



8 $\mu$ m

SAMPLE 6481

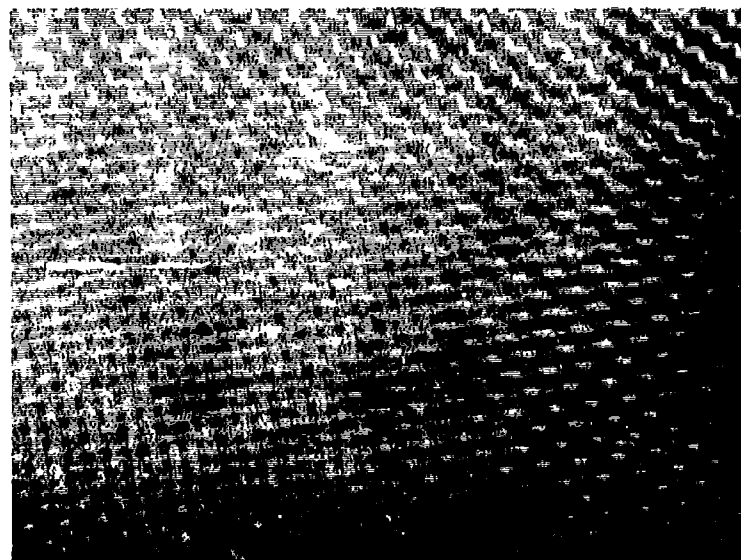
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A-25

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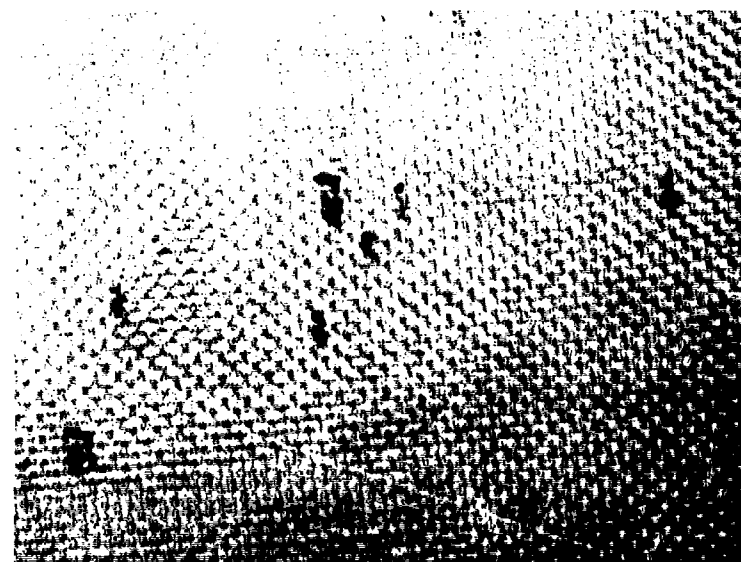
**APPENDIX A-5  
CASCADE FILTRATION PHOTOMICROGRAPHS  
SAMPLE NO. 6496**

**OH-58A, 71-20667  
(See Table 6)**



500μm

4X



300μm

4X

A-29

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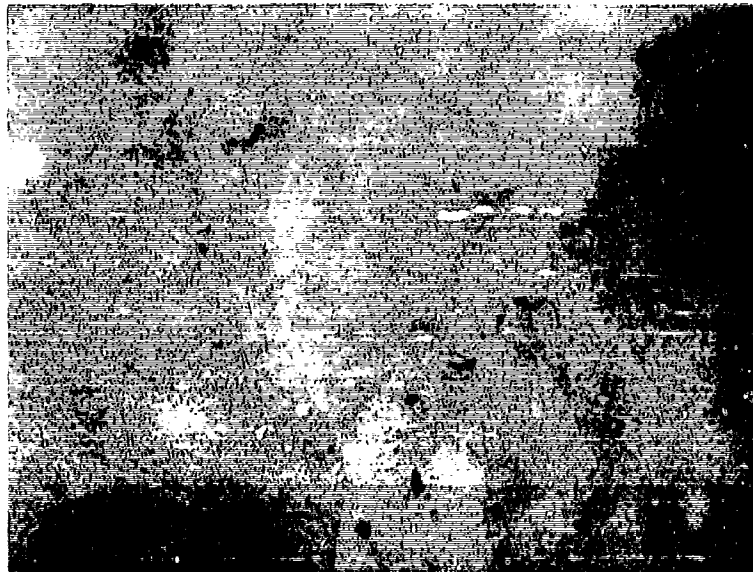
102 $\mu$ m

4X



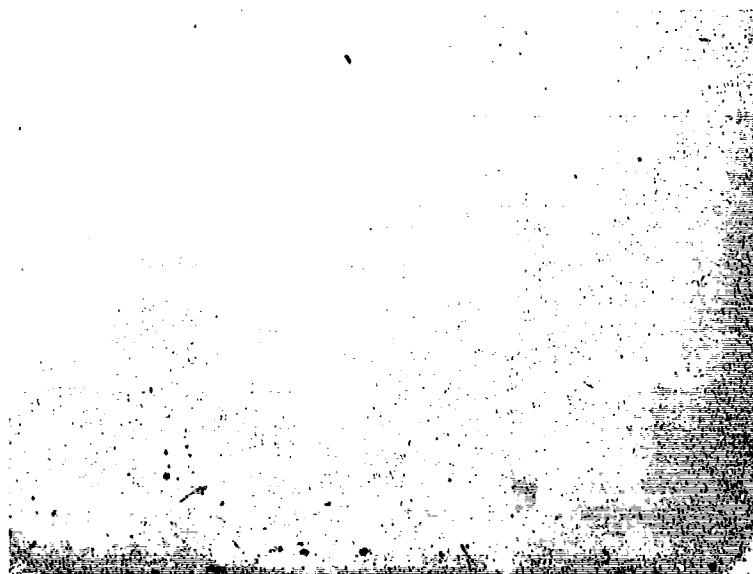
52 $\mu$ m

4X



26μm

4X

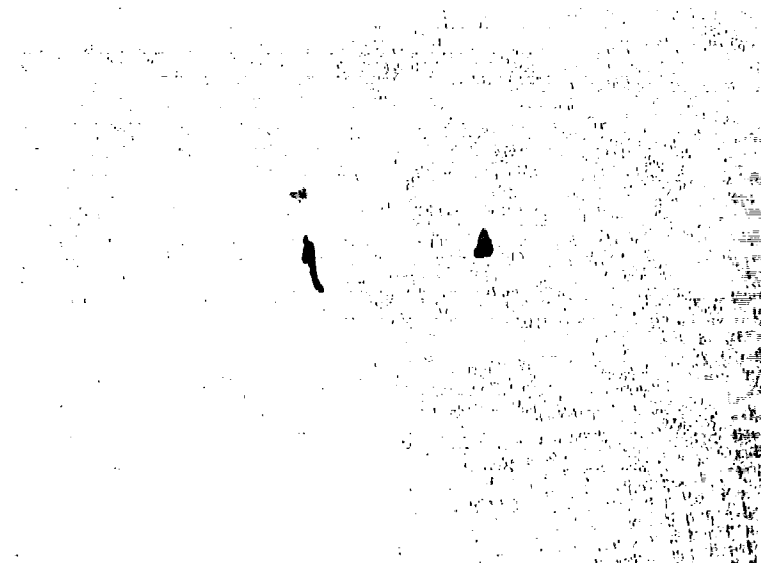


8μm

4X

APPENDIX A-6  
CASCADE FILTRATION PHOTOMICROGRAPHS  
SAMPLE NO. 6499

AH-1G, 70-15953  
(See Table 6)



500μm

4X

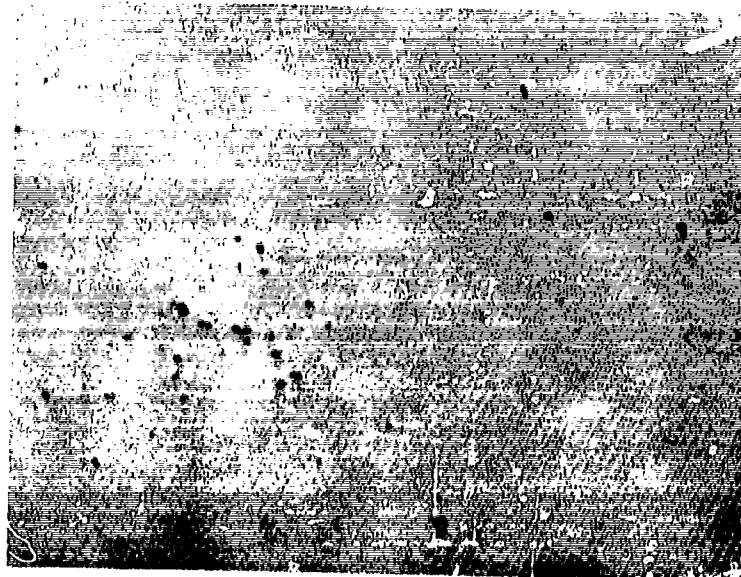


300μm

4X

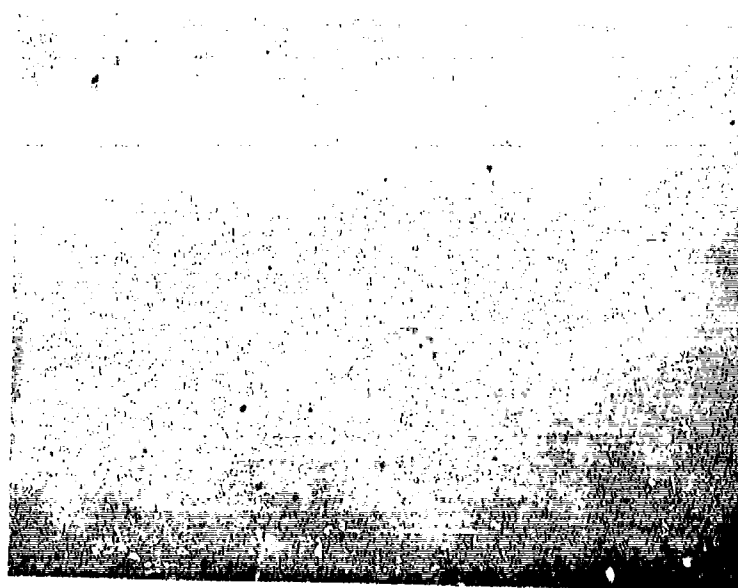
A-35

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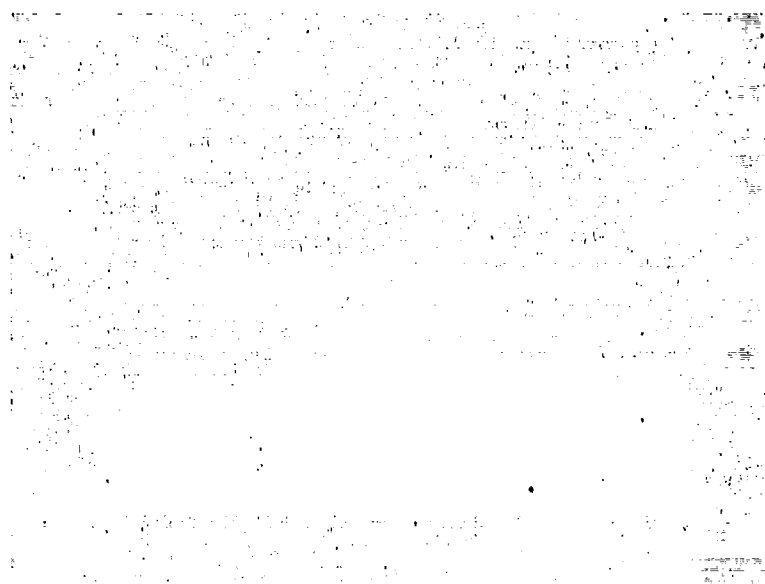
102μm

4X



52μm

4X



26μm

4X

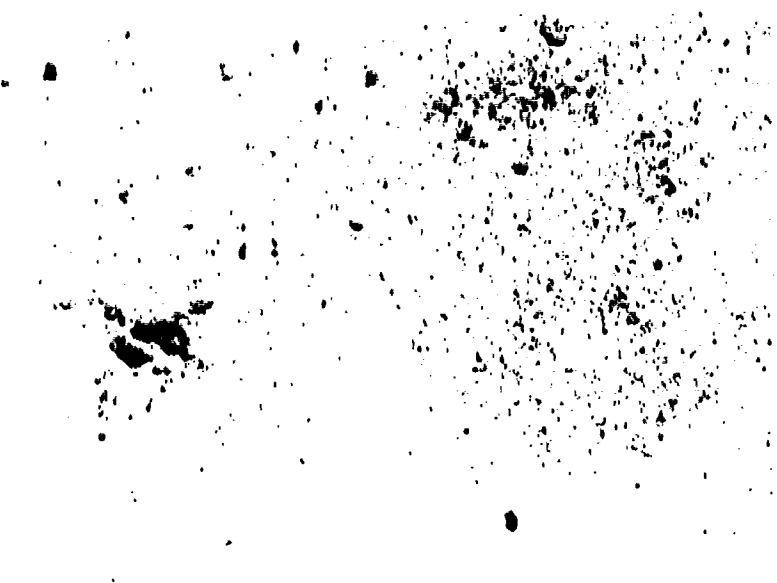
8μm

4X

A-37

**APPENDIX A-7**  
**8- $\mu$ m FILTRATION PHOTOMICROGRAPHS**  
**SAMPLE NO. 6487**  
(AH-1G, 71-20984 Aft Drain)  
and  
**SAMPLE NO. 6492**  
(AH-1G, 71-20984 Front Drain)

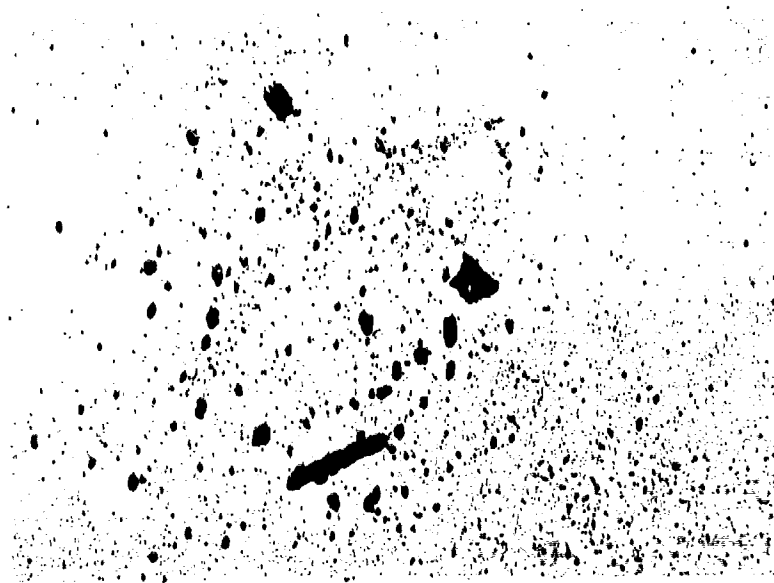
Biggs AAF  
(See Table G)



8 $\mu$ m

SAMPLE 6487

4X



8 $\mu$ m

SAMPLE 6492

4X

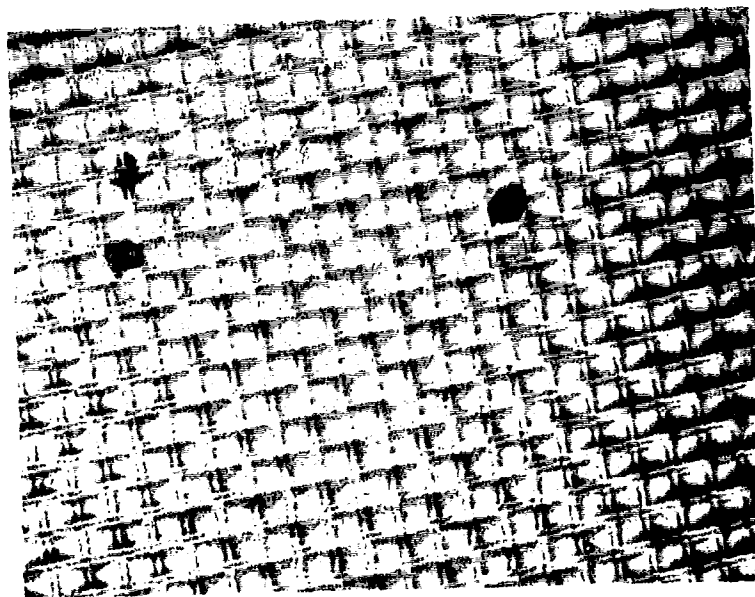
A-41

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**APPENDIX B**  
**FILTRATION PHOTOMICROGRAPHS FOR OPERATION REFORGER**

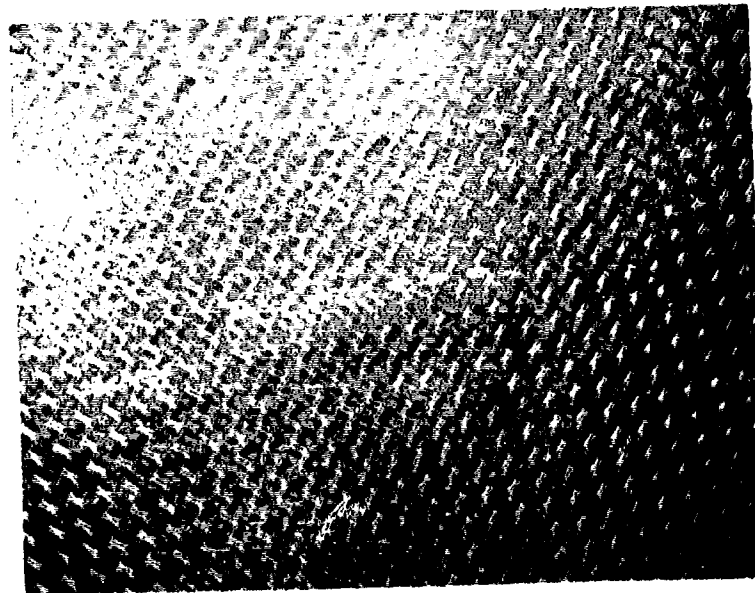
**APPENDIX B-1  
CASCADE FILTRATION PHOTOMICROGRAPHS  
SAMPLE NO. 6594**

**AH-1G, 70-16045 Front Drain  
(See Table 9)**



1000μm

4X



500μm

4X

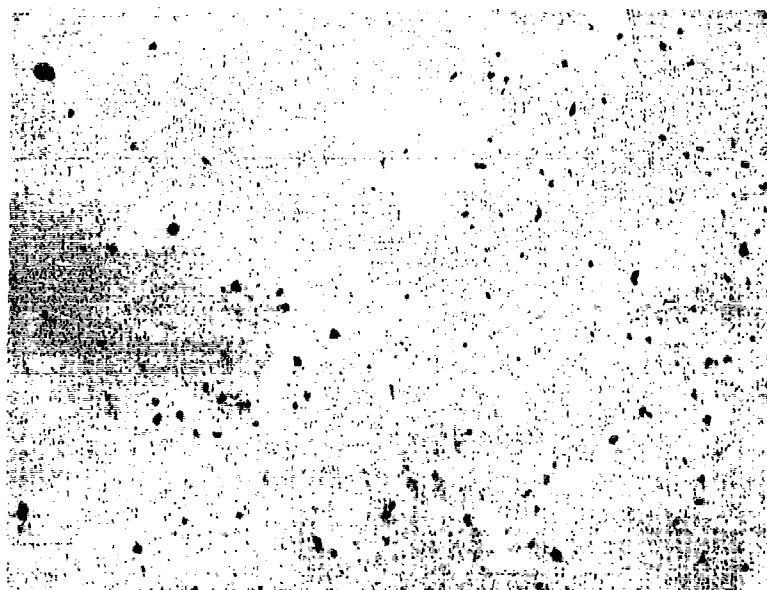
B-5

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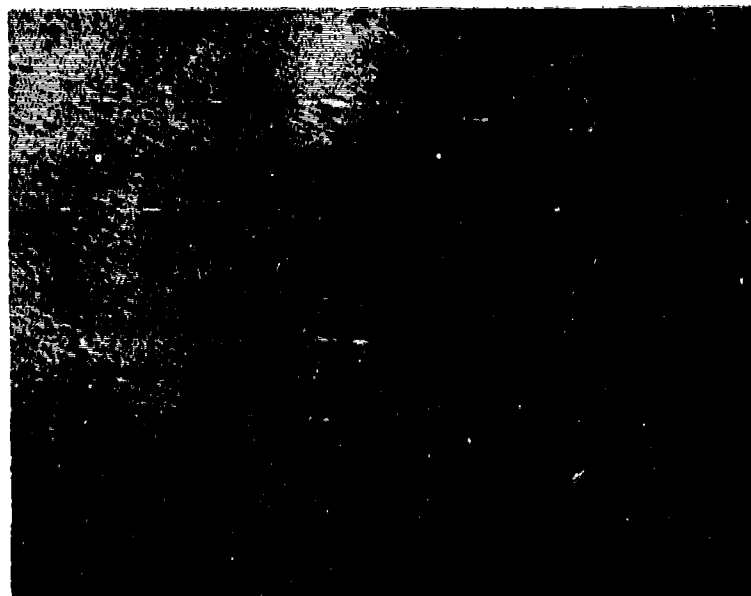
300 $\mu$ m

4X



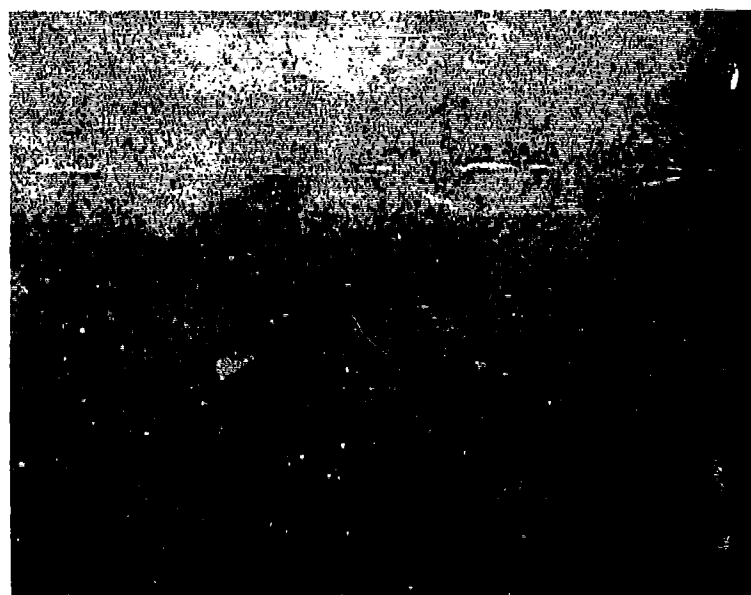
102 $\mu$ m

4X



52 $\mu$ m

4X



26 $\mu$ m

4X



8 $\mu$ m

4X

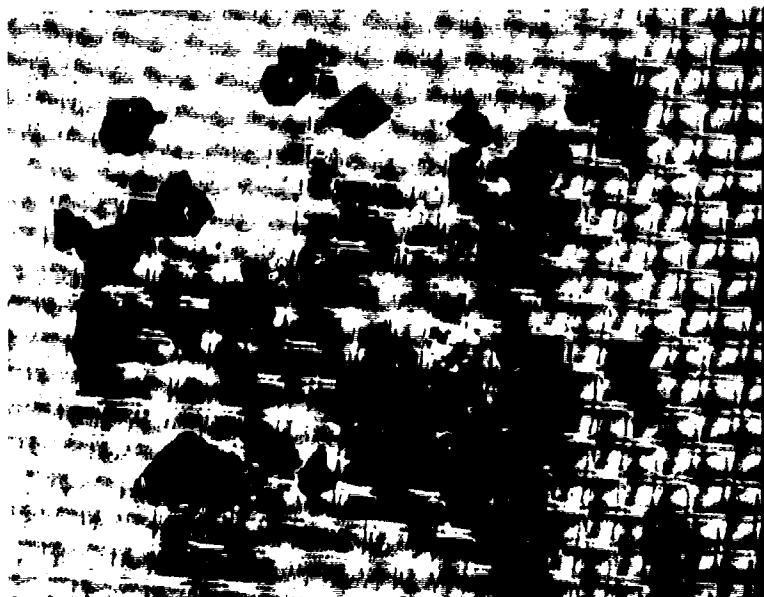


.45 $\mu$ m

4X

**APPENDIX B-2**  
**CASCADE FILTRATION PHOTOMICROGRAPHS**  
**SAMPLE NO. 6603**

**OH-58A, 71-20497**  
**(See Table 9)**



1000 $\mu$ m

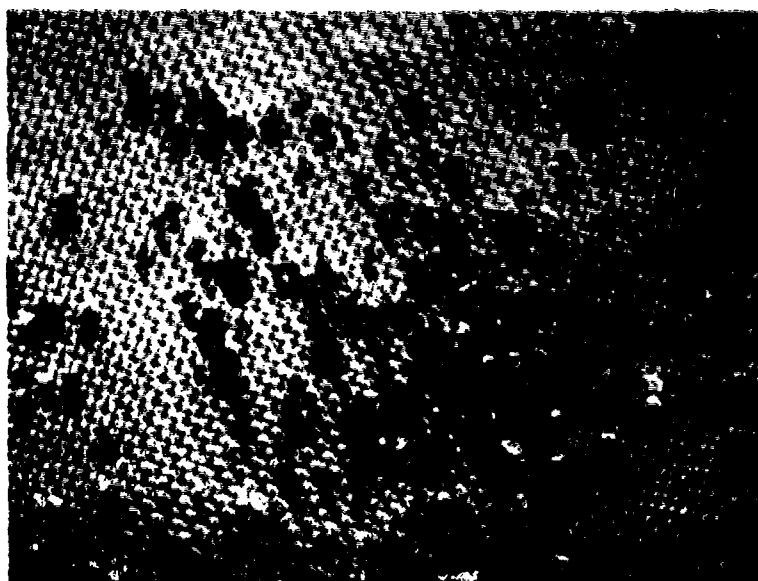
4X



500 $\mu$ m

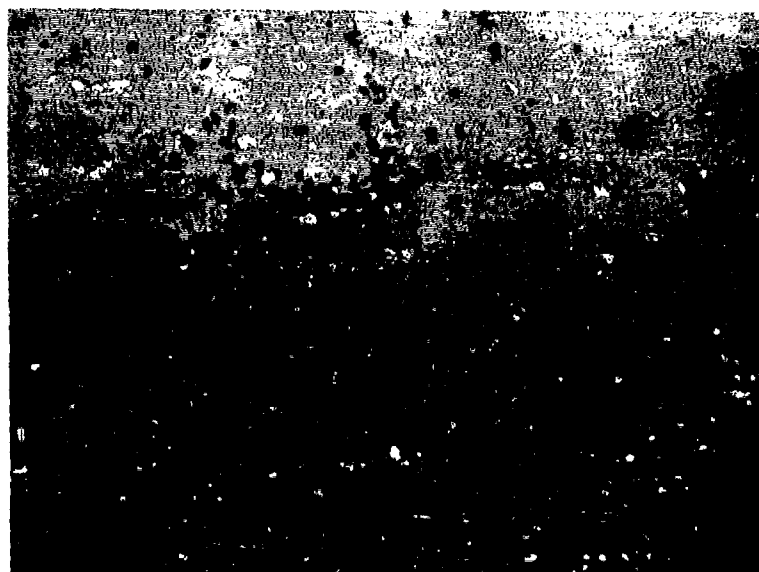
4X

B-11



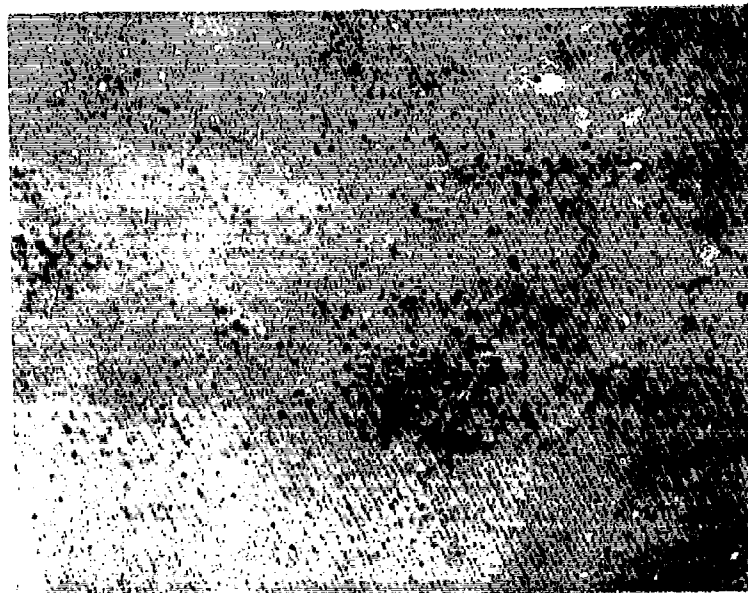
300 $\mu$ m

4X



102 $\mu$ m

4X



52μm

4X



26μm

4X



8 $\mu$ m

4X

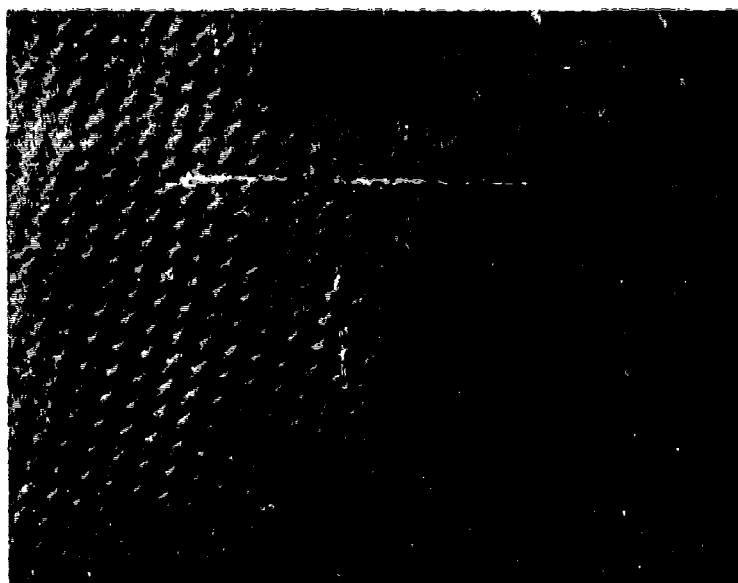


0.45 $\mu$ m

4X

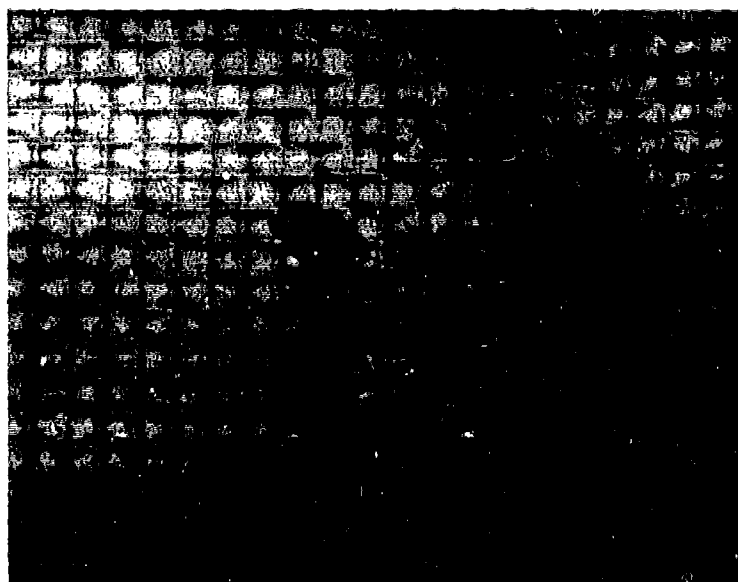
**APPENDIX B-3  
CASCADE FILTRATION PHOTOMICROGRAPHS  
SAMPLE NO. 6614**

**AH-1G, 71-21031 Front Drain  
(See Table 9)**



1000μm

4X

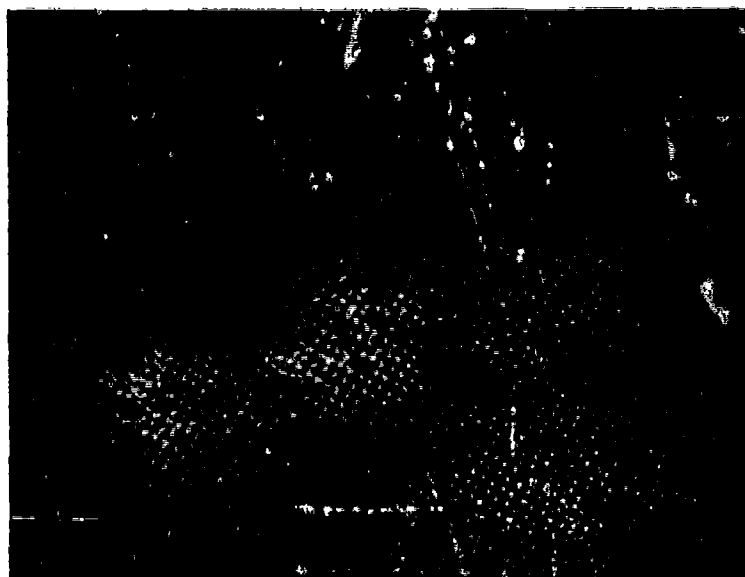


500μm

4X

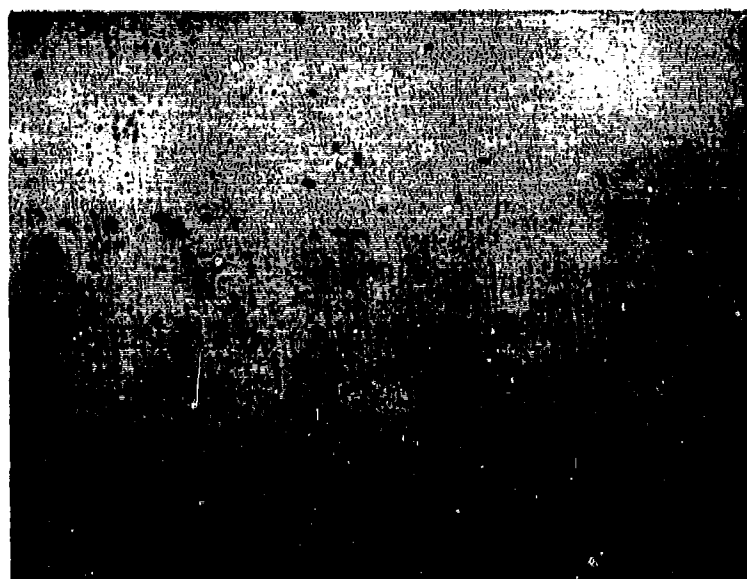
B-17

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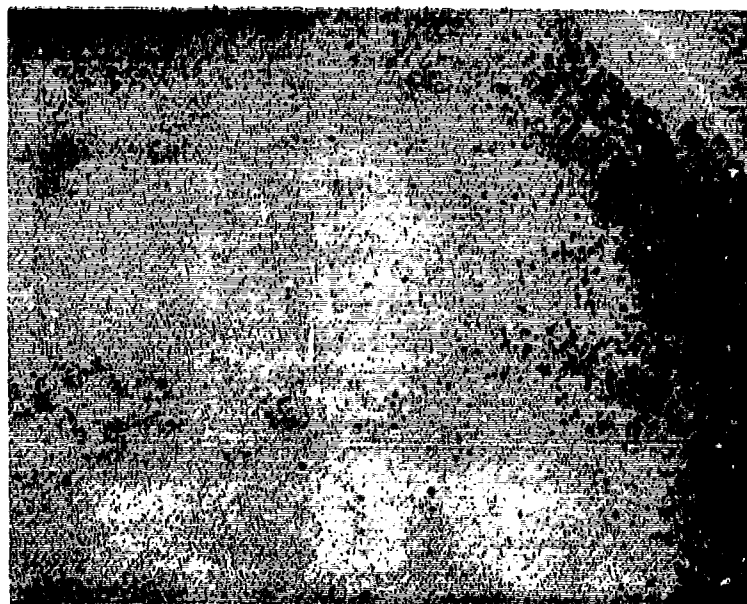
300 $\mu$ m

4X



102 $\mu$ m

4X



52μm

4X



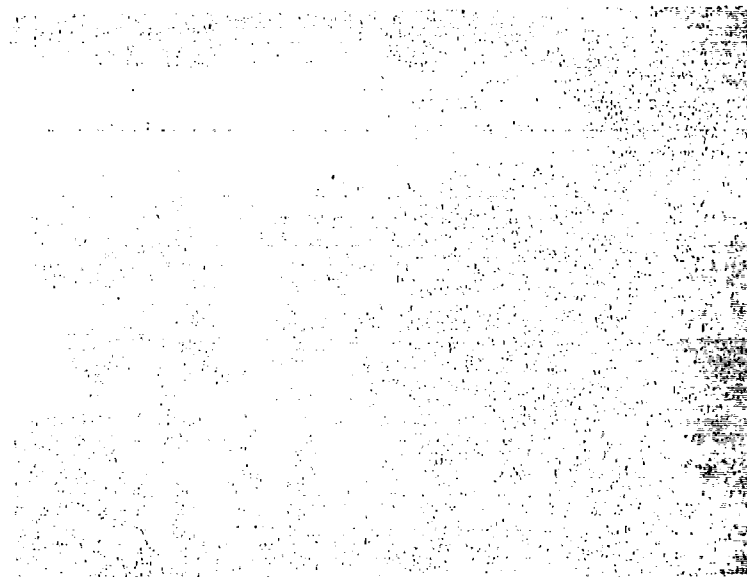
26μm

4X



8 $\mu$ m

4X

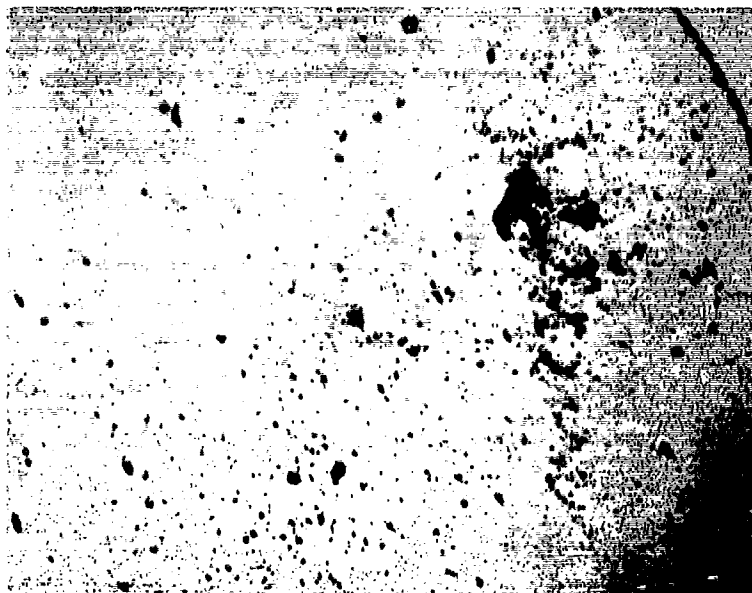


0.45 $\mu$ m

4X

**APPENDIX B-4**  
**8- $\mu$ m FILTRATION PHOTOMICROGRAPHS**  
**REFORGER-AIRCRAFT**

(See Table 8)



8μ

4X

SAMPLE 6578  
UH-1H, 71-20142 (LF)

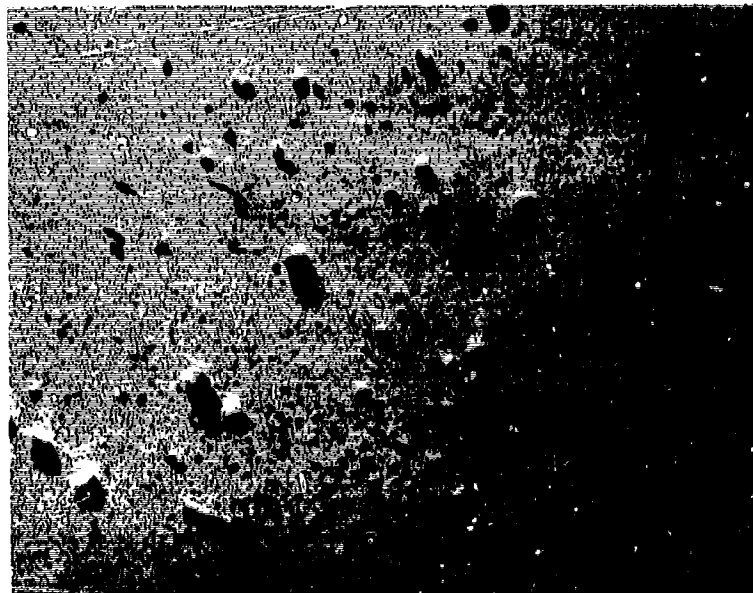


8μ

4X

SAMPLE 6580  
AH-1G, 67-15721 (F)

B-23



8μ

4X

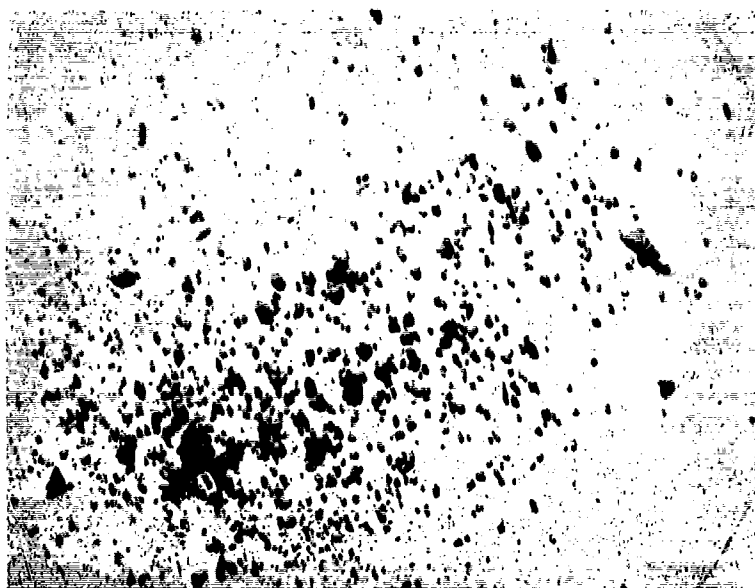
SAMPLE 6587  
UH-1H, 67-17672 (LF)



8μ

4X

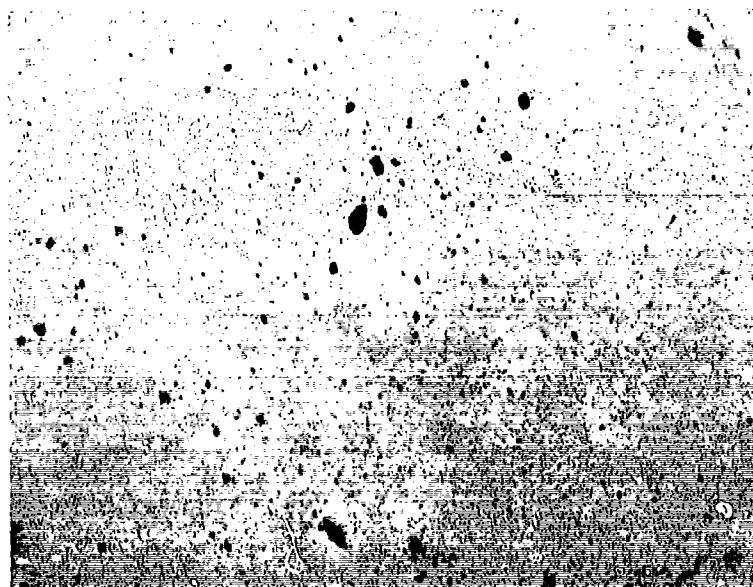
SAMPLE 6588  
UH-1H, 67-17672 (RF)



8μ

4X

SAMPLE 6589  
OH-58A, 68-16977



8μ

4X

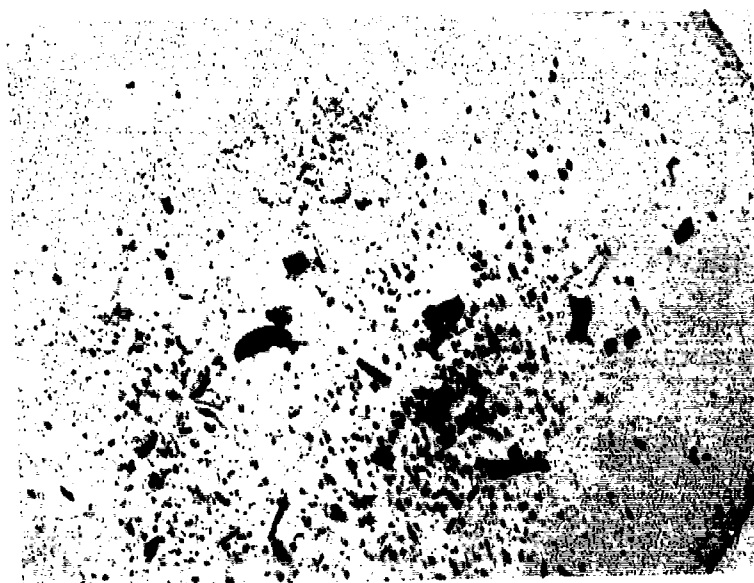
SAMPLE 6601  
OH-58A, 70-15561



8μ

4X

SAMPLE 6604  
OH-58A, 70-15172



8μ

4X

SAMPLE 6615  
OH-58A, 71-20838



8 $\mu$

4X

SAMPLE 6621  
CH-47C, 69-17126 (LF)



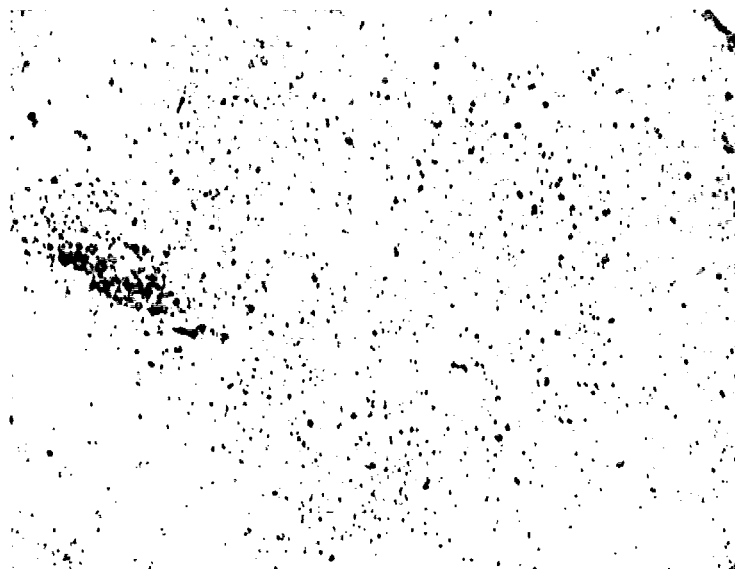
8 $\mu$

4X

SAMPLE 6622  
CH-47C, 69-17126 (RF)

**APPENDIX B-5**  
**8- $\mu$ m FILTRATION PHOTOMICROGRAPHS**  
**REFORGER--FUEL SUPPLY POINTS**

(See Table 8)



8μ

4X

SAMPLE 6596  
Bladder No. 2, POL Rapid Refill Point  
(at filter separator after filtration)



8μ

4X

SAMPLE 6600  
Railway Tank Car, 00/0-323 9P  
(at filter separator after filtration)

B-31

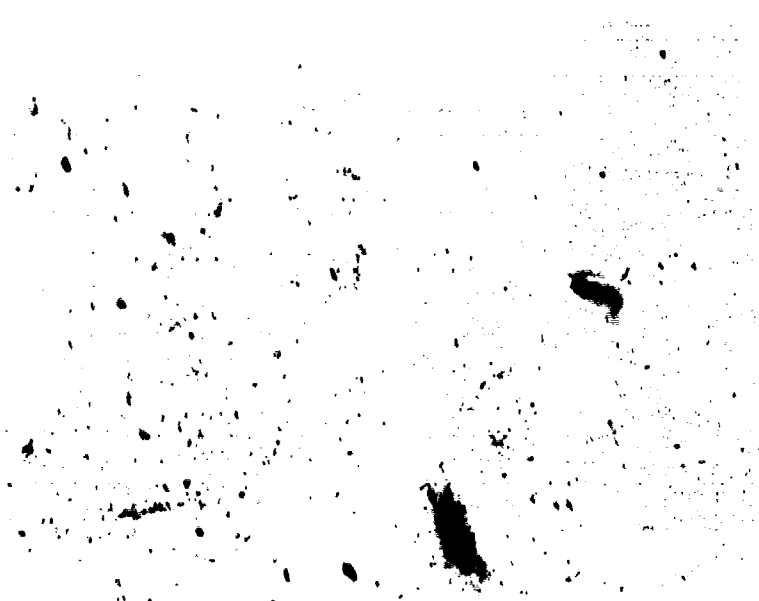
**APPENDIX C**  
**FILTRATION PHOTOMICROGRAPHS FOR OPERATION BRAVE SHIELD XIV**

C-1

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**APPENDIX C-1**  
**8- $\mu$ m FILTRATION PHOTOMICROGRAPHS**  
**BRAVE SHIELD XIV-AIRCRAFT**

(See Table 7)



8μ

SAMPLE 6546  
UH-1H, 74-22495 (LF)

4X



8μ

SAMPLE 6547  
OH-58A, 71-20806

4X

C-5

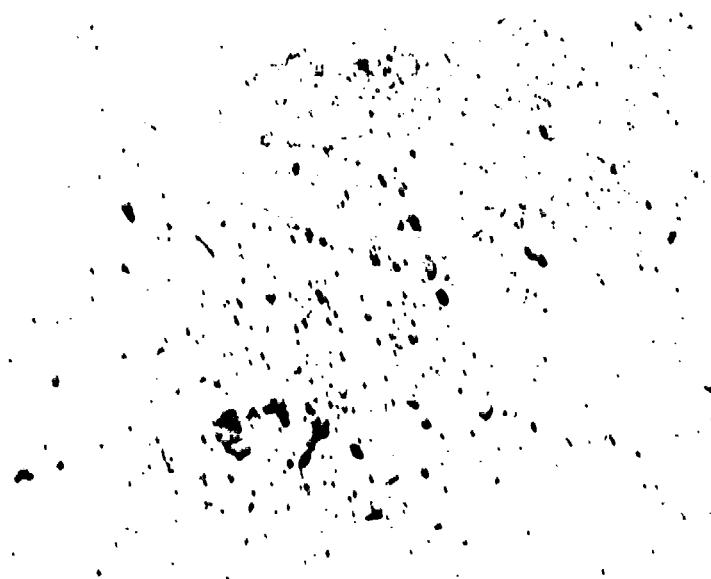
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8μ

4X

SAMPLE 6549  
OH-58A, 71-20444



8μ

4X

SAMPLE 6550  
OH-58A, 71-21087

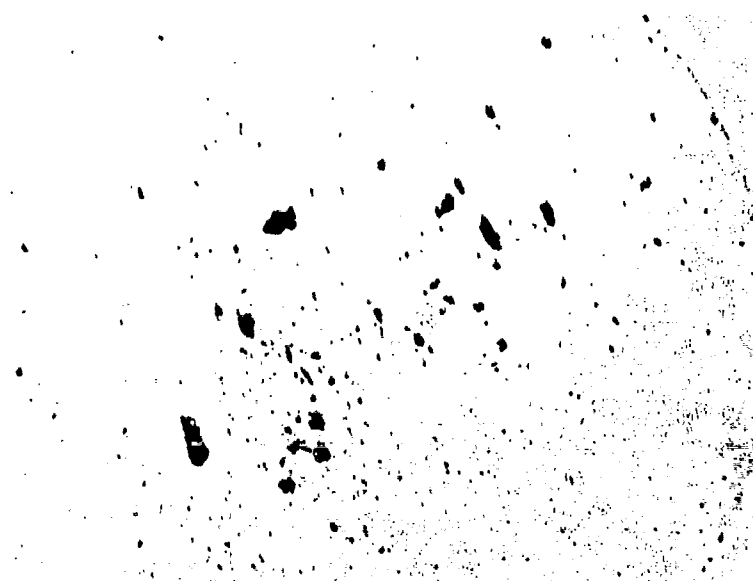
C-6



8μ

4X

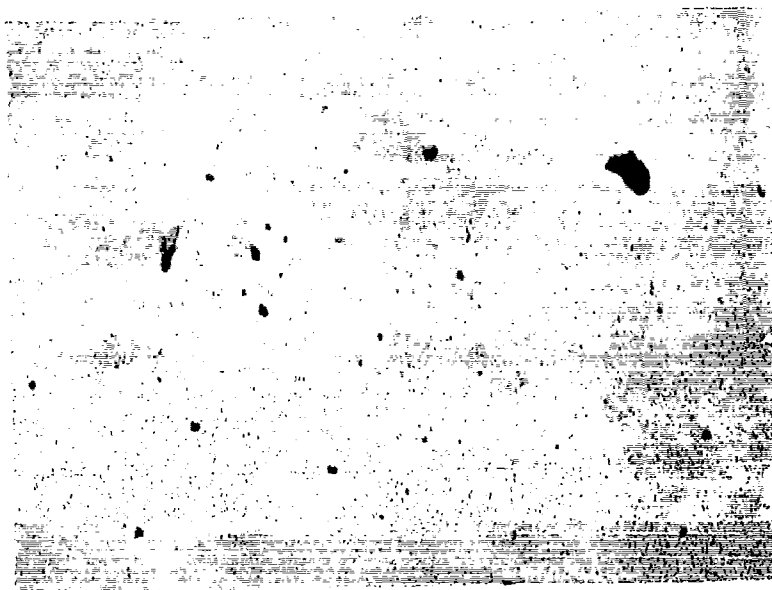
SAMPLE 6554  
OH-58A, 71-20763



8μ

4X

SAMPLE 6555  
OH-58A, 71-20586



8μ

4X

SAMPLE 6559  
OH-58A, 70-15254

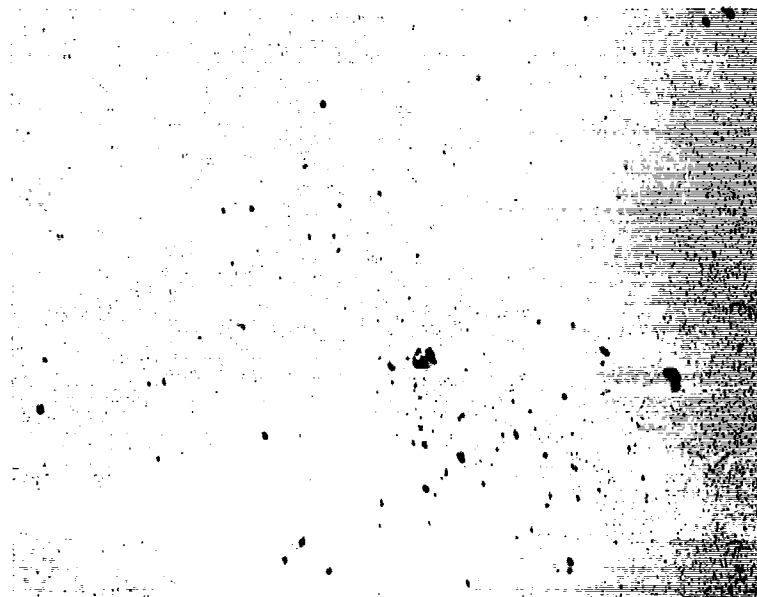


8μ

4X

SAMPLE 6560  
UH-1H, 68-16239 (LF)

C-8



8μ

4X

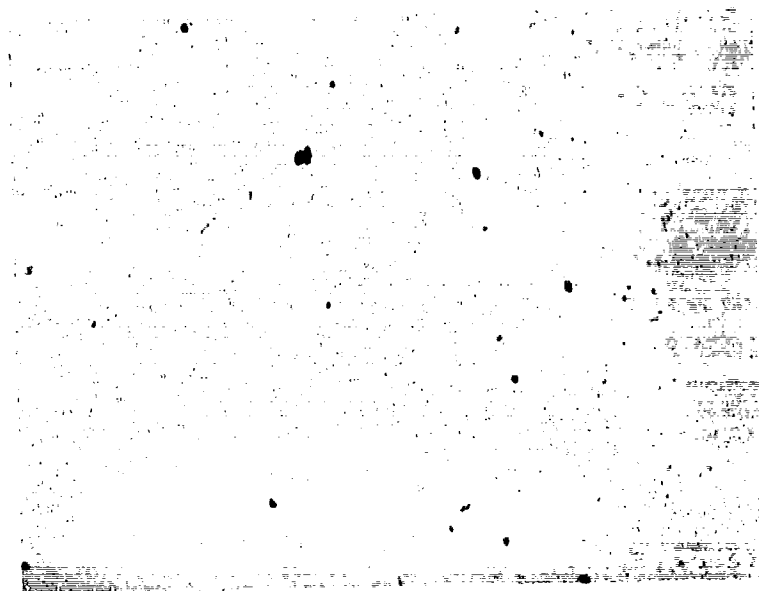
SAMPLE 6562  
UH-1H, 66-00856 (LF)



8μ

4X

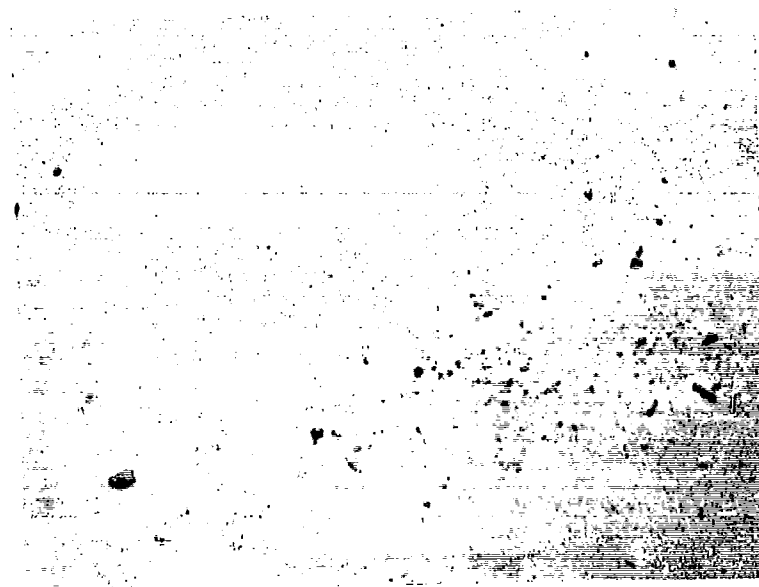
SAMPLE 6563  
UH-1H, 65-9967 (LF)



8μ

4X

SAMPLE 6565  
OH-58A, 70-15311



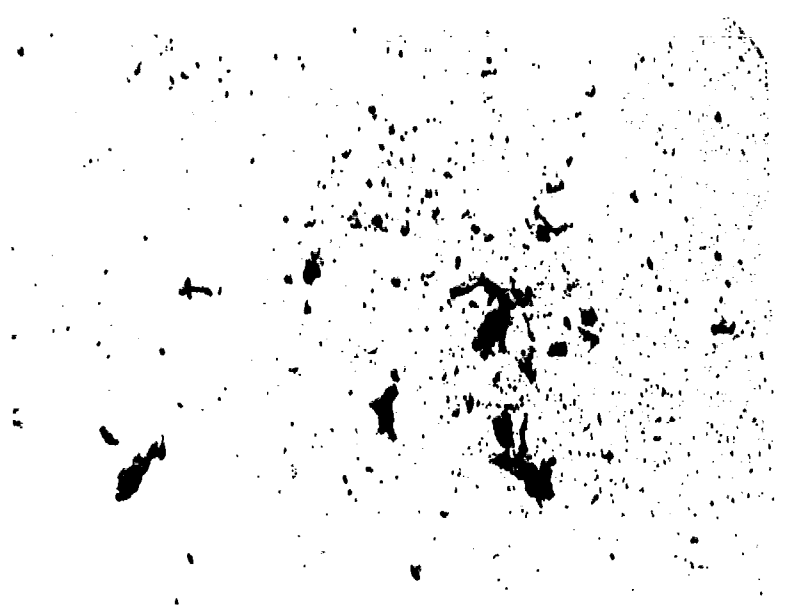
8μ

4X

SAMPLE 6567  
UH-1H, 73-21786 (LF)

**APPENDIX C-2**  
**8- $\mu$ m FILTRATION PHOTOMICROGRAPHS**  
**BRAVE SHIELD XIV--TANK TRUCKS**

(See Table 7)



8μ

4X

SAMPLE 6561  
Truck No. 2  
(Rear Cell, after filtration)



8μ

4X

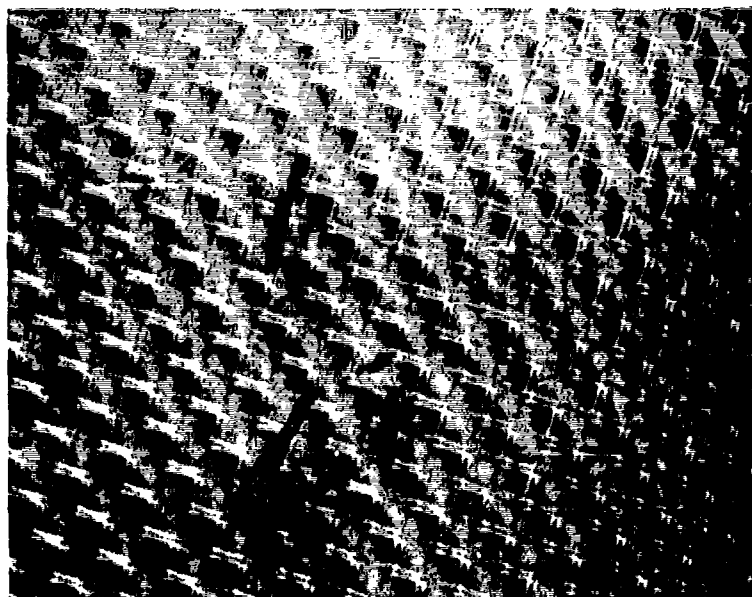
SAMPLE 6566  
Truck No. 3  
(Nozzle Sample)

C-13

**APPENDIX D**  
**FILTRATION PHOTOMICROGRAPHS FOR OPERATION BRAVE SHIELD XV**

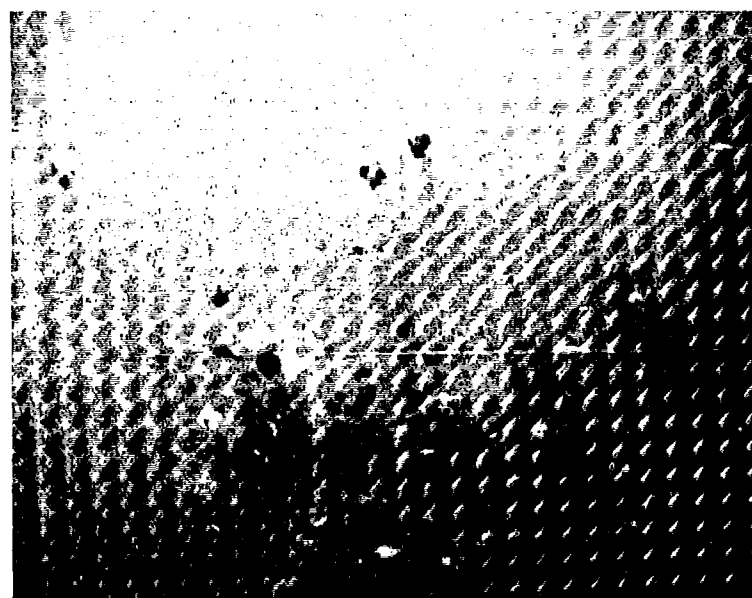
APPENDIX D-1  
CASCADE FILTRATION PHOTOMICROGRAPHS  
SAMPLE NO. 6664

OH-58A, 70-15613  
(See Table 11)



1000μm

4X

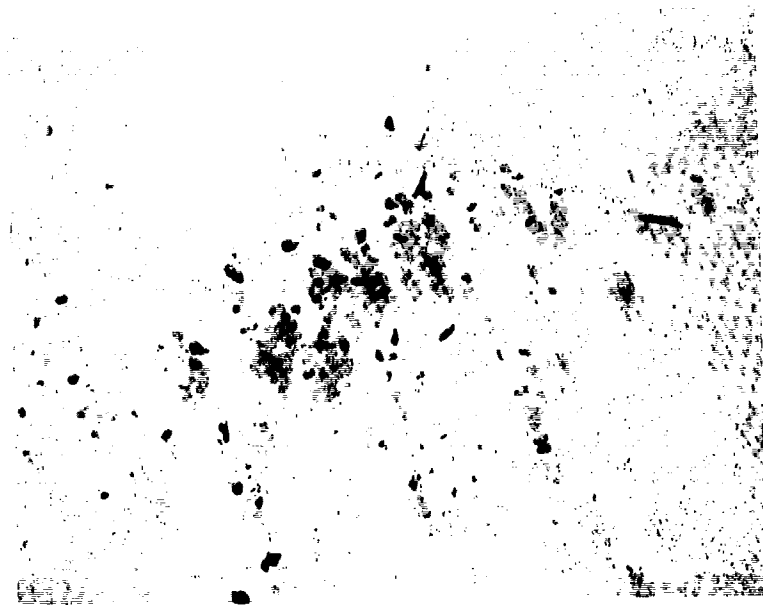


500μm

4X

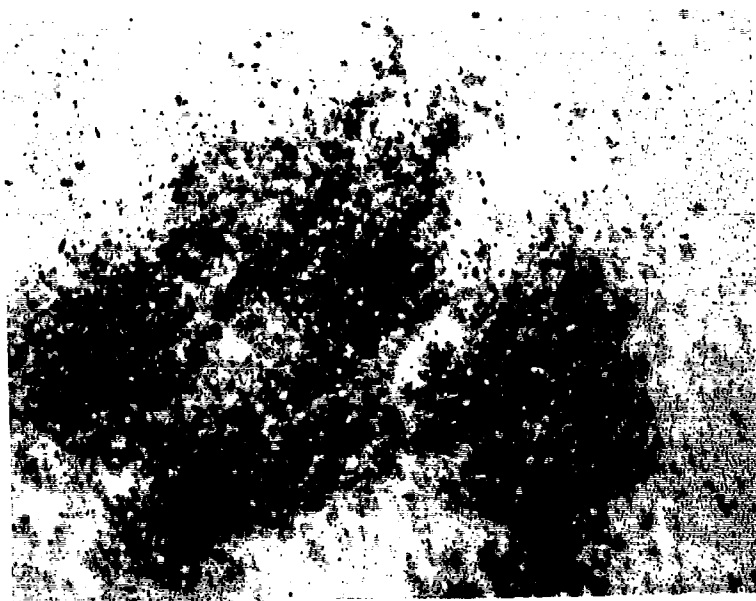
D-5

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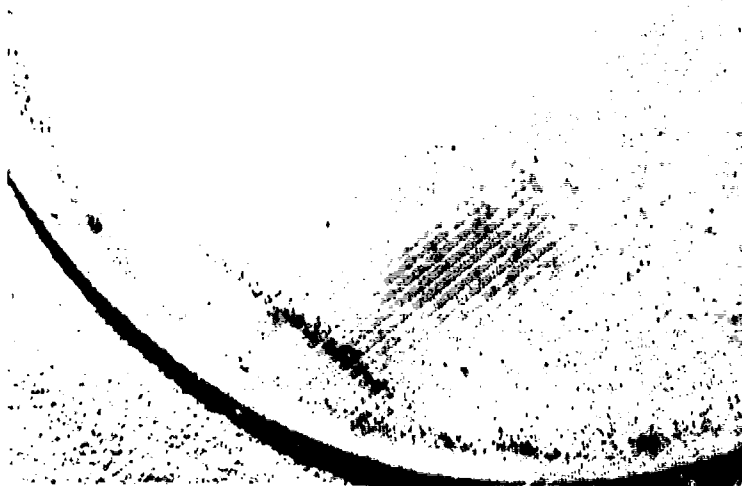
300 $\mu$ m

4X



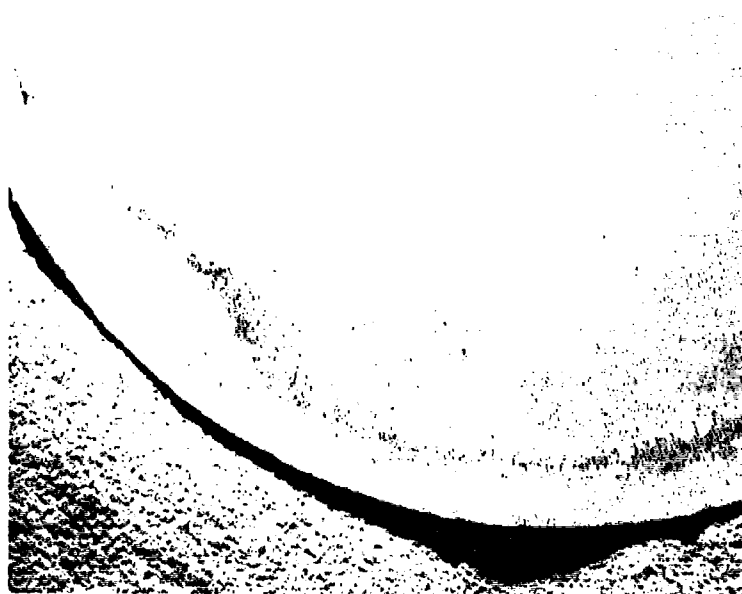
102 $\mu$ m

4X



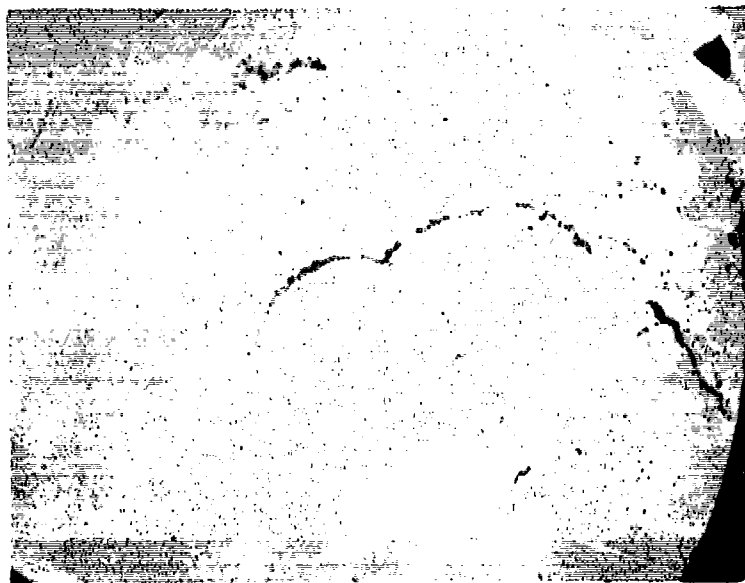
52 $\mu$ m

4X



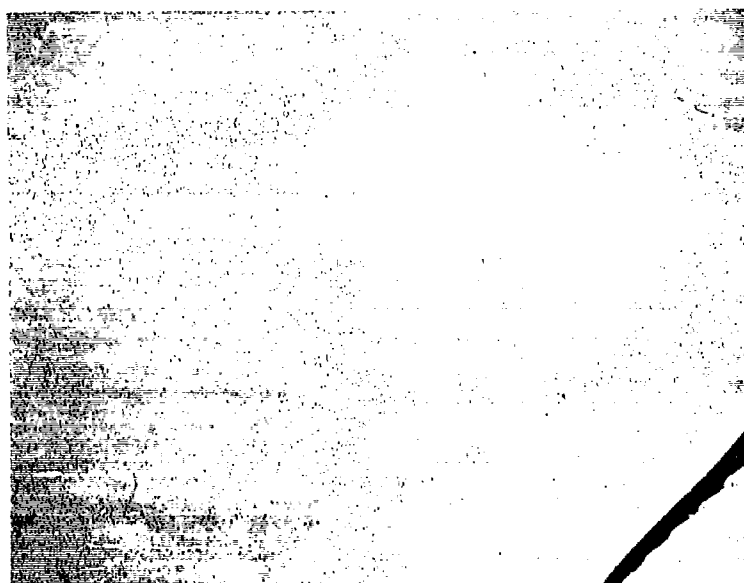
26 $\mu$ m

4X



8µm

4X



0.45µm

4X

**APPENDIX D-2**  
**SAMPLE NO. 6665**

**OH-58A, 72-21194**  
**(See Table 11)**



8µm

SAMPLE 6665

4X

D-11

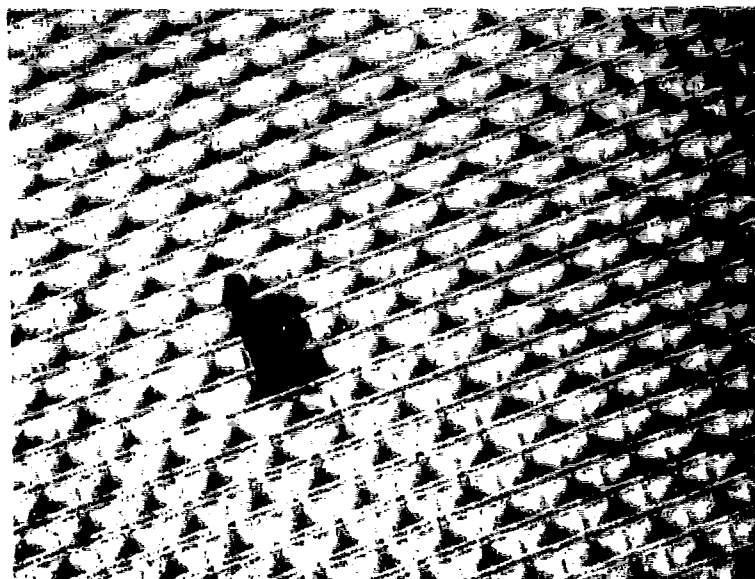
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**APPENDIX D-3**  
**CASCADE FILTRATION PHOTOMICROGRAPHS**  
**SAMPLE NO. 6666**

OH-58A, 70-15150  
(See Table 11)

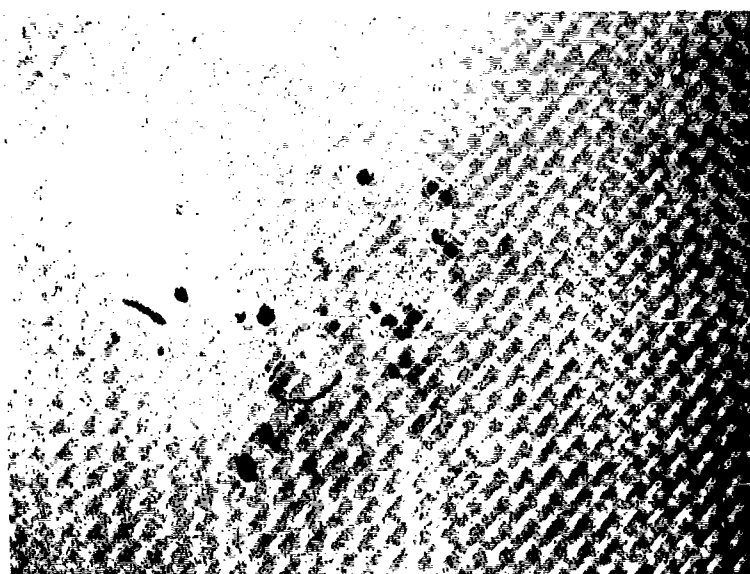
D-13

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1000 $\mu$ m

4X

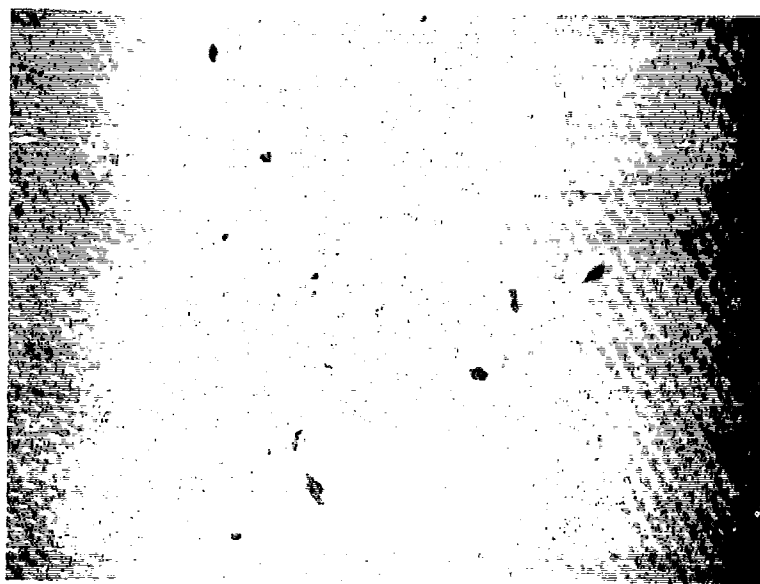


500 $\mu$ m

4X

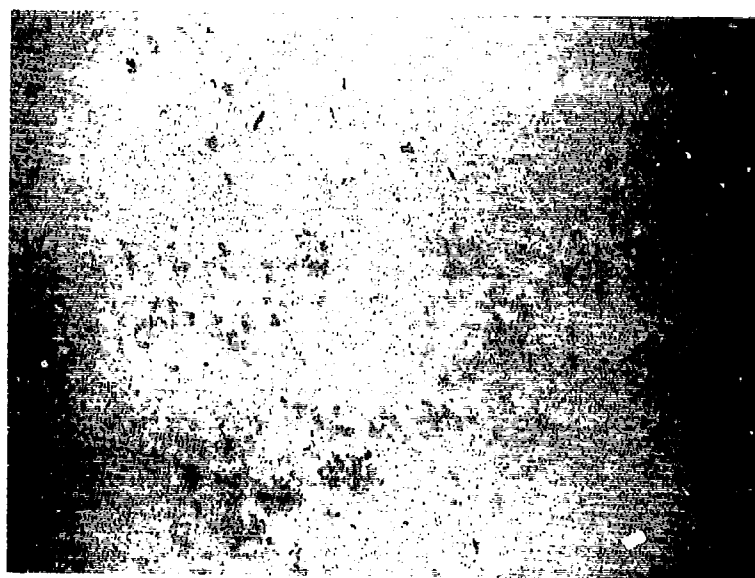
D-15

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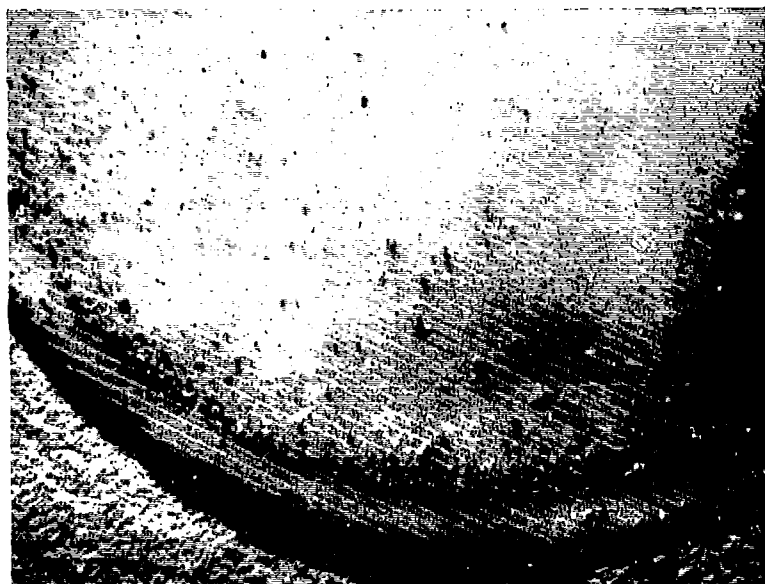
300 $\mu$ m

4X



102 $\mu$ m

4X



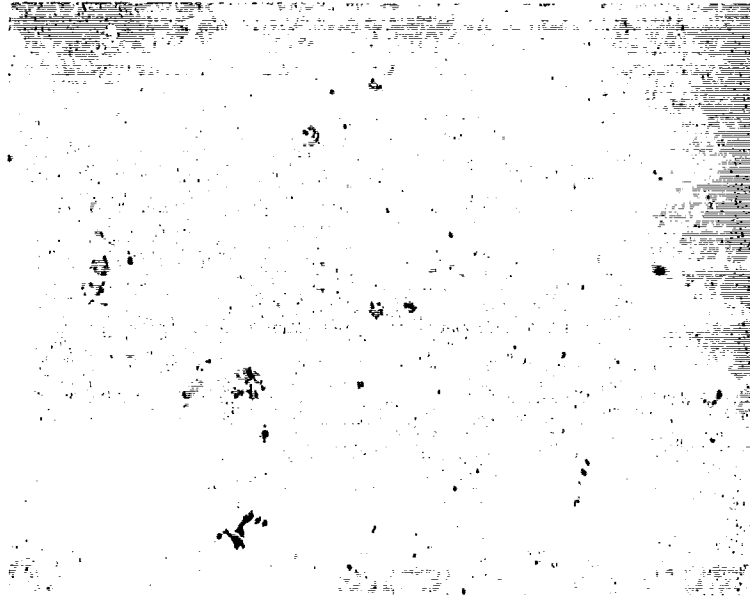
52 $\mu$ m

4X



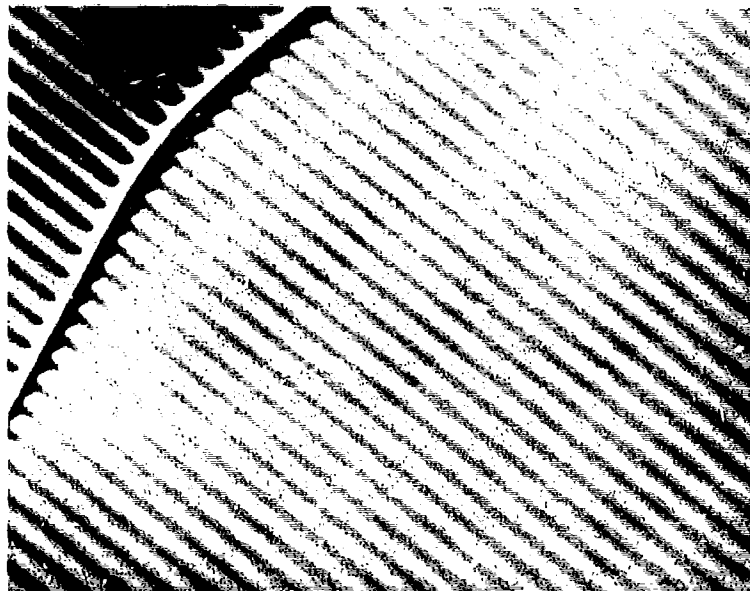
26 $\mu$ m

4X



8 $\mu$ m

4X

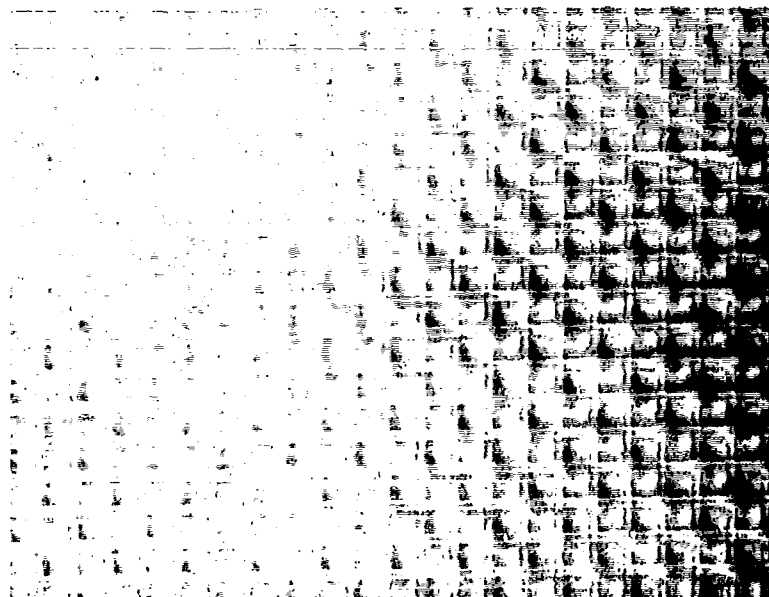


0.45 $\mu$ m

4X

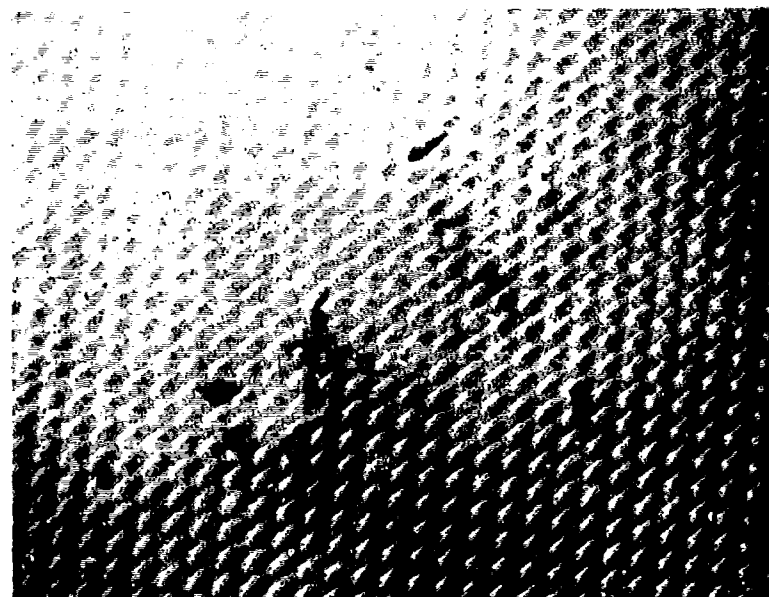
**APPENDIX D-4**  
**CASCADE FILTRATION PHOTOMICROGRAPHS**  
**SAMPLE NO. 6667**

**OH-58A, 69-16096**  
**(See Table 11)**



1000μm

4X

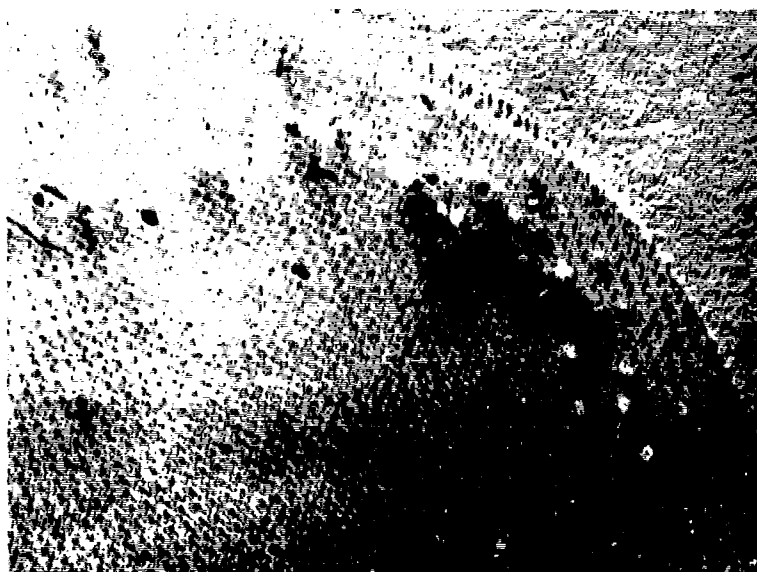


500μm

4X

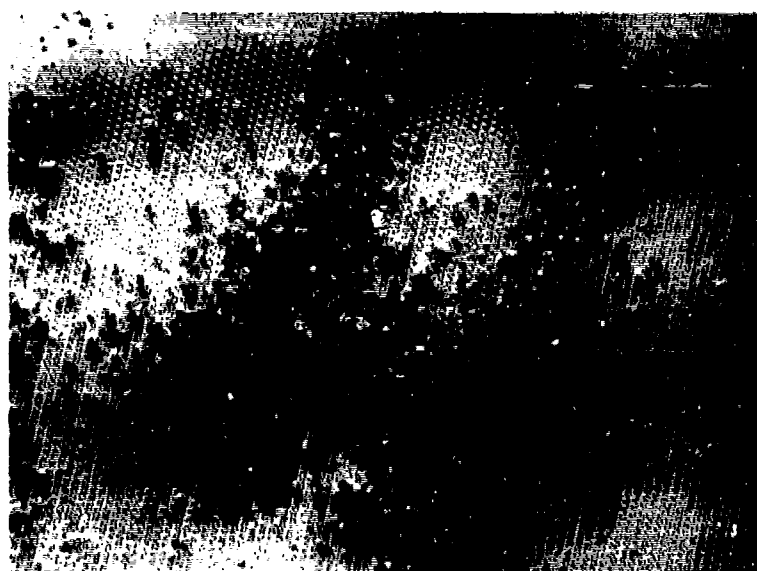
D-21

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300 $\mu$ m

4X



102 $\mu$ m

4X



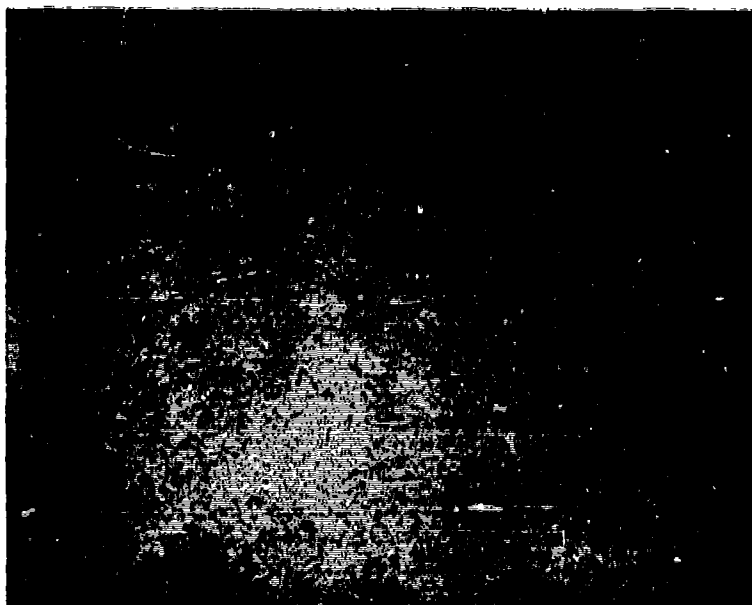
52μm

4X



26μm

4X



8 $\mu$ m

4X

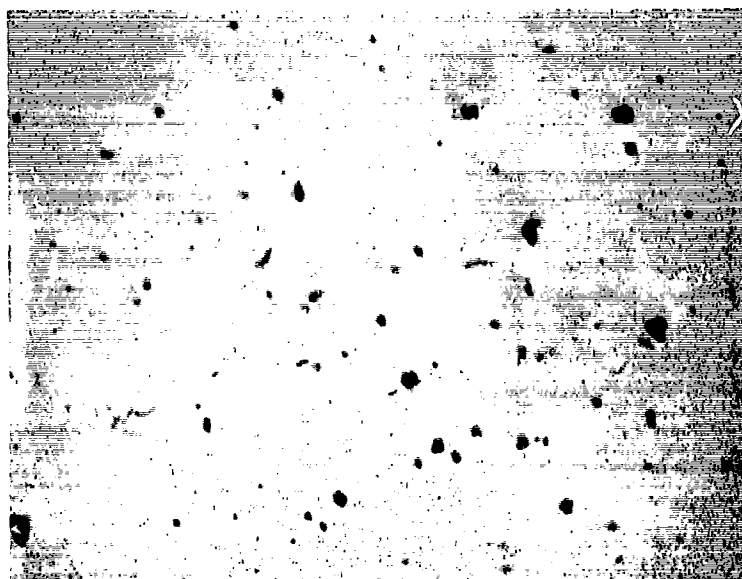


0.45 $\mu$ m

4X

**APPENDIX D-5**  
**8- $\mu$ m FILTRATION PHOTOMICROGRAPHS**  
**BRAVE SHIELD XV-AIRCRAFT**

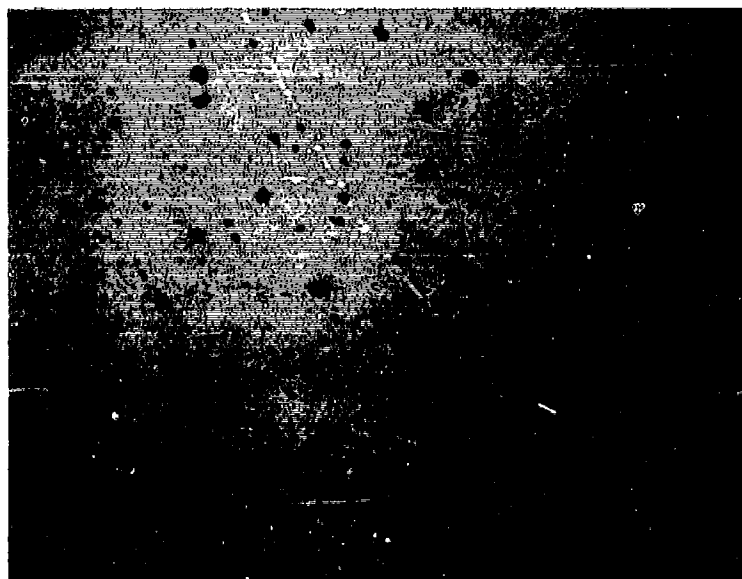
(See Table 10)



8μ

4X

SAMPLE 6642  
UH-1H, 70-16293 (LF)



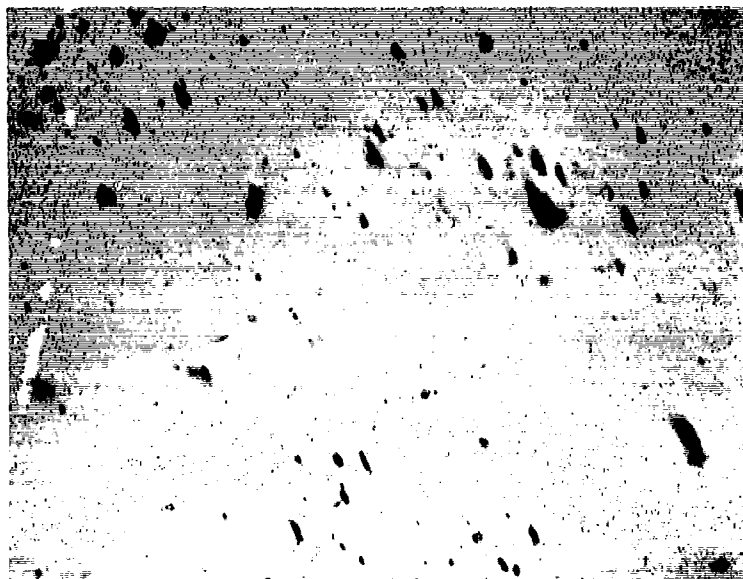
8μ

4X

SAMPLE 6643  
UH-1H, 70-16293 (RF)

D-27

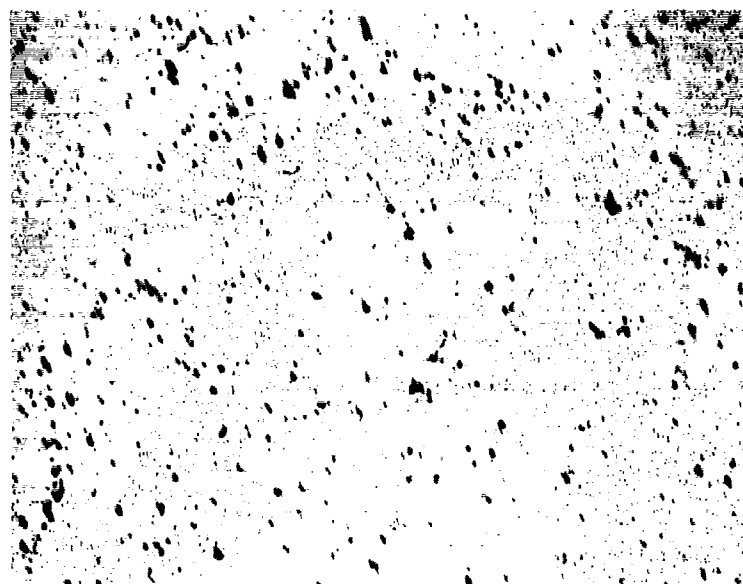
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8μ

4X

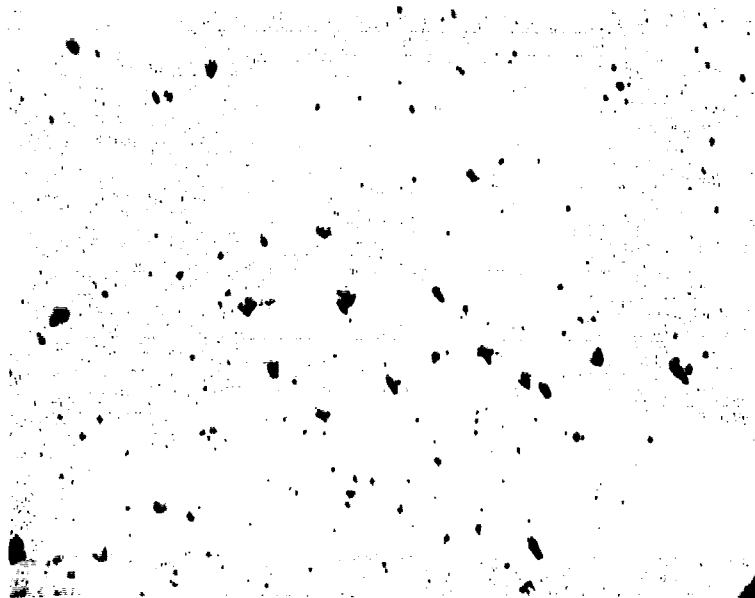
SAMPLE 6644  
UH-1H, 70-16472 (LF)



8μ

4X

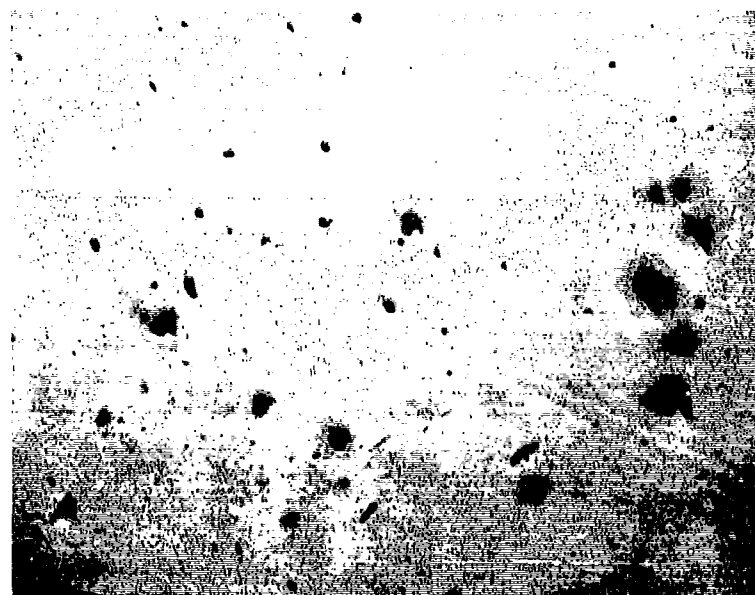
SAMPLE 6645  
UH-1H, 70-16472 (RF)



8μ

4X

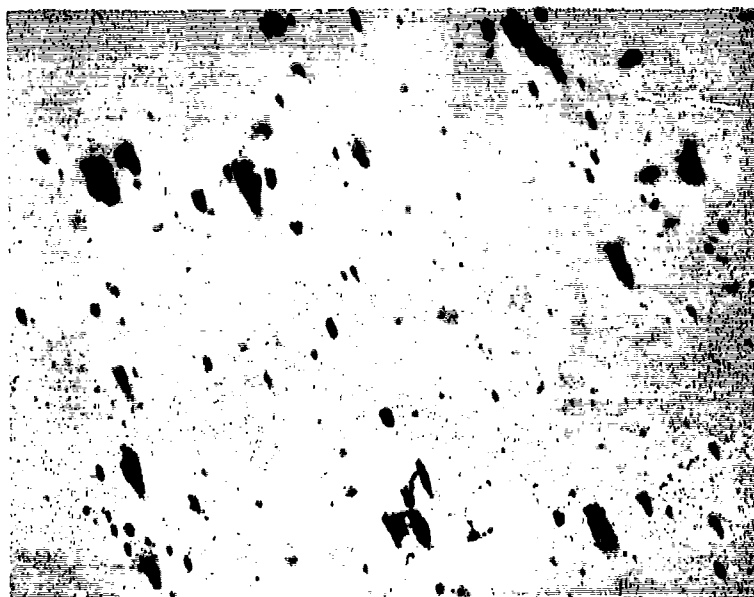
SAMPLE 6646  
UH-1H, 69-15314 (LF)



8μ

4X

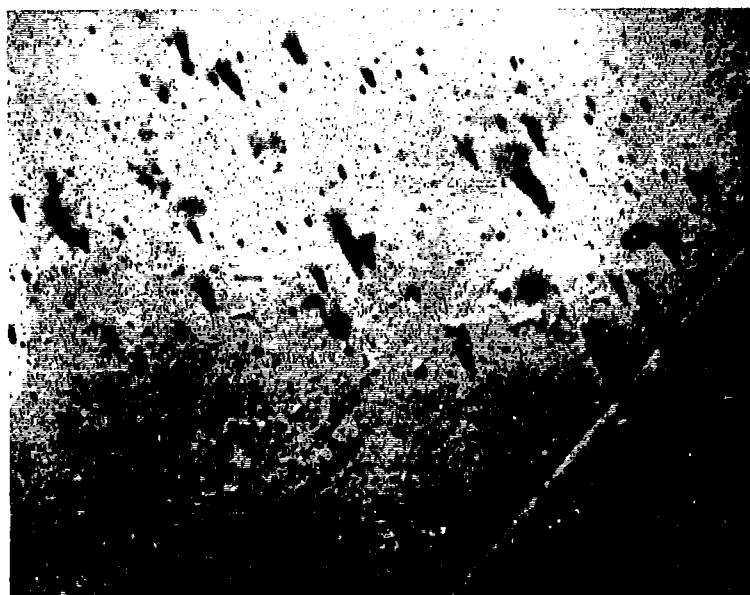
SAMPLE 6647  
UH-1H, 69-15314 (RF)



8 $\mu$

4X

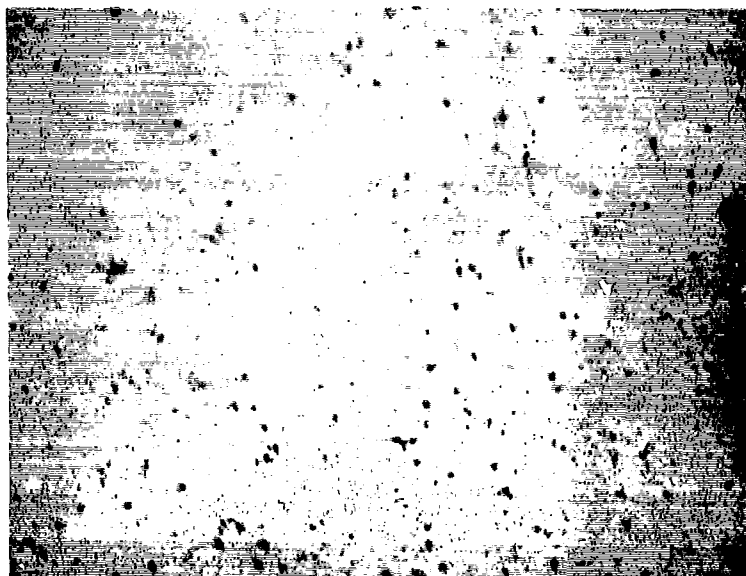
SAMPLE 6648  
UH-1H, 69-15853 (LF)



8 $\mu$

4X

SAMPLE 6649  
UH-1H, 69-15853 (RF)



8 $\mu$

4X

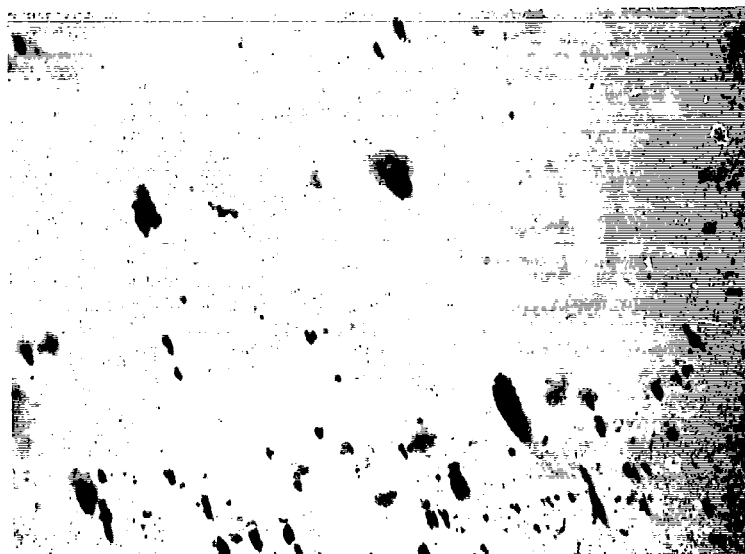
SAMPLE 6650  
UH-1H, 64-13536 (LF)



8 $\mu$

4X

SAMPLE 6651  
UH-1H, 64-13536 (RF)



8μ

4X

SAMPLE 6654  
UH-1H, 69-1600G (LF)



8μ

4X

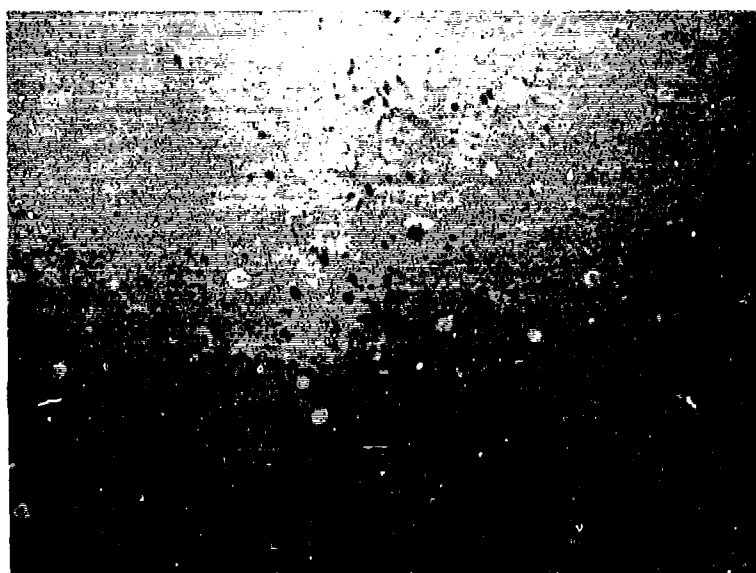
SAMPLE 6655  
UH-1H, 69-16000 (RF)



8 $\mu$

4X

SAMPLE 6656  
UH-1H, 69-15315 (LF)



8 $\mu$

4X

SAMPLE 6657  
UH-1H, 69-15315 (RF)



8μ

4X

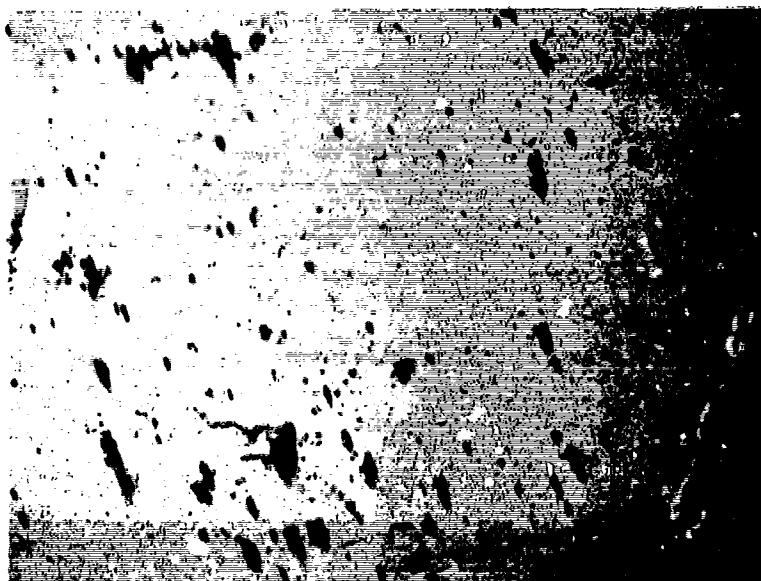
SAMPLE 6658  
UH-1H, 65-9749 (LF)



8μ

4X

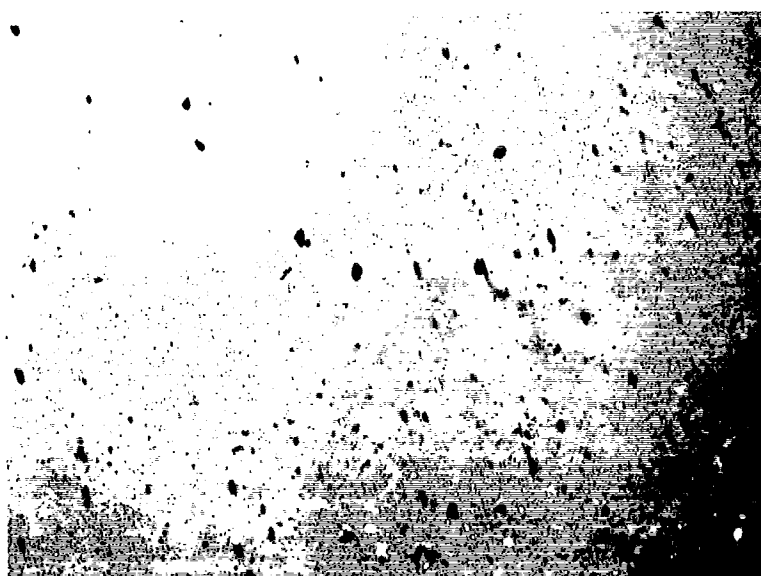
SAMPLE 6659  
UH-1H, 65-9749 (RF)



8μ

4X

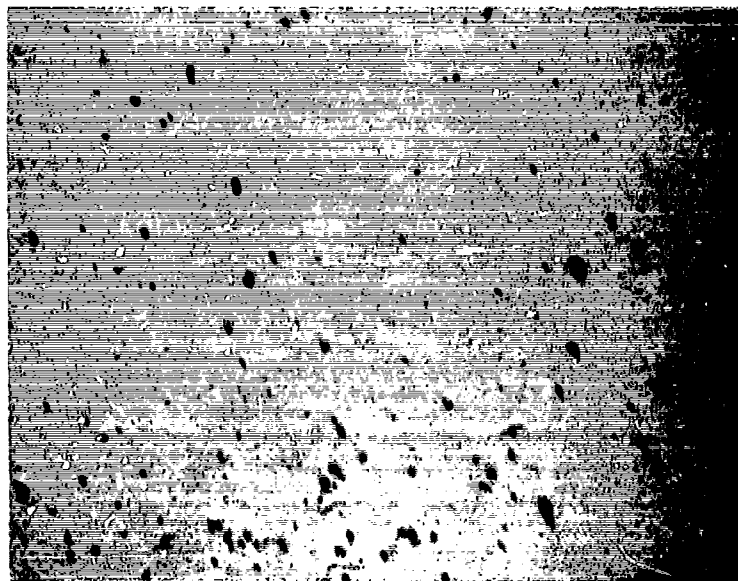
SAMPLE 6660  
UH-1H, 70-16470 (LF)



8μ

4X

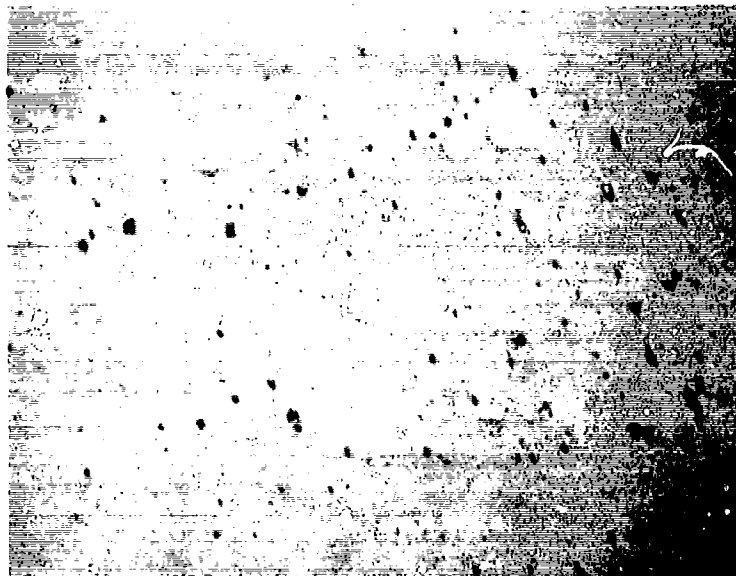
SAMPLE 6661  
UH-1H, 70-16470 (RF)



8μ

4X

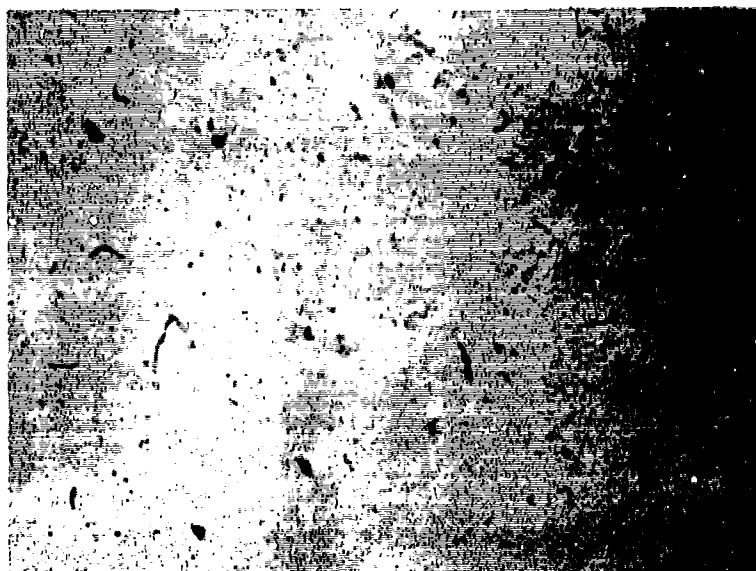
SAMPLE 6662  
UH-1H, 69-15318 (LF)



8μ

4X

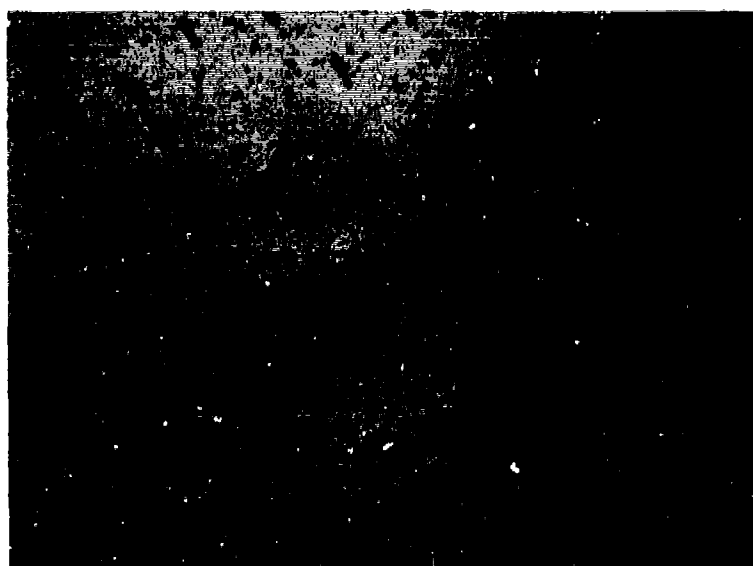
SAMPLE 6663  
UH-1H, 69-15318 (RF)



8μ

4X

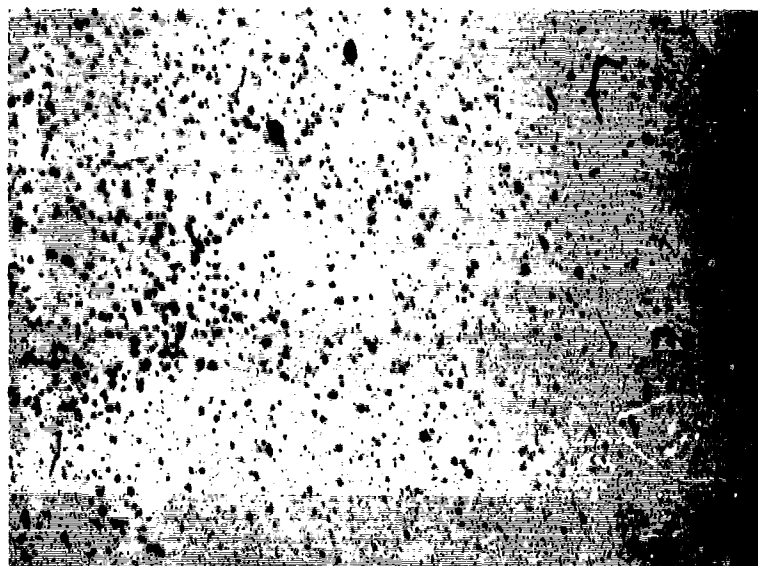
SAMPLE 6668  
CH-54A, 67-18430 (F)



8μ

4X

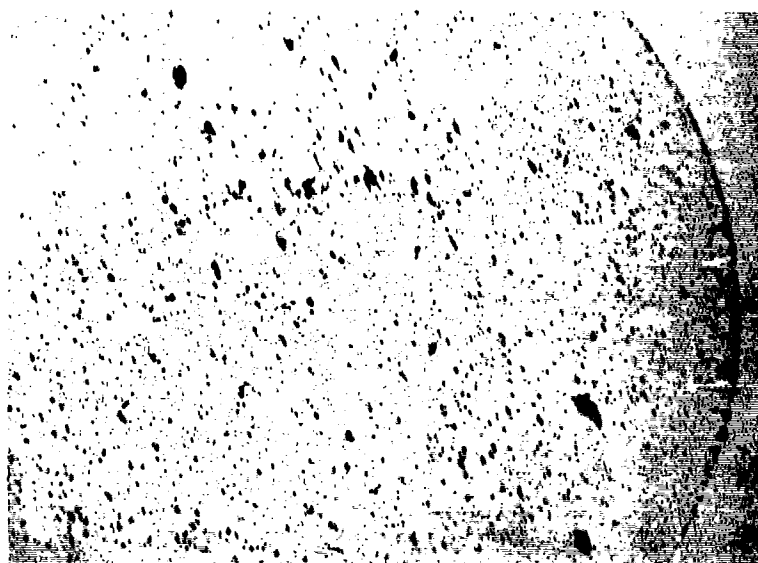
SAMPLE 6669  
CH-54A, 67-18430 (A)



8μ

4X

SAMPLE 6670  
CH-54A, 67-18420 (F)



8μ

4X

SAMPLE 6671  
CH-54A, 67-18420 (A)



8 $\mu$

4X

SAMPLE 6672  
CH-54A, 67-18424 (F)



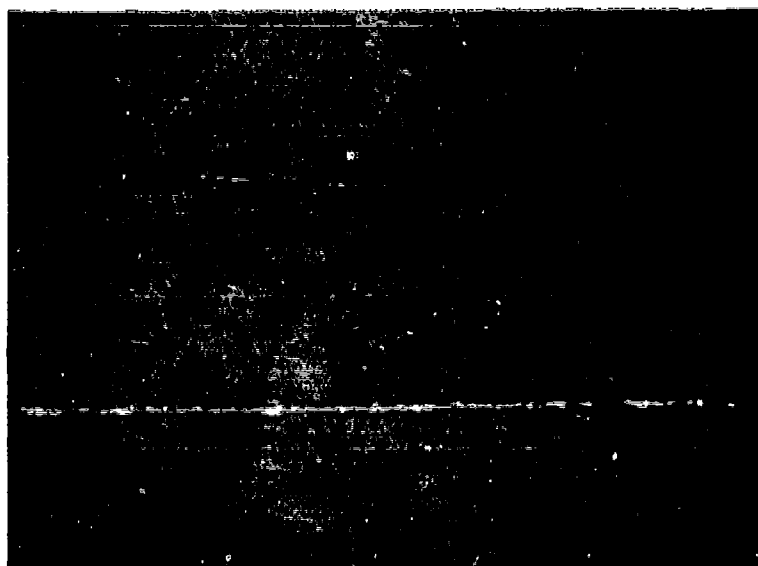
8 $\mu$

4X

SAMPLE 6673  
CH-54A, 67-18424 (A)

**APPENDIX D-6**  
**8- $\mu$ m FILTRATION PHOTOMICROGRAPHS**  
**BRAVE SHIELD XV--TANK TRUCKS**

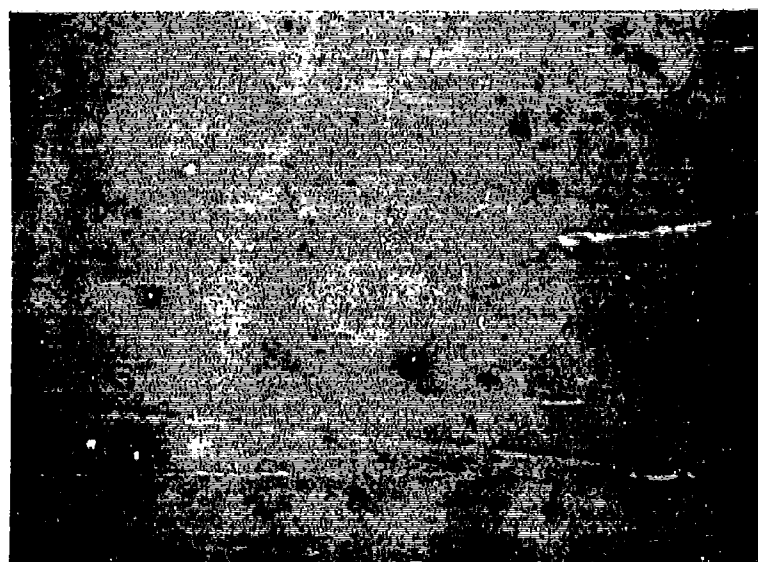
(See Table 10)



8 $\mu$

4X

SAMPLE 6652  
Tank Truck No. 47  
(Unfiltered)



8 $\mu$

4X

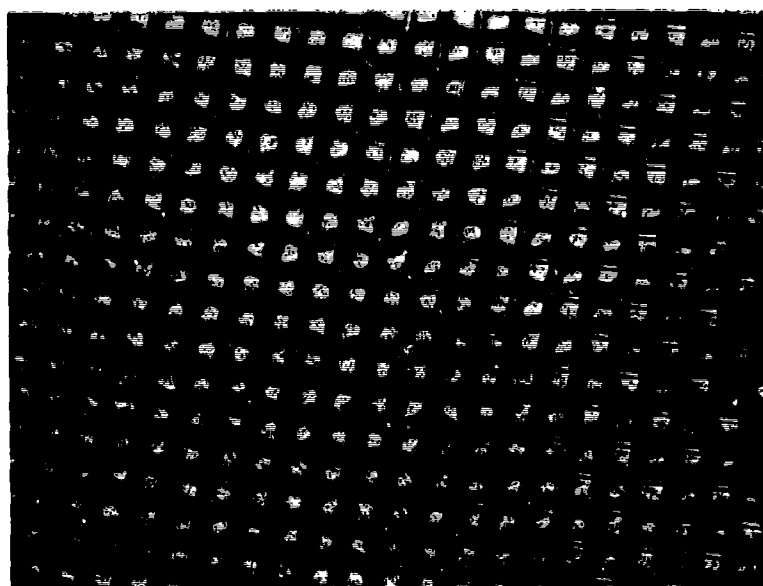
SAMPLE 6653  
Tank Truck No. 47  
(After Filter)

D-43

**APPENDIX E**  
**FILTRATION PHOTOMICROGRAPHS FOR OPERATION**  
**GALLANT CREW**

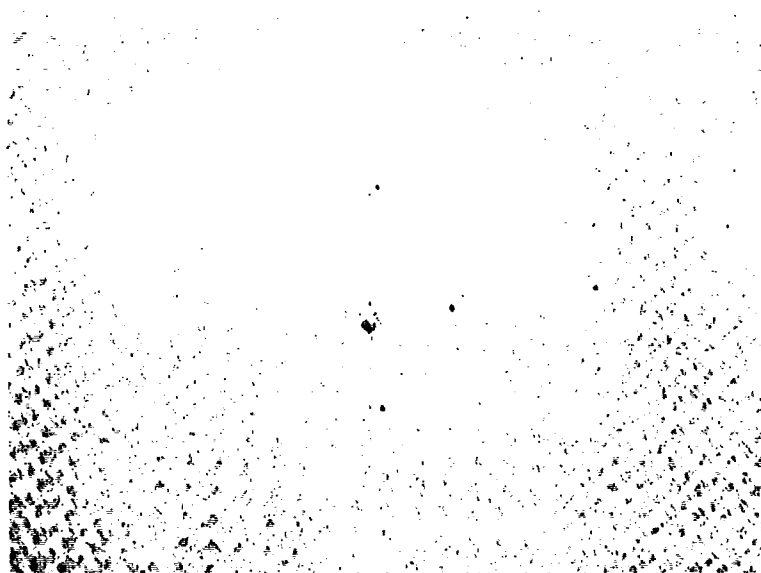
**APPENDIX E-1  
CASCADE FILTRATION PHOTOMICROGRAPHS  
SAMPLE NO. 6895**

**CH-47C, 70-15008 Left Front Drain  
(See Table 13)**



1000 $\mu$ m

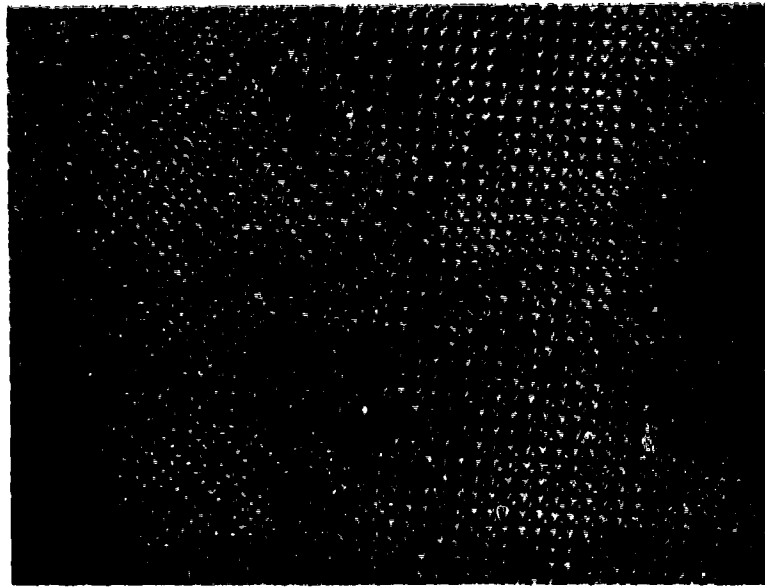
4X



500 $\mu$ m

4X

1E-5



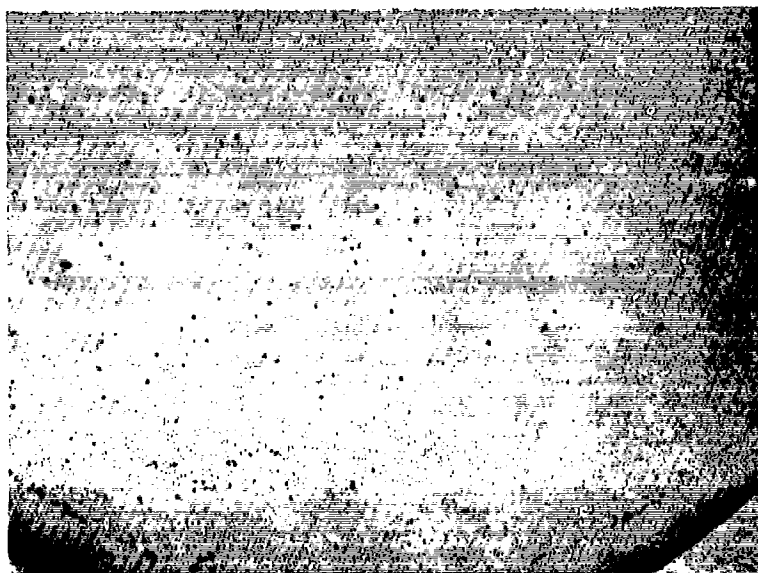
300 $\mu$ m

4X



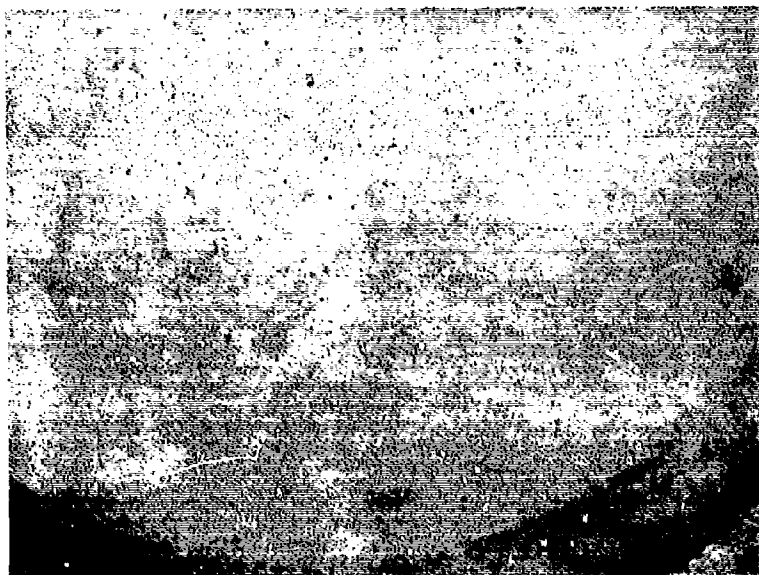
100 $\mu$ m

4X



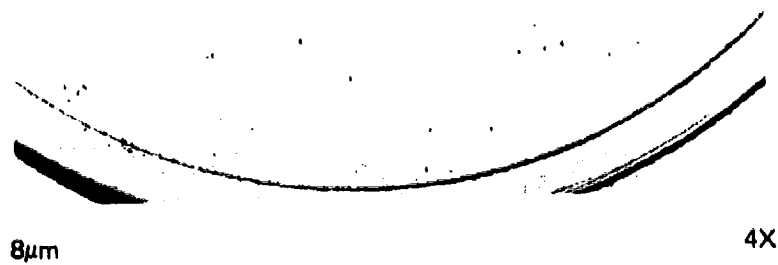
52μm

4X



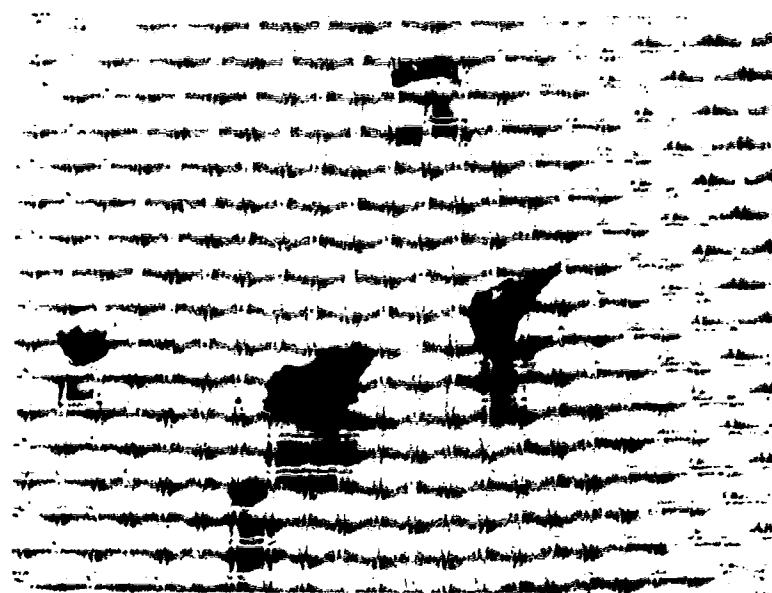
26μm

4X



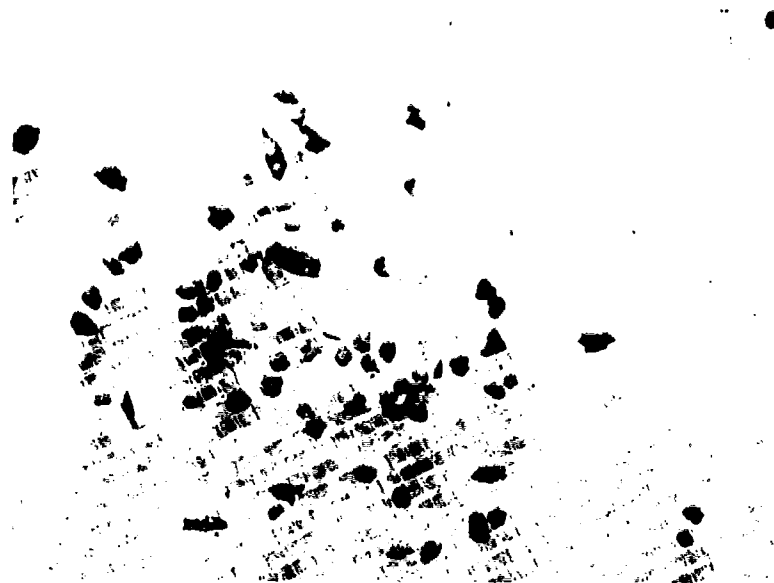
**APPENDIX E-2**  
**CASCADE FILTRATION PHOTOMICROGRAPHS**  
**SAMPLE NO. 6914**

**CH-47C, 70-15019 Right Front Drain**  
**(See Table 13)**



1000 $\mu$ m

4X

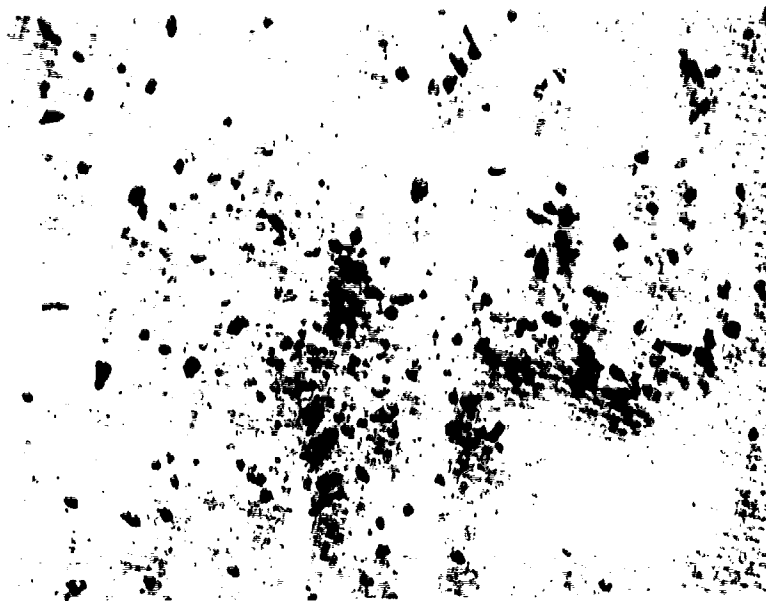


500 $\mu$ m

4X

E-11

PRECEDING PAGE BLANK-NOT FILMED



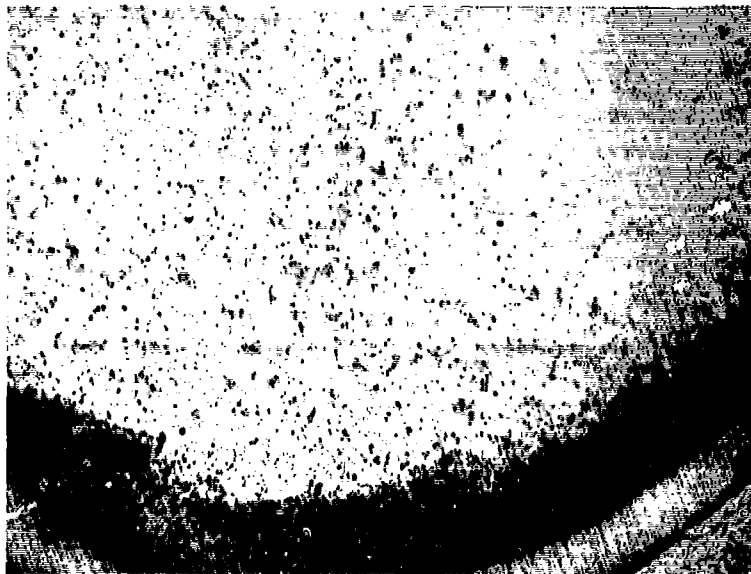
300 $\mu$ m

4X



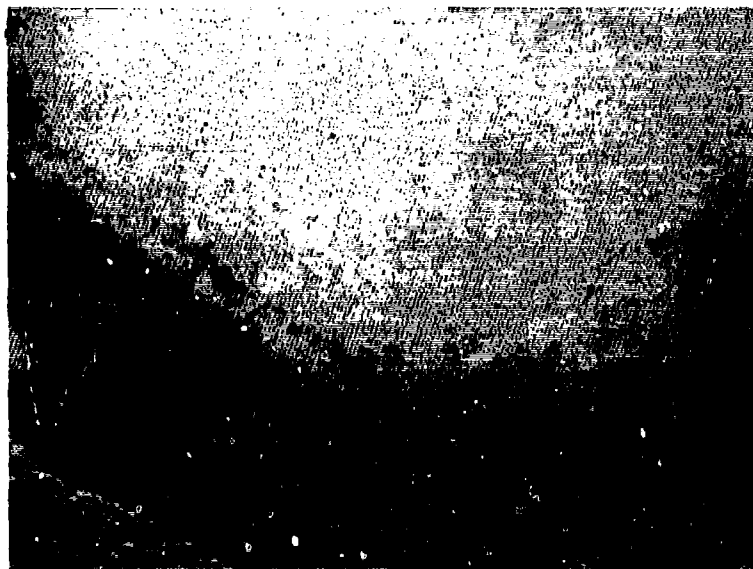
100 $\mu$ m

4X



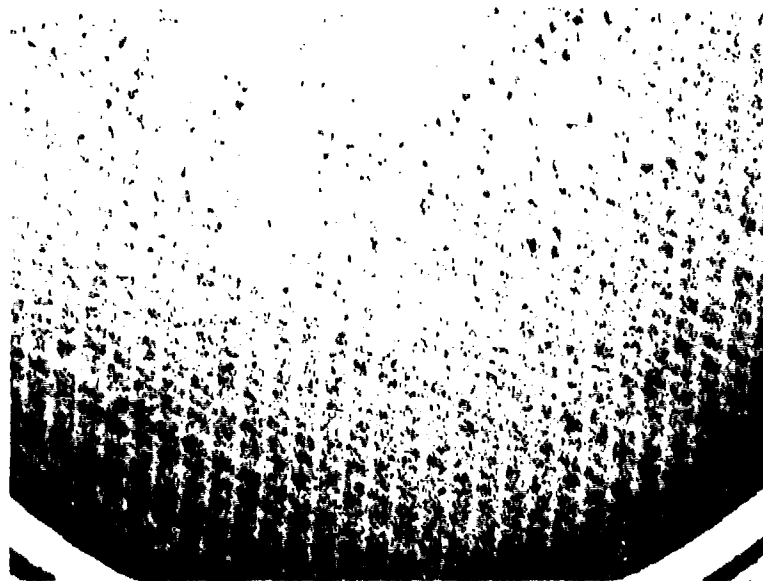
52 $\mu$ m

4X



26 $\mu$ m

4X

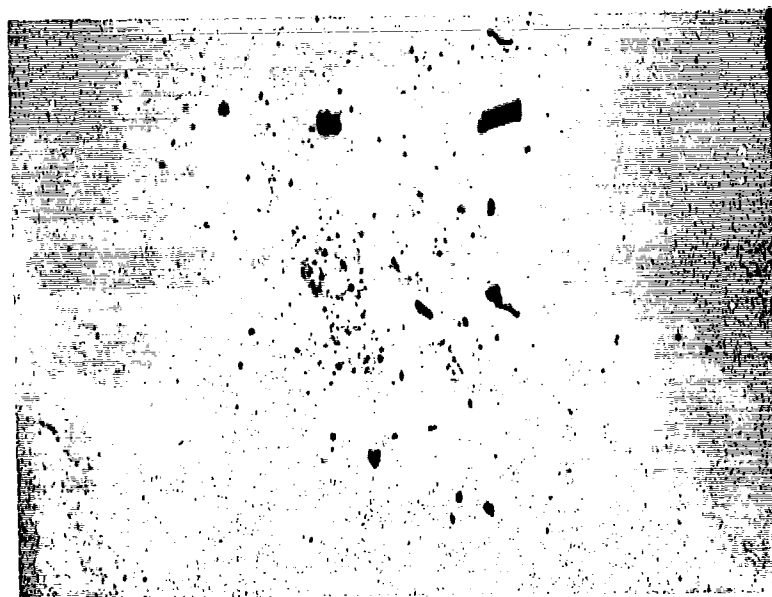


8μ

4X

**APPENDIX E-3**  
**8- $\mu$ m FILTRATION PHOTOMICROGRAPHS**  
**GALLANT CREW-AIRCRAFT**

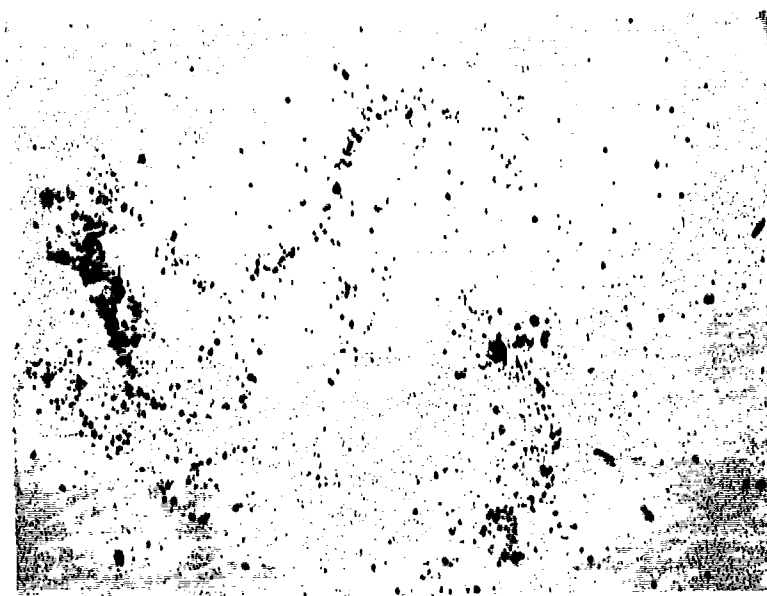
(See Table 12)



8μ

4X

SAMPLE 6890  
UH-1H, 71-20223 (LF)

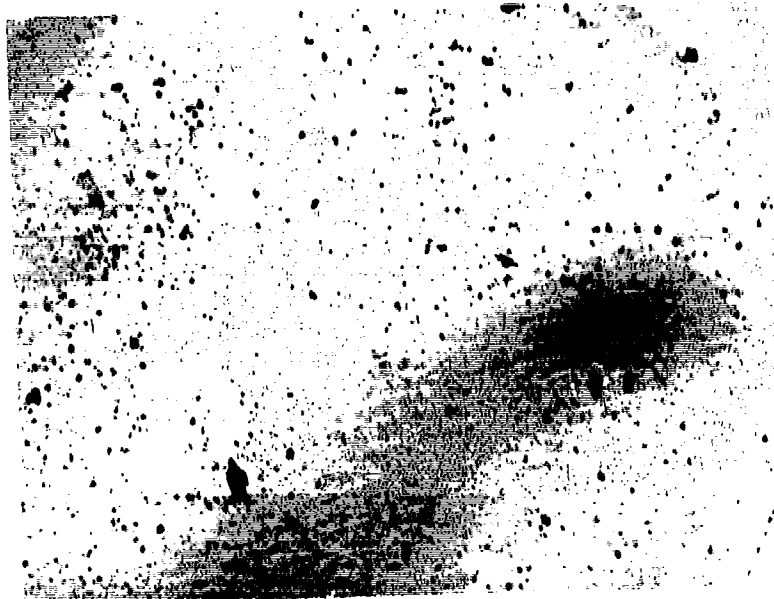


8μ

4X

SAMPLE 6891  
UH-1H, 71-20223 (RF)

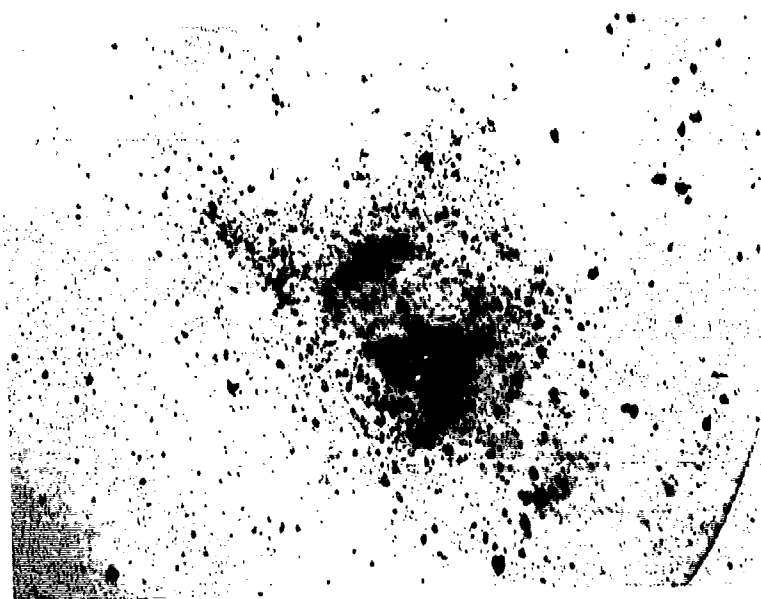
E-17



8 $\mu$

4X

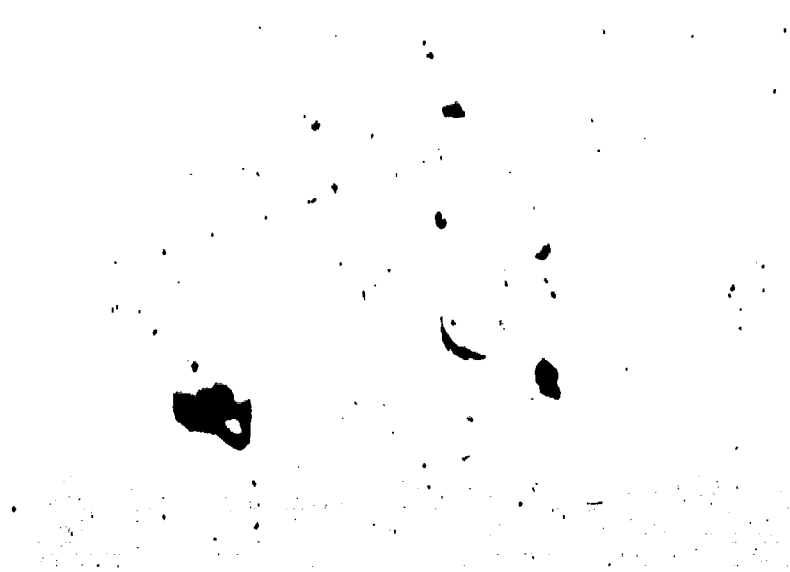
SAMPLE 6897  
CH-47C, 70-15027 (LF)



8 $\mu$

4X

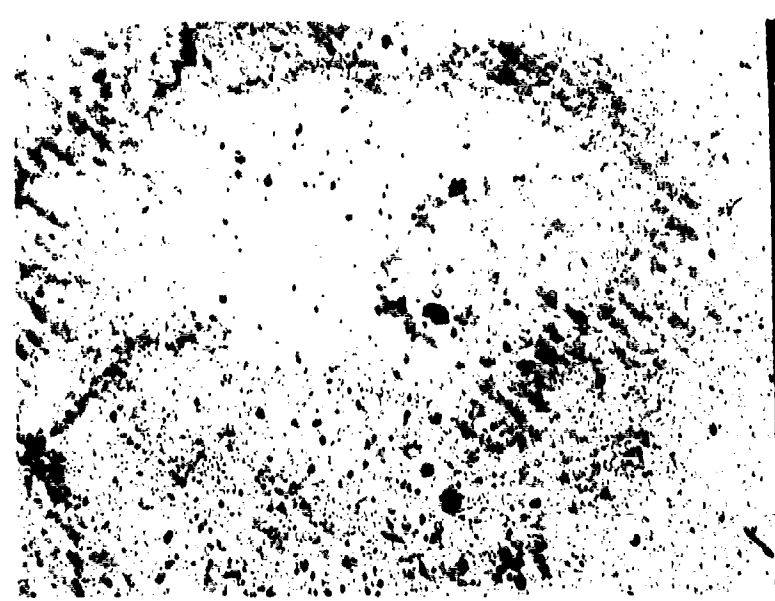
SAMPLE 6898  
CH-47C, 70-15027 (RF)



8μ

4X

SAMPLE 6915  
CH-47C, 70-15019 (RR)



8μ

4X

SAMPLE 6916  
CH-47C, 70-15019 (LF)



8μ

4X

SAMPLE 6917  
CH-47C, 70-15019 (LR)



8μ

4X

SAMPLE 6885  
OH-58A, 71-20554

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