BOEING AIRPLANE COMPANY

SEATTLE 14, WASHINGTON

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MODEL B-52 CONTRACT NO.

TITLE DECONTAMINATION PROGRAM

ISSUE NO. TO DATE

SHORT TITLE
(For Classified Data)

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THE AIR CONTAMINATION PROBLEM

The observations of the flight crews constitute the first evidence of the existence of the problem. They have repeatedly reported presence of smoke and odor in the occupied compartments of the airplane.

The XB-52 airplane flew a series of flights between October 19, 1953 and November 24, 1953 with the J-57-P-1 engines installed. The airplane had also, installed filters in accordance with MCR 66 such that all cabin conditioning air entering the forward compartment was filtered. The flight crews were requested to make a series of observations each flight in order to obtain qualitative data regarding the cabin contamination picture.

Several items should be noted:

1. The odor involved permeates the nasal passages of the men, their clothing, oxygen masks, cabin lining, etc., and lingers for a substantial period of time after exposure occurs.

2. The possible toxic effect of the contamination is still unknown. As a result, except for specific instances, the crew used 100% oxygen throughout all flights and made their observations by removing their masks for a moment or two.

3. The installation of the MCR 66 filter units undoubtedly had an effect on the degree of contamination observed. It is probable that this effect would be more obvious with smoke than with odor.

4. Just prior to Flight 73, the air conditioning system in the airplane was revised such as to obtain cabin heating air from the discharge of the first heat exchanger pass rather than from the upstream side of the heat exchanger. A restrictor was also installed in the line to reduce the flow during high engine power operation.

Figure 13 shows a tabulation of pertinent remarks and observations of the flight crews during this period of testing. The following resume' could be made:

1. The appearance of contamination with the J-57-P-1 engine is much more consistent that with the J-57-P-3 engine. On this series of flights, odor and/or smoke were observed on all flights; while earlier testing with the J-57-P-3 engine had a substantial number of flights with no contamination reported at all.

2. The contamination level appears to be lower with the J-57-P-1 engine than with the J-75-P3 engine. This, however, might be the effect of the MCR 66 filters.

3. Smoke or haze is reported on only a few flights with the J-57-P-1 while it was reportedly frequent with the J-57-P-3 engine. This could definitely be an effect of the MCR 66 filters.

4. From flight 73 and on, the contamination level was definitely reduced from that experienced during the earlier flights. This is probably the result of lower heating air temperature and flow with an accompanying increase in effectiveness of the MCR 66 filters.

5. In most instances, the worst contamination was noted immediately after the air conditioning system was first turned "on". The contamination then reduced to a lower level and appeared to remain there for all or most of the flight.

6. Obvious increases in the contamination level were noted during changes in engine power conditions but each time the level returned, within a few minutes, to approximately the earlier stable level.

7. The colder the temperature of the supply air to the compartment the more tolerable was the contamination level.

The inflight observations tabulated in Figure 13 are those of six men, only two to four of whom were in the airplane at one time, and only one of whom was in the airplane on all flights and reflect the concensus of opinion of the crew for each flight.

Flight Test Sampling

Figure 14 shows the compilation of carbonyl content data taken during flight in the XB-52 with the J57-P1 engines installed.

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FLIGHT NO.	ALT. RANGE SEA LEVEL TO	OXYGEN				CONTAMINATION OBSERVED						REMARKS
						SMOKE			ODOR			
		YES	NO	SETTING	CABIN AIR SUPPLY TEMP.	YES	NO	TYPE	YES	NO	DESCRIBE	
64	45,000	✓		100%	COOL		✓		✓		MILD	ODOR NOTED ONLY WHEN MASK OFF
65	18,000	✓		100%	COOL		✓		✓		STRONGEST OBSERVED YET	DUCT FAILURE EARLY IN FLIGHT PREVENTED LONGER EVALUATION
66	35,000	✓		100%	COOL TO WARM	✓		LIGHT	✓			HAZE AND ODOR WITH DEMAND FOR HEATING BY MANUAL CONTROL
67	45,000	✓ [1]		100%	FULL COLD		✓		✓		ONLY DURING TWO ATTEMPTS AT HEATING	VERY LITTLE CONTAMINATION ON THIS FLIGHT. [1] OBSERVERS MASK OFF 70% OF FLIGHT
68	MAX. ALTITUDE	✓		100%	WARM		✓		✓		WEAK	PRESSURE HELMET FACEPIECE REMOVED ONLY DURING CLIMB TO 35,000 FT.
69	7,000		✓		COOL TO FULL HOT		✓		✓		MODERATE TO LIGHT	DECREASED DURING FIRST FIVE MINUTES
70	45,000	✓		100%	COLD	✓		LIGHT	✓		MILD TO STRONG	SMARTING OF EYES REPORTED
71	45,000	✓		100%	COOL		✓		✓		STRONG	ODOR EXCESSIVE THROUGHOUT FLIGHT
72	45,000	✓		100%	COOL TO WARM	✓ [2]		MEDIUM	✓		MILD	THROUGHOUT FLIGHT [2] NOTED BRIEFLY ONCE IN FLIGHT
73	35,000	✓		NORMAL & 100%	COOL		✓		✓		MILD AT START THEN DIED AWAY	ODOR RETURNED INTERMITTENLY DURING ENGINE POWER CHANGES
74	0-10,000		✓		COOL TO HOT		✓		✓		MILD AT START DECREASED TO VERY LIGHT	
76	45,000	✓		100%	COOL	✓ [3]			✓		MILD	[3] ON GROUND AFTER LANDING, HAZE AND STRONG ODOR WERE OBSERVED
77	MAX.	✓		100%	COOL		✓		✓		MILD	PRESSURE SUIT WORN THROUGHOUT FLIGHT
79	45,000	✓		100%	WARM		✓		✓		WEAK	CONTINOUS ODOR NOT AFFECTED BY HEATING
80	45,000	✓		100%	COLD		✓		✓		WEAK	

PILOT'S OBSERVATIONS OF CABIN AIR CONTAMINATION
XB-52 AIRPLANE WITH J57-P-IW ENGINE AND MCR 66 FILTERS

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FIG 13

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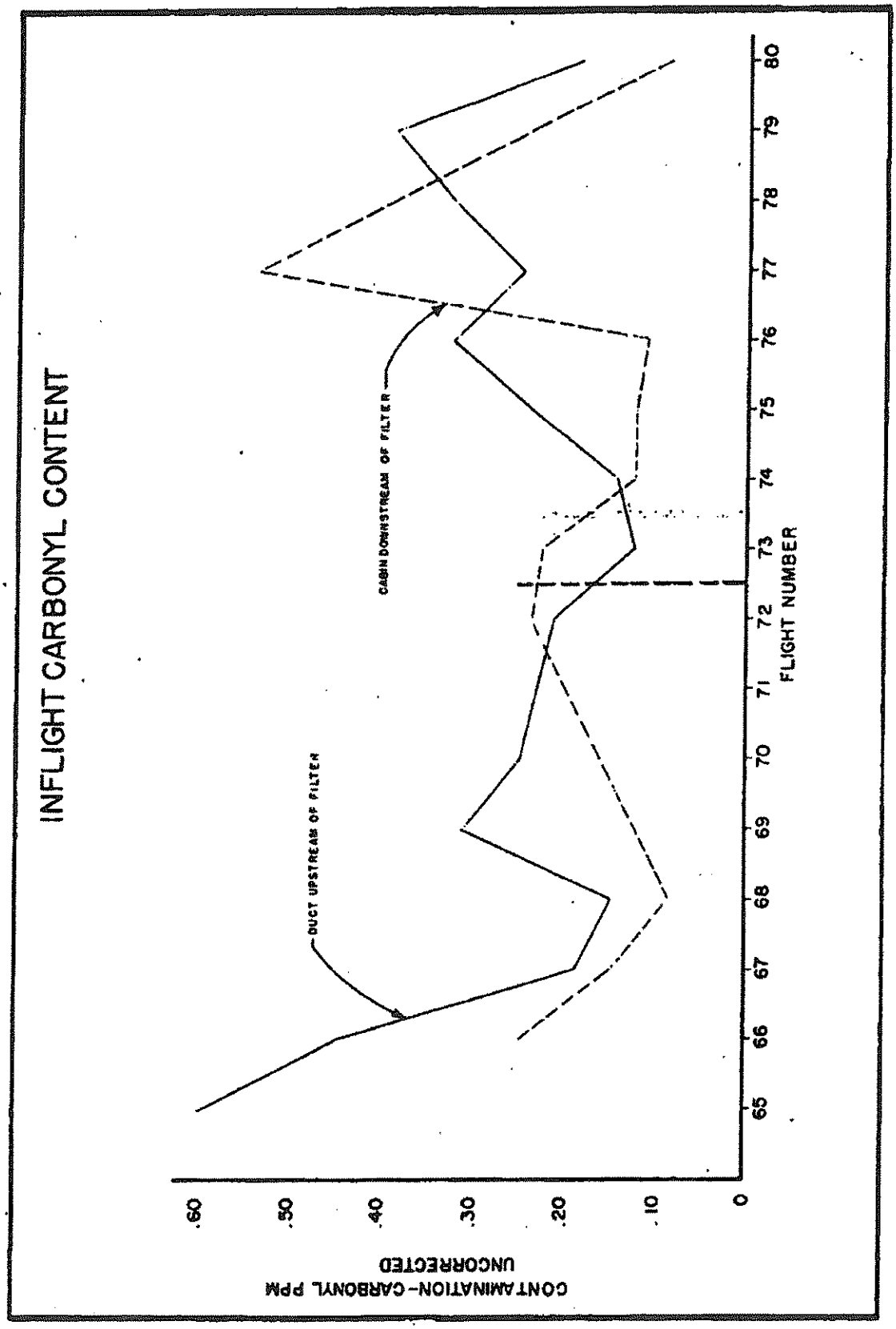

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FIGURE NO. 14

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THE FILTER DEVELOPMENT PROGRAM

To avoid confusion, it is probably advisable to define the generic term "Filter". Within the scope of this program, a filter is considered as any decontaminating unit which will purify engine bleed air to the point where it is suitable for cabin air conditioning.

Several considerations are important in determining the best attack in developing a filter. First, the conditions under which it must operate. In the B-52 three different locations are potentially available for filter location. These locations differ in filter environment with respect to Pressure, Temperature, Volume, Flow and effect on system design. Figure 15 has been prepared to assist in demonstrating these differences and their influence on selection of suitable filter systems. The upstream location with its maximum possible temperature of 720°F presents numerous problems rendering it unusable for any type of filter other than high temperature particulate and catalytic filters. However, this location demands minimum system change, is free of icing problems, has relatively low volume flows and is least sensitive to pressure drop. It is therefore very worthy of study.

The midstream location between the ram and blower heat exchanger with its relatively short temperature range and freedom from icing presents possibilities for a larger number of filter types but would require some system redesign. It is also worthy of study.

The downstream location has several serious problems with very few advantages. The temperature range is greater than midstream, icing becomes a serious problem without extensive redesign or maintenance of 35°F minimum control, volume flows are maximum and pressure drop is most critical. With extensive redesign some of the filter types could be applicable.

The second major consideration in planning of a filter concerns the physical and chemical nature of the contaminants to be removed. From a study of the oil used and its oxidation, it is considered that all of the contaminants will exist in one of three possible physical states.

1. Particulate matter - discrete particles suspended in air (Aerosols). This would include:
   a. Aerosols of unchanged oil.
   b. Aerosols of decomposition products (high molecular weight) and
   c. Aerosols of polymerized low molecular weight, oxidiation products.
2. Condensable vapors - Decomposition products which are volatile at the existing temperature. These products can become aerosols at lower temperatures where a change in state will occur.
3. Noncondensable vapors - Carbon monoxide only.

	POSSIBLE FILTER LOCATION					
	UPSTREAM		MIDSTREAM		DOWNSTREAM	
CONDITIONS	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
PRESSURE	15 PSIA	200 PSIA	15 PSIA	200 PSIA	9 PSIA	15 PSIA
TEMPERATURE	100 °F	720 °F	-20 °F	350 °F (GRD) 200 °F (FLT)	-100 °F	350 °F
FLOW	0	200 CFM	0	150 CFM	0	600 CFM
FILTER TYPE						
PARTICULATE	POSSIBLE BUT NOT TESTED AT MAX. TEMPERATURE		POSSIBLE		POSSIBLE ABOVE 32 °F	
ACTIVATED CARBON	IMPOSSIBLE - MAX. TEMP. ABOVE GLOW TEMP. OF MATERIAL.		POSSIBLE - BUT ONLY GOOD AT LOWER TEMPERATURES		POSSIBLE	
IMPREGNATED CARBON	IMPOSSIBLE - MAX. TEMP. ABOVE GLOW TEMP. OF MATERIAL		POSSIBLE WITHIN TEMPERATURE LIMITS		POSSIBLE	
CATALYTIC	POSSIBLE		POSSIBLE AT UPPER TEMPERATURE LIMIT		IMPOSSIBLE	
CONDENSATION PARTICULATE FILTER	IMPOSSIBLE		IMPOSSIBLE		POSSIBLE - CONTROLLED BY VAPOR PRESSURE OF CONTAMINATE AT REMOVAL TEMPERATURE	
CONDENSATION ELECTRO STATIC	IMPOSSIBLE		IMPOSSIBLE		POSSIBLE - CONTROLLED BY VAPOR PRESSURE OF CONTAMINATE AT REMOVAL TEMPERATURE	
LIQUID SCRUBBER	IMPOSSIBLE		POSSIBLE		POSSIBLE AT TEMP ABOVE 50 °F.	

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AIR CONDITIONING SYSTEM
POSSIBLE FILTER LOCATION CHART

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FIG 15

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The chemical nature of the contaminants will be discussed in detail later. It is sufficient here to indicate that the materials in question are without doubt numerous and complex and vary from essentially inert and stable compounds to materials of highly reactive labile nature. One specific material tri-cresyl phosphate contained within the oil is recognized as a progenitor of materials capable of deactivating many catalytic type filters rapidly.

Returning now to Figure 15 we find that, except for the "coffin corner" conditions of descent from high altitude at low power, only high molecular weight materials having a very low vapor pressure could exist as particulate matter in the upstream position. Here then particulate filters or electrostatic precipitators which will only remove particulate matter fall far short of the described goal of a filter. Physical absorbtion media such as activated carbon would also be eminently unsuccessful due to the fact that the temperature can be sufficiently high to cause the carbon to burn and under nearly all conditions the retentivity would be close to zero. This then leaves only one real practical solution, catalytic filter beds which will cause the organic compounds to be oxidized to carbon dioxide and water.

Careful selection of catalysts must be made to eliminate the problem of deactivation and to insure complete combustion throughout the entire temperature range from 300°F to 720°F. The use of a particulate filter upstream of the catalyst bed appears desirable to prevent coating of the catalyst with particulate matter particularly at low temperatures. Promising results are being obtained in this study.

At the midstream location many of the materials which would have been volatile at the upstream location should change state and become particulate matter, here, than a particulate filter becomes much more valuable. However, at the higher temperatures possible the contaminant vapor pressure may be expected to be high. Under these conditions physical absorbants would also be expected to be relatively inefficient. However, carbons impregnated with certain metal compounds and processed with heat become quite efficient as catalysts in this temperature area. Suchcarbons are called Whettlerites. Their efficiencies could be expected to drop at the maximum temperatures. Therefore a composite filter consisting of a high capacity particulate filter, Whettlerized carbon and activated carbon could be predicted as having an excellent opportunity of success. Certain of our data verifies this.

Another possibility in the midstream location is a liquid scrubber similar to those used industrially. This has not been explored yet.

As previously mentioned the downstream location can with redesign be adapted to numerous filter types. Water removal to prevent filter icing appears to be a major problem. Solution to this would allow a composite filter such as that described for the midstream location to be used effectively. A particulate filter or an electrostatic percipitator alone would be effective only if the air temp. were reduced to approximately 0°F prior to filtering. Maintaining a 35°F to 40°F control can prevent icing and would probably provide a

satisfactory temperature range for use with a particulate filter and activated carbon. This would of course demand increased cooling requirements for heat rejection and some post heating system for heating.

In this location also, liquid scrubbing is possible but has not been explored.

Since we have now defined briefly the principal considerations involved in approaching the problem of filter development, we should direct our attention to sources of knowledge and materials available for arriving at a suitable fix. Several Governmental agencies have offered immeasurable assistance and their extreme cooperation is deeply appreciated. With the assistance of Col. Silk we have related our problem to the Protective Division of Army Chemical Corps at Edgewood Arsenal. This appeared to be a logical starting point because the removal of low concentrations of toxic materials from the atmosphere is the principle concern of this group. Mr. Saul Hormatz the Chief of the Protective Division offered his complete cooperation and furnished us with a high capacity unit consisting of a particulate filter and activated carbon. He recognized that the high temperature extremes at either midstream or downstream positions would limit the usefulness of such a unit. However, since little data was available concerning the specific chemical nature of the contaminates, he believed that the data received from testing this unit would prove valuable in designing a filter effective throughout the range. The tests on the first unit have been completed and the data is being transmitted. It is anticipated that an improved Army Chemical Corps. filter will be available for test in the near future.

Because of the favorable anticipated characteristics of an upstream catalytic unit a number of possible sources were investigated. These included the W.B. Conner Co., the Oxy-Catalyst Co., the Catalytic Combustion Co., and the Catalyst Research Co. Because the problem of deactivation soon provided itself to be real, it was decided that an organization with a very broad background in catalyst research and with no shelf item to sell should be contracted for development. After evaluation of a number of institutions it was decided to contract with the Synthetic Fuels Laboratory of the United States Bureau of Mines. This contract had in addition to the catalyst development program, a separate program for assistance in sampling and analysis. The personnel assigned to this program by the Bureau of Mines have demonstrated that the choice was wisely made. Their ingenuity and vigor have already produced highly significant results. The future of the catalytic filter program appears very bright. Recently the Donaldson Co. submitted a small catalytic test filter. This has not as yet been evaluated.

High temperature particulate filters suitable for upstream usage have been obtained from Glass Fibers Inc. and the Cambridge Corp. for use on the engine test facility. For midstream filteration, samples of silver-copper Whettlerized carbon have been received from the Barnaby-Cheney Co. High order efficiency has been demonstrated on the laboratory smoke simulator throughout the entire midstream temperature range. The importance of these significant data will be discussed in more detail later.

An attempt is being made to obtain a high efficiency, low pressure drop particulate filter of small size from the Research Division of the Goodyear Tire and Rubber Company. This filter is in essence a self charging electrostatic filter based on the change developed by friction of particulate matter with loosely retained ribbons or filaments of plastics having a low leakage rate. Commercial filters of this type utilize polyethylene ribbon which does not possess adequate thermal properties for any of the possible locations. However, other plastics are available and this approach is being investigated further.

Trion Inc. and the manufacturers of Cottrell precipitators have been consulted concerning Electrostatic precipitators. They have indicated the problems and limitations of this type of air cleaner. Neither has yet presented a proposal. This method will be evaluated with the test unit supplied by the equipment laboratory of WADC.

Numerous other companies, agencies and individuals have been requested to submit proposals. They have not taken adequate positive action to merit spending time in discussion.

In order to reproduce as nearly as possible the conditions experienced in the airplane, it was decided that an engine should be set up with suitable air sampling and test equipment to study the contamination problem. This test facility provides a means of reproducing the contaminants we are dealing with and also gives us a chance to test full scale decontamination devices.

Figure 16 is a schematic diagram of this test facility. Air is brought in from a J-57-P-3 engine (2nd spool bleed) and goes into our test enclosure, where, in addition to airflow control valves, sampling taps are provided for sampling air as it comes from the engine. Bleed air then goes through a heat exchanger where it can be cooled to varying degrees and then through our filter or decontamination test devices or specimens. Sampling taps are provided upstream and downstream of the filter test specimen. Air is then discharged to the atmosphere.

It should be noted that an "exposure" room is provided downstream of the test specimen location and means is provided for discharging filtered air into this room. We use this room to run "sniff" checks on our test filters. We have also thought that the Air Force may desire to run animal tests at some later date on our filtered air. This could be accomplished in the "exposure" room.

In order to expedite sampling times and to obtain controlled conditions means have been provided for injecting oil spray into the engine inlet.

The lines shown on the chart as position "S" are some additional sampling lines which have been run to the sampling area from the engine high spool diffuser. These taps are used to study contamination stratification within the engine. (See Photographs A58635, A58637, A60019, A60021, 135777, 136879, 136880, 136882, 137971 and 137972).

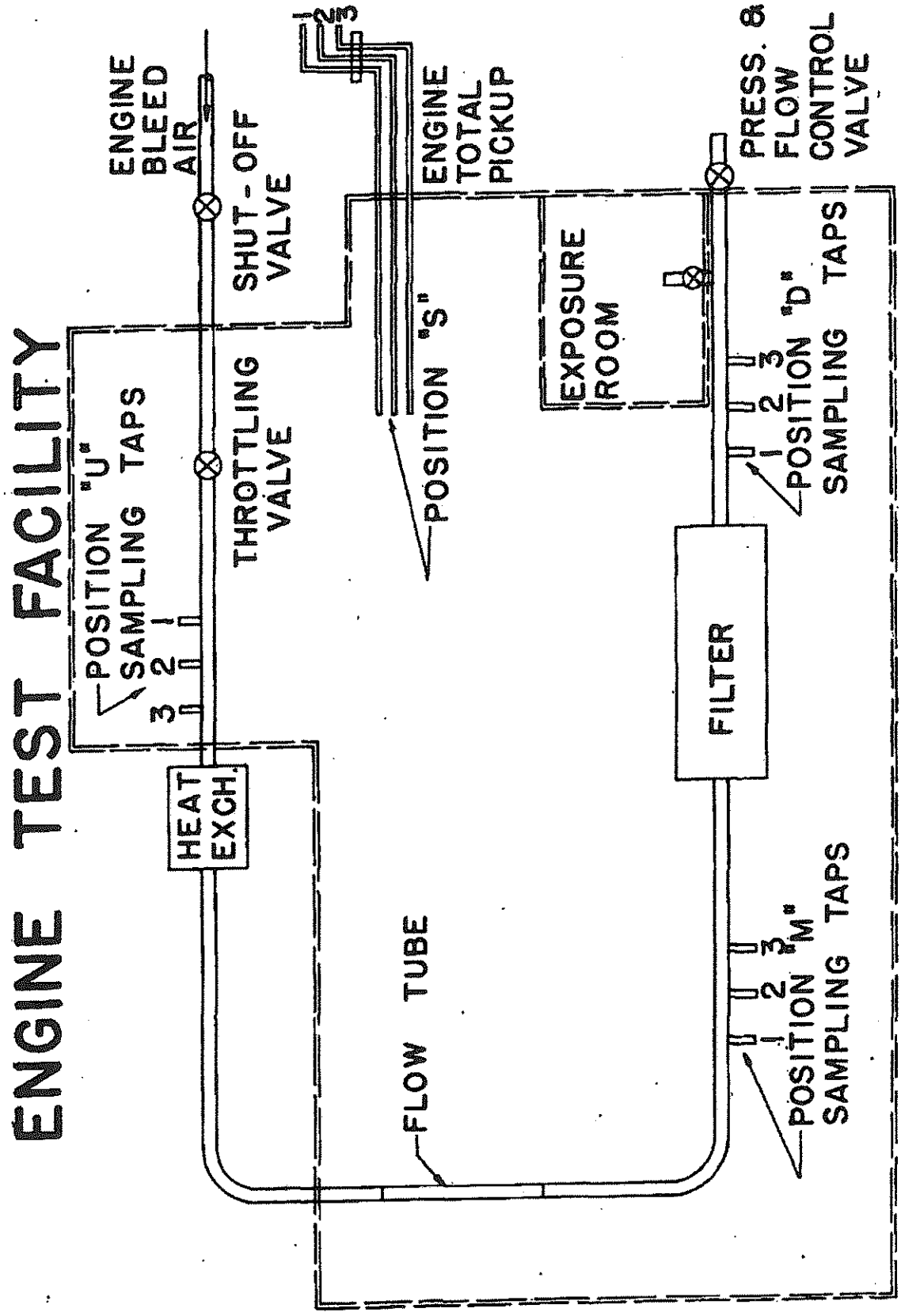

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FIGURE NO. 16

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THE SMOKE SIMULATOR

Since the cost of operating a jet engine is very high, a laboratory setup was devised to simulate the engine bleed air contamination on a small scale. Figure 17 is a schematic diagram of this smoke simulator. Air is compressed and heated to engine conditions and a means is provided for injecting controlled amounts of jet engine oil into the heated, pressurized air. Means are then provided for cooling the contaminated air to desired levels for testing various decontamination schemes. Sampling taps are located at various pertinent locations in order to measure effectiveness of various test specimens. Although we refer to this apparatus as a "smoke" simulator it is designed to reproduce the contaminants, both aerosols and vapors that exist in a contaminated jet engine. A smoke simulator unit similar to the one described here has been provided to the Bureau of Mines for their catalytic work.

For purposes of simplicity the simulator was originally designed as an unpressurized unit. However, due to lack of consistent data correlation between runs and engine results, it was decided to rebuild the simulator such that the oil is now injected into the hot air stream at pressures up to 125 psig. Our data correlation has improved considerably since this change was made.

The Test Program for Engine Rig and Smoke Simulator

Next, let us discuss the testing program on the engine and laboratory test setups. Figure 18 depicts the respective test programs.

It should be pointed out first of all that this phase I filter development program has been laid out time-wise as an eight month program which began in July, 1953, at which date CCN approval was granted. Thus, the end point in our present program is roughly the 1st of March, 1954.

Considering first of all the Engine Test Program, the tests which have been run to date fall into the following general categories:

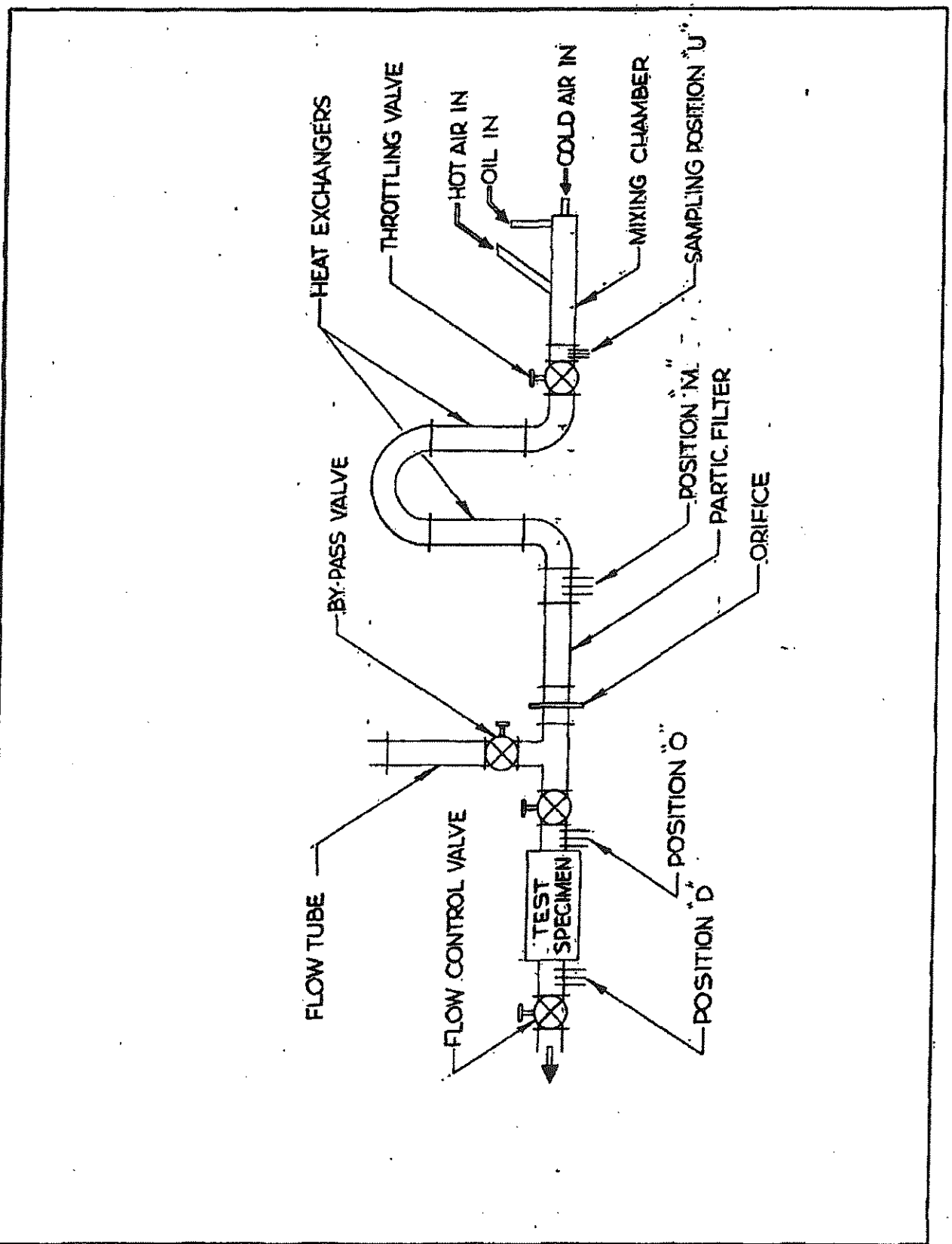
1. Tests on Boeing Filter No. 1

2. Tests on Edgewood Arsenal Filter No. 1

3. Tests run to determine effects of engine power and oil injection rate upon contamination.

4. Tests run to determine contamination stratification in engine high speed diffuser.

All in all, approximately 24 test runs have been made on the engine to date with a total engine running time of roughly 50 hours.



CALC			REVISED	DATE	LABORATORY SMOKE SIMULATOR	FIG 17
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Referring to the bar chart, Figure 18, we can see the time schedules on the engine test runs. Also shown are proposed future runs projected to the end of the Phase I time scale. It should be noted that very little testing is scheduled for the month of December. This is due to installation of the P-1 engine in the test cell adjacent to our P-3 test engine. The P-1 installation is for general power plant evaluation; however, we hope to be able to sample some bleed air from this engine for contamination analysis and comparison with P-3 engine contamination data.

Considering next the Lab Smoke Simulator Test Program, the tests which have been run to date generally fall into the following categories:

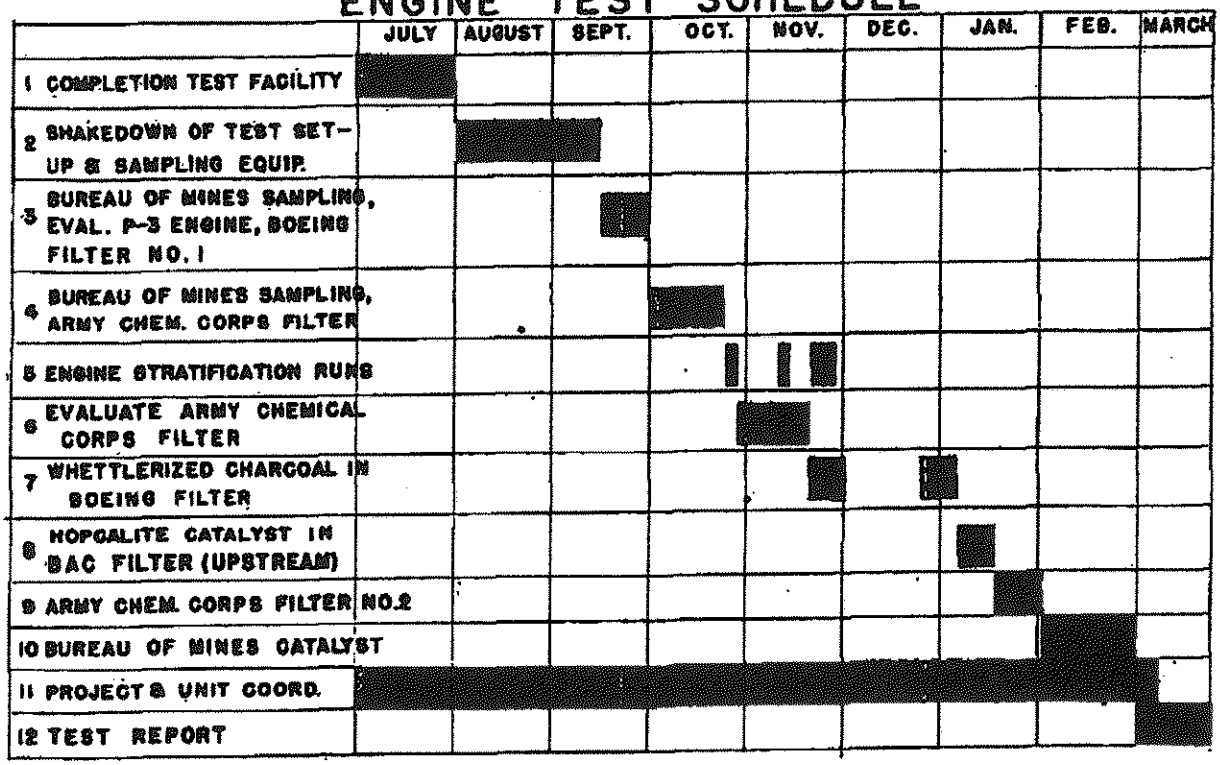
1. Tests on various catalytic removal schemes.
2. Tests on various adsorptive removal schemes.
3. Tests on contaminate removal by condensation method.
4. Tests to develop sampling techniques.
5. Tests to study effect of various significant parameters on contamination problem.

Figure 18 indicates the test schedule with respect to the time scale. Also, we have projected future tests out to the end of Phase I time scale.

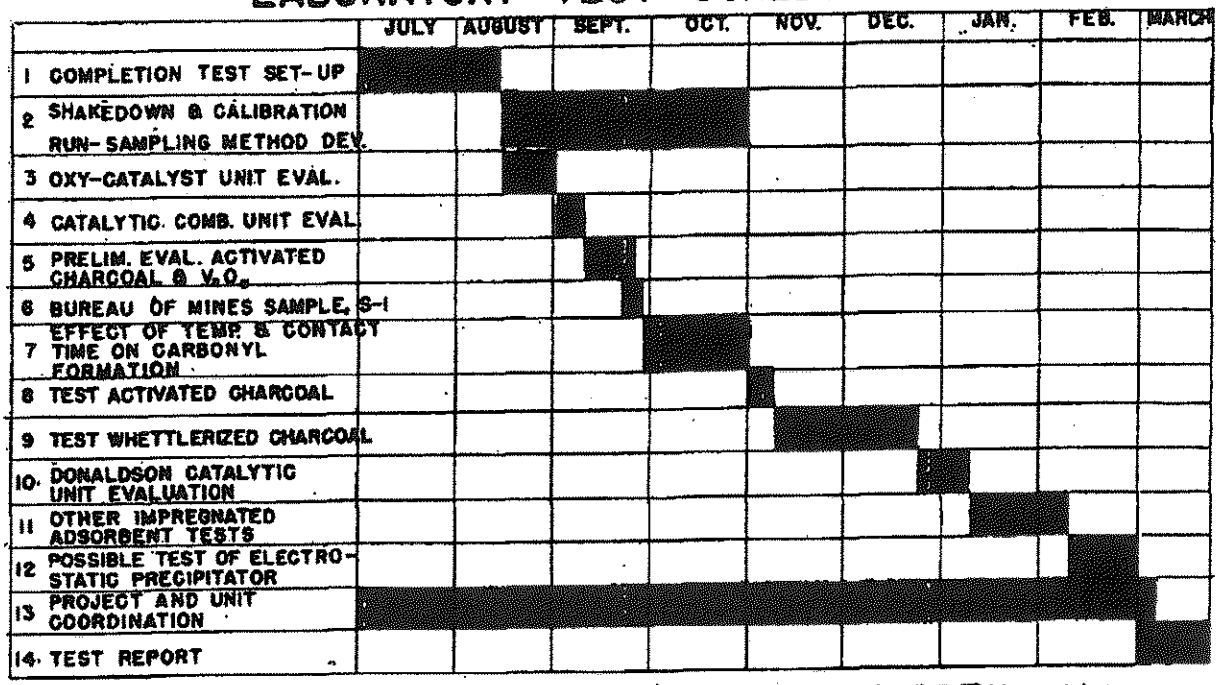
In order to present a better idea of the specific items we have tested and what we propose to investigate in the future we have graphed another chart, Figure 19, which shows what we have tested, where we have tested it, brief note on results, and indicates our future planning.

Referring to Figure 20, we have shown the Phase I Filter Development Program Time Scale. Also projected on this chart is a Phase II time scale for final development work and airplane installation design work on a final filter fix. We have made no formal Phase II proposals to the Air Force as yet, but we have made some preliminary studies to determine what a Phase II time scale and work statement might consist of; and this chart represents the results of these studies. We expect to be approaching the Air Force with formal proposals and recommendations on a Phase II program before March 1954 (end of Phase I time scale).

ENGINE TEST SCHEDULE



LABORATORY TEST SCHEDULE



PRELIMINARY PLANNING AND STUDY APRIL - JULY 1953

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FIGURE NO. 18

FIGURE NO. 19

SPECIMEN	SET UP ENG.	SET UP LAB.	TEST RESULTS	FUTURE TEST PLANS
1. PARTICULATE FILTERS				
(a) HI TEMP. GLASS FIBER BATT	✓	✓	EFFECTIVE IN PARTICULATE REMOVAL. TESTED IN CONJUNCTION WITH CATALYST & ADSORBENT UNITS	MORE SPECIFIC EVALUATION PLANNED
(b) PLEATED PAPER TYPE (ARMY CHEMICAL CORP.)	✓			
(c) GLASS FIBER BATT SILICONE BINDER	X			WILL BE TESTED
(d) PLEATED PAPER HI TEMP GLASS FIBER	X			WILL BE TESTED
2. ACTIVATED CARBON	✓	✓	EFFECTIVE AT LOW TEMP. ONLY	NO FURTHER TESTS PLANNED
3. IMPREGNATED CARBON				
(a) WHETTLERIZED	✓	✓	EFFECTIVE 50°F TO 300°F	FURTHER TESTS IN PROGRESS
(b) V_2O_5		✓	TESTS TO DATE INCONCLUSIVE	FURTHER TESTS MAY BE RUN
(c) OTHER	X	X		TRYING TO OBTAIN OTHER IMPREG. ADSORBENTS FOR TESTS
4. CATALYTIC				
(a) BUREAU OF MINES				
1. HOPCALITE	X	✓*	REMOVED PUNGENT ODOR OVER RANGE 300 - 700°F	FURTHER TESTS IN PROGRESS TO DEFINE PROPERTIES & LIMITS
2. RESEARCH	X	✓*	TESTS IN PROGRESS	35 CATALYSTS TO BE TESTED
(b) OXY - CATALYST CO.		✓	NEGATIVE RESULTS	VENDORS RECOMMENDATIONS REQUESTED
(c) CATALYTIC COMBUSTION CO.		✓	NEGATIVE RESULTS	NO FURTHER ACTION
(d) DONALDSON CO.		X	———	TEST SCHEDULED
5. CONDENSATION -- USING HEAT EXCHANGERS		✓	INADEQUATE — CONTAMINATION IN VAPOR STATE DETECTED DOWNSTREAM AT 40° F.	FURTHER TESTS PLANNED IN CONJUNCTION WITH OTHER SPECIMEN
6. ELECTROSTATIC PRECIPITATOR		X	———	MAY BE TESTED LATER
7. EVALUATION OF P-3 ENGINE	✓		RESULTS IN BUREAU OF MINES REPORTS	FURTHER TESTING IN CONJUNCTION WITH OTHER SPECIMEN

NOTES
✓ HAS BEEN TESTED
X WILL BE TESTED
* TESTED WITH BUREAU OF MINES SMOKE SIMULATOR

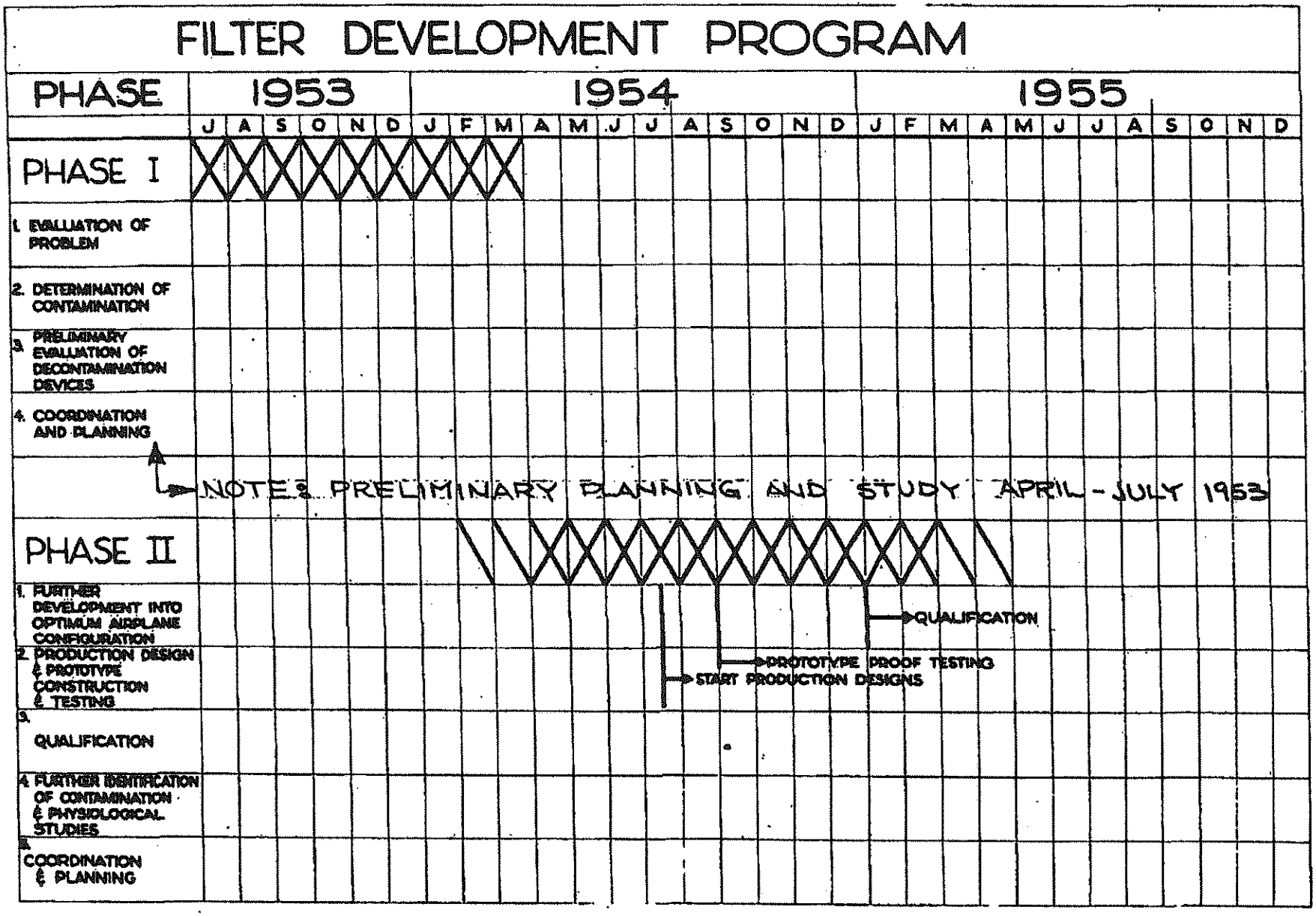

FIGURE NO. 20

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AIR SAMPLING AND ANALYSIS

We have assumed that the exact details of the sampling and analytical procedures used in this program would be of interest to only a relatively few of those in attendance. This information is therefore available to those who desire it in written form and this oral presentation will be of a general nature.

We are utilizing two distinct methods of obtaining samples. In the first of these, the intention is to collect all of the extraneous matter in the air without chemical change for analysis by physical methods at the Bureau of Mines Laboratory. This is accomplished by passing air from the duct system through the throttling valves and water cooled condensers and then through modified Shepard traps cooled with liquid oxygen (See Figure 21). All of the compounds not commonly found in the atmosphere except carbon monoxide are collected in the traps. Because of the large number of samples taken at one time, it has been necessary to utilize low volume precision rotometers for measuring airflow in lieu of the wet test meter commonly used for air and gas sampling. The temperature of the emergent air is measured for volume correction. After sampling is completed, the traps are pumped down at liquid oxygen temperature to eliminate dissolved oxygen which might react with the contaminants prior to analysis. Those materials boiling at the temperature of dry ice are transferred through a pumped down manifold system to two liter flasks equipped with high vacuum stop cocks. The traps are then sealed and the traps and flasks are placed in insulated shipping containers cooled with dry ice and shipped refrigerated to the Bureau of Mines Laboratories at Bruceton, Pennsyvania by air. It is an item of some interest that such trans-continental shipment of frozen out air pollution samples had never before been done.

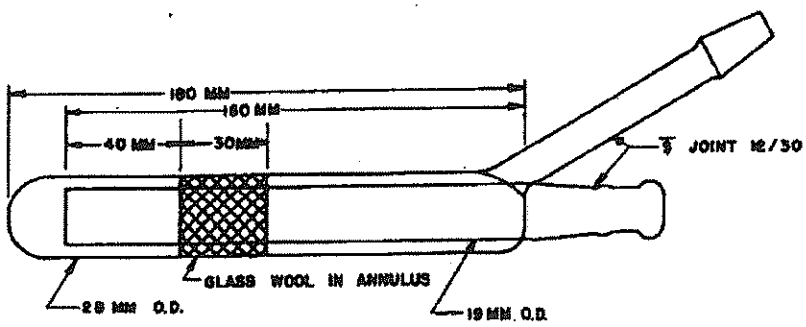
At the Bureau of Mines, the contents of the traps are analyzed by fractional distillation into the mass spectrometer. Further analysis is done on the low volatility materials by infra-red and ultra violet absorption. The total carbon content in certain fractions is determined by micro combustion. Recently it has been found desirable to withdraw a sample of the liquid collecting in the colder portions of the duct system, refrigerating it and sending it to Bruceton.

The second type of sampling performed is called chemical sampling. Its sole purpose is the analysis in Boeing laboratories for specific compounds or groups. Throttled air from the ducts is allowed to pass through ice cold water or chemical solutions contained in gas washing bottles equipped with fritted glass diffusers. The emergent from these scrubbers is dried with calcium chloride prior to measurement in the rotometers and temperature correction. If this is not done, water will condense in the rotometers and false readings are obtained.

Three different analyses are conducted on the collected samples. First, a carbonyl determination using the sodium bisulfite method of Goldman and Yogata.

BUREAU OF MINES

FREEZEOUT TRAPS



A

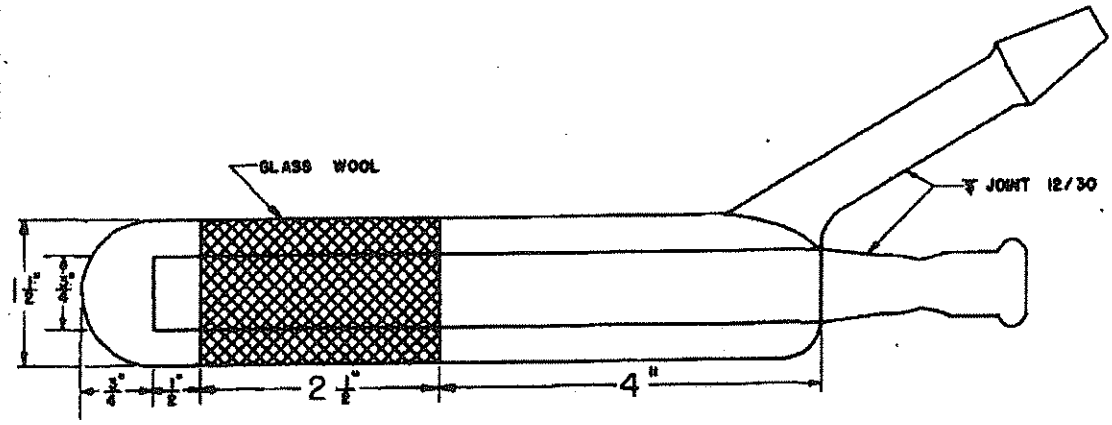


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FIGURE NO. 21

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Second, a formaldehyde determination using the chromatropic acid method. The third determination is for total oxidants using an unpublished method developed by Haagen-Smit, for use on the Los Angeles smog problem. Total oxidants can best be defined as the content of ozone, oxides of nitrogen and organic peroxides contained in the sampled air. This determination was initiated following the report from Dr. Friedel of the Bureau of Mines that organic peroxides were much in evidence in the freezeout samples submitted. Dr. Haagen-Smit was personally contacted at California Institude of Technology and he graciously presented his method. The method has been of considerable value.

It is common practice to collect samples over a three hour period with separate samples taken during the first, second and third hour as well as over the entire period as a method of checking. The use of total pick-ups (see Figure 22) rather than static taps was found to be important in obtaining consistency and is now standard.

In conclusion, we must point out that the highly sensitive and selective sniff test has not been ignored. It is utilized in every test.

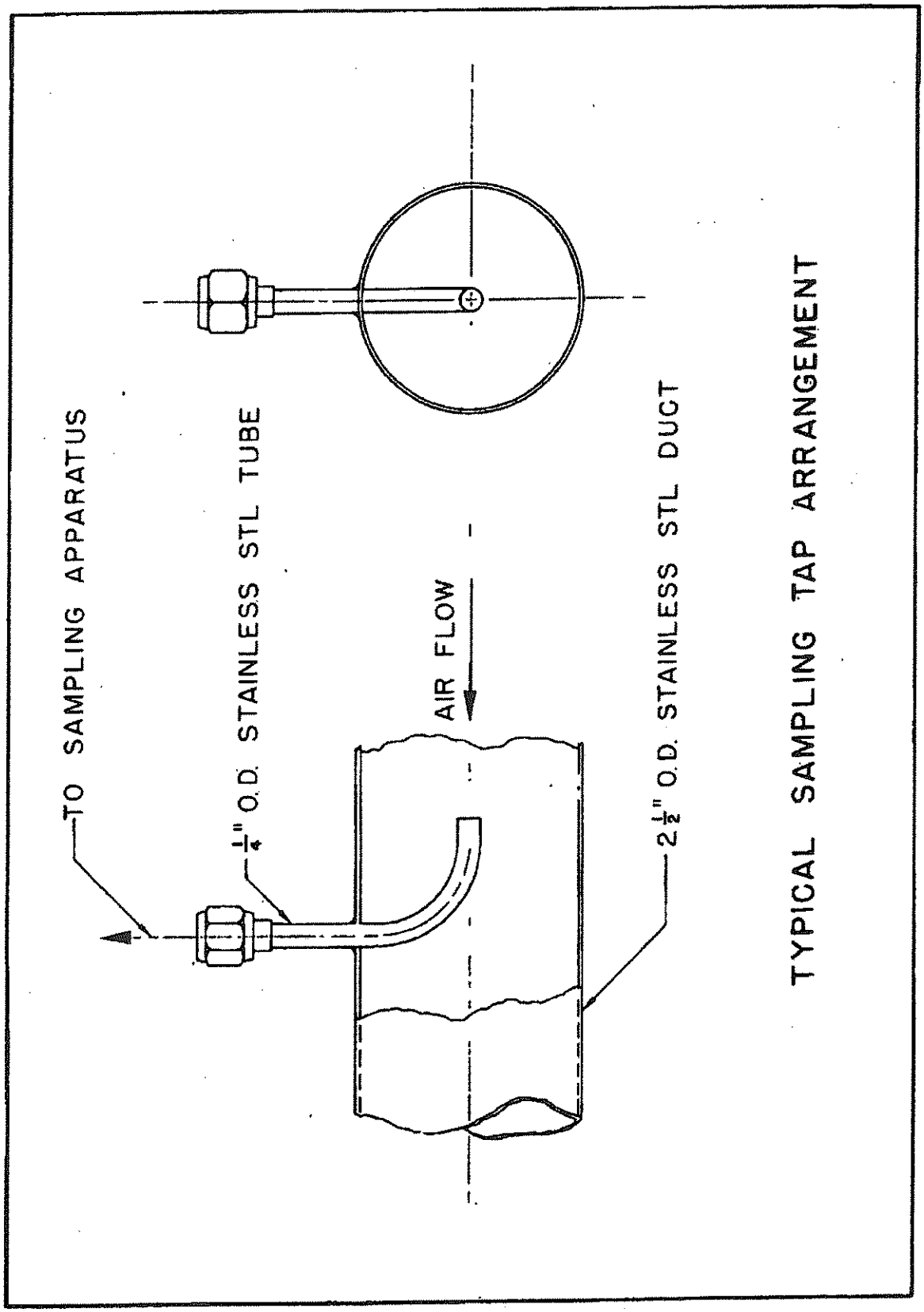

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FIGURE NO. 22

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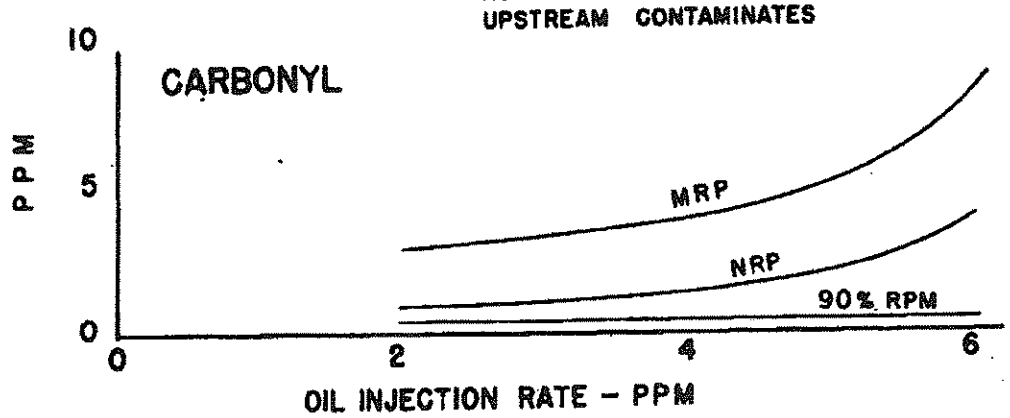
DESCRIPTION OF RESULTS

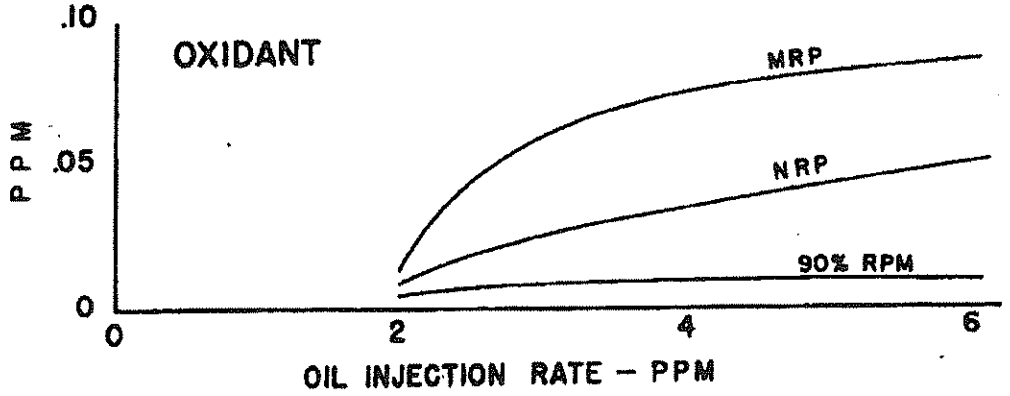
Analytical results for the filter development problem can be best discussed by dividing them into separate sections. We shall first discuss the data obtained from the United States Bureau of Mines. Samples for these analyses were taken from three different positions. The upstream position being immediately upstream of the heat exchanger, the midstream being just downstream of the heat exchanger and the downstream being immediately below the filter being tested. The first run made for the collection of these samples was made with the first P-3 engine operated at Normal Rated Power with no supplemental oil injection. Boeing Filter No. I was utilized with air temperatures of 200°F across the filter. This filter was composed of a fiberglass bat particulate element and coconut shell activated carbon. It was noted during this run that the predominant odor was similar to that of a new tire or inner tube. It is significant to note that even in the upstream position the total volatile contaminates amounted to only approximately .12 parts per million. Volatile in this case refers to compounds exerting a vapor pressure of at least 0.01mm. of mercury at room temperature. This would include most hydrocarbons up to C_{14} ketones and aldehydes up to C_{13}, alcohols up to C_{11} and acids up to C_8. Since adequate data on midstream and downstream samples are as yet not available, the most significant data with regards to this run are the existence of mass 112. This corresponds to the molecular weight of 2- Ethyl Hexene -1, an unsaturated hydrocarbon which could be expected to be formed during the pyrolysis of di-2 ethyl hexyl sebacate, the base stock of the snythetic oil.

Run E-2 was made with the same filter operated at the same temperature. The only variations were the injection of 6 ppm of PWA521A oil into the front of the compressor to increase the concentration of contaminates so that the analytical problem could be eased and to assist in filter evaluation and the use of military power (see Figure 23). Here we observe a number of interesting facts. The upstream samples analyzed by mass spectrometer show total volatiles amount to 1.2 ppm or 10 times that of the "dry" run E-1. The midstream samples show approximately the same quantity of volatiles as upstream but with an increase in carbon dioxide content, indicating that the oxidation reactions occur even at 200°F after original reaction has been initiated at high temperatures (see Figure 24). In both the upstream and midstream locations again the maximum mass found was 112. The downstream sample indicates two highly significant factors. First, a decrease volatile content to 0.24 ppm indicates a filter efficiency of 80 per cent of 200°F. Second, the highest mass found was 58. This would correspond to the molecular weight of the butane hydrocarbon, acetone, or propionaldehyde. The absence of higher mass weights can be credited to absorption by the carbon; polymerization or further oxidiation. The major portion of the contaminates from Run E-2 were found to be water soluble materials of low volatility. Infra-red adsorption spectra demonstrate the presence of carbonyl compounds and acids in the upstream and midstream positions. The concentration in the downstream samples was too low to obtain positive data. Ultra-violet spectra have indicated the presence of organic peroxides. These

CONTAMINATE QUANTITY VS OIL INJECTION RATE

SPECIMEN – ARMY CHEM. CORPS FILTER NO. 1
RUNS E8 THRU E19
UPSTREAM CONTAMINATES





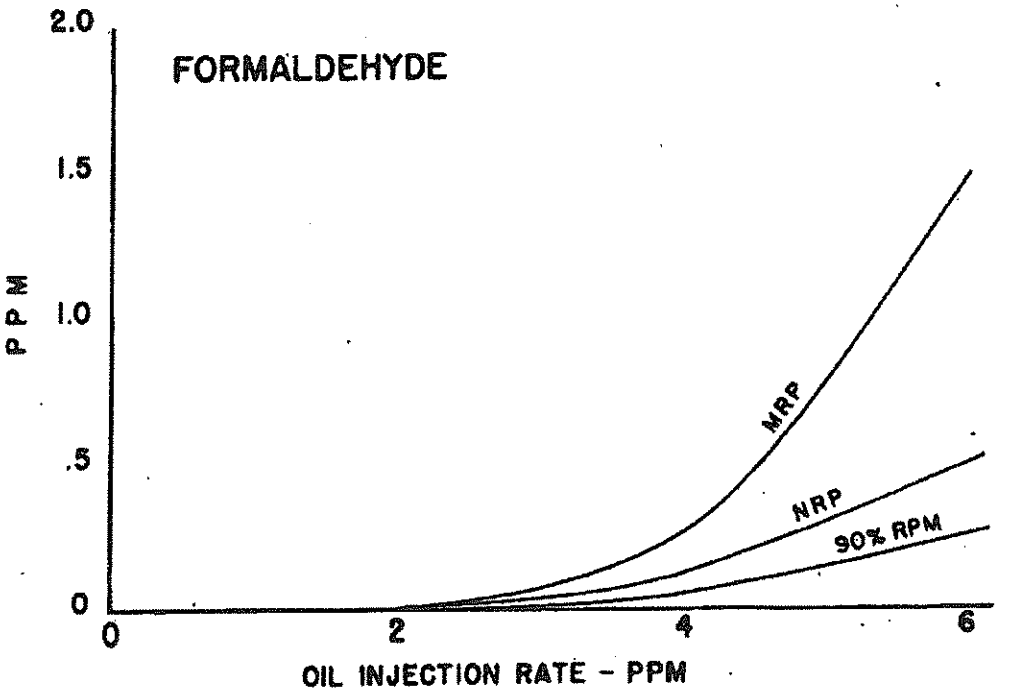


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FIGURE NO. 23

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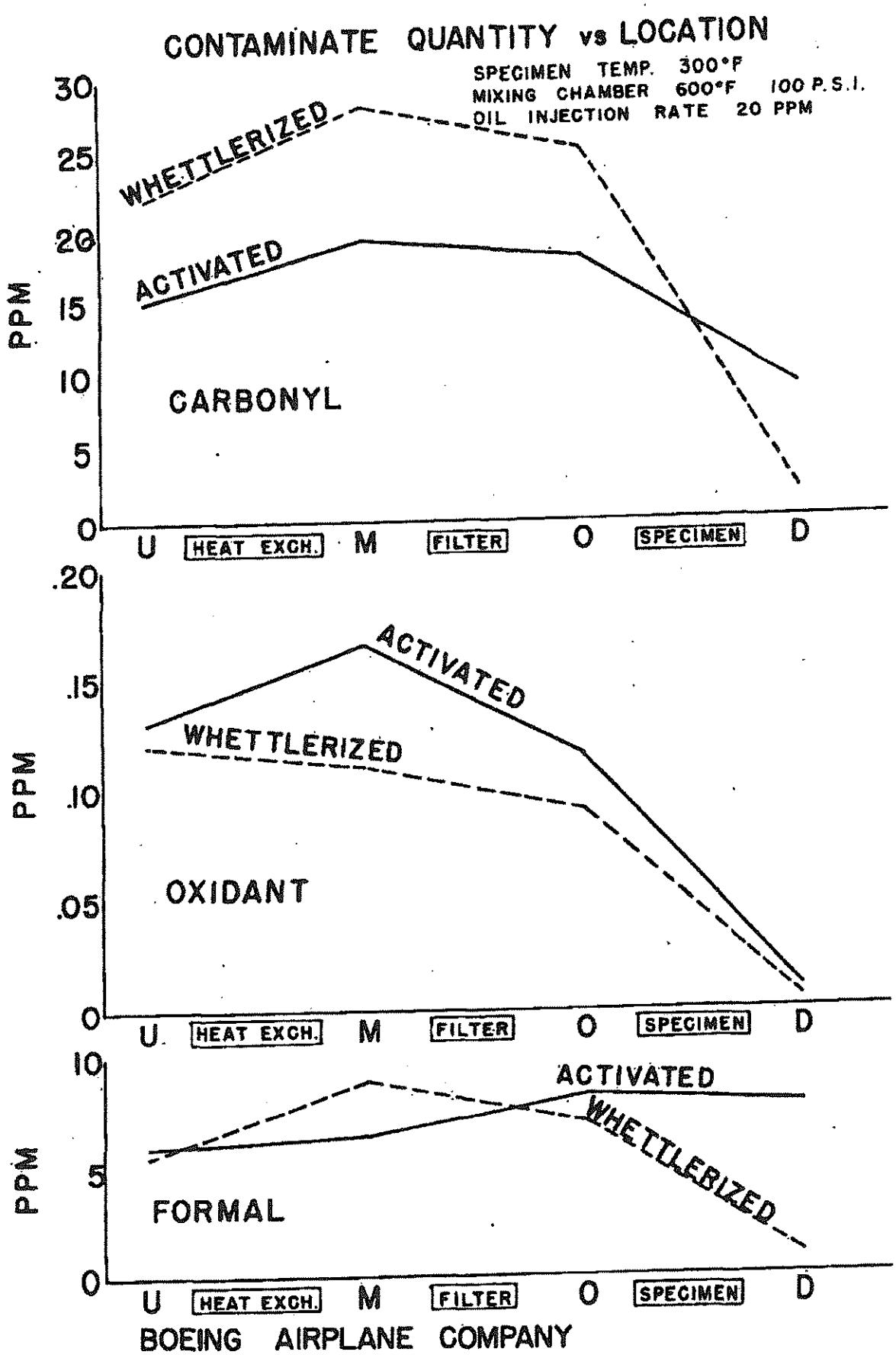

FIGURE NO. 24

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same spectra show an adsorption band at 262 mμ which shifts to 285 mμ on addition to alkali. The specific chemical or chemicals which causes this band have not as yet been identified but it is considered highly significant for several reasons. The samples from run E-4 with no oil injection show the band. This definitely associates the contamination with the engine oil. In addition, in a recent run E-5 testing the Edgewood Filter at 150°F with 6 ppm oil injection (see Figure 25) the ultra-violet adsorption intensity at 262 mμ in the various positions were as follows: Upstream 8, Midstream 14, Downstream .8. This indicates an efficiency of removal of approximately 90 per cent and again indicates the continuance of reactions in the heat exchanger (see Figure 26).

For the interest of the chemists in attendance we can point out that the compound or compounds producing this significant band are not simple aliphatic acids and it has been proven that the unknown must be an alkyl constituent rather than an aromatic. It therefore is derived from the diester rather than the additives.

Summarizing briefly the Engine Runs made for collection of freeze out samples:

1. The Bureau of Mines has established the uniformity of the volatile matter in runs with and without supplemental oil injection.

2. The volatile contaminant content even in the runs with oil injection is only around 1.2 ppm.

3. The highest concentration of contaminants are water soluble materials with low vapor pressure at room temperature. These have been found in concentration of 5 times as great as the volatiles. They appear to be base sensitive organic peroxides.

4. The specific noxious and toxic products have not as yet been identified.

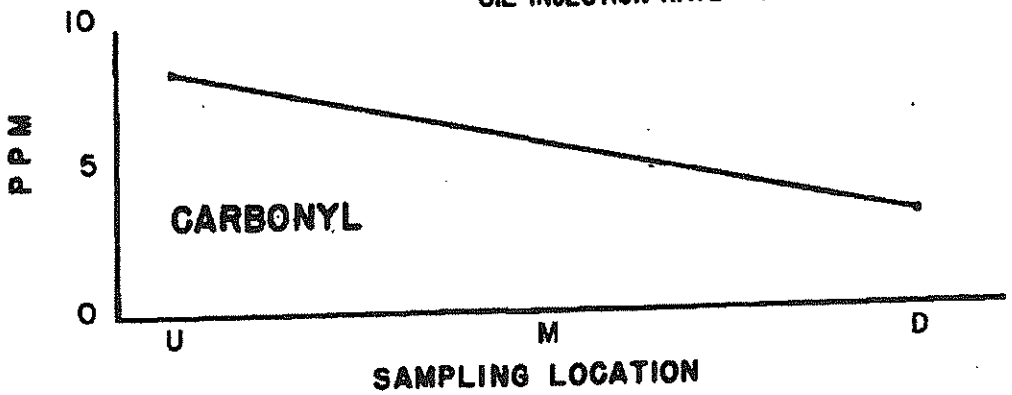
5. Particulate filter-activated carbon units have been demonstrated to be 80 percent to 90 percent efficient at temperatures of 200°F and 150°F.

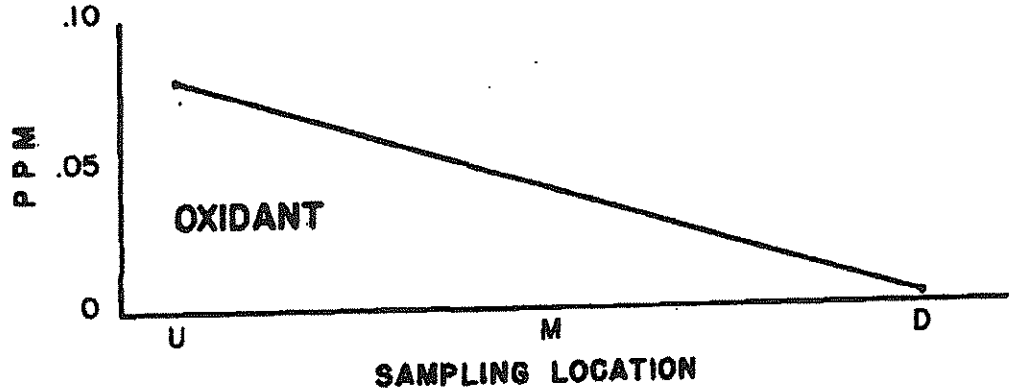
6. Odor in the purified air indicates that higher efficiencies are required when the oil leakage is significant.

The second set of data to be discussed are from the laboratory smoke simulator. Figure 27 shows the results of a series of runs made for the specific purpose of evaluating carbonyl production against temperature. Note that at a temperature of approximately 640°F the increase becomes very rapid. This temperature is probably lower in the engine as these runs were carried out prior to pressurizing the reaction chamber. However, the shape of the curve illustrates dramatically why the problem arose with new engines having higher compression ratios and why it may be expected to increase in severity in the future if oil leakage occurs.

CONTAMINATE QUANTITY VS SAMPLING LOCATION

SPECIMEN – ARMY CHEM. CORPS FILTER NO. 1
ENGINE AT MILITARY RATED POWER
OIL INJECTION RATE – 6 PPM





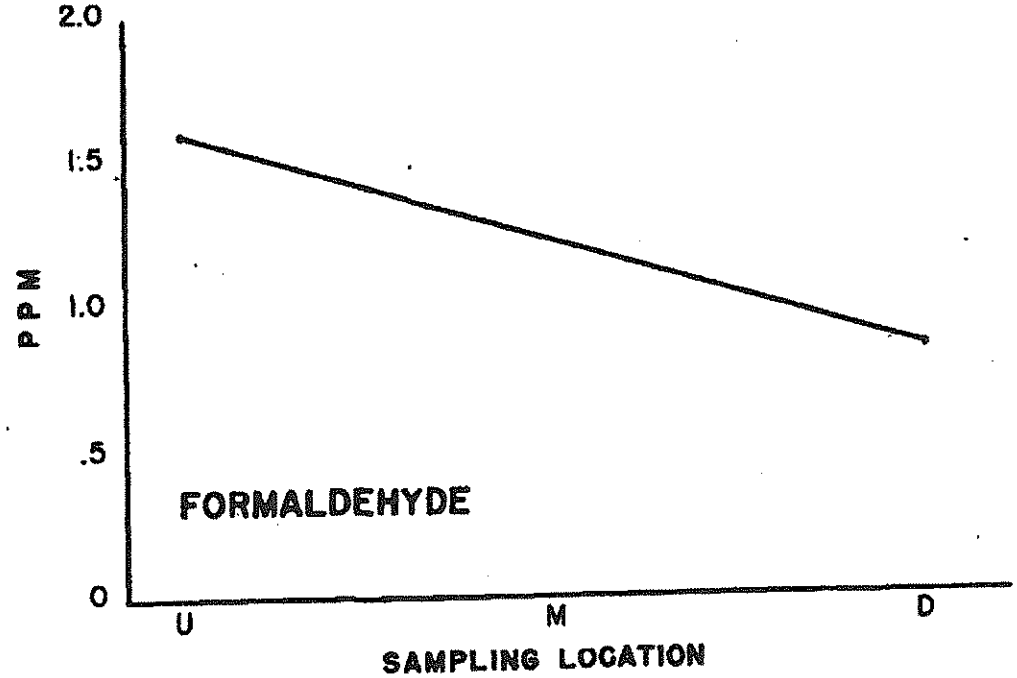


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FIGURE NO. 25

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CALC			REVISED	DATE	CABIN AIR CONTAMINATION
CHECK					
APR					
APR					

FIG 26

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K+E

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FIGURE NO. 27

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Tests have been conducted on particulate filters plus carbon in the midstream position over a range of temperatures from 50°F to 300°F. Figure 28 shows that high order efficiencies are obtained only at the lower temperatures. In fact on extrapolation it appears that temperatures near 0°F would be required to approach contaminate free air. The efficiencies at 200°F and at 160°F are about 10 percent lower than those demonstrated on the engine tests. However, this is probably due to the fact that the reaction chamber for these tests were at 600°F which produced significantly higher concentrations of formaldehyde than does the 550° engine temperature. The formaldehyde produced is measured along with other carbonyls and it is evident from Figure 28 that the efficiency against formaldehyde in these temperature ranges is less than 0. In other words, formaldehyde is formed within the carbon and rejected. Now by comparison let us observe the data from the series of tests on Whettlerized carbon. Here we observe that the curve assumes an opposite slope, the efficiency being greatest in the high temperature area and poorest in the low temperature area. This we can interpret to mean only that the specific action under high temperature conditions is one of catalytic oxidation converting to less effective physical adsorption at low temperatures. Here we have our first really good prospect and from "sniff" tests conducted during these tests we have physiological backing. This, of course, is now being intensely studied. Upstream catalytic units from the Oxy-catalyst Co. and the Catalytic Combustion Co. proved to be unsuccessful in early tests.

The reports from the Bureau of Mines tests have been much more promising. 35 different catalysts have been prepared. At last report seven had been tested and the manganese oxide types have been found to be effective. The most effective tested to date has been the commercial product Hopcalite, a processed granular co-precipitate of oxides of manganese and copper. This has been tested over a temperature range of 300°F-700°F with oil injections of 13-16 ppm for 6½ hours with no evidence of deactivation. Sniff tests have revealed only a slight sweet ordor similar to that of 2 ethyl hexanol -1 at the lower temperatures. These data are obviously of great value and every attempt will be made to initiate an engine test in the near future. The Bureau of Mines is continuing their work on the other catalysts prepared.

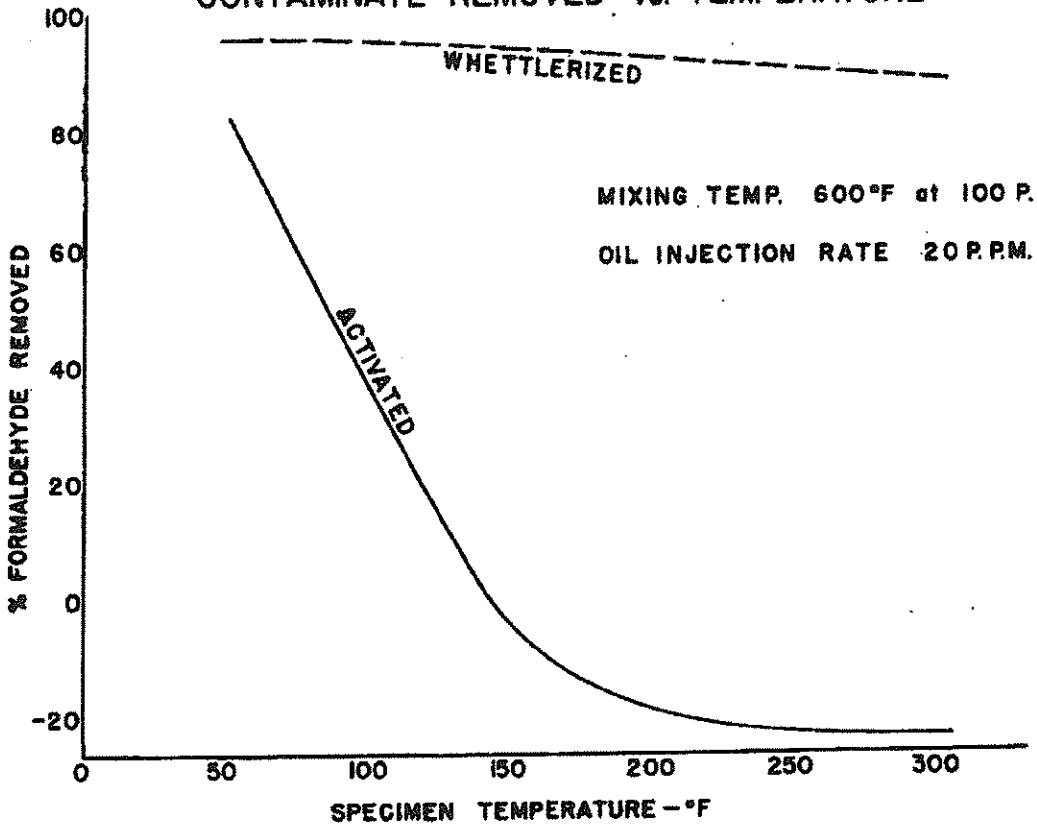
We may summarize the results from the lab smoke simulator in the following manner:

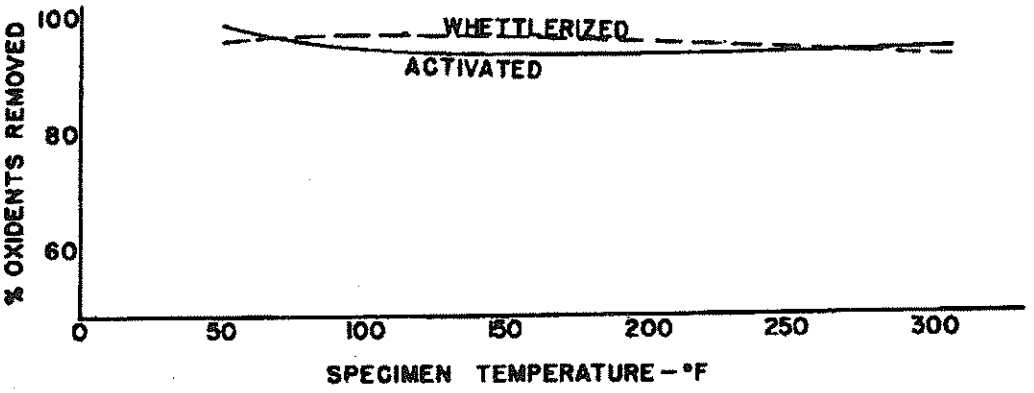
1. The critical relationship of temperature to oil breakdown has been demonstrated.

2. The removal of contaminants by the use of heat exchangers followed by particulate filters has been demonstrated to be unsuccessful even at 40°F temperatures.

3. A unit consisting of a particulate filter and activated carbon can be predicted to provide contaminate free air only in a modified system where the filtration occurs at or below 0°F.

CONTAMINATE REMOVED vs. TEMPERATURE





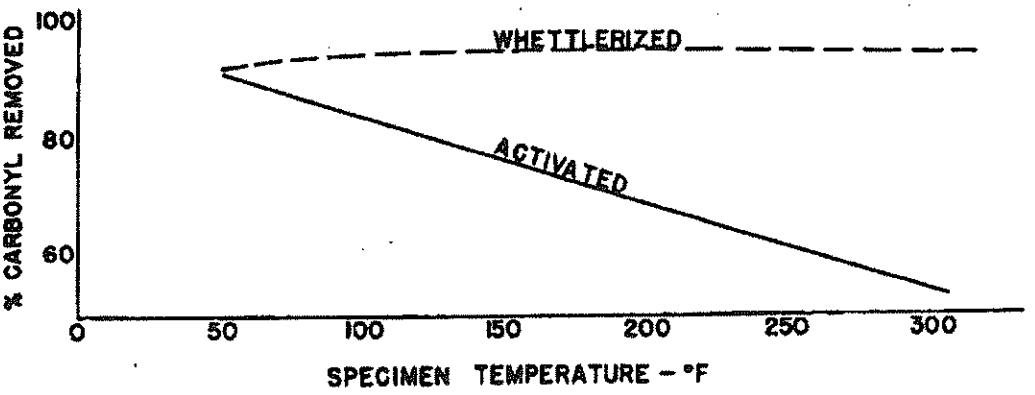


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FIGURE NO. 28

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4. A midstream unit consisting of Whettlerized carbon, activated carbon and a particulate filter can be predicted to give good performance over the entire midstream temperature range.

5. Based on the Bureau of Mines data, the satisfactory utilization of an upstream catalytic unit is not only possible but is very probable.

If we may now return briefly to the engine test facility work we should like to discuss a point of particular interest to the Power Plant people. Rather early in the study, discrepancies between the engine and the smoke simulator, with regards to carbonyl production, led to theories concerning the location of oil droplets during high temperature exposure. It is assumed that due to the great difference in density between oil droplets and air, centrifugal separation would occur. This would cause the oil to move slowly back along the case. Under this condition, the exposure to temperatures high enough to degrade the oil would be of long duration compared to that of dispersed droplets traveling axially through the compressor. If this premise is correct, it could also be inferred that higher concentrations of contaminants occur near the outer periphery of the annulus than occur on the inner periphery. Total pressure measurements previously made support this theory of stratification. Therefore, a special three pronged ram air pick-up was built and installed in annulus for sample collection. Visual investigation of this assembly after several tests were conducted on the J57-P3 engine revealed that the probe next to the outer perifphery of the annulus was coated with a carbon like material while the innermost probe was completely clean, indicating that stratification is taking place. Photographs No. 137971 and No. 137972 shows the exact condition after the Military Rated power runs. A review of preliminary test data indicates definite stratification at all power settings up to and including normal rated power conditions. Inconsistent results were obtained at military power. Accordingly, further tests are planned to investigate the possibility of stratification at military rated power.

Since verification of constant stratification conditions could lead to a source of suitable air directly from the engine by relocation of the bleed port, this study should be accentuated. We believe that the only true answer will be found by actually modifying an engine. This, of course, we cannot do but offer the suggestion that it be studied by those who can.