Parameter Monitoring for Corrosion Control of Utility Gas Turbines

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Prepared by
United Technologies Corporation
South Windsor, Connecticut

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ELECTRIC POWER RESEARCH INSTITUTE

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Prepared by

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ABSTRACT

Hot corrosion is a significant durability limiting factor in industrial gas turbine engines. It is caused primarily by alkali sulfates depositing on the turbine airfoils. The object of this program is to determine from field and laboratory test data the conditions that cause deposition of these corrodents and to define an engine control system that will minimize their effect.

Field data on 600 engines has been statistically analyzed to determine the influence on hot corrosion of fuel type, engine washing, air filtration and the proximity of the engine sites to oceans. Laboratory tests are being conducted on turbine materials, with and without protective coatings, to assess relative resistance to corrosion. Corrosion rates in the presence of sodium sulfate alone and with carbon, vanadium and lead are being defined.

The primary source of sodium is airborne sea salt and contaminated fuel. Atmospheric and fuel salt concentrations have been measured at a variety of U.S. sites. Sodium ion concentrations in the air stream inside engines were monitored for evidence of impulsive shedding of accumulated salt. An engine control system which will monitor the atmospheric and fuel-borne salt concentrations and signal the need for an engine water wash cycle to remove accumulated salt before corrosion has started is being defined. The control can also reduce power to slow the corrosion rate if the wash is not performed.

The program is approximately 50 percent complete at this point. Results show that water washing reduces the incidence of corrosion and that turbine materials can tolerate alkali sulfates for a limited period before hot corrosion commences. Remaining work will be directed at determining when the corrodents are released and/or deposited on the turbine. Ideally the control system will recognize the likelihood of this occurrence and signal a wash cycle.

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Section 1

INTRODUCTION AND SUMMARY

INTRODUCTION

Industrial gas turbine engines are the power plants for gas and oil pumping stations, cargo container ships, trains and electric power stations. The selection of construction materials for gas turbines is based upon their ability to perform over a wide temperature range, while exhibiting the necessary oxidation resistance for long life. However, in the presence of certain impurities, the rate of oxidation or corrosion of the superalloys used in the hot section of gas turbine engines can be increased orders of magnitude. The presence of condensed liquid metal oxides of vanadium and lead, as well as the alkali sulfates, is responsible for increased rates of oxidation.

The objectives of this program are:

- to determine the boundaries of the operational envelope in which the deleterious effects of the condensed corrodents are minimized

- to define and construct a control system that can ensure engine operation within this envelope

The first year of the program has been devoted to correlation of the field and laboratory data by using statistical methods to establish weighing factors for the important corrosion-influencing parameters. The data is being supplemented by new laboratory and field tests in a dedicated sulfidation study program, conducted by Power Systems Division at the Long Island Lighting Company Holbrook FT4 installation. Analysis of the corrosion test data is yielding a corrosion parameter model which will be devised and verified during the second year of the program.

Based on the work described above, a new corrosion control system is being designed with capabilities for refinements and new input information from the model. Sufficient flexibility will be provided to allow incorporation of new parameters and adjustment of operating limits under a variety of conditions. Sensing equipment for the control system has been defined and is being procured. This work will continue through most of the second year, with the final three months devoted to a functonal test of the corrosion control system on an FT4 installation.

The program has been organized into five tasks:

Task I	Establish Corrosion Model
Task II	Define Control Requirements
Task III	Design, Develop and Test Control System
Task IV	Program Management
Task V	Reporting

SUMMARY

This annual report presents the technical progress in Tasks I through III and summarizes the programmatic progress.

Task I Establish Corrosion Model

All of the laboratory oxidation and sulfidation tests have been completed on the uncoated turbine material specimens. The results showed that turbine inlet temperature (1500°F to 1800°F) has an influence on oxidation and sulfidation rate; furthermore, the influence of certain contaminants, such as carbon (no effect) and vanadium oxide and sodium chloride (accelerates sulfidation), has been identified. It has been found that cycling metal temperature increases sulfidation rate at 1650 and 1800°F.

Burner rig tests have shown that poor combustion is a means by which sodium in the fuel can initiate sulfidation at sodium-in-fuel levels below those sufficient for equilibrium condensation from a sodium sulfate cloud. The influence of lead contaminant on sulfidation is under investigation. Sulfidation tests on turbine specimens with aluminide and overlay protective coatings are also in progress. Preliminary results show overlay coatings yield greatest life.

Field experience data has been statistically analyzed. Results show that washing is beneficial to engines run with or without inlet filters. Strong dependency on distance from the ocean was not found when 50 miles was used as the break point. Insufficient data existed to use 100 miles as a break point, yet there are indications that a difference does exist at that distance.

Field tests have been conducted with a very sensitive sodium ion sensor to determine the effectiveness of air inlet filters, to identify the conditions that cause compressor salt shedding and to determine the atmospheric salt level variations over a period of time. Based on a limited number of tests, the inlet air filters do not seem to be effective in removing atmospheric salt during periods when the salt concentration is low, i.e. 0.5 to 1.0 PPB.

Monitoring the compressor-bleed air and inlet air during engine transients yielded evidence of salt shedding from the compressor and the engine inlet duct. This was probably due to the rapid changes in airflow.

Washing the engine and analyzing the wash water showed that sodium ions are present in both the compressor and turbine. Also, as much as 300 gallons of water is required for effective cleaning and salt removal.

Performance checks on engines, run approximately 2000 hours with and without inlet air filtration, showed a significant erosion of compressor blade tips on the unfiltered engines and a significant corresponding increase in heat rate. Filtered engines showed virtually no erosion or change in heat rate.

The task of defining a corrosion model and establishing a corrosion envelope has been started. A tentative list of significant corrosion parameters has been proposed.

Task II Define Control Requirements

Based on the work of Task I, the corrosion control system inputs and sensing requirements have been defined. System inputs will consist of sodium ion concentrations in the inlet air and fuel supply to be measured by dedicated sodium sensors. Operating events such as power changes or failure to wash the engine will also be input items because the corrosion model indicates both duration of sulfate on the turbine and temperature cycling accelerate corrosion. Abrupt power reductions can also cause the compessor to shed retained salt to initiate sulfidation in the turbine.

Sensor locations and parameter ranges have been identified. Sensor specifications have been written and sent to vendors for bid. The control logic has been defined but not finalized. We remain flexible in order to capitalize on all forthcoming data and analyses.

Operational control aspects have been reviewed with a limited number of users and plans are to expand this base before the control outputs are finalized.

Task III Design, Develop and Test Control System

The bulk of work in this task will be performed in the next half of the program. A vendor has been chosen for the sensor design and fabrication, which is now in progress.

The control system is being designed by PSD. A combination of functional controllers has been decided upon because it is easy to prepare in small quantities and easily modified. A digital computer control would be selected for production equipment because it would be smaller, more rugged and probably cheaper in larger quantities.

Section 2

TASK 1 - ESTABLISH CORROSION MODEL

The purpose of this task is to define the corrosion process, establish the corrosion envelope, define a corrosion model, and verify this model. The definition of the corrosion process and envelope has been done by means of laboratory and field tests. Verification of the corrosion model will occur when sufficient field and lab tests have been completed.

DEFINITION OF CORROSION PROCESS

Two primary efforts are involved with the definition process: a) laboratory tests, and b) field tests. Analyses of the laboratory and field data have provided the correlation necessary to complete the definition phase. Initial direction and guidelines were established from correlation of past field experience.

Correlation of Field Experience

The field data reported herein were taken from TPM* records of engines assigned to domestic electric utilities. The data bank considered those engines in service from about May 1973. In this study, the severity of sulfidation corrosion was not considered; the presence of the attack automatically led to the classification of "sulfidation." All other factors fell into the classification of "not sulfidized." The assumption was made that failure to report sulfidation meant that no sulfidation had been observed.

The engines were classified according to the fuel listed: liquid, gas, or dual. Also, engines were classified by distance from the ocean: less-than or more-than fifty miles. The data examined is summarized in Tables 2.1 and 2.2.

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*Turbo Power & Marine Department of Power Systems Division

Table 2.1 - Survey Engines Installed in Domestic Electric Utilities

	Year	1973	1974	1975	1976
Less	Liquid Fuel	158	170	180	188
than	Gas Fuel	21	21	21	21
50 Miles	Dual Fuel	262	263	263	265
		441	454	464	474
More	Liquid Fuel	56	68	68	68
than	Gas Fuel	19	19	19	19
50 Miles	Dual Fuel	125	125	125	125
		200	212	212	212
	Grand Total	641	666	676	686

Table 2.2 - Summary of Engine Removals

A. Cases with Sulfidation Reported

	Year	1973	1974	1975	1976	TOTAL
Less	Liquid Fuel	23	23	24	3	73
than	Gas Fuel	1	1	0	0	2
50 Miles	Dual Fuel	40	42	12	2	96
		64	66	36	5	171
More	Liquid Fuel	1	1	6	2	10
than	Gas Fuel	1	1	7	0	9
50 Miles	Dual Fuel	13	14	12	9	48
		15	16	25	11	67

B. Cases with No Sulfidation Reported

	Year	1973	1974	1975	1976	TOTAL
Less	Liquid Fuel	6	21	12	6	45
than	Gas Fuel	0	0	0	0	0
50 Miles	Dual Fuel	11	24	11	9	55
		17	45	23	15	100
More	Liquid Fuel	1	5	2	1	9
than	Gas Fuel	0	1	1	0	2
50 Miles	Dual Fuel	7	12	6	5	30
		8	18	9	6	41

In analyzing the data as to (a) the reporting of sulfidation and (b) the distance from ocean, the data were summarized as shown in Table 2.3.

Table 2.3 - Sulfidation and Distance from Ocean

	Number of Engines Removed	
	Less than 50 Miles	More than 50 Miles
Sulfidation	171	67
No Sulfidation	100	41

A simple statistical test reveals that the two methods of classification are independent. There were 171 cases of sulfidation for the 474 engines less than 50 miles from the ocean, and 67 cases of sulfidation for 212 installations at distances exceeding 50 miles. The ratios of sulfidation instances to installations is shown in Table 2.4.

Table 2.4 - Ratio of Sulfidation Instances

	Less than 50 Miles	More than 50 Miles	Total
Case of Sulfidation	171	67	238
Total Engines	474	212	686
Ratio	0.361	0.316	0.347

Statistically, the differences in these ratios is not significant, as shown below:

$$Z = \frac{0.361 - 0.316}{\sqrt{\frac{(0.361)\ (0.639)}{474} + \frac{(0.316)\ (0.684)}{212}}} = 1.16$$

In order to be significant, Z would have to be at least 1.65.

$$\text{where } Z = \frac{P_1 - P_2}{\sqrt{\frac{(P_1)\ (1-P_1)}{N_1} + \frac{(P_2)\ (1-P_2)}{N_2}}}$$

and N_1 and N_2 are the numbers of elements in each of the two categories; P_1 and P_2 are the figurations of elements having the tested characteristics in each category. Thus Z has approximately the standard normal distribution. If this is true, then P_1 and P_2 will be quite small, and Z will be near zero. As Z increases in absolute value, the hypothesis becomes more unacceptable. The value of 1.65 is the normal crossover point for rejection from acceptance.

Classification according to fuel used does make a difference in the sulfidation frequency as noted in Table 2.5.

Table 2.5 - Classification of Fuel Used

	Liquid	Gas	Dual
Cases of Sulfidation	83	11	144
Number of Engines	188	21	265
Ratio	0.441	0.524	0.543

When comparing the liquid fuel engines with the dual-fuel engines,

$$Z = \frac{0.543 - 0.441}{\sqrt{\frac{(.0543)\ (0.457)}{265} + \frac{(0.441)\ (0.559)}{188}}} = 2.15$$

Consequently, there is a significant difference favoring liquid-fueled engines, based upon the available data. Unfortunately, the number of gas-fueled engines is too small to provide any significant conclusions.

The conclusion of difference between liquid and dual-fuel engines is further substantiated by another analysis. Consider Table 2.6A.

Table 2.6A - Analysis of Liquid and Dual-Fuel Engines

	S	$\bar{S}$	S'	$\bar{S}'$	Total
L	73	45	10	9	137
D	96	55	48	30	229
Total	169	100	58	39	366

L and D represent fuel classifications. S is the number of removals with sulfidation at installations less than 50 miles from the ocean. S' are those at distances exceeding 50 miles. $\bar{S}$ and $\bar{S}'$ are the corresponding frequencies of removals where sulfidation was not reported. The question is - are these ways of classification independent? They should not be independent if the liquid and dual-fueled engines have different frequency ratios. The expected values in the tables, based on the assumption of independence, are shown in Table 2.6B.

Table 2.6B - Expected Values, Based on Assumption of Independence

	S	$\bar{S}$	S'	$\bar{S}'$
L	63.3	37.4	21.0	15.3
D	105.7	62.6	37.0	23.7

The test statistic is "V" where

$$V = \sum_{i=1}^{8} \frac{(Oi - Ei)^2}{Ei}$$

where Oi are the elements of Table 1.6 and Ei are the elements of Table 1.7

V is the chi-square test of goodness of fit. For these data, with 3 degrees of freedom, V must exceed 11.34 to be statistically significant. In this case V = 18.2, which is very significant and leads to the conclusion that there is dependence.

Results and Discussion

These studies show that the data available support the hypothesis that liquid-fueled engines have significantly lower-sulfidation likelihood than do dual-fueled engines. However, there is little difference in likelihood of sulfidation according to distance from the ocean. Indications are that conditions are less favorable for sulfidation at greater distances.

The following data relate sulfidation corrosion with the presence or absence of air filtration and wash capabilities for the engines available in the TPM data bank. The pertinent data are summarized in Table 2.7A.

Table 2.7A - Engines Evaluated in Sulfidation Study

	W	$\overline{W}$	Total
F	70	69	139
$\overline{F}$	144	256	400
Total	214	325	539

In the above table, W denotes the presence of waterwash capability and $\overline{W}$ denotes its absence, while F and $\overline{F}$ represent the presence and absence, respectively, of air filtration. Table 2.7B lists the data on engine removals where sulfidiation corrosion was reported. These data include removals that were sulfidation related and those that were not sulfidation related but in which sulfication corrosion was observed.

Table 2.7B - Removals where Sulfidation Corrosion was Present

	W	$\overline{W}$	Total
F	31	43	74
$\overline{F}$	39	77	116
Total	70	120	190

To determine the fraction of sulfidation occurrences in each of the categories, i.e., with or without waterwash and air filters, the corresponding elements in Table 2.7B were divided by those in Table 2.7A. This represents the fraction of engine removals where sulfidation was observed. These data are listed in Table 2.7C.

Table 2.7C - Fraction of Removals where Sulfidation Corrosion was Observed

	W	$\overline{W}$	Total
F	0.443	0.623	0.532
$\overline{F}$	0.271	0.301	0.290
Total	0.327	0.369	0.353

Results and Discussion

Examination of the data in Table 2.7C, whether there was waterwash capability or not, indicates that those engines with air filters exhibited a greater propensity to sulfidate than did those without air filters. The reason for this is unknown but may be related to the reason filters were installed, i.e., hostile environment, previous history of sulfidation, etc. The data also show that, whether or not the engines contained an air filtration system, those engines that had waterwash capabilities exhibited fewer instances of sulfidation than those without.

The Long Island Lighting Company has periodically removed first stage vanes from their engines located at Holbrook, Long Island, and the vanes were quantitatively chemically analyzed in order to determine the amount of sodium sulfate present on the surface. The vanes were then metallographically sectioned to confirm sulfidation corrosion. The results to date are summarized in Figure 2.1 where the amount of sodium sulfate milligrams found on the turbine vane, is plotted as a function of time in hours. The square data point symbols represent the vanes removed from engines that have air filtration. The circular data point symbols are from engines without air filtration. It should also be noted that some engines were water washed whenever possible, whereas the other units were water washed on a non-scheduled basis. The shading of the symbols indicates the results of both visual and metallographic analysis. The unshaded symbols indicate that both visually and metallographically the coating is in good condition, Figure 2.2, protecting the substrate from corrosion. Shaded symbols indicate that the vane is useable, Figure 2.3, but corrosion is occurring along the leading edge and on the concave surfaces. The filled symbols indicate complete coating breakdown and sulfidation attack of the substrate, Figure 2.4. The partially filled symbols indicate the transition from useable to failing.

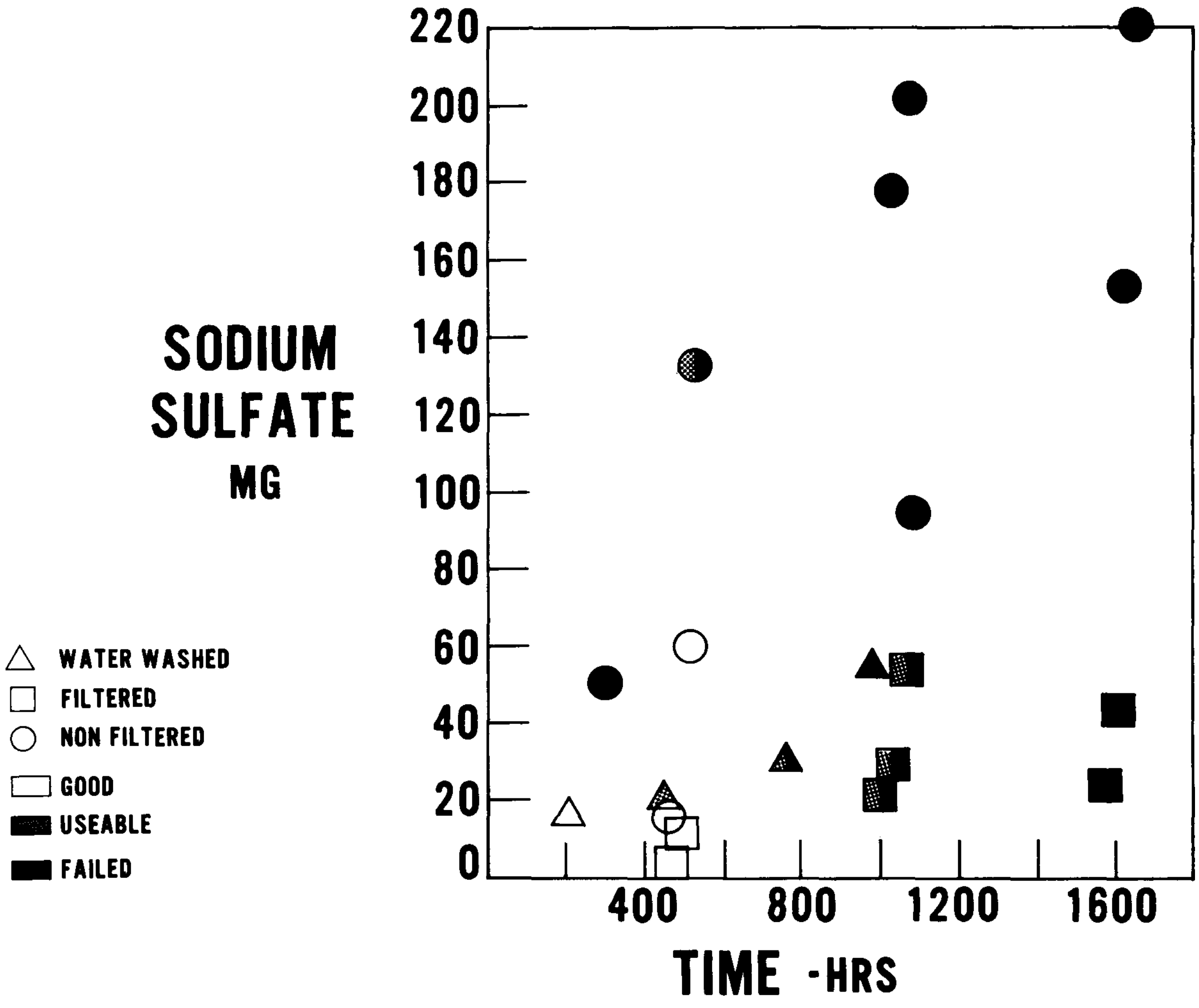


Figure 2.1 - LILCO Sulfidation Watch

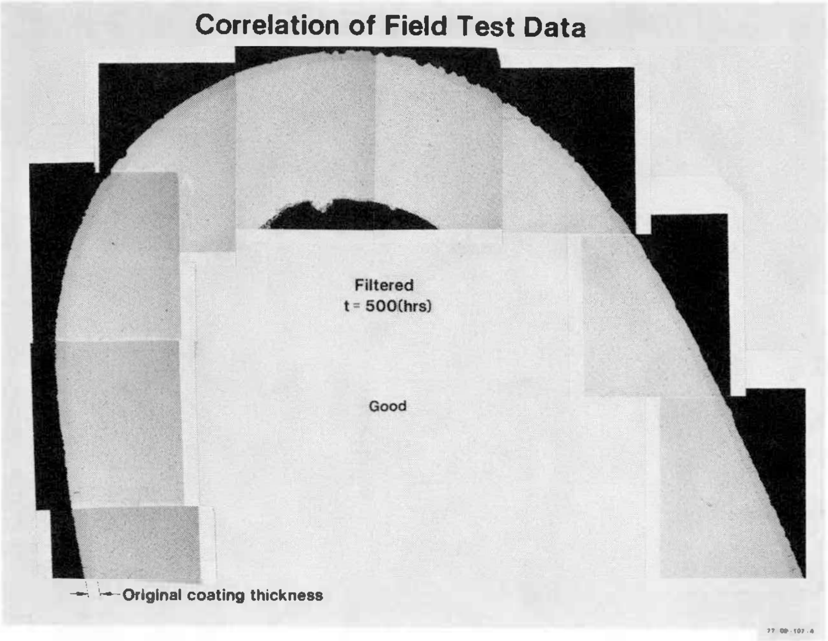


Figure 2.2 - Correlation of Field Data - Good Condition

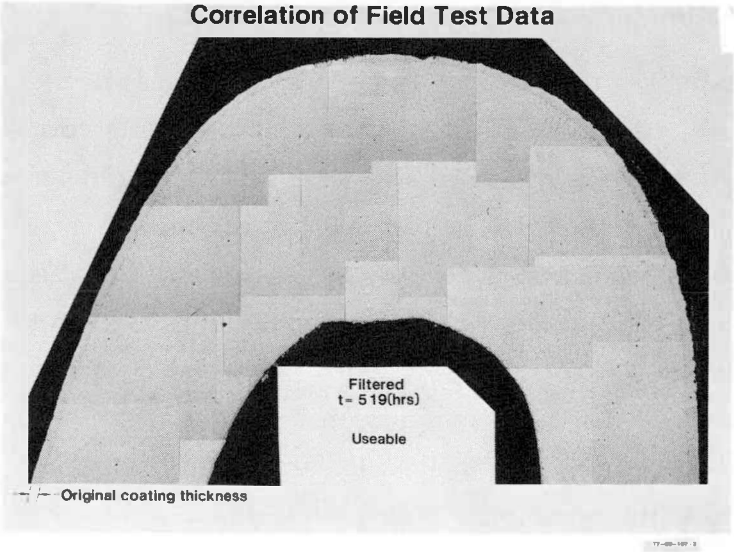


Figure 2.3 - Correlation of Field Test Data - Useable Condition

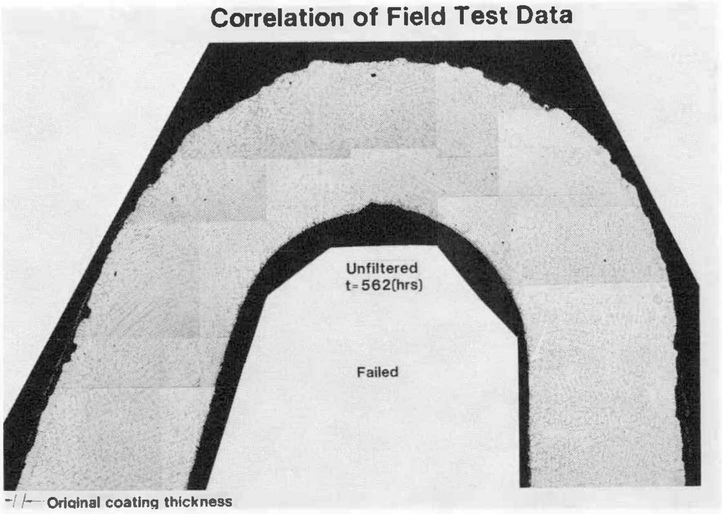


Figure 2.4 - Correlation of Field Data - Failed Condition

Based upon the experimental data, it is noted that for comparable times the amount of salt present on vanes removed from engines with air filtration varies from one-tenth to one-half of the amount noted on vanes removed from sister engines without air filtration.

Based upon the experimental data, the minimum time necessary for visual observation of failure due to sulfidation corrosion is 300 hours. The amount of salt found on the surface of a failed vane was fifty milligrams. However, vane removed from another engine after 500 hours had 60 mg. of salt present on its surface, and based upon both visual and metallographic analysis, the vane had not failed. It is observed that vanes with less salt and more time have failed and vanes with more salt and less time have not failed. The laboratory tests clearly show that once salt is present on the surface of the alloys, corrosion will occur. These results indicate that the quantity of salt found on the components was most likely not present on the surface of the vane for the life of the vane but had been deposited at some intermittent point in the history of the component.

Laboratory and Field Tests

Laboratory Tests

Oxidation

Experimental Procedures

The oxidation behavior of the four alloys - U700, In792, In738, and Mar-M-509 - was evaluated at 1500°F, 1650°F, and 1800°F. The test samples were in the shape of bars, approximately 1/2" x 3/8" x 3", weighing approximately 60 gms. The bars were initially weighed to an accuracy ± 0.001 gms. on a Mettler Type H 16 balance. The test bars were placed in electric resistance-type furnaces at temperature. The furnace temperatures were controlled via off/on controllers to ± 25°F. For the first 200 hours of the test, the bars were removed from the furnace every 25 hours, washed under running water, air dryed, and weighed to determine their change in weight. After the first 200 hours of testing, the bars were cleaned and weighed every 100 hours for the duration of the 1000-hour test.

At the completion of the tests, the bars were metallographically prepared for visual examination. Photomicrographs were prepared for documentation.

Results and Discussion

The isothermal oxidation behavior of the four alloys is shown in Figures 2.5 through 2.8. These curves show the change in sample weight as a function of time: the change in weight is associated with the growing oxide scale which forms as the substrate unites with oxygen. Weight losses occur when the scale spalls.

The high-temperature oxidation behavior of U700 at 1800°F, 1650°F, and 1500°F is shown in Figure 2.5. At both 1500°F and 1650°F, the oxidation behavior of the alloy was that of a material which had formed a protective oxide scale limiting the availability of oxygen to the surface. The very slight increase in weight as a function of time was consistent with the formation of a thin adherent oxide scale which resisted spallation due to the thermal cycles imposed by the test. However, at 1800°F, spallation of the oxide scale occured after only 85 hours, resulting in rapid weight losses after only 125 hours. The microstructure of the substrate is shown in Figure 2.9.

Figure 2.6 shows the high temperature oxidation behavior of In792. At all three temperatures - 1500°F, 1650°F, and 1800°F - the alloy formed an adherent oxide scale which showed no propensity to spall during the 1000-hour duration of the test. Figure 2.7 is a similar curve for In738. At 1500°F and 1650°F, the high-temperature oxidation behavior of this alloy was similar to that of U700 and In792. At 1800°F, In738 initially forms an adherent oxide scale, but after about 425 hours, the scale began to exfoliate. The scale was continuing to spall when the test was terminated after 1000 hours, although the spallation never became catastrophic.

Figure 2.8 shows the high temperature oxidation behavior of Mar-M-509. At 1500°F and 1650°F the oxidation behavior is similar to the other alloys discussed. At 1800°F Mar-M-509 shows a rapid oxide scale build up followed by an almost equally rapid exfoliation of the scale. All this occurs within the first 100 hours of the test. The spallation rate is then much lower for the balance of the test period.

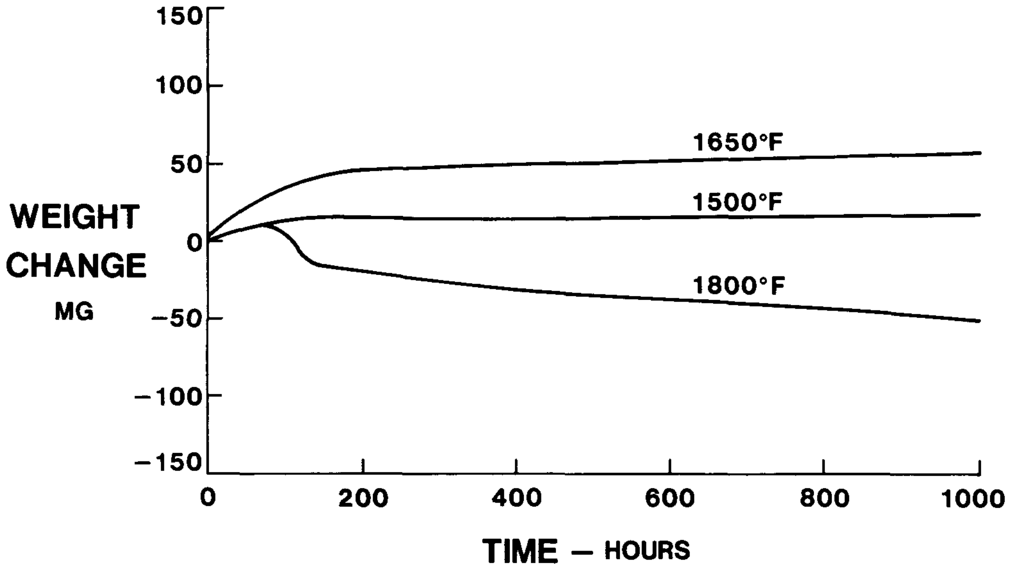


Figure 2.5 - Oxidation Studies of U 700

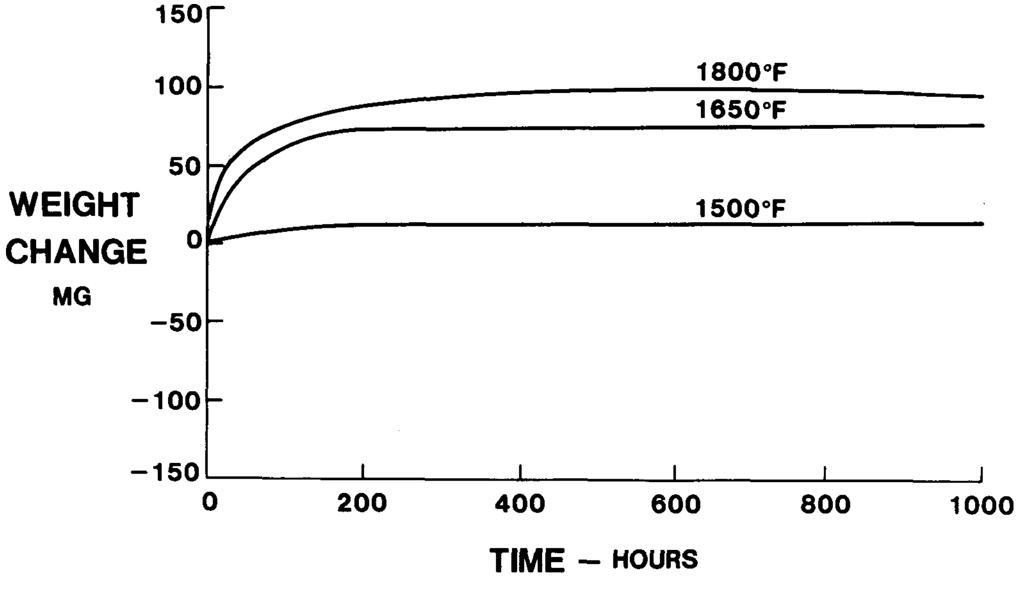


Figure 2.6 - Oxidation Studies of In 792

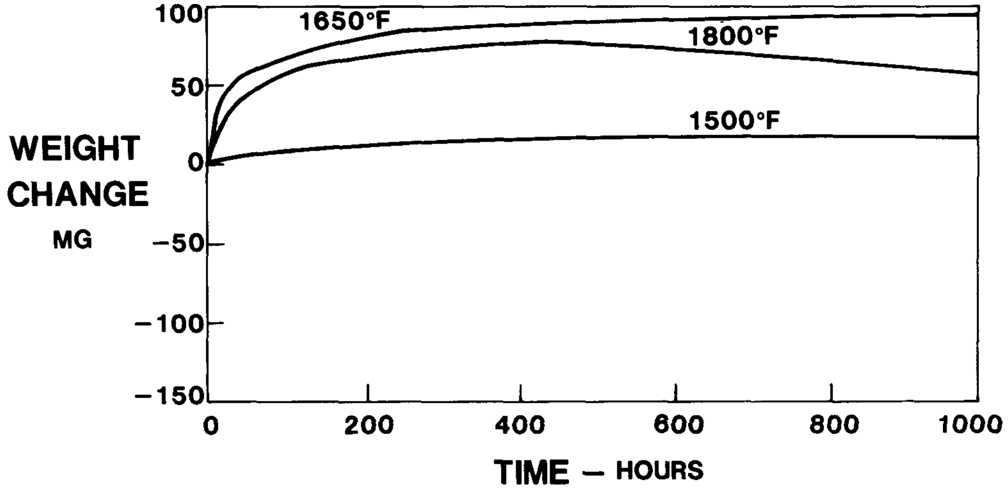


Figure 2.7 - Oxidation Studies of In 738

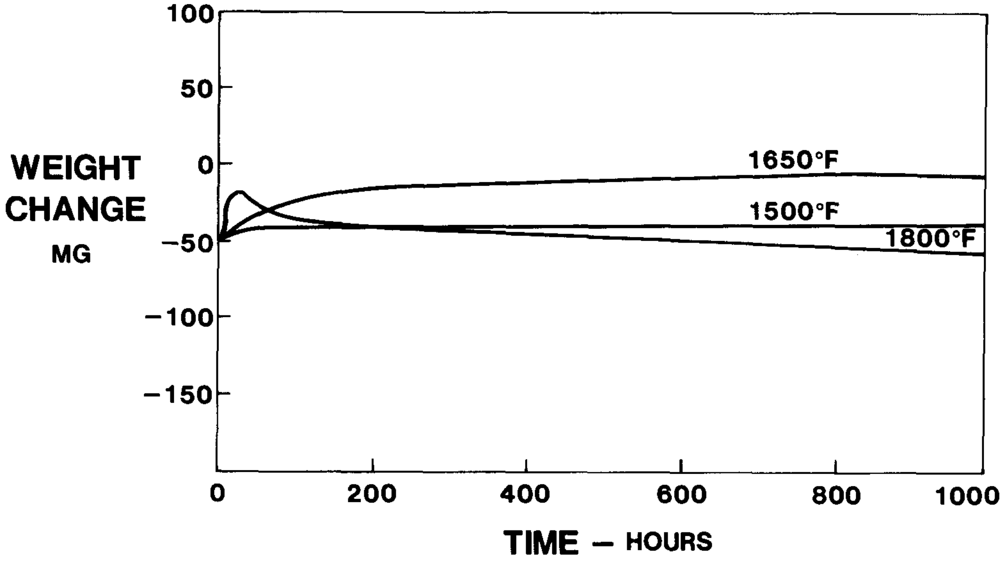


Figure 2.8 - Oxidation Studies of Mar-M-509

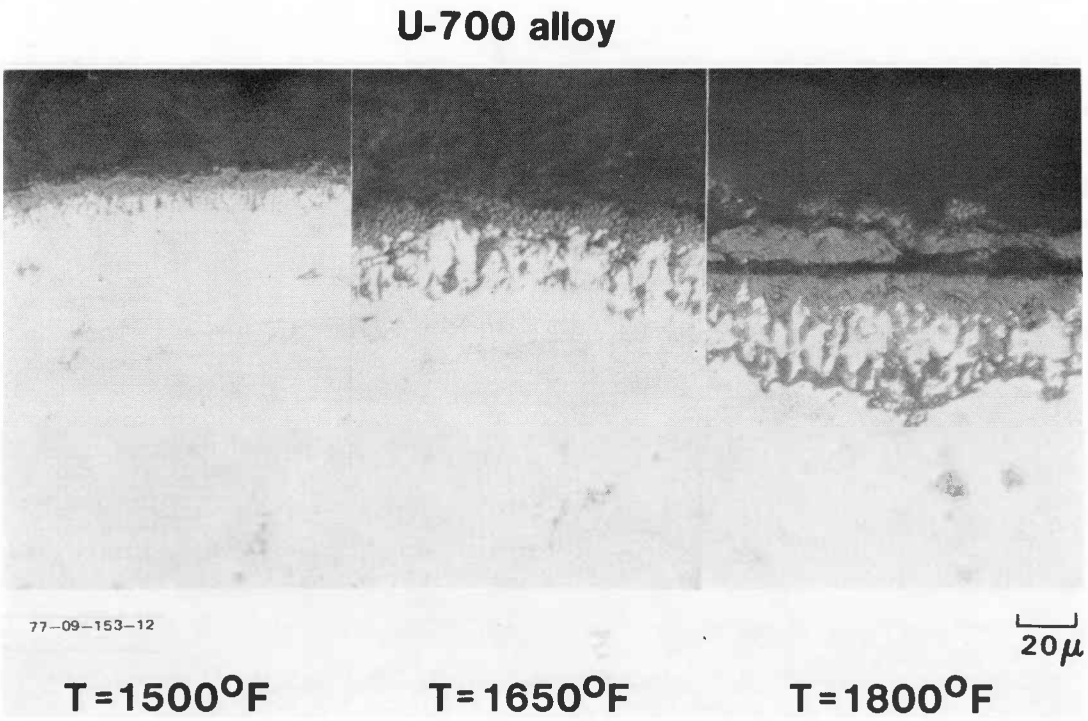


Figure 2.9 - Microstructure of Substrate

Corrosion

Experimental Procedures

The following procedures were used on all subsequent corrosion studies.

Isothermal Corrosion Tests

The geometry of the specimen for the corrosion studies was identical to that for the oxidation tests except that the surface of the bars was coated with a nominal 1mg/cm^2 of corrodent. For Na_2SO_4 (sulfidation) studies, the salt solution was made by saturating, at room temperature, 1 pint of distilled water with reagent grade Na_2SO_4. The test bars were heated on a hot plate and sprayed with the salt solution. The bars were coated prior to each heat-treatment cycle.

In order to determine the effect of impurities on the sulfidation behavior of the candidate alloys, the saline solution was modified: the solution contained 90 wt. % Na_2SO_4 + 10 wt. % impurity. The impurities studied included NaCl, C, and V_2O_5. The NaCl was added as reagent grade NaCl, and the C was added as Aquadag. The V_2O_5 was added as purified $VOSO_4$, which decomposes at elevated temperatures to form V_2O_5.

Na_2SO_4

Sulfidation corrosion has been studied intensively for more than two decades. The techniques used include weight-gain measurements, in which the amount of oxygen present as an oxide is determined, or by weight-loss measurements, in which the oxide scale is chemically removed in a fused-salt bath, as well as metallographic measurements, in which the cross-sectional area is determined. In the field, however, the gas turbine operator or refurbisher can neither determine the usefulness of a component by weight-change measurements, nor evaluate the component by destructive test, such as metallographic examination. His criteria for acceptance or questioning are based primarily upon visual observation. Experience has shown that the presence of a loose greenish friable scale on the surface indicates hot corrosion and the need for replacement or refurbishment. This same visual indicator of significant sulfidation attack is used to rank the results of laboratory studies reported herein. To assist in understanding these visual indications, weight-change measurements and metallographic examinations were made on selected specimens to verify depth of corrosion.

Results and Discussion

The sulfidation behavior of the nickel-base superalloys is presented in Figure 2.10. The coordinates of the graph are time (hrs) for visible corrosion versus the reciprocal of the absolute temperature. At 1800°F, there is little difference, if any, in the sulfidation resistance of the alloys. In this test, at the end of 175 hours all the nickel-base alloys had failed, and after only 20 hours, sufficient visual distress was noted in the Mar-M-509 alloy to label it as failed. Before concluding that 1 mg/cm^2 Na_2SO_4 is an unusually large amount of corrodent, it should be noted that many investigators commonly apply from one-to-five mg/cm^2 of salt while some immerse the alloy into a bath of salt. More importantly, the amount of alkali sulfate found on coated first-stage components removed from LILCO gas turbine engines is about 1 mg/cm^2 Na_2SO_4.

At 1650°F and 1500°F, the relative life of the alloy increases. The increase in life, as a function of decrease in temperature, is summarized in the Table 2.8.

Table 2.8 - Increase in Life

Alloy	1800°F - 1650°F		1650°F - 1500°F		1500°F - 1300°F (estimated)	
	Hours	%	Hours	%	Hours	%
U700	+ 45	26	+ 180	81	+ 589	138
In972	+140	80	+ 265	83	+ 820	141
In738	+405	331	+ 495	85	+1625	149
Mar-M-509	+680	3890	+1300	286	+6000	300

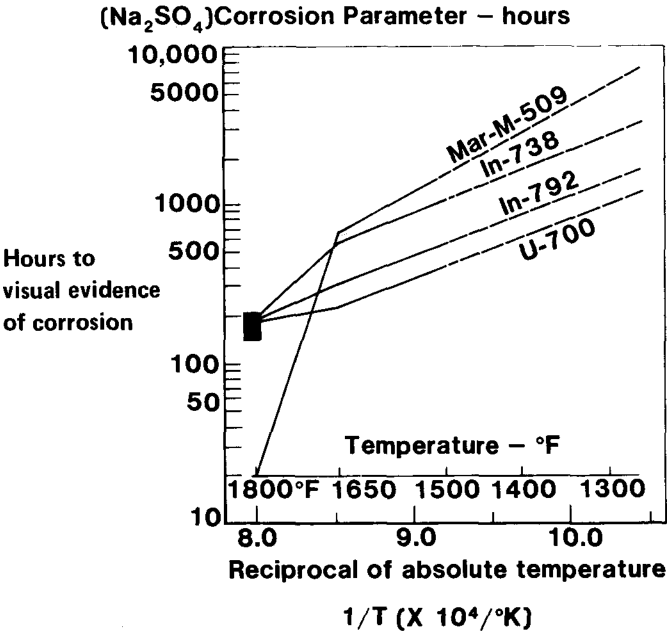


Figure 2.10 - Sulfidation Corrosion

It is important to realize that these numbers are based upon laboratory tests and do not take into account many engine variables, such as erosion, thermal gradients, and stresses - important nonlinear variables. However, the laboratory tests do indicate the directions and relative susceptibility of the materials and, hence, are useful and valid tests. The function relating laboratory results to industrial experiences must be experimentally determined. As indicated by Figure 2.10, the rate of corrosion of gas turbine components can be decreased markedly by decreasing the temperature. However, it is most important to realize that the temperature defined is the surface temperature of the alloy, not the average-or-bulk temperature, and that the emphasis, with respect to corrosion, is focused on the hot-spot temperature.

Na_2SO_4 + NaCl

The ability of NaCl to attack quickly and to destroy superalloys is not new; studies of the effect, with respect to nickel and cobalt base alloys, date back to Skyes and Shirley (1). More recently, Hancock has shown that under certain conditions, gaseous NaCl can adversely affect the oxidation properties of superalloys while Stringer and his associates have shown that molten chlorides readily attack and dissolve the carbide network present in superalloys. Although it is agreed that molten NaCl is a very corrosive salt and that a mixture of NaCl and Na_2SO_4 is quite aggressive, it has not been established that (a) mixtures of Na_2SO_4 and NaCl are present on turbine components, and (b) if present, the duration of stability, since the oxides of sulfur present in the environment would convert condensed NaCl into Na_2SO_4. Because trace quantities of NaCl can be observed in deposits (0.1 w/o), and because NaCl is the major component of sea salt, the effect of this component on the accelerated rate of oxidation of Na_2SO_4 coated substrate was evaluated.

Results and Discussion

The results are presented graphically in Figure 2.11 and summarized in Table 2.9. As previously noted, the life of a given salt-coated substrate increases with decreasing substrate temperature. Due to the presence of 10w/o NaCl, however, the absolute in life is quite severely decreased.

(1) Skyes, C; and Shirley, H. T. ISI Special Report #43 p. 152 (1951)

Table 2.9 - Effect of 10w/o NaCl on Na_2SO_4 Corrosion

Debit in Life

Alloy	Change at 1800°F Hours	% Change	Change at 1650°F Hours	% Change	Change at 1500°F Hours	% Change
U700	-160	91.4	-190	86.4	- 360	88
In792	-160	91.4	- 30	9.4	- 100	17
In738	-160	91.4	-540	90	-1030	96
Mar-M-509	- 15	75	-685	98	-1980	99

At 1800°F, the NaCl markedly increased the corrosivity of the salt, and for all practical purposes, failure occurred within 24 hours. The only alloy to offer resistance to the fused-salt mixture was In792. As shown in Table 2.9, at temperatures below 1800°F the presence of the NaCl decreased the life of the other alloys approximately ninety percent, but the life of the In792 alloy was decreased less than twenty percent.

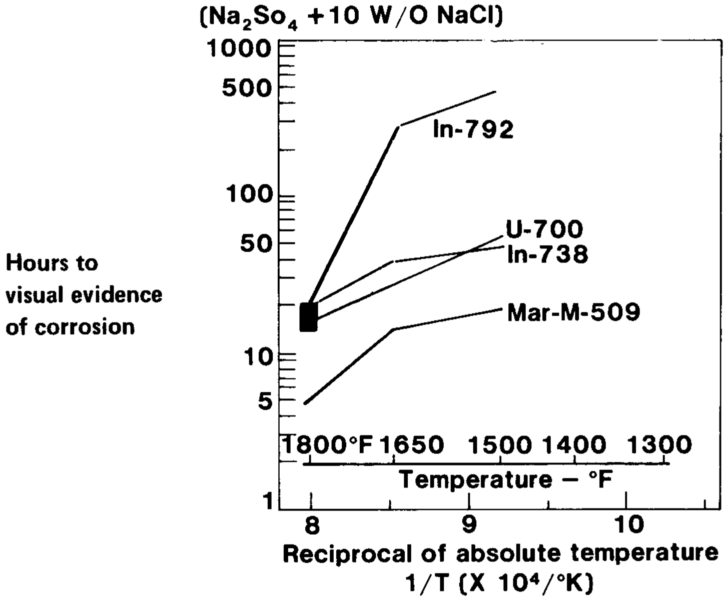


Figure 2.11 - Effect of 10% NaCl on Sulfidation Corrosion

Na_2SO_4 + C

As previously mentioned, carbon can be present on turbine components. The source of carbon is unburnt fuel. Carbon, a very strong reducing agent, can react with and alter oxide scales. In the presence of sodium sulfate, carbon can, by virtue of its affinity for oxygen, increase the oxide ion content of the fused salt making the salt more corrosive. In the tests performed, carbon was co-deposited with Na_2SO_4 onto the superalloy substrates.

Results and Discussion

At the conclusion of the test, it was noted that the corrosion life of the specimens coated with Na_2SO_4 + C was no different than that of the Na_2SO_4-coated specimens. Based upon these results, it is concluded that the surface films of carbon deposited during engine shutdown and combusted during engine operation do not influence sodium sulfate corrosion. A typical result for Na_2SO_4 + C is shown in Figure 2.12.

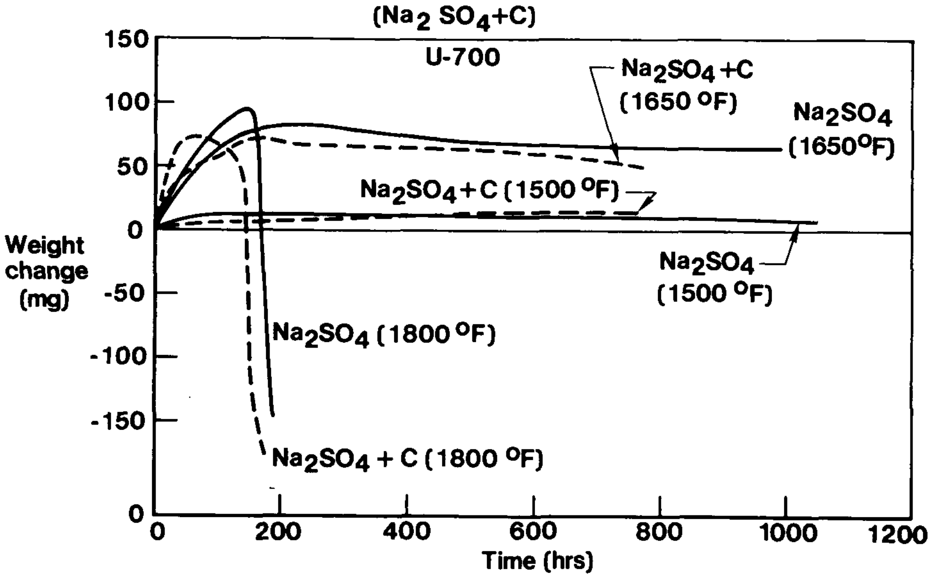


Figure 2.12 - Effect of Carbon on Sulfidation Corrosion

Na_2SO_4 + PbO

These tests are still to be performed, and no results are available at this time.

Na_2SO_4 + V_2O_5

Vanadium is an impurity in fuels that occurs naturally and that can be removed during the distillation process. It is not found in the light distillates, but can vary from less-than-one to more-than-200 ppm in heavy distillates and many residual oils. Vanadium oxide is a low-melting flux, readily capable of reacting with and altering the mechanical and chemical properties of oxide scales. In the presence of other salts, the effect of the corrosive liquid is the disruption of the normally protective oxide scale which allows the salt to contact the substrate.

Results and Discussion

The effect of the ten weight percent addition of V_2O_5 to Na_2SO_4 is presented graphically in Figure 2.13 and summarized in Table 2.10.

Table 2.10 - Effect of 10w/o V_2O_5 on Na_2SO_4 Corrosion

Debit in Life

Alloy	Change at 1800°F Hours	% Change	Change at 1650°F Hours	% Change	Change at 1500°F Hours	% Change
U700	-168	96	-190	83	- 210	50
In792	-168	96	-297	93	- 530	91
In738	-168	96	-530	91	- 820	76
Mar-M-509	-5	25	0	0	-1400	70

At 1800°F, the presence of the vanadium oxide markedly affects the corrosion resistance of the nickel-base superalloys, and the effect is, for all practical purposes, consistent across the temperature range. The cobalt-base alloy Mar-M-509 is affected least by the presence of vanadium oxide.

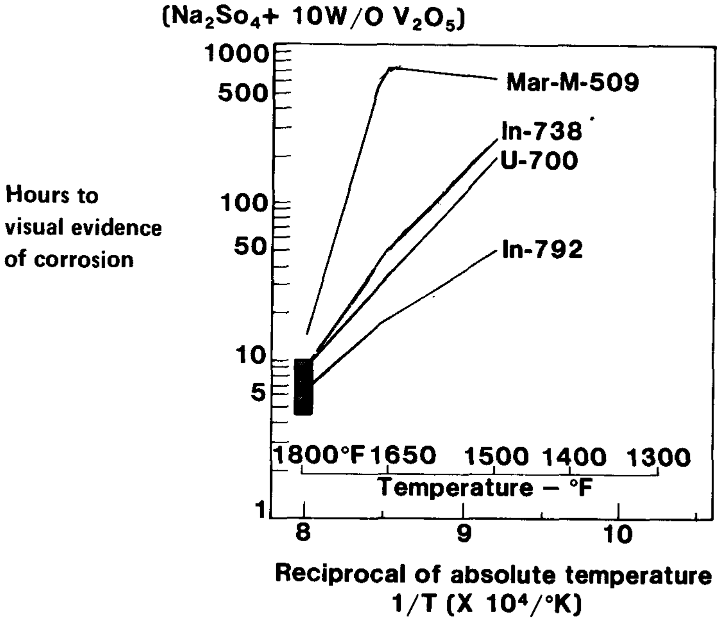


Figure 2.13 - Effect of 10% V_2O_5 on Sulfidation Corrosion

Cyclic Tests

Experimental Procedure

In the cyclic tests, the test bars were coated with the nominal 1 mg/cm^2 of corrodent and placed in the furnaces for one-hour intervals. At one hour intervals the bars were removed from the furnaces and allowed to air cool to room temperature; then they were cleaned and weighed. The specimens were then recoated and returned to the oven. After 8 hours, the heat-treatment time was extended to 2-hour intervals for the remainder of the test.

Results and Discussion

Gas turbine engines used for electric power generation are frequently required to be placed in operation on short notice and for short periods of time, as for example during peak load periods.

The thermal-cycling characteristics of salt-coated alloys, U700, In792, In738, and Mar-M-509, were found to be very similar at all three test temperatures. At 1800°F, the effect of thermal cycling was to decrease the life of the substrate by an order of magnitude. At 1650°F, the effect of thermal cycling was to decrease the life of all specimens; but the measured effect was a factor of two to four. At 1500°F, no noticeable differences were noted. It is neither stated nor inferred that at 1500°F, the scale formed resisted spallation or that spallation does not occur. It is stated that at 1500°F, the rate of visual corrosion has sufficiently decreased so that the effect of scale spallation is not a major factor.

Burner Rig Tests

Experimental Procedure

Burner rig tests (Figure 2.14) were conducted at 1650°F. The alloy used in these tests is B-1900, selected because it is an alloy known for its high susceptibility to hot corrosion attack. In the burner rig tests, the Na^+ was added to the fuel as a 6 wt% solution of naphthenate dissolved in 2-butoxyethanol. The sodium naphthenate was dissolved in 2-butoxyethanol to yield a solution of about 660 ppm Na^+. Each master mix solution was analyzed, via wet chemistry, to determine the actual Na^+ content. The required amount of master mix solution was added to the Jet A fuel to yield the desired Na^+ content. Samples of the doped fuel were periodically analyzed, via wet chemistry, to determine actual Na^+ content. The tests were conducted at an air/fuel ratio of about 16:1 and at doping levels of from 0 to 200 ppm of Na^+ in the fuel.

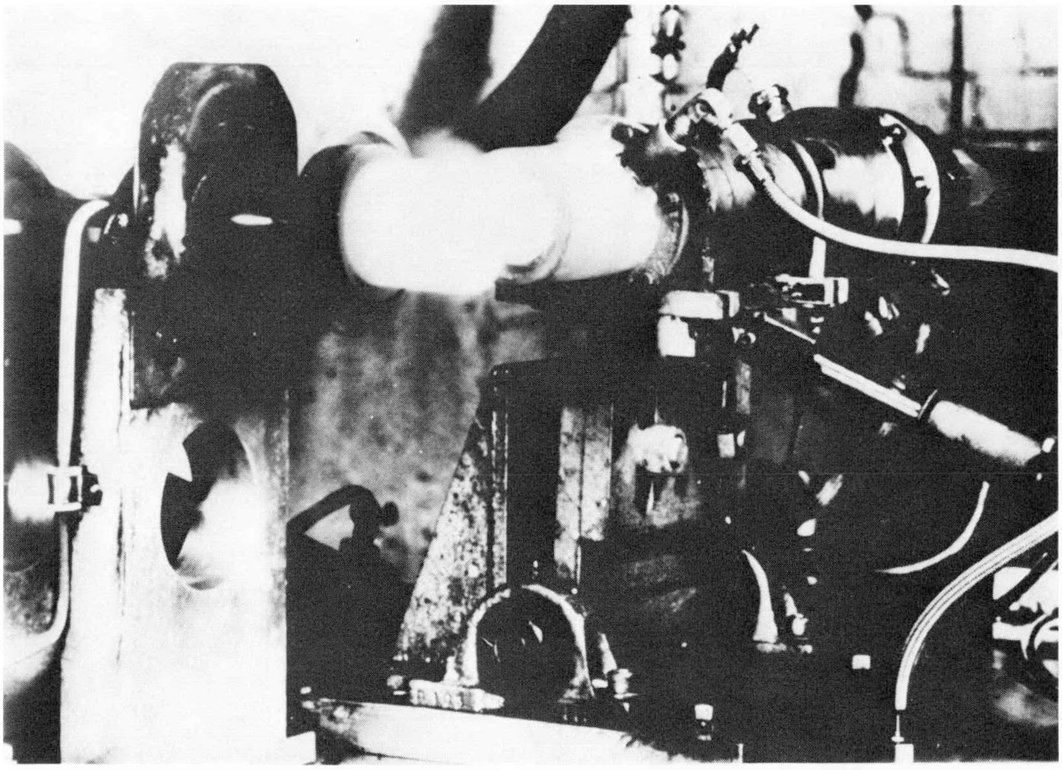


Figure 2.14 - Burner Stand Test Rig

Results and Discussion

The results of the burner rig tests are summarized in Table 2.11. For the first series of tests B-1900 specimens were exposed at 1650°F for 52 hours, and exhibited only slight surface discoloration due to the formation of a thin oxide scale. When ten parts per million (10 ppm) of sodium was added to the fuel, the results were unchanged; ie., after 35 hours the specimens were only slightly discolored.

Table 2.11

Laboratory Tests
EFFECT OF SODIUM IN FUEL

Time - Hours	NA^+ in Fuel (ppm)	Observation
11	150	Uniform Sulfidation Attack
11	60	Sulfidation Corrosion
6	65	Uniform Sulfidation Corrosion
11	45	Slight Attack at Periphery of Hot Zone
6	45	Slight Attack at Periphery of Hot Zone
6	35	Oxidation
35	10	Oxidation
52	0	Oxidation
11	30(1)	Sulfidation Corrosion

(1) Low air/fuel to induce poor combustion

In the next burner rig test the concentraton of sodium in the fuel was increased to 45 ppm, and at this concentration the first visible signs of sulfidation corrosion were noted after 6 hours at the periphery of the hot zone. After 11 test hours, sulfidation corrosion was established at the periphery but did not occur within the hot zone.

In order to establish the sodium concentration necessary in the fuel and the time required to produce sulfidation corrosion, the concentration of sodium was raised to 150 ppm and the experiment conducted for 11 hours. Under these conditions, severe sulfidation corrosion was noted in the hot section of the test specimen. Even after reducing the concentration of sodium from 150 to 60 ppm, severe sulfidation corrosion was noted after 11 hours of exposure. In the next series of tests, the concentration of sodium in the fuel was maintained at 65 ppm but the duration of the test reduced to six hours. Under these conditions uniform sulfidation corrosion was noted in the hot zone of the specimens. In the last experiment of this series, the concentration of sodium in the fuel was reduced to 35 ppm. At this point, it has been established that if salt condenses onto the hot zone or at the periphery of the hot zone, sulfidation corrosion will be observed within 6 hours. At the 35 ppm level, no corrosion was noted on the test specimens. These results indcate that under the test conditions the concentration of sodium in the fuel had to exceed the theoretical "dew point" concentration for sulfidation corrosion to occur. In the last series of tests, the burner was modified, and the burner tended to produce char particles. Under these conditions, sulfidation corrosion occurred within the hot section of the specimen when the sodium content of the fuel was only 30 ppm. Based upon the results of these tests, it is concluded that in order for sodium present in the fuel to be the principal source of the sulfidation precursor, it must be deposited by a nonequilibrium process. Deposition of sodium sulfate by equilibrium condensation requires rather high sodium levels within the fuel.

Coatings

Experimental Procedures

The coatings examined in this study are (a) simple aluminide, (b) precious metal aluminides, and (c) overlay CoCrAlY. All coatings were vendor produced. The simple aluminide coatings and the precious metal aluminide coatings were produced by Chromoloy, the overlay coatings were produced by P&WA.

In the corrosion tests, Na_2SO_4 was applied to the coated surface and the tests were conducted at 1800°F. Every 24 hours the samples were removed from the furnace, cooled to room temperature, washed in running water, and then fresh salt was applied. The coatings were examined visually each day. Samples that had been heat treated for 50, 100, and 400 hours were metallographically prepared and examined via light microscopy. Photomicrographs were taken to representative coating microstructure.

Results and Discussion

The superalloys used in gas turbine engines are quite complex with respect to alloying elements and phase distribution. In static oxidation tests, the alloys tend to form adherent protective oxide scales that separate the substrate from the oxidizing environment. In the gas turbine environments, the constant spallation of the scale depletes the surface of the alloy of those element(s) that form the protective scale; with time, the change in composition of the alloy can adversely affect both its chemical and mechanical properties. In order to increase the alloy life, the surface characteristics of the alloy are altered by the use of coatings. All coatings are therefore sacrificial in nature: the coating being a large source or reservoir of the active element(s) for protective oxide scale formation.

The protective coatings most widely used can be divided into three groups: namely, (a) simple aluminides, (b) precious metal aluminides, and (c) overlay coatings. In general, the simple aluminides are formed by the reaction and diffusion of aluminum into the alloy and the subsequent conversion of the alloy into the intermetallic compound. Since the substrate alloy is quite complex, the phases present in the coating consists of all the elements present in the substrate, and hence the behavior of the coating is strongly influenced by substrate composition.

The precious metal aluminides consist of the application of a layer of either platinum or rhodium or combinations of the two prior to the aluminizing step. It has been stated that the presence of the precious metal influences the rates of diffusion of aluminum into the substrate in addition to the formation of precious metal aluminides. Again, since the substrate components enter into the coating composition, the alloy influences the chemical characteristics of the coating.

The overlay coating consists of application of coating onto the substrate; all elements necessary for coating formation are simultaneously applied to the substrate. Thus, for the overlay coatings the coating composition is, for all practical purposes, independent of substrate composition. However, at elevated temperatures interdiffusion will occur; and with time, the composition of the coating will change.

The behavior of the simple aluminide on the superalloy U700 prior to testing, after 50 hours, 100 hours, and 400 hours at 1800°F coated with 1 mg/cm^2 of Na_2SO_4 is shown in Figure 2.15. The photomicrograph of the control sample shows diffusion layers that are made up of three zones: the outer zone contains a chromium rich precipitate in an NiAl matrix, the light gray middle zone is essentially pur NiAl, and the inner layer consists of NiAl and ordered phases that include carbides. After 50 hours the outer band is oxidized, denuded of the chromium-rich precipitates; while after 100 hours, the coating has failed. The substrate is under attack, and sulfides (small gray particles in depletion zone) are noted in the substrate.

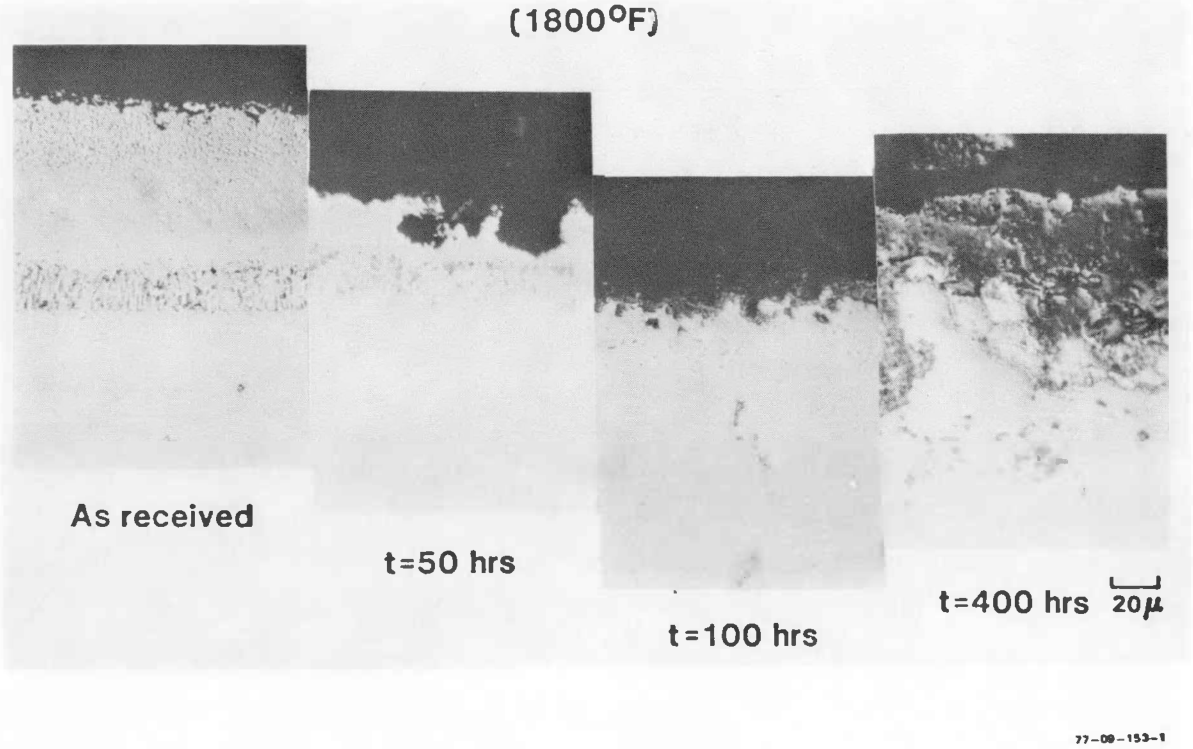
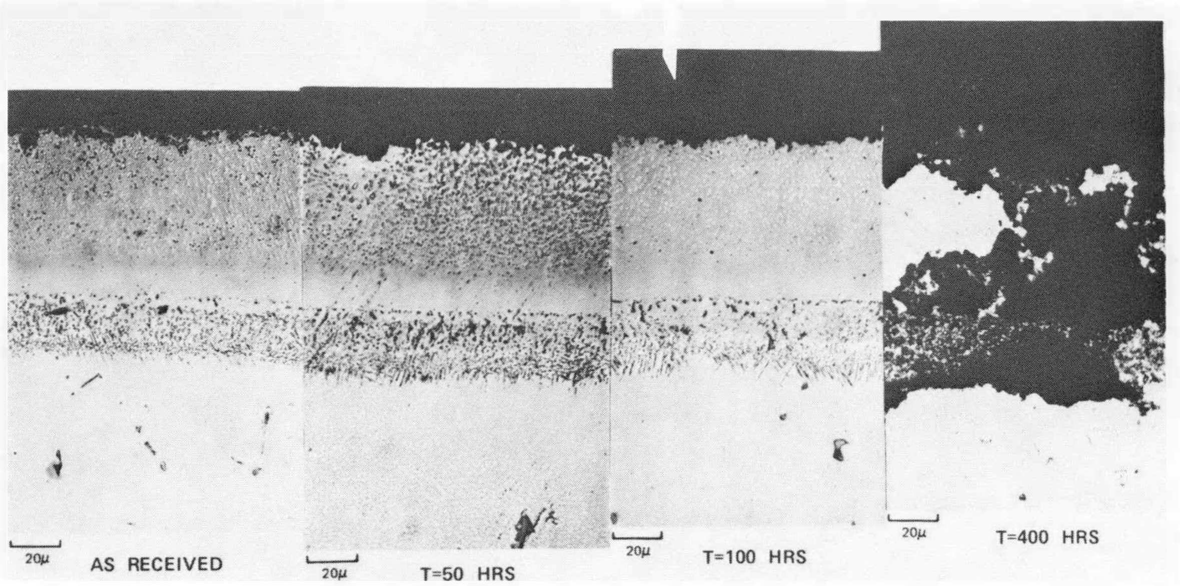


Figure 2.15 - Sulfidation of U700 with Simple Aluminide Coating T = 1800°F

The degradation of the other simple aluminide-coated specimens is comparable to that described for the alloy U700 and is shown in Figures 2.16, 2.17, and 2.18. The time required to produce sulfidation is presented graphically for these materials in Figure 2.19.



77 10 232 2

Figure 2.16 - Sulfidation of In792 with Simple Aluminide Coating T = 1800°F

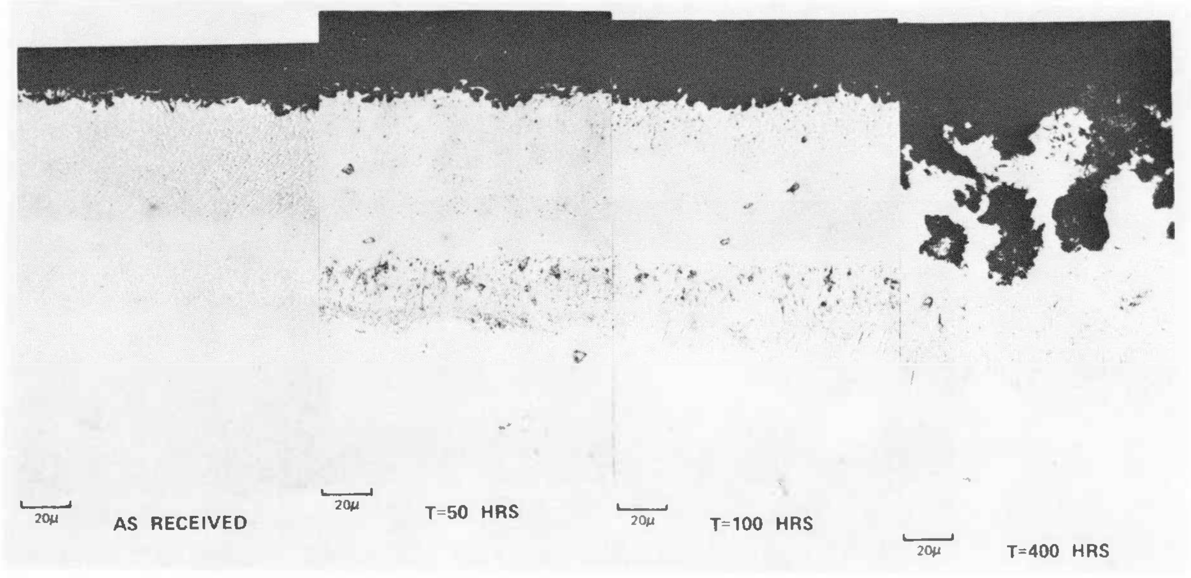


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Figure 2.17 - Sulfidation of In738 with Simple Aluminide Coating, T = 1800°F

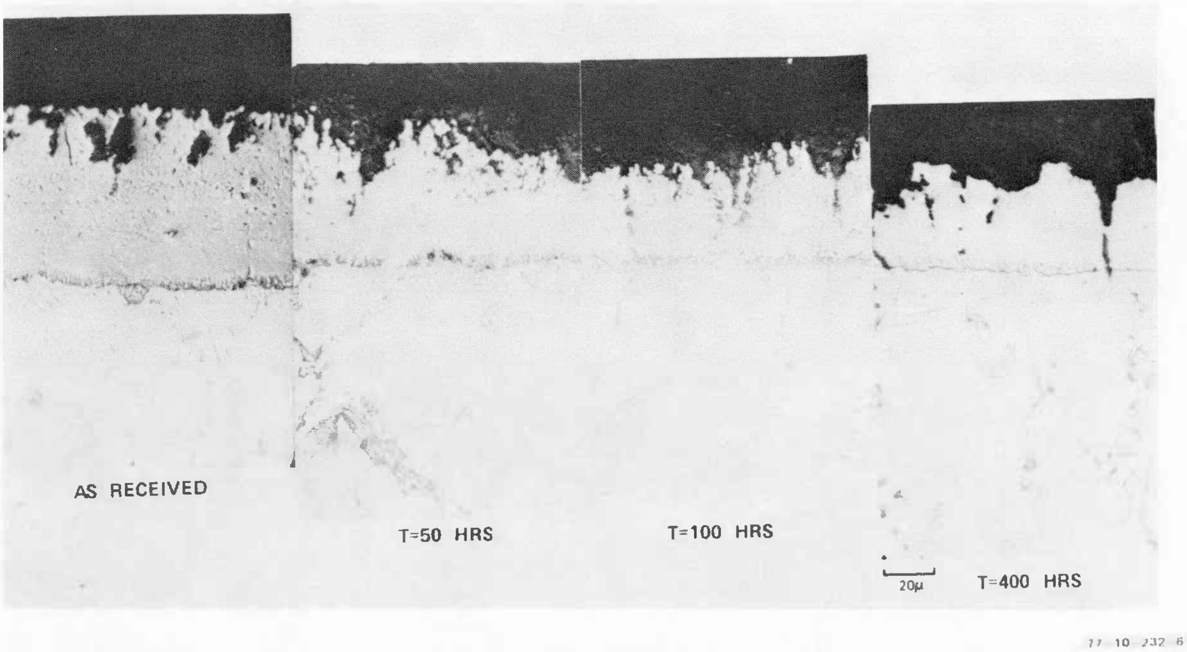

Figure 2.18 - Sulfidation of MAR-M-509 with Simple Aluminide Coating, T = 1800°F

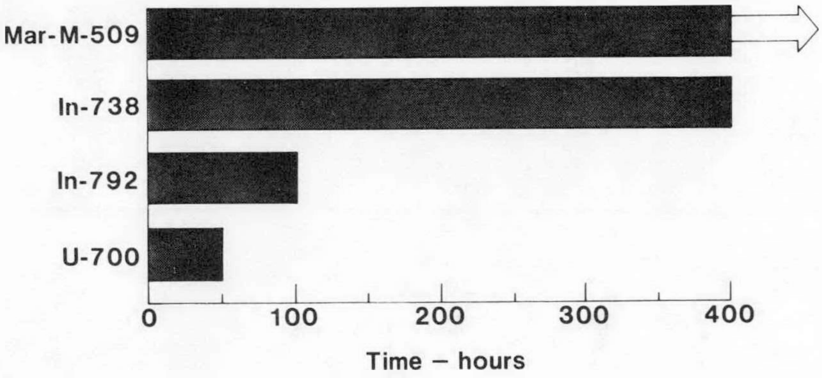

Figure 2.19 - Time for Sulfidation to Attack Simple Aluminide Coating at T = 1800°F

The behavior of the precious metal aluminide coatings is summarized in Figure 2.20 and 2.21. The microstructure of the BB (rhodium) coated U700 alloy is shown in Figure 2.22. After 50 and 100 hours, the coating was protecting the U700 substrate; however, after 400 hours, the coating was defeated and the substrate under attack. The same coating on the nickel-base alloy In792 performed in a similar manner. After 50 hours, the coating was in good condition, but at the end of 100 hours, the coating was severely attacked, and the substrate showed the beginning of sulfidation corrosion.

The In738 and Mar-M-509 alloys with the BB coating performed well. Even after 400 hours the coating was only slightly depleted, but still capable of protecting the superalloy substrates (as shown in Figure 2.23).

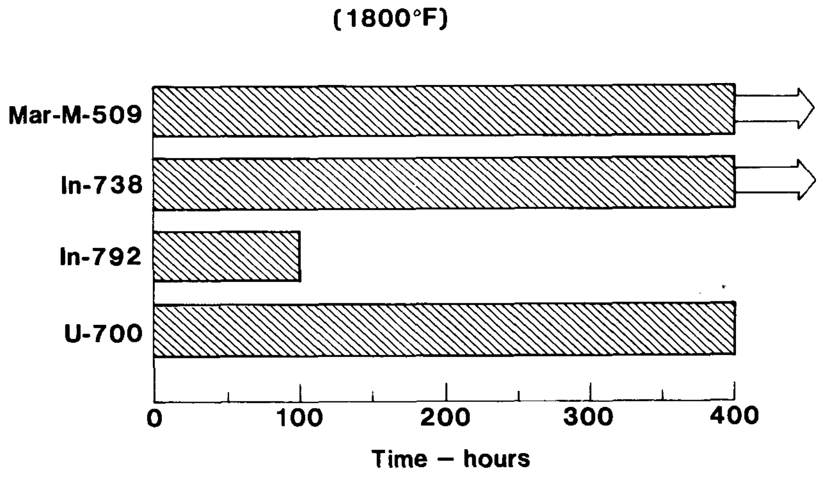

Figure 2.20 - Sulfidation Behavior of BB(Rh-Al) Coating at T= 1800°F

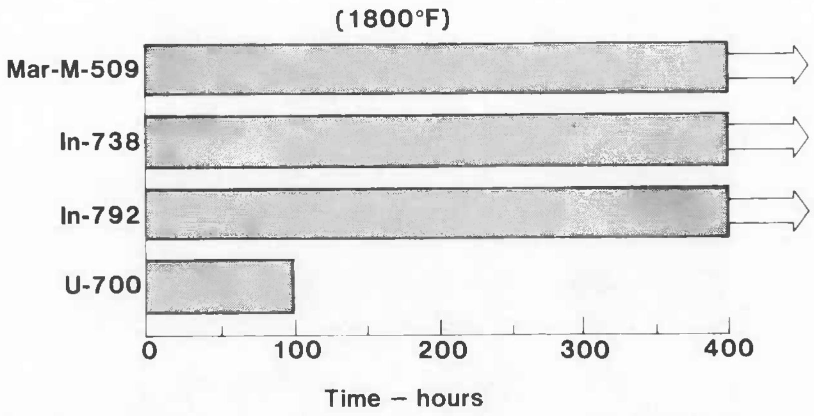

Figure 2.21 - Sulfidation Behavior of RT22 (RT44) Coating at T = 1800°F

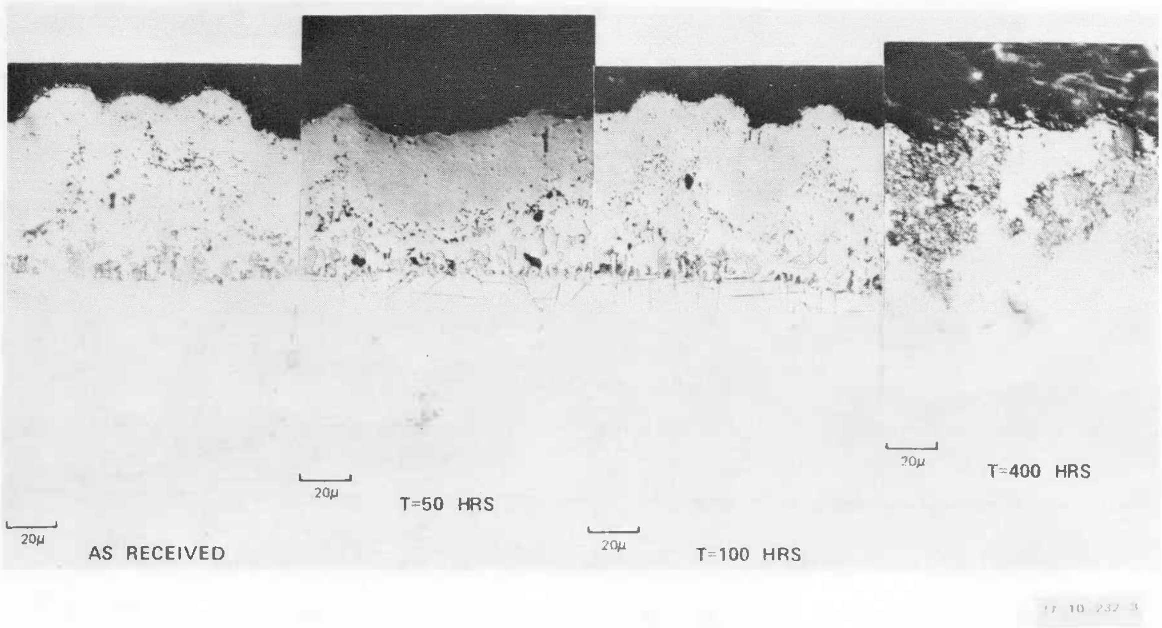

Figure 2.22 - Sulfidation of U700 with BB(Rh-Al) Coating, T = 1800°F

Figure 2.23 - Sulfidation of Mar-M-509 with BB (Rh-Al) Coating, T = 1800°F

Figure 2.24 shows the microstructure of the RT 22 coating applied to U700. Very little change was observed after 100 hours of testing; however, after 400 hours, the coating was severely corroded. The RT 44 coating on the cobalt base alloy Mar-M-509 was in very good condition after 400 hours of testing as shown in Figure 2.25.

In addition to the simple aluminide and precious metal aluminide, the overlay or CoCrAlY coatings were also evaluated. In the laboratory tests these coatings were, in general, unsurpassed in protecting the substrate from corrosion; however, in some specimens, corrosion was noted as occurring down the columner path present in the coatings, as shown in Figure 2.26. This had the effect of depleting the coating at both the free surface and internally, eventually allowing the corrosive to attack the substrate. The sulfidation behavior of the CoCrAlY coating is shown in Figure 2.27.

The ability of the four coatings to protect the substrate of the four candidate alloys under the laboratory test conditions is summarized in Figure 2.28. The data are presented with respect to both coatings and substrate.

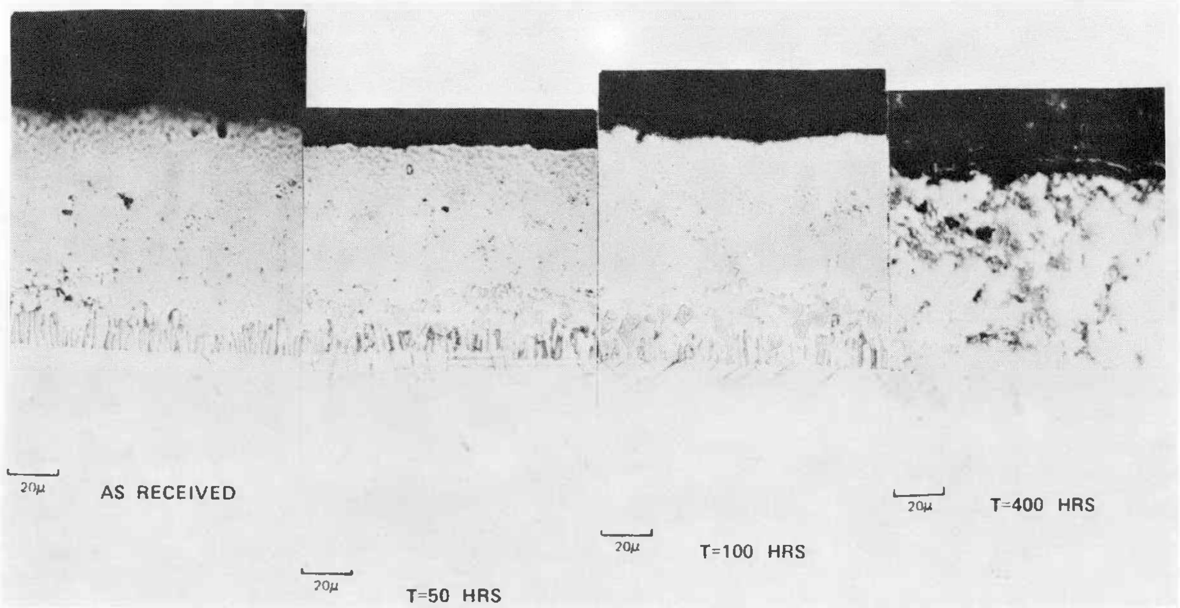

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Figure 2.24 - Sulfidation of U700 with RT 22 (Pt-Al) Coating, T = 1800°F

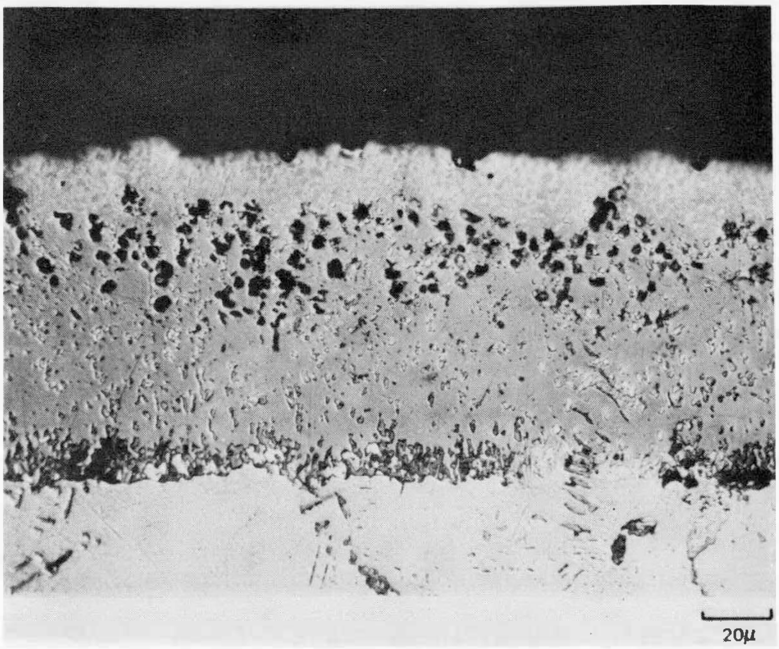

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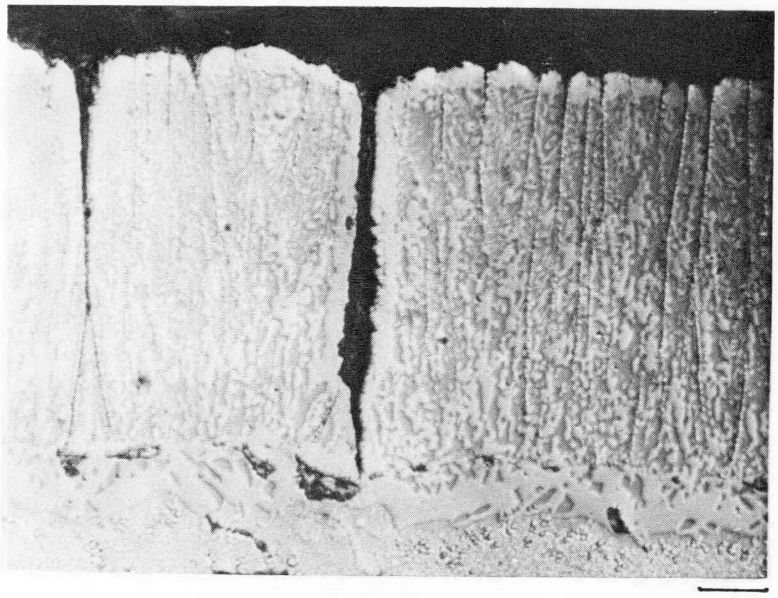
Figure 2.25 - Sulfidation of Mar-M-509 with RT 44 (Pt-Al) Coating, T = 1800°F



(t = 400 HRS)

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Figure 2.26 - Sulfidation of In738 with CoCrAlY Coating, T = 1800°F

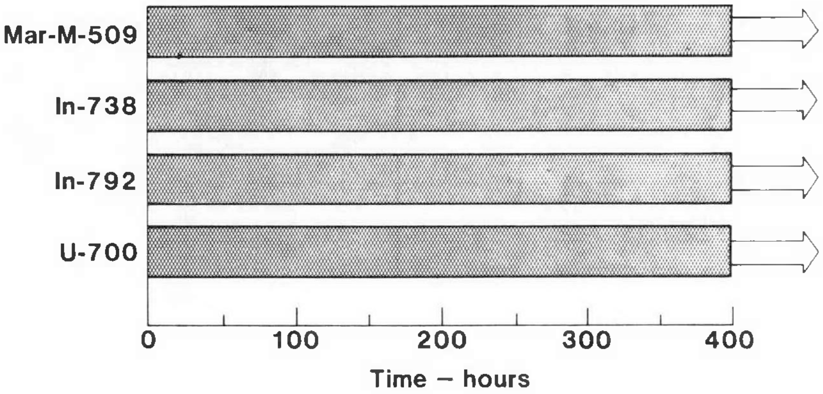


Figure 2.27 - Sulfidation Behavior of CoCrAlY Overlay Coating at T = 1800°F

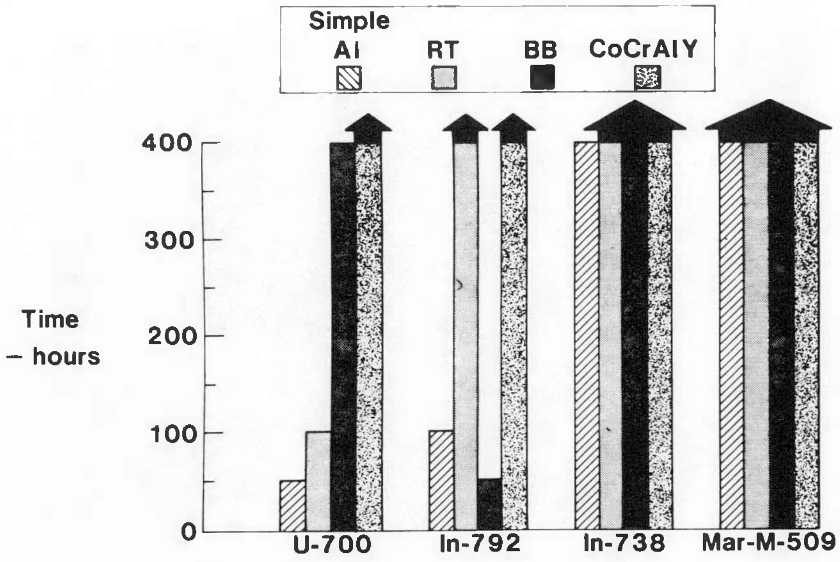


Figure 2.28 - Summary of Sulfidation Behavior

Field Tests

Prepare Monitors for Field

Two PSD-owned CSM-30 sodium ion (Na^+) monitors were overhauled and recalibrated by the manufacturer, Baird Atomic, for use at the LILCO Holbrook station and aboard a Seatrain ship. A third LILCO-owned monitor was calibrated at Holbrook. All units were calibrated for Na-in-air measurements using an aerosol generator that conformed to the requirements of British Standard Institute 4400/1969 specification, describing a method for sodium chloride particulate test for respirator filters. The LILCO unit was also calibrated to measure Na^+ in fuel.

Install CSM-30 at Sites

One CSM-30 with marine shock mounts was installed aboard GTS Asiafreighter on the port side near the gas turbine inlet plenum. The other CSM-30 is at LILCO but is not presently being used. The LILCO-owned monitor has been used for air-filter efficiency tests and Na-in-wash water investigation.

Air-Filter Efficiency Tests

Experimental Procedure

Air-filter efficiency tests were conducted at LILCO, Holbrook Station, on gas turbine unit 10B, and aboard GTS Asiafreighter (Seatrain ship). Ambient Na-in-air levels were measured on a probe 10 feet below the inlet air filter at Holbrook unit 10B. The after inlet filter probe was located at the 11 o'clock position alongside the inlet bellmouth. The BSI 4400 aerosol generator was placed at both sampling locations, and the CSM-30 was calibrated with the sampling tubing, made of polyvinyl chloride (flexible), in the circuit. It had been determined in the laboratory that this tubing does not capture Na^+ over an extended period of time (approx. 40-50 hours). Figure 2.29 shows the test set-up. Aboard GTS Asiafreighter, flexible PVC tubing was used again in the sampling circuit; calibration of the CSM-30 monitor was accomplished using the BSI 4400 aerosol generator at the probe. The after demister/filter probe was located in the inlet plenum opposite the engine inlet at the Ps_2 location (see Figure 2.30). The ambient air probe was located in the ventilation ducting, which is unfiltered, and supplied from the deck above the demister inlet.

Secondary air was also sampled with the ventilation air for comparison; its Na content was the same as ventilator air.

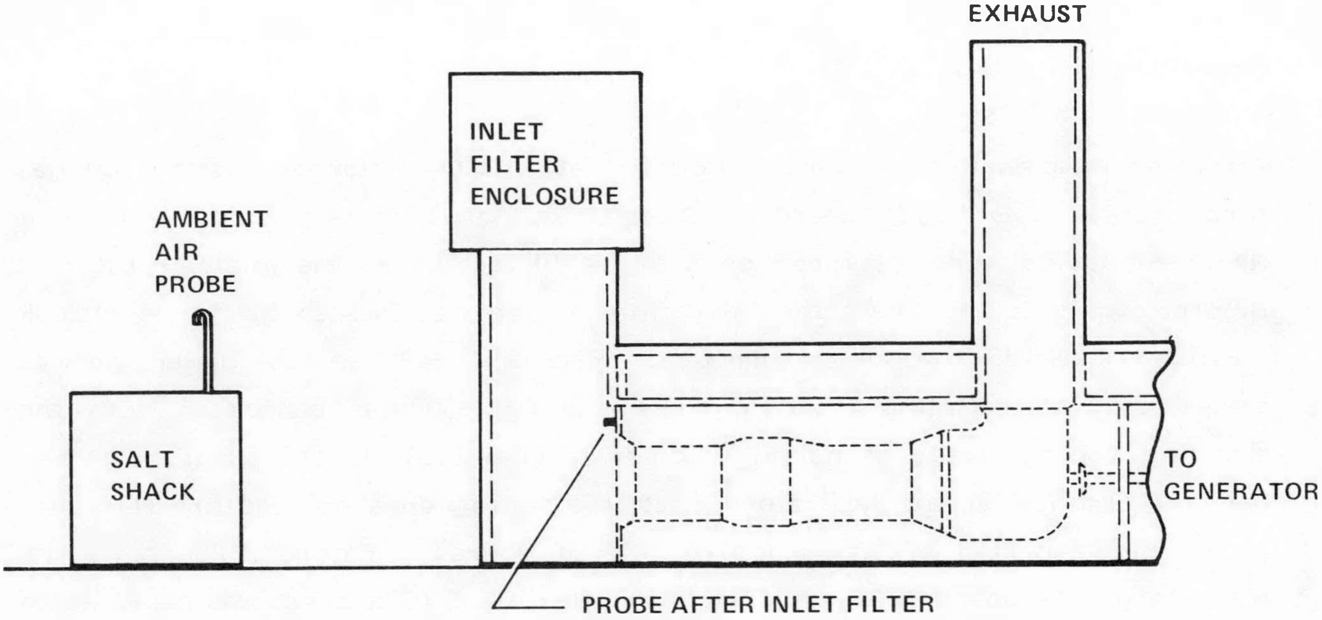


Figure 2.29 - LILCO Holbrook Inlet Filter Test

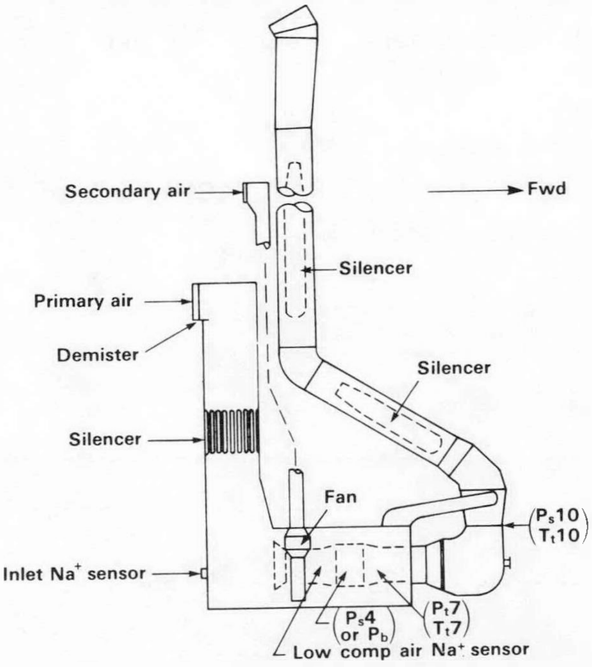


Figure 2.30 - Duct Systems

Results and Discussion

The results of the testing, to date, on the low-velocity filter installation (Farr HP-100) at Holbrook and the high-velocity demister installation (Peerless 3 stage) aboard GTS Asiafreighter are plotted on Figure 2.31. When additional data become available, they will be added.

Also presented in Figure 2.31 are the analysis results of the contents of used Farr HP-100 filter elements taken from PECO Eddystone Station, and the Florida Power Corp., Bayboro Site. Dirt in the filter showed a very low Na+ concentration in the dust; conductivity was used to measure Na+.

Conclusions drawn from Figure 2.31 were that at very low Na-in-air concentrations, the low-velocity filter removes very little salt from the air.

It must be noted that the seal around the engine bellmouth is not completely air tight and might compromise the filter efficiency test in this installation. Therefore, it is possible to pull ambient air in around the bellmouth seal that, in effect, bypasses the inlet filter.

Figure 2.32 is a plot of filter-material efficiency versus Na+-in-air concentration. This plot indicates that the aerosol generated by the BSI device was similar to that occurring at a coastal installation. These data were taken at Oceanside, L.I., N.Y. with an onshore southerly breeze. The BSI aerosol generator was used to generate an aerosol equivalent to existing ambient air. Three different filter materials - American Air Filter 6090, Farr HP-100, and the Peerless 2nd-stage coalescer material - were each placed in the filter holder, and the ambient air and BSI aerosol were pulled through it. The efficiency of the material is shown on Figure 2.32; similar material efficiencies are shown for both the ambient air and the BSI aerosol.

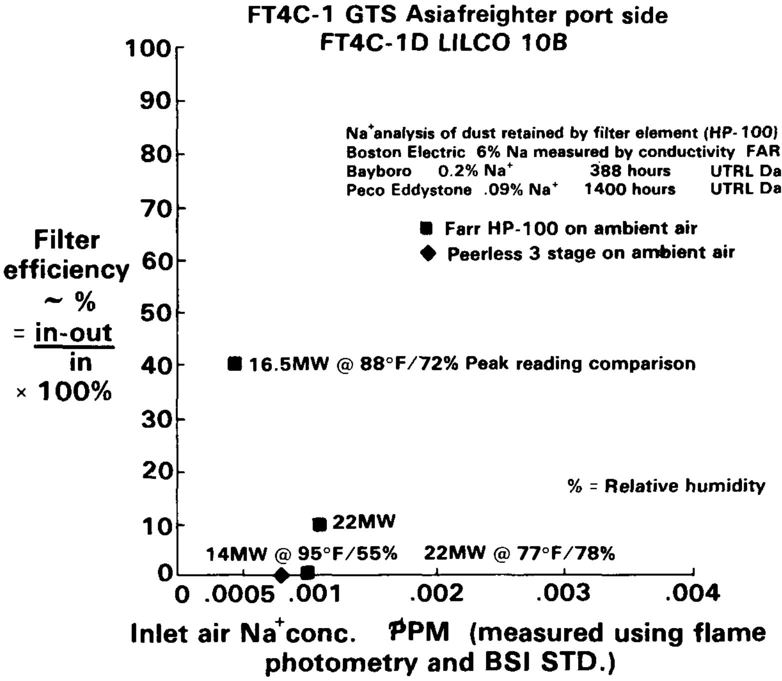


Figure 2.31 - Inlet Air Filter Efficiency

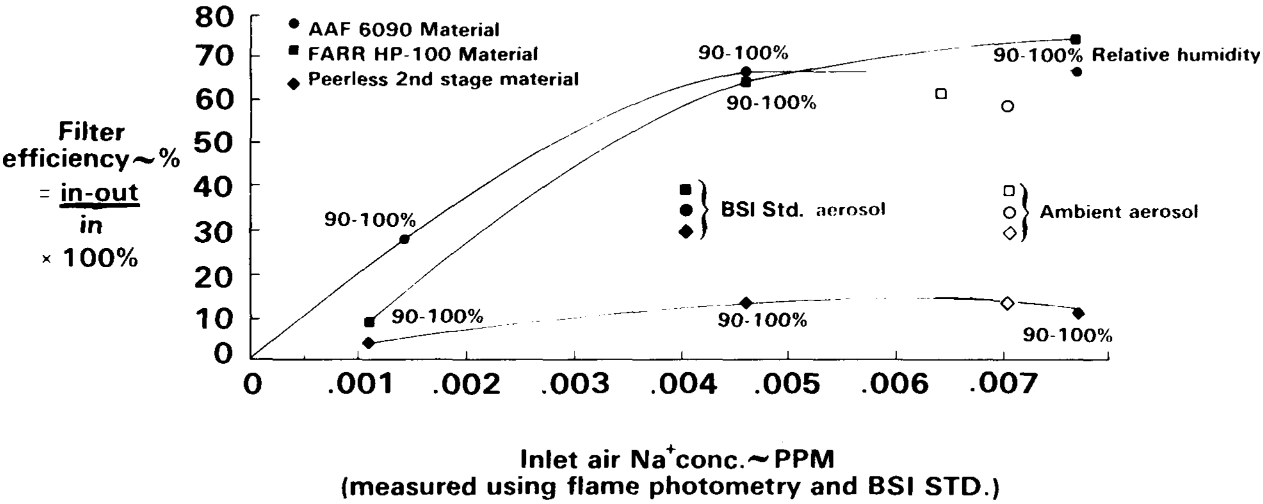


Figure 2.32 - Air Filter Material Test on BSI 4400 Aerosol and Ambient Air

The conclusion reached from this test was that the BSI aerosol was equivalent to that of ambient air when the air mass comes off the ocean.

The test results, plus the fact that the BSI aerosol used to calibrate the Moore flame photometer is used by Hamilton Standard and others in marine demister work, would indicate the BSI 4400 standard aerosal is as close to an absolute standard as one is likely to find for measuring Na-in-air.

It is concluded, based on the dust retained by the filter element and the low-filter efficiency at low concentrations, that inlet air filters do not remove appreciable amounts of Na+-in-air. At higher concentrations this may not be true.

The low Na^+ concentrations shown on Figure 2.33 are not uncommon. Figures 2.34 through 2.46 represent approximately 4000 hours of continuous Na-in-air data. These data indicate that high concentrations exist only a small percentage of the time.

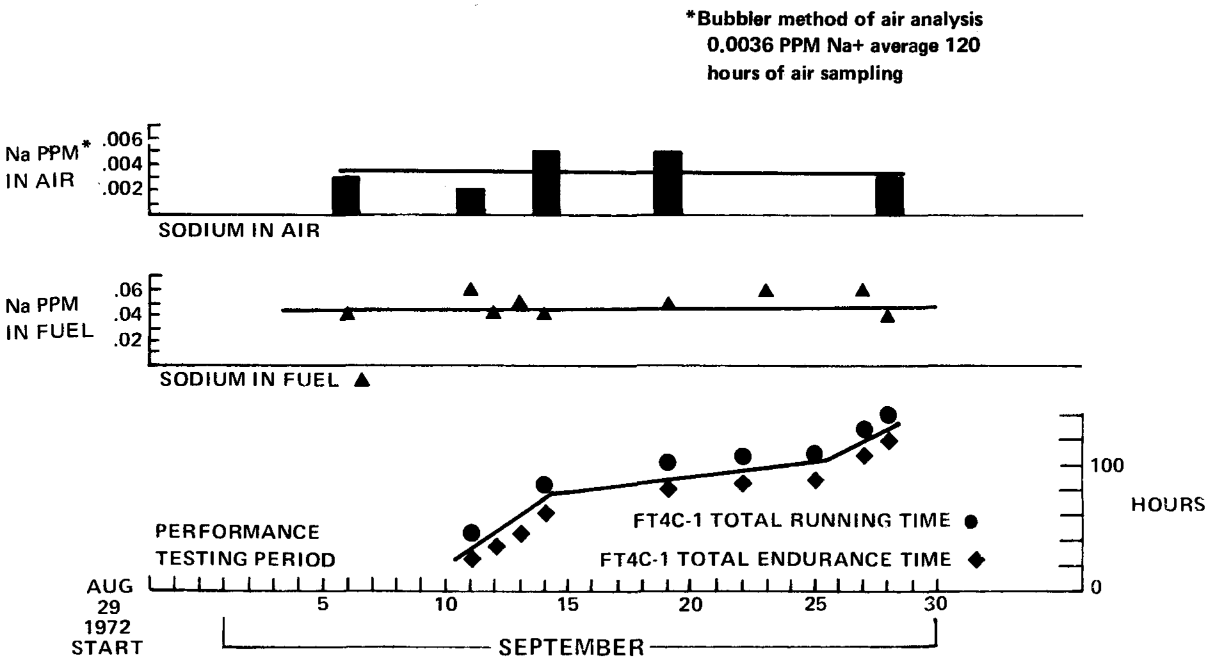


Figure 2.33 - Helco So. Meadows Air/Fuel Analysis

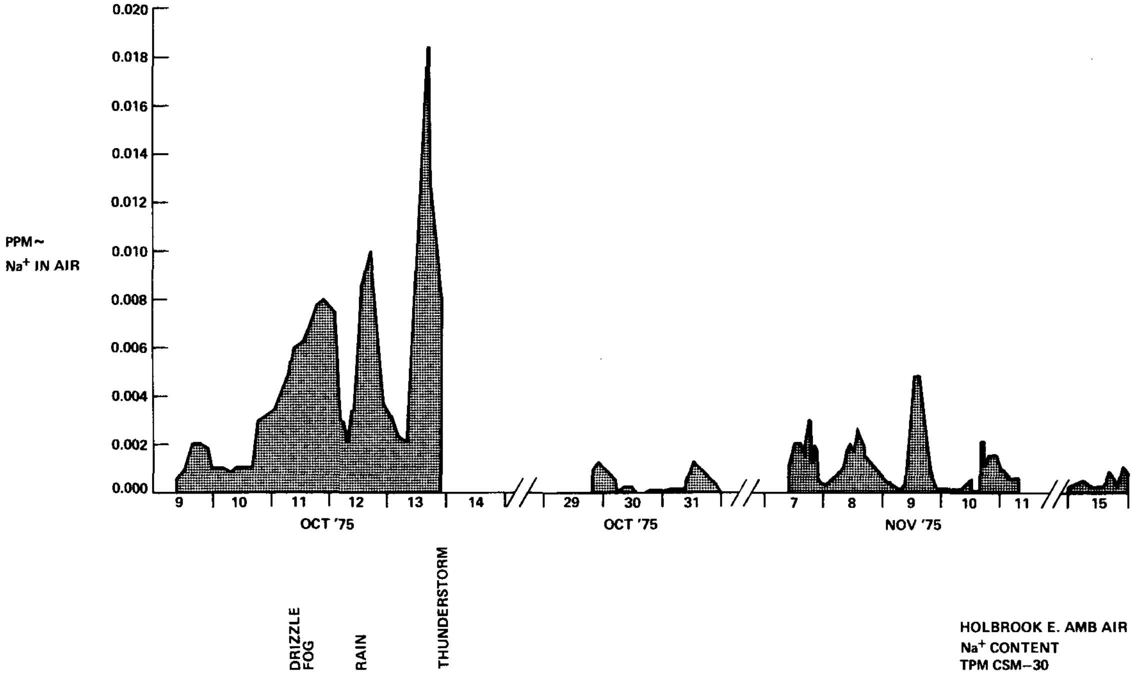


Figure 2.34 - Na in Air Data/Holbrook

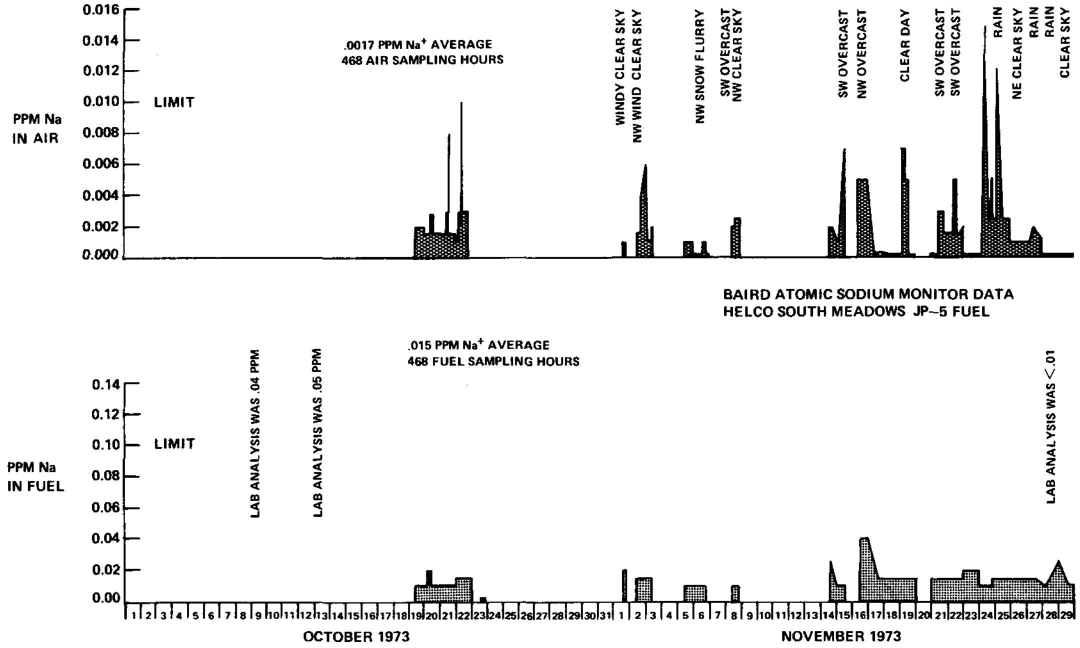


Figure 2.35 - Na in Air Data/Baird Atomic

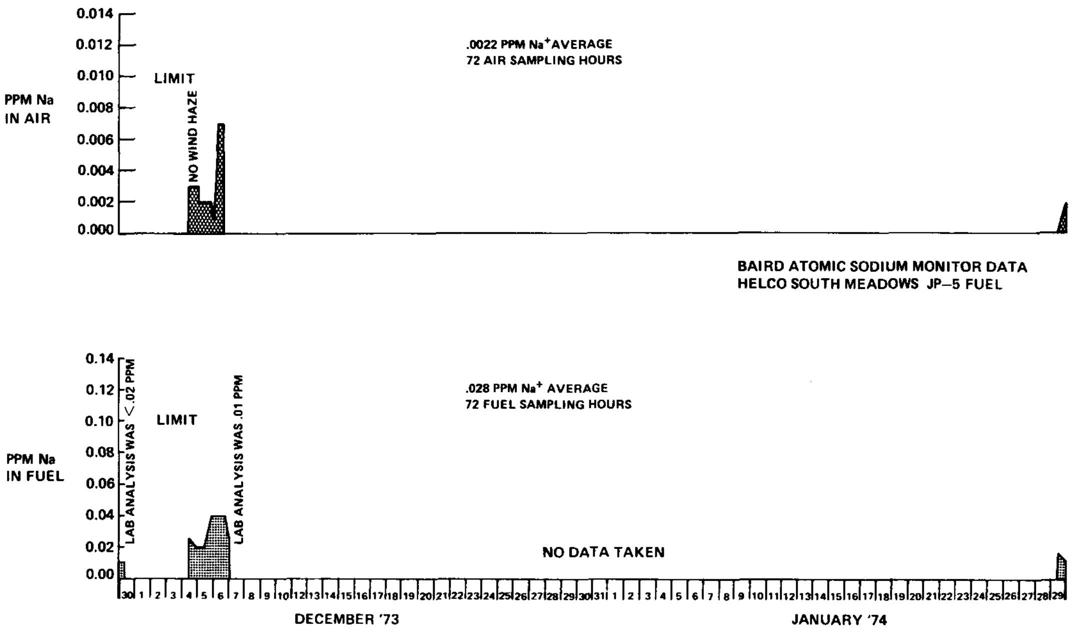


Figure 2.36 - Na in Air Data/Baird Atomic

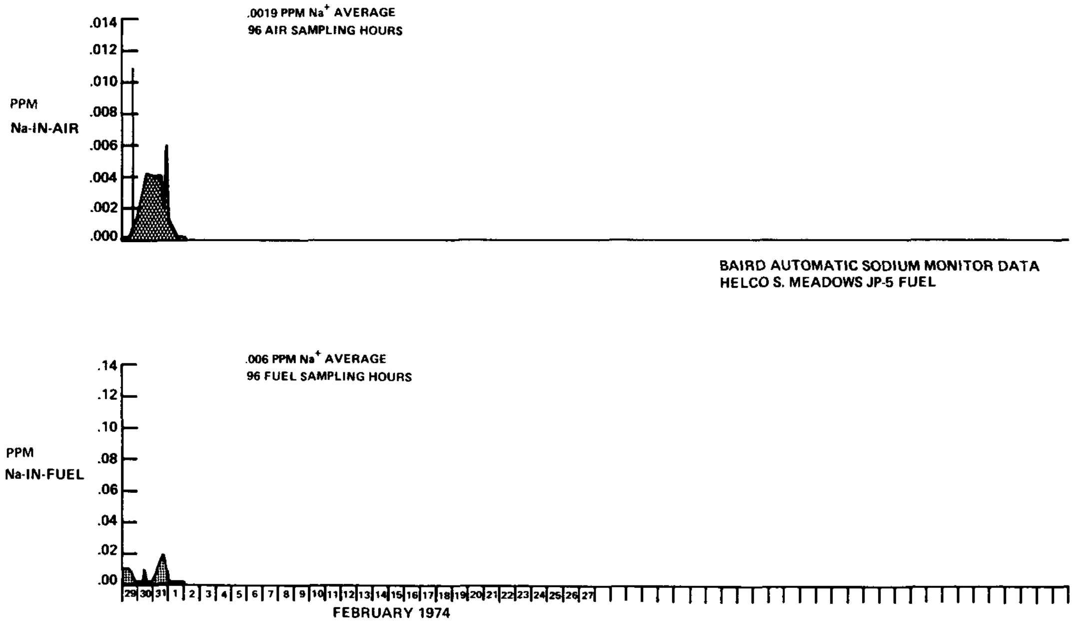


Figure 2.37 - Na in Air Data/Baird Atomic

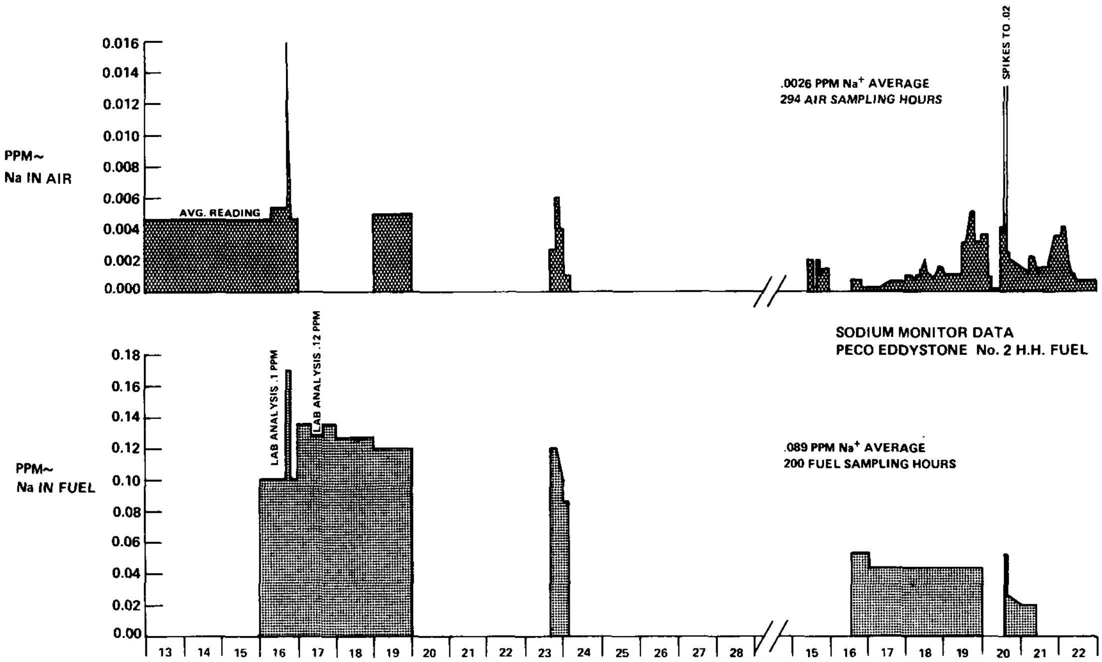


Figure 2.38 - Na in Air Data/Peco Eddystone

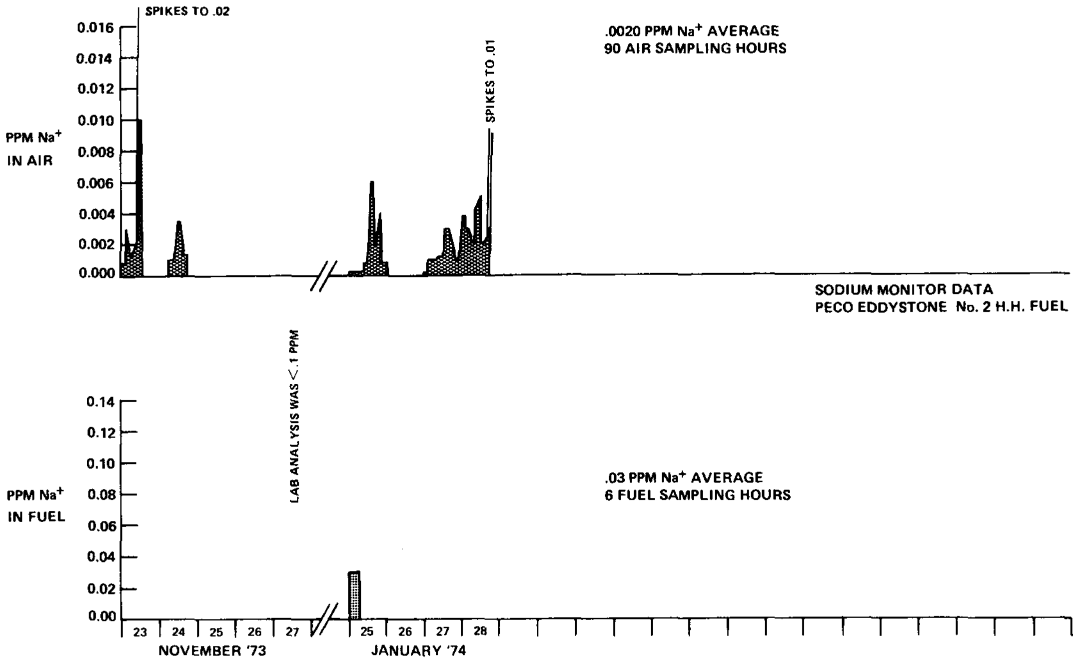


Figure 2.39 - Na in Air Data/Peco Eddystone

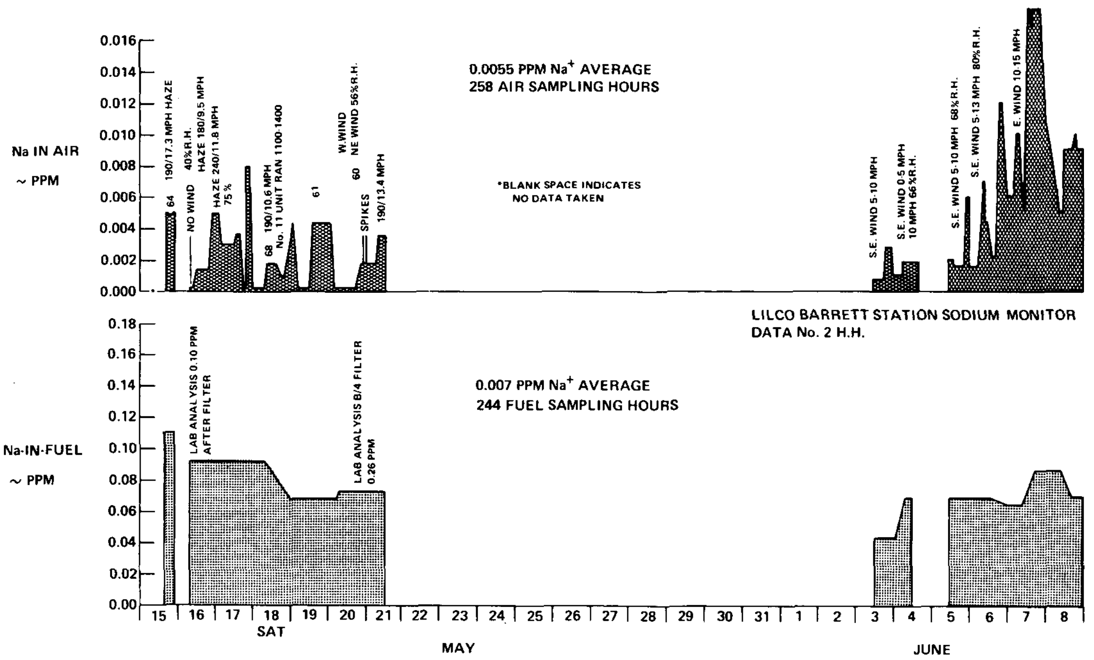


Figure 2.40 - Na in Air Data/Lilco Barrett

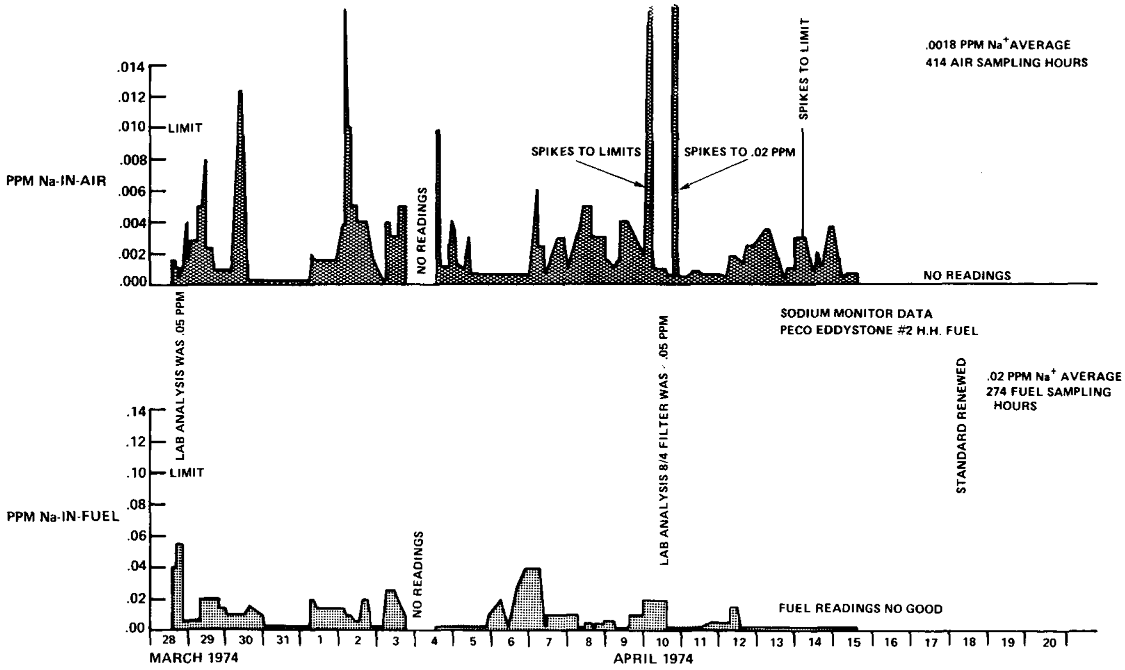


Figure 2.41 - Na in Air Data/Peco Eddystone

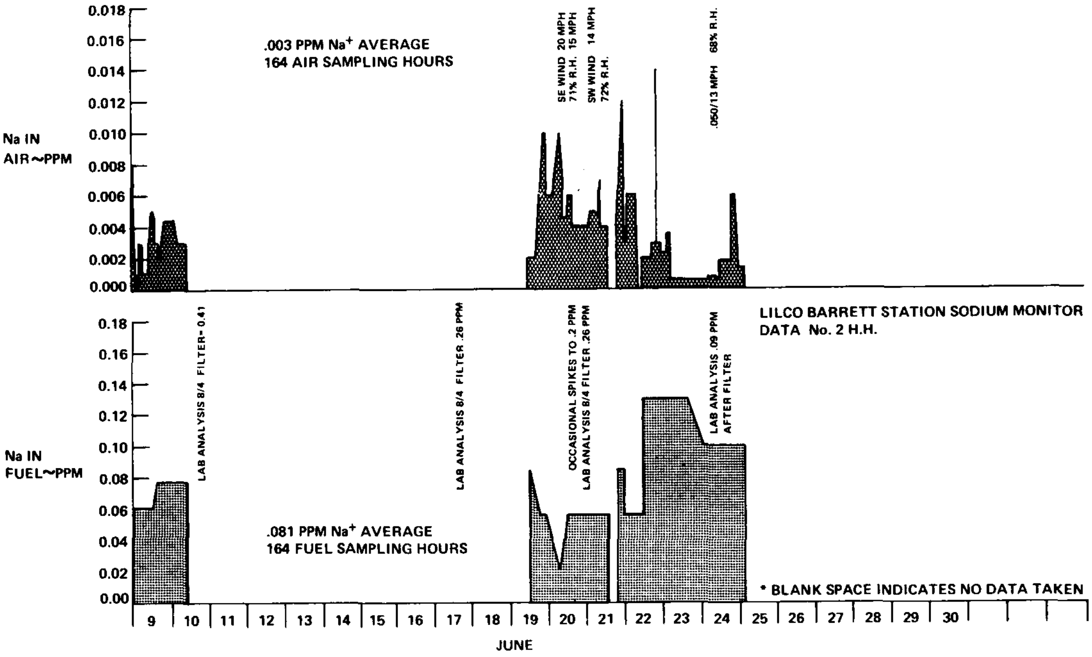


Figure 2.42 - Na in Air Data/Lilco Barrett

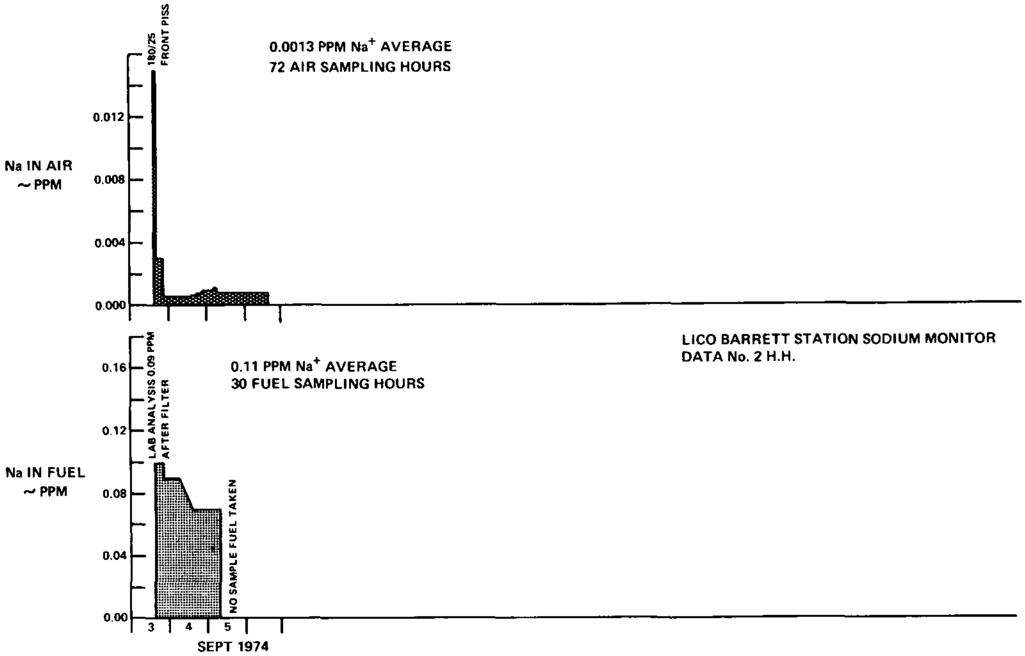


Figure 2.43 - Na in Air Data/Lilco Barrett

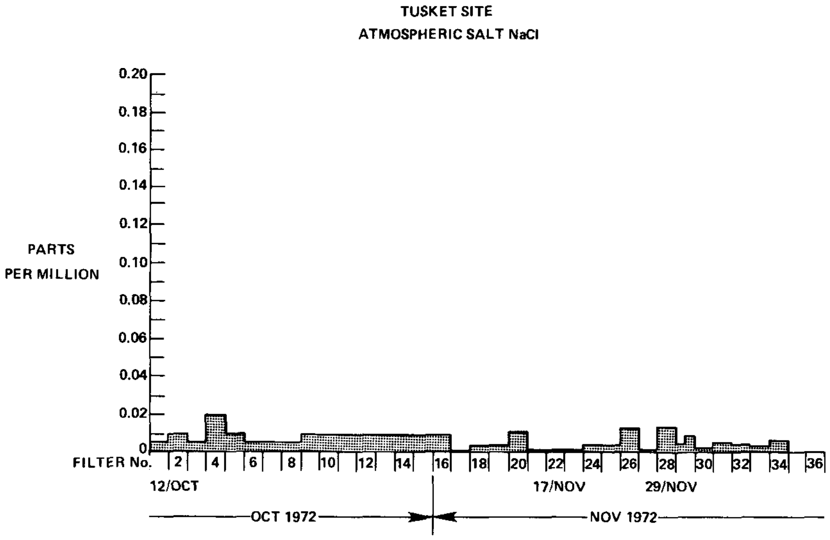


Figure 2.44 - Na in Air Data/Tusket Site

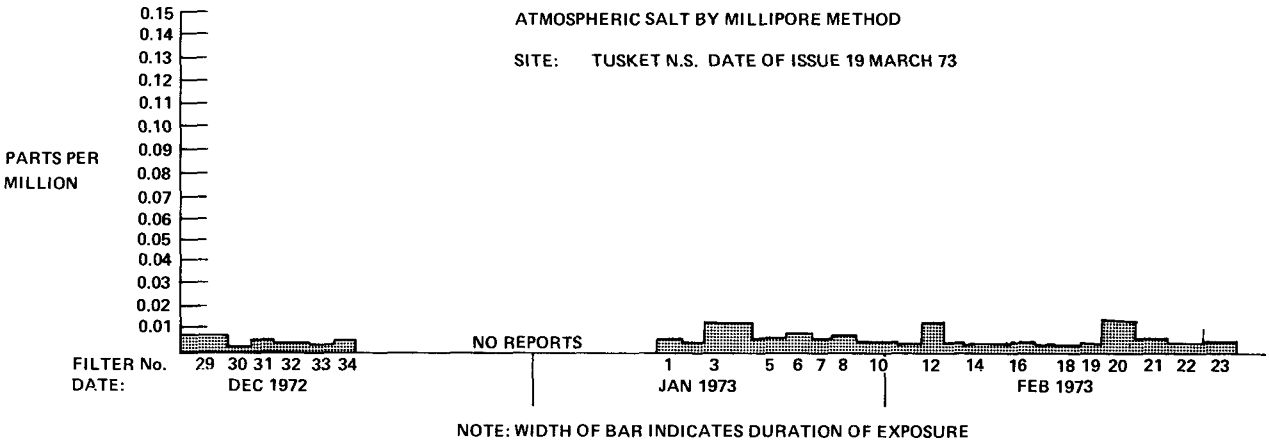


Figure 2.45 - Na in Air Data/Tusket Site

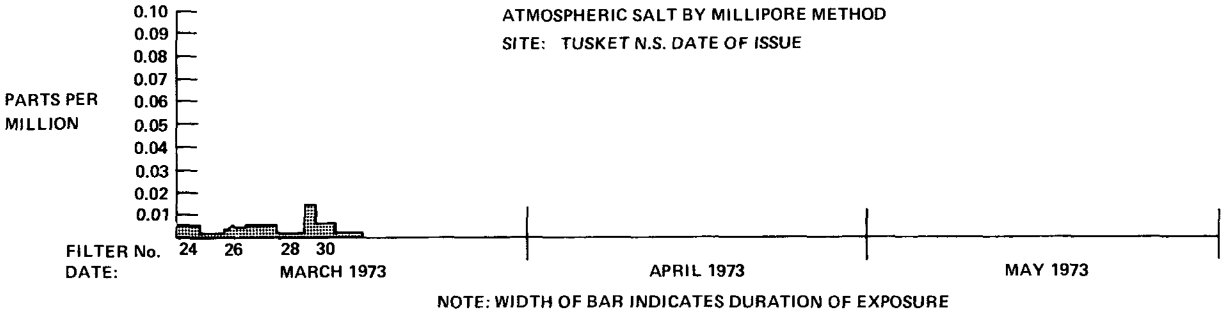


Figure 2.46 - Na in Air Data/Tusket Site

Since the filtered engines at Holbrook did sulfidate, it might be concluded that air filters do not prevent sulfidation. Figure 2.47 shows what inlet air filtration does for the operator. Units 10A and 10B at Holbrook are two back-to-back FT4 C-1DLF engines driving one electric generator. Unit 10B has an air inlet filter and 10A does not. Fuel flowmeters were installed in the engines, and performance data were taken, at 1700 and 1900 hours (respectively) of fired time, and when the units were installed. If both engines had started with the same heat rate (unit 10A was originally more efficient), the difference in fuel consumption at 2.68 GPR per engine (approx. 21 MW) would be approximately 3 to 3.5 gallons per minute. Of this deterioration, approximately 0.5 gpm was caused by turbine fouling.

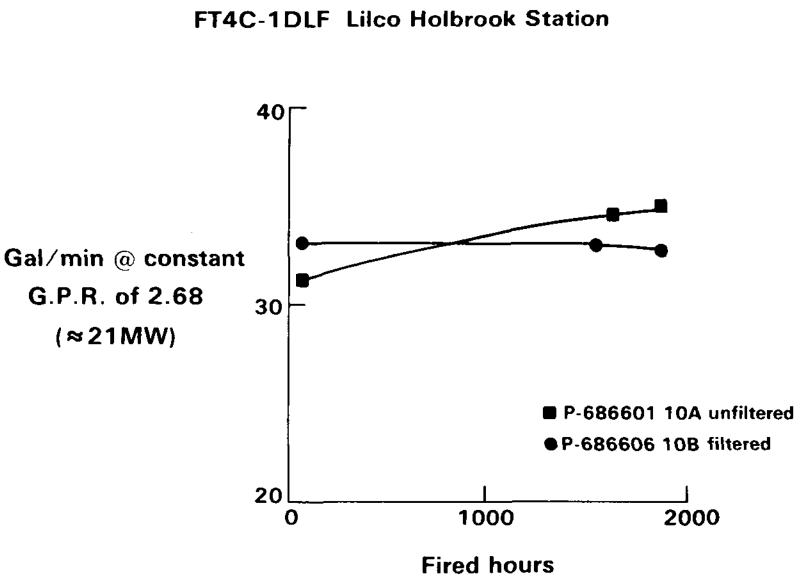
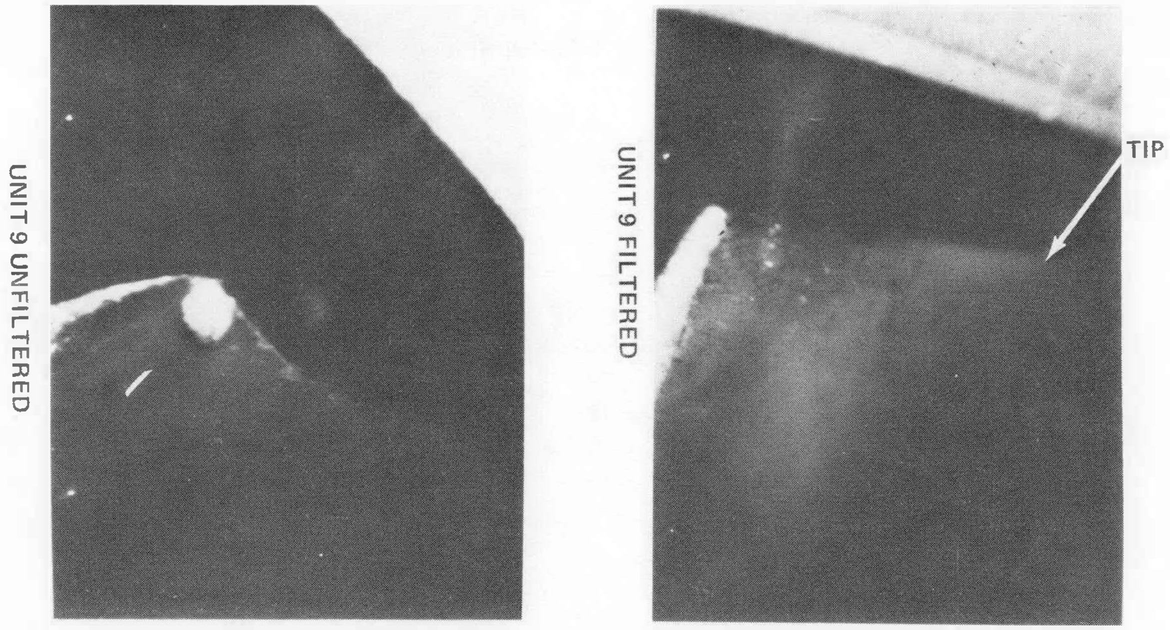


Figure 2.47 - Between Filtered and Unfiltered Inlet

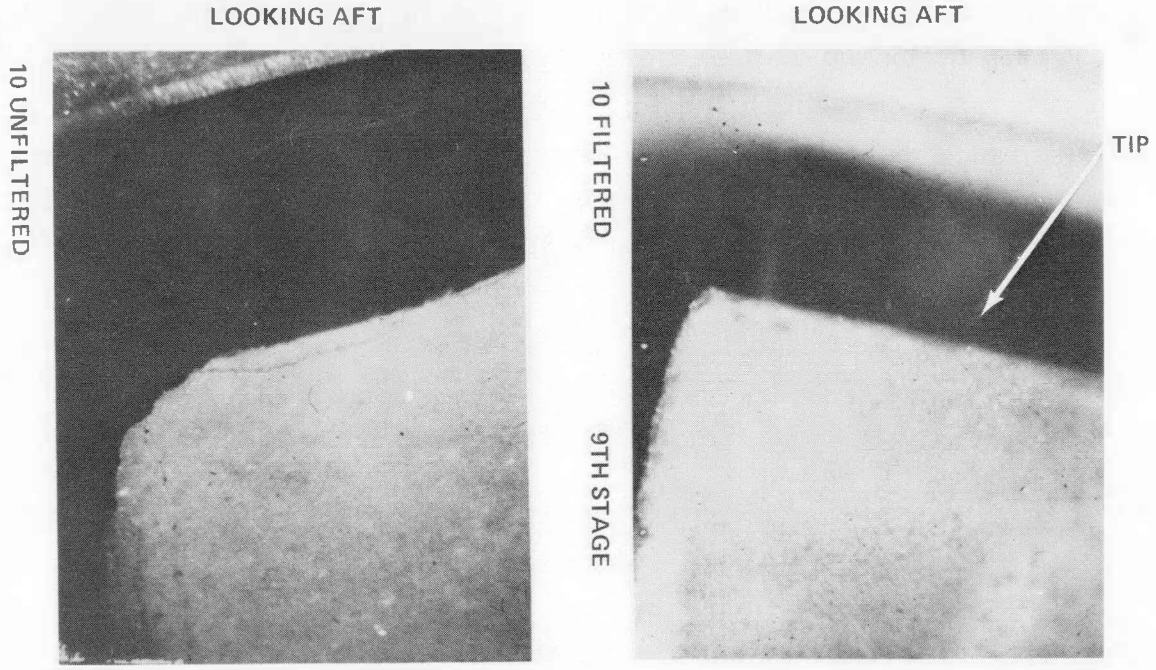
The remainder (~3 gpm) was the result of compressor erosion and fouling. Borescope photographs (Figures 2.48 and 2.49) illustrate what the 9th stage in the compressor looked like on units 10A and 10B and 9A and 9B. Unit 9B was also filtered. Erosion of the 9th stage blades was present on unfiltered engines and was absent on filtered units. Further data are being obtained on other back-to-back engines at LILCO and will be presented in a paper by C. Knauf of LILCO. The data on units 10A and 10B indicate that significant engine heat rate is lost due to erosion.



FIRED HOURS — 1439

FIRED HOURS — 1419

Figure 2.48 - Fire Hours 1419, 1439 (Filtered and Unfiltered)



FIRED HOURS — 1625

FIRED HOURS — 1562

Figure 2.49 - Fired Hours 1562, 1625 (Filtered and Unfiltered)

Compressor Retention, Shedding, and Turbine Retention

Figures 2.33 through 2.45 may only represent relative sodium levels (BSI 4400/1969 standard), but it is obvious from the data that Na-in-air levels fluctuate considerably with meterological conditions.

High steady-state Na+-in-air levels are rare. The Na-in-fuel values in this data tend to be low because the devices used for measurement were not capable of reading crystalline salt or water-soluable salt contained in the fuel. Sodium-in-fuel monitors in present use are much more accurate.

The two most obvious methods for depositing Na+ on the turbine parts are combustion inefficiency or compressor shedding.

Combustion inefficiency would result in unburned fuel residue containing sodium impurities being impacted on the turbine parts with subsequent sulfidation taking place under the deposits. However, if unburned fuel is deposited on the turbine parts at low power, it will burn off at high power. This has been observed when a hot-section inspection performed on an engine that had been run on residual-type fuel and was shut down on this fuel. Tar-like deposits were found all over the hot section. A subsequent run at power, after the engine was closed up with tar left on the parts, resulted in the deposits being burnt off at high power. Confirmation of this burn-off was obtained by gas-path analysis and post-test hot section inspection. These results indicate that desposition due to combustor inefficiency may be self correcting to some degree.

Figure 2.50 shows evidence of the low-compressor collecting and shedding sodium. It was obtained by monitoring the lefthand bleed-valve discharge during cyclic engine operation aboard Asiafreighter. The sampling line was located in the bleed-valve discharge air path. Unfortunately, the PVC tubing melted when the engine was taken into the power range (bleed closed) because of the heat in the enclosure. The test will be repeated with different hardware.

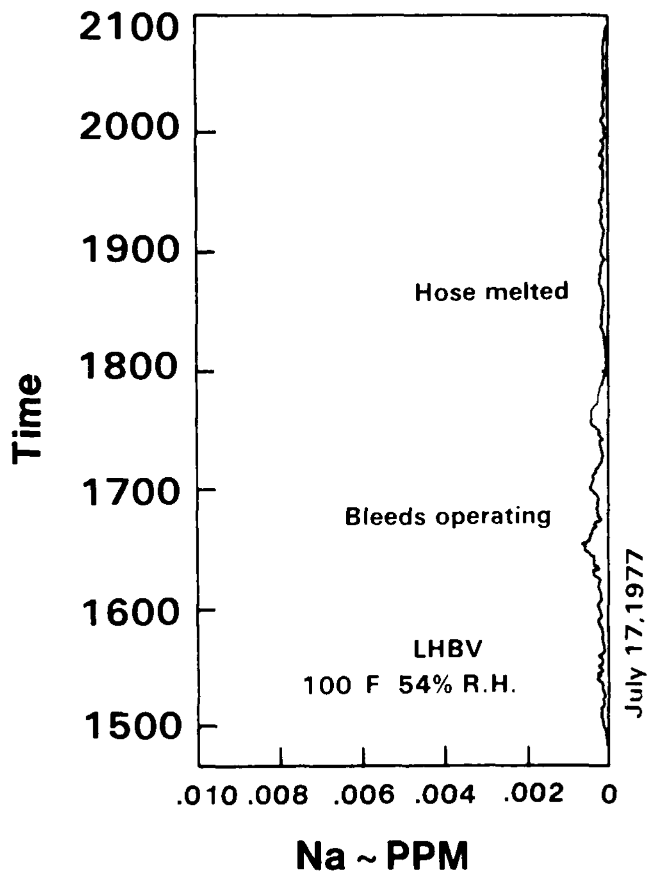


Figure 2.50 - Voyage Norfolk to Baltimore Na^+ Monitor Sampling Left-Hand Bleed Discharge Air While Operating in Bleed Closing Range

Figure 2.51 shows a trace from the same voyage, where the sampling probe was located in the inlet plenum (P_{s2} location). On this trace, the Na+-in-air levels were constant (and equal to the ambient air Na^+ value) except when engine power levels changed. In appears that the rapid changes in air flows caused salt to shed from the inlet ducting on both the accel points, 0010 hours, and on the decel at 0500 hours. Note: new (PVC) tubing was used for all testing done on this voyage to ensure against Na^+ being retained on the walls of the tubing.

It was concluded that rapid change of the gas generator air flow tends to cause shedding.

The sodium monitor was used in these tests to detect shedding but the conclusions arrived at as a result of using it can be backed up by gas path analysis data.

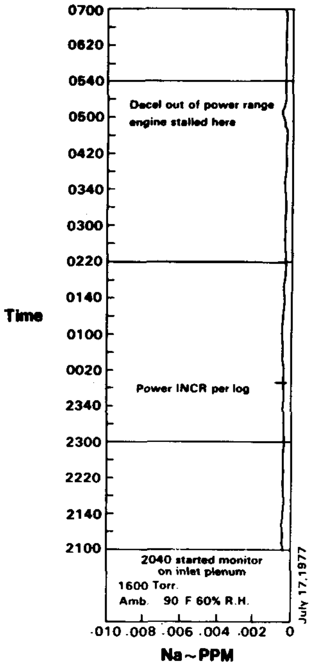
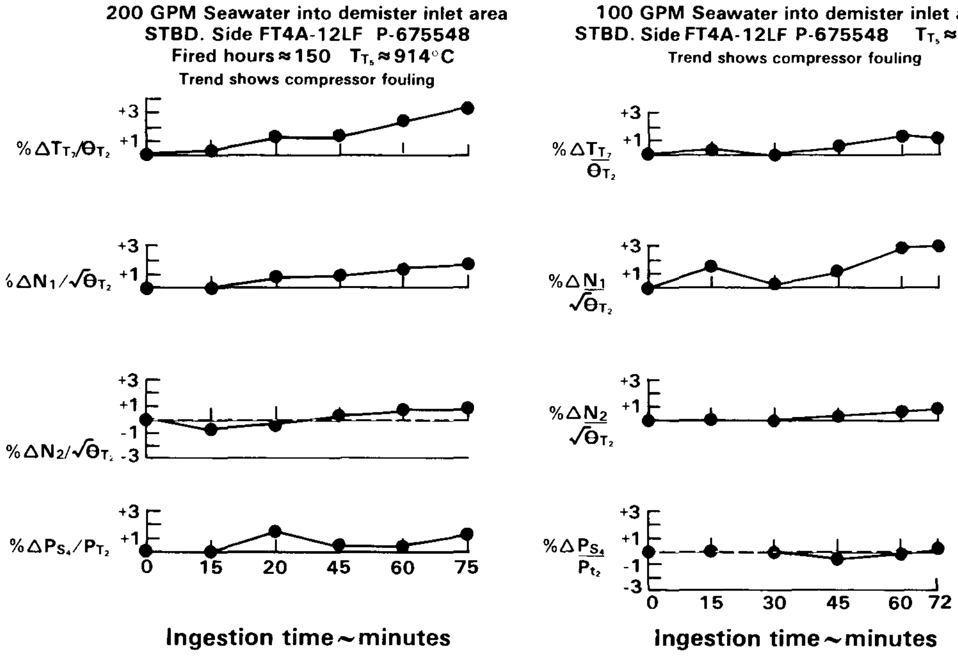


Figure 2.51 - Voyage Norfolk to Baltimore Na^+ Monitor Sampling Inlet Air Trace Shows Inlet Shedding During Power Excursions

During a sea trial aboard a Seatrain vessel, sea water was sprayed into the demister area while the engine was running at power (Tt_5 = 914°C). The test was done twice, using two fire hoses for one test and only one for the other test. The engine was washed immediately after both tests. Observations made of the demister while the hoses were spraying showed salt spray carryover from the rear of the demister. Inspection of the inlet and compressor prior to water washing showed salt water on the plenum deck and salt deposits in the compressor.

Data were taken during these tests at 15-minute intervals until the tests were terminated because of engine performance deterioration. These data are plotted on Figure 2.52. The gas-path analysis of these data showed that the compressor had indeed fouled. There was no definite indication of turbine fouling; therefore, it can be concluded that the compressor caught and retained a majority of the salt entering the engine. These tests were run at a constant biased N_2 (throttle lever position constant); there were no power excursions to cause shedding.

The engine subjected to this test was opened at 1287 hours; there was no sulfidation damage. This would indicate that if the compressor had shed, when power was reduced to idle for shutdown or during the fouling process, it did no damage because the water wash removed the salt before it could do any harm. In other words, the salt did not remain on the parts long enough to exceed the incubation time.



200 GPM Seawater into demister inlet area
STBD. Side FT4A-12LF P-675548
Fired hours ≈ 150 $T_{T_5} \approx 914°C$
Trend shows compressor fouling

100 GPM Seawater into demister inlet area
STBD. Side FT4A-12LF P-675548 $T_{T_5} \approx 914°C$
Trend shows compressor fouling

Figure 2.52 - G.T.S. Asiafreighter Seawater Ingestion Test

Figure 2.53 shows another interesting gas-path analysis. On both these units, one on shore and one marine, high-velocity type inlet filtration was used on the intake air. When the humidity cycled to 100 percent, after a period of relatively dry conditions, the contents of the inlet filter were released into the engine. Data were taken by the automatic data recording equipment on Asialiner and manually in the Dow incident. Analyses of the data have indicated that the compressor fouled in both cases. Fouling was verified by visual examination in the Dow incident.

It is concluded that the compressor does a good job of removing the salt in the air stream. The compressor can retain a considerable amount of salt and only sheds under certain conditions, such as engine transients.

Manipulation of the engine in the Dow incident caused the compressor to shed, as indicated by the fact that some performance was recovered after cycling the bleed valves. The engine was shut down, and large deposits with portions missing could be seen four stages back in the low compressor.

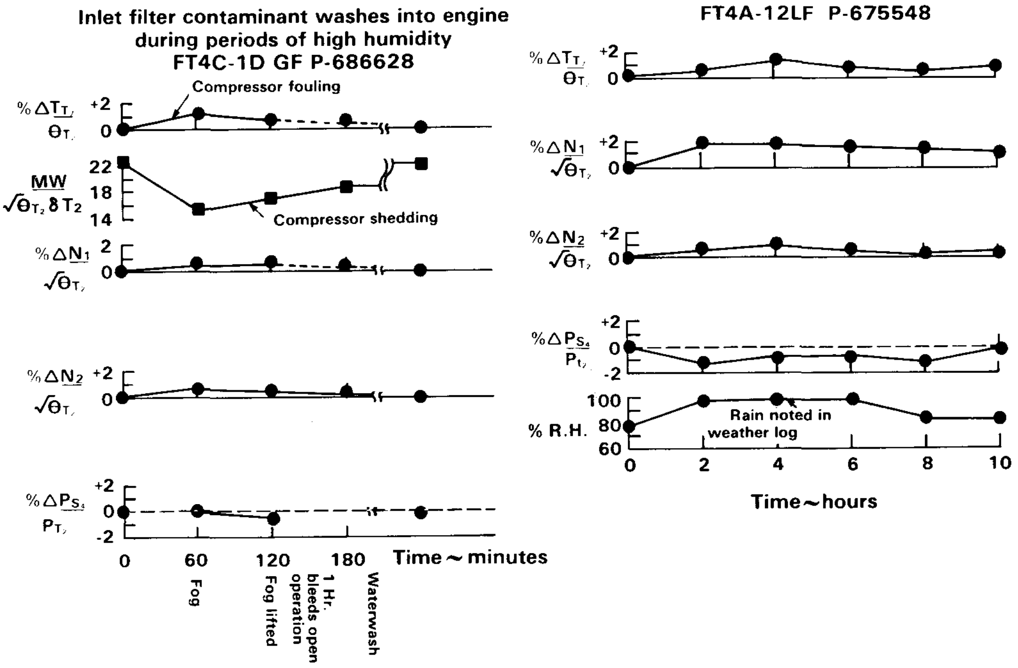


Figure 2.53 - Dow Chemical Inertia Separator Dumping/Asialiner Demister Dumping During Rain

Since the compressor did not appear to shed until the engine was manipulated, there appears to be time to take corrective action: for example, shutdown and water wash or lower firing temperatures to reduce sulfidation damage, in the event the engine cannot be shut down.

Another tool used to analyze what goes on inside the engine is water-wash analysis. If it were convenient, the engine could be split into individual modules: low compressor, high compressor, compressor turbine, and power turbine section, and each module would be placed in separate large tanks of water solution. Analysis of the water in the individual tanks would reveal what elements, in what concentrations, could be found at different locations in the engine. If the average amount of ions in the ingested fuel and the air were known, for example, an ion balance could be made by comparing the input values with what was washed out.

Since it is impractical to place the modules in tanks of water, the water was pumped through the engine via a water washing system. Samples were taken from various drains in the engine and plotted on curves similar to Figures 2.54 through 2.57. Normally the water from the drains is collected in a large bucket; a given number of gallons is used per wash; and a sample is taken from the bucket after each wash. The samples are then analyzed in the lab for element content. The amount of elements per sample has been plotted on Figure 2.55 for LILCO and Figure 2.57 for Asiafreighter. The area under the curve on the plot equals the amount of ion washed from the engine.

Conductivity measurements were also taken of the wash drainage to provide information for a conductivity plot, Figures 2.54, and 2.56. This information gives a measure of water-wash effectiveness.

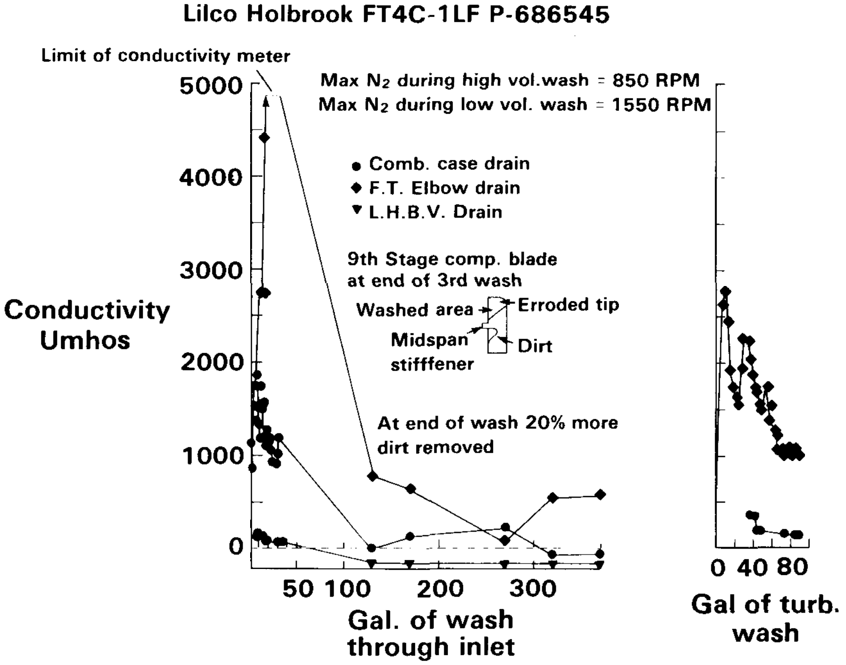


Figure 2.54 - Conductivity Plot of Wash Test

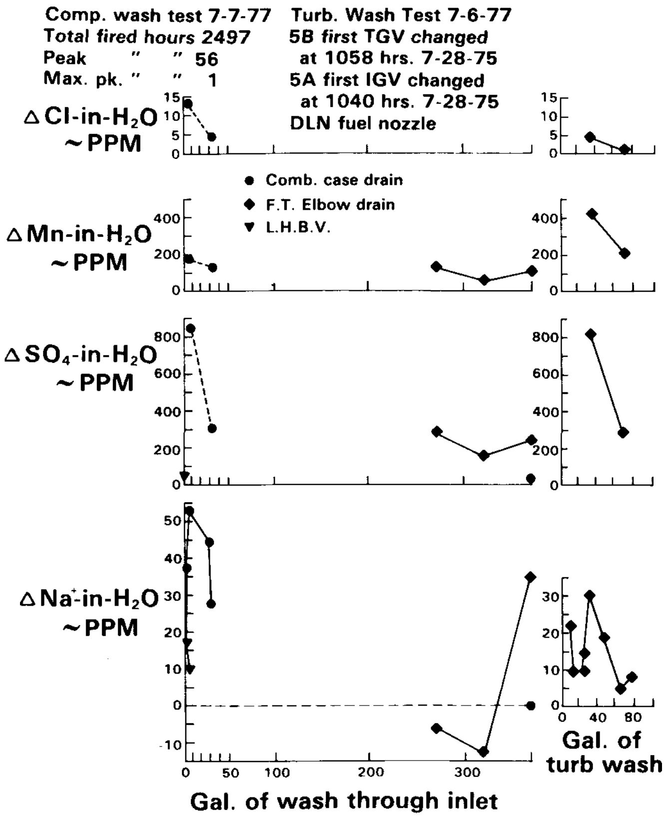


Figure 2.55 - Ion Plot of Wash Test LILCO Holbrook

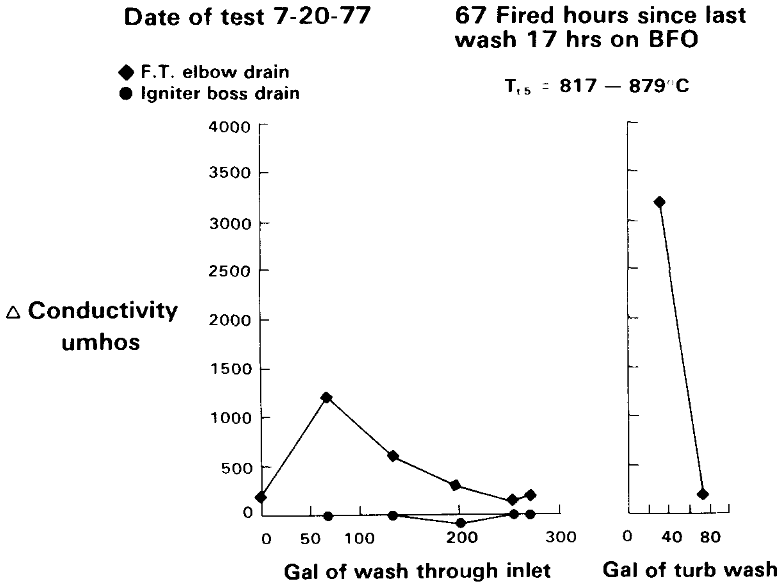
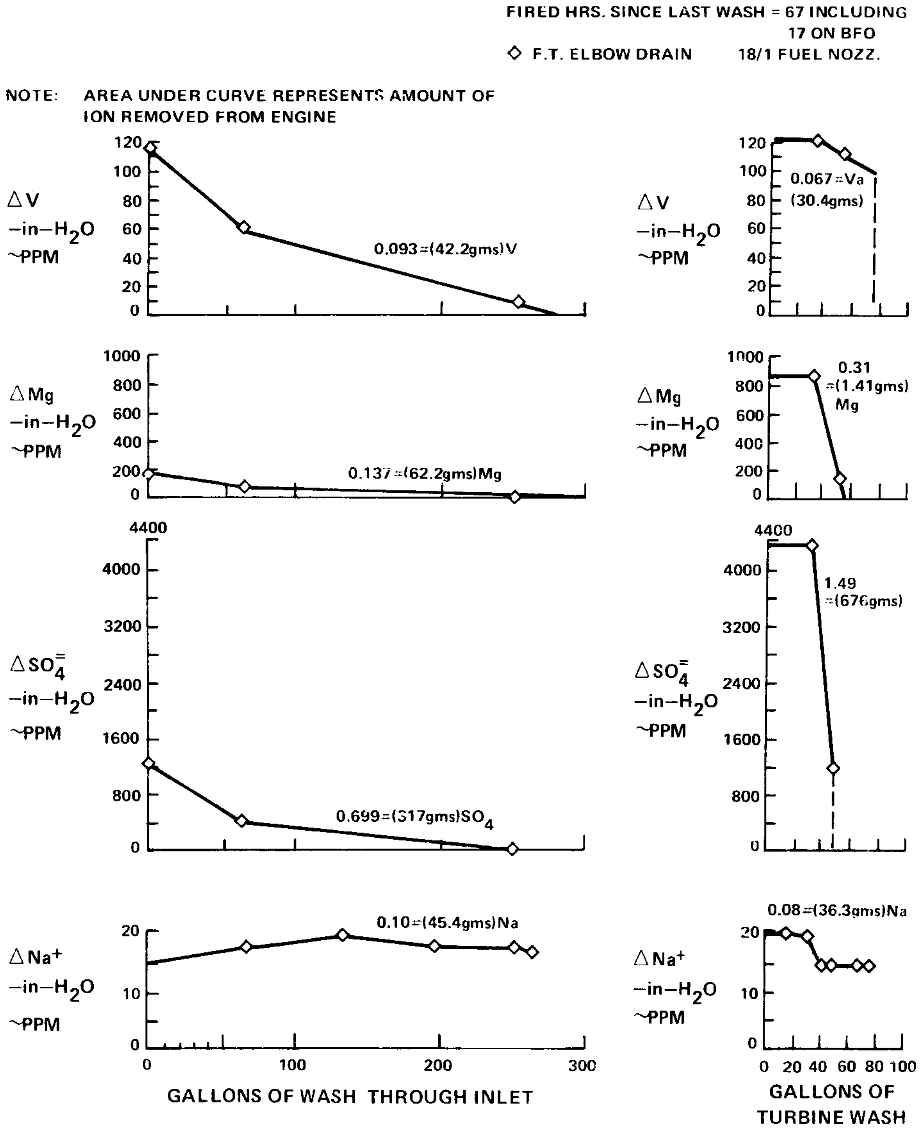


Figure 2.56 - Conductivity Plot of Wash Test GTS Asiafreighter FT4A-12F


FIRED HRS. SINCE LAST WASH = 67 INCLUDING 17 ON BFO

◇ F.T. ELBOW DRAIN 18/1 FUEL NOZZ.

NOTE: AREA UNDER CURVE REPRESENTS AMOUNT OF ION REMOVED FROM ENGINE

Figure 2.57 - Ion Plot of Wash Test GTS Asiafreighter FT4A-LF - Date of Test 7-20-77

ION	Measured ION in air level PPM	Total air ingested by engine-lbs	Total ION ingested by engine in air lbs.	Measured level in fuel PPM	Total fuel ingested by engine lbs.	Total ION ingested by engine via fuel	Total ION washed from high compressor	Total ION washed from F.T. elbow lbs	% Total ION ingested removed from the engine by wash
Na	.0008	47×10^6	.037 (17 gms)	(4) .34	$.493 \times 10^6$	.17 (77 gms)	Not measured	.18 (81.6 gms)	87%
V	None			(3) 52	$.493 \times 10^6$	25.6 (11622 gms)		.16 (72 gms)	.6%
Mg	(1) .00009	47×10^6	.0047 (2 gms)	150	$.493 \times 10^6$	74 (33573 gms)		.45 (204 gms)	.6%
SO_4	(2) .0002	47×10^6	.009 (4.3 gms)					2.2 (999 gms)	
S			.0045 (2.15 gms)	(3) 11,700 S	$.493 \times 10^6$	5768 (262×10^3 gms)		1.1 (499 gms)	.02%

(1) *Ratio of Na:Mg in seawater* 8.3:1

(2) Ratio of Na:SO_4 in seawater 4:1

(3) UTRL analysis

(4) Suspect this level is low

Figure 2.58 - Ion Balance of 67 Hr FT4A - 12LF Run Aboard GTS Asiafreighter

The LILCO wash was performed on an engine with high time that never had been washed effectively because of water-wash system problems. The Asiafreighter wash test was performed on an engine using blended fuel oil that was washed thoroughly prior to the start of the 67-hour test. Finnjet wash data are also shown in terms of salinity on Figures 2.59, 2.60 and 2.61. The Finnjet engine was brand new at the time of the test. A future wash test will be run on Dow Chemicals FT4C-1DGF that has accumulated 17,000 hours.

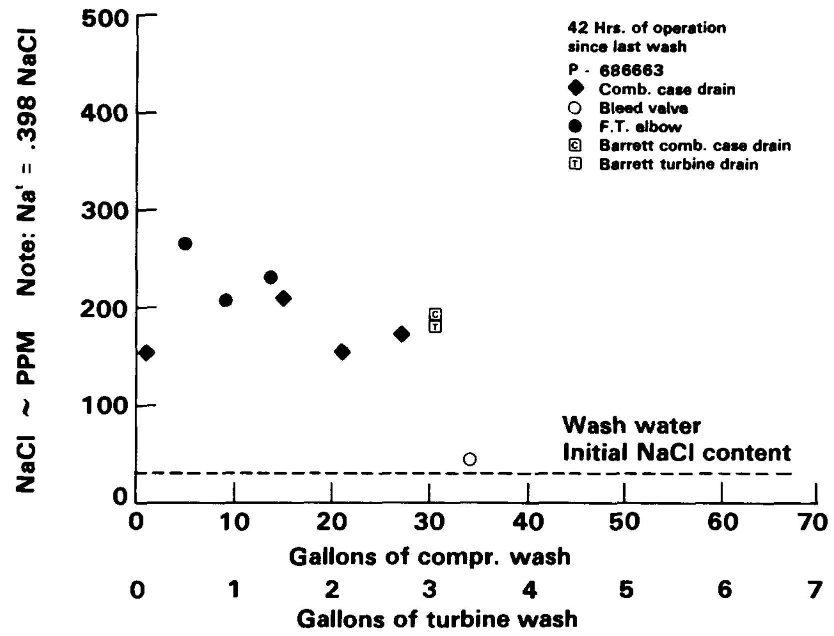


Figure 2.59 - Salinity of Water Wash Solutions

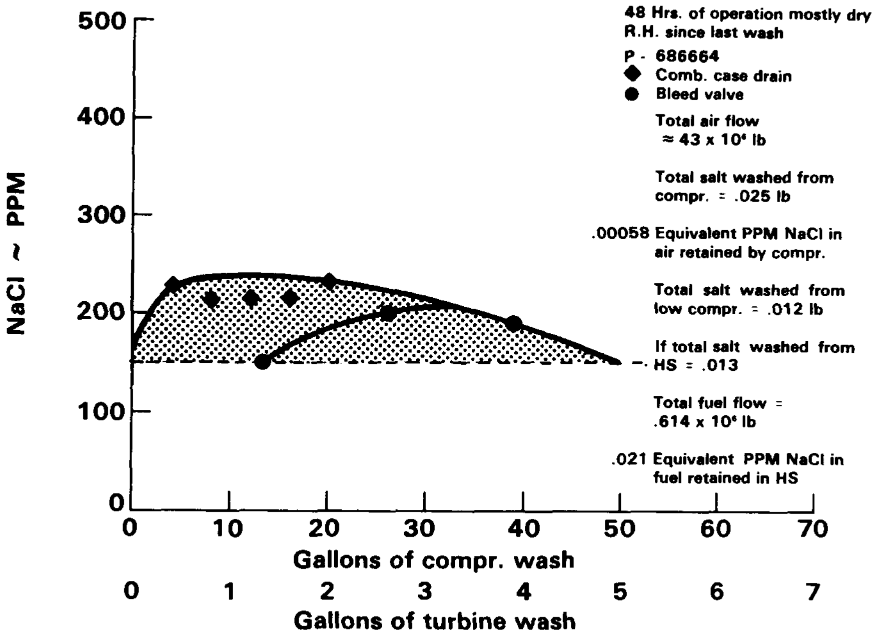


Figure 2.60 - Salinity of Water Wash Solutions

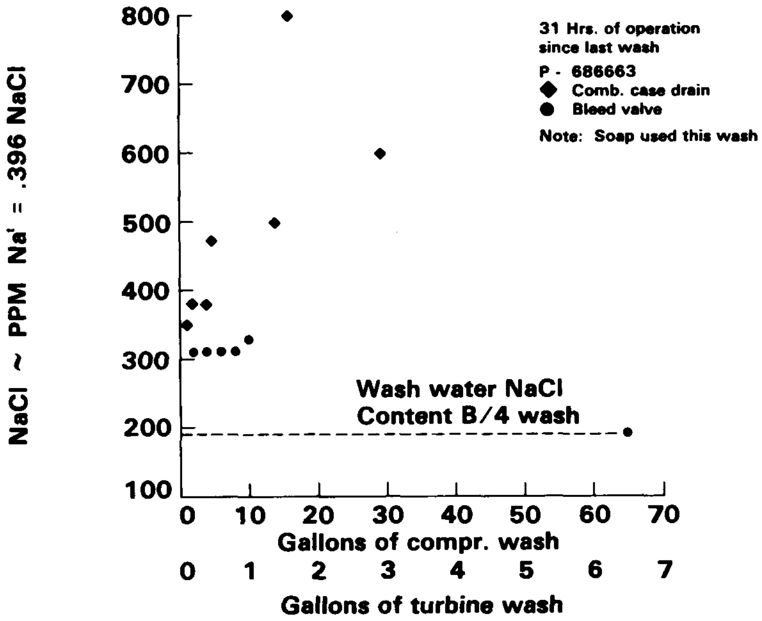


Figure 2.61 - Salinity of Water Wash Stations

Analysis of this data presented indicates large volumes of water are needed for a good wash. The LILCO wash was done back-to-back with an engine that was not washed, and a first turbine vane was taken from each engine for comparison purpose. Analysis of the washed-versus-unwashed vane indicate that about 80 percent of the SO_4, Mn, Pb, etc. was removed on the washed engine's first vane with respect to the unwashed first vane. The Na+ ion was relatively unchanged. Visual inspection of the compressor (see Figure 2.51) indicated that even after this massive wash, the engine was not completely clean.

An ion balance was attempted using the Asiafreighter wash data and CSM-30 readings obtained during the voyage. This balance is presented in Figure 2.56. The most significant thing on this balance is that the Na+ level did not reduce as the engine was washed (Figure 2.55), and that the Na+ content in the wash water was above what can reasonably be attributed to the fuel as a source. Since the other ions present diminished as the wash proceeded, the Na^+ levels are questionable.

Fuel Nozzle Efficiency

Experimental Procedure

Gas fuel, Delavan air blast liquid fuel, and 18/1 liquid fuel nozzles were tested to determine nozzle efficiencies at various powers. In all cases, FT4C-1D engines were used to obtain the data. Gas calorimeter and flow measuring equipment were used for BTU/sec determination on the GF (gas fuel) engines. Liquid fuel samples were analyzed for the LF (liquid fuel) calculations.

In the tests conducted, there was a difference in the low-power region combustion efficiency between liquid and gas fuels and nozzles. At high power, there was little difference (less than .5%) in combustion efficiency.

Results and Discussion

The significance of this data is that a liquid-fuel nozzle tends to form and deposit more char on the turbine parts at low power. These deposits would tend to burn off as the engine increased power. This has been demonstrated on engines burning residual-type fuels; after shutting down on residual fuels, HSI (hot section inspection) showed a large amount of tar inside the engine. Subsequent HSI, after running the tarred engine at power on a #2 HH, showed the deposits had disappeared.

Originally, a water-wash test on an engine using fuel manifold purge on shutdown, and a test on an engine using fuel manifold dump was to be performed at LILCO. LILCO now uses fuel manifold dump on all engines to avoid white smoke on shutdown; therefore, this test is no longer feasible.

Sodium in Water Analysis

Experimental Procedure

In order to facilitate field testing, a procedure to analyze wash-water samples using the BSI aerosol generator was developed. The wash water to be analyzed was placed in the atomizer of the aerosol generator and changed to an aerosol. The aerosol was then analyzed in the CSM-30 for Na-in-air. By selecting the correct aerosol flow rate, it was possible to read Na+ ppm in water directly from the CSM-30 digital readout. The accuracy of the method was confirmed by comparison with UTRC lab analysis. The Na-in-water range of the CSM-30 was 0 to 300 ppm before it became saturated.

Other

Analysis of lab and field data to date indicate two areas where more information is required: one is a water wash analysis of a gas-fired engine, the other is further verification of the engine manipulations that cause compressor shedding.

Dow Chemical, Pittsburg, California, shut down an FT4C-1D GF with 17,000 hours at the end of September for water wash and hot section inspection. We intend to run a water-wash test on that engine and to remove a first turbine vane/or vanes for lab analysis. An attempt will be made to find additional gas-path analysis data during the inertia separator shedding phenomena by reviewing the station logs.

Engine manipulation to cause compressor shedding will probably be done at LILCO or aboard GTS Asiafreighter. To accomplish this task at LILCO, preferential running will be required.

Hard plumbing and an air cooler will be required to get the compressor air temperature down to a level the CSM-30 can handle, since compressor discharge air is at approximately 700°F.

Analysis of Lab and Field Data

As data becomes available from the laboratory and from the field, it is analyzed and collated as shown in the previous discussion. A final correlation of all data will occur around the end of January 1978, and this correlation will be factored into the control system in the form of limits and operational ranges.

ESTABLISH CORROSION ENVELOPE

Select Significant Corrosion Parameters

Determine Weighing Factors for Parameters

Preliminary work has been done in this area but the finalization of the parameters and the determination of weighing factors is scheduled for later this year and early next year.

VERIFY CORROSION MODEL

This subtask is scheduled for next year.

Section 3

TASK II - DEFINE CONTROL REQUIREMENTS

DEFINE CORROSION CONTROL INPUTS AND SENSING REQUIREMENTS

Define Sensing Requirements Based on the Corrosion Model

The corrosion model has not been completed but preliminary data indicates that the following parameters are the biggest contributors to hot corrosion.

- Firing temperature - In the FT4 gas turbines, a measure of gas generator or power turbine speed request coupled with the load schedule selected in the engine fuel control will give the best operating indication of firing temperature.

- Cyclic operation - This is determined by the number of starts and stops as well as the number of gas generator and power turbine speed requests. Cyclic operation is also related to the compressor shedding phenomena.

- Na-in-air - This parameter is most important in terms of PPM-hours. It represents how much Na+ the compressor has available to retain and eventually shed. Inputs from the corrosion model will be used to define PPM-hours limits, via analysis of compressor and turbine wash and of Na+ on first turbine vanes. Absolute Na-in-air levels may be important during extremely high Na-in-air periods, which are rare (see Figure 2.31 to Figure 2.45). High Na-in-air readings are usually related to meteorological phenomena such as on-shore breezes, thunderstorms, and/or salt fog conditions.

- Na-in-fuel - This parameter is probably less important because the Na^+ levels required to cause steady-state sulfidation are far above those normally seen with #2 HH fuels. It would become important as a measure of fuel-filter coalescer performance, because salt water could be carried into the engine with the fuel if the filters should fail. As laboratory tests have indicated, the presence of NaCl on the parts accelerated corrosion.

- Water wash effectiveness - This item represents the most important tool available to the operator to prevent or limit sulfidation. It has been demonstrated to be effective on engine P-675548 where the gas turbine was sprayed with approximately 100 gpm of sea water for 1½ hours and washed immediately afterwards. A hot section inspection (HSI) at 1298 hours showed no sulfidation. A Finnjet engine was inspected at 2000 hours following a procedure of water washing every 44 hours of operation with a 50-gal wash. This HSI also showed no sulfidation.

  Water-wash tests have indicated that a measure of the water passing through the engine was necessary to determine if the wash was effective. Therefore, a means of checking the effectiveness of the wash procedure should be a corrosion-control system input. Water-wash tests have indicated that removal of contaminants in addition to Na+ is possible.

Define Means of Sensing and Quantitative Measurement of Parameter

The means of sensing and measuring the corrosion parameters related to Na+ have been defined. Listed below are the parameters, range, and means of sensing.

- Firing temperature - 1000 to 2000°F via power control and temperature limiting in the gas turbine fuel control

- Na-in-air 0 to .020 PPM Na^+ - measured by flame photometry utilizing a device described in PSD IPA-6803 Specification (see addendum)

- Na-in-fuel 0 to 50 PPM Na^+ - measured by flame photometry utilizing a device described in PSD IPA-7056 Specifcation (see addendum)

- Water wash effectiveness - 0 to 7000 µmhos - A comparison of conductivity of the wash water in and out via differential measurement is a practical indication of water-wash effectiveness. It is realized that conductivity is not an absolute yardstick. However, field tests have shown that it is an adequate measure of wash effectiveness.

- Cyclic Operation - This parameter is still under study and should be finalized in the last quarter of 1977.

Define Location of Sensors and Determine Sensor Environmental Conditions

All sensors should be capable of handling temperatures and pressures similar to those existing in the vicinity of the gas turbine, for example: temp. -20°F to +120°F. Ideally, the Na sensors should be located far enough from the engine to allow corrective action to be taken prior to the fuel or air being sampled reaching the engine. With fuel this is possible by locating the Na-in-fuel sensor close to the fuel filtration system and minimizing transit times in the sensor. With Na-in-air measurement locating the sensor far enough from the engine to allow corrective action to be taken if the Na-in-air level goes up is not practical or necessary, since Na+ accumulates in the compressor prior to shedding providing time for corrective action.

The environmental conditions are defined in more detail in IPA-6803 and IPA-7056, attached to this report. Sensor location will depend upon the particular site, but portability is a feature in the specification to minimize the location problems.

Determine Signal Conversion for Control Output

All major control components will perform the signal conversion from input to output within the component. In most cases, the conversion will be from analog to contact closure or to another analog level.

DEFINE CONTROL OUTPUTS

Ideally, if the control outputs are contact closures, the control system becomes one of logic circuitry. The sensors are being specified to provide this type of output. Because the system is still conceptual, analog outputs are also available. This type of logic allows sufficient flexibility to incorporate additions or deletions, if required.

Analyze Operational Information and Review Operational Control

These two tasks are dependent on each other, and the results of this analysis and review are shown in Figure 4.1. The general theme of the control system is to provide components that can be added to an existing system, in part or in total. The option of whether to use all or part of the anti-sulfidation control system should be left with the operator via a switch. The relative merit of each control loop will be determined after field tests of the control system.

PREPARE CONTROL SYSTEM SPECIFICATIONS

Sodium-in-Air Monitor (Sensor) IPA-6803

Specification has been written, quoted upon, and are being fabricated by Baird Atomic.

Sodium-in-Fuel Monitor (Sensor) IPA-7056

Specification was written and sent to Baird Atomic for quote.

Automatic Control System

The automatic control system specfication is being prepared at the present time. Field data continue to be analyzed, reviewed, and refined. A specification will be issued in the second year of the contract.

Sensors

Conductivity cells will be required for water-wash analysis. The devices used for the water-wash testing presented in this report under Field Test, had insufficient range. No problem is expected in this area as conductivity devices are common process control type devices and are available in a wide variety of ranges. Sodium in air and sodium in water sensors are explained above.

Section 4

TASK III - DESIGN, DEVELOP AND TEST CONTROL SYSTEM

CORROSION CONTROL SYSTEM DESIGN

As a result of the field testing to date, the control system design has been simplified from what was originally conceived (Figure 4.1). This simplification appears reasonable based on the results of laboratory and field testing to date.

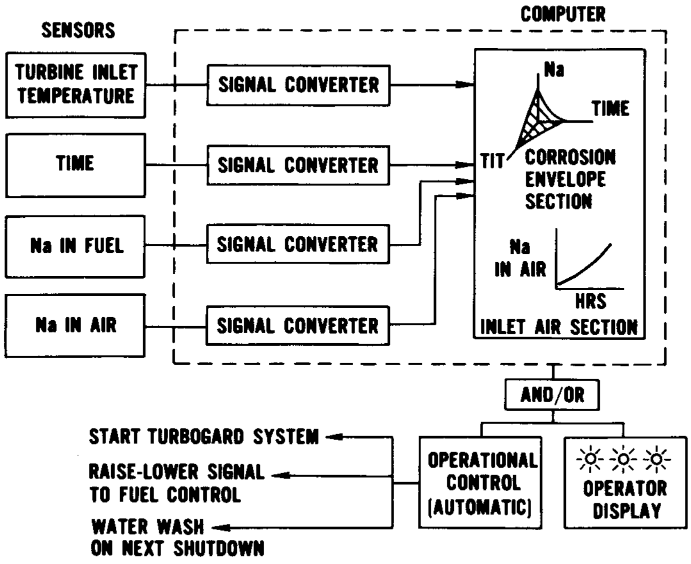


Figure 4.1 - Original Control System

The proposed system, as now envisioned, is presented in Figure 4.2. A Na+-in-air sensor is still needed to determine both PPM and PPM-hours. The sensor will require propane and electrical power to operate. It will be mounted outside the gas turbine, near the inlet, ideally in one package.

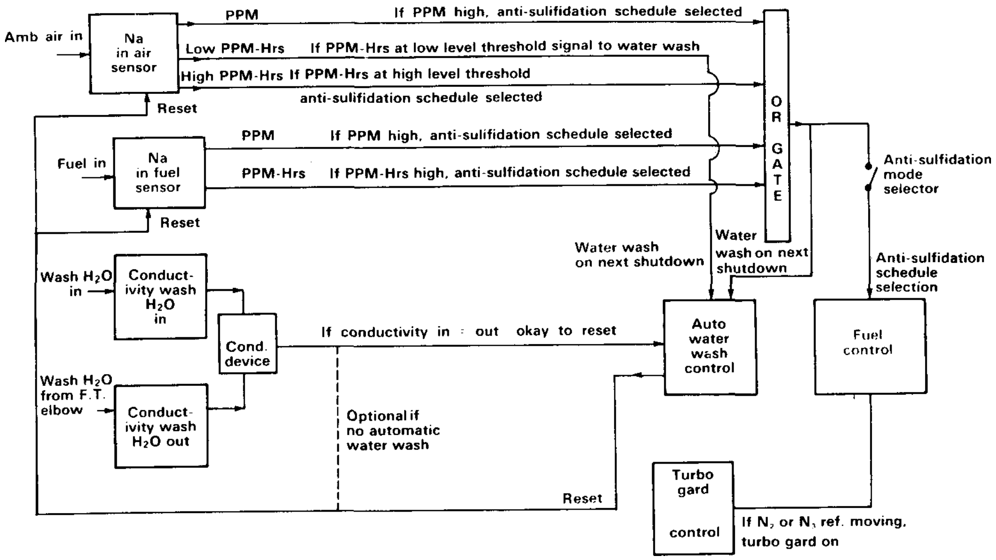


Figure 4.2 - Proposed Control Sytem

Outputs from the Na+ sensor will be of two types: contact closures, and 0-50 milliamp analog signal proportional to Na-in-air levels. The contact closures will be from threshold alarms on both the PPM and PPM-hour analog outputs.

The PPM and PPM-hour output features will be sequenced to work when the engine is operating.

When a preset value of either PPM or PPM-hours is exceeded, the anti-sulfidation schedule in the fuel control will be selected. This approach of using the fuel-control features to control firing temperature reduces the complexity of the corrosion-control system considerably; no separate turbine inlet temperature feedback loop is required.

Both PPM and PPM-hours are used to handle the absolute Na-in-air values and to keep a record of the potential Na+ retention by the engine compressor. When the PPM-hour parameter reaches the preset alarm point, an indication will warn the operator to water wash the engine. If the second PPM-hour threshold is reached, the anti-sulfidation schedule will be selected. Removal of the anti-sulfidation schedule can only be accomplished after an adequate water wash has been performed. The operator has the option of defeating this anti-sulfidation schedule by means of a switch.

The Na-in-fuel sensor will be mounted near the fuel sampling point (after the fuel filtration system) to reduce fuel transit time to the photometry section of the sensor. Operation of the Na-in-fuel sensor will be similar to the Na-in-air sensor; except PPM-hours may not be used as an active control output.

In order to insure that the engine is adequately washed, conductivity cells will be placed in the water supply to the engine and in the free turbine drain. When the wash water out falls within "X" ohms of the wash water in, the wash will be considered complete, and the water wash required alarm will be removed. The action will reset the PPM-hour counter in the Na-in-air sensor control loop.

The compressor shedding data indicates that transients cause the Na_2SO_4 accumulated in the compressor to shed (Figures 2.50 and 2.53 Seatrain, Dow Chemical). Transients occur normally when the gas generator and power turbine reference potentiometers in the fuel control are changing. Therefore, any time these pots are moving, an additive to prevent sulfidation such as Turbogard could be injected.

The gas path analysis technique used to demonstrate compressor and turbine fouling may be accomplished automatically with a system similar to the HSD Trends or a Howell performance monitor. An output from this type of system may be used as an input to select the anti-sulfidation schedule, as well as the other inputs.

As now proposed, any section of the corrosion control system can be used separately to reduce sulfidation, but the complete system offers the most protection as well as the most available power output from the gas turbine.

COMPONENTS

Specification PSD IPA 6803 was written, quoted upon, and a contract awarded to Baird Atomic for an Na-in-air sensor. Since this is the first-of-a-kind unit, the costs included non-recurring engineering. Baird expects to be able to produce production-type devices for approximately $10K. Delivery of the prototype unit is scheduled for February 1978.

A specification for an Na-in-fuel sensor has been written and submitted for quote.

Conductivity measuring devices have yet to be specified.

CORROSION CONTROL SYSTEM

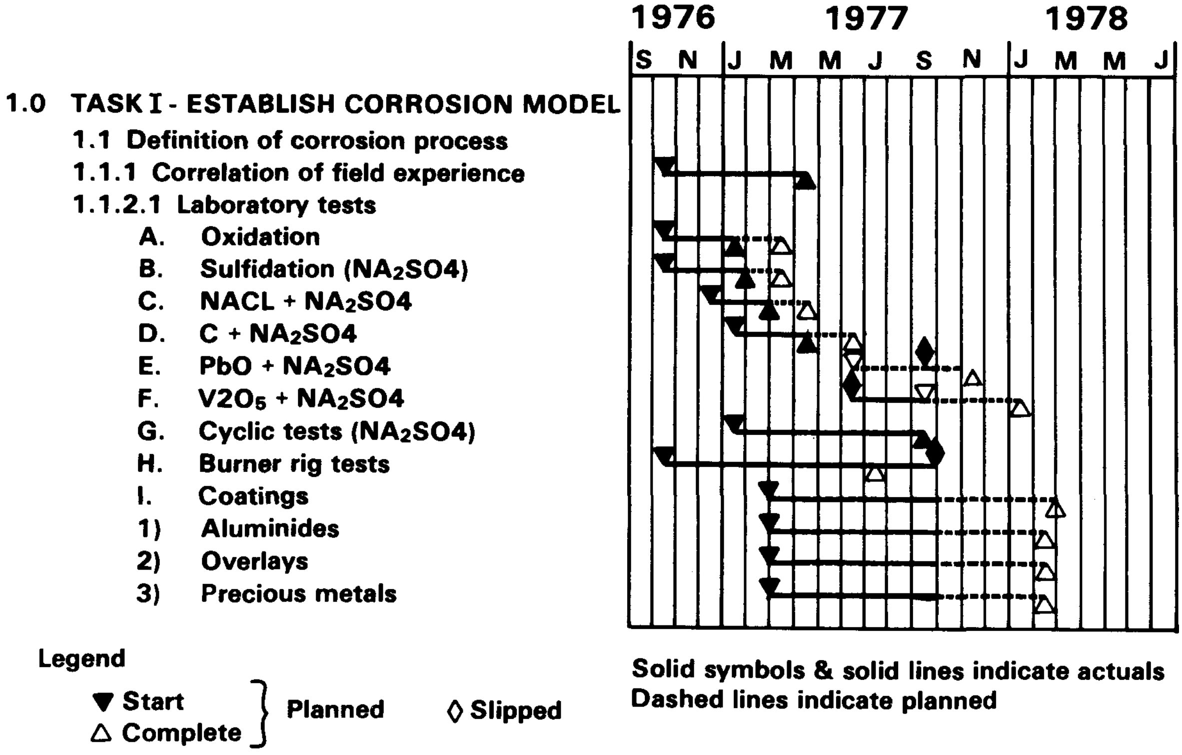
No work is scheduled under this subtask until February 1978.

Section 5

TASK IV - PROGRAM MANAGEMENT

PROGRAM SCHEDULE

Figures 5.1 through 5.4 present a subtask level breakdown of the program and indicate that the program is essentially on schedule. Satisfactory completion of all tasks is expected to be accomplished by the scheduled end of the program.



Solid symbols & solid lines indicate actuals
Dashed lines indicate planned

Figure 5.1 - Task I

1.0 TASK I - ESTABLISH CORROSION MODEL
1.1.2.2 Field tests
A. Prepare monitors for field
B. Install CSM-30 at sites
C. Air filter Eff tests
D. Compressor retention
E. Compressor shedding
F. Turbine retention (NA)
G. Fuel nozzle efficiency
H. Sodium in water analysis (method)
I. Other
1.1.3 Analysis of lab & field data
1.2 Establish corrosion envelope
1.2.1 Select significant corrosion parameters
1.2.2 Determine weighing factors for parameters
1.3 Verify corrosion model
1.3.1 Correlate field data
1.3.2 Correlate lab data & analyze

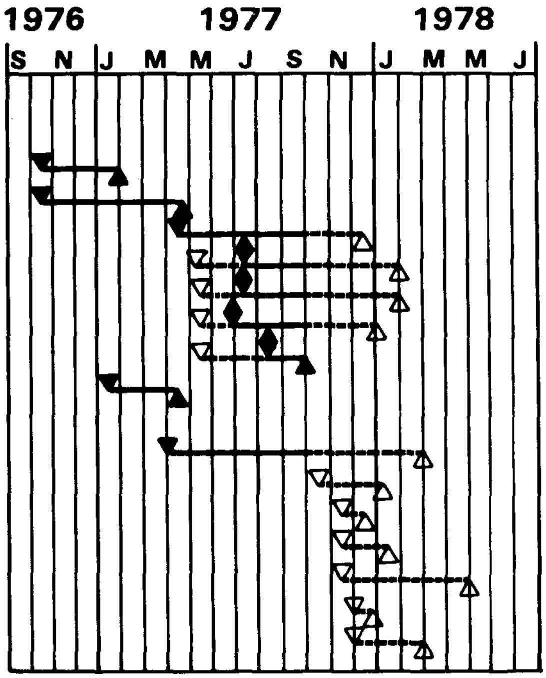


Figure 5.2 - Task I (Continued)

2.0 TASK II - DEFINE CONTROL REQUIREMENTS
2.1 Define corrosion control inputs & sensing requirements
2.1.1 Define sensing requirements based on corrosion model
2.1.2 Define means of sensing & quantitative measurement of parameter
2.1.3 Define location of sensors & determine sensor environmental conditions
2.1.4 Determine signal conversion for control output
2.2 Define control outputs
2.2.1 Analyze operational information
2.2.2 Review operational control
2.3 Prepare control system specs
2.3.1 Sodium in air monitor
2.3.2 Sodium in fuel monitor
2.3.3 Automatic control system
2.3.4 Sensors

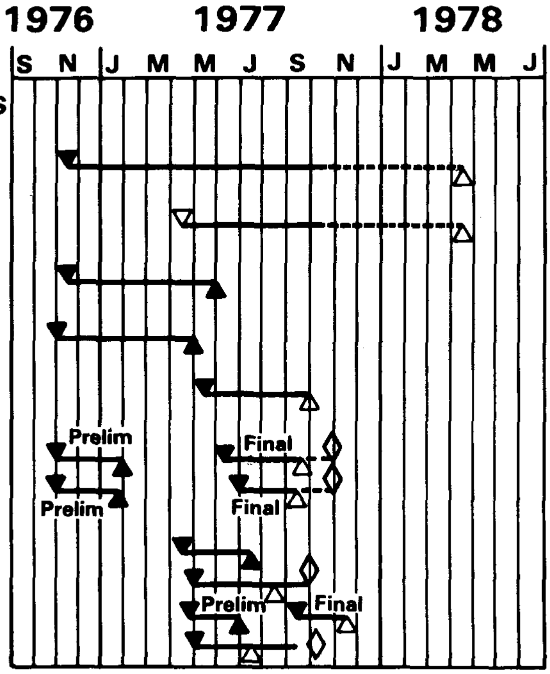


Figure 5.3 - Task II

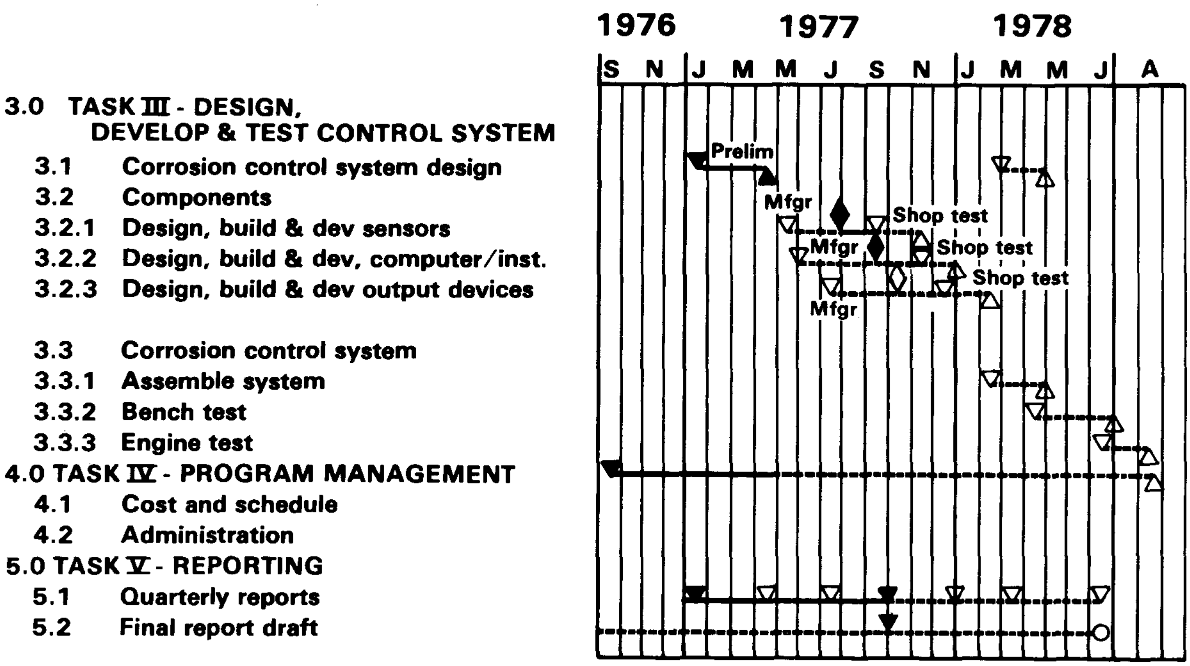


Figure 5.4 - Task III

APPENDIX I

SODIUM IN AIR SENSOR
FOR SULIFIDATION CONTROL SYSTEM
(EPRI)

CONTRACT NO. /
JOB NO. PROJECT RP643-1

REF. EOS 411000

	INITIALS	DATE
CHECKED	EMB	5-18-77
APPROVED		5/18/77

UNITED TECHNOLOGIES
POWER SYSTEMS DIVISION
Farmington, Connecticut 06032

TITLE
SODIUM-IN-AIR SENSOR FOR
SULIFIDATION CONTROL SYSTEM

CODE IDENT. NO	NO.	SHEET	REV.
54794	IPA - 6803	1 of 15	A

REVISION STATUS

SH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15					
REV	A	A		A		A	A	A			A	A	A							
SH																				
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REV LET	SHEETS AFFECTED	SHEETS ADDED	DESCRIPTION	REV BY & DATE	APPVD & DATE
A	4		Para. 3.3 add "the electronics can be mounted separately----".	10/24	JEZ 10-26-77
A	4		Para. 3.4 add "forty to 120°F temperature range in control house".	10/24	
A	6		Para. 4.1.3 change "5/8" I.D. tygon to 1" I.D."	10/24	
			Para. 4.1.5 add 5-reset totalizer	10/24	
			Para. 4.2 item 1) change PPM to PPB	10/24	
			Para. 4.2 item 2) change 100.000 to 9.999 minimum	10/24	
A	7		Para. 4.2 item 4) change to read"terminals for remote PPB reading from digital meter".	10/24	
			Para. 7.1.1 sample air hose,-change 5/8" to 1".	10/24	
A	8		Para 7.2 add "calibration will be to nominal schedule".	10/24	
A	8		Para. 7.4 change word locally in third sentence to electrically. Add"calibration will be to nominal schedule".	10/24	
A	11		Change 5/8" I.D.to 1" I.D.	10/24	
A	12		Added current limit and lowered high and low limit	10/24	
A	13		Added current limit	10/24	

DWG NO IPA - 6803	
REV A	SHEET 2

1.0 BACKGROUND

A sensor package is desired to detect and measure continually sodium-in-air in an aerosol form. The measured output from the sensor will be transmitted to a control system to control a gas turbine such as to keep the engine out of a sulifidation envelope.

2.0 SCOPE OF EQUIPMENT AND MATERIAL TO BE SUPPLIED BY VENDOR

2.1 NA-IN-AIR SENSOR PACKAGE

This package shall include the following:

2.1.1 Photometer and associated electronics.

2.1.2 Any propane or hydrogen regulators.
Note: To be mounted on the tank.

2.1.3 Operation manual.

2.1.4 Preliminary prints for review prior to start of sensor fabrication.

2.1.5 As installed prints.

2.1.6 Any regulated power supply should be supplied with the electronic package.

2.1.7 Any air compressors or pumps necessary to operation of the sensor.

2.1.8 Calibration curves as described in the performance section of this specification.

2.1.9 Provisions for infield calibration to the mod. BSI 4400 or comparable standard. Self calibration is not required or desired.

2.1.1.0 Proper interfaces for electrical, air, and propane connections.

2.1.1.1 If a Coanda effect air mover is used and gas generator compressor air is desired as a motive force, the vendor will provide air to air cooler necessary to utilize this air. Specifications on available compressor air are included under the environmental design requirements.

2.1.1.2 A chart recorder will be part of the package.

2.1.1.3 Items requiring cleaning (for example, burner grid) should have spares included to lessen down time when cleaning required.

2.1.1.4 List of recommended spares.

3.0 ENVIRONMENTAL AND LOCATION DESIGN REQUIREMENTS

The sensor shall be designed to handle the following requirements.

3.1 PACKAGING

The unit shall be self contained in that only electrical power and propane or hydrogen will be needed to operate the unit. The electrical portion of the system can be separated from the photometer package, if the vendor so desires. Compactness and one-man portability are considered a virtue in the packaging.

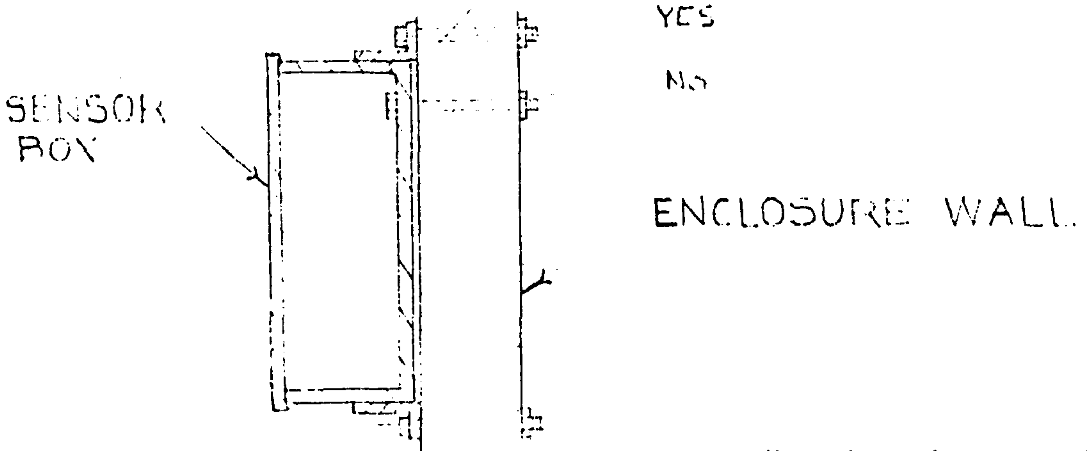
3.2 FUTURE APPLICATION

The unit should be considered a prototype for future gas turbine control systems and as an add-on to existing installations. Provisions for adjustment and modification should be incorporated in the design to allow field alteration.

3.3 MOUNTING LOCATION

The unit will be mounted on the outside of a gas turbine enclosure or control house enclosure. Provisions to prevent propane leakage into the adjacent enclosed space should be incorporated into the packaging.

Exhaust and venting will be to ambient air. Attachment to the vertical enclosure wall will be by means of through bolts at least 1/2" diameter. The bolts should not pass through the inside of the sensor box. PSD will provide the bolts.



The electronic can be mounted separately in a 19" rack in the control house.

3.4 AMBIENT REQUIREMENTS

-20°F TO 120°F (40 to 120° F in control house)

Typical Ambient Pressure Range from 0 to 5000' ASL

Exposure to rain, snow, thunderstorms, etc..

3.5 VIBRATION

3.5.1 GAS TURBINE INDUCED VIBRATION

The unit will be attached to a structure that has a gas turbine attached to it. Therefore, the vibration levels will be those associated with the gas turbine. Fig. 5 is a plot of vibration levels associated with the gas turbine. It can be assumed that these levels will be reduced in amplitude at the sensor location.

3.5.2 SURGE INDUCED VIBRATION

When the compressor of a gas turbine is fouled or bleed valves operating improperly, the engine can surge producing rapid oscillations of the enclosure structure. The following is typical of surge induced vibration levels:

7 mm Peak to peak at 3 - 10 H_z.

3.6 MOTIVE AIR FOR COANDA AIR MOVERS

3.6.1 GAS TURBINE COMPRESSOR AIR AVAILABLE

STAGE	PRESSURE RANGE	TEMP. RANGE	NOMINAL
3			
5			
7			
9			
16			

An air compressor for the air mover is desired with provisions (a connection) for using compressor air if desired. This will permit costs reductions and greater reliability in future units if prototype development indicates compressor air use is feasible.

4.0 INTERFACE REQUIREMENTS

4.1 INPUTS

4.1.1 POWER SUPPLY AVAILABLE

110	VAC	60 H_z	± 10% on all voltage level 6% on frequency
220	VAC	50-60 H_z (optional)	
125	VDC	(optional)	

4.1.2 PROPANE OR HYDROGEN

Tank will be PSD supplied and installed outside. Regulator to be supplied by vendor. Typical tank of propane is the common 90 # household LPG.

4.1.3 SAMPLE AIR

The sample air will be drawn by the sensor's pump. Normally, sample air will be drawn from the ambient, but it may be taken after a gas turbine inlet air filter. Therefore, the sample may be at a pressure up to 10" of H_2O below ambient.

The PSD supplied sample air line will be between 0 and 50 foot of 1" I. D. tygon (flexible PVC).

4.1.4 TERMINAL STRIP

The electrical interface will be via terminal strip internal to the sensor. Cable access will be from the bottom of the sensor. Provisions to prevent wire lugs from slipping off the terminals shall be provided (for example; sealant, snap connectors, ring connectors.). Terminal strip will be accessible for trouble-shooting and terminals will be labeled.

4.1.5 CONTACT CLOSURES REQUIRED

1. Chart drive on - off(should be OR function with local switch).
2. Flame out indication on - off.
3. Totalizer on - off.
4. Threshold alarms - (one on Na-in-air)
5. Reset totalizers (two on totalized Na-in-air)

4.2 OUTPUT REQUIREMENTS

LOCAL INSTRUMENTATION

1) Digital panel meter (PPB Na^+) 000.0 to 100.0 range min.
2) Totalizer (PPM-HRS) .000 to 9.999
3) Flame out indication
4) Propane flow meter
5) Air flow meter
6) Air mover motive air pressure
7) Any other instrumentation necessary to determine if the unit is producing accurate data (for example; photo tube voltage, etc.).

OUTPUT SIGNALS

1) An analog current output versus PPM schedule, see Fig. 2, will be one output. Impedance range this output will be placed across will be from 100 to 1000 ohms.
2) An analog output proportional to PPM-HRS will be

required. The schedule is shown on Fig. 3.

3) Contact closures per section 4.1.5.

4) Terminals for remote reading from the digital output.

5) 10% spares shall be required on the output terminal strip.

6) Shorting on output signal to ground shall not damage a sensor component.

5.0 RFI REQUIREMENT

5.1 The electronics of the sensor shall be designed such that keying a communication's transmitter (for example; a walkie talkie) next to the sensor will not effect the output signal.

5.2 Shielding on output signal wiring shall be floating on the sensor side. The shield will be carried through the PSD wiring and grounded at the PSD end.

6.0 EMI REQUIREMENTS

Solenoids, motors, relay coils, shall be suppressed to prevent inductive spikes being transmitted to the signal outputs. PSD procedures are shown on Fig. 4, TRANSIENT SUPPRESSION.

The fuel control specification calls for less than 20 V peak with a 0.010 second duration between line and ground on any fuel control terminal. The sensor will be connected to the fuel control.

7.0 PERFORMANCE REQUIREMENTS

7.1 DIGITAL METER (PPM) CALIBRATION

The multipoint calibration procedure established in BSI 4400/1969 section 6 p. 11 will be the calibration standard on the Na-in-air sensor. An as shipped calibration curve will be provided with the sensor. Fig. 1 is a model.

7.1.1 Accuracy based on the BSI 4400/1969 standard will fall within the band shown on Fig. 1 throughout the ranges of the following variables:

Relative Humidity	- 30 to 100%
Ambient Temperature Range	- -20°F to +120°F
Power Supply Voltage	- ± 10% variation in voltage
Darkness versus Daylight	
Sample Air Hose	- 0 to 50' 1" Flexible PVC.
Propane Supply Flow	- ± .2 SCFH

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REV A	SHEET 7

7.1.1.1 The effect of the variables in section 7.1.1 shall be plotted without corrective bias to establish whether corrective biasing is necessary. These plots will be made available to the cognizant PSD engineer for approval.

7.1.2 DIGITAL METER CALIBRATION ADJUSTMENTS

Adjustments to vary the calibration should be included in the design. They should not be readily accessible to discourage unauthorized tampering.

7.1.3 CHART RECORDER

The chart recorder should reflect the reading on the digital meter. A two pen recorder is desired. The second pen to be a spare.

7.2 OUTPUT SIGNAL

The output signal should be independent of the digital meter, that is, the signal output should be adjustable within the band shown of Fig. 2. These adjustments should not be readily accessible to discourage unauthorized tampering. One threshold alarm should be included. Calibrate to nominal schedule.

7.3 RESPONSE TIME

The time constants used in the Na detection circuits should be such as to respond to step inputs at the rate of .001 PPM Na+/minute. Consideration should be given to designing adjustment into the response time.

7.4 TOTALIZER OUTPUT

The totalizer (PPM-HRS) will produce a schedule as shown on Fig. 3. The totalizer output will have two adjustable threshold alarms. The totalizer shall be resetable to zero electrically. Shutting off the unit will not erase totalizer output signal. Calibrate to nominal schedule.

7.5 UNATTENDED OPERATION

The sensor will be designed to operate for one month minimum unattended with no maintenance.

8.0 QUALITY ASSURANCE

8.1 PERFORMANCE

8.1.1 The curves, accuracy, and response requirements stated in section 6 will be supplied to the cognizant PSD engineer prior to PSD's acceptance of the unit.

8.1.2 The unit will satisfactorily complete a one month continuous operation test prior to acceptance of the unit. This test can be accomplished after delivery with concurrence of the cognizant PSD engineer.

8.1.3 The monitor will be functionally demonstrated to the cognizant PSD Engineer, or his representative, at the vendor's facility prior to shipment.

8.1.4 Shipment will not be initiated until the cognizant PSD Engineer issues a written approval stating the unit meets the requirements of this specification.

8.1.5 The items called out under section 2 of this specification are considered part of the delivered package. A list of recommended spares shall be supplied, also.

9.0 INSTALLATION

9.1 The vendor shall provide a three-day installation, calibration and instruction period with each instrument. Normally, this instruction will be carried out during installation at the ultimate location of the device. The vendor will not be responsible for hookup outside his interface; for example, installing propane tanks, venting pipes, etc.

10.0 PREPARATION FOR SHIPMENT AND DELIVERY

10.1 Packaging for shipment shall be with generally accepted shipping practices, such as to insure an "as shipped" condition at the site when shipped by air, ship, rail or truck.

10.1.1 Shipment shall be to a location specified by PSD.
10.1.2 The unit shall be suitably protected from the effects of transit and prolonged outdoor storage by the packaging.

10.2 WARRANTY

10.2.1 The vendor shall warrant the equipment as specified by the PSD Purchasing Department.

10.2.2 Generally the warranty shall be for a period of one (1) year from the date of commercial operation.

start-up or a period of two (2) years from the date of shipment, whichever occurs first. The vendor shall repair or replace without delay at his expense all items mutually deemed defective in material or manufacturing, and all items not conforming to this specification. The repair or replacement of defective items, or whatever corrective actions are deemed necessary, shall take place at either the vendor's facility, PSD facility, or the installation site, whichever is mutually acceptable to PSD and the vendor.

11.3 VENDOR RESPONSIBILITY

11.3.1 The vendor acknowledges that he is, and PSD relies upon the vendor as, an expert, fully competent in all phases of the work involved in furnishing and supporting the sodium sensor. In this context, the vendor agrees that he will not deny any responsibility or obligation to PSD on the ground that PSD approved any specification, drawing, plan or other documentation prepared by the vendor, or that PSD provided recommendations or assistance in any phase of the work involved in furnishing or supporting the equipment.

11.3.2 The vendor shall give written notice of all known foreseeable hazards or dangers which may be encountered by any persons using, storing, or handling the supply of vendor goods within the scope of their intended use.

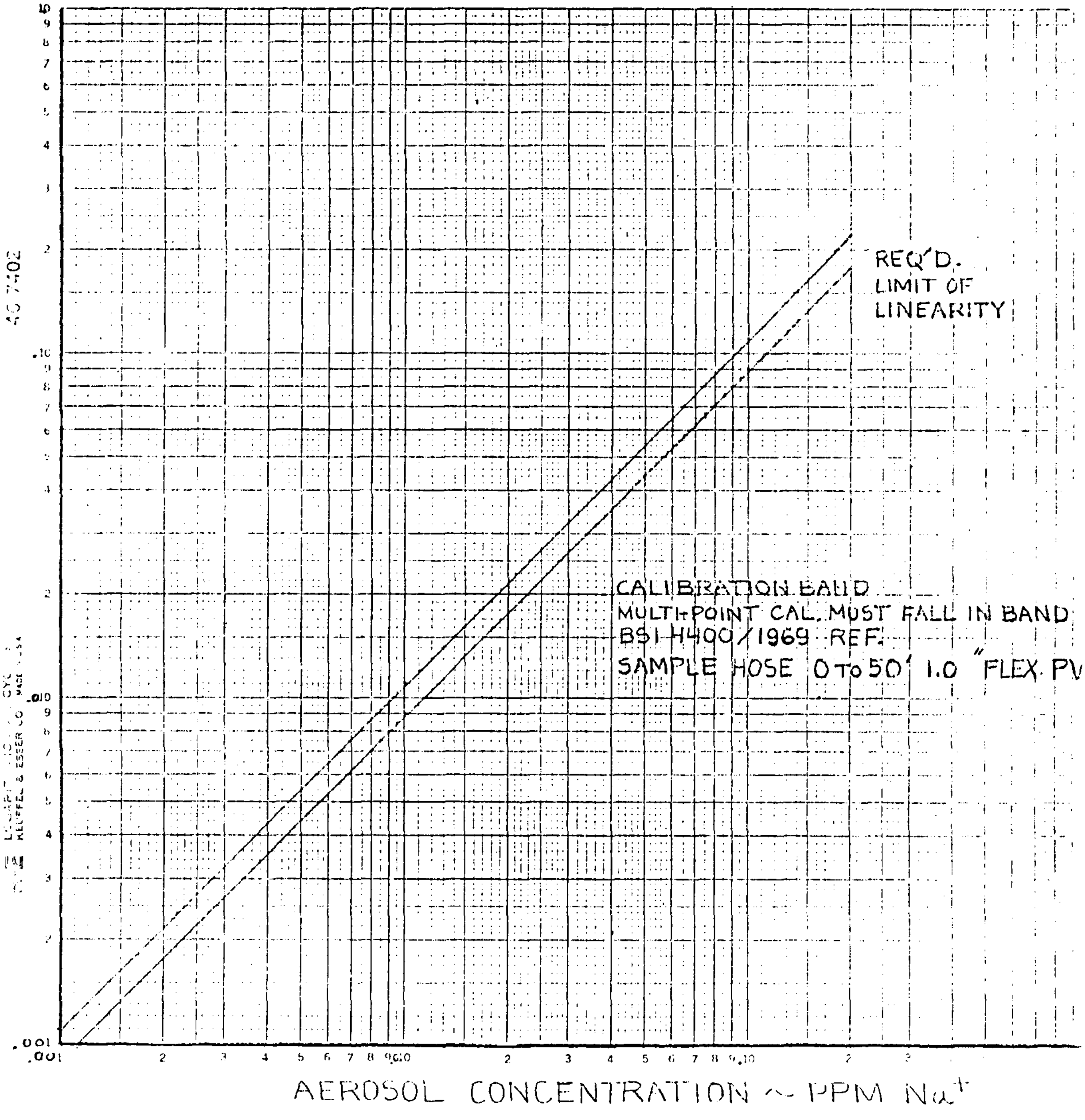


FIG. 1 CALIBRATION SCHEDULE

[illegible] SCHEDULE SHOULD BE ADJUSTABLE IN SLOPE AND [illegible]
SIGNAL OUTPUT TO BE INDEPENDENT OF DIGITAL [illegible]

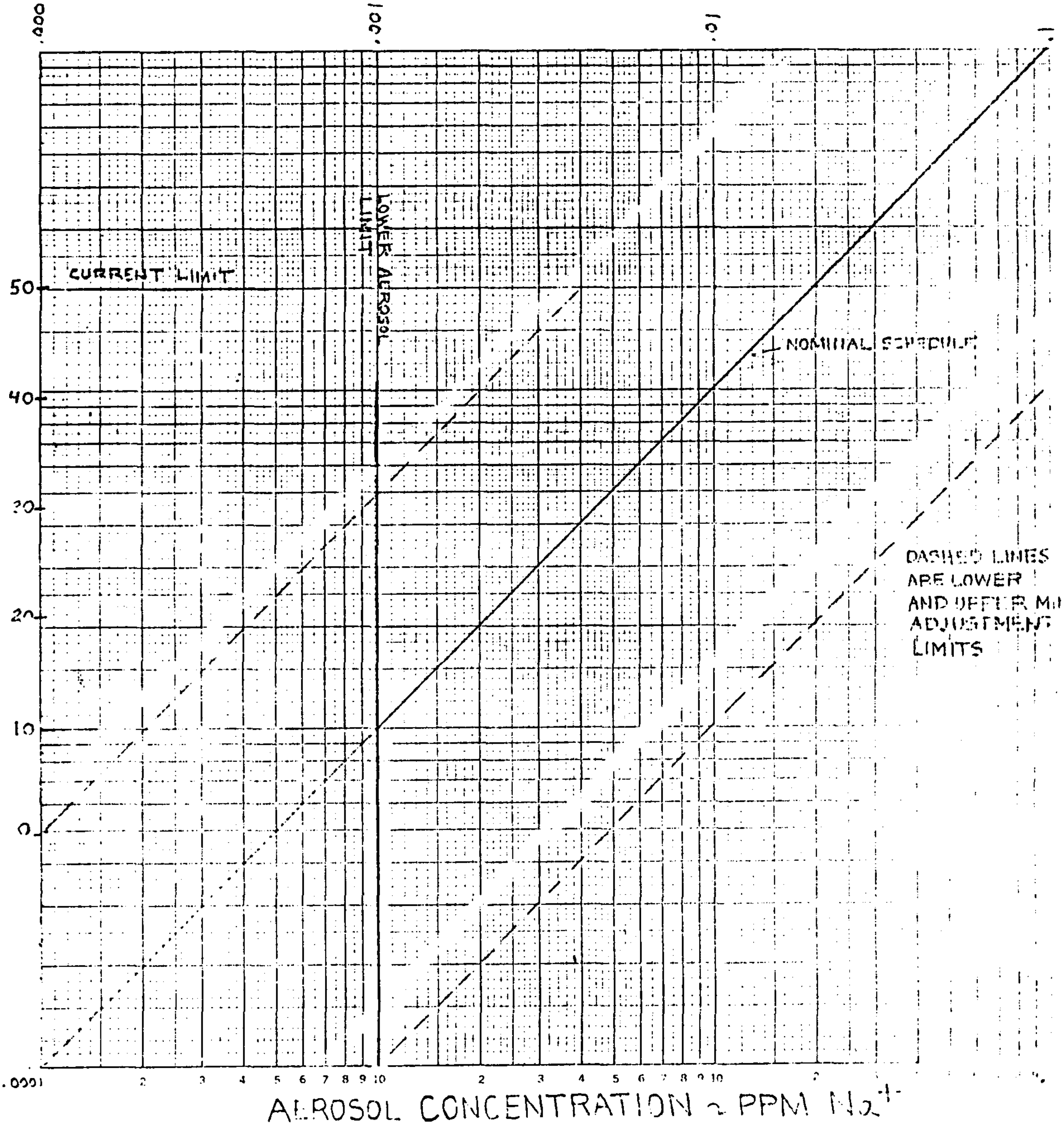


FIG. 2 OUTPUT SIGNAL vs PPM Na [illegible]

TWO THRESHOLD ALARMS REQ'D
THE SCHEDULE SHOULD BE ADJUSTABLE IN SLOPE AND
INTERCEPT. SIGNAL OUTPUT TO BE [illegible]
OF TOTALIZER READING

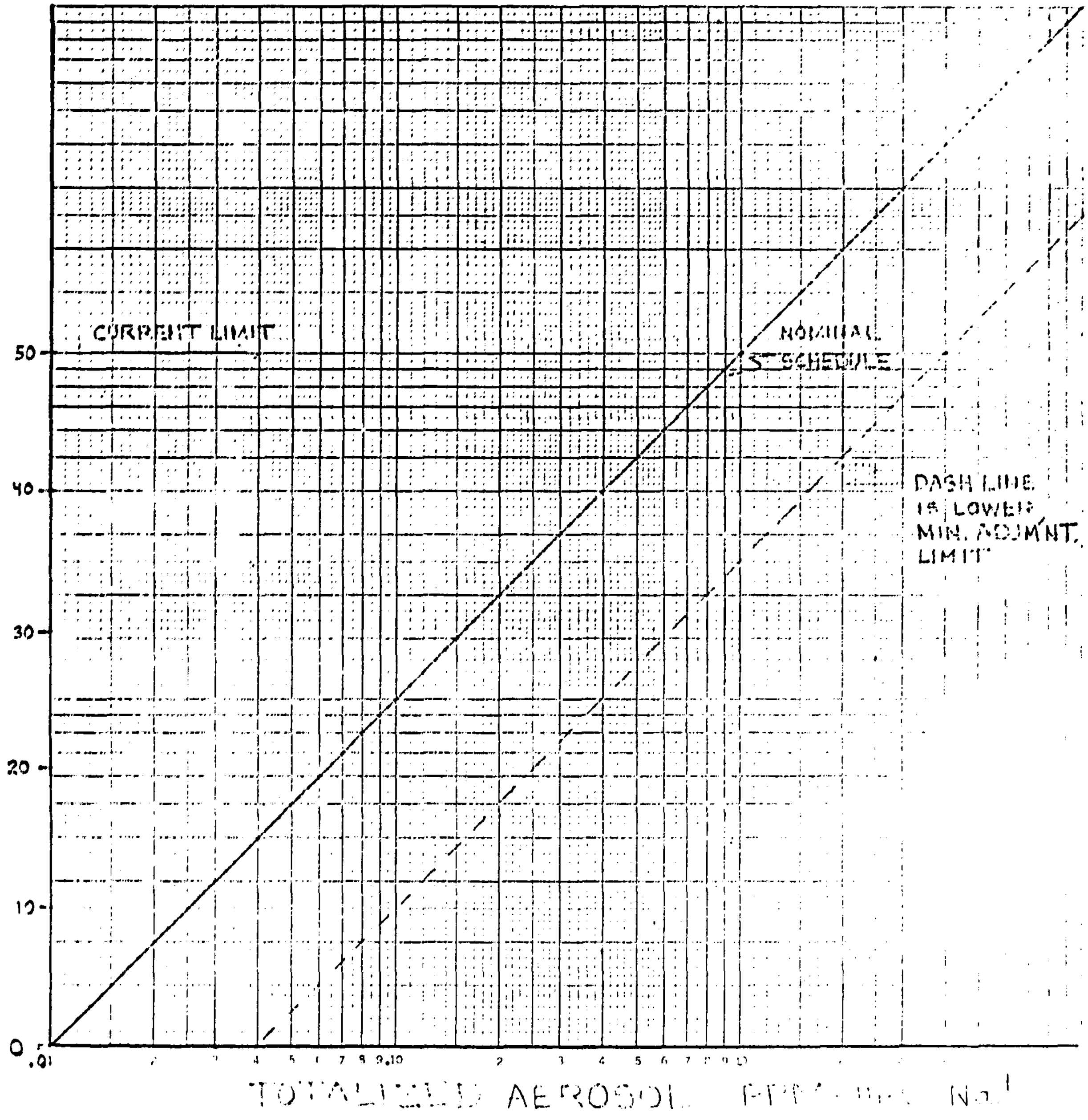
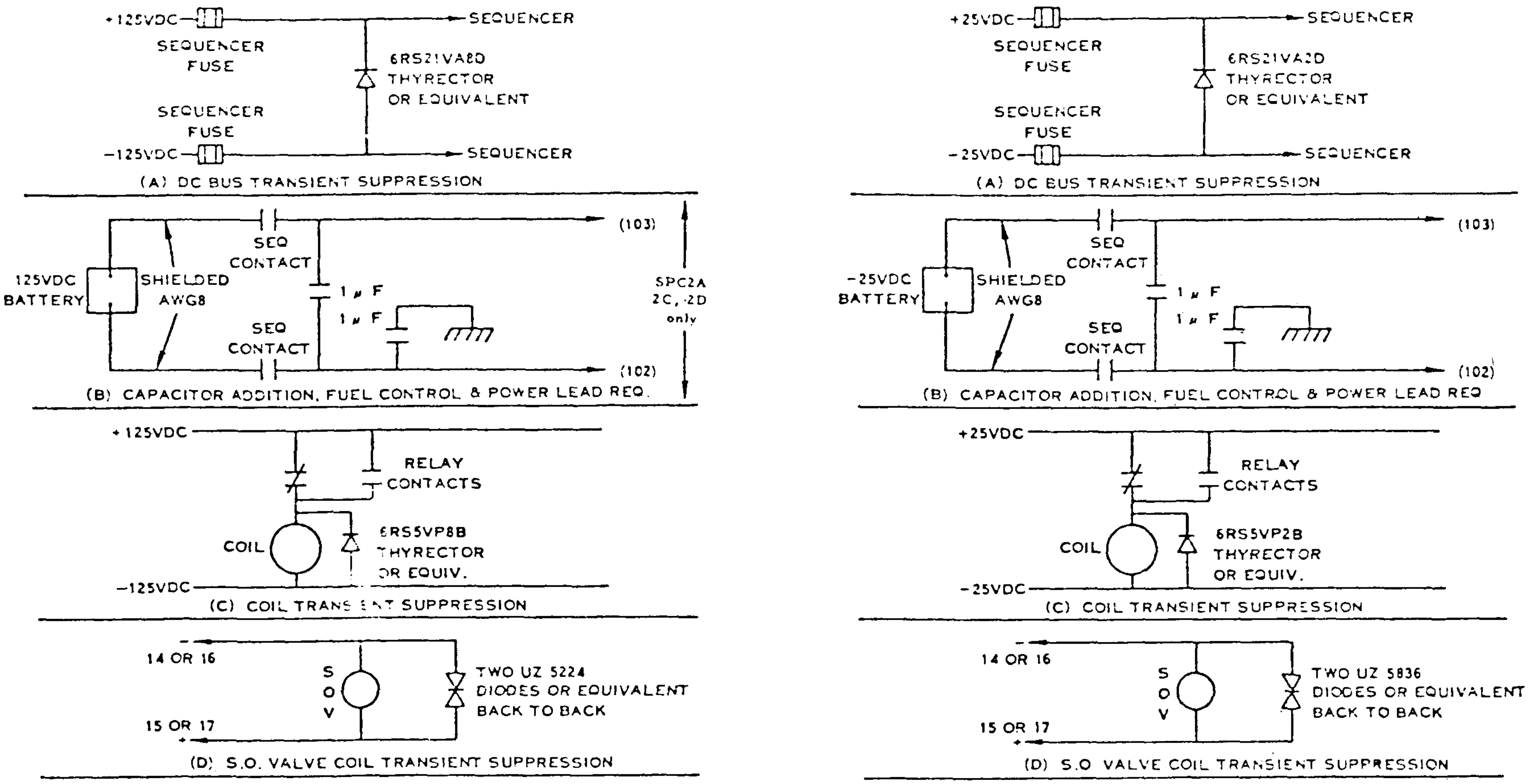


FIG. 3 TOTALIZER SIGNAL vs PPM-HR



SPC2A, 2B, 2C, 2D - 125 VDC System

SPC2A, 2B, 2C, 2D - 25 VDC System

Figure 4. Transient Suppression

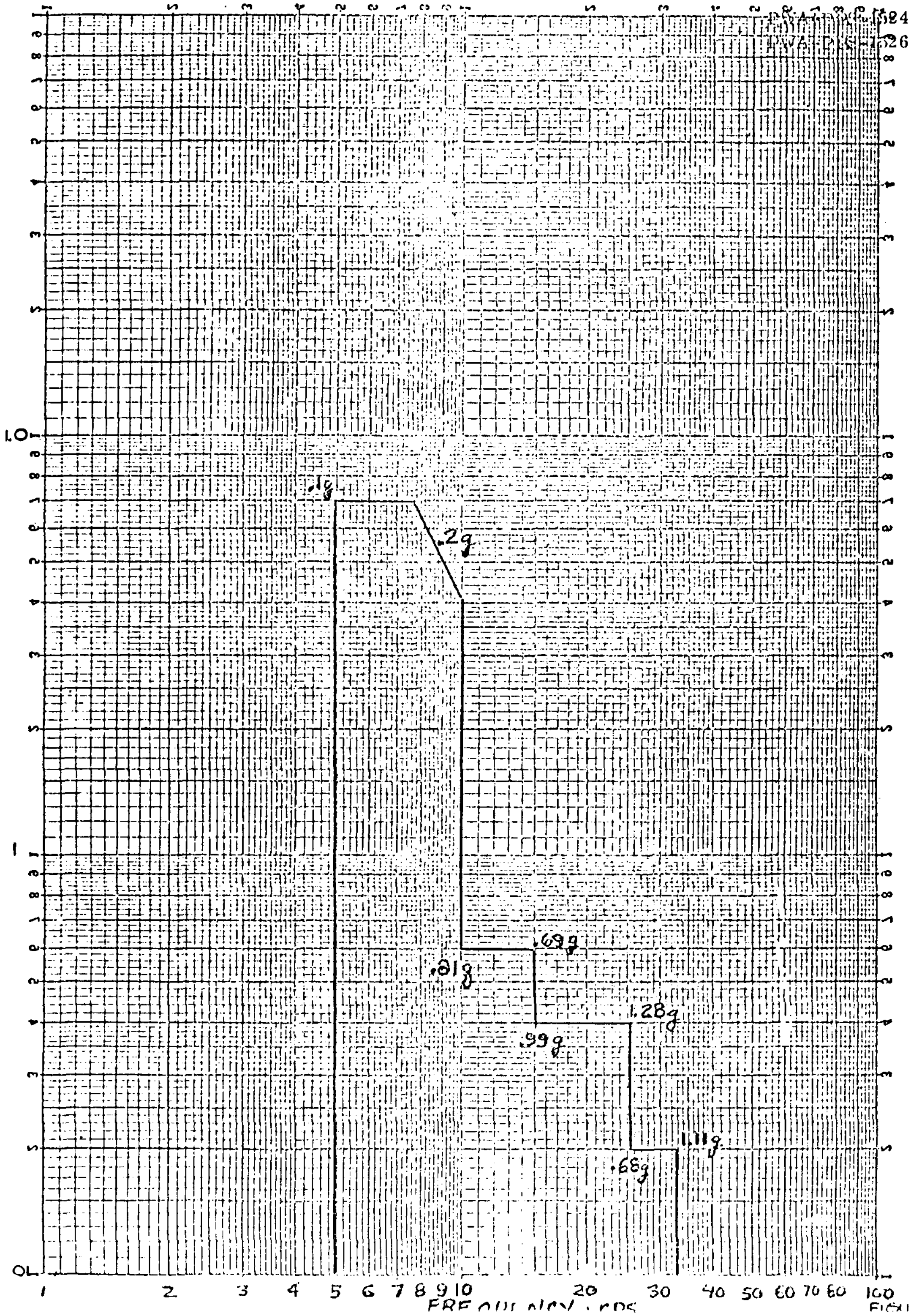

1.0
1
.01
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
100
FREQUENCY, CPS
.1g
.2g
.81g
.69g
.99g
1.28g
.66g
1.11g

FIGURE 5

APPENDIX II

SODIUM IN FUEL SENSOR
FOR SULFIDATION CONTROL SYSTEM
(EPRI)

CONTRACT NO. / JOB NO. Project RP 643-1

REF. EOS 411000

	INITIALS	DATE
CHECKED	BMB	10/20/77
APPROVED	JEZ	10/26/77

UNITED TECHNOLOGIES
POWER SYSTEMS DIVISION
Farmington, Connecticut 06032

TITLE
SODIUM-IN-FUEL SENSOR FOR
SULFIDATION CONTROL SYSTEM

CODE IDENT. NO.	NO.	SHEET	REV.
54794	IPA 7056	1 OF 10	

REVISION STATUS

SH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17			
REV																				
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REV LET	SHEETS AFFECTED	SHEETS ADDED	DESCRIPTION	REV BY & DATE	APPVD & DATE

DWG NO IPA - 7056	
REV	SHEET 2

1.0 BACKGROUND

A sensor package is desired to detect and measure continually sodium-in-fuel regardless of form, for example, crystalline, water or fuel soluble. The measured output from the sensor will be transmitted to a control system to control a gas turbine such as to keep the engine out of a sulfidation envelope.

2.0 SCOPE OF EQUIPMENT AND MATERIAL TO BE SUPPLIED BY VENDOR

2.1 NA-IN-FUEL SENSOR PACKAGE

This package shall include the following:

2.1.1 Photometer and associated electronics.
2.1.2 Any propane or hydrogen regulators.
Note: To be mounted on the tank.
2.1.3 Operation manual.
2.1.4 Preliminary prints for review prior to start of sensor fabrication.
2.1.5 As installed prints.
2.1.6 Any regulated power supply should be supplied with the electronic package.
2.1.7 Any air compressors or pumps necessary to operation of the sensor.
2.1.8 Calibration curves as described in the performance section of this specification.
2.1.9 Provisions for infield calibration.
2.1.1.0 Proper interfaces for electrical, air, and propane connections.
2.1.1.2 A chart recorder will be part of the package.
2.1.1.3 Items requiring cleaning (for example, burner grid) should have spares included to lessen down time when cleaning required.
2.1.1.4 List of recommended spares.

3.0 ENVIRONMENTAL AND LOCATION DESIGN REQUIREMENTS

The sensor shall be designed to handle the following requirements.

3.1 PACKAGING

The unit shall be self contained in that only electrical power and propane or hydrogen will be needed to operate the unit. The electrical portion of the system can be separated from the photometer package, if the vendor so desires. Compactness and one-man portability are considered a virtue in the packaging.

3.2 FUTURE APPLICATION

The unit should be considered a prototype for future gas turbine control systems and as an add-on to existing installations. Provisions for adjustment and modification should be incorporated in the design to allow field alteration.

3.3 MOUNTING LOCATION

The unit will be mounted on the outside of a gas turbine enclosure or control house enclosure near the fuel to be analyzed. Provisions to prevent propane leakage into the adjacent enclosed space should be incorporated into the packaging.

Exhaust and venting will be to ambient air. Attachment to the vertical enclosure wall will be by means of through bolts at least 1/2" diameter. The bolts should not pass through the inside of the sensor box. PSD will provide the bolts.

The electronics can be mounted separately in a 19" rack in the control house.

3.4 AMBIENT REQUIREMENTS

-20°F TO 120°F
40°F to 120°F in control house
Typical Ambient Pressure Range from 0 to 5000' ASL

Exposure to rain, snow, thunderstorms, etc.

3.5 VIBRATION

3.5.1 GAS TURBINE INDUCED VIBRATION

The unit will be attached to a structure that has a gas turbine attached to it. Therefore, the vibration levels

DWG NO IPA - 7056	
REV A	SHEET 4

will be those associated with the gas turbine. Fig. 5 is a plot of vibration levels associated with the gas turbine. It can be assumed that these levels will be reduced in amplitude at the sensor location.

3.5.2 SURGE INDUCED VIBRATION

When the compressor of a gas turbine is fouled or bleed valves operating improperly, the engine can surge producing rapid oscillations of the enclosure structure. The following is typical of surge induced vibration levels:

7 mm Peak to Peak at 3 - 10 Hz.

4.0 INTERFACE REQUIREMENTS

4.1 INPUTS

4.1.1 POWER SUPPLY AVAILABLE

110 VAC	60 Hz	
220 VAC	50-60 Hz (optional)	± 10% on all voltage level
125 VDC	(optional)	6% on frequency

4.1.2 PROPANE OR HYDROGEN

Tank will be PSD supplied and installed outside. Regulator to be supplied by vendor. Typical tank of propane is the common 90 # household LPG.

4.1.3 SAMPLE FUEL

Fuels to be sampled are described in TPM-FR-1 and PWA 539. Normally, these fuels are delivered to the engine at ambient temperature and at pressures from 10 to 125 psig.

4.1.4 TERMINAL STRIP

The electrical interface will be via terminal strip internal to the sensor. Cable access will be from the bottom of the sensor. Provisions to prevent wire lugs from slipping off the terminals shall be provided (for example; sealant, snap connectors, ring connectors.) Terminal strip will be accessible for trouble-shooting and terminals will be labeled.

4.1.5 CONTACT CLOSURES REQUIRED

1. Chart drive on - off (should be OR function with local switch).
2. Flameout indication on - off.
3. Totalizer on - off.
4. Threshold alarms - (one on Na-in-fuel
5. Reset totalizer (two on totalized Na-in-fuel)

4.2 OUTPUT REQUIREMENTS

INSTRUMENTATION

1) Digital panel meter (PPM Na+) .0 to 50 range min.
2) Totalizer (PPM-HRS) .00 to 999.99
3) Flameout indication
4) Propane flow meter
5) Air flow meter
6) Any other instrumentation necessary to determine if the unit is producing accurate data (for example; photo tube voltage, etc.).

OUTPUT SIGNALS

1) An analog current output versus PPM schedule, see Fig. 2, will be one output. Impedance range this output will be placed across will be from 100 to 1000 ohms.

2) An analog output proportional to PPM-HRS will be required. The schedule is shown on Fig. 3.

3) Contact closures per section 4.1.5.

4) Terminals for remote PPM reading from the digital meter.

5) 10% spares shall be required on the output terminal strip.

6) Shorting on output signal to ground shall not damage a sensor component.

5.0 RFI REQUIREMENT

5.1 The electronics of the sensor shall be designed such that keying a communication's transmitter (for example; a walkie talkie) next to the sensor will not affect the output signal.

5.2 Shielding on output signal wiring shall be floating on the sensor side. The shield will be carried through the PSD wiring and grounded at the PSD end.

6.0 EMI REQUIREMENTS

Solenoids, motors, relay coils, shall be suppressed to prevent inductive spikes being transmitted to the signal outputs. PSD procedures are shown on Fig. 4, TRANSIENT SUPPRESSION.

The fuel control specification calls for less than 20 V peak with a 0.010 second duration between line and ground on any fuel control terminal. The sensor will be connected to the fuel control.

7.0 PERFORMANCE REQUIREMENTS

7.1 DIGITAL METER (PPM) CALIBRATION

An as shipped calibration curve will be provided with the sensor. Fig. 1 is a model.

7.1.1 Accuracy will fall within the band shown on Fig. 1 throughout the ranges of the following variables:

Relative Humidity	-	30 to 100%
Ambient Temperature Range	-	20 to +120°F
Power Supply Voltage	-	± 10% variation in voltage
Darkness versus Daylight		
Propane Supply Flow	-	± .2 SCFH
Fuels Described in FR-1 and PWA 539		
Fuels with Sea Water Contents Up to.1% by Volume Showed Fall Within Fig. 1.		

7.1.1.1 The effect of the variables in section 7.1.1 shall be plotted without corrective bias to establish whether corrective biasing is necessary. These plots will be made available to the cognizant PSD engineer for approval.

7.1.2 DIGITAL METER CALIBRATION ADJUSTMENTS

Adjustments to vary the calibration should be included in the design. They should not be readily accessible to discourage unauthorized tampering.

7.1.3 CHART RECORDER

The chart recorder should reflect the reading on the digital meter. A two pen recorder is desired. The second pen to be a spare.

7.2 OUTPUT SIGNAL

The output signal should be independent of the digital meter, that is, the signal output should be adjustable within the band shown on Fig. 2. These adjustments should not be readily accessible to discourage unauthorized tampering. One threshold alarm should be included.

7.3 RESPONSE TIME

The time constants used in the Na detection circuits should be such as to respond to step inputs at the rate of .1 PPM Na+/sec. Consideration should be given to designing adjustment into the response time. Transient time of sample fuel through the sensor should be added to the sampling time of the totalizer and chart recorder when the engine is shutdown.

7.4 TOTALIZER OUTPUT

The totalizer (PPM-HRS) will produce a schedule as shown on Fig. 3. The totalizer output will have two adjustable threshold alarms. The totalizer shall be resetable to zero electrical. Shutting off the unit will not erase the totalizer output signal.

7.5 UNATTENDED OPERATION

The sensor will be designed to operate for one month minimum unattended with no maintenance.

8.0 QUALITY ASSURANCE

8.1.1 The curves, accuracy, and response requirements stated in section 6 will be supplied to the cognizant PSD engineer prior to PSD's acceptance of the unit.

8.1.2 The unit will satisfactorily complete a one month continuous operation test prior to acceptance of the unit. This test can be accomplished after delivery with concurrence of the cognizant PSD engineer.

8.1.3 The monitor will be functionally demonstrated to the cognizant PSD Engineer, or his representative, at the vendor's facility prior to shipment.

8.1.4 Shipment will not be initiated until the cognizant PSD Engineer issues a written approval stating the unit meets the requirements of this specification.

8.1.5 The items called out under section 2 of this specification are considered part of the delivered package. A list of recommended spares shall be supplied, also.

9.0 INSTALLATION

9.1 The vendor shall provide a three-day installation, calibration and instruction period with each instrument. Normally, this instruction will be carried out during installation at the ultimate location of the device. The vendor will not be responsible for hookup outside his interface; for example, installing propane tanks, venting pipes, etc.

10.0 PREPARATION FOR SHIPMENT AND DELIVERY

10.1 Packaging for shipment shall be with generally accepted shipping practices, such as to insure an "as shipped" condition at the site when shipped by air, ship, rail or truck.

10.1.1 Shipment shall be to a location specified by PSD.

10.1.2 The unit shall be suitably protected from the effects of transit and prolonged outdoor storage by the packaging.

10.2 WARRANTY

10.2.1 The vendor shall warrant the equipment as specified by the PSD Purchasing Department.

10.2.2 Generally the warranty shall be for a period of one (1) year from the date of commercial operation start-up or a period of two (2) years from the date of shipment, whichever occurs first. The vendor shall repair or replace without delay at his expense all items mutually deemed defective in material or manufacturing, and all items not conforming to this specification. The repair or replacement of defective items, or whatever corrective actions are deemed necessary, shall take place at either the vendor's facility, PSD facility, or the installation site, whichever is mutually acceptable to PSD and the vendor.

11.3 VENDOR RESPONSIBILITY

11.3.1 The vendor acknowledges that he is, and PSD relies upon the vendor as, an expert, fully competent in all phases of the work involved in furnishing and supporting the sodium sensor. In this context, the vendor agrees that he will not deny any responsibility or obligation to PSD on the ground that PSD approved any specification, drawing, plan or other documentation prepared by the vendor, or that PSD provided recommendations or assistance in any phase of the work involved in furnishing or supporting the equipment.

11.3.2 The vendor shall give written notice of all known foreseeable hazards or dangers which may be encountered by any persons using, storing, or handling the supply of vendor goods within the scope of their intended use.

MULTI-POINT CALIBRATION MUST FALL IN BAND WITH Na^+ ADDED TO FUEL IN CRYSTALLINE FORM, OR SOLUBLE FORM, AND UP TO 0.1% SEAWATER CONTENT BY VOL.
FUELS DESCRIBED TPM-FR-1 AND PWA 539

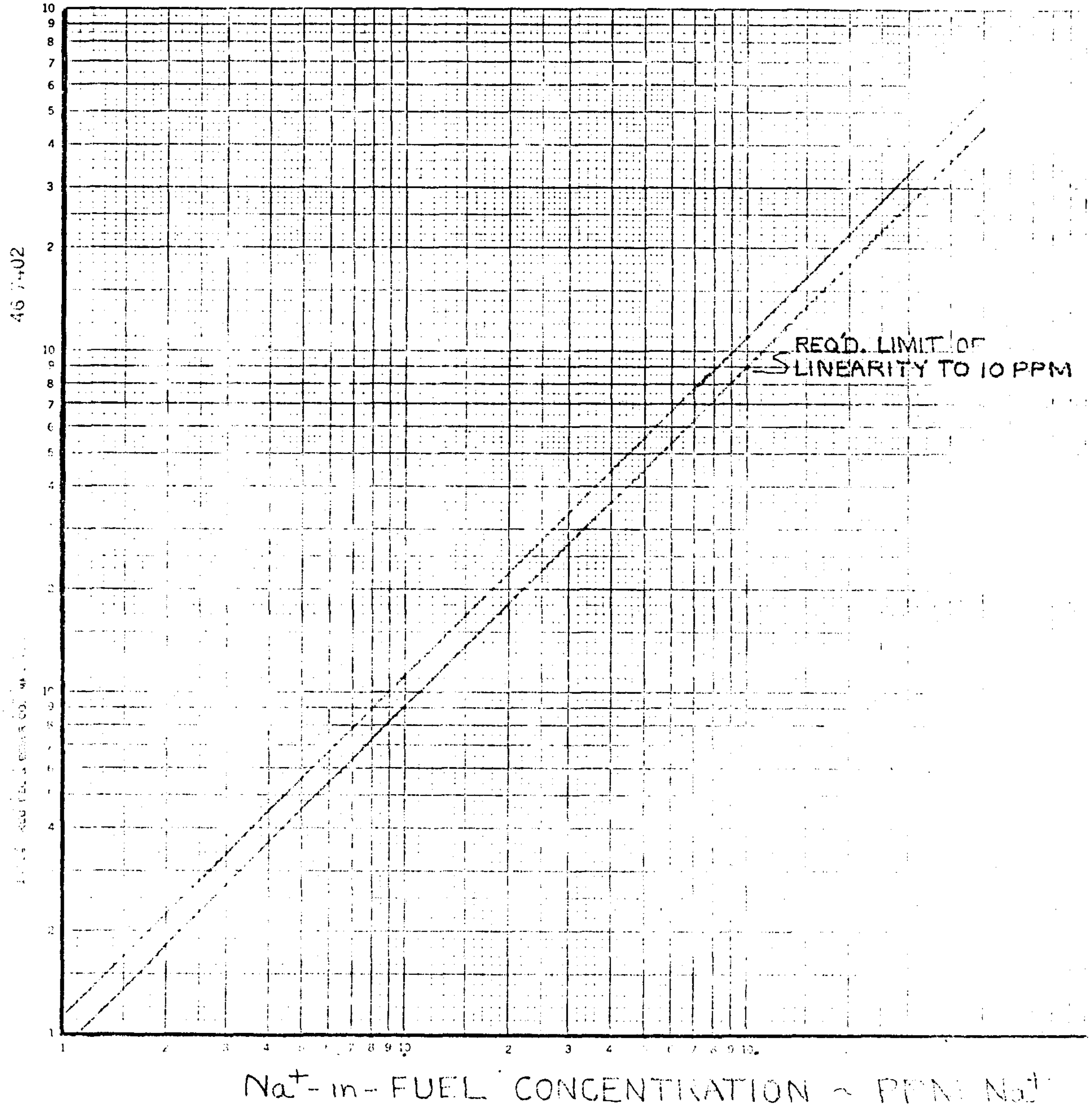


FIG. 1 CALIBRATION SCHEDULE

NOM. SCHEDULE SHOULD BE ADJUSTABLE IN SLOPE AND INTERCEPT AND INDEPENDANT OF DIGITAL DISPLAY

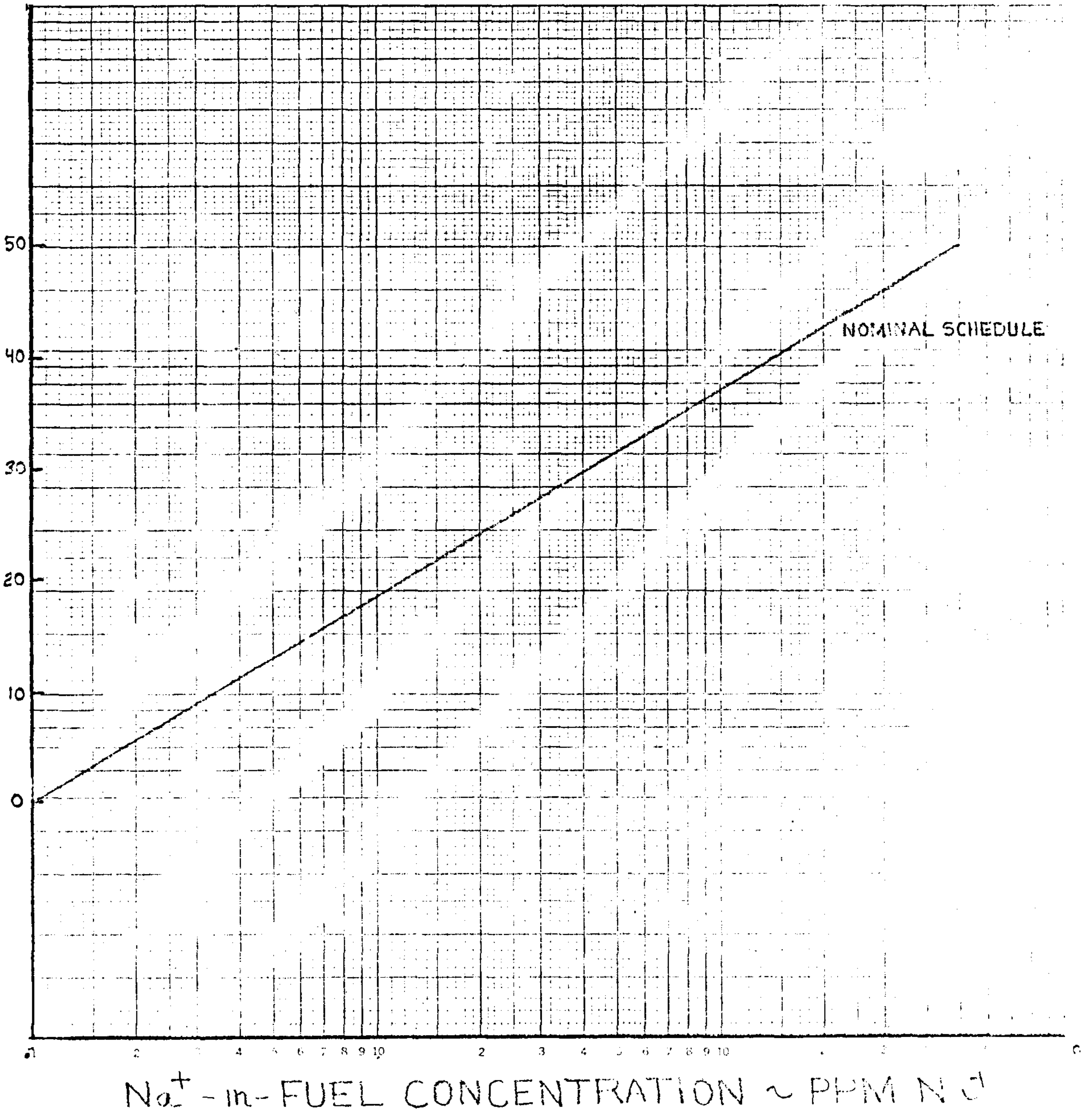


FIG. 2 OUTPUT SIGNAL vs PPM Na^+ in FUEL

TWO THRESHOLD ALARMS REQ'D.
NOMINAL SCHEDULE SHOULD BE ADJUSTABLE IN SLOPE AND INTERCEPT. SIGNAL OUTPUT TO BE INDEPENDANT OF TOTALIZER READING

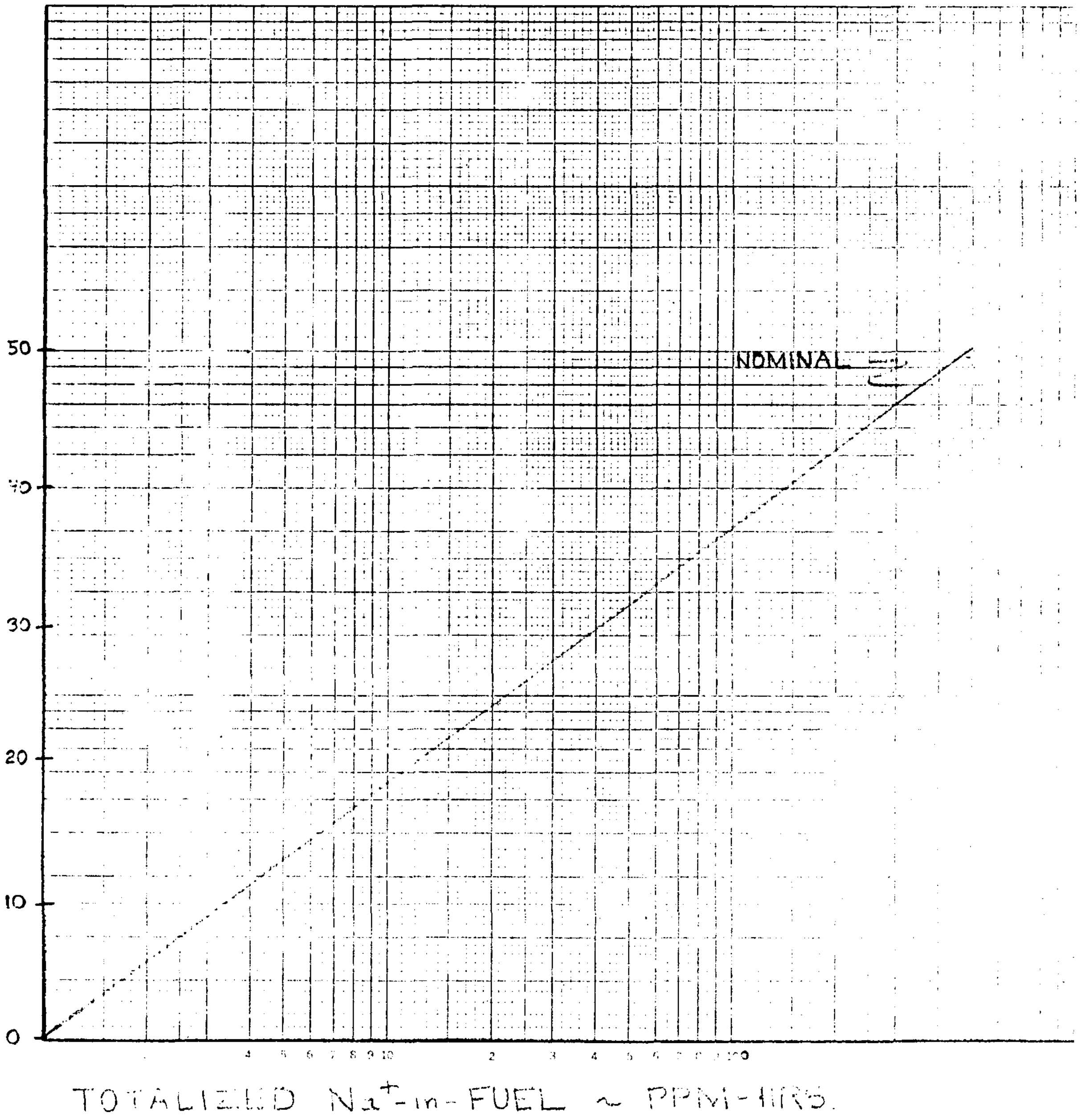
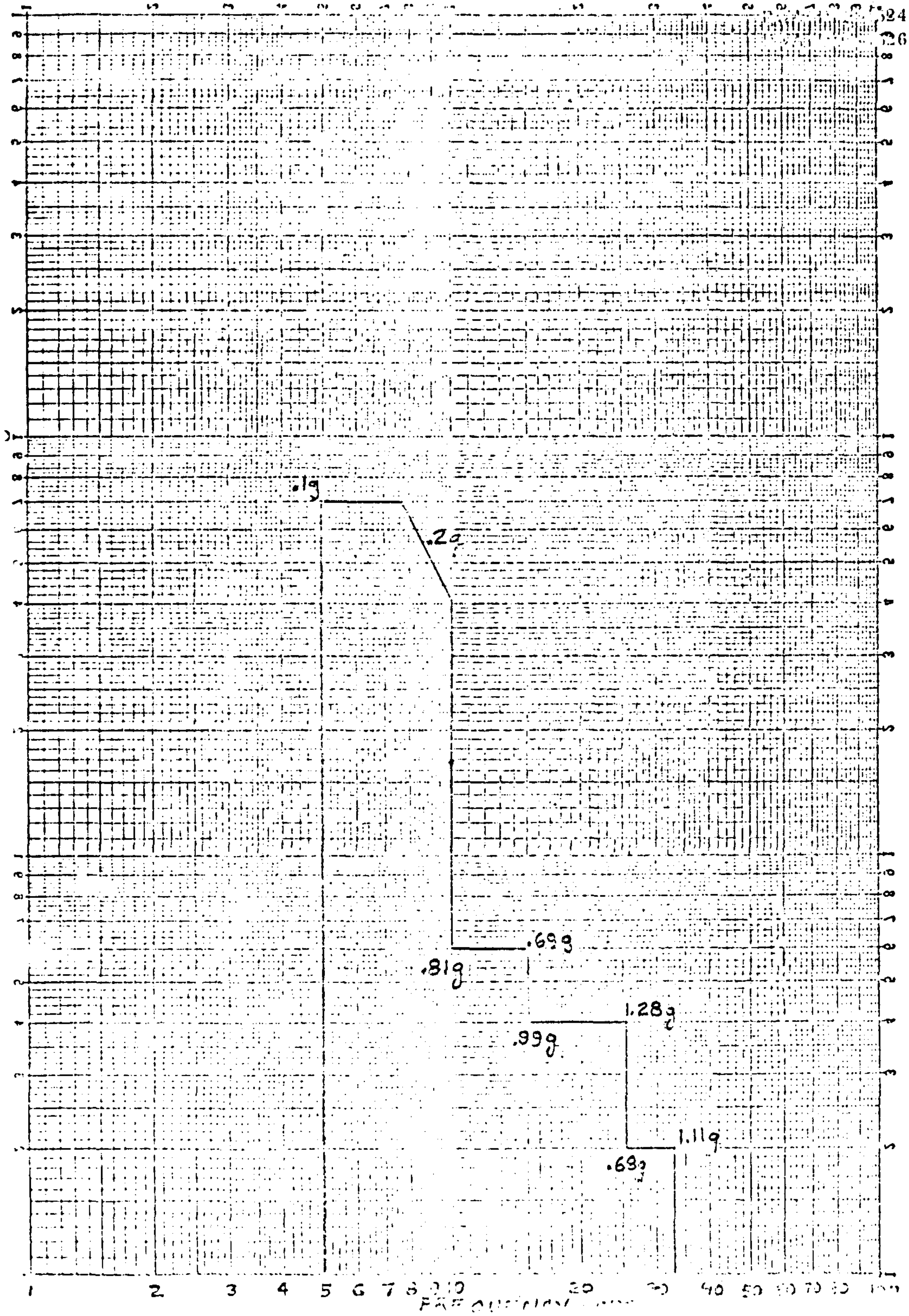


FIG. 3 TOTALIZER SIGNAL vs. PPM-HRS


.1g
.2g
.69g
.81g
1.28g
.99g
1.11g
.68g
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
100
FREQUENCY

TURBO POWER AND MARINE SYSTEMS Subsidiary of UNITED TECHNOLOGIES

TPM - FR-1
Dated: 11/16/71
Rev.:

GAS TURBINE DISTILLATE FUEL REQUIREMENTS

GENERAL

Distillate fuels are complex hydrocarbon fluids which are processed from a wide variety of crude oils. Because of the large number of different producers of distillate fuels, the commercial fuel as an actual product is quite broad in property values. To institute a good fuel management program, the customer is urged to review the available commercial fuels, examine the methods used to store and transport the fuels, design and install an adequate fuel storage/forwarding system.

GUIDELINES FOR EFFECTIVE FUEL MANAGEMENT

The customer's initial step in fuel management is to determine the types of fuels that are available for utilization in gas turbines, and their fuel properties. Contaminants, not normally present in the fuel at the refinery, can be inadvertently introduced into the fuel as a result of contact with sea water, other fuels, or unclean systems during transportation and storage. (It is stated in the ASTM D2880 Gas Turbine Fuel specification supplement that, "since lead is only rarely found in significant quantities in crude oils, its appearance in the fuel oil is primarily the result of contamination during processing or transportation".) Therefore, how the fuel will be stored, handled, and transported between the refinery and the customer's storage facility should also be investigated. The fuel supplier should be contacted for his comments and recommendations on fuel and fuel handling.

With the above information, it is suggested that a preliminary fuel system design be made. Design consideration should be given to such items as: 1) The types of fuel that will give the best overall fuel system and operating economics; 2) How is the fuel going to be handled and stored between the refinery and the customer's storage facility; 3) The filtration/treatment system necessary on site to provide good quality fuel to the gas turbine; 4) The fuel storage tank; and 5) The fuel heating requirements for starting and/or operation.

Now a fuel can be selected that will provide the least investment with the minimum operating cost. The TPM fuel property requirements, contained in this document, are recommended as a minimum. Individual assessment can be made by TPM to judge the suitability of other fuels having certain properties which do not conform to the TPM fuel requirements.

The design details of the fuel handling, storage, and conditioning systems can be finalized based on the selected fuel properties that are expected to be delivered to the customer's storage facility and the gas turbine requirements. The following fuel system items should be considered in detail: tank capacity and fuel storage time, types of filtration systems before and after the storage tank, methods of removing fuel from the storage tank, and safety precautions for handling and storage.

In order to protect the customer's equipment, a program to monitor periodically the fuel being supplied to the gas turbine is recommended. This is an important step in ensuring that the proper quality fuel is provided to the gas turbine. If less-than-desirable fuel is detected, the fuel supplier should be contacted for his comments and corrective action.

A further important step in ensuring the quality of the fuel supplied to the gas turbine is the adoption of reasonable maintenance programs in regard to fuel handling, storage, and filtration facilities. Some items recommended for consideration are periodic filter element replacement, periodic draining of water and sediment from the filter and storage tank sumps, etc.

Additional detailed guidance can be obtained through the customer's TPM representative.

RECOMMENDED DISTILLATE FUELS

The following distillate fuels can be used in the gas turbine, provided the additional fuel property requirements, listed in Table 1 on Sheet 2, are met when the fuel is delivered to the gas turbine site.

Category a

Light virgin naptha and unleaded gasoline types, or wide-cut fuels of the JP-4 (MIL-T-5624) and Jet B (ASTM D 1655) types.

Category b

Kerosenes or other distillates of the JP-5 (MIL-T-5624), Jet A, A-1 (ASTM D 1655), No. 1-D diesel fuel (ASTM D 975), No. 1 fuel oil (ASTM D 396), and No. 1 GT gas turbine fuel oil (ASTM D 2880) types.

Category c

Distillates of the No. 2 D diesel fuel (ASTM D 975), No. 2 fuel oil (ASTM D 396), No. 2 GT gas turbine fuel oil (ASTM D 2880), and marine diesel (MIL-F-16884) types.

TABLE 1 - DISTILLATE FUEL PROPERTY REQUIREMENTS

Properties	Limit	Test Method (See Note 1)
1) Sulfur, %	To be reported. (See Note 2.)	ASTM D129
2) Flash Point, °F	To be reported. (See Note 3.)	ASTM D93
3) Water & Sediment, % by Volume	To be reported. (See Note 4.)	ASTM D1796
4) Carbon/Hydrogen Ratio	To be reported. (See Note 5.)	See Note 9.
5) Metal Contaminants - ppm		
Vanadium (V)	To be reported. (See Note 6.)	ASTM D2787
Sodium (Na) plus Potassium (K)		ASTM D2788
Calcium (Ca)		ASTM D2788
Lead (Pb)		ASTM D2787
Copper (Cu)		See Note 9
6) Fuel Category a) only		
Reid Vapor Pressure, lbs.	Max. 12.5.	ASTM D323
Lubricity	See Note 7.	See Note 9.
7) Fuel Category b) only		
Cloud Point, °F	To be reported. (See Note 8.)	ASTM D2500
8) Fuel Category c) only		
Cloud Point, °F	To be reported.	ASTM D2500
Carbon Residue (on 10% bottoms), %	Max. 0.25	ASTM D524

NOTES TO REQUIREMENTS

Note 1

The latest issue of the ASTM test methods should be used insofar as practicable. If applicable, equivalent test methods may be used in lieu of the ASTM test methods.

The ASTM test methods for metal contaminants are under review because test results for low metallic levels may have poor repeatability.

Note 2

No limit is imposed on sulfer content. However, there may be local air pollution regulations on the fuel sulfur content that may hve to be met and further there may be requirements for a fuel sulfur limit when exhaust heat recovery equipment is utilized in order to minimize corrosion of the cold end surfaces.

Note 3

No flash point limitation is specified; however, there may be legal limits, and safety regulations that must be met.

Note 4

The fuel delivered to the inlet of the gas turbine is to have a sediment level (ASTM D2276) less than 24 mg/gallon of fuel and a free water content (ASTM D1744) less than 0.01% by volume. For practical filter life, the fuel should have low sediment levels.

Note 5

No limit is imposed on carbon/hydrogen ratio; however, the lowest number available in fuel category a, b, or c is recommended for optimum combustion.

Note 6

Metallic levels up to 0.2 ppm V, 0.6 ppm Na plus K, 0.1 ppm Pb, and 0.02 ppm Cu have demonstrated compatibility with the gas turbine. Higher metallic levels may increase gas turbine maintenance cost.

Note 7

The fuel must demonstrate lubricity characteristics essentially equivalent to that of kerosene type fuel for proper operation of the gas turbine fuel pump.

Note 8

No limit is imposed on cloud point; however, the cloud point shall be at least 15° F below the anticipated gas turbine fuel inlet temperature. Depending on ambient temperatures and maximum fuel viscosity, additional heating may be required.

Note 9

Test method to be agreed upon by purchaser and vend

Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION	P&WA SPECIFICATION	PWA 539 REVISION ISSUED 3/16/70 REVISED

HEAVY DISTILLATE FUEL, MARINE & INDUSTRIAL
Gas Turbine Engine

1. ACKNOWLEDGMENT: Vendor shall mention this specification number in all quotations and when acknowledging purchase orders.

2. PURPOSE: To establish requirements of a liquid heavy distillate fuel for use in P&WA marine and industrial gas turbine engines.

3. TECHNICAL REQUIREMENTS: The liquid fuel must be 100% distillate consisting wholly of hydrocarbons. It shall be free from cracked stock and contaminants subject to the limitations as listed.

3.1 Properties: Tests shall be performed insofar as practicable in accordance with the latest issue of the ASTM test methods. Corresponding equivalent test methods may be used in lieu of ASTM methods where applicable. Properties denoted by (*) refer to limits at the engine inlet.

Gravity, API	report	ASTM D287
Viscosity, cs at 100F, max.	11.0 max	ASTM D445
Distillation, °F		ASTM D86 and D1160
IBP	report	
10%	550 max	
20%	report	
50%	675 max	
90%	report	
EP	850 max	
Sulfur, % wt	1.3 max	ASTM D129
Flash Point, °F	150 min or legal	ASTM D93
Carbon Residue, %	0.10 max	ASTM D524
Ash, % wt	0.01 max	ASTM D482
Pour Point, °F	75 max	ASTM D97
Cloud Point, °F	report	Note 1
Wax Forming Temperature, °F	115 max	Note 1
Net Heat of Combustion, BTU/lb	report	ASTM D240
*Sediment, mg/gallon	36 max	Note 1 or ASTM D2276
*Free Water Content, % vol.	0.01 max (Note 2)	Note 1
*Metals Contamination, ppm	Note 3	Note 1

Note 1: Test method to be agreed upon by purchaser and vendor

Note 2: If water contamination is by salt water, the allowable level is subject to the limitation on Sodium plus Potassium.

Note 3: Trace metal contaminants are normally present in the heavy distillate fuel in very low ppm concentration at time of manufacture. These could increase to levels that are unsatisfactory for gas turbine engine operation as a result of contact with sea water, other fuels and unclean systems during transport and storage. Because of the harmful effect such increase in trace metal concentration can have on turbine materials, it has been found necessary by experience to date to impose the following limitations:

Vanadium	0.2 ppm weight max
Sodium plus Potassium	0.6 ppm weight max
Calcium	report
Lead (Pb)	report

Code Ident No. 77445
Furnished Under Contract

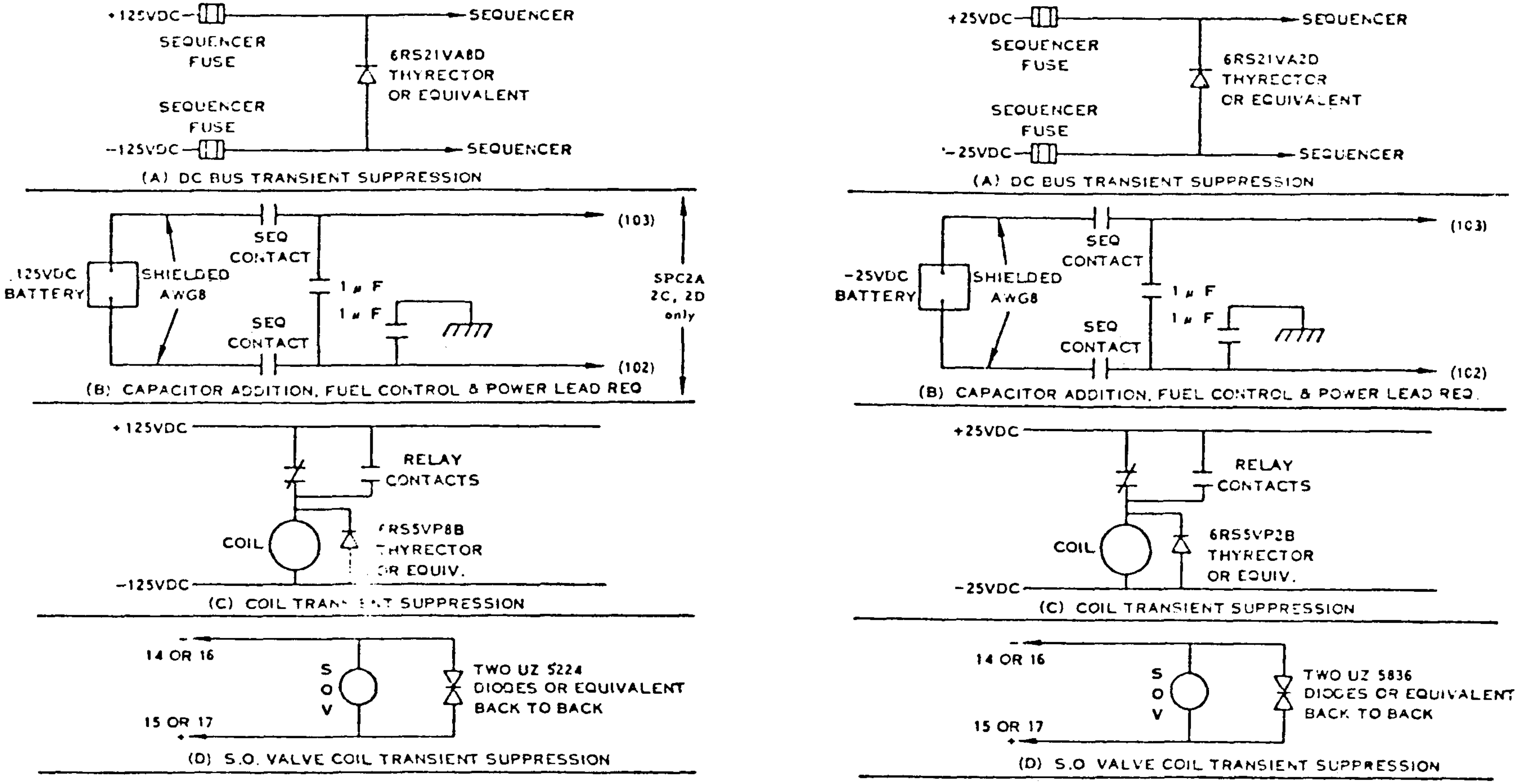
3.2 Additives: Only additives approved by P&WA are permitted. If used, the type and concentration shall be included on the report of analysis.

4. QUALITY: The fuel shall be entirely distillate consisting solely of hydrocarbons and shall be free from water sediments and suspended matter as specified. It shall be suitable for use in marine and industrial gas turbine engines.

5. CONTROL: Control of quality and shipments shall be in accordance with the latest issue of PWA Specification 300.

6. REJECTIONS: Fuel having certain properties not conforming to Section 3.1 may be acceptable but will require individual assessment by Pratt & Whitney Aircraft to approve their suitability.

NOTE: Sections 1 and 5 apply only to Pratt & Whitney Aircraft operations.



SPC2A, 2B, 2C, 2D - 125 VDC System

SPC2A, 2B, 2C, 2D - 25 VDC System

Figure 4. Transient Suppression