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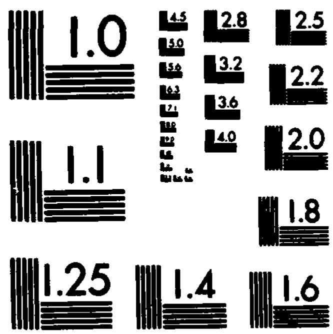
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1981 CRC DIESEL FUEL LOW-TEMPERATURE OPERABILITY FIELD TEST

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September 1983

COORDINATING RESEARCH COUNCIL, INC.
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1981 CRC DIESEL FUEL LOW-TEMPERATURE OPERABILITY FIELD TEST (CRC PROJECT NO. CD-15-69)

Prepared by the

Low-Temperature Operability Analysis Panel

of the

CRC Heavy-Duty Fuel and Fuel Systems Group

DAAK-70-81-C-0128

September 1983

CRC Heavy-Duty Vehicle Fuel, Lubricant, and Equipment Research Committee

of the

Coordinating Research Council, Inc.

ABSTRACT

A cooperative experimental program including seven diesel-powered vehicles and eight specially prepared fuels was run at low ambient temperatures to define the low-temperature operability limit for each vehicle-fuel combination. The vehicle fleet consisted of four passenger cars and three heavy-duty trucks. The fuel set included three base fuels of differing cloud points and five additive-treated versions of these base fuels. The vehicle program was run in Kapuskasing, Ontario, Canada, during January to April 1981. Participants of the Coordinating Research Council developed the program plan, provided the special fuels, arranged for the loan of vehicles and instrumentation, volunteered technical support during the running of the program, and prepared the analysis report. Laboratory tests considered for correlative purposes included the Low Temperature Flow Test (LTFT), Cold Filter Plugging Point (CFPP), Cloud Point (CP), Pour Point (PP), and combinations of CP and PP. Of the laboratory tests examined, LTFT appeared to offer the most promise, although none of the laboratory tests appeared to be completely satisfactory in their present form.

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CHAPTER 1

INTRODUCTION

INTRODUCTION

Diesel fuels contain normal paraffins with chain lengths ranging from about 10 to 25 carbon atoms. At low temperatures, some of these paraffins come out of solution and form wax crystals. In diesel vehicle fuel systems, the wax crystals can: (1) collect in fuel filters causing the filters to plug; (2) adhere to fuel line walls causing fuel lines to restrict; and/or (3) form a solid matrix reducing fuel pumpability. These factors can restrict the flow of fuel to the engine and cause engine stumbling or stalling. In severe cases of wax formation, the vehicle may not even start.

One of the solutions to the problem is to use flow improvers in the fuel. Flow improvers do not alter the cloud point of a fuel, but do depress its pour point and generally reduce the size of the wax crystals which form. This often enables operation of diesel vehicles at lower temperatures than are achievable with untreated fuels.

Previous work conducted by the CRC(1) and by others(2-9) has shown that both vehicle fuel system design and fuel properties are important in determining the susceptibility of a particular diesel vehicle operating on a particular fuel to filter plugging and other low-temperature operational problems. Some of these investigations have also shown substantial benefits in low-temperature operation when flow improvers are included in the fuel. As yet, however, no laboratory test has been identified which predicts the behavior of fuels both with and without flow improvers in a wide range of fuel system designs.

The purpose of the work reported herein was to obtain data on the low-temperature performance of a wide variety of diesel fuel systems operating on a wide range of diesel fuels under real-world temperature conditions. It was intended that these data be used to evaluate laboratory techniques that may characterize the low-temperature performance of diesel fuels in both light-duty and heavy-duty equipment more realistically than does the ASTM D 2500 cloud point method.

CHAPTER 2

SUMMARY

SUMMARY

Vehicle tests were conducted in Kapuskasing, Ontario, Canada, during the winter of 1980-1981 to establish the minimum operating temperatures of a variety of vehicles operated on diesel fuels with a wide range of low-temperature flow properties, and to relate the vehicle performance to laboratory test predictions. The mechanical performance of the test operation was conducted by a contractor, Kaptest Engineering Ltd., while technical decisions relative to daily operations were handled by on-site participating personnel. Four diesel passenger cars and three heavy-duty trucks were included in the program, and eight fuels were tested in each vehicle. Three base (untreated) fuels with cloud points of -19, -9, and -2°C and five flow-improved fuels derived from additive treatment of these three base fuels comprised the fuel set. The laboratory tests which were evaluated included cloud point, pour point, Cold Filter Plugging Point (CFPP), and Low Temperature Flow Test (LTFT). In addition, an empirical relationship incorporating cloud point and pour point was developed and evaluated.

Vehicles were conditioned outdoors overnight with the test fuel in the vehicles. The following morning, each vehicle was started and run for approximately one hour at 88 km/h, or until fuel filter plugging resulting from a buildup of wax precipitated from the fuel caused the vehicle to stall. Definitions of pass, borderline, and fail operation were established, and each test run was rated according to whether the vehicle completed the test schedule with no problems, experienced partial filter plugging, or stalled during the test, respectively. An attempt was made to establish the pass/fail limit within a few degrees Celsius for each vehicle-fuel combination, and the data were used to define an estimated minimum operating temperature (EMOT) for each vehicle-fuel combination.

The results showed large differences in performance among both the fuels and the vehicles. As expected, the low cloud point base fuel provided satisfactory operation in all vehicles at lower temperatures than those achieved with the high cloud point base fuel, with results for the intermediate cloud point base fuel falling in between for all vehicles. The addition of flow improvers to the fuels generally permitted satisfactory operation at lower temperatures than those achieved with the corresponding base fuel in all vehicles, although in some cases the improvements were quite small. The average improvement in estimated minimum operating temperature afforded by use of a flow improver was 4.5°C. Much greater improvements (up to 17°C) were achieved in some cases.

The range of minimum operating temperatures among vehicles operating on the same base fuel was as low as 3°C for the high cloud point base fuel and as high as 14°C for the intermediate cloud point base fuel. Similarly, for flow-improved fuels, the range was as low as 7°C and as high as 13°C. The same vehicle did not always exhibit the best or worst performance with all of the fuels, although certain trends in vehicle severity did emerge. The passenger car with a bypass in the tank filter, the passenger car with a coarse tank filter, and the truck with the high fuel recirculation rate appeared to be less severe than the other vehicles.

Because of differences among vehicles, it was recognized that no laboratory test which predicts a single value for each fuel could possibly predict the performance of all vehicles on a 1:1 basis. This was evident in comparisons of the results from the four laboratory tests investigated with all of the vehicle data. The distributions of average EMOT's relative to the four laboratory test results were:

Percent of Total EMOT's	Cloud Point	LTFT	CFPP	Pour Point
>2°C Above Lab Test Result	2	11	36	87
At Lab Test Result (±2°C)	24	42	42	11
>2°C Below Lab Test Result	74	47	22	2

From this table, it is clear that while CFPP was a better predictor than pour point both methods often overpredicted minimum operating temperatures. For this reason, these tests were judged to be inadequate predictors of low-temperature performance and were dismissed from further consideration.

The cloud point and LTFT temperatures showed varying degrees of predictive capability, and offered distinctly different advantages. Both predicted the performance of the base fuels well, but LTFT more accurately predicted the performance of the flow-improved fuels. On the other hand, cloud point came closest to a fail-safe predictor of vehicle performance for all vehicles, with only one of the vehicle-fuel combinations demonstrating an EMOT more than 2°C higher than the corresponding fuel cloud point. In the case of LTFT, six of fifty-five vehicle-fuel combinations had EMOT's more than 2°C higher than the corresponding LTFT temperatures.

Of the four single laboratory tests investigated, LTFT also showed the best correlation of individual vehicle performance on the eight fuels for four of the seven vehicles. Overall, it provided the best compromise of statistical parameters for all vehicles. No one particular fuel appeared to be an outlier in all vehicles, although one fuel (107) performed substantially worse than predicted by LTFT (2 to 7°C) in four of the seven vehicles.

The Wax Precipitation Index (WPI), a multiple parameter empirical relation involving cloud point and pour point, was developed from the data in this report and shown to correlate with EMOT's at least as well as LTFT. Differences in the correlations were not sufficiently great to identify either technique as the better in predicting the vehicle performance obtained in this program.

CHAPTER 3

CONCLUSIONS AND RECOMMENDATIONS

I. CONCLUSIONS

Based on the results from this test program in which eight fuels were evaluated in seven vehicles marketed in North America, the following conclusions were reached:

1. The use of flow-improver additives in some diesel fuel permits some vehicles to operate satisfactorily at temperatures substantially below the fuel cloud point.

2. Significant differences exist in the severity of diesel vehicles in terms of their low-temperature operation.

   - In light-duty vehicles, the severity is related to the pore size of the tank filter and the presence of a tank filter bypass.

   - In heavy-duty vehicles, the severity is related to the placement of the secondary fuel filter relative to the fuel transfer pump and to fuel heating and recirculation characteristics.

3. No single laboratory test was found which adequately predicts the performance of all fuels in all vehicles. Because of differences in vehicle severity, however, no single laboratory test will ever be able to predict minimum operating temperatures of all vehicle-fuel combinations on a 1:1 basis.

4. Of the individual laboratory tests investigated in this program, the Low Temperature Flow Test (LTFT) provided the best correlation with vehicle performance for both untreated and flow-improved fuels, although for some vehicles LTFT tended to overestimate the effectiveness of one flow-improver additive and underestimate the effectiveness of another.

5. Cloud point adequately predicted the behavior of untreated fuels. As expected, it was overly severe in predicting the performance of flow-improved fuels; however, cloud point came the closest to providing a fail-safe prediction of low-temperature performance for all vehicle-fuel combinations investigated.

6. The correlation of the Wax Precipitation Index (WPI) with estimated minimum operating temperatures was comparable to that of LTFT. WPI, however, was optimized for the data set considered in this report and should not be universally applied until it has been fully evaluated.

II. RECOMMENDATIONS

Two measures of low-temperature vehicle performance (LTFT and WPI) have been identified in this program as providing better correlations with performance than fuel cloud point. It is recommended that the appropriate technical groups consider whether the improvements afforded by these two measures are sufficient to warrant use of either method in place of cloud point as an indicator of low-temperature diesel fuel performance.

Because of the room for further improvement in the correlation of laboratory test results with the field data obtained in this program, however, it is also recommended that work be done to improve the predictive capabilities of LTFT or other bench tests by modifying either the test conditions or the experimental apparatus (screen type or size, cooling rate, test duration, flow rate, etc.).

The improvement in correlation observed with *average* vehicle performance, rather than individual vehicle performance, suggests that much of the correlation error between laboratory tests and field data is due to differences in vehicle fuel system configuration, which result in different responses to fuel cold flow characteristics. Future work should address these fuel system differences, and a scheme for quantifying their effects on vehicle performance should be developed to provide guidelines for the improvement of fuel system low-temperature operation.

CHAPTER 4

TEST FUELS

I. SELECTION CRITERIA

It was agreed that a test fuel matrix should address the following:

- flow-improver additive-treated versus non-treated fuels;
- non-treated fuels covering a range of operation limits assumed to be defined by cloud point;
- treated fuels covering those additives which show good response in CFPP only, and those which show good response in both LTFT and CFPP;
- the effect of additive concentration.

Based on these criteria and the time available to test each vehicle-fuel combination, eight fuels were selected covering three levels of cloud point (low, moderate, and high). Various commercially available flow-improver additives were evaluated in each fuel to meet the filterability test performance criteria (above). No attempt was made to optimize additive treatment, or to provide the maximum improvement in performance. Rather, performance improvements were to be significant, and represent a performance improvement typical of commercial practice. The four additives selected, A, B, C, and D, are commercially available and include either an ethylene-vinyl acetate or chlorinated polyethylene co-polymer.

A summary of fuel properties is presented in Table 4-1. Fuel 101 was the low cloud point (-19°C) base fuel; Fuel 104 contained Flow Improver A which lowered LTFT from -19°C to -22°C. Fuel 102 was the moderate (-9°C) cloud point fuel. Two treatments of Flow Improver B were used in this fuel: Level B; and twice the concentration, Level 2B. Although Treatment B (Fuel 105) had a minimal effect on LTFT, doubling the concentration (Treatment 2B, Fuel 106) lowered LTFT from -9°C to -17°C. Comparing Fuels 106 and 107, both lowered LTFT about 8°C, but Treatment C lowered CFPP from -13°C to -25°C, while Treatment 2B lowered CFPP only from -13°C to -16°C. Fuel 103 was the high (-2°C) cloud point base fuel; Fuel 108 contained Flow Improver D which lowered LTFT from -4°C to -6°C.

II. FUEL ANALYSIS

Eighteen independent laboratories were supplied with fuel samples and asked to run ASTM specification tests for diesel fuels, as well as LTFT and CFPP. These test data are summarized in Table 4-2. Individual laboratory inspection data for the three base fuels and five additive-treated fuels are presented in Appendix C1. Means and standard deviations for all tests are also shown in Appendix C1. In a few cases, an inspection varied by more than two standard deviations from the mean; that test (underlined) was deleted, and the mean and standard deviation were recalculated. Participants were also asked to run any other low-temperature performance tests or composition tests which might correlate with the field test data. The results of these additional tests are presented in Appendix C2. Methods for all non-ASTM standardized tests are described in Appendix C3.

TABLES

AND

FIGURES

TABLE 4-1

SUMMARY OF TEST FUEL LOW-TEMPERATURE PROPERTIES

Fuel	101	104	102	105	106	107	103	108
Base Fuel	101	101	102	102	102	102	103	103
Additives	None	A	None	B[1]	2B[1]	C	None	D
Performance Property								
Cloud Pt., °C	-19	-19	- 9	- 9	- 9	- 9	- 2	- 2
LTFT, °C	-19	-22	- 9	-10	-17	-17	- 4	- 6
CFPP, °C	-21	-30	-13	-12	-16	-25	- 5	-14
Pour Pt., °C	-26	-33	-15	-29	-49	-49	- 6	-27

(1) Additive Treatment 2B is twice the concentration of Treatment B.

TABLE 4-2

FUEL PROPERTIES

(Laboratory Means)

Inspection Test Properties	ASTM Test Number	FUELS 101	104	102	105	106	107	103	108
Cloud Point, °C	D 2500	-19.4	-19.0	- 9.1	- 8.7	- 8.9	- 9.5	- 2.4	- 2.3
Pour Point, °C	D 97	-25.8	-32.9	-15.5	-29.2	-49.1	-49.3	- 6.0	-26.6
CFPP, °C	--	-21.2	-29.7	-13.2	-12.0	-15.6	-24.7	- 4.9	-14.2
LTFT, °C	--	-18.7	-22.2	- 9.2	- 9.6	-16.6	-16.9	- 3.7	- 5.9
Distillation, °C	D 86								
IBP		151	153	179	185	180	177	200	203
10%		195	196	219	219	216	218	233	233
50%		262	261	270	270	270	269	268	271
90%		306	307	318	319	318	318	320	321
EP		345	341	352	345	345	347	341	340
Cetane Number	D 613	44.4	45.0	45.7	45.6	46.2	46.0	54.8	56.1
Gravity, °API	D 1250	35.0	35.0	33.4	33.4	33.4	33.4	36.9	37.1
Flash Point, °C	D 93	52.8	53.0	69.5	70.4	70.6	67.8	77.7	81.1
Viscosity @ 40°C, cSt.	D 445	2.41	2.44	3.02	3.04	3.04	3.03	3.08	3.11
Carbon Residue on 10% Residuum, %	D 524	0.14	0.15	0.13	0.11	0.13	0.14	0.10	0.09
Ash, wt. %	D 482	0.008	0.003	0.004	0.002	0.002	0.002	0.014	0.007
Sulfur, wt. %	D 129, D 1552, D 2622	0.25	0.25	0.22	0.22	0.22	0.22	0.09	0.09
Sediment & Water, wt. %	D 1796	0.038	0.030	0.030	0.024	0.030	0.034	0.100	0.110
Water, ppm	D 1744	60	55	58	58	57	67	--	--

CHAPTER 5

TEST VEHICLES

TEST VEHICLES

Seven vehicles were included in the test program: four light-duty passenger cars, and three heavy-duty trucks. Vehicle selection was based on the number sold, engine displacement, and fuel system design characteristics. A wide variety of vehicles was included to ensure that data obtained on low-temperature operation would be representative of the North American commercial market, and to minimize the possibility of overlooking low-temperature operational effects associated with a specific vehicle fuel system design.

Different vehicle manufacturers denote their filters by different names; e.g., primary, secondary, main, engine, prefilter, strainer, sock, etc. For the purposes of this report, the fine pore-size filter located just ahead of the fuel injection pump will be denoted as the secondary filter. The term tank filter will be used to denote any fuel filter located in the fuel tank. The term primary filter will be used to denote any filter located outside of the fuel tank, but before the secondary filter. For the one vehicle (126) which has only one filter in the system, this filter will be denoted as the secondary filter.

A more detailed description of the vehicles and their fuel system design characteristics is provided in the following two sections.

I. LIGHT-DUTY PASSENGER CARS

A description of the four passenger cars is shown in Table 5-1. Cars 121 and 123 were 1980 models, while Cars 122 and 124 were 1981 models. Cars 121 and 122 were supplied by the same manufacturer and contained fuel system differences to be discussed in the following paragraph. These two vehicles each contained a 5.7 ℓ V-8 diesel engine. Car 123 contained a 3.0 ℓ L-5 diesel engine, and Car 124 contained a 1.6 ℓ L-4 diesel engine. Fuel tank capacity varied from 41.5 to 102 ℓ, as indicated in Table 5-1.

Table 5-2 summarizes the fuel system design characteristics of the four passenger cars. Except for Car 124, each of the vehicles had a separate fuel transfer pump, so that fuel supplied to the fuel injection pump under pressure (34 to 81 kPa, depending upon the vehicle). In Car 124, fuel was supplied to the injection pump under vacuum. All four vehicles had coarse tank filters, ranging in nominal pore size from 40-50 μm to 600 μm. In Car 122, this filter contained a vacuum relief valve which was designed to open when the vacuum across the filter reached 14-21 kPa (as, for example, occurs when the filter becomes plugged with wax). All four of the cars also had a fine secondary filter, ranging in nominal pore size from 4-5 μm (Car 124) to 8-10 μm (Cars 121 and 122). Car 123 also had a nominal 200-μm primary filter, located just before the fuel transfer pump. Filter areas and types are also provided in Table 5-2. Car 122 was the only vehicle equipped with an electric in-line fuel heater. The heater was located between the fuel transfer pump and the secondary fuel filter; however, for reasons to be discussed later, runs during which the heater was operational were omitted from the data analysis.

Schematic diagrams of the four passenger car fuel systems, showing the location of fuel filters, pumps, etc., are included in Figures 5-1 through 5-4. Also shown on the schematics are the locations of thermocouples and pressure transducers used to make temperature and pressure measurements during each test.

II. HEAVY-DUTY TRUCKS

Descriptions of the three test trucks are given in Table 5-3. The trucks were all Class 8 vehicles powered by heavy-duty, turbocharged diesel engines in the 270-290 hp range. Three of the four major US heavy-duty engine manufacturers were represented by these engines. Vehicles 125 and 126 were equipped with in-line, six-cylinder, four-cycle engines with displacements of 14.6 ℓ and 14.0 ℓ, respectively. Vehicle 128 was equipped with a 9.0-ℓ, two-cycle V-6 engine. It was intended that a fourth truck, to be designated as Vehicle 127, be included in the program; however, it could not be made available.

Table 5-4 summarizes the fuel system characteristics of each of the three trucks. Each fuel system included a fine secondary filter and a significant amount of fuel recirculation to the fuel tank. None of the systems included any fuel-line heating device. Schematic diagrams of the three truck fuel systems, illustrating the relative position of fuel filters, transfer pumps, etc., are shown in Figures 5-5 through 5-7. Also shown are the locations of thermocouples and pressure transducers used to make temperature and pressure/vacuum measurements during the tests.

In Vehicle 125 (see Figure 5-5), fuel was pulled through a 178-μm wire screen in the tank by the transfer pump. After being boosted to a low pressure, the fuel was pumped through a nominal 3-5 μm secondary filter and supplied to the injection pump. At full load, 33 percent of the fuel flowing to the injection pump was returned to the tank.

The fuel system of Vehicle 126, shown in Figure 5-6, did not have either a tank filter or a primary filter. Instead, fuel was pulled through a nominal 15-μm secondary filter under vacuum, and then delivered to the injectors under high pressure. At all conditions, 75 percent of the fuel delivered to the injection pump was returned to the tank. This was the only truck fuel system to have the secondary filter located on the suction side of the transfer pump.

Vehicle 128 did not have a tank filter, but it did have a 30-μm primary filter, as shown in Figure 5-7. Fuel was pulled through the primary filter by the transfer pump, boosted to moderate pressures, pushed through a 10-μm secondary filter, and delivered to the injectors. At all conditions, 60-70 percent of the fuel supplied to the injectors was recirculated to the fuel tank.

TABLES

AND

FIGURES

TABLE 5-1

PASSENGER CAR DESCRIPTION

Vehicle Designation	Model Year	Displacement, ℓ	Number of Cylinders	Fuel Tank Capacity, ℓ
121	1980	5.7	8	102
122	1981	5.7	8	102
123	1980	3.0	5	70
124	1981	1.6	4	41.5

TABLE 5-2

PASSENGER CAR FUEL-SYSTEM CHARACTERISTICS

Vehicle No.	121	122	123	124
Fuel Filters				
Tank				
Pore Size, μm	130	130**	600	40-50
Area, cm^2	102	93	40	40
Type	Saran Sock	Saran Sock	Wire Mesh	Wire Mesh
Primary				
Pore Size, μm	--	--	200	--
Area, cm^2	--	--	26	--
Type	--	--	Wire Mesh	--
Secondary				
Pore Size, μm	8-10	8-10	5-8	4-5
Area, cm^2	7740	7740	***	5300
Type	Pleated Paper	Pleated Paper	Felt	Pleated Paper
Transfer Pump Outlet Pressure,* kPa	34	34	81	None
Fuel Flow Through Secondary Filter,* ℓ/hr	20	20	46	26
Return Fuel Flow Rate to Tank,* ℓ/hr	14	14	40	22

---

* Values at 88 km/h and road load.

** Tank filter contains vacuum relief valve which opens at 14-21 kPa vacuum.

*** No rated area. Felt depth filter in 7.6-cm diameter by 7.6-cm long cylindrical housing.

TABLE 5-3

HEAVY-DUTY TRUCK DESCRIPTION

Truck No.	Engine Description			Fuel Tank
	Cylinders	Displacement, ℓ	hp at RPM	Capacity, ℓ
125	6	14.6	290 at 1900	757
126	6	14.0	290 at 2100	454
128	V-6	9.0	270 at 2100	379

TABLE 5-4

HEAVY-DUTY TRUCK FUEL-SYSTEM CHARACTERISTICS

Vehicle No.	125	126	128
Fuel Filters			
Tank			
Pore Size, μm	178	-	-
Area, cm^2	323	-	-
Type	Wire Screen	-	-
Primary			
Pore Size, μm (Nom/Abs)	-	-	30/-
Area, cm^2	-	-	-
Type	-	-	Cotton Sock
Secondary			
Pore Size, μm (Nom/Abs)	3-5/30	15/22	10/-
Area, cm^2	7742	3935	5516
Type	Pleated Paper	Pleated Paper	Pleated Paper
Transfer Pump Output Pressure, kPa			
at Low Idle	-	7-14	-
at High Idle	-	103	-
at Typical Load	-	758-896	345-517
at Full Load	172	1172	469
Fuel Flow Rate through Secondary Filter, ℓ/hr			
at Idle	-	45	76
at 88 km/h Road Load	-	167	-
at Full Load	106	240	454
Return Fuel Flow Rate to Tank, ℓ/hr			
at Idle	-	34	46-53
at 88 km/h Road Load	-	125	-
at Full Load	53	181	272-318

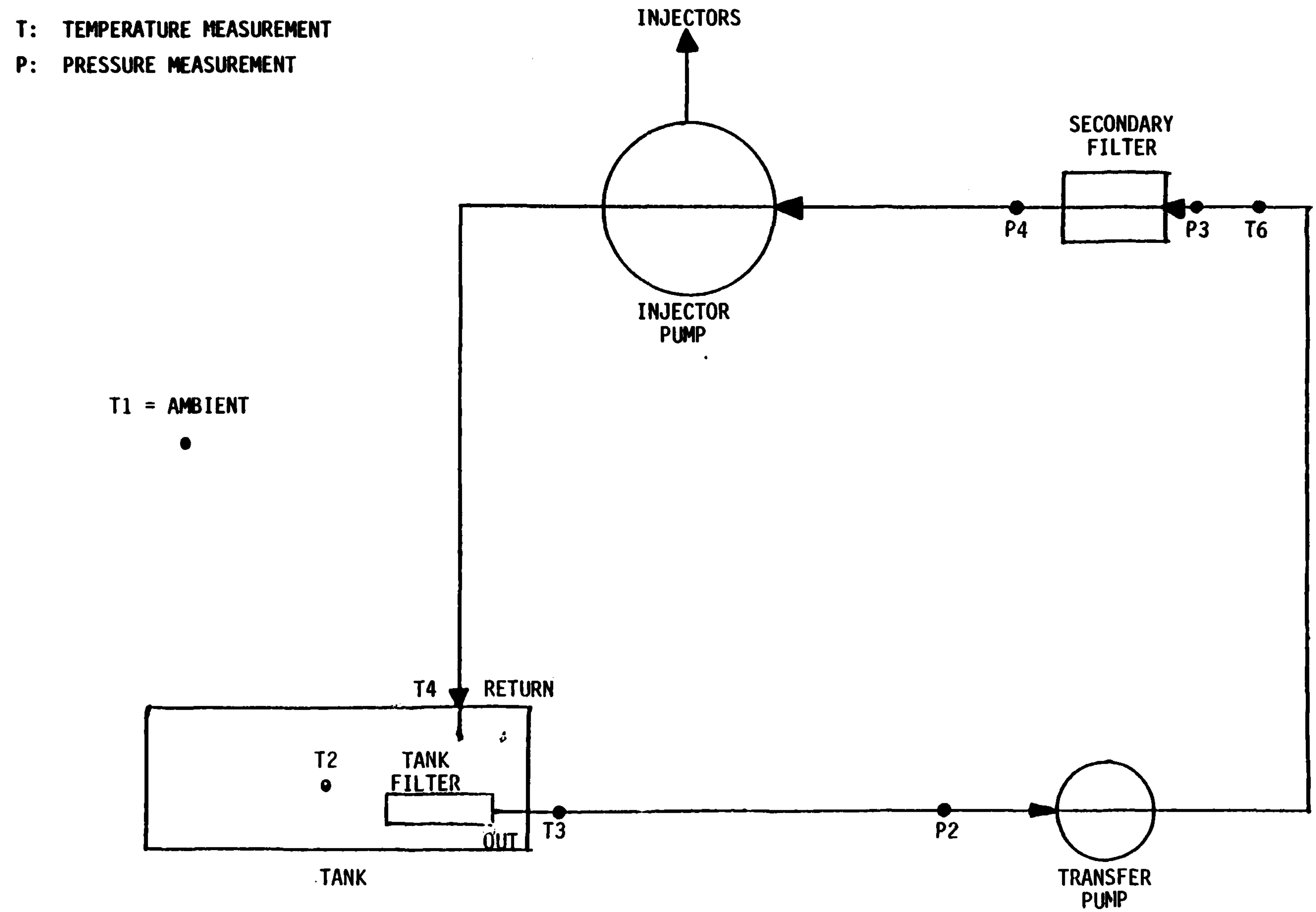


FIGURE 5-1. FUEL SYSTEM - VEHICLE 121

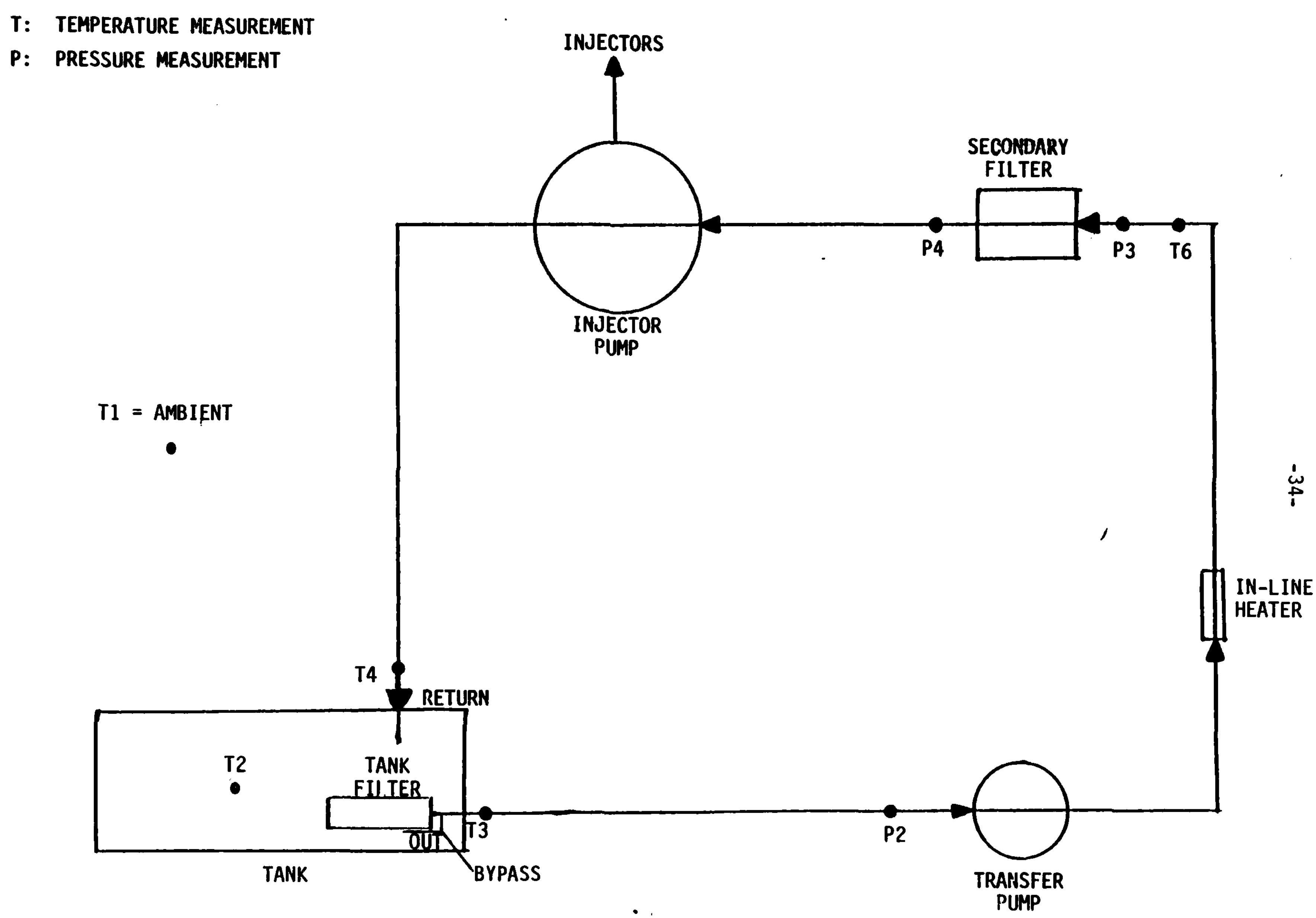


FIGURE 5-2. FUEL SYSTEM - VEHICLE 122

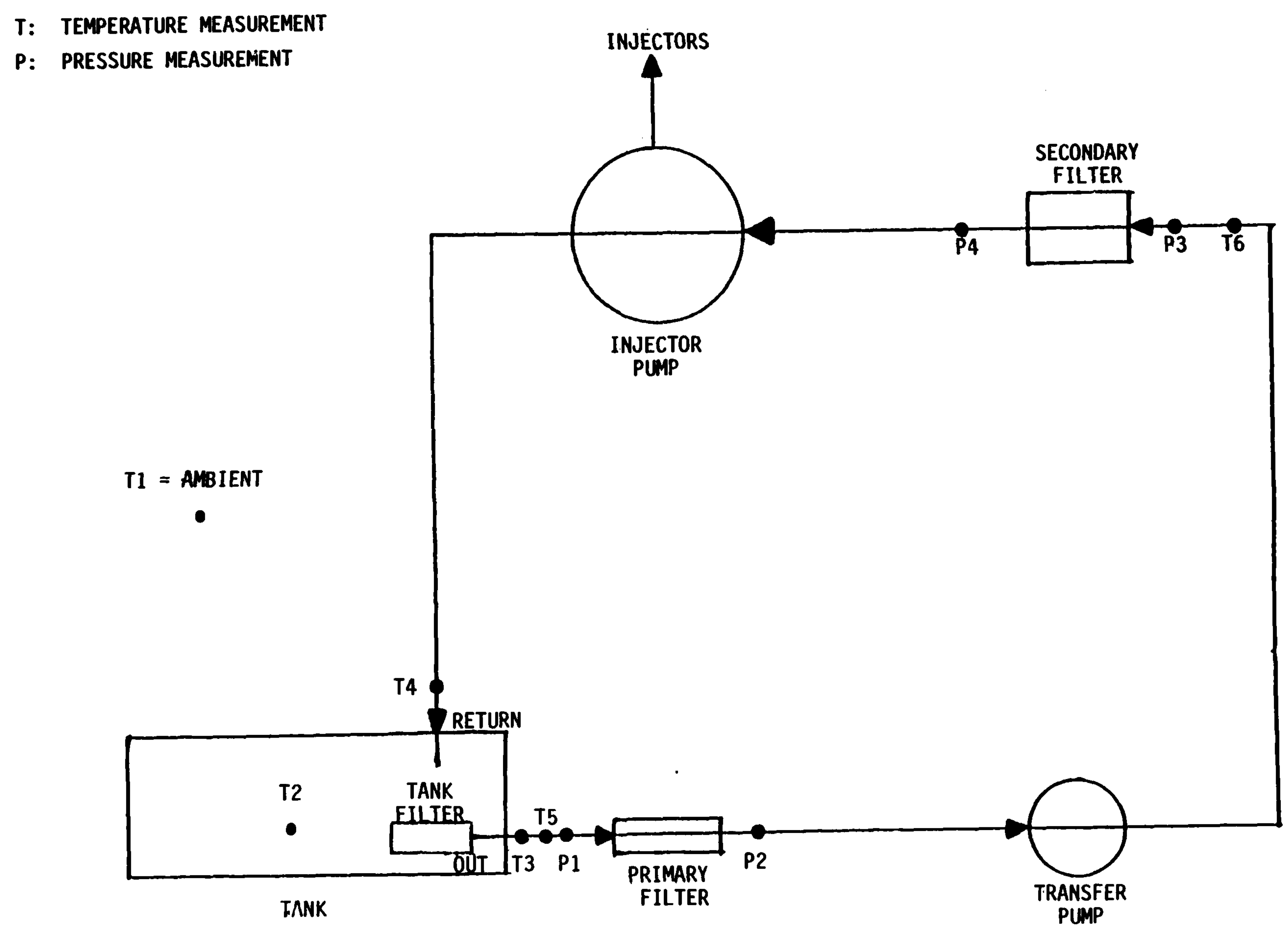


FIGURE 5-3. FUEL SYSTEM - VEHICLE 123

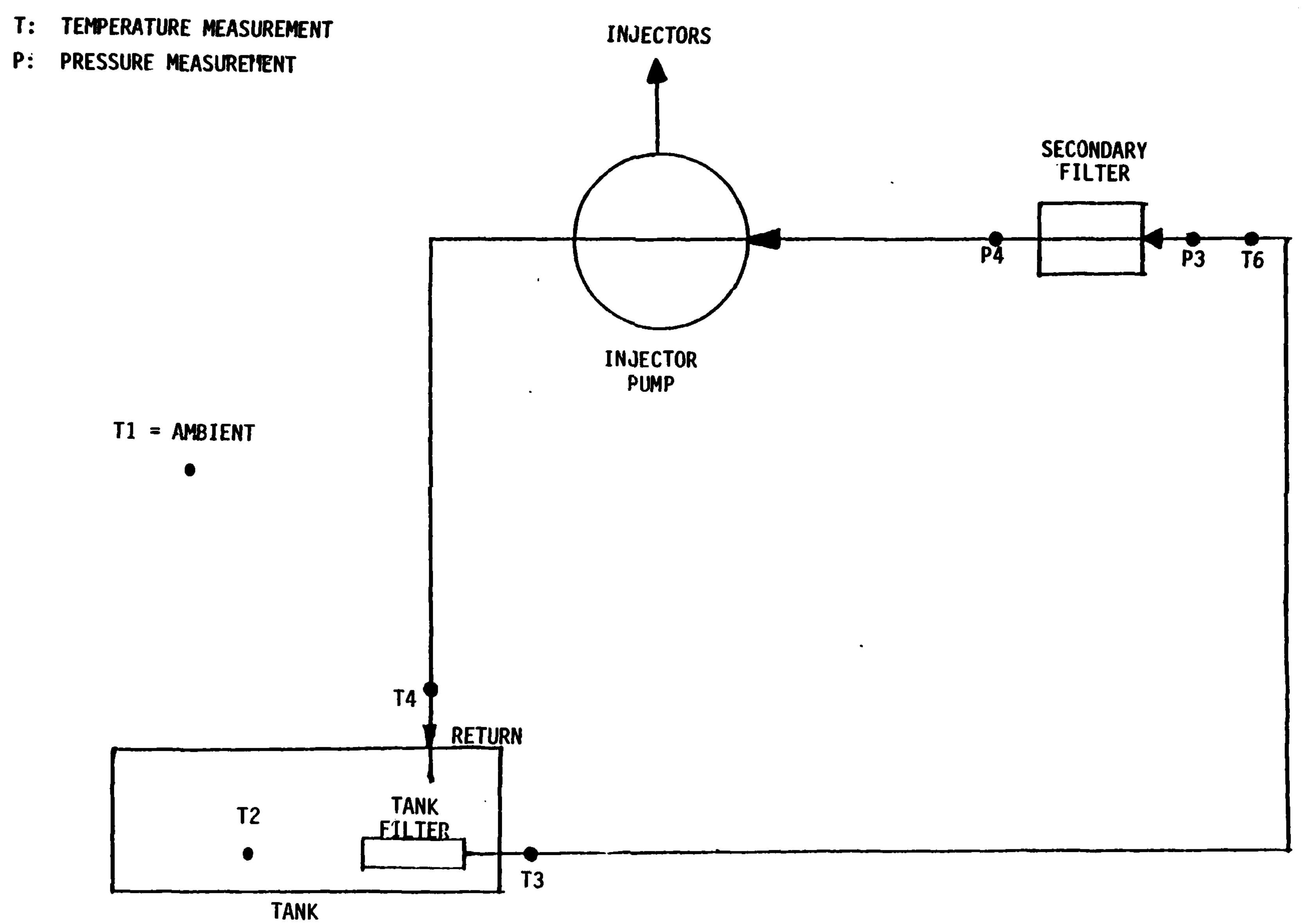


FIGURE 5-4. FUEL SYSTEM - VEHICLE 124

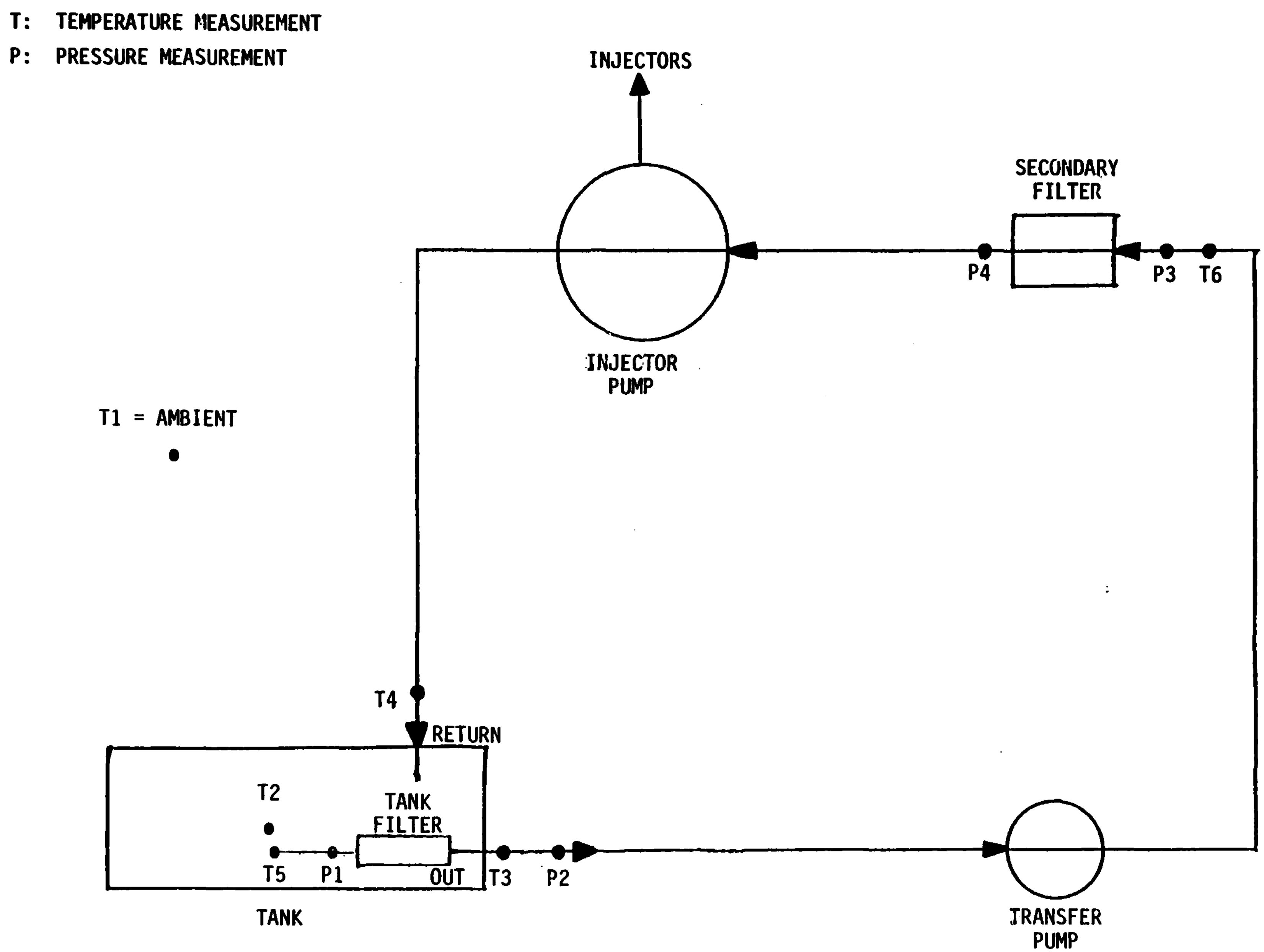


FIGURE 5-5. FUEL SYSTEM - VEHICLE 125

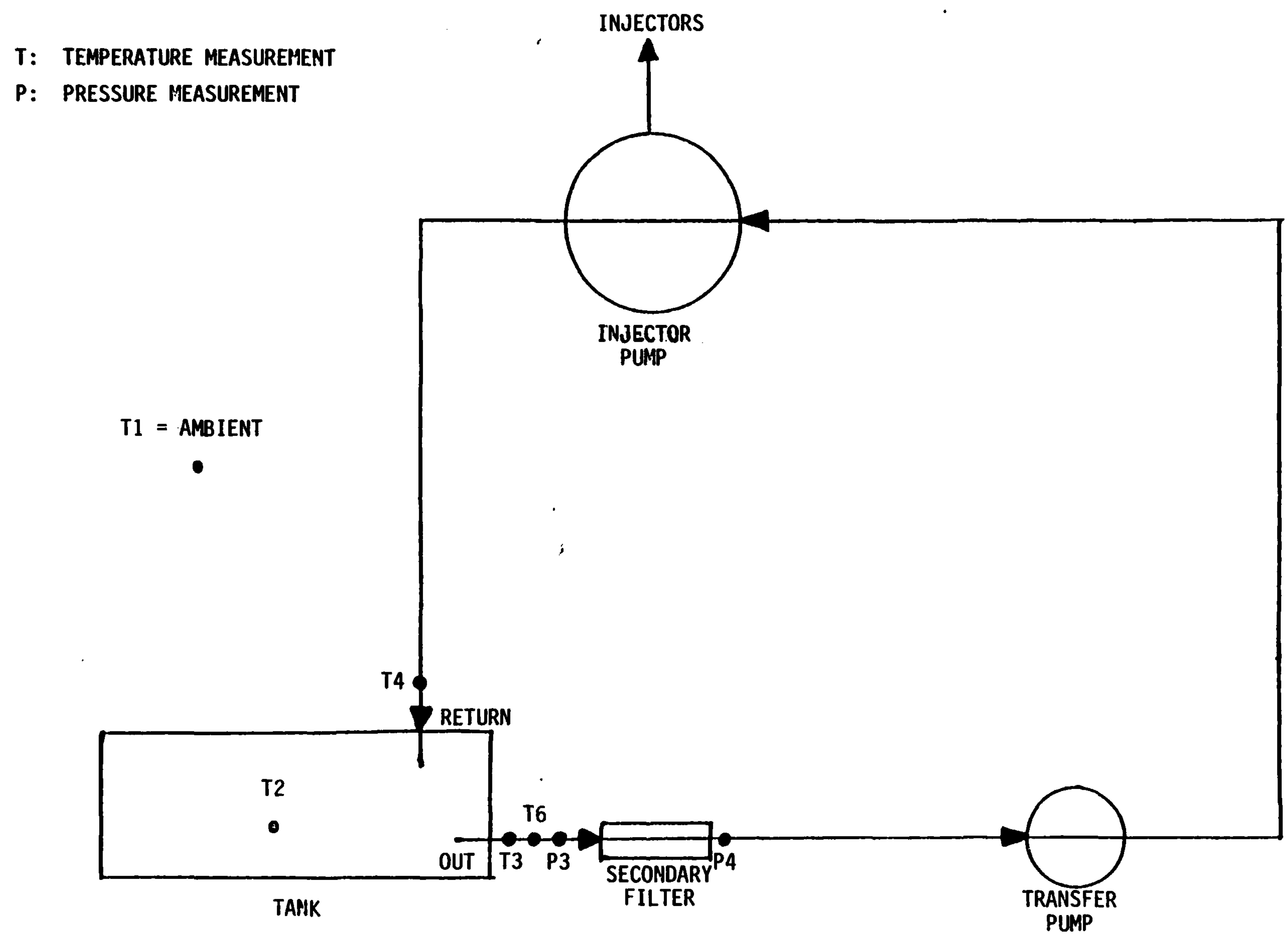


FIGURE 5-6. FUEL SYSTEM - VEHICLE 126

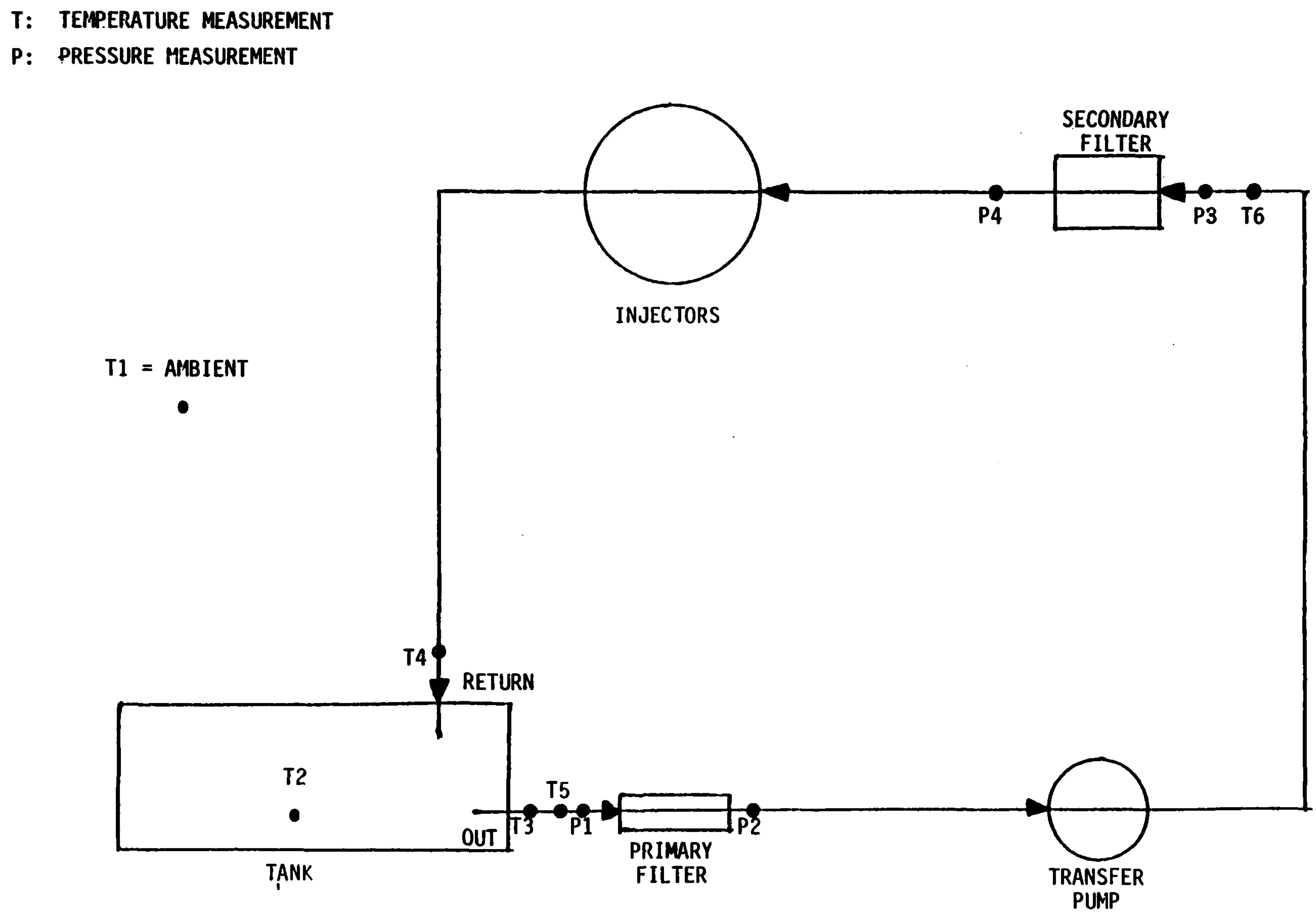


FIGURE 5-7. FUEL SYSTEM - VEHICLE 128

CHAPTER 6

TEST PROCEDURES

I. TEST SCHEDULING

Each day a decision was made by the on-site CRC supervisory personnel as to the vehicle-fuel combinations to be tested on the next test day. The decisison was made on the basis of the predicted morning low temperature for the next day, and the relative value of data at that temperature for each vehicle-fuel combination. As part of this decision, a temperature window, i.e., a temperature above which the test results would be of no value and a temperature below which the test results would be of no value, was specified for each vehicle-fuel combination. Initially, these windows were fairly wide, but as data accumulated, the windows became progressively narrower. A weather forecast, which was generally available at 10:00 a.m. from the local airport, was used to predict the test temperature. Because the refueling operation required most of the afternoon, the 10:00 a.m. forecast was used for fuel selection, even though later forecasts would have been more helpful. Unfortunately, the temperature conditions in the morning were often sufficiently different from the forecasted temperature conditions to preclude testing in several of the vehicles which had been prepared.

II. DAILY TEST PROCEDURES

Table 6-1 lists an ideal daily time schedule for the test procedures. The procedures are described in more detail in the following paragraphs.

A. Preparation Procedure

Each individual test began with the vehicle preparation, normally conducted the afternoon prior to the test. This included a complete drain of the test fuel after the vehicle fuel tanks had been warmed to 10°C, a flush with the next test fuel, a second complete drain, and a filter change. Following the fuel changes, the vehicles were warmed up by driving for at least 24 km. This warmup served to flush the system of residual fuel in the lines which had not been completely drained, and provided a consistent temperature condition from which to start the cooling period. Following the warmup, the vehicles were parked in the test compound for an overnight cooldown and soak. Pertinent information regarding the preparation, warmup, and cooldown were documented on a Test Data Sheet (see example in Table 6-2).

B. Driving Test Procedure

The first step at the start of the test day was to determine which of the prepared vehicle-fuel combinations were within their temperature windows. This decision was made on the basis of the temperatures at 7:30 a.m.

Because only four drivers were available, the vehicles were generally run in two groups. The first group of four vehicles was normally scheduled to start at 8:00 a.m., and the second group of three vehicles at 9:30 a.m. In the latter stages of the test program, frequently only one group was required. This occurred when the predicted morning temperature was outside of the useful windows for all of the fuels in three or more vehicles. In some cases; however, if the tank temperature was slightly below the window, the vehicle was included in the second group to allow the temperature to come up into the window. To assure starting regardless of the condition of the vehicle battery, a warm, auxiliary booster battery pack was used. Engine-block heaters were used if it was anticipated that they would be required. While there may have been an effect of the block heater on the temperatures in the fuel system and subsequently on the meaning of the data, it was felt that the necessity of starting the vehicles was of greater concern. Occasionally, ether injection was used, again because of the overriding necessity of starting the engines.

Once a cold start had been achieved, each automobile was allowed to idle for approximately one minute and then driven away. This was believed to be the typical practice of most passenger car diesel operators. The heavy-duty trucks were idled for at least ten minutes before being driven away. This time period was consistent with general operator practice. Occasionally, additional time was required for the pressure in the air-brake systems to come up to normal.

The cars were driven on the local highway at nominally 88 km/h for 42 km, turned around, and driven back. The course was selected to minimize interference with local traffic. Because of the area requirements for turning around, the trucks were driven only 30 km before being turned around. If severe operating problems occurred, the vehicles were pulled to the side of the road. Often, it was possible to return to the test site after allowing the vehicle to idle for a period of time. In such cases, no attempt was made to complete the course. If the only operating difficulty was an inability of the vehicle to maintain speed, the course was generally completed, but the problem was noted on the Test Data Sheet. In some cases, the vehicles could be started, but would not produce enough power to leave the test site.

C. Weekend Test Procedures

Testing was not generally carried out on Sundays because of the extra labor costs; thus, the vehicle-fuel combinations being tested on Monday were usually prepared on Saturday. When this was done, the vehicles were not driven the last 24-km warmup drive on Saturday. This step was delayed until Sunday afternoon. In addition, if possible, the cars were stored inside over Saturday night to minimize the effect of the extra 24-hour soak on the test results. Unfortunately, it was impossible to do this with the trucks, so the fuels in the tests on Mondays generally were cooled Saturday night, warmed Sunday afternoon by the 15-minute warmup drive, and then cooled a second time on Sunday night. While this was an undesirable deviation in the test procedure, there appeared to be no reasonable alternative.

D. Other Exceptions to Standard Procedures

There were numerous exceptions to the standard test procedures, as is normally the case when a field test of this magnitude and duration is operated under prevailing conditions. The major cause was the difficulty in predicting the morning low temperature twenty hours ahead of time. Thus, vehicles which had been prepared for testing often were not tested, because the tank temperature was not within the window. In this case, if the temperature on the next day was predicted to be within the window for that vehicle-fuel combination, the fuel was left in the vehicle. Additional fuel was added to bring the level up to the standard level, and the vehicle was given the normal 15-minute warmup drive. If on the following day the temperature was again outside of the window, the same procedure was followed. Consequently, in some cases, the same charge of fuel was in the vehicle for several days. In a few cases, if the temperature was considerably below the cloud point of the fuel in the vehicle, or if the fuel had been in the vehicle for an extended period, the fuel was drained and discarded without having been tested and a fresh charge of the same fuel was added. In the cases in which the temperature on the next day was predicted to be within a window for a different fuel in that vehicle, the fuel was drained and discarded, even though it had not been tested.

III. VEHICLE INSTRUMENTATION

As described in Chapter 5, each vehicle was equipped with thermocouples and pressure transducers. The outputs from these instruments were scanned at 30-second intervals by portable data-logging systems which included a multiplexer, signal conditioner, and a cassette tape recorder. Five of these data-logging systems were used. These systems and their batteries were enclosed in insulated boxes to keep the instrumentation and recorders within their operating temperature range. Wires were connected between the recording systems and externally-mounted plugs on the boxes to minimize opening the boxes while in the vehicles. While not being used, the systems, in their boxes, were kept indoors and a charger was connected to the batteries. The data-logging systems were calibrated once a week.

IV. DATA HANDLING

After returning to the test site, the Test Data Sheets were reviewed by the operations engineer and the CRC supervisory personnel to ensure that they were complete. A single cassette reader connected to a computer was used to transfer the data from the tape cassettes onto floppy disks and onto paper. The data were put on the disk so that they could be reduced to tables and graphs by computer. Originally, this was to be done on a daily basis to aid the on-site CRC personnel in the selection of vehicle-fuel combinations. Unfortunately, the computer at the test site was not operating properly, and the data were not reduced until after the field test was completed.

A separate data-recording system was used to record the tank and ambient temperatures throughout the night. The tank temperature measurements were made using the same thermocouples that were used by the on-board data-logging systems. The ambient temperature measurement was made using a thermocouple permanently mounted on a pole near the center of the test compound. These temperatures were recorded at 15-minute intervals and the results were printed on paper as the readings were made. Plots of these temperatures were made by hand each day.

V. VEHICLE MAINTENANCE

Because of the length of the test program, some maintenance of vehicles was necessary. During the program, vehicle maintenance was limited to that normally required by the manufacturer, or that necessary to keep the vehicles operational. This also included maintenance on the truck auxiliary systems and the tractor-trailers.

TABLES

AND

FIGURES

TABLE 6-1

CRC DIESEL FUEL LOW-TEMPERATURE OPERABILITY
FIELD TEST PROCEDURE

Step	Nominal Time	Procedure
1	7:30a.m.	Note tank temperature recorded and decide which vehicles of those prepared will be tested.
2	7:45a.m.	Install data-logging systems in first group of vehicles.
3	8:00a.m.	Start vehicles and drive away after prescribed warmup.
4	8:00a.m.-9:15a.m.	Test first group of vehicles, and bring back stalled vehicles.
5	9:15a.m.	Install data-logging systems in second group of vehicles.
6	9:30a.m.	Start vehicles in second group, as above.
7	9:30a.m.-10:45a.m.	Test second group of vehicles, and bring back stalled vehicles.
8	11:00a.m.-5:30p.m.	Prepare vehicles for tests on following day: (a) Heat tanks to 10°C. (b) Drain all fuel. (c) Add 7-1/2 ℓ of next test fuel to cars. Add 46 ℓ of next test fuel to trucks. (d) Idle 15 minutes to flush system. (e) Drain fuel. (f) Change fuel filters. (g) Add 53 ℓ in Vehicles 121 and 122; Add 34 ℓ in Vehicle 123; Add 19 ℓ in Vehicle 124; Add 137 ℓ in Vehicles 125, 126, and 128. (h) Drive 24 km for warmup. (i) Park and soak overnight.

TABLE 6-2

SAMPLE TEST DATA SHEET

KAPTEST
ENGINEERING LIMITED

CRC
DIESEL FUEL
OPERABILITY
DATA SHEET

PROJECT:	VEHICLE:	OPERATOR:	TEST NO:
P101	C124	REG	C124-22

SYNCHRONIZED WATCH

MATRIX	PREPERATION 01	WARM-UP 02	START 03	FAIL	PARK
TAPE START TIME					
DATE:	81/01/21	81/01/21	81/01/22		
AMBIENT:	+1.0				
TANK TEMP			-1.0		
ODOMETER	851		847		918
TIME	15:45	17:15	9:18		10:26
START AIDS					
FUEL TYPE	105				
BARREL NUMBER	22				

	CHANGE	PARK			
WARM TANK	✓	TIME: 17:38	DATA LOGGER #:	WOULD NOT START AFTER 3 ATTEMPTS TIME:	RETURN TIME: SPEED: ODO:
DRAIN	✓	T/C#: 13			
FLUSH	✓	POST #:	DRIVEAWAY TIME:		
IDLE	✓	BLOCK HEATER ON: NO			
CHANGE FILTER	✓		YARD STALL TIME: NUMBER OF STALLS:	LOSS OF POWER TIME: SPEED: ODO:	TOWED YES: NO:
ADD FUEL	5 GALS	TANK TEMP:			
COMMENTS:					USE OF HEAT YES: NO:
CARS BATTERY			RESTART TIME:	STOP & IDLE TIME: ODO:	
CARS OTHER			WOULD NOT RESTART TIME:		
TRACTORS START				STALLED TIME: ODO:	
TRACTORS OTHER					
TRAILERS BRAKES					
TRAILERS AXLES					
TRAILERS OTHER					

CHAPTER 7

DISCUSSION OF RESULTS

DISCUSSION OF RESULTS

As indicated earlier in this report, the primary objective of this program was to develop a comprehensive set of data on diesel vehicle operability at low temperatures which encompassed a wide range of vehicle and fuel types. These data are presented and discussed in this section.

I. DATA BASE

The raw data for each vehicle-fuel-temperature combination consisted of the following:

1. Vehicle fuel tank temperature during the overnight cooldown.

2. A digital listing of pressures and temperatures at the locations indicated previously at 30-second intervals throughout the test. (In some cases, however, these data were either unintelligible or not recorded at all.)

3. Computer-developed plots of pressures and temperatures as a function of time throughout the test.

4. A driver log sheet documenting the conditions of the run, and indicating the time and mileage at which various events occurred.

5. Notes made by the on-site personnel pertaininig to conditions of the run, malfunctions, etc.

In addition, weather data provided by the local Kapuskasing weather station were available subsequent to the conclusion of the program. All of these raw data are on file at the CRC offices.

In analyzing the data, the Data Analysis Panel extracted from the raw data pertinent temperature and pressure information; classified each run as a pass, borderline pass, borderline fail, or fail; and noted any abnormalities associated with each run. These analyzed data, which are included in this report as Appendix D, formed the data base from which all subsequent analyses and comparisons were made. The definitions of the variables used in the data base are provided at the beginning of Appendix D.

II. ANALYSIS RATIONALE

As the first step in establishing a minimum operating temperature for each vehicle-fuel combination, the result of each vehicle-fuel combination tested at each temperature was categorized as a pass, borderline pass, borderline fail, or fail as follows:

> Pass - The vehicle started and completed the trip with no more than minor driveability complaints (rating of 1).
>
> Borderline Pass - The vehicle started and completed the trip with no more than minor driveability complaints, but excessive pressure drops occurred across one or more fuel filters during the trip (rating of 2).
>
> Borderline Fail - The vehicle started and completed the trip, but could not reach or maintain 88 km/h during the test because of fuel waxing (as confirmed by pressure data) (rating of 3).
>
> Fail - The vehicle would not start, or started but did not complete the trip, because excessive fuel waxing produced stalling or extremely slow speeds (rating of 4).

It was decided that the temperature of a given run should be designated as the lowest fuel system temperature experienced either before or during the test. This temperature is the minimum of:

1. The minimum vehicle fuel-tank temperature experienced during the overnight cooldown.

2. The minimum temperature experienced anywhere in the fuel system upstream of a plugging condition during the over-the-road test.

This temperature is designated as MINFTEMP in Appendix D and is the temperature which will be used as the basis for determining the minimum operating temperature of each vehicle-fuel combination. Since n-paraffin solubility is a function of temperature, and since once n-paraffins crystallize they do not redissolve readily, it was believed that this minimum fuel temperature was the best measure of whether the vehicle in question could be operated with the given fuel. MINFTEMP could be either above or below the prevailing ambient temperature, depending upon the cooldown conditions which occurred during a given test. Ambient temperature records are also on file at the CRC offices.

III. COMPARISONS OF FUEL PERFORMANCE IN EACH VEHICLE

Figures 7-1 through 7-7 show the results obtained for each of the eight fuels in each of the seven vehicles, one figure corresponding to each vehicle. The numerical symbols 1 through 4 indicate the operability rating of a given test run as defined in the previous section, and are plotted at the minimum fuel temperatures determined for each test run, as also defined in the previous section. The vertical bars associated with each vehicle-fuel combination represent the minimum operating temperature ranges, as will be discussed in a later section. The results for each vehicle will be discussed separately.

A. Vehicle 121

Figure 7-1 shows the results obtained in Vehicle 121 for the eight test fuels. Except for Fuel 108, for which only two temperatures were investigated, all of the fuels were run at a minimum of four temperatures. A total of thirty-seven valid test runs was obtained for this vehicle.

Runs categorized as a pass (rating of 1) were obtained on six of the eight fuels. Borderline pass results (rating of 2) were also obtained on six of the fuels, and fail results (rating of 4) were obtained on all eight fuels. No borderline fail conditions (rating of 3) were obtained with any of the fuels.

This vehicle was equipped with a fuel tank filter (130-μm pore size) and a transfer pump followed by a secondary filter (8-10 μm) before the injector pump. In the investigation of the mode of failure, the pressure data were the most useful. Pressure and temperature data for a typical pass run are plotted in Appendix E, Figures E-1 and E-2; and for a case in which there was partial blockage of the secondary filter in Appendix Figures E-3 and E-4. This partial blockage was not sufficient to reduce the vehicle speed, and was cleared as the system warmed up. The test run was therefore classified as a borderline pass.

With the base fuels, failures appeared to be caused by blockage of the tank filter, except for Fuel 102. In all the borderline and fail runs on this fuel, the ambient temperatures during the runs were lower than the tank temperatures by about 5^{o}C, and the secondary filter was blocked.

With the flow-improved fuels near their failure temperatures, the borderline and fail conditions were due to blockage of the secondary filter occurring when fuel-tank and ambient temperatures were similar. This suggests that the flow improvers did reduce the wax-crystal size, allowing the fuel to pass more readily through the system, particularly through the large pore-size tank filter. Typical pressure and temperature data corresponding to a fail condition caused by plugging of the secondary filter are shown in Appendix Figures E-5 and E-6.

B. Vehicle 122

Figure 7-2 shows the results obtained in Vehicle 122 for the eight test fuels. All of the fuels were run at a minimum of two temperatures. Analysis of the data indicated a total of thirty-four valid test runs. Because the fuel-line heater in this vehicle failed to operate during most of the test program due to either mechanical difficulties or too high an ambient temperature, the decision was made to omit those tests in which the heater did function and consider the vehicle as not having a fuel-line heater. This resulted in two runs being omitted, leaving the thirty-two valid test runs indicated in Figure 7-2 for this vehicle. Because the tank filter on this vehicle contained a bypass valve which opened whenever the filter became coated with wax particles (see Figure 5-2), the only filter which registered a pressure drop when seriously plugged in these tests was the secondary fuel filter.

Runs categorized as a pass (rating of 1) were obtained on all eight test fuels, so that a minimum pass temperature could be defined for all fuels. Borderline pass results (rating of 2) were obtained on three of the fuels, borderline fail results (rating of 3) were obtained on two of the fuels, and fail results (rating of 4) were obtained on six of the fuels. Some condition other than a pass was obtained on each of the eight fuels.

Appendix Figures E-7 through E-12 show typical pressure and temperature traces from this vehicle corresponding to a pass, a borderline pass, and a fail condition, respectively. As indicated in Figure E-7, during normal operation the pressure drop across the secondary filter remained about 7 kPa throughout the test. During the run corresponding to Figure E-9, the pressure drop across the secondary filter increased to about 56 kPa after about forty minutes, but returned to normal by the end of the test. No driveability problems were encountered during the test, so the result was classified as a borderline pass. Figure E-11 represents a test in which the vehicle would idle, but would not run without stalling. The test schedule could not be completed, and the result was classified as a fail.

C. Vehicle 123

This passenger vehicle was of medium size in terms of weight, tank size, and engine displacement. The fuel system differed from the other cars in that it contained a tank filter, a primary filter, and a secondary filter. The pore size of the tank filter was appreciably larger than that in the other cars. Vehicle 123 was tested more than four times on all but one fuel. As is evident in Figure 7-3, both passing and failing results were achieved on all but one fuel, with which a borderline fail (rating of 3) was obtained. The windows between failing and passing temperatures were wider than 4°C for Fuels 103, 104, and 107. With the base fuels, the failure temperatures were generally higher than those for the other passenger cars; but with the flow-improved fuels, the failure temperatures were generally lower than those of the other cars. This may have been because the primary and tank filter pore sizes were larger than the tank filter pore size of the other cars.

The predominant type of failure was plugging of the primary filter, although in several cases, failures on base fuels were caused by plugging in the secondary filter. Of the eighteen non-passing tests, one was a borderline pass (rating of 2), and two were borderline failures.

This vehicle returned appreciable quantities of warm fuel to the tank. Unfortunately, the return line exit was not close to the tank pickup, so the warm returned fuel did not preferentially heat the fuel leaving the tank.

Appendix Figures E-13 through E-16 show the normal pattern for the pressures and temperatures for passing and failing tests, respectively. Unique to this vehicle, there were difficulties in accurately recording the temperature data; therefore, caution must be exercised when utilizing these temperature data.

D. Vehicle 124

Figure 7-4 shows the results obtained in Vehicle 124 for the eight test fuels. Analysis of the data indicated a total of thirty-five valid test runs. This vehicle represents the smallest engine tested, and one which had both the tank filter and secondary filter on the suction side of the fuel pump. Specific details are in Chapter 5. The major failure mode for this vehicle was plugging of the tank filter. This was concluded by noting that when failure occurred, the pressure drop across the tank filter increased, but the pressure drop across the secondary filter did not. The only exception was with Fuel 106. The failure mode with this fuel was plugging of the secondary filter. It appears that the flow-improver additive in this fuel probably permitted the waxy fuel to pass through the tank filter, but not through the secondary filter.

On several occasions, the ambient temperature dropped during the test run. While this did not affect the fuel-tank temperature, it did decrease the fuel-underhood temperature and the fuel temperature entering the secondary filter. In one case, this resulted in borderline failure performance due to partial plugging of the secondary filter during the run. Appendix Figures E-17 through E-22 show typical pressure and temperature traces from this vehicle corresponding to pass, borderline fail, and fail conditions, respectively.

E. Vehicle 125

Figure 7-5 shows the results obtained in this vehicle with the eight test fuels. Twenty-six valid test runs were made. Passing results (rating of 1) were obtained on all fuels except Fuel 107. The only borderline pass condition (rating of 2) observed occurred with Fuel 107; however, technical problems with the secondary filter pressure transducers may have prevented additional borderline pass conditions from being recognized. Failures (rating of 4) were observed with all fuels except Fuels 105 and 108, and no borderline failures occurred with any fuel. Typical pressure and temperature traces corresponding to pass, borderline pass, and fail conditions are shown in Appendix Figures E-23 through E-28.

With the three base fuels (101, 102, and 103), fuel system failure appeared to be caused by plugging of the 178-μm fuel tank filter located on the suction side of the transfer pump. Typical pressure traces under these conditions (shown in Figure E-27) revealed a high pressure drop across the tank filter with only a small pressure drop across the secondary filter.

Because of the aforementioned technical problems with the pressure transducers, no secondary filter pressure data were obtained for any of the failures observed with fuels containing a flow improver. However, since restriction of fuel flow was not evident elsewhere in the fuel system, it is conjectured that plugging of the secondary fuel filter was the cause of fuel system failure with flow-improved fuels. This hypothesis is supported by the one borderline pass rating obtained with Fuel 107, in which a high pressure drop across the secondary filter was observed, as shown in Figure E-25.

The temperature of the fuel recirculated to the fuel tank increased rapidly as heat was generated by the injection pump. Other temperatures in the fuel system rose very slowly, increasing only 5-15°C after almost an hour.

F. Vehicle 126

The thirty-three valid test runs obtained in this vehicle with the eight test fuels are shown in Figure 7-6. Pass ratings (rating of 1) were obtained on all fuels, and fail ratings (rating of 4) were obtained on all fuels except Fuel 104. No borderline conditions were observed in this vehicle with any of the fuels.

Appendix Figures E-29 through E-34 show typical pressure and temperature traces corresponding to pass conditions and two modes of failure. Under satisfactory operating conditions (rating of 1), the temperatures in the fuel system rose normally, and the pressure drop across the secondary filter remained constant.

In the first mode of failure, fuel flow was severely restricted at the secondary filter resulting in a high pressure drop across that filter (see Figure E-31). The temperature of the fuel in the tank or in the lines to the engine showed no warming trend, and the temperature increase for the recirculated fuel was lower than normal. In the second mode of failure, the secondary filter showed no abnormal restriction (see Figure E-33), and the temperature of the fuel in the lines to the engine increased moderately. In this case, fuel flow was restricted at some unknown location.

Due to instrumentation difficulties, pressure data were not available for a large number of tests on this vehicle; and it was not possible to determine which of the two modes of failure was most common. Within the limited data available, failure mode and fuel type did not appear to be related.

G. Vehicle 128

Because of a large number of mechanical problems with this vehicle, only twenty-four valid test runs were obtained. No tests were conducted with Fuel 104, and no failures or borderline failures were obtained with Fuels 101, 102, and 107, so that minimum operating temperatures could not be determined with these four fuels. This lack of data occurred because the truck was not reliably operational during the cold weather, and by the time the problems had been corrected, the cold weather had passed. Consequently, only four fail ratings and two borderline fail ratings were obtained from this vehicle. Where there were data, however, the vehicle appeared to be able to handle fuels below their cloud points. As shown in Table 7-3, this vehicle was the least severe for Fuels 103 and 107.

The predominant type of failure for this vehicle was plugging in the primary filter. However, this filter apparently could pass sufficient fuel to keep the vehicle operating even though there was an 83-kPa pressure drop across it. Occasionally, plugging also occurred in the secondary filter.

A second characteristic of this vehicle which contributed to its generally good low-temperature performance was that it normally returned large quantities of warm fuel to the tank, which caused the tank temperature, and the rest of the system temperatures with it, to rise at more than 1°C/min. Thus, once this vehicle had been started, it would usually complete a test. If the primary filter was severely plugged, insufficient quantities of warm fuel were returned to raise the tank temperature. Appendix Figures E-35 through E-40 show the normal pattern for the pressures and temperatures for passing, borderline passing, and failing tests, respectively.

The data on failing tests were too sparse to permit a meaningful analysis of the fuel type on the location or type of failure.

IV. COMPARISONS OF VEHICLE PERFORMANCE FOR EACH FUEL

In addition to grouping the results from this program by vehicle as was done in Figures 7-1 through 7-7, the results can also be grouped by fuel. Figures 7-8 through 7-15 present the results in this fashion, one figure corresponding to each fuel. The numerical symbols 1 through 4 again indicate the operability rating of a given test run as defined earlier. Each symbol has been plotted at the minimum fuel temperature determined for that run, as also defined earlier. The vertical bars again represent minimum operating temperature ranges, as will be discussed in a subsequent section of this report. The results for each fuel will be discussed separately.

A. Fuel 101

This fuel was the lowest cloud point base fuel (-19°C) included in the program. Figure 7-8 shows very little difference in performance among the seven vehicles in which data were obtained with this fuel. In each case, it appears that the vehicles operated satisfactorily at temperatures down to about the cloud point, but encountered problems (except perhaps Vehicle 128) at slightly lower temperatures. The wax crystals which formed in this base fuel at the cloud point temperature were apparently large enough to plug fuel filters in all of the vehicles and cause operational problems.

B. Fuel 102

This base fuel had a cloud point of -9°C. The results shown in Figure 7-9 indicate a range of performance for the seven vehicles. Vehicle 126 could be operated satisfactorily only down to temperatures about 3°C above the cloud point; Vehicles 121, 123, and 124 operated satisfactorily at temperatures slightly below the cloud point; Vehicles 122, 125, and 128 operated satisfactorily at temperatures substantially below the cloud point. The reasons for this variation in vehicle performance are not clear.

C. Fuel 103

This was the highest cloud point base fuel (-2°C) included in the test program. Results for the seven vehicles in which this fuel was tested are shown in Figure 7-10. With the exception of Vehicle 128, operating problems were encountered in all of the vehicles at temperatures only slightly below the cloud point. Vehicle 128 could be operated satisfactorily about 5°C below the fuel cloud point.

D. Fuel 104

As indicated in an earlier section, Fuel 104 is composed of base Fuel 101 plus Flow Improver A. The cloud point of Fuel 104 (-19°C) was essentially the same as that of Fuel 101. The results obtained with this fuel in the six vehicles in which it was evaluated are shown in Figure 7-11. All of the vehicles were able to operate below the fuel cloud point with Fuel 104, most by about 2-4°C. In Vehicle 122, the improvement may be even more substantial, although, as indicated in Figure 7-11, the failure temperature for this vehicle was not well defined in this program.

E. Fuel 105

This fuel contained base Fuel 102 plus Flow Improver B. The cloud point of Fuel 105 (-9°C) was essentially the same as that of Fuel 102. The results of the vehicle tests with this fuel are shown in Figure 7-12. As was the case with Fuel 104, all vehicles could be operated on Fuel 105 at temperatures below the fuel cloud point. The minimum temperatures at which satisfactory operation was achieved varied greatly among vehicles. Vehicles 121, 122, 124, and 126 operated satisfactorily at temperatures about 3-6°C below the fuel cloud point, while Vehicles 123, 125, and 128 operated satisfactorily at temperatures 15°C or more below the fuel cloud point.

F. Fuel 106

This fuel was the same as Fuel 105, except that Flow Improver B was added to the base Fuel 102 at twice the concentration included in Fuel 105. The cloud point of Fuel 106 was -9°C, essentially the same as that of Fuels 102 and 105. Vehicle test results obtained with Fuel 106 are shown in Figure 7-13. Again, all of the vehicles could be operated satisfactorily at temperatures ranging from about 5°C (Vehicle 124) to about 15°C (Vehicles 122 and 123) below the cloud point. Some of the vehicles (123, 125, and 128) could be operated satisfactorily at lower temperatures with Fuel 105 than with Fuel 106, despite a higher concentration of flow improver in Fuel 106. This will be discussed further in a subsequent section on flow-improver effectiveness.

G. Fuel 107

This fuel contained the same base Fuel 102 as Fuels 105 and 106, but was treated with Flow Improver C. The cloud point of Fuel 107 was -9°C, essentially the same as that of Fuels 102, 105, and 106. The vehicle test results obtained using this fuel are shown in Figure 7-14. Satisfactory operation substantially below the cloud point temperature was obtained with at least five of the seven vehicles. Because of the large spread between pass and fail results achieved with Vehicles 121 and 124, one cannot tell whether they would have operated satisfactorily at temperatures below the fuel cloud point.

H. Fuel 108

This fuel contained base Fuel 103 plus Flow Improver D. The cloud point was -2°C, essentially the same as the cloud point of Fuel 103. Vehicle results obtained with Fuel 108 are shown in Figure 7-15. It appears that all seven vehicles could be operated satisfactorily at temperatures below the fuel cloud point with this fuel; however, none of the vehicles (with the possible exception of Vehicle 125, for which insufficient data were obtained) was operated satisfactorily more than 5 or 6°C below the fuel cloud point.

V. MINIMUM OPERATING TEMPERATURE RANGES FOR EACH VEHICLE-FUEL COMBINATION

The data in Figures 7-1 through 7-7 or in Figures 7-8 through 7-15 can be used to establish minimum operating temperature ranges for each vehicle-fuel combination. Table 7-1 lists these ranges. The minimum pass temperatures (MPT) listed represent the minimum temperatures at which a pass, a borderline pass, or a borderline fail condition (a rating of 1, 2, or 3) was obtained on each vehicle-fuel combination. The maximum fail temperatures (MFT) represent the maximum temperatures at which a fail condition was obtained on each vehicle-fuel combination. Missing values indicate that either no passing or no failing conditions were encountered with those particular vehicle-fuel combinations. The ranges listed in Table 7-1 also correspond to the vertical bars shown for each vehicle-fuel combination in Figures 7-1 through 7-7 and in Figures 7-8 through 7-15.

In Figure 7-1, for example, for Fuel 102 in Vehicle 121, the minimum pass temperature is -12°C (rating of 2), while the maximum fail temperature is -15°C (rating of 4). For Fuel 101 in this vehicle, the minimum pass temperature is -23°C (rating of 2), even though a fail condition was experienced at a higher temperature. The maximum fail temperature is -21°C, although a pass was obtained at a lower temperature. Thus, as is evident in Table 7-1, the maximum fail temperature can be higher than the minimum pass temperature for a particular vehicle-fuel combination.

The differences between the minimum pass and maximum fail temperatures listed in Table 7-1 represent the uncertainties which exist in attempting to define a single value for the minimum operating temperature of each vehicle-fuel combination. For those combinations in which both minimum pass and maximum fail temperatures are listed in Table 7-1, this uncertainty ranges from 0 (Vehicle 124, Fuel 101) to 9°C (Vehicle 122, Fuel 104). The average value of this uncertainty range is 3.2°C.

VI. ESTIMATED MINIMUM OPERATING TEMPERATURES FOR EACH VEHICLE-FUEL COMBINATION

For the purposes of making comparisons among fuels and vehicles, as well as for correlating vehicle performance with laboratory test predictions, it is useful to have a single temperature to represent the minimum operating temperature of each vehicle-fuel combination. Although exact values of these temperatures were not determined, as indicated in the previous section, estimates of these temperatures can be made from the minimum operating temperature ranges presented in Table 7-1 and from Figures 7-1 through 7-7.

To estimate these temperatures, several criteria were established based on the premise that a borderline fail condition was the best representation of the estimated minimum operating temperature of a vehicle-fuel combination. Examples of how these criteria, which are listed below, were applied are shown for four hypothetical fuels in a hypothetical Vehicle X in Figure 7-16.

1. If one borderline fail condition was obtained, that temperature was taken to be the estimated minimum operating temperature (Fuel A in Figure 7-16).

2. If more than one borderline fail condition was obtained, the lowest value was taken to be the estimated minimum operating temperature (Fuel B in Figure 7-16).

3. If the lowest pass temperature was a borderline pass (rating of 2), and the highest fail temperature was a fail (rating of 4), the estimated minimum operating temperature was taken to be halfway between the lowest pass and highest fail temperatures (Fuel C in Figure 7-16), regardless of whether the lowest pass temperature was above or below the highest fail temperature.

4. If the lowest pass temperature was a pass (rating of 1), and the highest fail temperature was a fail, the estimated minimum operating temperature was taken to be two-thirds of the way toward the highest fail temperature (Fuel D in Figure 7-16), regardless of whether the lowest pass temperature was above or below the highest fail temperature.

Table 7-2 lists the minimum operating temperatures for each vehicle-fuel combination estimated by using these criteria. Values indicated as less than some value represent vehicle-fuel combinations in which passing conditions were obtained, but in which failing conditions were not obtained. For example, for Fuel 101 in Vehicle 128, a pass was obtained at -19°C, but this particular vehicle-fuel combination was not run at lower temperatures. Missing values in Table 7-2 indicate that no valid test runs were obtained on that particular vehicle-fuel combination.

Table 7-2 also gives the average and median estimated minimum operating temperatures of all seven vehicles for each fuel. In calculating both the averages and the medians, values indicated as less than a certain temperature were assumed equal to that temperature. For example, in calculating the average and median estimated operating temperatures for Fuel 101, the value for Vehicle 128 was assumed to be -19°C.

The values shown in Table 7-2 represent the best estimates available of the minimum operating temperatures of the vehicle-fuel combinations investigated in this program. They will be used in subsequent sections of this report to make comparisons among vehicles and fuels, as well as to determine how well various laboratory bench tests predict low-temperature vehicle operation.

VII. COMPARISON OF TRENDS IN VEHICLE SEVERITY

One objective of this program was to determine the relative vehicle severity as related to fuel system design. These results may provide insight into design factors which are critical in their effect on fuel system waxing. Previous programs of this nature[1,2] have identified fuel filter pore size, capacity, and location as being particularly important factors, as well as fuel recirculation rate, fuel-line sizes, and fuel-line location.

The estimated minimum operating temperatures in Table 7-2 provide one basis for comparing vehicle severity. Based on this table, Table 7-3 was constructed, in which the most and least severe passenger car, truck, and overall vehicle are listed for each fuel. The missing values for the trucks for Fuels 104 and 108 arise because insufficient data were obtained with these fuels in the trucks. Nevertheless, Table 7-3 reveals some interesting patterns.

For the passenger cars, Vehicles 124 (four fuels) and 121 (three fuels) appear to be the most severe, while Vehicles 122 (four fuels) and 123 (three fuels) appear to be the least severe. While a number of factors contribute to the performance of an overall fuel system, it would appear that these results can be explained in terms of the filter pore sizes of the tank filters on the passenger cars. As indicated previously in Table 5-2, Vehicles 124 and 121 have relatively fine pore-size tank filters (40-50 μm and 130 μm, respectively), while Vehicle 123 has a 600-μm tank filter. Vehicle 122 also has a 130- m tank filter, but this filter is essentially eliminated from the system by the bypass valve which opens when the filter becomes plugged with wax. Since the secondary fuel filter pore sizes are basically the same in all of the passenger cars, it appears that tank filter characteristics have the most pronounced effect on low-temperature passenger car fuel system waxing.

For heavy-duty trucks, Vehicle 126 appears to be more severe than either Vehicle 125 or 128. This appears to be due primarily to the fact that Vehicle 126 relies on vacuum to pull the fuel through the secondary filter, while the transfer pumps in Vehicles 125 and 128 push the fuel through the secondary filter at pressures over 170 kPa.

The last two columns in Table 7-3 indicate the most and least severe vehicle among passenger cars and trucks combined for each of the eight fuels. The most severe vehicles appear to be 124 (three fuels) and 126 (three fuels). None of the other vehicles stands out as being the least severe, although Vehicles 123 and 128 each demonstrated the lowest average estimated minimum operating temperature for two of the eight fuels.

A more quantitative assessment of vehicle severity is provided by Table 7-4, in which the estimated minimum operating temperatures in Table 7-2 have been averaged for the eight fuels to yield a single average estimated minimum operating temperature for each vehicle. For this comparison only, a value of -25°C was assumed for the estimated minimum operating temperature of Vehicle 128 operating with Fuel 104, and any entry in Table 7-2 indicated as less than some value was included in the average as that value. The data in Table 7-4 confirm the trends just discussed in connection with Table 7-3. Of the passenger cars, Vehicles 124 and 121, which were seen to be most severe in Table 7-3, have the highest average estimated minimum operating temperatures in Table 7-4, -13.0 and -14.2°C, respectively. Vehicles 122 and 123, which were least severe, have lower averages, -16.1 and -16.4°C, respectively. Of the trucks, Vehicle 126, which was judged to be most severe in Table 7-3, has an average estimated minimum operating temperature of -14.4°C, while Vehicles 125 and 128, which were judged to be less severe, have averages of -15.5 and -17.6°C, respectively.

The differences among vehicles demonstrated in Table 7-4 are relatively small. The difference between the most severe and least severe passenger car, as measured by the average estimated minimum operating temperature, is 3.4°C, while for the heavy-duty trucks it is 3.2°C. Somewhat larger differences arise if the data for the base and flow-improved fuels are considered separately. This comparison is also shown in Table 7-4. A difference of only 3°C exists between the average minimum operating temperatures of the passenger cars with the base fuels, while about 6°C exists with the flow-improved fuels. Note that Vehicle 123 appeared to be most severe with the base fuels and least severe with the flow-improved fuels. About the same ranking and spread seem to exist for the trucks, whether the data are considered all together, or separated into base and flow-improved fuels. Vehicle 128, however, did appear to be noticeably less severe with the flow-improved fuels than did the other trucks.

It should be noted that the data in Table 7-4 are averages over several fuels. For specific fuels, however, the differences can be large, as was indicated by the data in Table 7-2. This suggests that fuel system design is an important factor in determining low-temperature operation.

VIII. FLOW IMPROVER EFFECTIVENESS

Another objective of this program was to determine whether commercially available flow improvers are effective in lowering the minimum temperatures at which diesel vehicles can be operated. Some discussion of the flow-improved fuels in this program enabling operation below the fuel cloud point was included in Section IV of this chapter, Comparisons of Vehicle Performance for Each Fuel. A better way to evaluate flow improver effectiveness, however, is to compare the results obtained with the flow-improved fuels in each vehicle with the results obtained with the base fuel in the same vehicle.

These comparisons are shown in Figures 7-17 through 7-21. In each figure, the minimum operating temperature ranges for each vehicle for one of the flow-improved fuels are plotted on the same figure as the minimum operating temperature ranges for the corresponding base fuel. Estimated minimum operating temperatures are indicated by solid circles for the base fuels and by open diamonds for the flow-improved fuels.

Figure 7-17 compares the performance of flow-improved Fuel 104 with that of base Fuel 101. With the possible exception of Vehicle 121, for which the estimated minimum operating temperatures are nearly identical, all of the vehicles operated satisfactorily at lower temperatures with the flow-improved fuel than with the base fuel. No comparison could be made for Vehicle 128, since Fuel 104 was not run in this vehicle.

Figures 7-18, 7-19, and 7-20 compare the performance of flow-improved Fuels 105, 106, and 107, respectively, with that of base Fuel 102. Figure 7-18 indicates that Fuel 105 permitted operation at lower temperatures than did Fuel 102 for all vehicles for which the minimum operating temperature ranges were defined. Figure 7-19 shows the same to be true for Fuel 106, except for Vehicle 125 in which performance with the flow-improved fuel was nearly the same as performance with the base fuel. With flow-improved Fuel 107 (see Figure 7-20), performance in four of the vehicles (121, 122, 124, and 125) was slightly worse than that with the base fuel, while performance in two of the vehicles (123 and 126) was substantially better. No comparison can be made for Vehicle 128, since failing performance was not achieved with either the base or the flow-improved fuel.

The comparison between flow-improved Fuel 108 and base Fuel 103 is shown in Figure 7-21). With Vehicles 121 and 126, the flow-improved fuel enabled operation at somewhat lower temperatures (2 to 5°C) than did the base fuel. With the other vehicles, essentially no difference between operation with the flow-improved and operation with the base fuel was found.

Table 7-5 summarizes the improvements in estimated minimum operating temperatures of the flow-improved fuels relative to the corresponding base fuels for each vehicle. Missing values and those indicated as ">" or "<" (ten of the thirty-five data points) in Table 7-5 arise because insufficient data were obtained with either the flow-improved or the base fuel or both for the particular vehicle-fuel combination in question.

It is clear from the data in Table 7-5 that, in general, all of the flow improvers reduced the minimum operating temperatures in some vehicles. The average improvement was 4.5°C; data used in this calculation do not include ">" or "<" values. The improvements shown by some of the flow-improved fuels varied greatly with the vehicle in which the fuel was evaluated. Fuel 105, for example, performed much better than the base Fuel 102 in Vehicles 123, 126, and 128 (particularly in Vehicle 123), but essentially the same as the base fuel in Vehicles 121, 122, and 124. Fuel 105 also performed better than Fuel 106 in Vehicles 125 and 128, despite the fact that Fuel 106 contained the same flow improver as Fuel 105 but at a higher concentration. Fuel 107 performed much better than the base Fuel 102 in Vehicles 123 and 126, essentially the same as the base fuel in Vehicles 121, 122, and 124, and much worse than the base fuel in Vehicle 125. In general, Vehicles 123 and 126 responded most favorably to the use of flow-improved fuels.

It should be emphasized that these improvements were obtained with fuels not specifically blended to maximize flow-improver effectiveness. No attempt was made to optimize the concentration of flow improver for a given fuel, or to tailor the flow improver to the fuel based on fuel composition.

TABLES

AND

FIGURES

TABLE 7-1

Minimum Operating Temperature Ranges (°C) for Each Vehicle-Fuel Combination

MPT = Minimum of ratings, 1, 2, or 3 (i.e., Minimum Pass Temperature)
MFT = Maximum of rating 4 (i.e., Maximum Fail Temperature)

	Fuel 101		Fuel 102		Fuel 103		Fuel 104		Fuel 105		Fuel 106		Fuel 107		Fuel 108	
	MPT	MFT	MPT	MFT	MPT	MFT	MPT	MFT	MPT	MFT	MPT	MFT	MPT	MFT	MPT	MFT
Vehicle 121	-23	-21	-12	-15	-2	-4	-21	-22	-15	-14	-17	-24	-9	-13	-6	-10
122	-20	-24	-15	--	-3	-6	-23	-32	-15	--	-22	-24	-12	-18	-4	-5
123	-19	-21	-9	-11	-1	-6	-22	-25	-27	-25	-24	-25	-20	-13	-3	-4
124	-21	-21	-12	--	-3	-4	-25	-24	-15	-14	-17	-14	-6	-12	-2	-4
125	-18	-24	-15	-21	-3	-4	-23	-26	-21	--	-17	-22	-12	-15	-1	--
126	-19	-25	-4	-6	-2	-4	-24	--	-12	-13	-17	-21	-17	-24	-2	-6
128	-19	--	-18	--	-6	-7	--	--	-24	-26	-19	--	-23	--	-6	-13

TABLE 7-2

ESTIMATED MINIMUM OPERATING TEMPERATURES (°C) FOR EACH VEHICLE-FUEL COMBINATION

	Fuel 101	Fuel 102	Fuel 103	Fuel 104	Fuel 105	Fuel 106	Fuel 107	Fuel 108
Vehicle 121	-22	-13	-3	-22	-14	-20	-12	-8
122	-22	<-15	-5	-29	-15	-23	-15	-5
123	-20	-9	-4	-24	-25	-25	-20	-4
124	-21	-12	-4	-24	-14	-16	-10	-3
125	-22	-19	-3	-25	<-21	-20	-13	<-1
126	-23	-5	-3	<-24	-13	-20	-22	-5
128	<-19	<-18	-6	--	-25	-19	<-23	-6
Average All Vehicles	-21.3	-13.0	-4.0	-24.7	-18.1	-20.4	-16.4	-4.6
Median All Vehicles	-22	-13	-4	-24	-15	-20	-15	-5

TABLE 7-3

COMPARISON OF VEHICLE SEVERITY FOR EACH FUEL

Fuel	Passenger Car Most Severe	Passenger Car Least Severe	Heavy Duty Truck Most Severe	Heavy Duty Truck Least Severe	Overall Most Severe	Overall Least Severe
101	123	122	125	126	123	126
102	123	122	126	125	126	125
103	121	122	126	128	126	128
104	121	122	-	-	121	122
105	121,124	123	126	125 or 128	126	123
106	124	123	128	125,126	124	123
107	124	123	125	128	124	128
108	124	121	-	-	124	121

TABLE 7-4

AVERAGE ESTIMATED MINIMUM OPERATING TEMPERATURES FOR EACH VEHICLE

Vehicle	Average Estimated Minimum Operating Temperature, °C		
	All Fuels	Base Fuels	Flow-Improved Fuels
Passenger Cars			
121	-14.2	-12.7	-15.2
122	-16.1	-14.0	-17.4
123	-16.4	-11.0	-19.6
124	-13.0	-12.3	-13.4
Trucks			
125	-15.5	-14.7	-16.0
126	-14.4	-10.3	-16.8
128	-17.6	-14.3	-19.6

TABLE 7-5

IMPROVEMENTS IN ESTIMATED MINIMUM OPERATING TEMPERATURE
OF FLOW-IMPROVED FUELS OVER THEIR BASE FUELS

	Improvement, °C, for Fuel				
Vehicle	104	105	106	107	108
121	0	1	7	-1	5
122	7	<0	<8	<0	0
123	4	16	16	11	0
124	3	2	4	-2	-1
125	3	>2	1	-6	-
126	>1	8	15	17	2
128	-	>7	<1	-	0

Average improvement: 4.5°C
(Data used in calculating the average improvement do not include > or < values.)

Figure 7-1

PERFORMANCE OF THE TEST FUELS IN VEHICLE 121

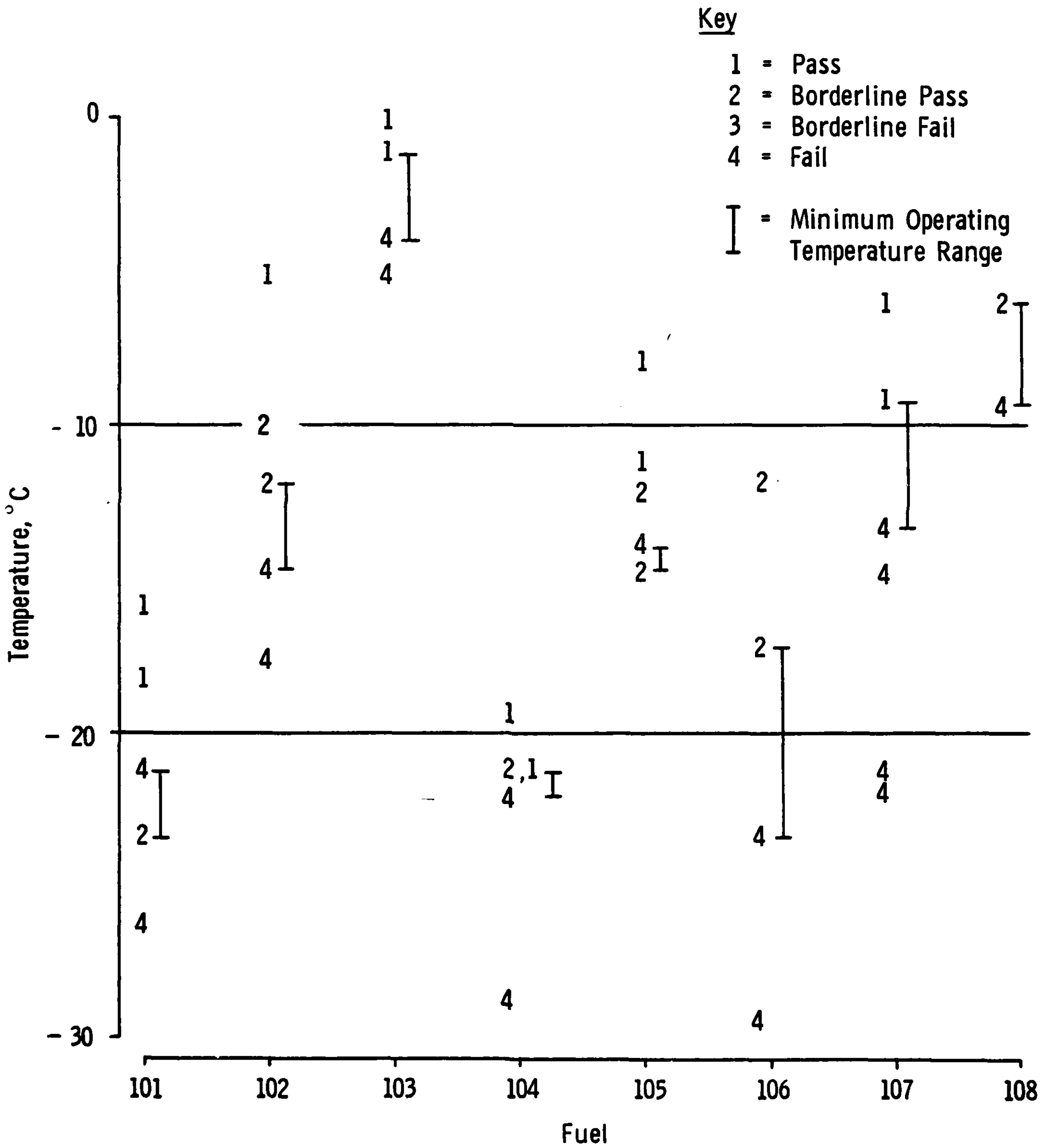


Figure 7-2

PERFORMANCE OF THE TEST FUELS IN VEHICLE 122

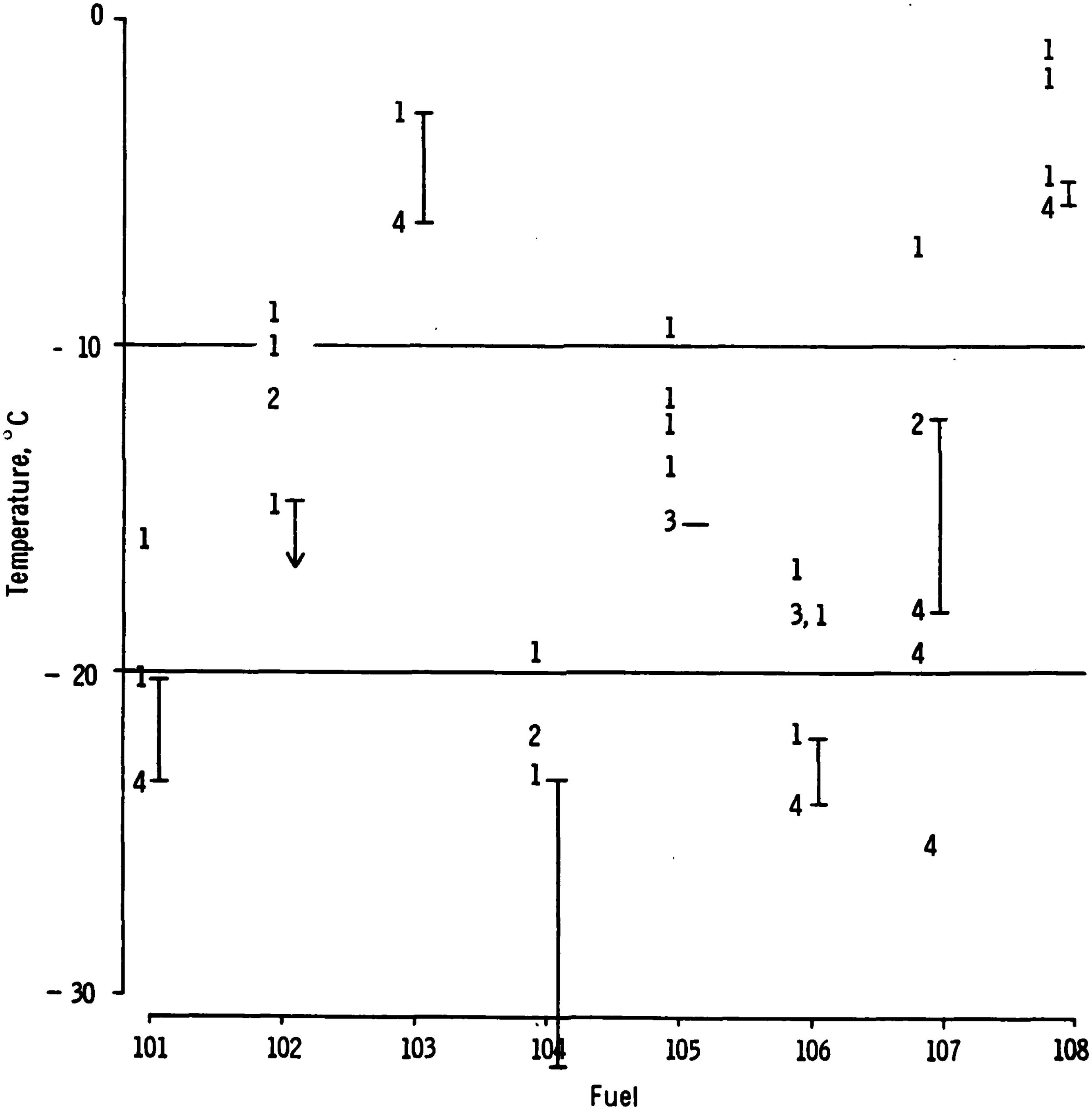


Figure 7-3

PERFORMANCE OF THE TEST FUELS IN VEHICLE 123

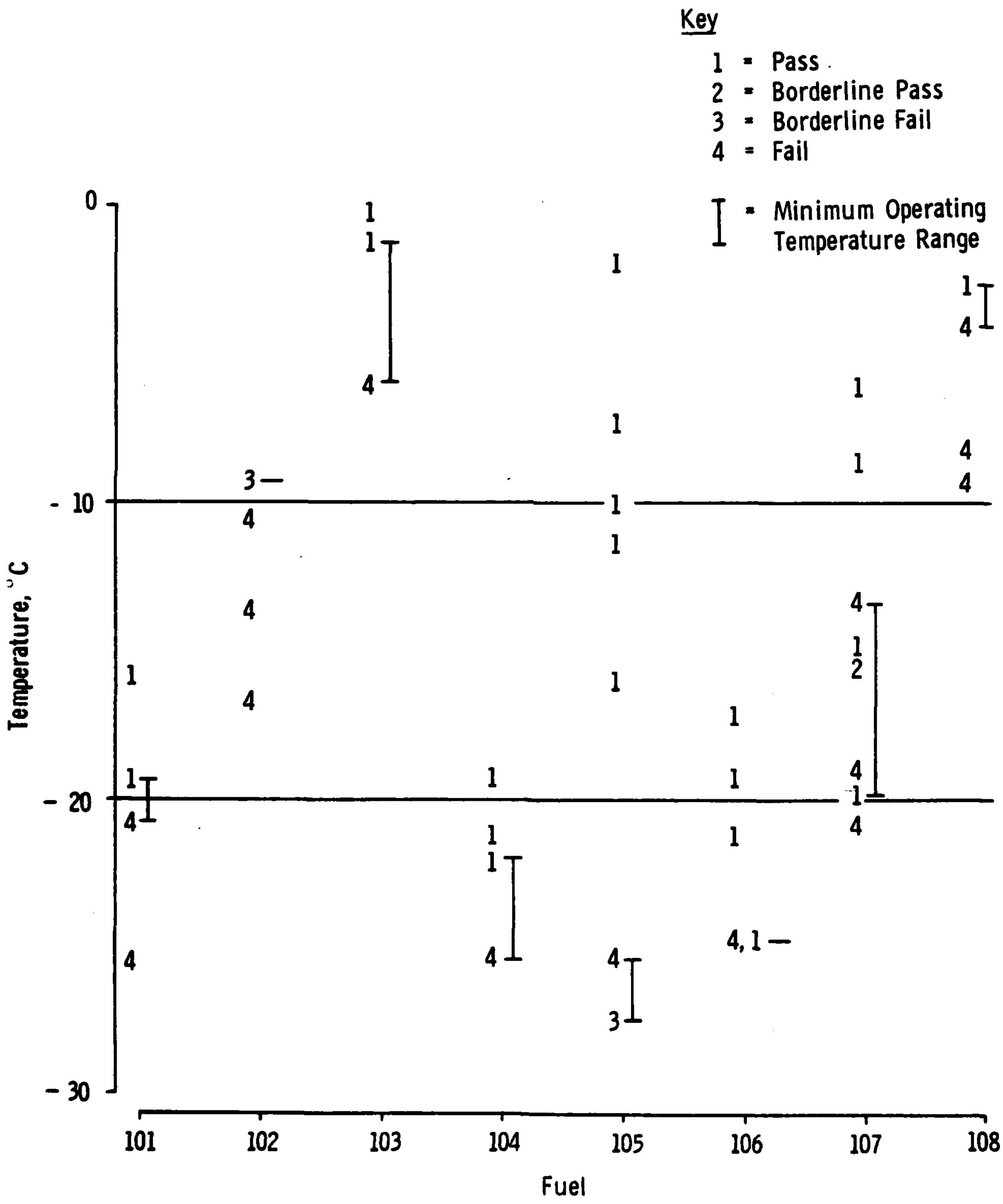


Figure 7-4

PERFORMANCE OF THE TEST FUELS IN VEHICLE 124

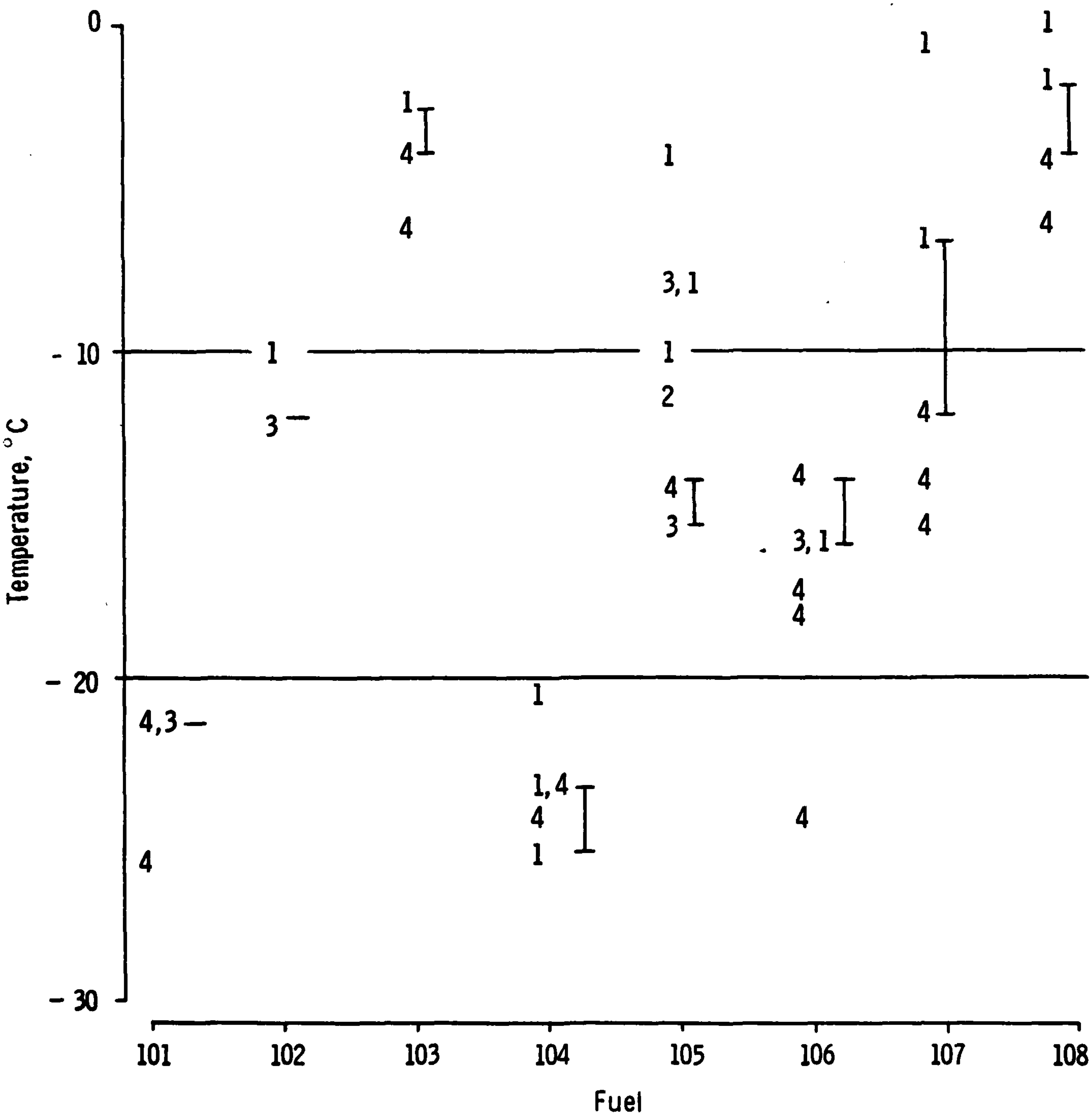


Figure 7-5

PERFORMANCE OF THE TEST FUELS IN VEHICLE 125

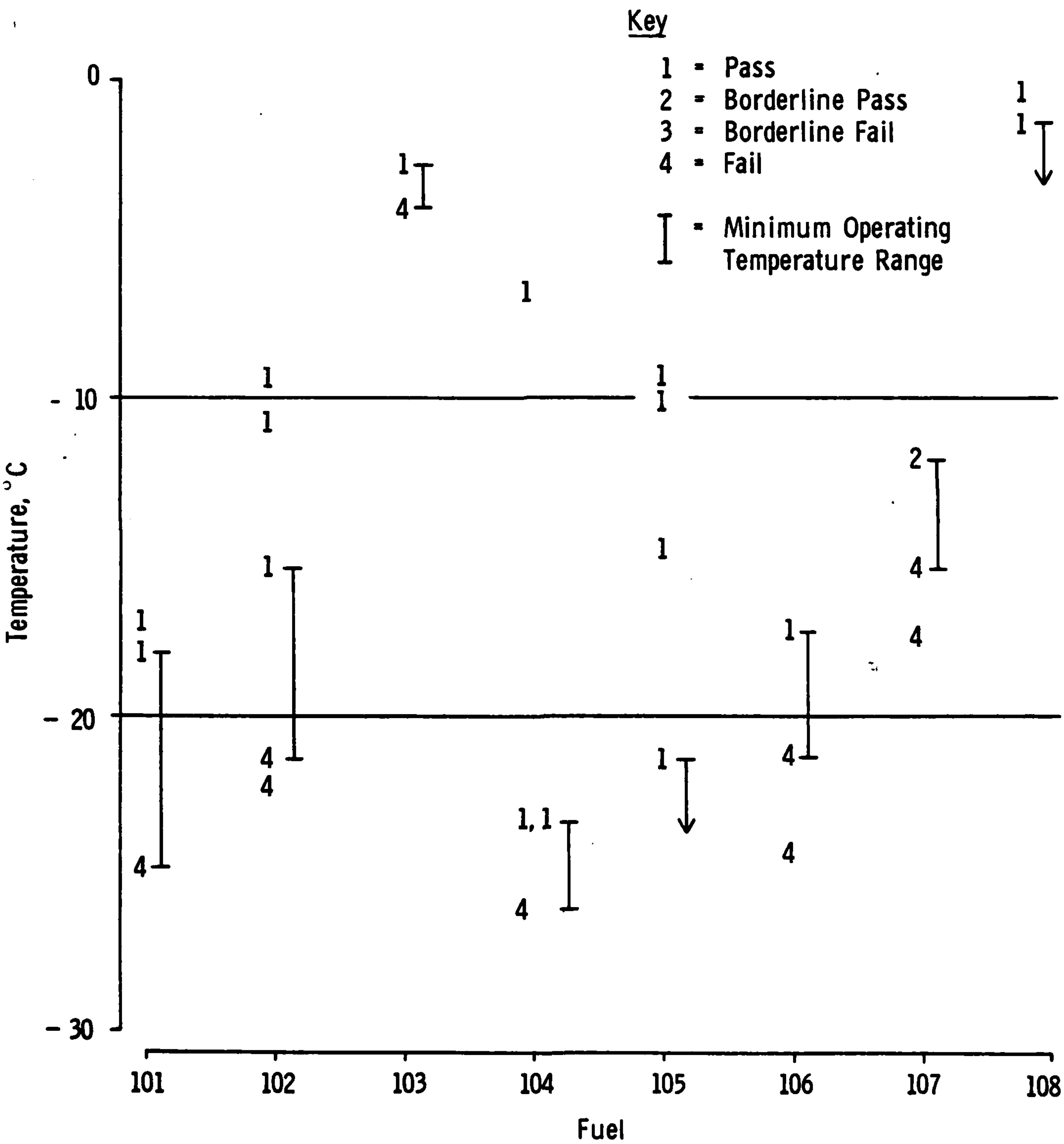


Figure 7-6

PERFORMANCE OF THE TEST FUELS IN VEHICLE 126

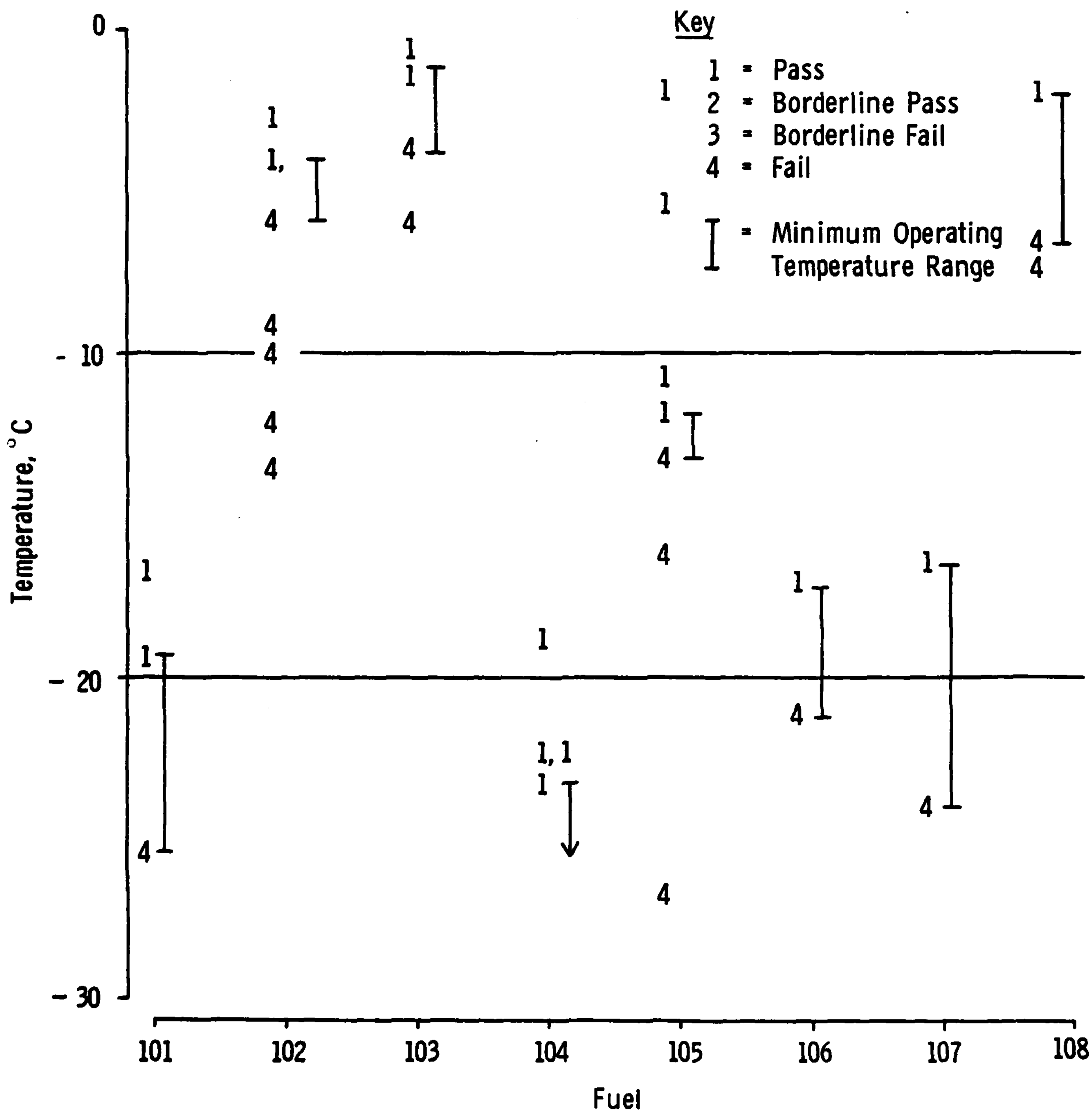


Figure 7-7

PERFORMANCE OF THE TEST FUELS IN VEHICLE 128

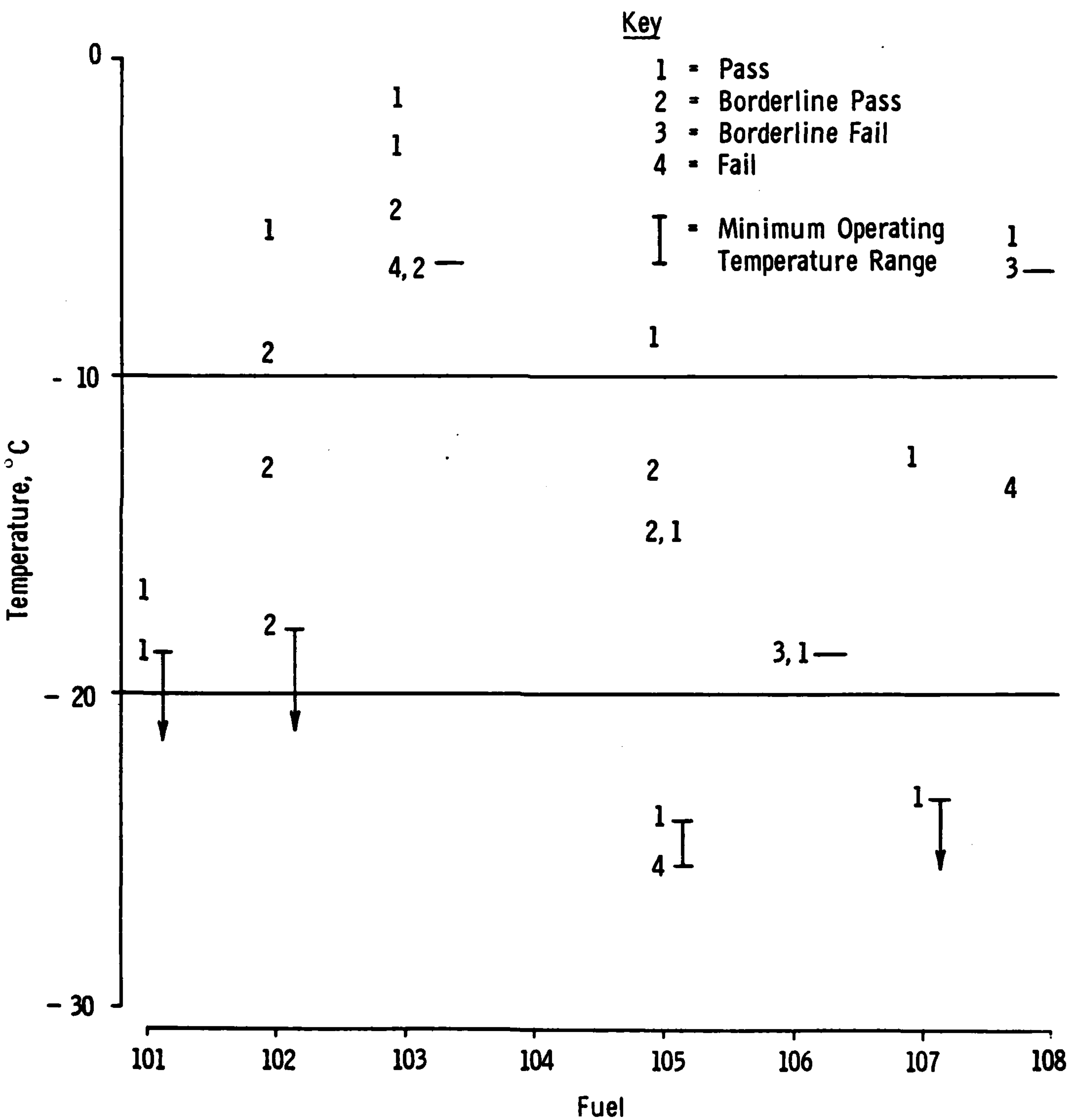


Figure 7-8

PERFORMANCE OF THE TEST VEHICLES ON FUEL 101

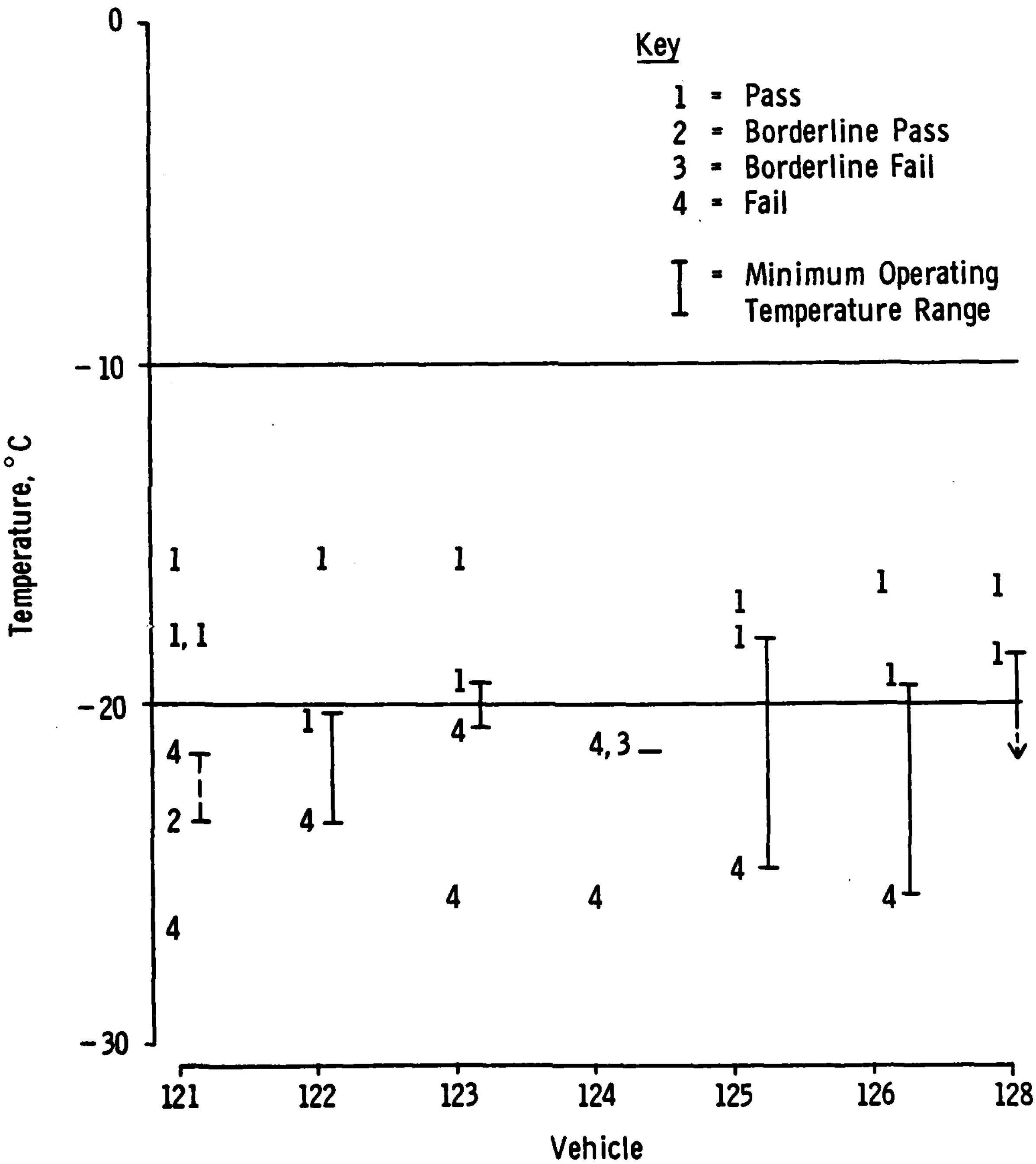


Figure 7-9

PERFORMANCE OF THE TEST VEHICLES ON FUEL 102

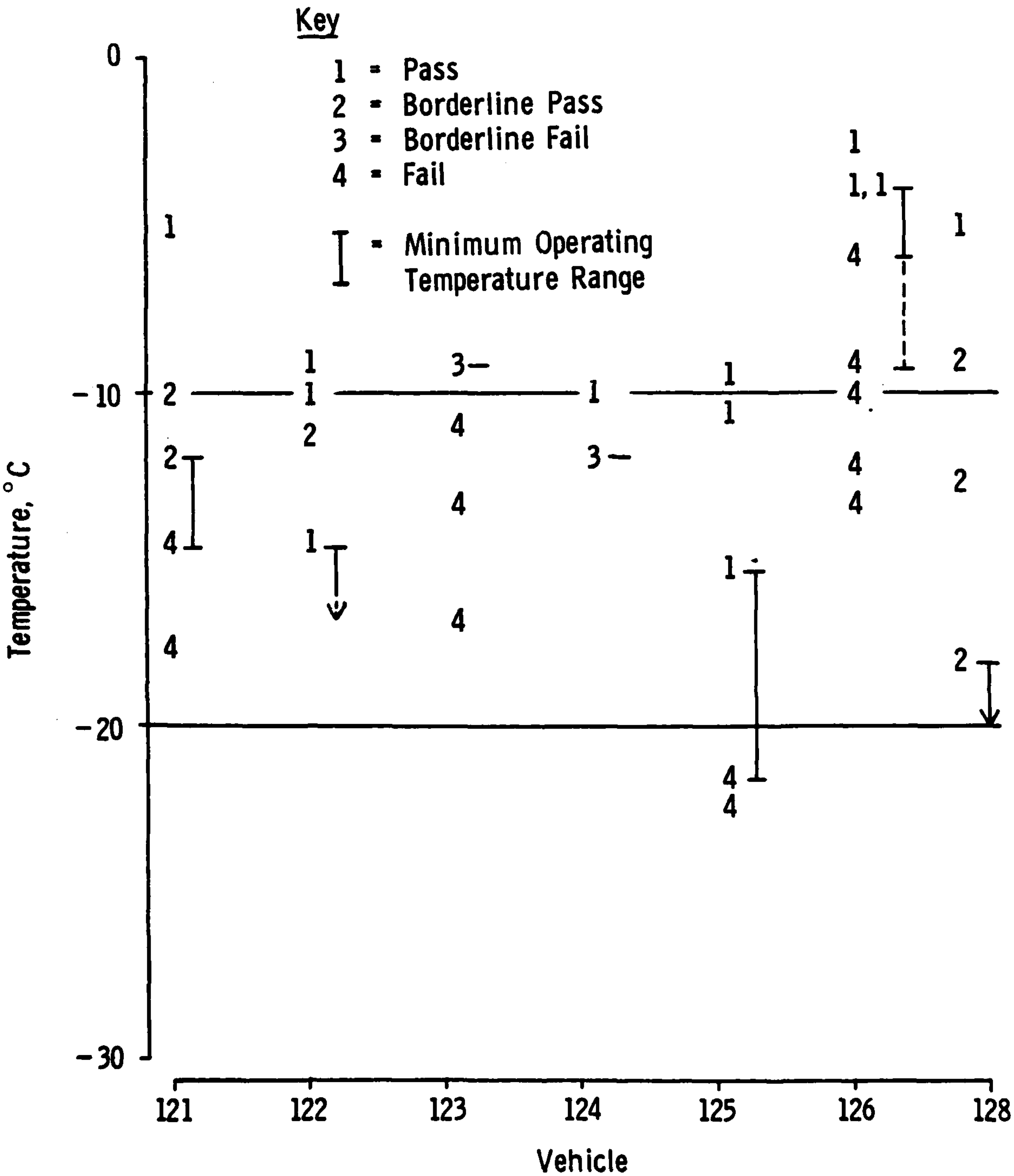


Figure 7-10

PERFORMANCE OF THE TEST VEHICLES ON FUEL 103

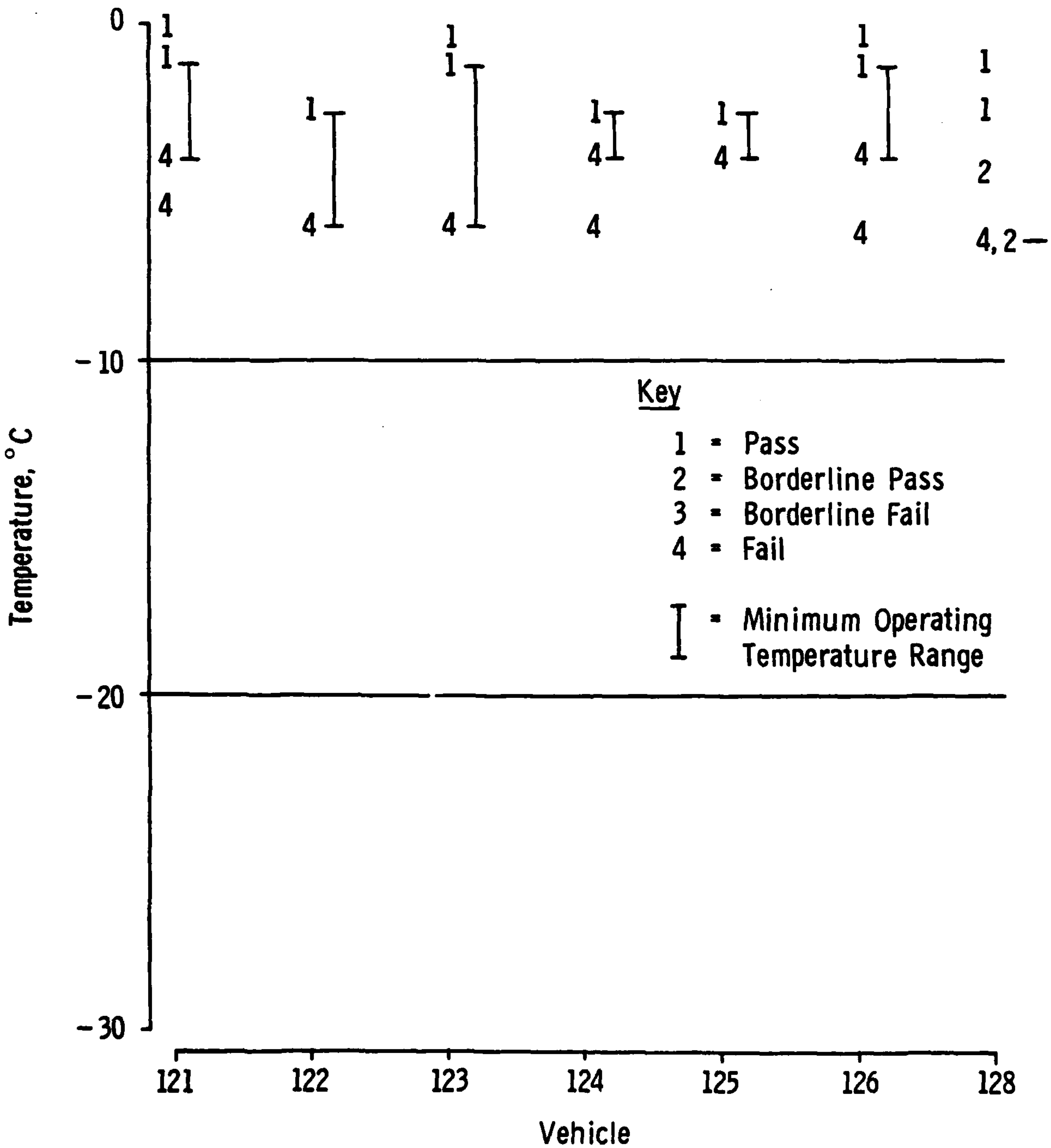


Figure 7-11

PERFORMANCE OF THE TEST VEHICLES ON FUEL 104

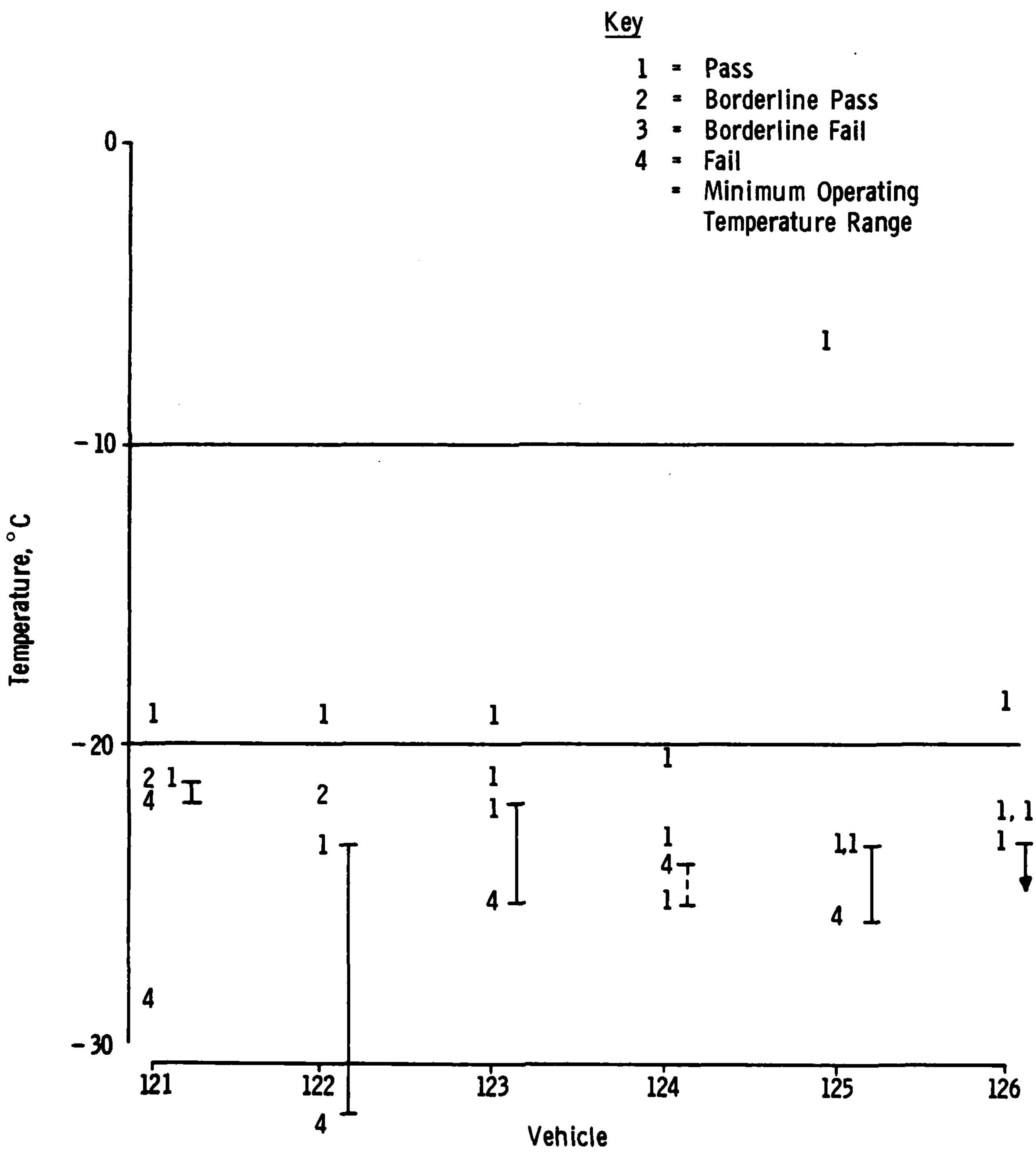


Figure 7-12

PERFORMANCE OF THE TEST VEHICLES ON FUEL 105

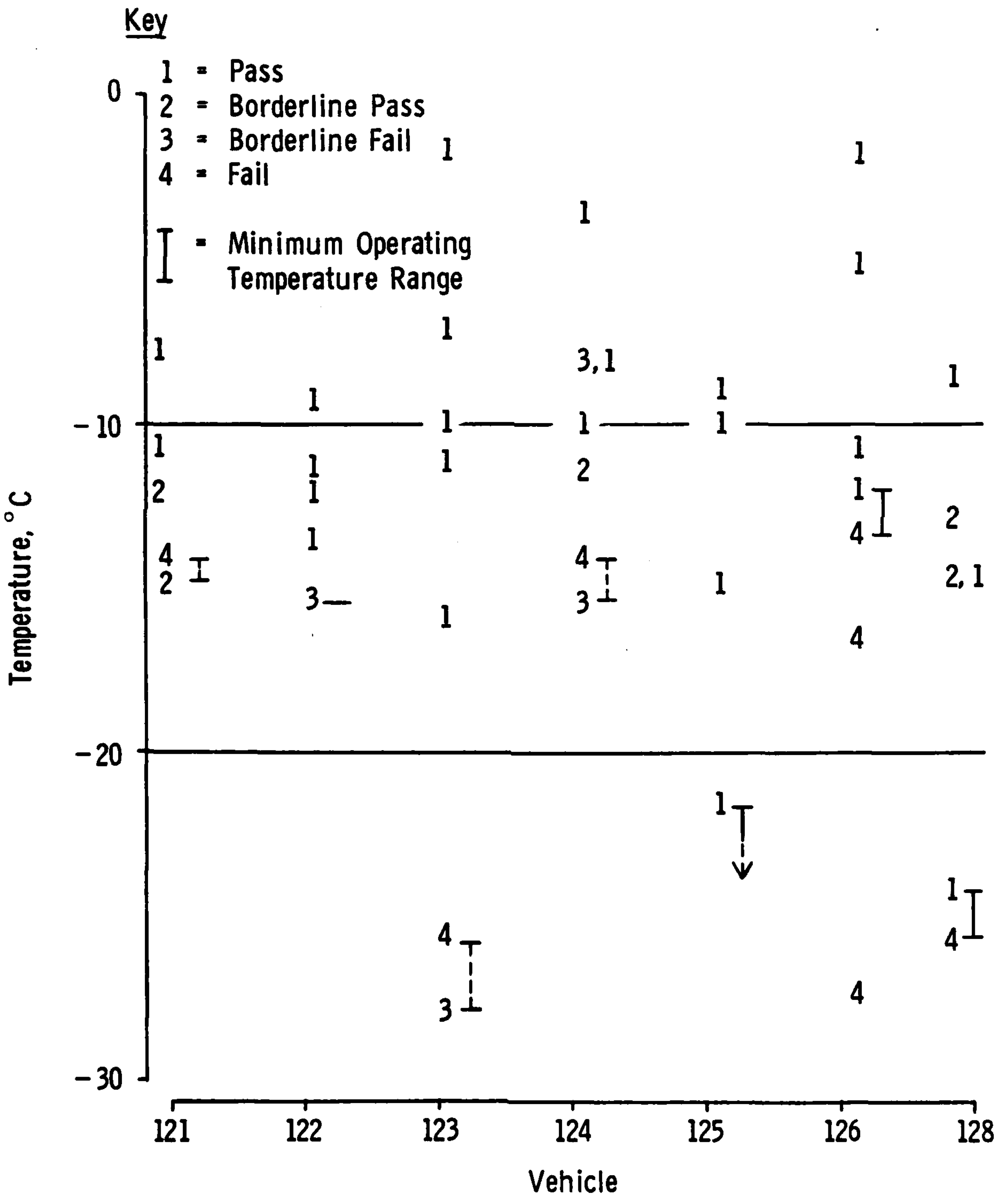


Figure 7-13

PERFORMANCE OF THE TEST VEHICLES ON FUEL 106

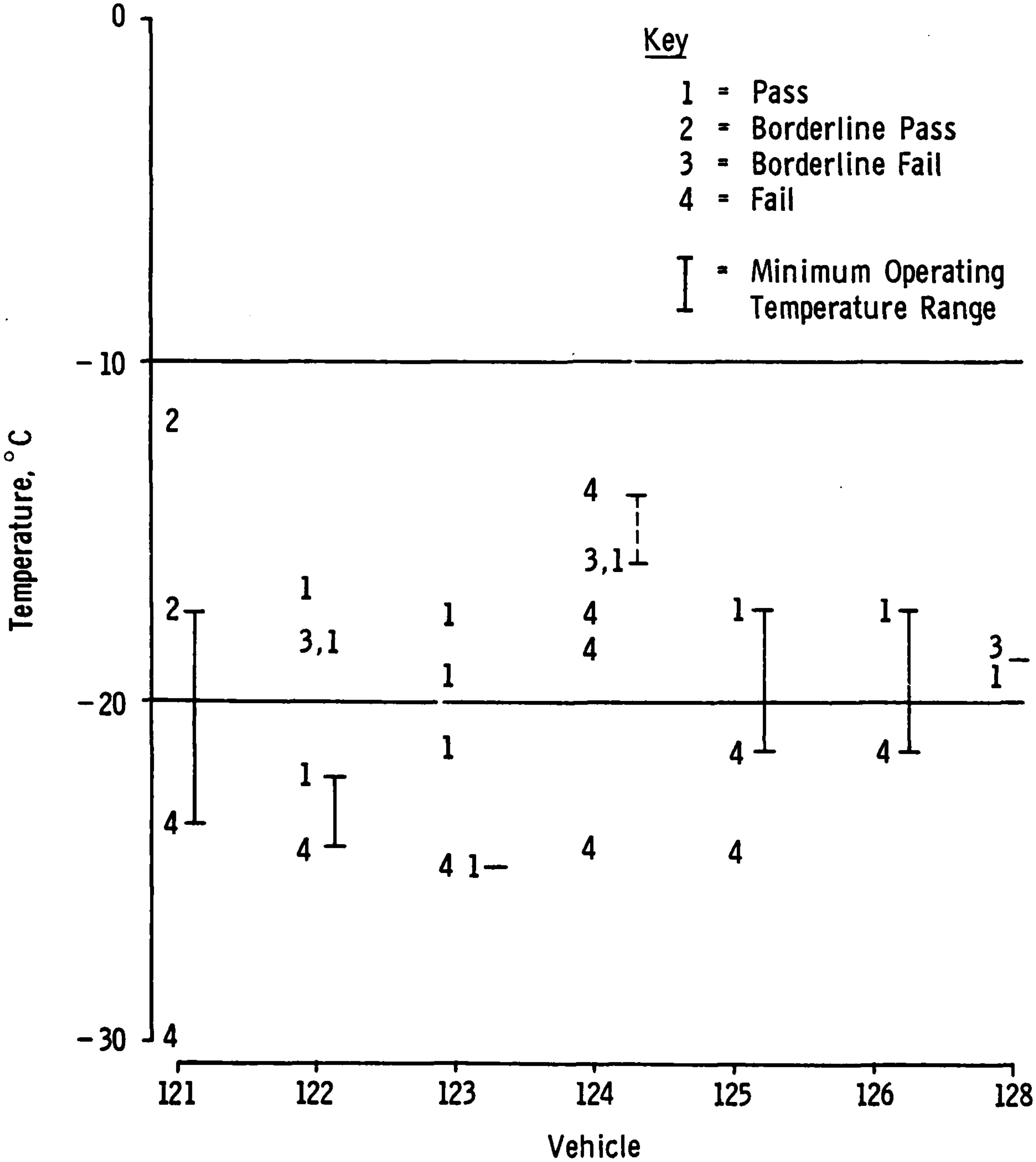


Figure 7-14

PERFORMANCE OF THE TEST VEHICLES ON FUEL 107

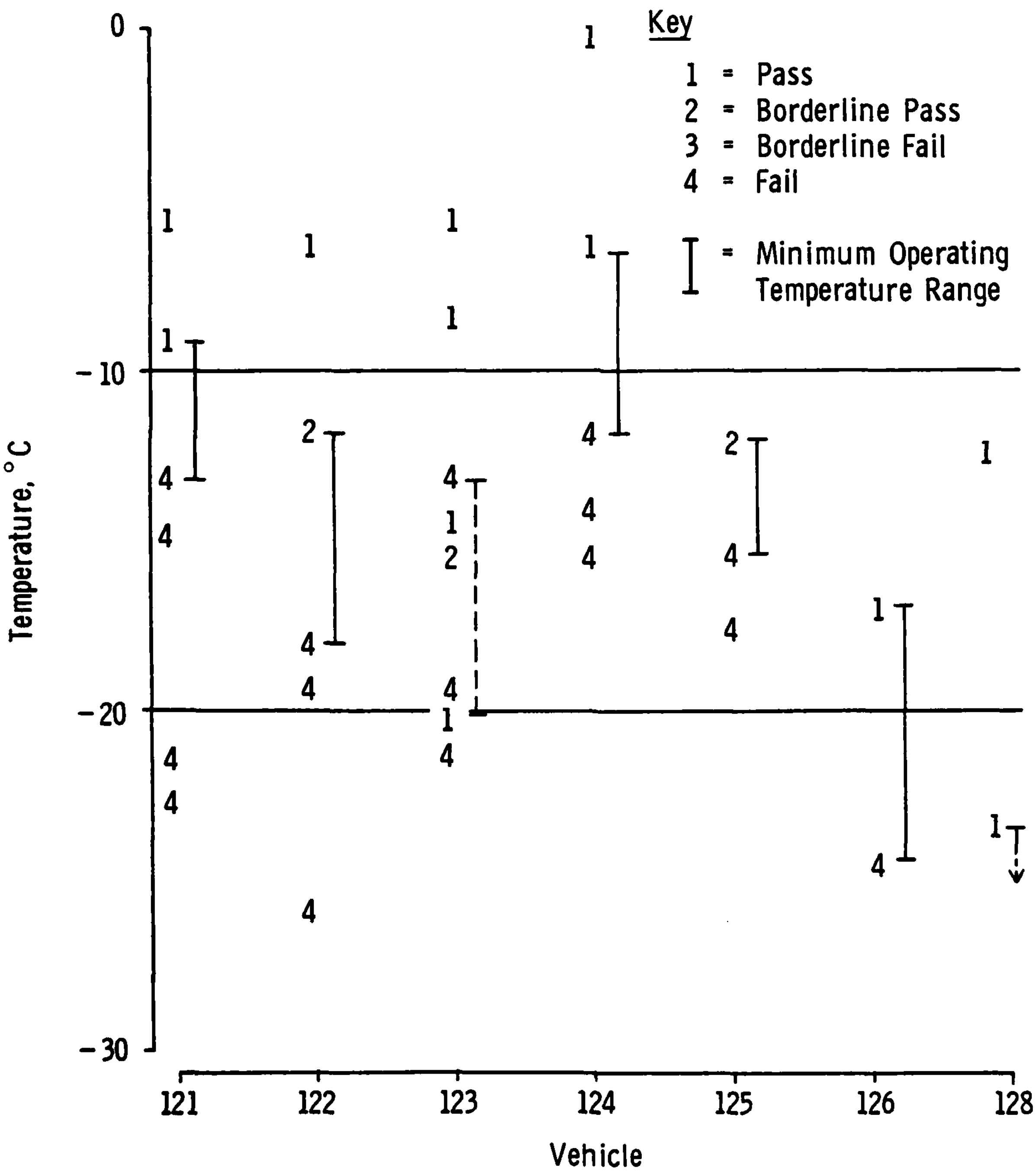


Figure 7-15

PERFORMANCE OF THE TEST VEHICLES ON FUEL 108

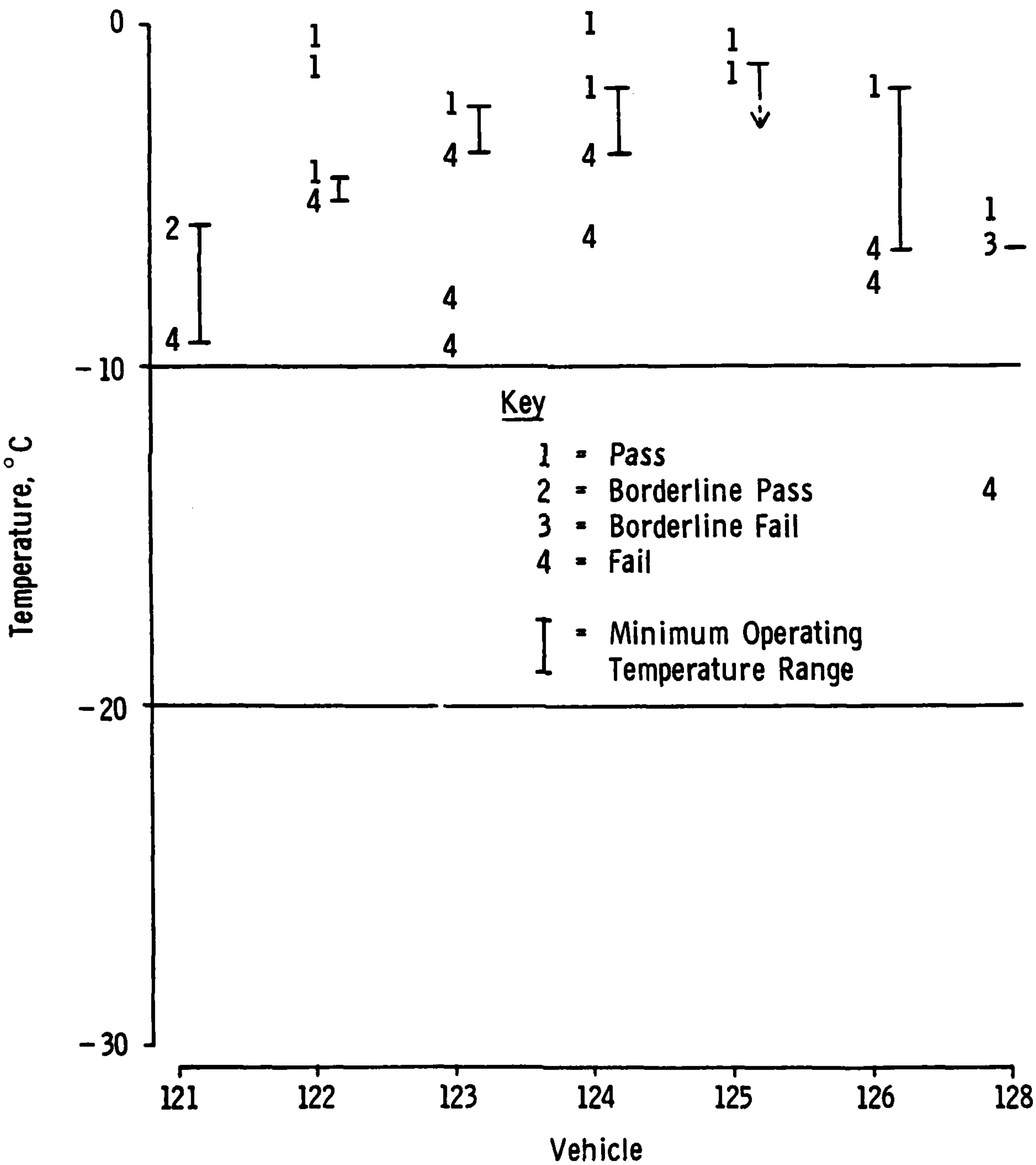


Figure 7-16

ILLUSTRATION OF METHODS USED TO DETERMINE ESTIMATED MINIMUM OPERATING TEMPERATURE

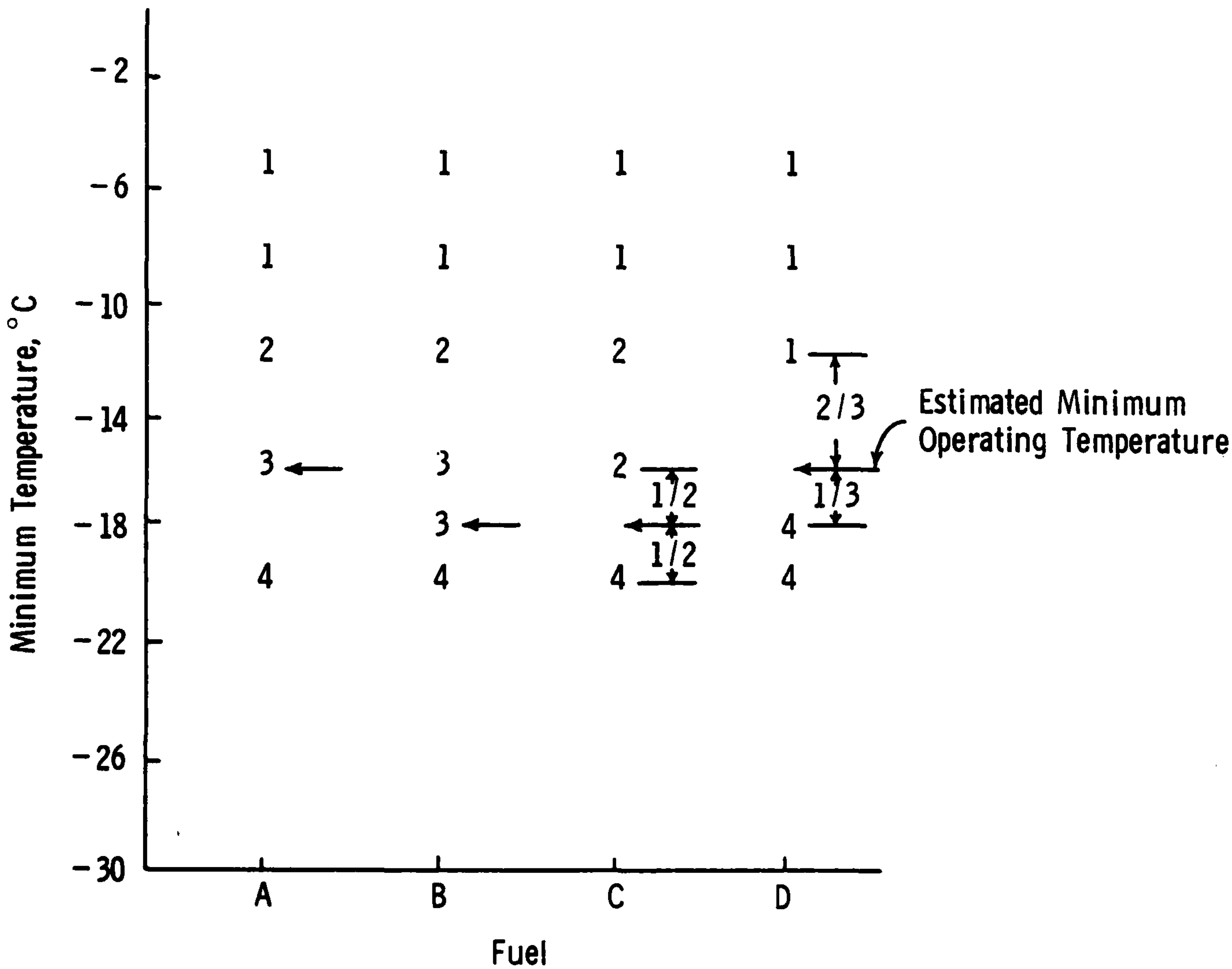


Figure 7-17

COMPARISON OF PERFORMANCE OF FLOW-IMPROVED FUEL 104 WITH BASE FUEL 101

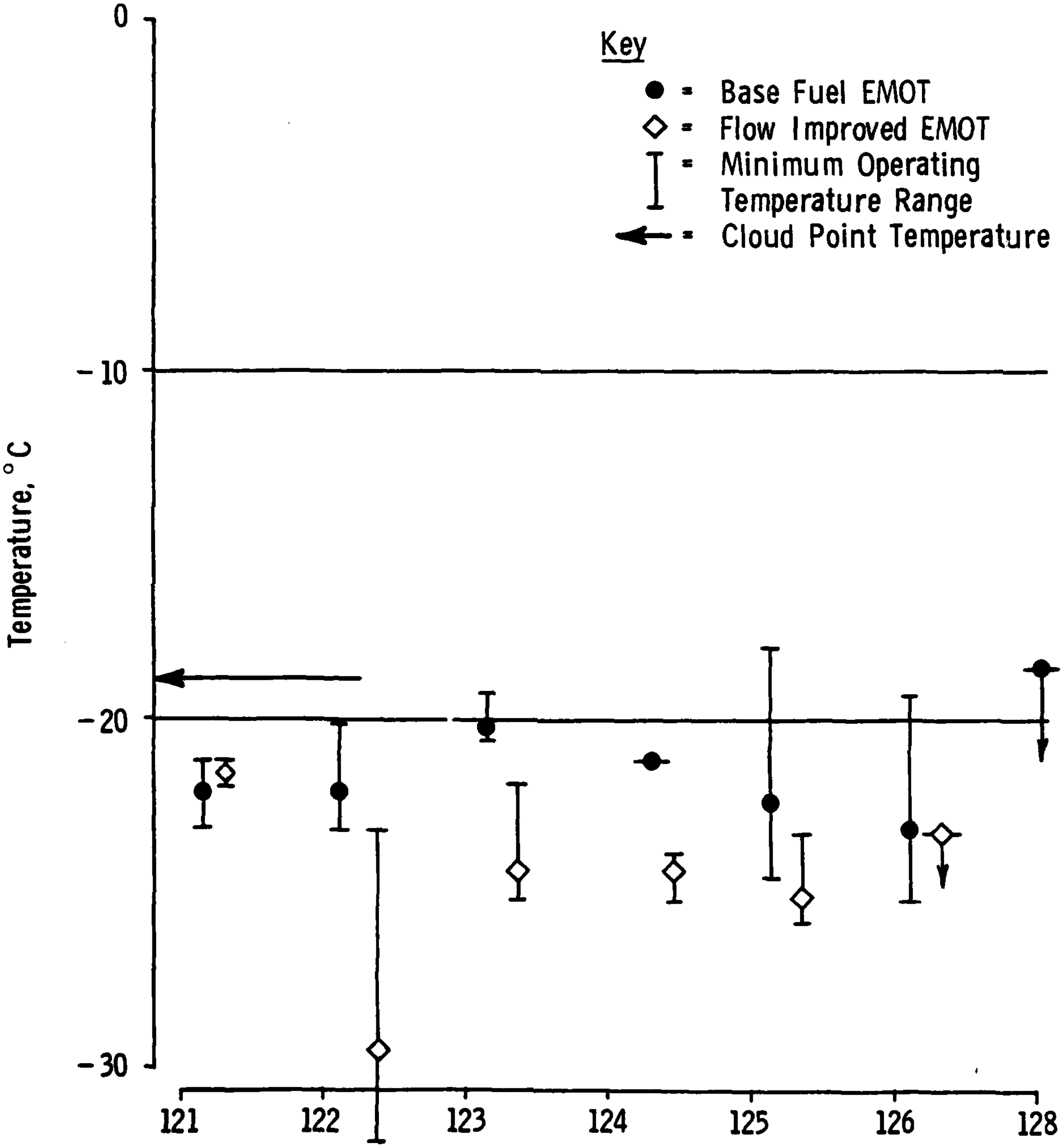


Figure 7-18

COMPARISON OF PERFORMANCE OF FLOW-IMPROVED FUEL 105 WITH BASE FUEL 102

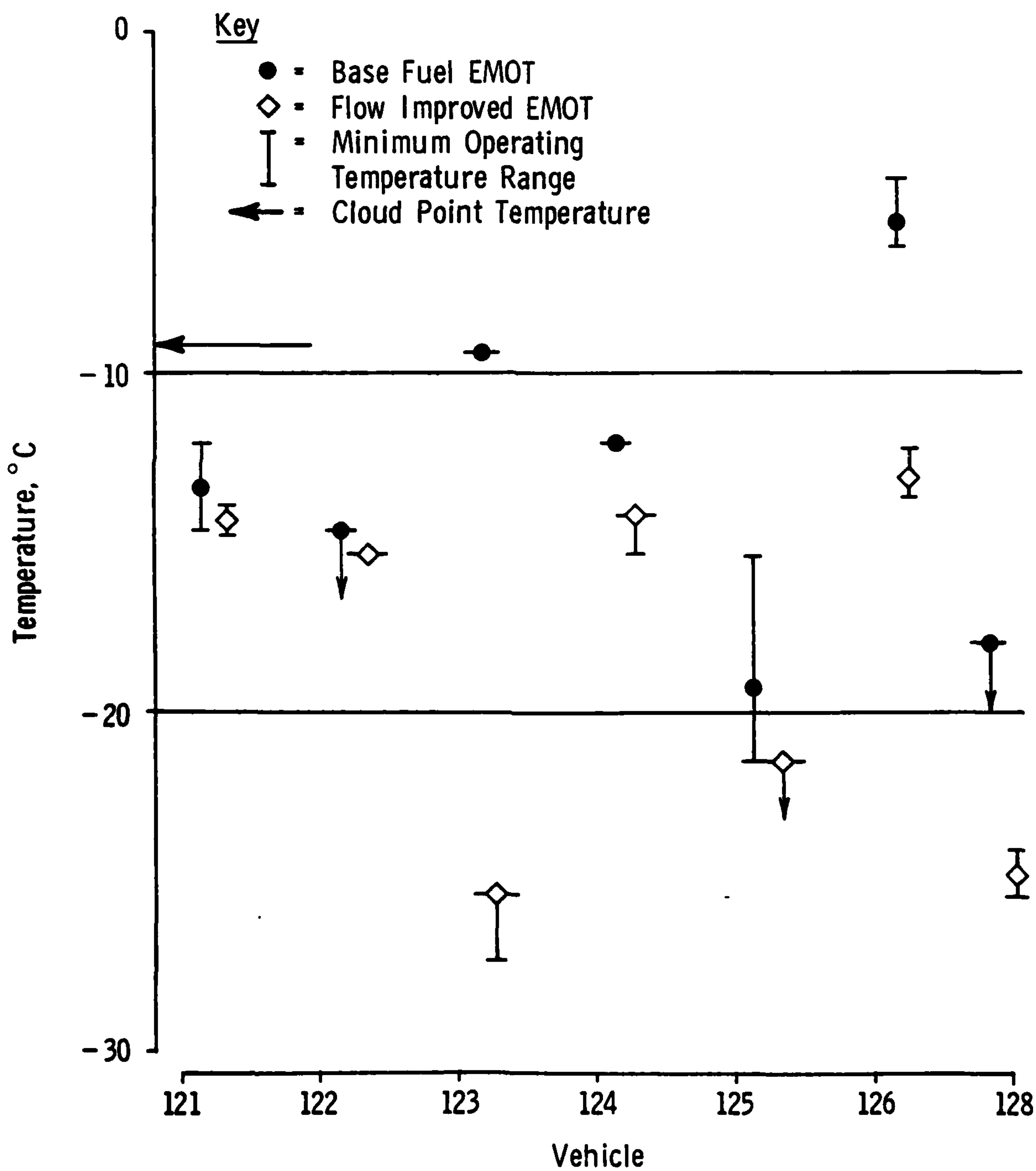


Figure 7-19

COMPARISON OF PERFORMANCE OF FLOW-IMPROVED FUEL 106 WITH BASE FUEL 102

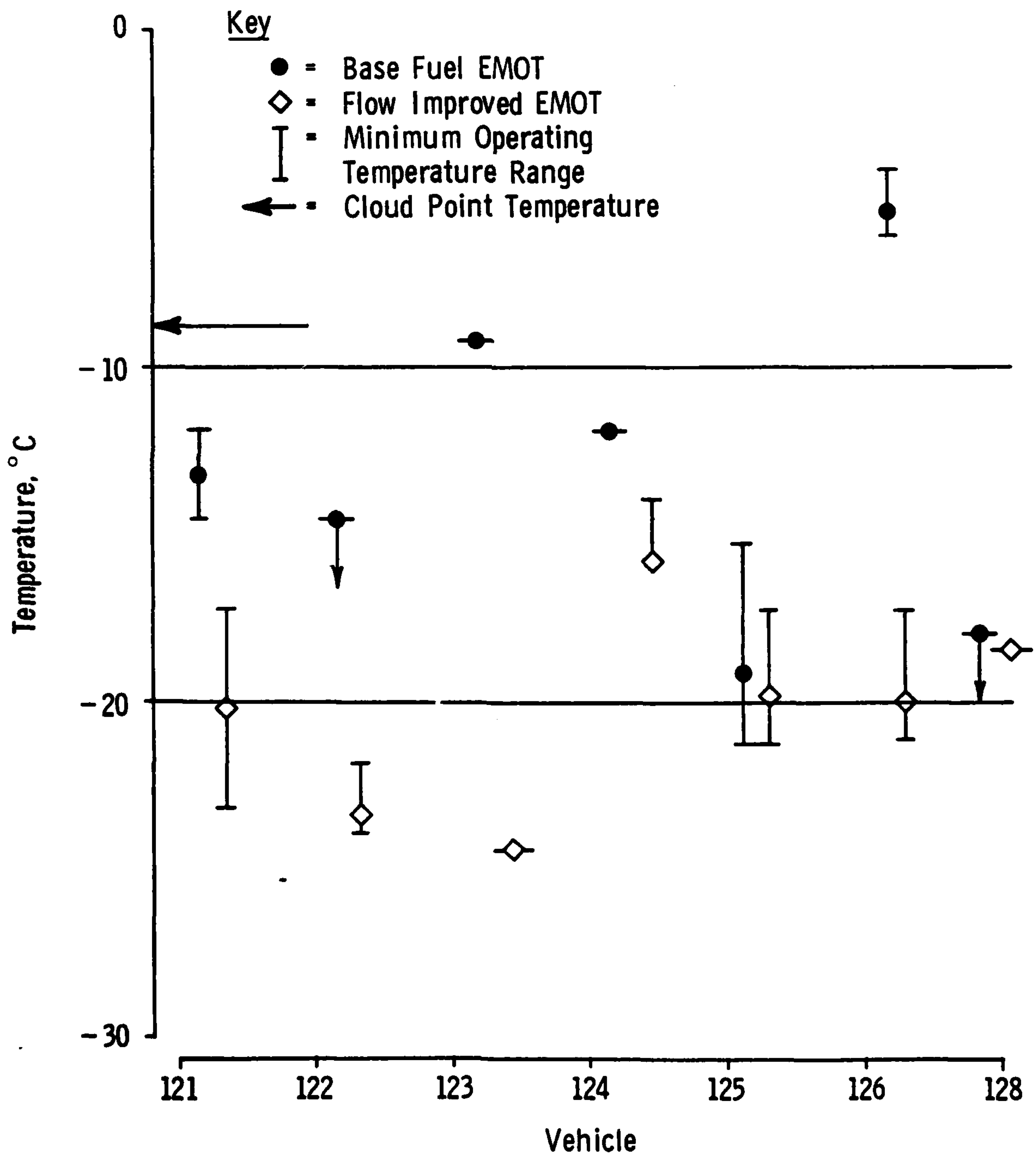


Figure 7-20

COMPARISON OF PERFORMANCE OF FLOW-IMPROVED FUEL 107 WITH BASE FUEL 102

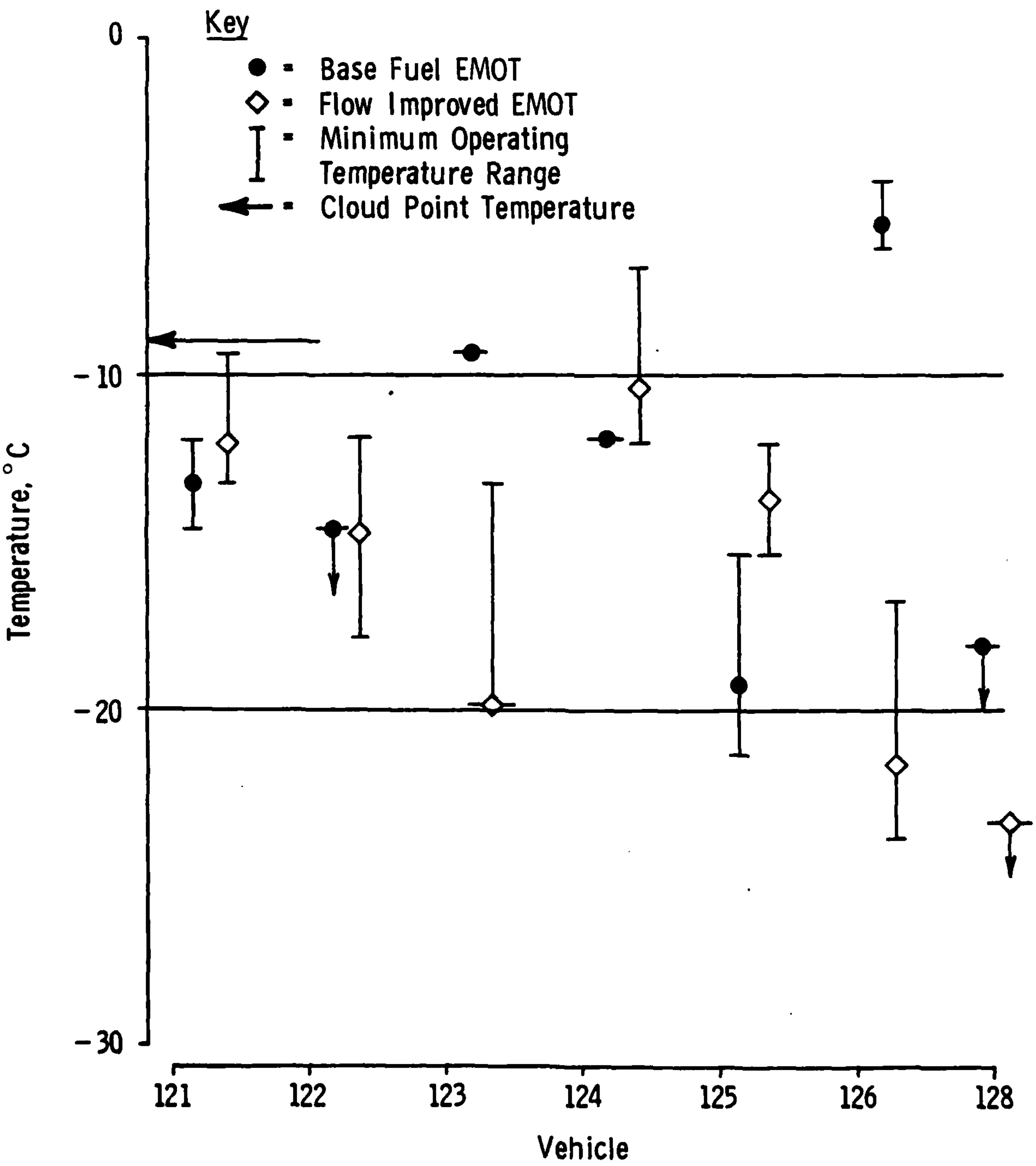
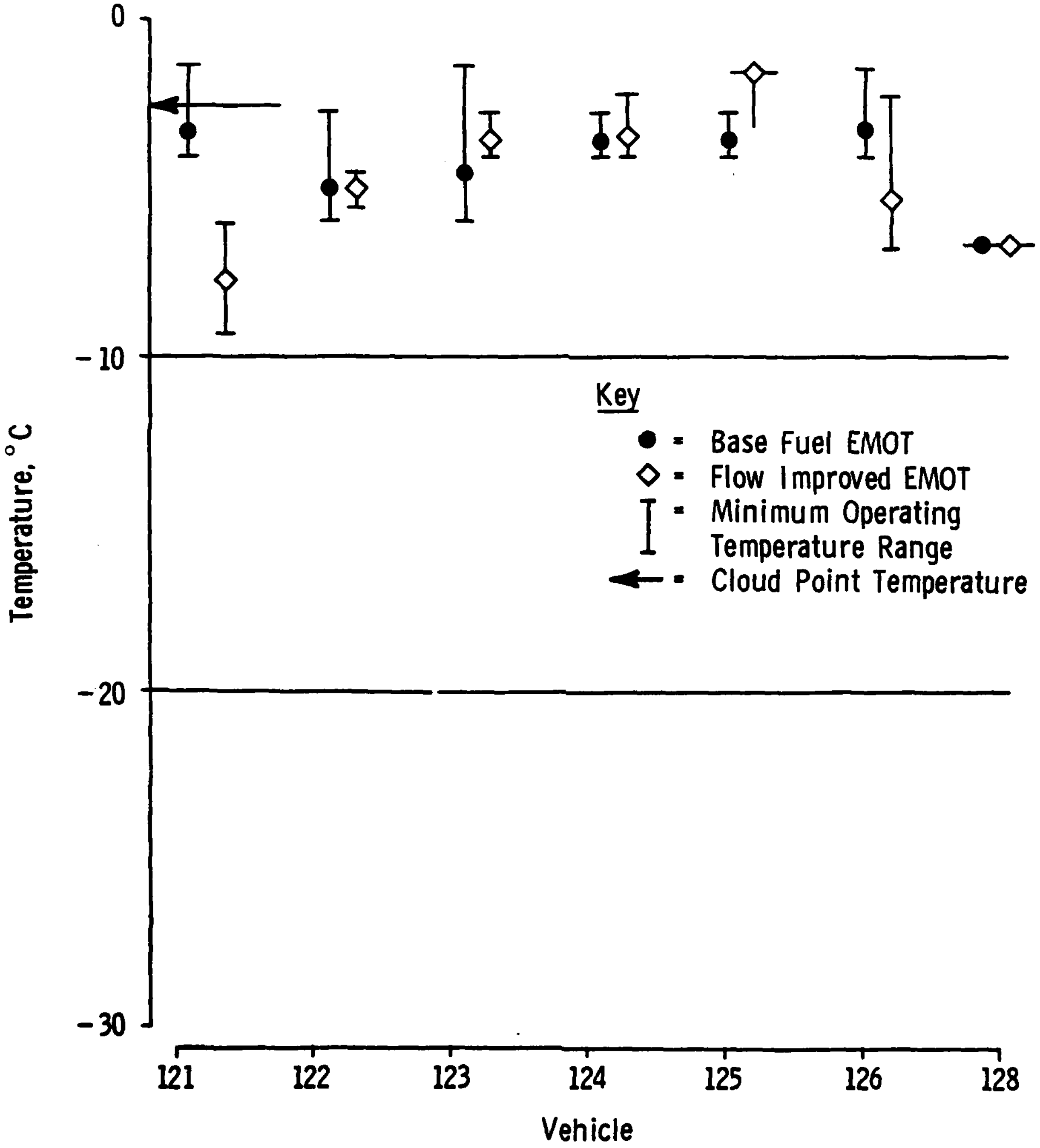


Figure 7-21

COMPARISON OF PERFORMANCE OF FLOW-IMPROVED FUEL 108 WITH BASE FUEL 103



CHAPTER 8

CORRELATION OF VEHICLE OPERATION WITH LABORATORY BENCH TEST PREDICTIONS

CORRELATION OF VEHICLE OPERATION WITH LABORATORY BENCH TEST PREDICTIONS

As stated earlier in this report, one of the objectives of this program was to establish whether any currently available laboratory test can predict satisfactorily the low-temperature performance of a wide range of vehicles. Since the estimated minimum operating temperatures of each vehicle-fuel combination given in Table 7-2 are the best estimates of low-temperature performance, these values will be used as the basis for evaluating the laboratory tests.

The following four laboratory tests were evaluated:

1. Cloud Point
2. Pour Point
3. Cold Filter Plugging Point (CFPP)
4. Low Temperature Flow Test (LTFT)

The cloud and pour point temperatures are frequently used to estimate distillate low-temperature performance, and are measured according to standard ASTM test methods (D 2500 and D 97, respectively). Cloud point is also included as a guideline in ASTM D 975, "Standard Specification for Diesel Fuel Oils," despite indications from previous studies[1,4-9] that cloud point is not a good predictor of diesel vehicle low-temperature operation with flow-improved fuels. The CFPP test[2,3] is currently used to predict the minimum operating temperature of various diesel fuels in European vehicles. LTFT was developed to predict minimum operating temperatures of diesel fuels in North American vehicles. The latter two tests (CFPP and LTFT) are filter-plugging laboratory tests, while the former two tests (cloud and pour point) measure inherent fuel properties.

The cloud point, pour point, CFPP, and LTFT temperatures for the eight test fuels included in this program were determined by several laboratories and are included in Appendix C1. The average values of these temperatures rounded to the nearest whole degree Celsius are included in Table 8-1, along with the estimated minimum operating temperatures for each vehicle-fuel combination (from Table 7-2).

I. QUALITATIVE ASSESSMENT OF LABORATORY TEST EFFECTIVENESS

Clearly, a laboratory bench test which gives a single value for a given fuel cannot predict differences among vehicles operating with the same fuel such as shown in Table 8-1. Neither is a perfect correlation likely with any test when the true minimum operating temperatures for vehicle-fuel combinations must be *estimated* in the range between the lowest pass and highest fail temperatures as has been done in generating Table 8-1. Ideally, all of the pass data should occur at temperatures at or *above* the laboratory bench test value for the fuel, and all of the fail data should occur at or *below* the laboratory bench test value. Because of the limitations of the data, however, the reasonable compromise was to aim for a minimum of failures above and a minimum of passes below the laboratory bench test value.

A convenient way to make such a qualitative assessment of laboratory test predictions of vehicle performance for the various fuels is shown in Table 8-2, in which the vehicle performance data in Tables 7-1 and 7-2 are compared with the laboratory test predictions. For each of the four laboratory tests, the MPT column shows the distribution of the fifty-five minimum pass temperatures in Table 7-1 with the laboratory test results, the MFT column shows the distribution of the forty-five maximum fail temperatures in Table 7-1 with the laboratory test results, and the EMOT column shows the distribution of the fifty-five estimated minimum operating temperatures from Table 7-2 (or Table 8-1) with the laboratory test results. For example, the value 2 in the MPT column under cloud point in the row designated as "3-6^{o}C Above Lab Test Result" means that of the fifty-five vehicle-fuel combinations for which minimum pass temperatures were obtained (see Table 7-1), two of the minimum pass temperatures were between 3 and 6^{o}C above the cloud point of the corresponding fuel. Table 8-3 compares in the same way the average estimated minimum operating temperatures of each fuel obtained from Table 7-2 with results from the four laboratory tests for each fuel.

The data in Tables 8-2 and 8-3 show that there were many cases in which vehicle failures occurred at 7^{o}C or more above the CFPP and pour point temperatures. For this reason, it is clear that while CFPP was a better predictor than pour point, both tests ofen overpredicted minimum operating temperatures. Such failures well above the cloud point and LTFT temperatures are not evident in Tables 8-2 and 8-3; and as such, these two laboratory tests warrant a closer examination to determine whether LTFT offers any advantages over cloud point.

In Table 8-4, the individual pass/fail data are detailed for each fuel and compared with the cloud points of the fuels. A similar comparison with LTFT by fuel is shown in Table 8-5. It is evident from these two tables that for the three base fuels (Fuels 101, 102, and 103), vehicle performance is well predicted by both the cloud point and LTFT temperatures.

For the five flow-improved fuels, however, vehicle performance appears to be more closely predicted by LTFT than by cloud point. Of the thirty-four minimum pass temperatures obtained with the five flow-improved fuels, twenty-six (or 76 percent) occurred more than 2^{o}C below the fuel cloud point, while only eleven (or 32 percent) occurred more than 2^{o}C below the LTFT temperature of the fuel. Of the twenty-eight maximum fail temperatures obtained with the five flow-improved fuels, none occurred more than 2^{o}C above the fuel cloud point, while four (or 14 percent) occurred more than 2^{o}C above the LTFT temperature of the fuel. Thus, although cloud point was a better fail-safe predictor of vehicle performance with flow-improved fuels than LTFT, the margin of safety was achieved at the expense of predictability.

Table 8-6 compares the vehicle performance data with the LTFT temperatures for the individual vehicles. It should be noted that the five maximum fail temperatures which occurred more than 2^{o}C above the LTFT temperature of the fuel correspond to four different vehicles, with Fuel 107 accounting for three of these cases.

In summary, the qualitative assessment of laboratory test effectiveness in predicting low-temperature vehicle performance indicates that:

1. Pour point and CFPP were not sufficiently severe to predict the performance of the test fuels in the diesel vehicles included in this program.

2. On the basis of the number of field failures above the laboratory test results, both LTFT and cloud point predicted closely the performance of vehicles operated with base fuels.

3. Cloud point was the best fail-safe predictor of vehicle operation, although in confirmation of previous studies, it did not predict the improvements in operation provided by flow-improved fuels.

4. Of the four laboratory tests investigated, LTFT best minimized both the number of vehicle failures above and passes below the laboratory test results.

II. QUANTITATIVE ASSESSMENT OF LABORATORY TEST EFFECTIVENESS

Quantitative assessments of the suitability of laboratory bench test predictions of vehicle performance can be made from statistical correlations of the vehicle performance data with the laboratory test predictions. To use this approach, it was necessary to establish discrete values of vehicle performance with each of the fuels. As discussed in an earlier section, the estimated minimum operating temperatures for each vehicle-fuel combination were the best estimates of vehicle performance which could be gleaned from this program. These values are listed in Table 8-1 and, together with the average values of the laboratory bench test predictions also listed in Table 8-1, formed the basis for all comparisons made in this section of the report. Estimated minimum operating temperatures listed as less than a certain value were taken to be that value in each comparison.

A. Correlation of Estimated Minimum Operating Temperatures with Laboratory Test Predictions - All Vehicles

Figures 8-1 through 8-4 illustrate the relationships between the estimated minimum operating temperatures (EMOT's) for all fifty-five vehicle-fuel combinations for which an EMOT was determined and the estimates of vehicle performance as predicted by the four laboratory tests. The data in each figure were subjected to a least squares linear regression analysis using the model:

$$y = mx + b \qquad (1)$$

in which

y = predicted minimum operating temperature

x = laboratory test result

m = slope of regression equation

b = intercept of regression equation

The variability in the data which is explained by Equation (1) is given by the index of determination (r^2) and the standard error of estimate (s). A perfect 1:1 correlation of actual versus predicted vehicle performance would yield an r^2 of one, a slope (m) of one, an intercept (b) of zero, and a standard error of estimate (s) of zero.

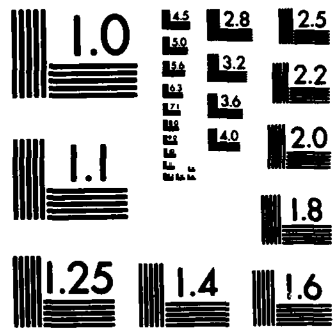
The 1:1 correspondence line, regression line, and r^2 and s values are provided in each figure, and the values of r^2, m, b, and s for the four laboratory test correlations are listed in Table 8-7. In actual practice, if the slope and intercept are close to one and zero, respectively, then the laboratory test results can be used as though there were a 1:1 relationship with actual field performance, and the values of the r^2 and s for the regressions are realistic estimators of the goodness-of-fit. If the slope and intercept differ from these ideals, however, then r^2 and s are not realistic estimators of the goodness-of-fit when the laboratory results are used directly.

It is evident from Figures 8-1 through 8-4 that there was considerable scatter in the data in all cases. This was due primarily to the variability in performance of different vehicles using the same fuel. Although a given fuel was characterized by a single value in a given laboratory test, the EMOT's among vehicles using the same fuel differed by as much as 14°C (see Table 8-1). Consequently, it was not possible for a laboratory test yielding a single value to predict the performance of all vehicles with a high degree of correlation.

It is also clear from Figures 8-2 and 8-3 that neither the pour point nor the CFPP temperature was suitable for predicting low-temperature vehicle operation. There were numerous cases in which vehicle operation was much worse than predicted by these two laboratory tests (data points above the 1:1 line), and the low r^2 and high s values indicate extremely poor correlation of the vehicle data with the laboratory predictions. On the other hand, Figures 8-1 and 8-4 indicate better correlations with cloud point and LTFT temperature. Since the slopes of the two regression lines are nearly identical and close to 1.0, the difference in intercepts indicates the offset from the 1:1 line which is evident in Figures 8-1 and 8-4. The intercept of the LTFT regression line is -1.5°C, while the intercept of the cloud point regression line is -5.1°C. Thus, the cloud point regression line is a more conservative estimate of vehicle performance. The large value of cloud point intercept indicates that the r^2 and s values are not valid measures of the goodness-of-fit when the test results are used directly. The fact that the slope is close to one suggests that, on a statistical basis, the r^2 and s values would be valid when a correction factor of -5°C is applied. As has been found in numerous previous studies[4-9], however, cloud point alone with no correction is a good predictor of vehicle performance with untreated fuels. Figures 8-1 and 8-4 confirm quantitatively what was stated in the previous section on a qualitative basis; namely, that cloud point was a better fail-safe predictor of low-temperature vehicle operation, but LTFT correlated better with the vehicle data, particularly for the flow-improved fuels.

AD-A133 543 1981 CRC (COORDINATING RESEARCH COUNCIL) DIESEL FUEL LOW-TEMPERATURE OPERABILITY FIELD TEST(U) COORDINATING RESEARCH COUNCIL INC ATLANTA GA SEP 83 CRC-528 2/3

UNCLASSIFIED DAAK70-81-C-0128 F/G 21/4 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

B. Correlation of Estimated Minimum Operating Temperatures with Laboratory Test Predictions - Individual Vehicles

Comparisons such as shown in Figures 8-1 through 8-4 ignore the possibility that a laboratory test might have correlated well with each vehicle individually, but because of differences among vehicles, might not have correlated well with the data from all vehicles. To determine whether such a condition existed in this program, the EMOT's from each individual vehicle in Table 8-1 were compared with the values predicted for each of the fuels by the four laboratory tests. Linear regression analyses were performed on each set of data, and the results are listed in Table 8-8. Also included are the results of linear regression analyses of the data from all the vehicles (same data as included in Table 8-7), as well as the results of linear regression analyses of the average EMOT for each fuel (Row 8 in Table 8-1) versus each of the four laboratory test predictions.

The results in Table 8-8 show that on the basis of r^2 and s values, LTFT best predicted the EMOT's in four of the seven vehicles, as well as the EMOT's of the "average" vehicle. For the three vehicles for which cloud point gave the highest r^2 value, the LTFT correlation yielded slopes closest to 1.0 in two of the three cases, and intercepts closest to zero in all cases. It would thus appear that LTFT provided the best compromise of r^2, s, m, and b for all vehicles, both individually and collectively. Cloud point was the next best predictor, while CFPP and pour point were extremely poor predictors for all vehicles.

The regression lines for the seven individual vehicles defined in Table 8-8 are plotted in Figures 8-5 and 8-6 for LTFT and cloud point, respectively. The regression lines for each vehicle are shown merely to illustrate the differences among vehicles which were inherent in this program, and should not be interpreted as predictions of specific vehicle field performance. Figures 8-5 and 8-6, however, do illustrate once again that cloud point was too severe a predictive test, at least based on the performance represented by the regression lines.

Figures 8-7 and 8-8 show the plots corresponding to the correlations summarized in the last four columns of Table 8-8 of estimated minimum operating temperatures of each of the seven vehicles with the LTFT data. Correlations for the four passenger cars are grouped together in Figure 8-7, and correlations for the three trucks are grouped together in Figure 8-8. In each of the plots, the fuel corresponding to each data point is identified, and the regression line through the data points as well as the 1:1 correspondence line are shown.

It is readily apparent from Figures 8-7 and 8-8 that LTFT predicted the performance of some vehicles better than others. It did very well for Vehicles 121, 122, and 126; did reasonably well for Vehicles 123 and 124; but did not do very well for Vehicles 125 and 128 (although LTFT did better than any of the other laboratory tests for these latter two vehicles).

Also, no one particular fuel appears to have been an outlier in all vehicles. The data point corresponding to Fuel 107 is the farthest removed from the regression line for Vehicles 121, 122, 124, and 125, but falls on or below the regression line for the other three vehicles. The data point for Fuel 108 lies on or above the regression line for all vehicles, but lies more than about 2^{o}C above the line only for Vehicles 125 and 128. Data points for Fuel 105 lie substantially below the regression line for Vehicles 123, 124, 125, and 128, while the data point for Fuel 106 lies substantially below the regression line for Vehicle 123. The data point for Fuel 102 lies substantially below the regression line for Vehicle 125, but substantially above the regression line for Vehicle 126.

The deviation of the data points for Fuel 107 from the regression line are of greater concern than those of other fuels. As shown in Figures 8-7 and 8-8, the data points for four vehicles (Vehicles 121, 122, 124, and 125), lie above the regression line by about 6^{o}C. This means that for these vehicles, LTFT predicted (on the basis of the regression equation) satisfactory low-temperature operation about 6^{o}C lower than the temperatures at which trouble was experienced in the vehicles. The deviations from the 1:1 line, however, are generally not as large. The only laboratory bench test which provided a fail-safe estimate of performance of all vehicles with Fuel 107 was cloud point (see Table 8-1); however, cloud point was an extremely poor predictor of overall performance in three vehicles which operated satisfactorily more than 10^{o}C below cloud point.

The scatter in Figures 8-7 and 8-8 is caused largely by measurement error of the EMOT and by the different response of each vehicle to low-temperature fuel properties. The influence of these factors can be minimized by averaging the EMOT's for each of the eight fuels over the seven vehicles (see Table 8-1).

Figure 8-9 shows the relationship between these average EMOT's and the corresponding LTFT temperatures. The correlation is quite good, with many of the deviations evident in the data for the individual vehicles having been smoothed out by averaging the EMOT's of all the vehicles for each fuel. The data point for Fuel 107 still lies above the regression line, and the data point for Fuel 105 still lies below the regression line. In addition, no data points lie more than 1^{o}C above the 1:1 correspondence line, indicating that LTFT provided a safe estimate of "average" vehicle performance, when "average" is defined as it has been here.

C. Other Laboratory Bench Tests

The emphasis in this chapter has been on comparison of vehicle results with four laboratory bench tests; however, the eight test fuels were also analyzed using several other laboratory bench tests. Results of these tests are reported in Table C2-1 of Appendix C2, and the test methods are described in Appendix C3. Some of the tests yielded results which were not in a form suitable for direct comparison with the vehicle data. Other tests (e.g., the Setapoint, DIFCOFIT, and other flow tests) yielded appropriate data, but were not considered in the analyses reported herein, either because only a single laboratory provided the data or because the results were submitted after the data analysis had been completed. The test results are included in this report for completeness, as they may be useful in future efforts to improve the correlation of laboratory tests with vehicle performance.

Correlations discussed so far have defined the most effective single laboratory test for the prediction of the minimum operating temperature of vehicles; multiple parameter regressions have not been considered. This section will discuss use of a two-parameter expression involving cloud point and pour point for prediction of minimum vehicle operating temperature.

The cloud point defines a fuel temperature slightly below the onset of wax precipitation. The pour point defines a fuel temperature below which the fuel does not readily flow. It would be expected that the minimum operating temperature of a vehicle would occur between the cloud and pour point temperatures.

An expession of the following form was considered:

$$WPI = CP + a(CP-PP-b)^{c} \qquad (2)$$

in which

WPI = Wax Precipitation Index, ^{o}C

CP = Cloud Point, ^{o}C

PP = Pour Point, ^{o}C

Examination of Equation (2) shows that WPI is directly related to cloud point, and that the intercept depends upon the difference between the cloud and pour points. Since the cloud point of a fuel is essentially unchanged by the addition of flow improver, Equation (2) implies that improvements in vehicle operation with flow-improved fuels are related to pour point reduction.

Regression of the individual EMOT's in Table 8-1 with this equation yielded the values for the coefficients shown in the following equations:

$$WPI = CP - 1.3 \sqrt{(CP-PP-1.1)} \qquad (3a)$$

for CP-PP > 1.1°C

$$WPI = CP \qquad (3b)$$

for CP-PP ≤ 1.1°C

WPI is a function of cloud point only when the difference between cloud point and pour point is less than or equal to 1.1°C. A graphical solution to Equation (3) is presented in Figure 8-10, and calculated values of WPI for each fuel are given in Table 8-10. A comparison of these calculated values of WPI with the estimated minimum operating temperatures (EMOT's) is shown in Figure 8-11. This plot is comparable to the one presented in Figure 8-4 for LTFT.

D. Comparison and Limitations of WPI and LTFT

As shown in Table 8-11, WPI correlated with EMOT somewhat better than did LTFT, with an r^2 of 0.74 versus 0.69. Correspondingly, WPI also had a somewhat better standard error of estimate, 4.0°C versus 4.5°C for LTFT.

The relatively high standard errors of estimate for WPI and LTFT, as presented in Table 8-11, were caused largely by measurement uncertainty of EMOT and by the different response of each vehicle to low-temperature fuel properties. As was done in the last section for LTFT, the influence of these factors could be minimized by averaging the EMOT's for each of the eight fuels. The relationships between these average EMOT's and WPI and LTFT are shown in Figures 8-12 and 8-9, respectively. Correlation of the data yielded indices of determination of 0.91 versus 0.84, and standard errors of estimate of 2.4°C versus 3.3°C for WPI and LTFT, respectively.

These results indicate that both WPI and LTFT were fair predictors for ranking the low temperature behavior of fuels. The differences in the correlations of WPI and LTFT were not sufficiently great for objective determination of the best laboratory test. Even though WPI is not a filterability test, WPI and LTFT were closely related, as shown in Figure 8-13.

The relationships shown in Figures 8-9 and 8-12 also suggest that for improved correlations between laboratory test results and field behavior, further attention to laboratory test methods may not be as important as investigation of vehicle-to-vehicle differences and improvement of the measurement of minimum operating temperatures.

The advantage of a filter-plugging test, such as LTFT, is that it attempts to assess wax particle size. However, results from such tests are highly dependent upon selection of screen mesh size and sample cooling rate, as evidenced by the different results for LTFT and CFPP. Furthermore, LTFT was developed using a vehicle of a particular design which field test data have shown to be the most severe.(10) This suggests a dependency between vehicle fuel system design and the predictive capabilities of a filter-plugging test. Tests of this nature may require modification to reflect evolution in fuel system design.

WPI has the advantage of using test methods which are simple and well-established for ranking low-temperature behavior of fuels. These test methods measure inherent fuel properties, namely cloud point and pour point.

Of concern is the high measurement error with both the cloud point and pour point tests. An extreme example is the measurement of pour point for Fuel 108 by thirteen laboratories, which ranged from -7°C to less than -37°C. Nevertheless, WPI is only weakly affected by pour point. For the range of pour points reported for Fuel 108, the corresponding WPI's would have ranged from -5°C to -10°C.

As noted in Section 8C, WPI implies that, for a given cloud point, improvements in vehicle operation with flow-improved fuels are related to pour point reduction. This is supported by the data obtained in this program. Work by others(4-9) has also shown that, generally, improvements in vehicle operation are associated with a reduction in pour point; however, the magnitudes of the improvements in operation are not consistently related to the magnitudes of the pour point reductions. This suggests that, while WPI provides a good correlation with the field data from this program, correlation with data obtained in other programs may not be good.

E. Correlation of WPI and LTFT with Low-Temperature Operability

The prior sections have shown that, of the techniques evaluated, LTFT and WPI correlate best with the vehicle's low-temperature operability. The regression of average EMOT against LTFT temperature has an index of determination (r^2) of 0.84 and a standard error (s) of 3.3°C; for the average EMOT versus WPI, the r^2 is 0.91 and s is 2.4°C. This good agreement would seem to imply that either correlation could be used without modification to predict the level of improvement in low-temperature operability of individual diesel vehicles resulting from various treatment levels of commercial and experimental flow-improver additives.

Due to the restrictions of this test program (i.e., vehicle types, fuel types, additive type, and concentration), as well as the need to improve laboratory test precision, however, it is recommended that (until further correlation work is reported) specific predicted improvements in operability due to various additive treatments be confirmed by field evaluation.

T A B L E S

AND

F I G U R E S

TABLE 8-1

ESTIMATED MINIMUM OPERATING TEMPERATURES FOR EACH VEHICLE-FUEL COMBINATION AND LABORATORY TEST PREDICTIONS

	Fuel 101	Fuel 102	Fuel 103	Fuel 104	Fuel 105	Fuel 106	Fuel 107	Fuel 108
Estimated Minimum Operating Temperatures (°C)								
Vehicle 121	-22	-13	-3	-22	-14	-20	-12	-8
122	-22	<-15	-5	-29	-15	-23	-15	-5
123	-20	- 9	-4	-24	-25	-25	-20	-4
124	-21	-12	-4	-24	-14	-16	-10	-3
125	-22	-19	-3	-25	<-21	-20	-13	<-1
126	-23	- 5	-3	<-24	-13	-20	-22	-5
128	<-19	<-18	-6	--	-25	-19	<-23	-6
Average All Vehicles	-21.3	-13.0	-4.0	-24.7	-18.1	-20.4	-16.4	-4.6
Laboratory Test Predictions (°C)								
Cloud Point	-19	- 9	-2	-19	- 9	- 9	- 9	- 2
Pour Point	-26	-15	-6	-33	-29	-49	-49	-27
CFPP	-21	-13	-5	-30	-12	-16	-25	-14
LTFT	-19	- 9	-4	-22	-10	-17	-17	- 6

TABLE 8-2

DISTRIBUTION OF VEHICLE PERFORMANCE PARAMETERS
RELATIVE TO LABORATORY TEST RESULTS*

Number of Field Test Results	Cloud Point			LTFT			CFPP			Pour Point		
	MPT	EMOT	MFT	MPT	EMOT	MFT	MPT	EMOT	MFT	MPT	EMOT	MFT
≥ 7°C Above Lab Test Result	0	0	0	2	1	0	17	12	11	38	34	26
		>(2)**			>(11)			>(36)			>(87)	
3-6°C Above Lab Test Result	2	1	1	8	5	5	8	8	4	12	14	6
At Lab Test Result (±2°C)	20	13 (24)	10	28	23 (42)	18	20	23 (42)	19	5	6 (11)	12
3-6°C Below Lab Test Result	19	25	20	12	19	13	6	7	5	0	1	1
		>(74)			>(47)			>(22)			>(2)	
≥ 7°C Below Lab Test Result	14	16	14	5	7	9	4	5	6	0	0	0
Total Runs	55	55	45	55	55	45	55	55	45	55	55	45

* This table compares three different vehicle performance criteria -- minimum pass temperature (MPT), maximum fail temperature (MFT), and estimated minimum operating temperature (EMOT) -- with laboratory test predictions for each vehicle-fuel combination for which data were obtained.

** Numbers in parentheses indicate percent of total runs.

TABLE 8-3

DISTRIBUTION OF AVERAGE ESTIMATED MINIMUM OPERATING TEMPERATURE RELATIVE TO LABORATORY TEST RESULTS

Number of Average EMOT's	Cloud Point	LTFT	CFPP	Pour Point
≥ 7°C Above Lab Test Result	0	0	2	5
3-6°C Above Lab Test Result	0	0	1	1
At Lab Test Result (±2°C)	2	4	3	1
3-6°C Below Lab Test Result	3	3	2	1
≥ 7°C Below Lab Test Result	3	1	0	0
Total Fuels	8	8	8	8

TABLE 8-4

DISTRIBUTION OF EMOT RELATIVE TO CLOUD POINT BY FUEL

Fuel:	101	102	103	104	105	106	107	108	Base Fuels	Flow-Imp. Fuels	Overall
Number of EMOT's:											
≥ 7°C Above Cloud Point	0	0	0	0	0	0	0	0	0	0	0
3-6°C Above Cloud Point	0	1	0	0	0	0	0	0	1	0	1
At Cloud Point (±2°C)	3	1	5	0	0	0	1	3	9	4	13
3-6°C Below Cloud Point	4	3	2	5	4	0	3	4	9	16	25
≥ 7°C Below Cloud Point	0	2	0	1	3	7	3	0	2	14	16
Total	7	7	7	6	7	7	7	7	21	34	55

TABLE 8-5

DISTRIBUTION OF EMOT RELATIVE TO LTFT BY FUEL

Fuel:	101	102	103	104	105	106	107	108	Base Fuels	Flow-Imp. Fuels	Overall
Number of EMOT's:											
≥ 7°C Above LTFT	0	0	0	0	0	0	1	0	0	1	1
3-6°C Above LTFT	0	1	0	0	0	0	2	2	1	4	5
At LTFT (±2°C)	3	1	7	4	0	2	1	5	11	12	23
3-6°C Below LTFT	4	3	0	1	5	4	3	0	7	13	19
≥ 7°C Below LTFT	0	2	0	1	2	1	0	0	2	4	7
Total	7	7	7	6	7	7	7	7	21	34	55

TABLE 8-6

DISTRIBUTION OF EMOT RELATIVE TO LTFT BY VEHICLE

Vehicle:	121	122	123	124	125	126	128	Overall
Number of EMOT's:								
≥ 7°C Above LTFT	0	0	0	1 (107)	0	0	0	1
3-6°C Above LTFT	1 (107)*	0	0	1 (108)	2 (107) (108)	1 (102)	0	5
At LTFT (2°C)	3	3	5	4	1	3	4	23
3-6°C Below LTFT	4	4	1	2	3	4	1	19
≥ 7°C Below LTFT	0	1	2	0	2	0	2	7
Total	8	8	8	8	8	8	7	55

* For EMOT's occurring above the LTFT temperature, the corresponding fuel is shown in parenthesis.

TABLE 8-7

CORRELATION OF LABORATORY PREDICTIONS WITH ESTIMATED MINIMUM OPERATING TEMPERATURES FROM ALL VEHICLES

Laboratory Test	r^2	s, °C	m	b, °C
Cloud Point	0.64	4.8	1.05	-5.1
Pour Point	0.27	6.8	0.29	-6.6
CFPP	0.43	6.0	0.70	-3.4
LTFT	0.69	4.5	1.06	-1.5

TABLE 8-8

CORRELATION OF ESTIMATED MINIMUM OPERATING TEMPERATURES OF INDIVIDUAL VEHICLES WITH LABORATORY TEST PREDICTIONS

	Cloud Point				Pour Point				CFPP				LTFT			
	r^2	s, °C	m	b, °C	r^2	s, °C	m	b, °C	r^2	s, °C	m	b, °C	r^2	s, °C	m	b, °C
Vehicle 121	0.81	3.2	0.95	-5.0	0.27	6.3	0.24	-7.3	0.50	5.2	0.60	-4.0	0.80	3.3	0.92	-2.2
122	0.80	4.0	1.17	-4.7	0.25	7.9	0.29	-7.8	0.56	6.1	0.79	-2.6	0.85	3.5	1.18	-0.7
123	0.47	7.3	0.97	-6.9	0.50	7.1	0.44	-3.6	0.36	8.0	0.69	-4.7	0.64	5.9	1.12	-1.8
124	0.92	2.3	1.10	-2.3	0.11	7.6	0.17	-8.1	0.47	5.8	0.64	-2.1	0.76	3.9	0.98	-0.2
125	0.73	5.0	1.19	-3.9	0.12	9.1	0.21	-9.4	0.30	8.1	0.62	-4.9	0.58	6.3	1.04	-2.0
126	0.65	5.7	1.12	-3.5	0.54	6.6	0.44	-1.4	0.72	5.1	0.95	1.9	0.94	2.4	1.32	2.8
128	0.43	0.3	0.88	-9.2	0.32	6.9	0.27	-8.8	0.33	6.9	0.68	-6.3	0.48	6.0	0.89	-6.1
All Vehicles	0.64	4.8	1.05	-5.1	0.27	6.8	0.29	-6.6	0.43	6.0	0.70	-3.4	0.69	4.5	1.06	-1.5
"Average" Vehicle	0.79	3.7	1.04	-5.1	0.33	6.7	0.29	-6.7	0.54	5.6	0.70	-3.3	0.84	3.3	1.06	-1.5

TABLE 8-9

INDIVIDUAL LABORATORY DETERMINATIONS OF ADDITIVE TREATMENT EFFECTIVENESS

Laboratory	Additive A Effect., °C	Additive B Effect., °C	Additive 2B Effect., °C	Additive C Effect., °C	Additive D Effect., °C
1	3	0	10	6.5	2
3	2	1	9	9	1
4	5.5	0	5.5	6.5	2
5	2.5	1	6	7	2
7	7	0	8	7	2
8	3	2	8	9	2
9	8.5	0	6.5	10	2
10	2	0	1	10	3
12	7.5	0	12.5	6	2.3
14	5	1	10	4	3
15	4	0	8.5	7	3
18	3	0	4	10.5	2
Maximum °C	8.5	2	12.5	10.5	3
Minimum °C	2	0	1	4	1
Range °C	6.5	2	11.5	6.5	2
Average °C	4.4	0.6	7.4	7.7	2.2

TABLE 8-10

WAX PRECIPITATION INDEXES FOR TEST FUELS

Fuel	WPI, °C
101	-22.2
102	-11.9
103	-4.2
104	-23.7
105	-14.7
106	-17.1
107	-17.1
108	-8.4

$$WPI = CP - 1.3\sqrt{CP-PP-1.1}$$

in which WPI = Wax Precipitation Index, °C
CP = Cloud Point, °C
PP = Pour Point, °C

TABLE 8-11

COMPARISON OF CORRELATIONS OF WPI AND LTFT WITH ESTIMATED MINIMUM OPERATING TEMPERATURES FROM ALL VEHICLES

Test	r^2	s, °C
LTFT	0.69	4.5
WPI	0.74	4.0

FIGURE 8-1

CORRELATION OF ESTIMATED MINIMUM OPERATING TEMPERATURES (EMOT's) OF ALL VEHICLES WITH CLOUD POINT

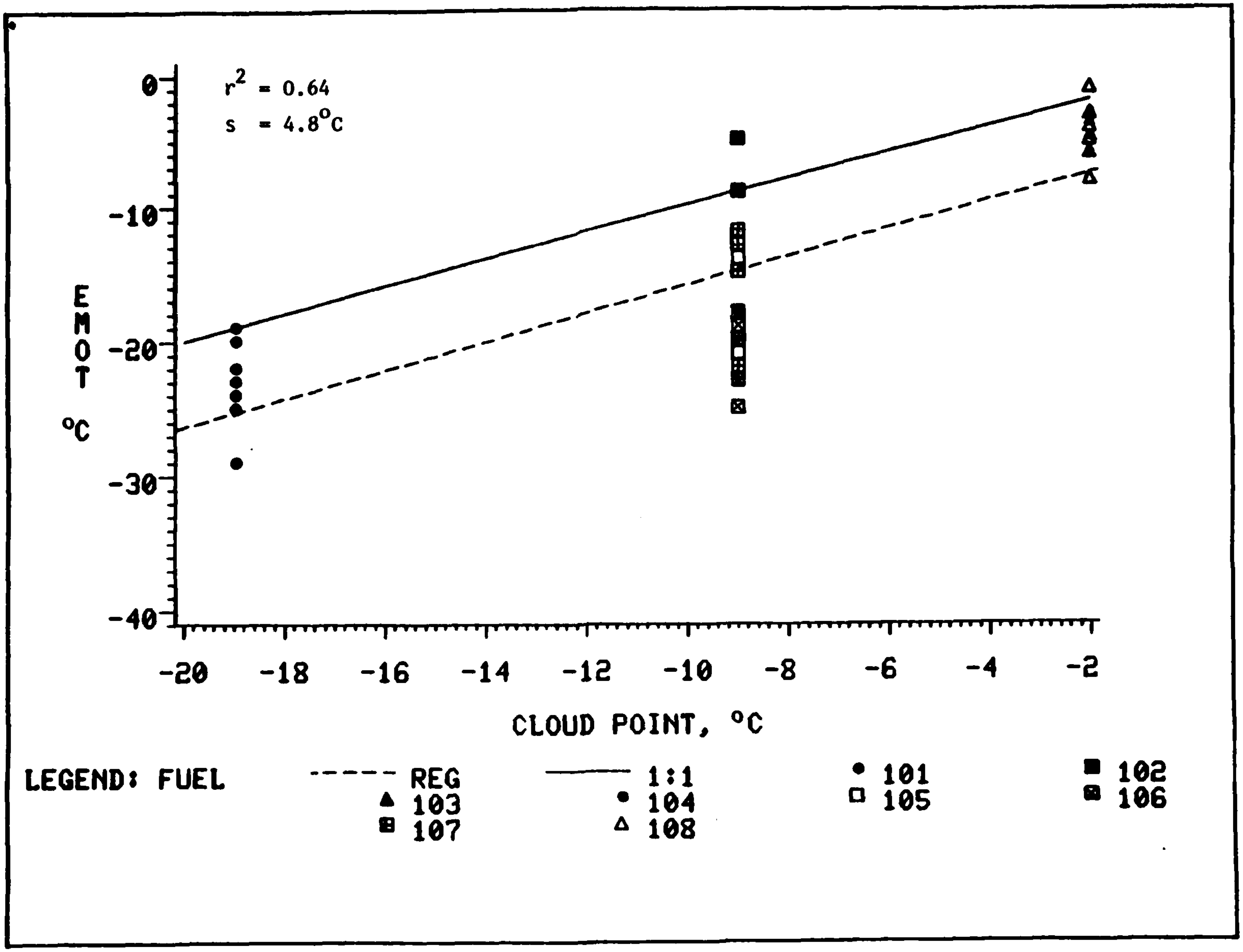


FIGURE 8-2

CORRELATION OF ESTIMATED MINIMUM OPERATING TEMPERATURES (EMOT's) OF ALL VEHICLES WITH POUR POINT

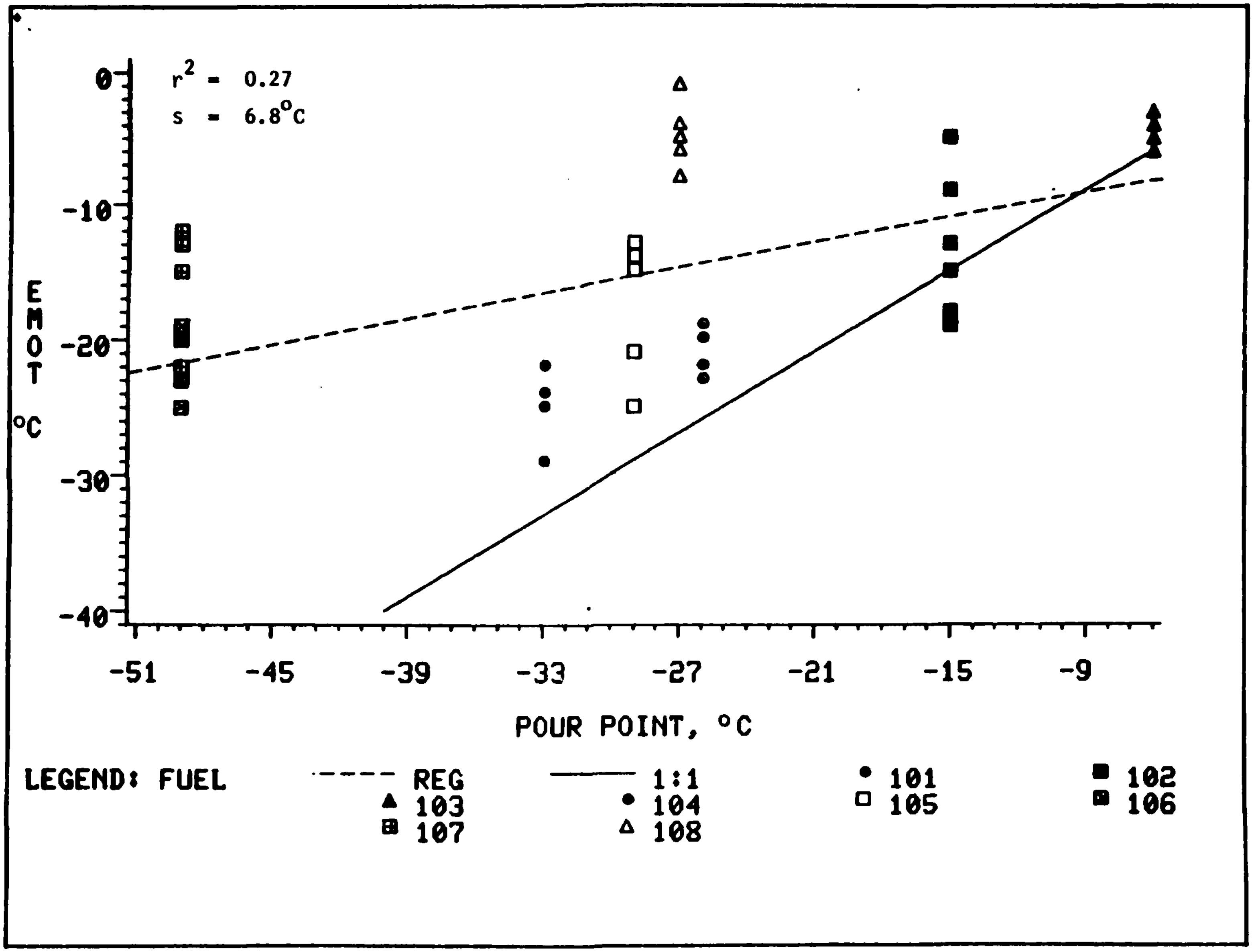


FIGURE 8-3

CORRELATION OF ESTIMATED MINIMUM OPERATING TEMPERATURES (EMOT's) OF ALL VEHICLES WITH CFPP

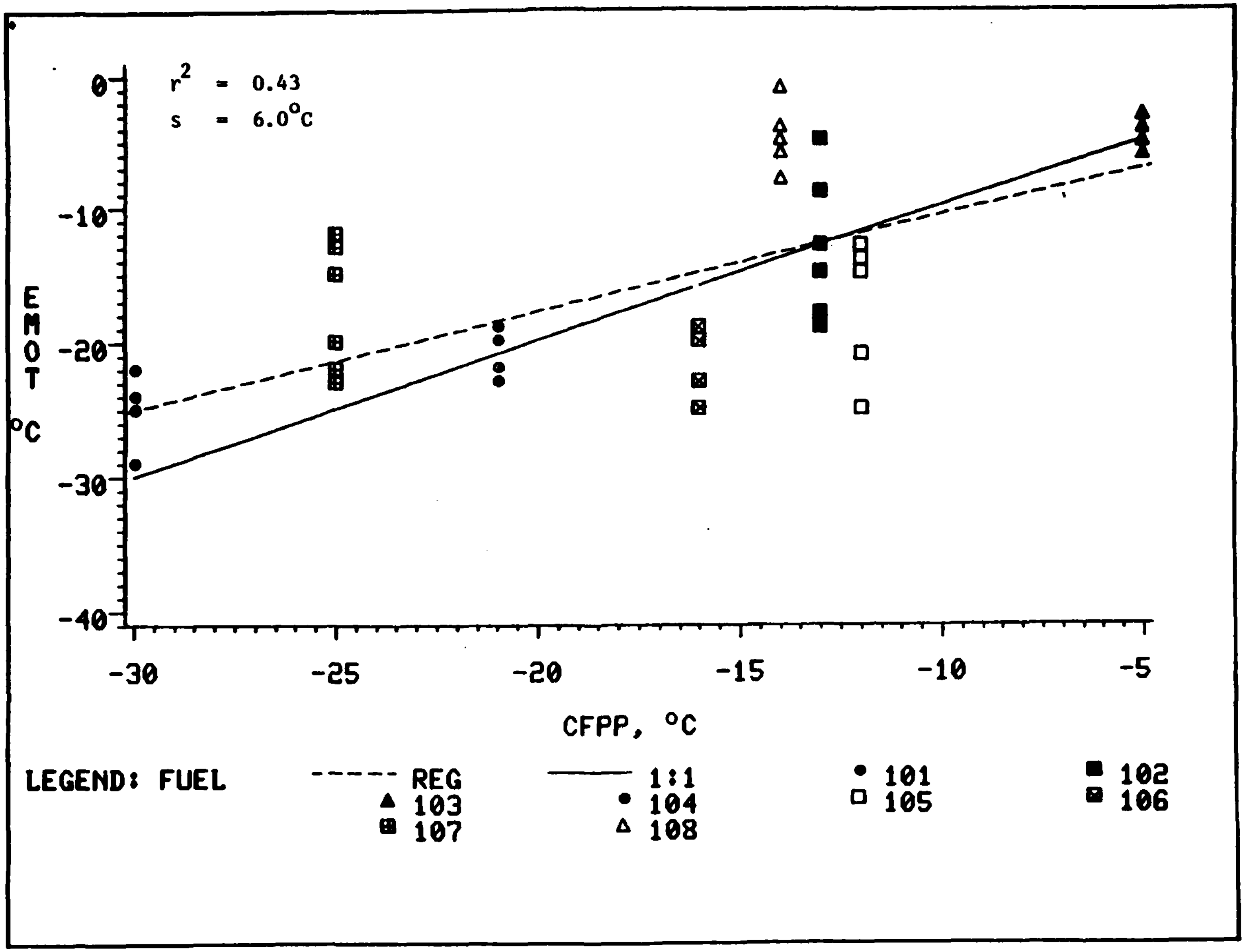


FIGURE 8-4

CORRELATION OF ESTIMATED MINIMUM OPERATING TEMPERATURES (EMOT's) OF ALL VEHICLES WITH LTFT TEMPERATURES

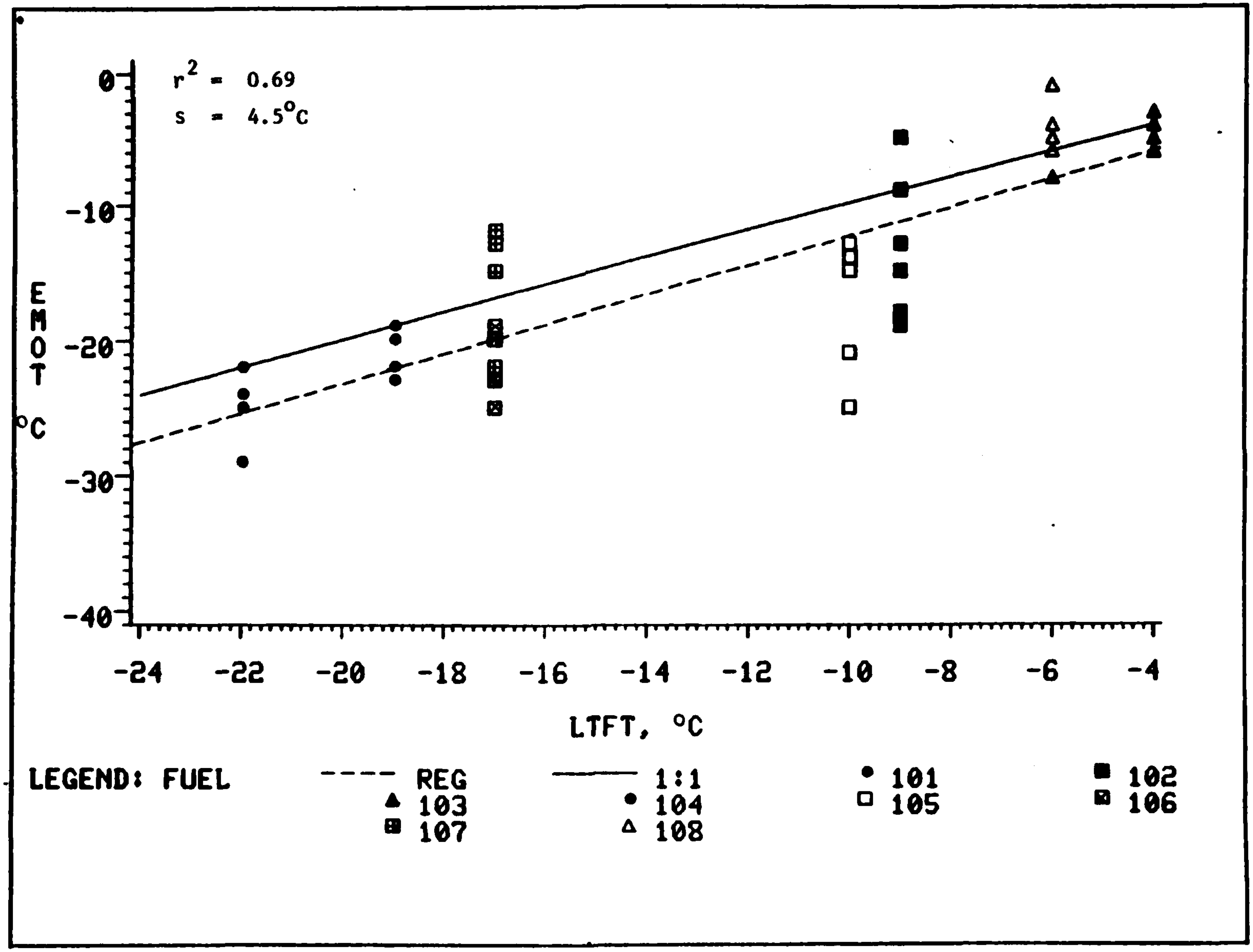


FIGURE 8-5

REGRESSION LINES OF INDIVIDUAL VEHICLE ESTIMATED MINIMUM OPERATING TEMPERATURE (EMOT) AS FUNCTION OF LTFT TEMPERATURE

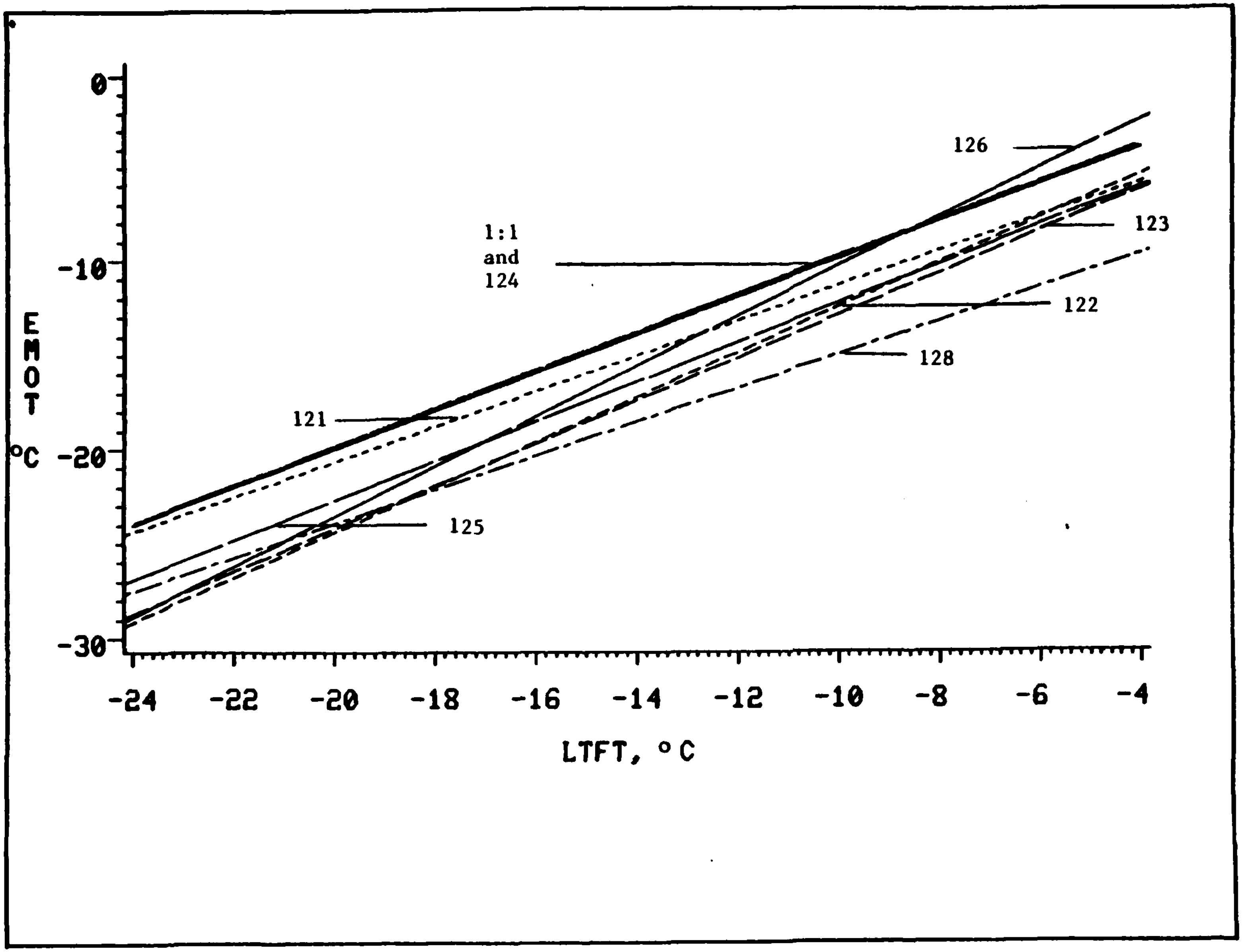


FIGURE 8-6

REGRESSION LINES OF INDIVIDUAL VEHICLE ESTIMATED MINIMUM OPERATING TEMPERATURE (EMOT) AS FUNCTION OF CLOUD POINT

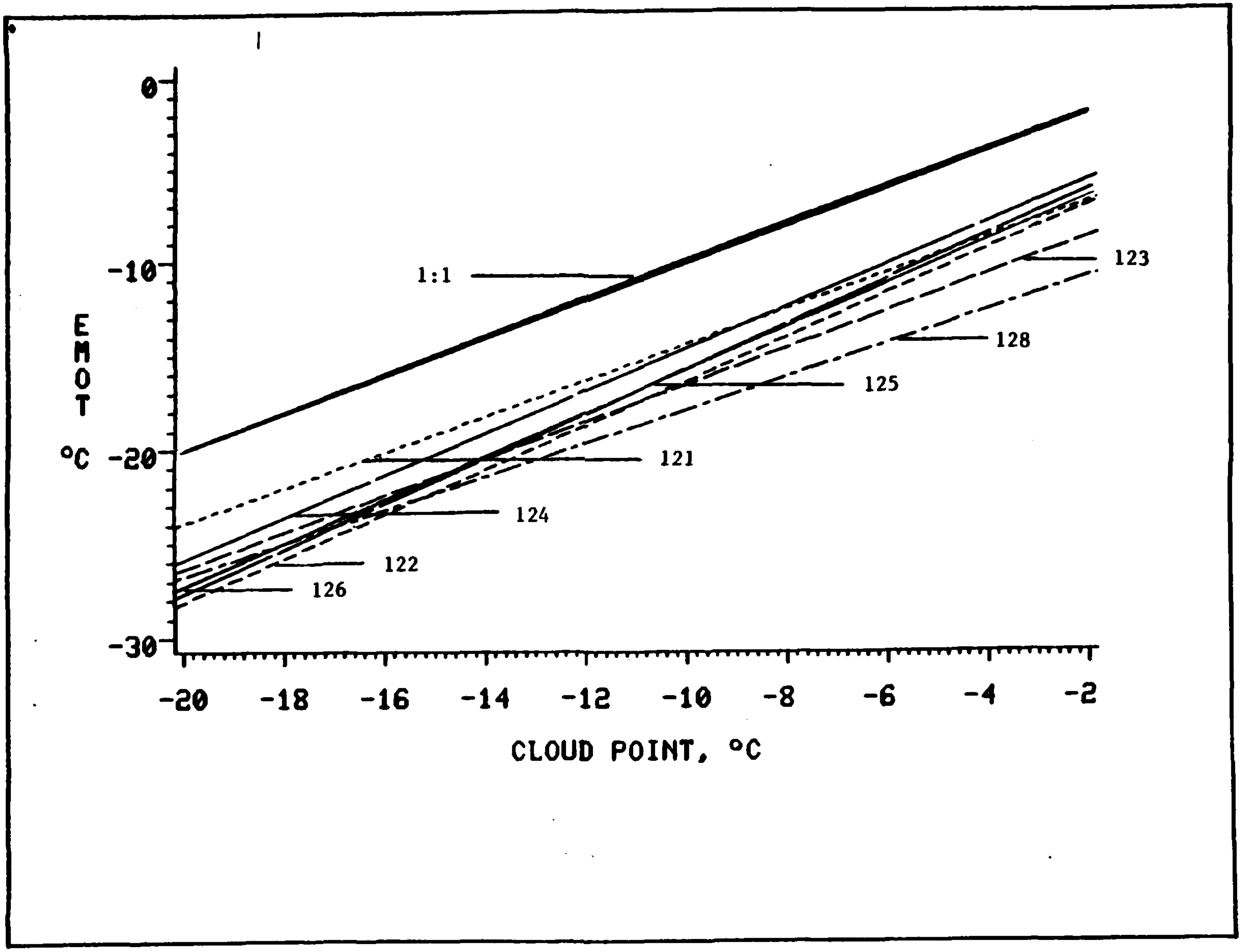


FIGURE 8-7

CORRELATION OF ESTIMATED MINIMUM OPERATING TEMPERATURES (EMOT'S) OF INDIVIDUAL PASSENGER CARS WITH LTFT TEMPERATURES

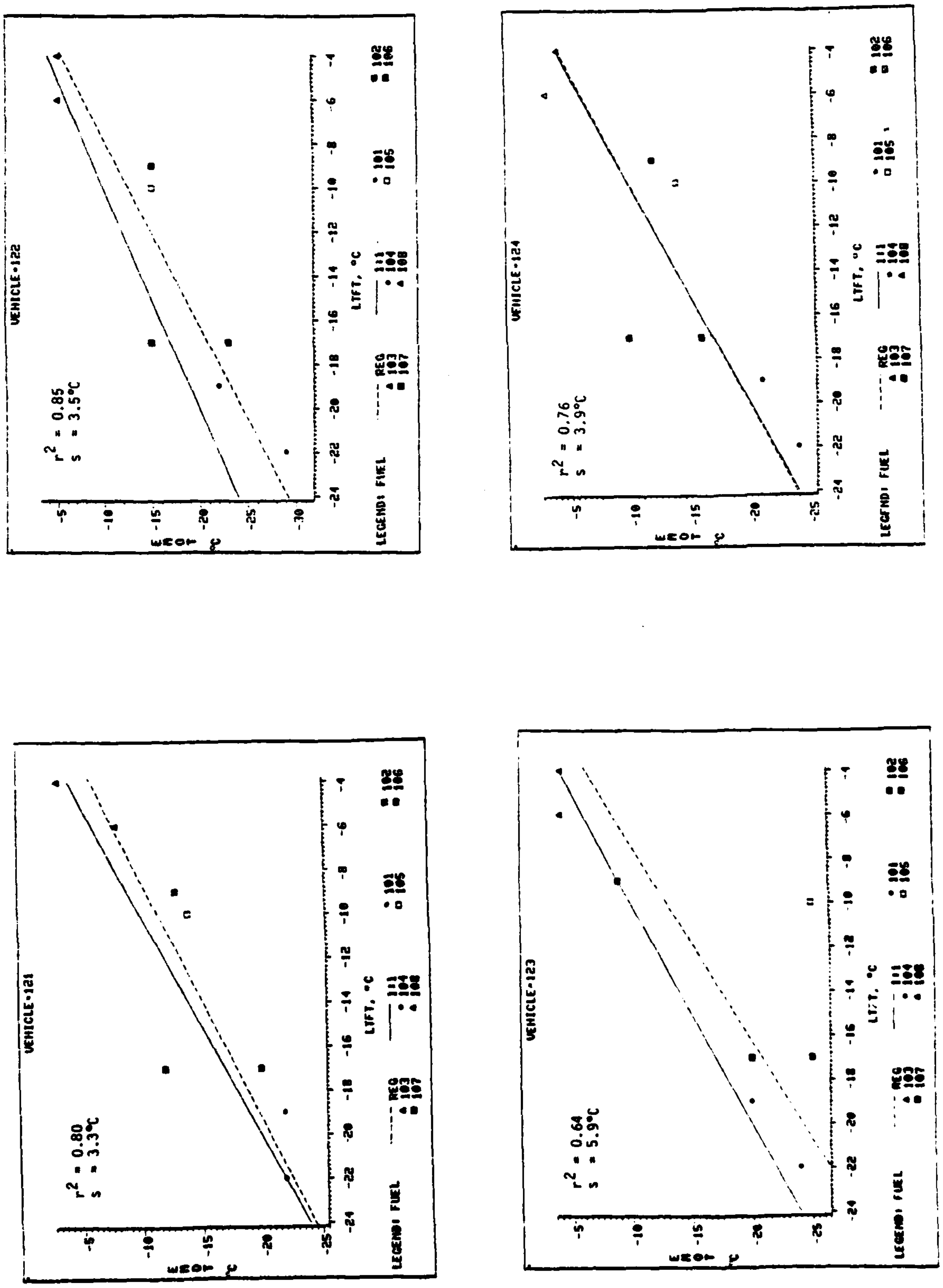
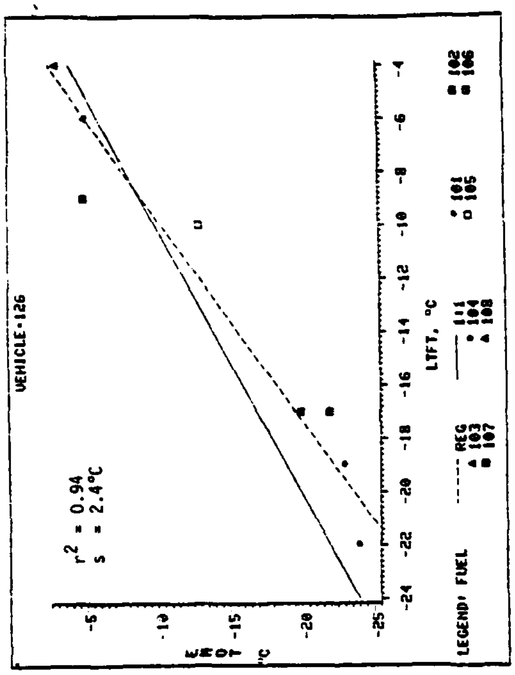
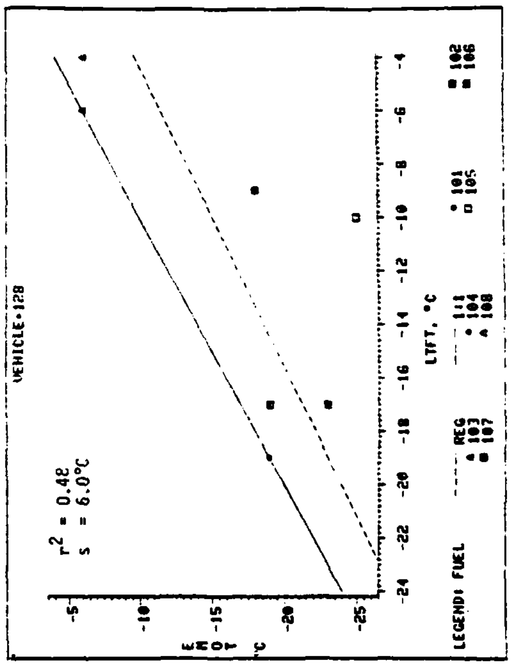


FIGURE 8-8

CORRELATION OF ESTIMATED MINIMUM OPERATING TEMPERATURES (EMOT'S) OF INDIVIDUAL TRUCKS WITH LTFT TEMPERATURES





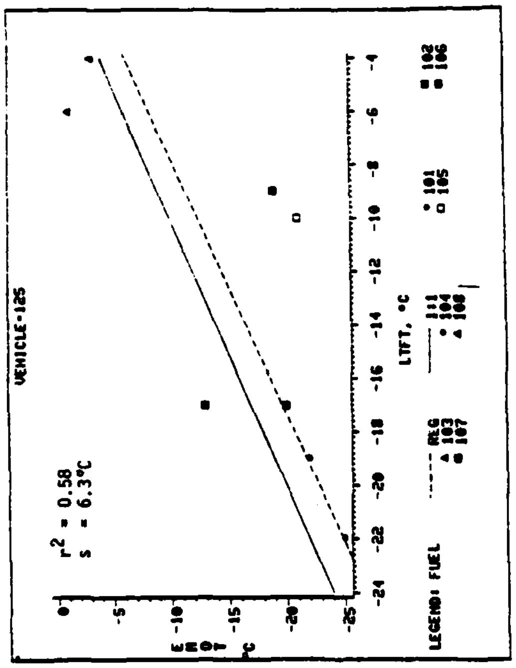


FIGURE 8-9

CORRELATION BETWEEN LTFT AND
AVERAGE ESTIMATED MINIMUM OPERATING TEMPERATURE
(AVERAGE EMOT)

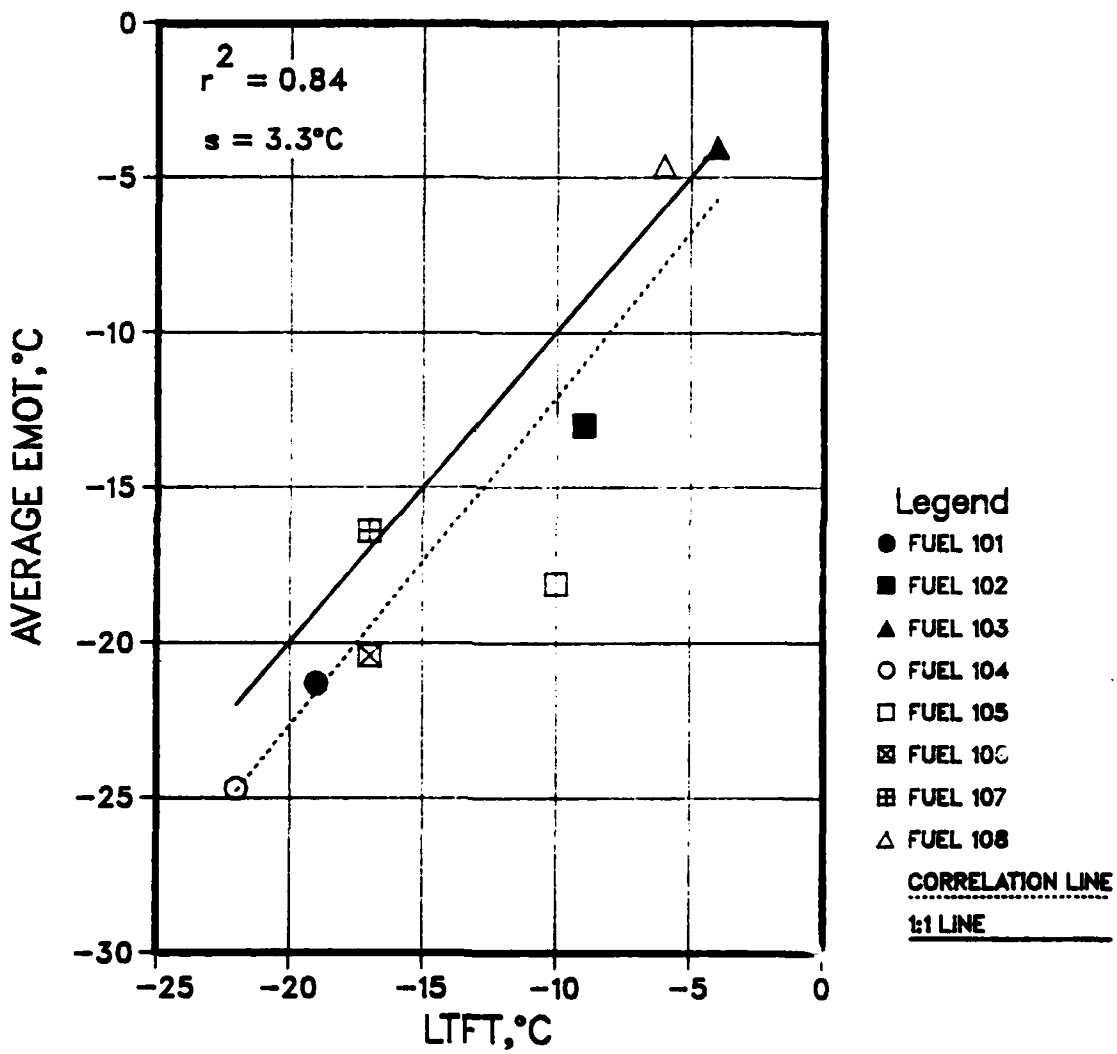
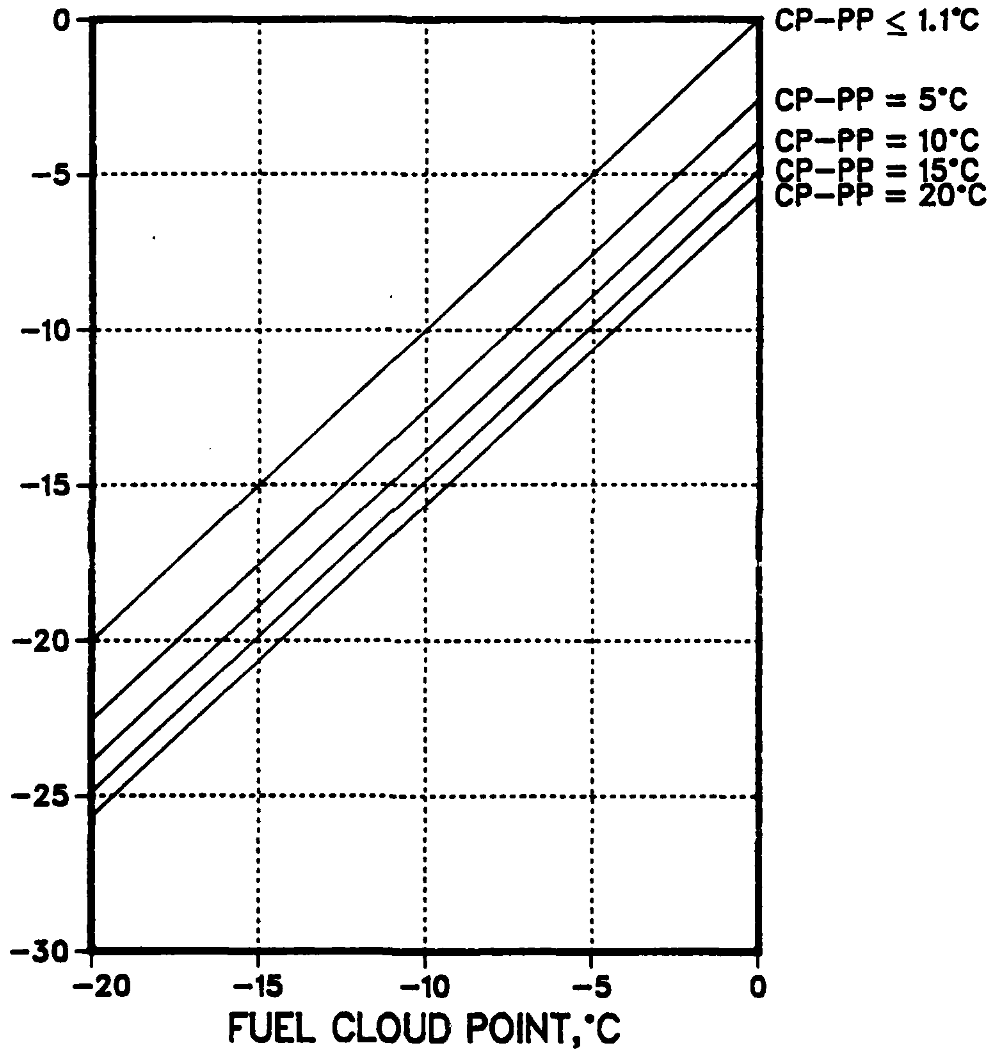


FIGURE 8-10

ILLUSTRATION OF WAX PRECIPITATION INDEX FOR ESTIMATION OF MINIMUM VEHICLE OPERATING TEMPERATURES



FOR CP−PP ≤ 1.1: WPI = CP

FOR CP−PP > 1.1: WPI = CP − $1.3\sqrt{CP-PP-1.1}$

WHERE

CP = CLOUD POINT

PP = POUR POINT

WPI = WAX PRECIPITATION INDEX

FIGURE 8-11

CORRELATION BETWEEN WAX PRECIPITATION INDEX AND ESTIMATED MINIMUM OPERATING TEMPERATURE (ALL VEHICLES)

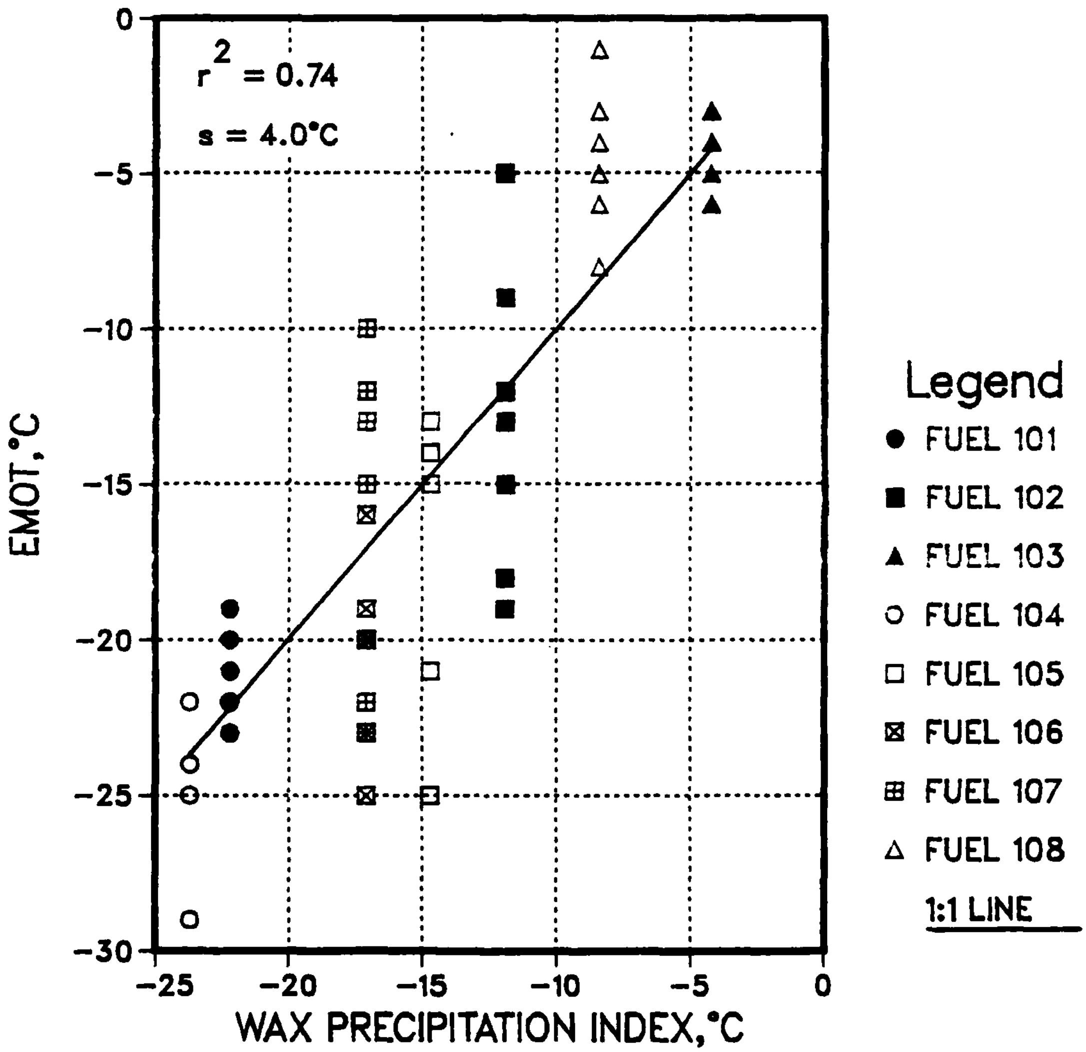


FIGURE 8-12

CORRELATION BETWEEN WAX PRECIPITATION INDEX AND AVERAGE ESTIMATED MINIMUM OPERATING TEMPERATURE (AVERAGE EMOT)

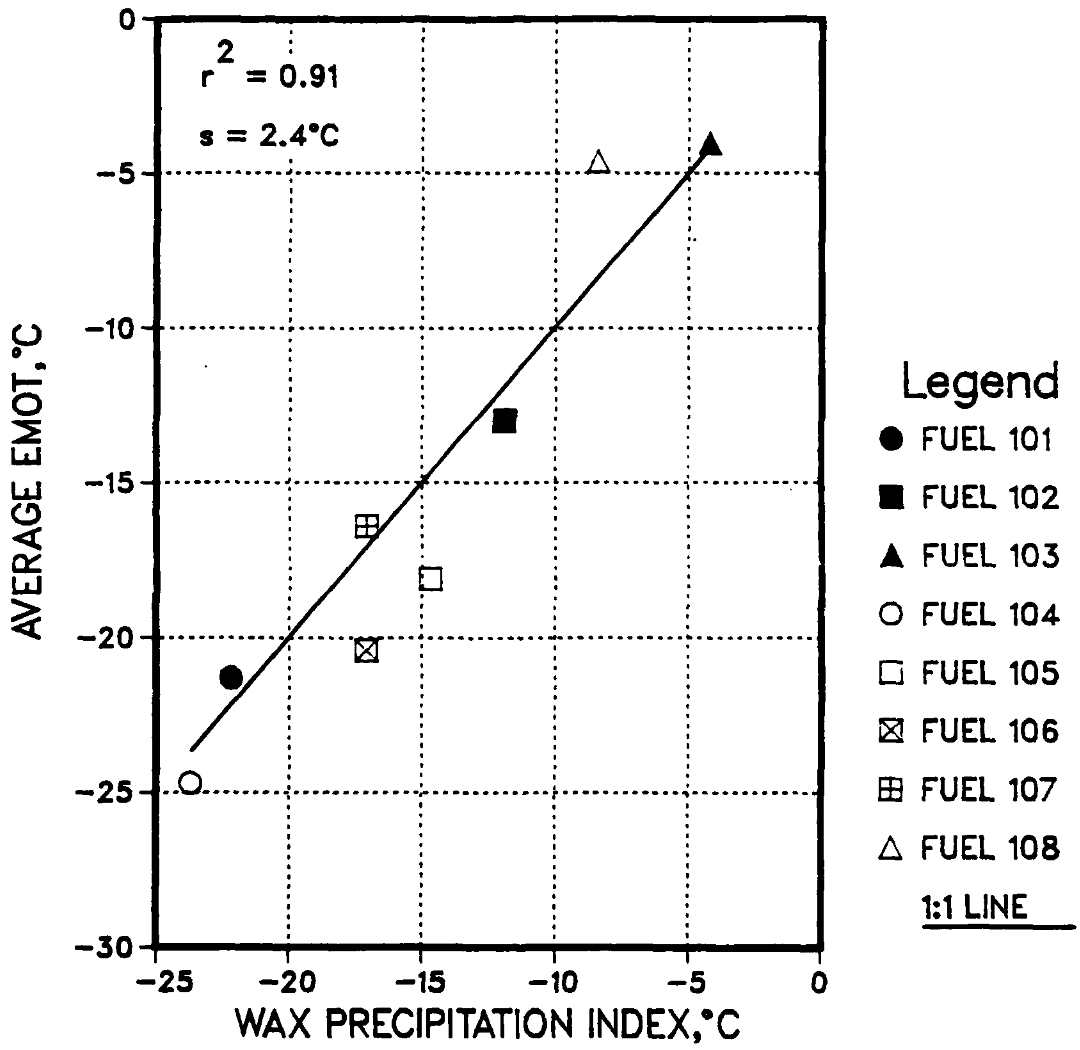
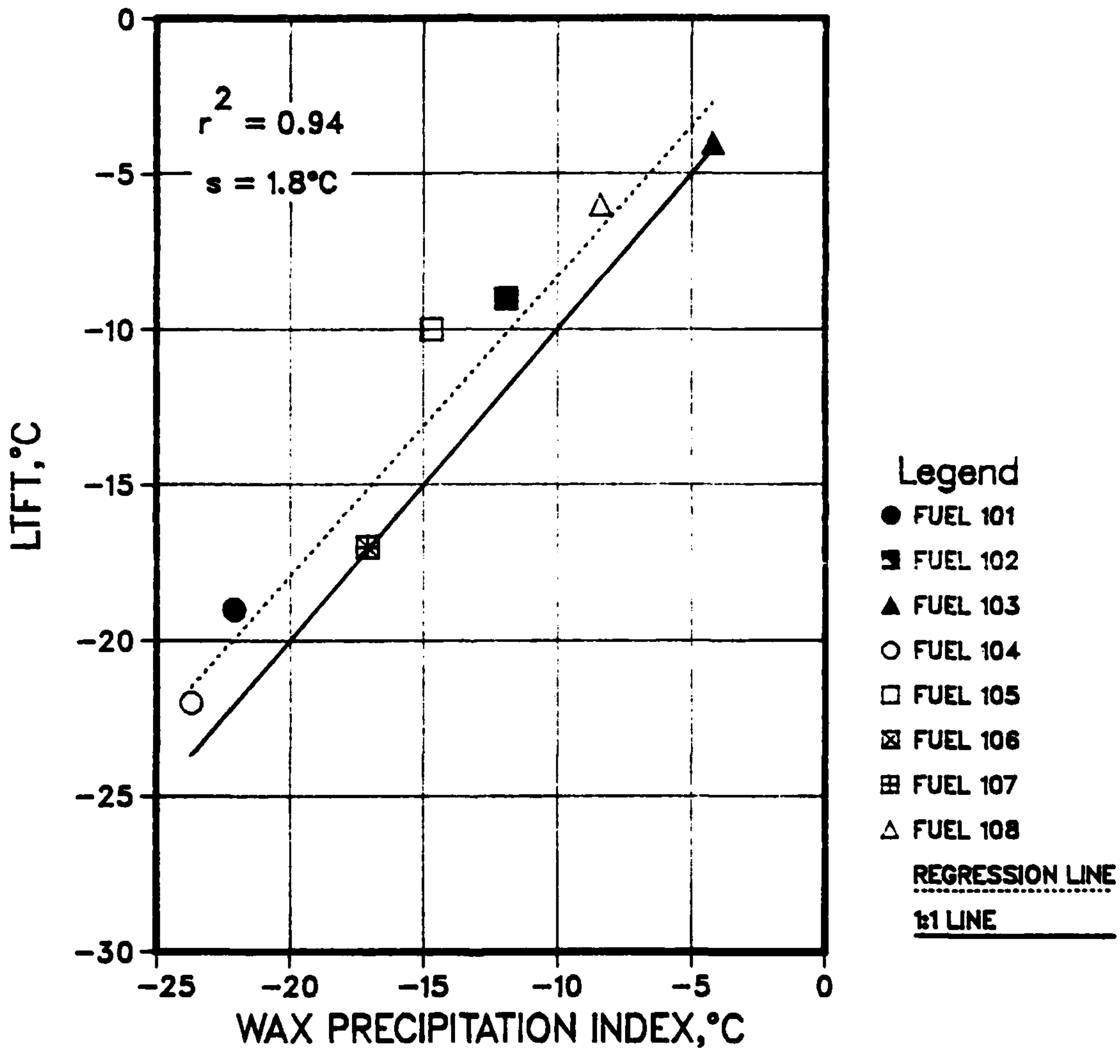


FIGURE 8-13

CORRELATION BETWEEN WAX PRECIPITATION INDEX AND LOW TEMPERATURE FLOW TEST (LTFT)



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A P P E N D I X   A

MEMBERSHIP: DATA ANALYSIS PANEL

AND

PARTICIPATING LABORATORIES

LOW-TEMPERATURE OPERABILITY DATA ANALYSIS PANEL

of the

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M. L. McMillan	General Motors Research Laboratories
R. E. Paterson	Chevron Research Company
T. J. Hansel	> Contributors
B. Y Taniguchi	
Anne Stevens	Exxon Chemical Company
D. H. Rehrer	> Contributors
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INSTRUMENTATION LOANED BY:

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APPENDIX B

PROGRAM: CRC DIESEL FUEL LOW-TEMPERATURE
OPERABILITY FIELD TEST

PROPOSED CRC PROGRAM FOR LOW-TEMPERATURE DIESEL FUEL OPERABILITY STUDY

OBJECTIVE

To obtain a body of data, representative of real-world conditions, suitable for use as the basis for the development of a research technique that would describe the low-temperature operability limits of diesel fuel in both light-duty and heavy-duty equipment more realistically than the ASTM D-2500 cloud point method.

PROGRAM LIMITATIONS

This program represents the first CRC cooperative effort on low-temperature operability and should be undertaken in the spirit, that by cooperation of both the petroleum and automotive industries, a worthwhile "best effort" exercise will result. In order to implement this program expeditiously within the constraints of available resources, it is necessary to proceed on a smaller scale than the group would like. It must be realized that the results from the program outlined herein may not encompass all variables which will affect the operability and that future efforts in this area, building on the experience gained in this program, may be necessary.

BACKGROUND

Historically, the cloud point has been used as the limiting temperature for low-temperature diesel fuel operation. The current increasing demand for the mid-distillate portion of the crude barrel, makes it increasingly difficult to satisfy the low-temperature diesel market. Considerable effort has been directed toward the development of additives to extend the low-temperature operability of fuels. However, as a practical matter, the additives approach is not viable until their effectiveness has been adequately demonstrated in field performance and a test method that recognizes the "real" performance of such fuels is available.

SUMMARY OF PROGRAM

This program is targeted for operation beginning January 1981 at Kapuskasing, Ontario, Canada. It will utilize a mixed fleet (passenger cars and trucks) of eight vehicles and eight selected test fuels. Vehicle/fuel/ambient temperature factors will be matched on a day-to-day basis to obtain maximum utility of available temperatures. The mechanical performance of the test operation will be conducted by a contractor, Kaptest Engineering Ltd. and the technical decisions relative to daily operations will be handled by on-site participating personnel. The fuels and the vehicles are to be supplied by the participants. It is expected that the program may run from early January through April 1981. Maximum effort will be made to complete the program during this period. However, if certain critical data are not obtained during the spring warming trend (for example because of unfavorable weather or equipment malfunction), it may be necessary to reconvene the program in November 1981. When the vehicle test phase is completed and the low-temperature operability limits of the eight fuels are identified, that information will be utilized to examine the adequacy of available laboratory tests as viable indicators for low-temperature diesel fuel operability.

TEST FUELS

The series of eight test fuels is built on three base fuels having cloud points of -19°C, -9°C, and -2°C. Five of the test fuels will contain additives. A description of the test fuels is presented in Table B-1.

TEST VEHICLES

The recommended vehicle fleet includes four heavy-duty trucks and four passenger cars. Specific models will be selected by the following manufacturers:

Caterpillar
Cummins
Detroit Diesel Allison
Mack Truck
Oldsmobile (1980 model)
Oldsmobile (1981 model)
Mercedes
Volkswagen

Each vehicle will be equipped with pressure and temperature sensors in the locations shown in Figure B-1. The trucks will be loaded with suitable ballast. The data (temperature, pressure, time) will be recorded automatically by a magnetic tape recording device located in the passenger area of each vehicle.

DRIVING CYCLE

Each vehicle will be started with a warm battery pack, using other starting aids only as required. The vehicle will then be driven off and operated at 90 km/h until the vehicle stops or until a one-hour run is completed.

FUEL CHANGEOVER

At the completion of a run, the test fuel will be drained, the system will be flushed, the filter will be replaced, the next test fuel will be added, and the vehicle will be run-in and parked to await the next day's test.

TEST SCHEDULING

Each day a decision will be made by the on-site participant as to what fuel will next be scheduled for each vehicle. That decision will be based on results of previous tests and the ambient temperature anticipated for the next day.

LABORATORY TEST PHASE

At the completion of the field test, an Analysis Panel will review all field data and attempt to establish correlations with data from existing laboratory tests. Examples of such tests include Low Temperature Flow Test (LTFT) and Cold Filter Plugging Point (CFPP). One criterion for a successful laboratory test is that it must be better than the cloud point.

TABLE B-1

DESCRIPTION OF TEST FUELS

Revised - 7/8/80

Fuel No.	Base Fuel	Criteria for Selection
1	Base #1	Good lab performance (low C.P. = -19°C)
2	Base #2	Intermediate lab performance (intermediate C.P. = -9°C)
3	Base #3	Poor lab performance (high C.P. = -2°C)
4	Base #2 + Additive A	Good additive performance as judged by lab tests other than cloud point. (current practice concentration)
5	Base #2 + Additive B	Poor additive performance as judged by lab tests other than cloud point
6	Base #2 + Additive A	Same as fuel 4 except higher additive concentration
7	Base #1 + Additive C	Better lab performance than Base #1
8	Base #3 + Additive B	Better lab performance than Base #3

INSTRUMENTATION LOCATIONS AND NOTES

- Pressure gauges should indicate in vacuum and pressure range.
- The thermocouple sensing tank temperature should be located near center of tank.
- Fuel temperature out of tank should be sensed in the fitting at the tank outlet.
- Secondary filter should be equipped with pressure taps and gauges before and after filter.
- Fuel temperature at inlet of secondary filter should be sensed.
- The "ambient" thermocouple on the chassis should be located to sense the air temperature in front of the vehicle. (right front of roof)

INSTRUMENTED FUEL SYSTEM

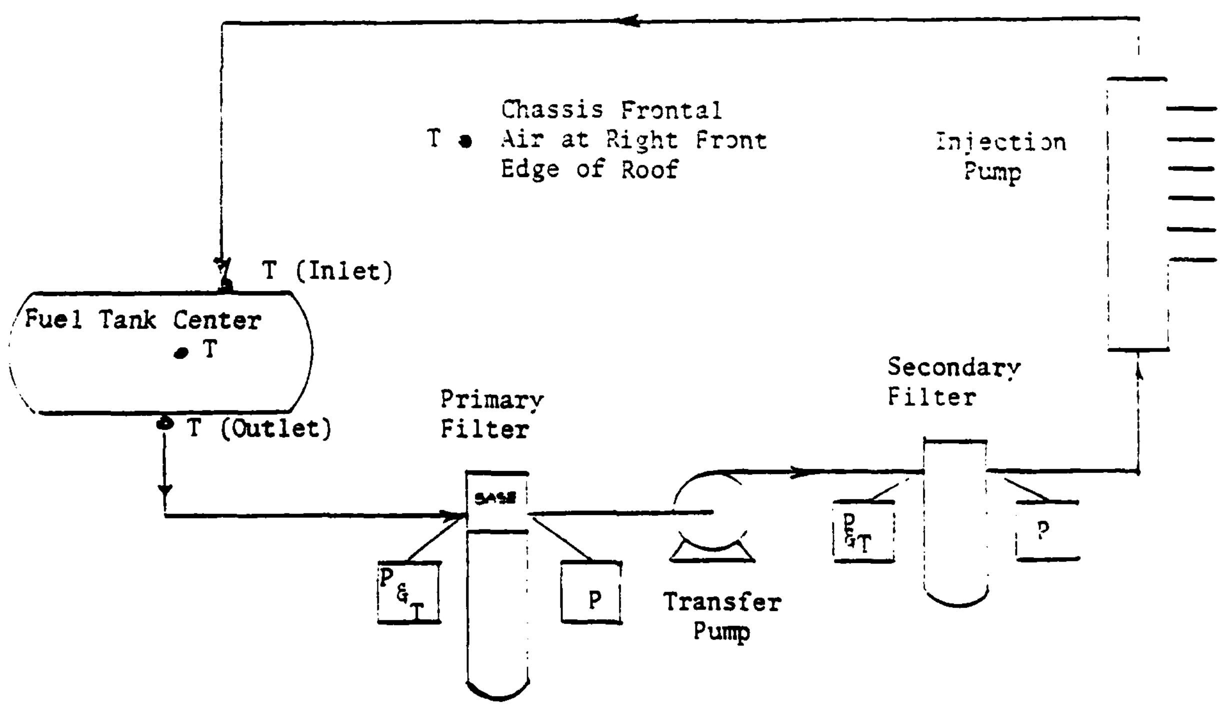

Figure B-1

APPENDIX C

INDIVIUDAL LABORATORY DATA ON TEST FUELS AND DESCRIPTION OF NON-ASTM STANDARDIZED TEST METHODS

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APPENDIX C1 - REQUESTED LABORATORY INSPECTION DATA

APPENDIX C2 - ADDITIONAL LABORATORY DATA

APPENDIX C3 - NON-ASTM STANDARDIZED TEST METHOD DESCRIPTIONS

TABLE C1-1

FUEL 101

LAB ID	Cold Flow Inspections, °C: Cloud Point	Pour Point	CFPP	LTFT	D86 Distillation, °C: IBP	10	50	90	EP	Cetane Number	API° Gravity	Flash Point, °C	Viscosity @ 40°C, cSt	Carbon Residue On 10% Bottoms	Ash, wt.%	Sulfur, wt.%	Copper Strip Corrosion	Sediment & Water, wt.%	Water, ppm
1	-19.0	-26.0	-21.0	-18.0	151	200	262	307	345	44.8	35.1	53.0	-	0.19	0.020	0.26	-	0.05	-
2	-19.0	-29.0	-	-	167	199	262	304	338	44.0	-	51.0	-	0.11	<0.001	0.24	1A+	Trace	-
3	-19.0	-31.5	-23.0	-19.0	160	198	263	304	351	-	35.0	56.5	-	0.11	<0.002	0.25	1A	NIL	-
4	-20.0	-26.0	-21.0	<u>-15.5</u>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-19.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-21.0/ -19.0	-26.0/ -20.5	-20.0/ -18.0	-18.0	159	199	268	307	345	44.0/ 44.6	35.0	52.0	2.45	0.14	<0.001	0.24	1	0.10	83
8	-19.0	-24.0	-22.0	-18.0	124	181	260	299	<u>320</u>	-	35.1	53.0	2.31	-	-	0.27	-	-	-
9	-21.0/ -21.0	-30.0/ -30.0	-21.0/ -21.0	-19.0/ -19.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-19.0	-24.0	-21.5	-20.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-20.0/ -20.0	-23.0/ -23.0	-20.0	-19.0	157	202	264	311	348	-	35.2	-	-	-	-	-	-	<0.001	51/49
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-20.0	-24.0	-	-18.0/ -18.0	158	202	262	308	348	-	35.1	51.0	2.47	-	-	0.25	-	-	-
15	-	-	-	-19.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-19.0/ -19.0	-23.0/ -23.0	-22.0/ -22.0	-	132	178	259	308	340	-	34.7	-	-	-	-	-	-	-	-
18	-16.0/ -19.0	-27.0/ -24.0	-	-19.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	-19.4	-25.8	-21.2	-18.5	151	195	262	306	342	44.4	35.0	52.8	2.41	0.14	0.008	0.25	-	0.018	66
Std. Dev.	0.9	2.9	1.2	1.1	15.0	9.6	2.7	3.6	9.8	0.4	0.2	2.0	0.09	0.04	0.001	0.01	-	0.048	21.3
Corr. Mean	-	-	-	-18.7	-	-	-	-	345	-	-	-	-	-	-	-	-	-	-
Corr. Std Dev	-	-	-	0.6	-	-	-	-	4.6	-	-	-	-	-	-	-	-	-	-

NOTE: Corrected means and standard deviations do not include underlined values.

TABLE C1-3

FUEL 103

LAB ID	Cold Flow Inspections, °C Cloud Point	Pour Point	CFPP	LTFT	D86 Distillation, °C IBP	10	50	90	EP	Cetane Number	API° Gravity	Flash Point, °C	Viscosity @ 40°C, cSt	Carbon Residue On 10% Bottoms	Ash, wt.%	Sulfur, wt.%	Copper Strip Corrosion	Sediment & Water, wt.%	Water, ppm
1	-2.0	-6.5	-7.0	-3.5	206	236	269	317	344	56.4	37.2	81.0	-	0.16	0.020	0.09	-	0.05	-
2	-4.5	-12.0	-	-	204	237	271	321	336	55.9	-	78.0	-	0.11	0.026	0.08	1A+	Trace	-
3	-2.0	-4.0	-9.0	-5.5	210	237	272	332	349	52.8	36.7	71.5	-	0.08	0.007	0.09	1A	0.05	-
4	-2.0	-6.5	-3.5	-3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-4.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-2.0/ -3.5/ -2.0	-6.5/ -6.5	-2.0/ -4.5	-3.0	202	232	269	319	348	-54.3/ -54.9	36.8	82.0	3.18	0.08	<0.001	0.08	1	0.30	53
8	-3.0	-6.0	-3.0	-3.0	195	229	267	317	340	-	37.2	75.0	3.04	-	-	0.09	-	-	-
9	-3.0/ -4.0	-7.0/ -9.0	-7.0/ -7.0	-3.5/ -3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-1.0	-4.0	-3.0	-4.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-4.5	-4.0	-4.0	-	198	235	264	321	341	-	-	78.5	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-1.0	-6.0	-	-2.0/ -2.0	194	232	268	317	341	-	37.0	78.0	3.03	-	-	0.09	-	-	-
15	-	-	-	-4.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-2.0/ -2.0	-4.0/ -4.0	-4.5/ -4.5	-	188	225	267	314	331	-	36.7	-	-	-	-	-	1A	-	-
18	0/ -1.0	-6.0/ -3.0	-	-4.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	-2.4	-6.0	-4.9	-3.7	200	233	268	320	341	54.8	36.9	77.7	3.08	0.10	0.014	0.09	-	0.100	-
Std. Dev.	1.3	2.3	2.2	0.9	7.2	4.3	2.5	5.5	5.9	1.6	0.2	3.6	0.08	0.04	0.012	0.01	-	0.135	-
Corr. Mean	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Corr. Std. Dev.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE C1-4

FUEL 104

LAB ID#	Cold Flow Inspections, °C Cloud Point	Pour Point	CFPP	LTFT	D86 Distillation, °C IBP	10	50	90	EP	Cetane Number	API° Gravity	Flash Point, °C	Viscosity @ 40°C, cSt	Carbon Residue On 10% Bottoms	Ash, wt.%	Sulfur, wt.%	Copper Strip Corrosion	Sediment & Water, wt.%	Water, ppm
1	-19.0	-31.5	-29.0	-21.0	157	200	262	306	346	45.5	35.1	53.0	-	0.18	0.008	0.26	-	0.05	-
2	-18.0	-34.5	-	-	167	200	262	307	336	44.6	-	52.0	-	0.11	<0.001	0.24	1A+	Trace	-
3	-19.0	-37.0	-31.0	-21.0	169	205	263	304	349	45.0	35.0	57.0	-	0.12	<0.002	0.25	1A	Nil	-
4	-19.0	-31.5	-26.5	-21.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-21.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-19.0/ -19.0	-31.5/ -34.5	-26.5/ -25.5	-25.0	154	194	261	307	334	45.8	34.9	52.0	2.47	0.19	<0.001	0.24	1	0.10	61
8	-19.0	-33.0	-34.0	-21.0	131	182	260	299	331	-	35.2	54.0	2.37	-	-	0.28	-	-	-
9	-20.0/ -20.0	-35.0/ -35.0	-34.0/ -33.0	-23.5/ -24.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-19.0	-34.5	-29.5	-22.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-19.0/ -19.0	-31.5/ -31.5	-28.0	-26.5	157	202	264	309	349	-	35.1	-	-	-	-	-	-	<0.001	48/50
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-20.0	-30.0	-	-23.0/ -23.0	155	200	262	306	346	-	35.1	50.0	2.48	-	-	0.25	-	-	-
15	-	-	-	-23.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-19.0/ -19.0	-31.5/ -31.5	-30.0/ -30.0	-	135	182	257	307	340	-	34.7	-	-	-	-	-	1A	-	-
18	-17.0/ -17.0	-30.0/ -33.0	-	-22.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	-18.9	-32.9	-29.7	-22.6	153	196	261	306	341	45.0	35.0	53.0	2.44	0.15	0.003	0.25	-	0.030	55
Std. Dev.	0.8	2.0	2.8	1.8	13.6	8.9	2.1	3.0	7.1	0.4	0.2	2.4	0.06	0.04	0.003	0.02	-	0.044	8.5
Corr. Mean	-19.0	-	-	-22.2	-	-	-	307	-	-	-	-	-	-	-	-	-	-	-
Corr. Std. Dev.	0.6	-	-	1.4	-	-	-	1.5	-	-	-	-	-	-	-	-	-	-	-

TABLE C1-5

FUEL 105

LAB ID	Cold Flow Inspections, °C Cloud Point	Pour Point	CFPP	LTFT	D86 Distillation, °C IBP	10	50	90	EP	Cetane Number	API° Gravity	Flash Point, °C	Viscosity @ 40°C, cSt	Carbon Residue On 10% Bottoms	Ash, wt.%	Sulfur, wt.%	Copper Strip Corrosion	Sediment & Water, wt.%	Water, ppm
1	-8.0	-26.0	-13.0	-10.0	186	222	270	318	349	47.1	33.4	70.0	-	0.12	0.004	0.23	-	0.05	-
2	-8.0	-31.5	-	-	193	218	271	320	343	44.6	-	70.0	-	0.10	<0.001	0.20	1A+	Trace	-
3	-10.0	-34.5	-14.0	-10.0	193	223	270	319	353	45.8	33.5	71.5	-	0.10	<0.002	0.22	1A	Nil	-
4	-8.0	-29.0	-12.0	-9.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-10.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-4.5/-5.5 -10.0/-5.5	-37.0/ -34.5	-10.0/ -5.5/ -10.0	-8.0	185	220	271	319	342	45.1	33.5	69.0	3.11	0.10	<0.001	0.22	1	0.07	72
8	-8.0	-27.0	-10.0	-10.0	172	212	269	318	339	-	33.5	72.0	3.02	-	-	0.23	-	-	-
9	-10.0/ -11.0	-31.0/ -33.0	-15.0/ -14.0	-10.0/ -10.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-9.0	-29.0	-11.5	-10.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-9.0/ -9.0	-26.0/ -26.0	-11.0	-9.0/ -9.0	187	219	273	321	354	-	33.5	-	-	-	-	-	-	0	41/49
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-9.0	-27.0	-	-9.0/ -9.0	178	220	268	317	344	-	33.3	70.0	2.98	-	-	0.21	-	-	-
15	-	-	-	-9.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-9.0/ -9.0	-26.0/ -26.0	-13.0/ -14.5	-	138	199	264	316	337	-	33.3	-	-	-	-	-	1A	-	-
18	-10.0/ -9.0	-27.0/ -27.0	-	-10.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	-8.7	-29.2	-12.0	-9.6	179	217	270	319	345	45.6	33.4	70.4	3.04	0.11	0.002	0.22	-	0.024	58
Std. Dev.	1.1	3.4	2.0	0.7	18.0	7.9	2.7	1.6	6.3	1.1	0.1	1.1	0.07	0.01	0.001	0.01	-	0.034	19.1
Corr. Mean	-	-	-	-	185	219	270	-	-	-	-	-	-	-	-	-	-	-	-
Corr. Std. Dev.	-	-	-	-	7.6	3.6	1.6	-	-	-	-	-	-	-	-	-	-	-	-

TABLE C1-6

FUEL 106

LAB ID	Cold Flow Inspections, °C Cloud Point	Pour Point	CFPP	LTFT	D86 Distillation, °C IBP	10	50	90	EP	Cetane Number	API° Gravity	Flash Point, °C	Viscosity @ 40°C, cSt	Carbon Residue On 10% Bottoms	Ash, wt.%	Sulfur, wt.%	Copper Strip Corrosion	Sediment & Water, wt.%	Water, ppm
1	-8.0	≤-43.0	-16.0	-20.0	183	221	270	317	349	46.6	33.4	70.0	-	0.14	0.005	0.23	-	0.05	-
2	-8.0	-54.0	-	-	193	221	273	323	342	45.6	-	70.0	-	0.11	<0.001	0.18	1A+	Trace	-
3	-11.0	≤-37.0	-16.0	-18.0	188	221	270	317	352	46.2	33.4	73.0	-	0.08	<0.002	0.22	1A	Nil	-
4	-8.0	≤-54.0	-15.5	-14.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-15.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-6.5/-3.5 -10.0/-6.5	-43.0/ -45.5	-18.0/ -13.0/ -14.5	-16.0	174	212	269	316	347	46.2	33.5	70.0	3.11	0.17	<0.001	0.22	1	0.10	71
8	-8.0	-51.0	-16.0	-16.0	173	210	269	314	337	-	33.5	66.0	3.03	-	-	0.24	-	-	-
9	-10.0/ -11.0	-53.0/ -52.0	-17.0/ -17.0	-16.5/ -16.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-9.0	-48.5	-15.0	-11.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-9.0/ -9.0	-45.5/ -45.5	-28.0	-21.5	186	219	272	322	352	-	33.5	-	-	-	-	-	-	0.003	43/43
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-10.0	-50.0	-	-18.0/ -18.0	176	218	269	318	344	-	33.3	70.0	2.99	-	-	0.21	-	-	-
15	-	-	-	-18.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-9.0/ -9.0	-51.0/ -51.0	-14.5/ -13.5	-	164	207	266	316	339	-	33.3	-	-	-	-	-	1A	-	-
18	-10.0/ -9.0	-45.0/ -45.0	-	-14.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	-8.9	-49.1	-16.9	-16.6	180	216	270	318	345	46.2	33.4	70.6	3.04	0.13	0.002	0.22	-	0.030	57
Std. Dev.	1.3	3.5	4.2	2.8	9.5	5.6	2.1	3.1	5.7	0.4	0.1	1.3	0.06	0.04	0.002	0.02	-	0.044	19.8
Corr. Mean	-	-	-15.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Corr. Std. Dev.	-	-	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE C1-7

FUEL 107

LAB ID#	Cold Flow Inspections, °C: Cloud Point	Pour Point	CFPP	LTFT	D86 Distillation, °C: IBP	10	50	90	EP	Cetane Number	API° Gravity	Flash Point, °C	Viscosity @ 40°C, cSt	Carbon Residue On 10% Bottoms	Ash, wt.%	Sulfur, wt.%	Copper Strip Corrosion	Sediment & Water, wt.%	Water, ppm
1	-9.0	<-43.0	-28.0	-16.5	183	223	270	319	350	48.1	33.5	67.0	-	0.18	0.005	0.23	-	0.05	-
2	-8.0	-51.0	-	-	192	218	269	317	339	45.5	-	65.5	-	0.13	<0.001	0.21	1A+	Trace	-
3	-11.0	<-37.0	-25.0	-18.0	186	217	271	320	354	45.0	33.4	69.0	-	0.07	<0.002	0.22	1B	Nil	-
4	-8.0	-48.5	-26.5	-15.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-16.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-6.5/-3.[illegible]/ -10.0/-6.5	-51.0/ -43.0	-28.0/ -26.5/ -24.5	-15.0	182	219	271	319	349	45.4	33.2	70.0	3.11	0.19	<0.001	0.22	1	0.12	69
8	-9.0	-54.0	-22.0	-17.0	162	213	268	315	335	-	33.6	67.0	2.98	-	-	0.23	-	-	-
9	-13.0/ -11.0	-52.0/ -53.0	-32.0/ -35.0	-20.0/ 20.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-11.0	-48.5	-20.5	20.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-11.0/ -11.0	-48.5/ -48.5	-24.0	-15.0	176	218	272	319	354	-	33.6	-	-	-	-	-	-	0.002	64/66
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-11.0	-52.0	-	-12.0/ -12.0	178	218	270	319	348	-	33.4	68.0	2.99	-	-	0.21	-	-	-
15	-	-	-	-16.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-10.0/ -10.0	-45.5/ -45.5	-24.5 -25.5	-	154	203	264	318	344	-	33.3	-	-	-	-	-	1A	-	-
18	-5.0/ -9.0	-45.0/ -45.0	-	-20.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Mean	-9.5	-49.3	-25.7	-16.9	177	216	269	318	347	46.0	33.4	67.8	3.03	0.14	0.002	0.22	-	0.034	67
Std. Dev.	1.8	3.0	3.7	2.5	12.7	6.0	2.5	1.6	6.8	1.4	0.1	1.6	0.07	0.05	0.002	0.01	-	0.052	2.8
Corr. Mean	-	-	-24.7	-	-	218	-	-	-	-	-	-	-	-	-	-	-	-	-
Corr. Std. Dev.	-	-	2.5	-	-	2.9	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE C1-8

FUEL 108

	Cold Flow Inspections, °C				D86 Distillation, °C														
LAB ID	Cloud Point	Pour Point	CFPP	LTFT	IBP	10	50	90	EP	Cetane Number	API° Gravity	Flash Point, °C	Viscosity @ 40°C, cSt	Carbon Residue On 10% Bottoms	Ash, wt.%	Sulfur, wt.%	Copper Strip Corrosion	Sediment & Water, vt.%	Water, ppm
1	-2.0	<-29.5	-13.0	-5.5	203	234	269	318	342	58.3	37.1	80.0	-	0.09	0.02	0.09	-	0.05	-
2	-3.5	-6.5	-	-	212	237	272	324	337	56.9	-	82.0	-	0.09	0.006	0.08	1A+	Trace	-
3	-1.0	<-26.0	-16.0	-6.5	206	232	269	318	344	52.8	36.6	84.0	-	0.09	<0.002	0.09	1A	0.05	-
4	-3.5	-26.0	-11.0	-5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	2.0/ -2.0/ -2.0	-29.0/ -37.0/ -29.0	-16.5/ -15.5	-5.0	208	229	272	327	335	56.3	37.1	85.5	3.21	0.10	<0.001	0.09	1	0.40	42
8	-3.0	-21.0	-11.0	-5.0	197	231	269	320	336	-	37.2	77.0	3.08	-	-	0.09	-	-	-
9	-3.0/ -5.0	-25.0/ -27.0	-15.0/ -15.0	-5.5/ -5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	2.0	-26.0	-19.5	-7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-4.5	<-34.5	-10.0	-	198	234	272	322	344	-	-	79.0	-	-	-	-	-	-	-
12	-2.0/ -2.0	-20.5/ -20.5	-16.0	-6.0	203	234	271	322	347	-	37.1	-	-	-	-	-	-	0.05	83/85
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-2.0	-33.0	-	-5.0	195	234	271	320	345	-	36.9	80.0	3.04	-	-	0.09	-	-	-
15	-	-	-	-7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-2.0/ -2.0	-20.5/ -20.5	-13.5/ -14.5	-	157	213	260	308	327	-	36.7	-	-	-	-	-	1A	-	-
18	0/ 0	-33.0/ -36.0	-	-6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	-2.0	-24.6	-14.2	-5.9	198	231	269	320	340	56.1	37.0	81.1	3.11	0.09	0.007	0.09	-	0.110	-
Std. Dev.	1.8	8.2	2.9	0.7	16.2	7.1	3.8	5.3	6.4	2.3	0.2	2.9	0.09	0.01	0.009	0.01	-	0.164	-
Corr. Mean	-2.3	-26.6	-	-	203	233	271	321	-	-	37.1	-	-	-	-	-	-	-	-
Corr. Std. Dev.	1.4	5.4	-	-	5.8	2.4	1.4	3.1	-	-	0.1	-	-	-	-	-	-	-	-

TABLE C2-1

ADDITIONAL LABORATORY INSPECTIONS

INSPECTIONS	FUELS 101	102	103	104	105	106	107	108	Performing Lab
Saturates (ASTM D 1319)	65	63	79	65	65	63	63	78	Lab 14
Aromatics	34	36	21	34	34	36	36	22	
Olefins	1	1	0	1	1	1	1	0	
Wax Appearance (ASTM D 3117) Point, °C	-20.0	-10.5	-3.5	-20.5	-10.5	-11.5	-11.0	-3.5	Lab 18
Fluidity Test, % Recovery (ml of flow)									
-29.0°C	35 (14)	0 (0)	0 (0)	95 (38)	95 (38)	92.5 (37)	92 (37)	8 (3)	
-34.5°C	0 (0)	0 (0)	0 (0)	14 (5.5)	Trace (Trace)	94 (37.5)	95 (38)	0 (0)	Lab 9
-39.5°C	Not Run	Not Run	Not Run	0 (0)	0 (0)	73 (29)	78 (31)	Not Run	
Pumpability Test, Seconds to Pump 200 ml/rating									
-18.0°C	9.4/G	9.9/G	NF/US	Not Run	8.4/G	Not Run	Not Run	8.7/G	
-23.5°C	9.9/G	NF/US	NF/US	Not Run	9.4/G	Not Run	Not Run	13.7/G	Lab 9
-29.0°C	14.3/G	LF/US	NF/US	10.4/G	16.4/G	12.9/G	16.7/G	16.3/G	
-34.5°C	NF/US	NF/US	NF/US	LF/P	27.3/G	17.5/G	15.6/G	33.4/F	
KEY: F=Fair; G=Good; P=Poor; LF=Little Flow; NF=No Flow; and US=Unsatisfactory									
Setapoint									
Visual Cloud, °C	-17.0	-8.0	-	-18.0	-9.0	-9.0	-9.0	-	Lab 12
No Flow, °C	-24.5	-15.0	-	-30.5	-23.5	-39.5	-39.5	-	
Flow, °C	-20.0	-16.5	-	-30.0	-25.0	-36.5	-39.0	-	
No Flow, °C	-26.5/-27/ -25.5/-26	-20.5/-18.5/ -18.5/-16	-8/-9/ -7.5/-5.5	-32.5/-32.5/ -32/-33	-27.5/-27/ -27.5/-27	-43/-42.5/ -46/-44.5	-41.5/-43/ -41.5/-42	-21.5/-19.5/ -19/-22	Lab 13
Flow, °C	-25.5/-26/ -25.5/-26	-22/-21/ -19.5/-18.5	-5.5/-6.0/ -5.5	-31.5/-30.5/ -30.5/-33.5	-28/-27/ -28/-27	-43/-44/ -46.5/-46	-42.5/-42.5/ -43.5/-43	-19.5/-18/ -21/-19.5	
Proprietary Cold Flow Test, °C	-25.5/-27/ -25/-23.5	-24.5/-19.5 -18.5/-15	-5.5/-7.5/ -12.5/-7	-33/-32/ -26/-27.5	-14.5/-15.5/ -16/-15.5	-50/-49/ -47/-45.5	-47/-50/ -48/-47	-25.5/-24/ -24.5/-25	Lab 13

TABLE C2-2

DIFCOFIT PLUGGING TEMPERATURES (°C)

LAB #6

Fuel	Screen Size			
	37 μm	130 μm	125 μm	420 μm
101	-20	-20	-20	-27
102	-12	-20	-22	< -22
103	- 4	- 4	- 4	- 9
104	-21	-31	< -32	< -32
105	-13	-19	< -22	< -22
106	-17	< -22	< -22	< -22
107	-21	< -22	< -22	< -22
108	- 4	- 6	- 7	< -16

TABLE C2-3

NORMAL PARAFFIN INSPECTION
BASE FUELS

	Normal Paraffin Content, wt %					
	Lab #1			Lab #3		
Fuel:	101	102	103	101	102	103
Carbon Chain Length						
5	-	-	-	-	-	-
6	-	-	-	-	-	-
7	Trace	Trace	-	-	-	-
8	.42	.03	.04	-	-	-
9	.67	.11	.10	.83	.18	.17
10	.91	.42	.34	1.11	.52	.40
11	1.09	.83	1.04	1.30	.61	.91
12	1.37	1.10	2.29	1.27	.89	2.07
13	2.05	1.31	3.03	1.52	1.01	2.66
14	2.23	1.24	3.09	2.20	1.18	3.29
15	3.70	1.56	3.19	3.88	1.34	3.20
16	3.32	1.65	2.96	3.46	1.41	2.97
17	1.25	1.41	2.79	1.57	1.68	2.93
18	.52	1.02	2.19	.70	1.15	2.24
19	.44	.97	2.03	.56	.92	1.92
20	.44	.62	1.55	.40	.59	1.41
21	.36	.49	1.16	.31	.41	1.00
22	.19	.33	.69	.17	.28	.60
23	.12	.22	.40	.10	.19	.36
24	.06	.15	.22	-	.12	.20
25	.02	.10	.12	-	.07	.12
26	.01	.05	.06	-	.04	.06
27	Trace	.03	.03	-	.02	.03
28	Trace	.01	.01	-	-	.02
29	-	.01	Trace	-	-	-
30	-	Trace	-	-	-	-
Total n-Paraffin Content, wt %	19.2	13.6	27.3	19.4	12.6	26.6

80-012
(April, 1975 as 100.65)
Revised December, 1980

LOW-TEMPERATURE FLOW TEST FOR DIESEL FUELS

1. Scope

1.1 This method is for the determination of the operability of diesel fuels in automotive equipment at low temperatures.

1.2 The method is applicable to all distillate diesel fuels. Fuels passing this test are expected to provide satisfactory operability at temperatures equal to or higher than that of the test.

2. Summary of Method

2.1 A series of 200-mL samples of test fuel are gradually lowered to the desired testing temperature at a controlled cooling rate (-1°C or -2°F per hour). At 1°C intervals, a sample from the series is filtered through a 17-μm screen at 20-kPa (6-in. Hg) pressure. If 180 mL of sample can be filtered in less than 60 seconds, it shall be considered as having passed the test. This procedure is repeated until a sample from the series does not pass the test. The minimum operability temperature is the lowest temperature, expressed as a multiple of 1°C (2°F), at which 180-mL of sample, when cooled under the prescribed conditions, can be filtered in less than 60 seconds.

2.2 Alternatively, a single sample may be tested at a predetermined temperature to determine whether it passes or fails at that temperature.

3. Precision

3.1 Repeatability, the difference between successive test results, obtained by the same operator with the same apparatus under constant operating conditions on identical test material, would in the long run, in the normal and correct operation of the test method, exceed the following value only in one case in twenty: 1.4°C (2.5°F).

3.2 Reproducibility, the difference between two single and independent results, obtained by different operators working in different laboratories on identical test material, would in the long run, in the normal and correct operation of the test method, exceed the following value only in one case in twenty: 5°C (9°F).

4. Apparatus

4.1 Glass bottles, two, clear, wide-mouthed, one having 240-mL (8-oz.) capacity and marked with a line indicating the 200-mL level, the other having 500-mL (16-oz.) capacity and graduated in 10-mL increments.

4.2 Filtering assembly, as shown in Figure 1.

4.3 Filter, as shown in detail in Figure 2. The fine wire mesh cloth has a nominal filtration rating of 17 microns. The nominal filtration rating indicates a 98 percent removal by weight of all particles equal to or greater than 17 microns. This filter cloth may be obtained from:

Pall Trinity Micro Corporation
Cortland, New York 13045.

The catalog description is:

Regimesh Sintered Woven Wire Mesh, Grade M, 304 SS.

4.4 Temperature controller, capable of cooling at a rate of -1°C (-2°F) per hour between +10°C (50°F) to -40°C (-40°F).

4.5 Cooling bath, capable of cooling multiple samples to the required temperatures using refrigeration or suitable freezing mixtures. The size and shape are optional.

4.6 Stop watch or electric timer, capable of measuring tenths of a second.

4.7 Vacuum source, capable of maintaining pressure at 20 kPa (6 in. Hg).

5. Procedure

5.1 Filter the sample under test through dry, lintless filter paper at 15°C (60°F) or higher.

5.2 Wash the filter assembly in acetone and heptane using a vacuum to suck solvent through the fine wire-mesh cloth.

NOTE 1: Periodically, dismantle and inspect the filter assembly. Replace damaged or plugged filter cloths. A reference fluid can be used to determine when screens must be replaced.

5.3 Pour 200 mL of clean, dry sample into a 240-mL (8 oz.) wide-mouthed bottle.

5.4 Insert a clean filter assembly into the sample and cover the joint (point A of Figure 1) and lid with aluminum foil to exclude condensation from internal moisture.

5.5 Insert either a thermometer or thermocouple into a separate bottle containing an equal amount of sample.

5.6 Place the two bottles (from Steps 5.3 and 5.5) into the cooling bath at a temperature that is at least 8°C (15°F) above the cloud point (see ASTM D2500) or wax-appearance point of the fuel under test. Close the lid of the cooling bath.

5.7 Start the temperature programmer at -1°C (2°F) per hour.

5.8 Before the sample reaches the desired test temperature, check the following:

5.8.1 Point B (Figure 1) should be closed.

5.8.2 An empty sample receiver should be in position.

5.8.3 Pressure should be adjusted to 20 kPa.

5.8.4 The timer should be reset.

NOTE 2: Be sure that the next two steps (5.9 and 5.10) can be completed in less than one minute.

5.9 Cool to the desired testing temperature. Using the stem of the filter assembly, gently stir (15 revolutions) the sample to disperse any settled wax crystals. Connect the joint to the tubing of the filtration apparatus at point A (Figure 1).

5.10 Filter the sample by opening the valve at point B (Figure 1) while starting the timer. If necessary, adjust the vacuum bleed to maintain a pressure of 20 kPa (6 in. Hg).

5.10.1 If 180 mL of the sample can be filtered in less than 60 seconds, stop the timer at the instant the filter assembly loses suction on the sample and begins sucking air. Close the valve at point B. Measure the volume of sample filtered in mL. Record the testing temperature in °C (°F), the volume of sample filtered in mL, and the filtration time in seconds. This is considered a passing result.

5.10.2 If 180 mL of sample cannot be filtered within 60 seconds, stop the timer and close the valve at point B at 60 seconds. Measure the volume of sample filtered in mL. Record the testing temperature in °C (°F), the volume of sample filtered in mL, and the filtration time in seconds. This is considered a failing result.

5.11 To determine the minimum operability temperature, repeat Steps 5.8 through 5.10 at 1°C intervals until at least one passing result (Step 5.10.1) and one failing result (Step 5.10.2) are obtained. Record the temperature of the last passing result that preceded the failing result in °C (°F).

6. Reporting

6.1 Report the temperature recorded in Step 5.11 as: Minimum Operability Temperature (AM-S 80-012) = _____°C (_____°F).

6.2 Alternatively, report the result recorded in Step 5.10.1 or 5.10.2 as: Pass or Fail (AM-S 80-012) at ___°C (____°F).

.ıGURE 1

LTFT SAMPLE FILTRATION ASSEMBLY

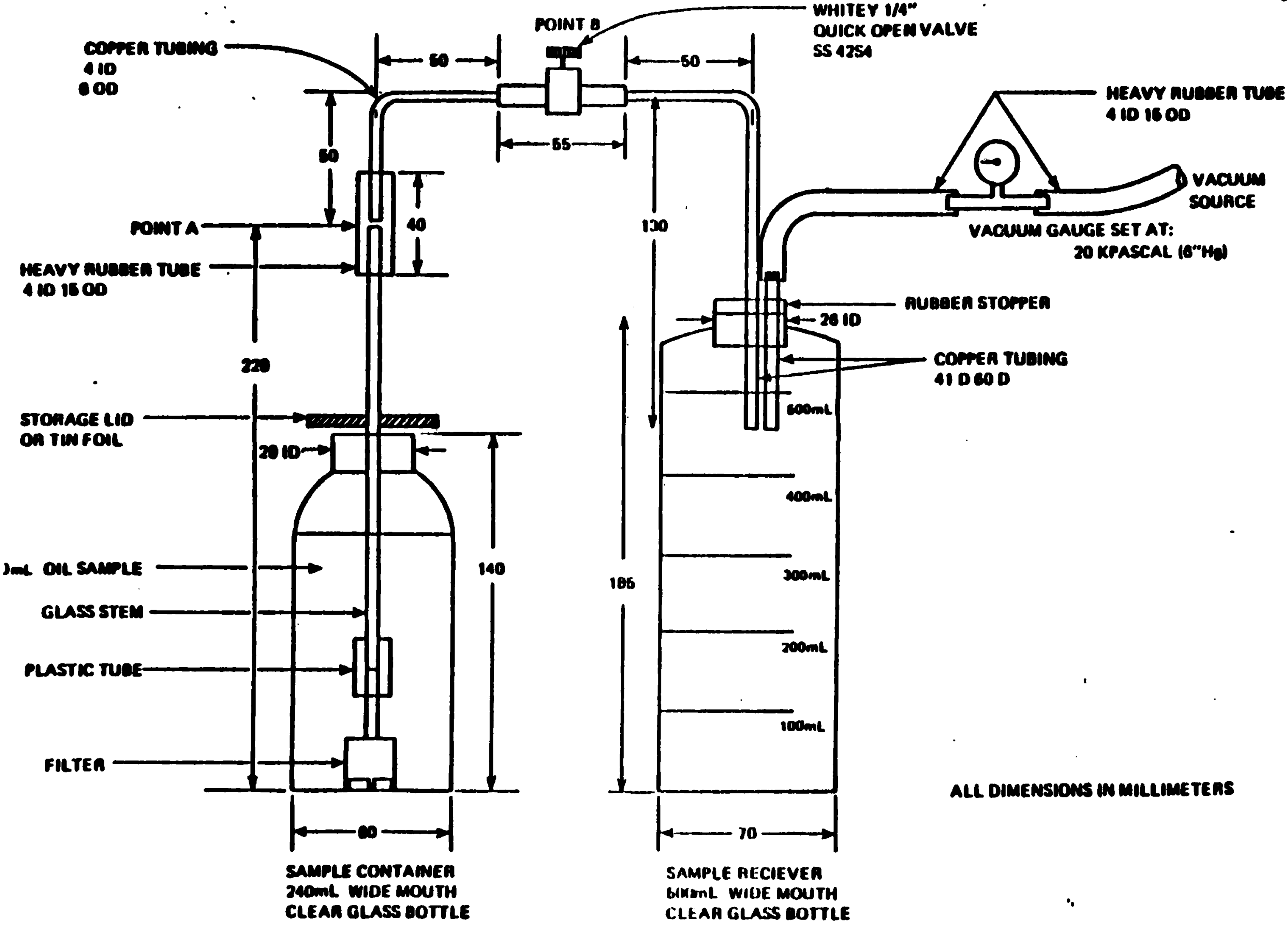
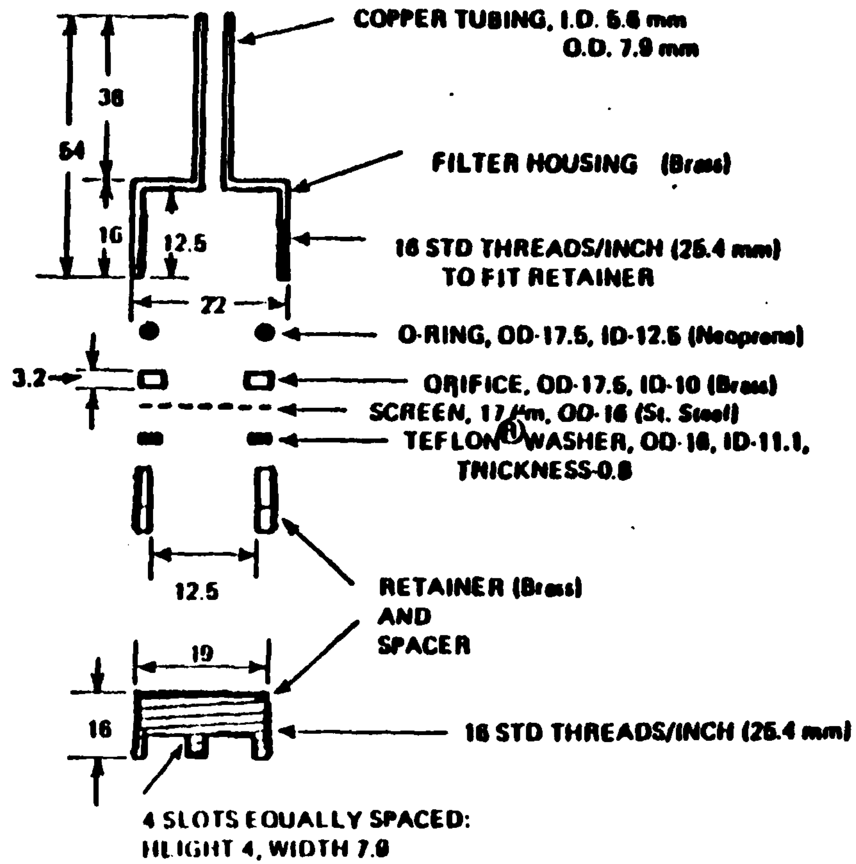


FIGURE 2

LTFT FILTER DETAILS



ALL DIMENSIONS IN MILLIMETERS

Equipment List for LTFT

Supplier of Glassware

I. Lab Glass, Inc.
1172 N. W. Boulevard
Vineland, NJ 08360
(609) 691-3200

Catalog No.	Description	Price, Feb. 1980
ERC-779-86	500 ml graduated receiving bottle	$7.02/ea.
ERC-780-86	8 oz. sample bottle	$4.40/ea.
LG 1000-104	10/30 inner ground joint	$2.66/ea.

Supplier of Filter Screens

II. Pall Trinity Micro Corp.
Cortland, New York 13045
(607) 753-6041

17 micron rigimesh "M" 304 SS
Sintered woven wire mesh

Sold by ft^2

5/8" OD screens

COLD FILTER PLUGGING POINT TEST

FOR DIESEL FUELS (CFPP)
IP 309/76

The CFPP method was designed to correlate with diesel engine operability under low temperature conditions as influenced by the formation of wax crystals in the fuel. The Cold Filter Plugging Point is the temperature (in multiples of 1°C or 2°F) at which the fuel ceases to flow through a fine wire mesh filter after a prescribed cooling sequence.

Test Outline

A standard volume of fuel is drawn through a fine wire mesh filter at successively decreasing temperatures using a pressure differential of 20 cm of water vacuum. The presence of precipitated fuel wax will cause the flow rate to decrease, and eventually complete plugging of the filter will occur. The temperature at which flow finally ceases is the cold filter plugging point.

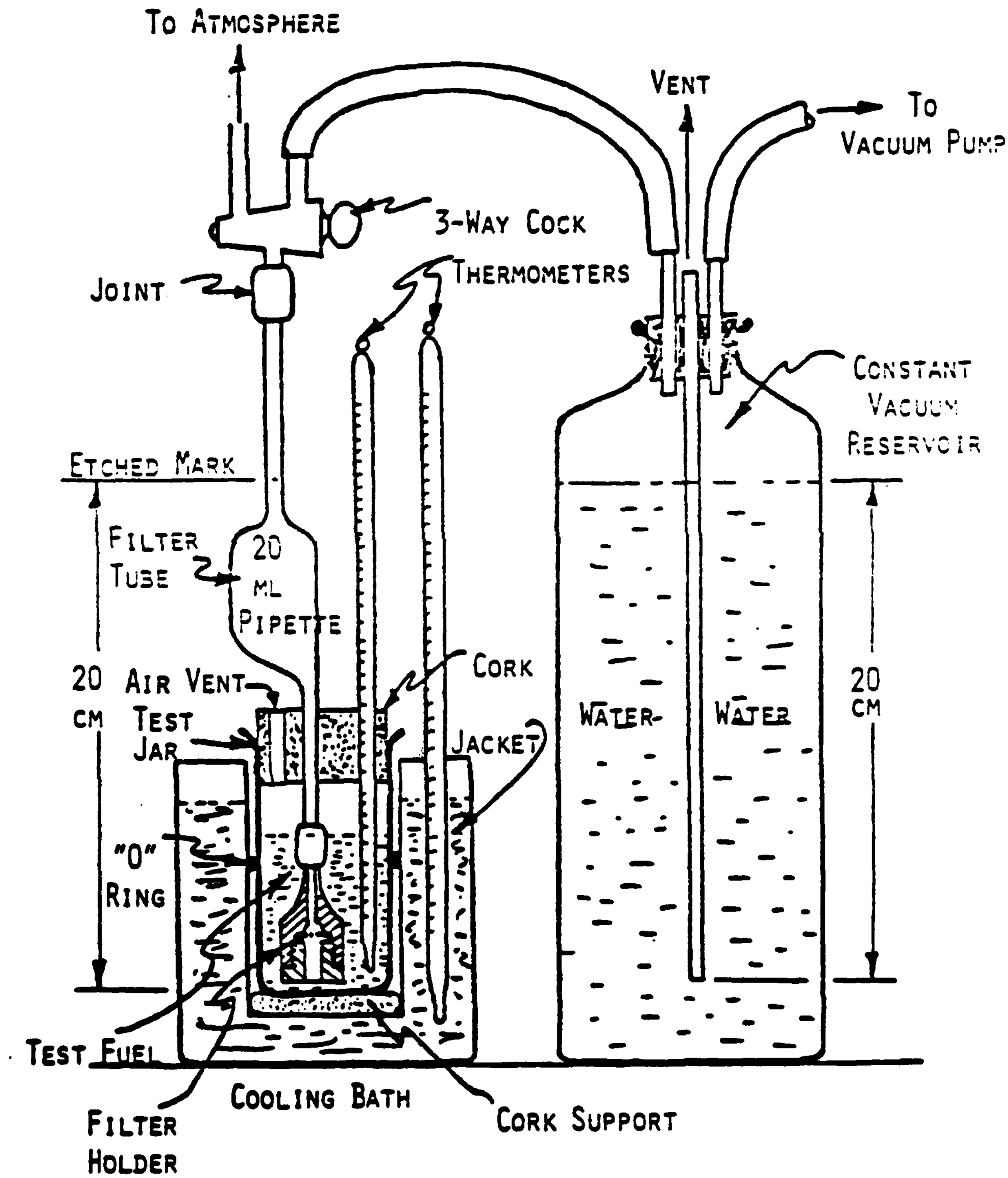
Test Equipment

As shown in the following schematic drawing, the filter tube is a 20 ml pipette with the top end affixed to a three-way cock to enable venting to atmosphere or to apply a constant vacuum of 20 cm of water. The stopcock is connected by rubber tubing to the constant vacuum reservoir (a large glass bottle). The constant vacuum is maintained at 20 cm by ensuring a continuous air bleed into the reservoir.

The bottom end of the filter tube is connected to the filter funnel made of brass to hold the stainless screen (45 μ openings) of 1.2 cm diameter. The funnel assembly is immersed in the test fuel contained in a glass jar (as used in ASTM D97-57 or IP 15/65). The test jar is covered with a cork having holes for the filter tube, thermometer and vent to atmosphere.

Surrounding the test jar is a cooling jacket with temperature controlled at -34°C (or -51°C for samples with CFPP below -20°C).

COLD FILTER PLUGGING POINT APPARATUS



Cold Filter Plugging Point Test
For Diesel Fuels (CFPP) (continued)

Procedure

1) The filtered fuel sample (45 ml) is poured into the test jar and covered with the stopper carrying the pipette, filter unit and thermometer.

2) The test jar assembly is inserted in the cooling jacket at -34°C and the top of the pipette connected to the vacuum system.

3) At 1°C (2°F) intervals, the three-way cock is turned so that the vacuum causes the fuel sample to be drawn up through the filter screen into the pipette. Once the fuel reaches the etched mark on the pipette, the three-way cock is turned to vent the pipette to the atmosphere allowing the sample to return to the test jar.

4) Repeat the operation in item 3) until the temperature is reached at which the sample ceases to flow through the filter or the pipette is not filled to the reference line in 60 seconds. Record the temperature at which this last filtration commenced. A CFPP is recorded also if the fuel fails to flow back into the cell.

Results Reported

The temperature as recorded in item 4) above is reported as the Cold Filter Plugging Point.

Precision

The following criteria can be used for judging the acceptability of results (95 percent confidence).

Repeatability: Duplicate results by the same operator should be considered suspect if they differ by more than the appropriate value given below.

Reproducibility: The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the appropriate value given below.

Level of Results °C	Manual Apparatus Repeatability °C	Manual Apparatus Reproducibility °C	Automatic Apparatus Repeatability °C	Automatic Apparatus Reproducibility °C
-1 to -5	1	2	1	3
-6 to -10	1	2	1	4
-11 to -15	2	3	1	4
-16 to -20	2	3	1	5
-21 to -25	2	4	1	5
-26 to -30	2	4	2	6
-31 to -35	3	5	2	7

FLUIDITY TEST

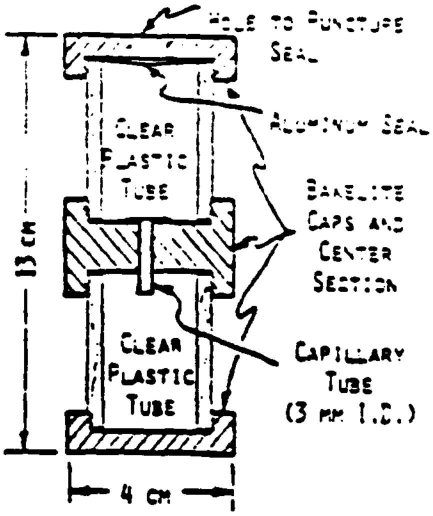
The Fluidity Test is a simple bench test method to determine the flow properties of middle distillate fuel at low temperatures where wax crystallization can cause filter plugging or otherwise stop the flow of fuel.

Test Outline

Forty ml of test fuel are soaked for two hours at the desired low temperature in one chamber of a two-chambered plastic holder. The chambers are connected by a capillary tube. At two hours the holder is inverted for one minute with the fuel on top. A thin gasket is punctured to allow the fuel to flow through the capillary into the lower chamber for three minutes. A pass result is when 80 percent or more of the fuel reaches the lower chamber.

Test Equipment

As shown on the right, the small plastic holder consists of two transparent cylindrical chambers connected by a central bakelite piece containing the capillary tube through which the test fuel flows. Two bakelite caps seal the extreme ends of the assembly. One cap contains a hole through which the thin aluminum seal can be punctured to allow the fuel to flow into the lower chamber.



Procedure

1) Forty ml of test fuel are poured into the chamber sealed at the outer end with aluminum seal. The center section is screwed on with the capillary tube extending away from the fuel. The other chamber is screwed into place.

2) The test fuel should initially be at least ten degrees above its cloud point. The complete assembly is lowered into a standard ASTM pour point bath at the chosen test temperature (see test position sequence in sketch below).

Fluidity Test (continued)

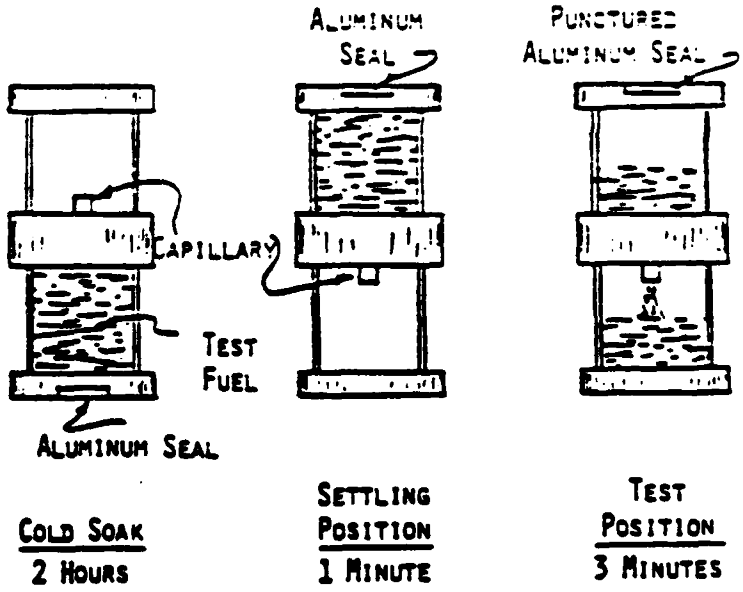
Procedure

3) After the two hour soak, the test unit is removed from the bath, inverted slowly and lowered back into the bath.

4) After one minute settling time, the aluminum seal on the unit still in the bath is punctured to make an opening approximately 5/16 inch diameter.

5) A stopwatch is started at the time the seal is punctured. After three minutes, the unit is removed from the bath and the volume recorded of test fuel recovered in the lower chamber.

SEQUENCE OF TEST UNIT POSITIONS



6) Test temperatures may be lowered as desired until a fail result is determined as the limiting temperature. Typical bath temperatures may range from +32 to -40°C.

Results Reported

The volume of fuel recovered in the lower chamber is recorded along with the test temperature.

Fuel flowability is considered a pass if 80 percent or more of the fuel has passed into the lower chamber in three minutes.

PUMPABILITY TEST FOR DISTILLATE FUELS

The pumpability test is designed to measure the ability to pump distillate fuels through a fine filter screen under low temperature conditions where fuel wax crystals may interfere.

Test Outline

The fuel is subjected to cooling through a programmed sequence of temperatures. It is forced to flow by a controlled pressure of 15 psig through a short length of tubing and filter screen. The criteria for cold-flow performance, or pumpability, are the following:

a) Volume of fuel that flows through the tubing and screen

b) Fuel flow rate

Test Equipment

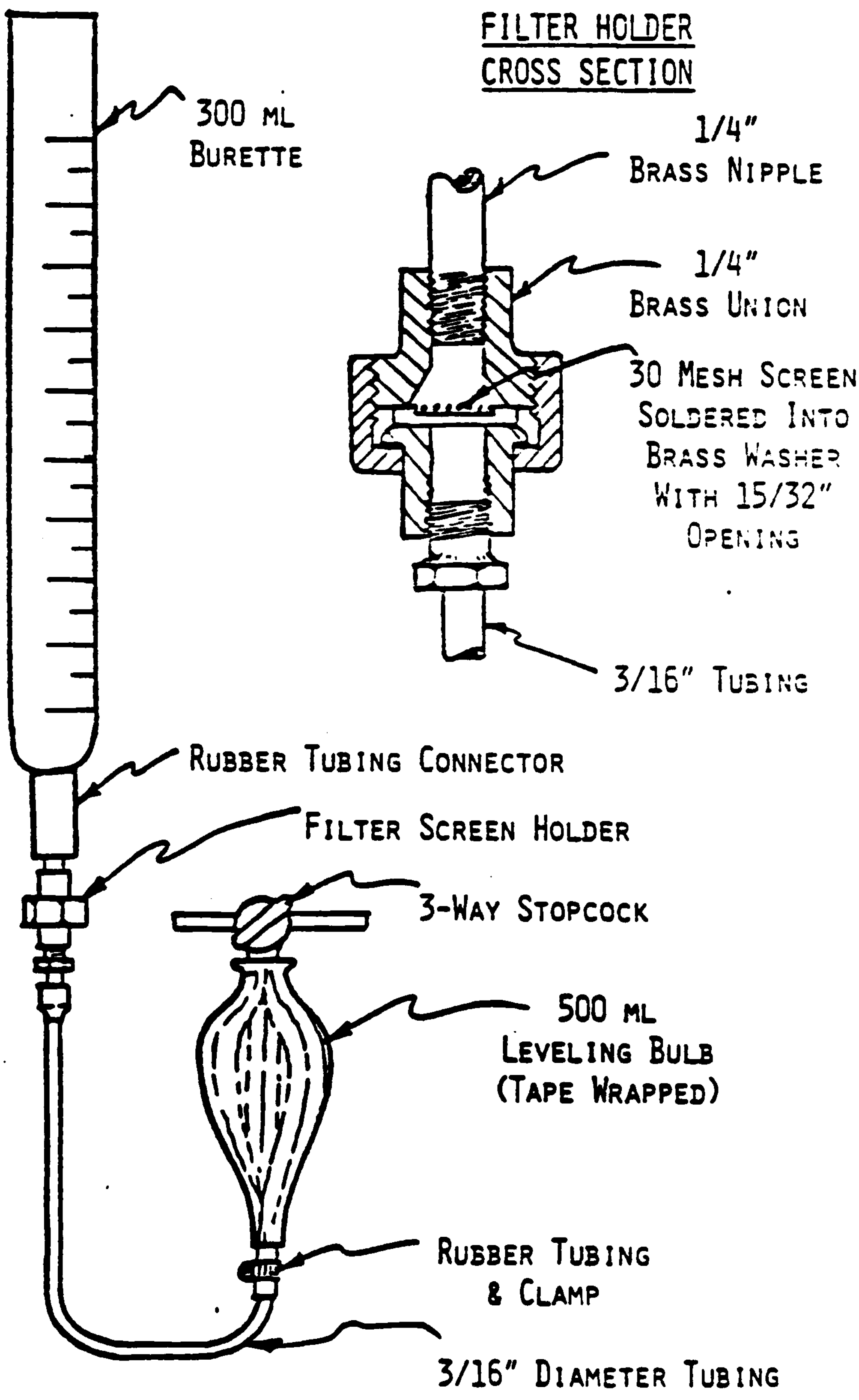
As shown in the following schematic drawing, a 300 ml burette is attached to the filter holder into which a 30 mesh brass screen has been soldered. A 14 inch U-tube of 3/16 inch copper tubing then connects to the fuel holder. The holder is 500 ml leveling bulb, wrapped with cloth tape for safety. The top of the bulb is sealed with a three-way stopcock wired securely to the leveling bulb prior to each test run.

A cold chest large enough to house the complete apparatus* is required with a capacity to achieve a minimum -30°F (-34°C) temperature. A temperature programmer-controller must be capable of the following sequence:

	Temperature Program, °F (°C)			
Test Temperature ▶	0 (-18)	-10 (-23)	-20 (-29)	-30 (-34)
Elapsed Time, hours				
0	75(24)	75(24)	75(24)	75(24)
2	40(4.4)	30(-1)	20(-6.7)	10(-12)
8	0(-18)	-10(-23)	-20(-29)	-30(-34)
12	15(-9.4)	5(-15)	-5(-20)	-15(-26)
16	0(-18)	-10(-23)	-20(-29)	-30(-34)

* except for the burette

PUMPABILITY TEST APPARATUS



Pumpability Test for Distillate Fuels (continued)

Procedure

1) 300 ml of test fuel are poured into the clean, dry fuel holder. The stopper and stopcock are installed and wired.

2) With the stopcock open, the holder and filter screen assembly are placed in the cold chest and the temperature programmed according to the selected test temperature.

3) At the end of the cooling period, the burette is attached and the stopcock set to block one outlet to which is now attached the rubber pressure tubing.

4) With nitrogen pressure adjusted to 15 psig, the stopcock is turned to admit nitrogen to the fuel holder.

5) Start a stopwatch or other accurate timer when the fuel rises to the first mark in the burette. Record the time to deliver 200 ml beyond this mark.

   The test is stopped after 60 seconds, even if 200 ml have not been delivered.

6) Shut off nitrogen pressure, remove apparatus, clean and prepare for next sample.

Results Reported

The time in seconds required to pump 200 ml into the burette are recorded. Or, when less than 200 ml are pumped, report the volume in ml pumped in the 60 second test period.

The following rating scale is arbitrary but selected to generally correlate with full-scale commercial equipment:

Rating	Seconds to Pump 200 ml	ml Pumped in 60 Seconds
Good	1 to 30	
Fair	30 to 60	
Poor		100 to 200
Unsatisfactory		0 to 100

SETAPOINT TEST

The Setapoint Detector was developed by Stanhope-Seta, Ltd. as a direct response to a need expressed at the 1976 ASTM Low Temperature Jet Fuel Symposium and by IATA's Aviation Fuel SubCommittee for a quick field test to measure the freezing point of jet fuels. In prototype form it proved to be equally useful for sensing the freezing point of jet fuel and the Cloud Point or Cold Filter Plugging Point of distillates. On the basis of promising prototype data, the Section I Task Force was formed to conduct a cooperative program to establish precision. The program was completed in 1980.

The Setapoint Detector is an automatic apparatus that utilizes a 5 ml fuel sample and provides low temperature data as digital readouts as the test proceeds. The rate of cooling of the sample (by a combined refrigeration and thermo-electric (Peltier) cell) is controlled as the fuel is passed from an outer to an inner cell through 325 mesh filter using a mercury pump at the rate of one movement per second. As wax builds up on the filter, pressure drop increases. At a ΔP of 10 mm, the temperature of the fuel in the cell registers as the "NO FLOW" point and a warming cycle automatically starts. The pump continues to exert pressure on the partially blocked filter and at the point that wax melts sufficiently to reduce the pressure drop below 10 mm, a second temperature registers as the "FLOW" Point. A test requires about 15-20 minutes.

The apparatus is housed in a 60 cm cubic block box weighing about 30 kg. It requires only normal electrical power for operation. Cleaning the cell to change fuels is a simple step. A viewing port permits the operator to see the moving fuel in the cell and look for wax crystals. Stanhope-Seta prices the device at $12,500.

DIESEL FUEL COLD FILTERABILITY TEST (DIFCOFIT)

This test was developed at General Motors Research Laboratories to study the low-temperature filter plugging characteristics of diesel fuels, in particular diesel fuels treated with flow improver additives. In this test a sample of diesel fuel is cooled at a rate of 2°C/h and filtered at 1°C decrements below its cloud point through 37, 125, and 420 µm square mesh screens to determine their plugging temperatures and then to determine a relationship between filter plugging temperature and filter pore size. The details are discussed in SAE paper No. 811181.

Apparatus

A schematic of the experimental apparatus for the DIFCOFIT is shown in Figure 1. All of the test apparatus is inside a temperature programmable cold box (similar to Tenney Model 14 of Tenney Engineering, Inc., 1090 Springfield Road, Union, New Jersey 07083). Gelman filter holders (Gelman Science, Inc., Ann Arbor, Michigan 48106, Filter Holder No. 1109) are used to hold 2.5 cm diameter discs of 400 mesh (420 µm), 120 mesh (125 µm), and 40 mesh (37 µm) standard square mesh screens. The following modifications are made to the filter holders: (1) remove and discard the permanently positioned support screen inside the filter holder base; (2) increase the opening of the cap from 1 cm to 2 cm diameter. The modified Gelman filter holder is shown in Figure 2.

Test Procedure

The procedure for determining the filter plugging temperatures is as follows:

1. Equip the filter holders with the filter screens and place the assembly in the cold box.

2. Submerge the filter holders in a beaker containing 2 L of the test fuel.

3. Program the temperature controller to cool the sample at 30°C/h until it reaches a temperature 4°C above the cloud point, and then cool at a rate of 2°C/h.

4. At the cloud point temperature and at every 1°C interval thereafter, attempt to filter 200 mL of fuel through the 37 µm screen. If it takes more than 30 s for the 200 mL to flow through the screen, the 37 µm screen is considered plugged. Note this temperature as the filter plugging temperature for the 37 µm screen. If the flow time is less than 30 s, none of the three screens are plugged at that temperature. After the temperature at which the 37 µm screen plugs is determined, test the 125 µm screen for plugging in the same manner. The 125 µm screen is considered plugged if it takes more than 20 s for 200 mL of fuel to flow through it. Next test the 420 µm screen for plugging; the screen is considered plugged if it takes more than 15 s for 200 mL of fuel to flow through it. If one or more of the screens remain unplugged at a given temperature, repeat the filtration procedure for the unplugged screens at 1°C decrements until all three screens have plugged.

5. Report the filter plugging temperature of each of the three screens.

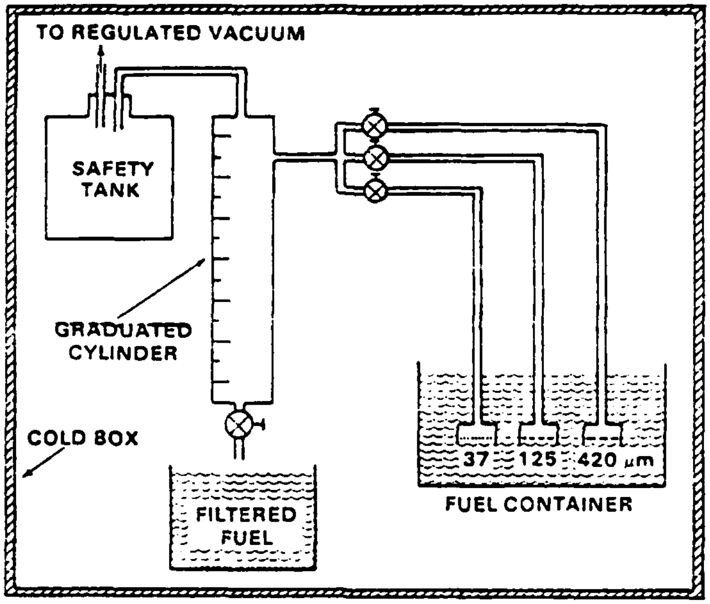
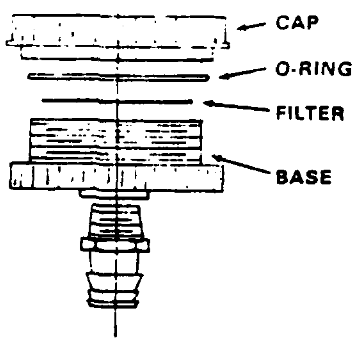


Fig. 1 - Schematic of the DIFCOFIT experimental apparatus



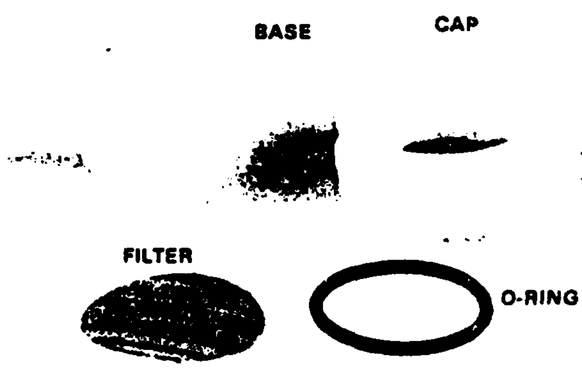


Fig. 2 - Filter holder assembly

GAS CHROMATOGRAPHIC DETERMINATION OF n-PARAFFINS IN LIGHT CATALYTIC CYCLE OILS, DIESEL FUELS, AND HEATER OILS

Lab #1

Scope

This method was developed to determine the weight per cent of nC_{15} thru nC_{28} in light catalytic cycle oils (LCCO), diesel oils, and heater oils. Weight per cents of the lower boiling n-paraffins (nC_6 - nC_{14}) are estimated, but because of the incomplete separation of many of the non-normal components from the n-paraffins in this boiling point portion of the sample, the results must be regarded as semi-quantitative.

Summary

A qualitative run is made on the sample to be analyzed to determine which of the n-paraffins are present and approximately in what amount. The "pilot" run is compared against a chromatogram of an analysis of a calibration standard which contains only n-paraffins. From this comparison, a n-paraffin not found in the sample to be analyzed is chosen to be an internal standard. The n-paraffin picked as the internal standard is weighed into a known weight of sample. A portion of the weighed sample with the internal standard is injected into a gas chromatograph which is equipped with a non-polar column. The column oven temperature is programmed until all of the components have been eluted. The non-polar column provides a boiling point order separation. The concentration of each n-paraffin in the sample is compared to the concentration of the internal standard, and calculated as weight per cent.

Apparatus and Reagents

A. A gas chromatograph equipped with dual flame ionization detectors and temperature programming capability.

B. Non-polar analytical column 20' x 1/8" stainless steel packed with 10% OV-1 on 80/100 mesh Gas Chrom Q.

C. Reference column: Same as the analytical column.

D. 1mV recorder.

E. 10 microliter syringe.

F. Research grade quality of the n-paraffin used as the internal standard.

N-PARAFFIN ANALYSIS

LAB #3

The n-paraffin analysis is a gas chromatographic procedure for determining normal paraffin content and carbon number distribution of waxes and gas oils. A sample is diluted in CS_2 and injected, using a splitter, onto a fused silica capillary column which is temperature programmed. The signal from a flame ionization detector is stored in digital form in a computer and is integrated in two ways. First, the n-paraffin peaks are integrated, with the top of the oil envelope serving as a baseline. Second, the baseline is held horizontal during integration. The non-normal paraffins (i.e., all other molecules present, including aromatics, naphthenes, etc.) are determined by subtraction.

APPENDIX D

COMPUTERIZED DATA BASE

DEFINITION OF VARIABLES USED IN DATA ANALYSIS COMPUTER PROGRAM

VARIABLE	DEFINITION
FUEL	Test Fuel
RUN	Run Number
COOLDOWN	Indicates whether Cool Down data available (Y = Yes, N = No)
HEATER	Whether Block Heater was used (Y = Yes, N = No)
DELTA1	Maximum ΔP at Primary Filter (ΔPSI)
DELTA2	Maximum ΔP at Secondary Filter
MINP4	Minimum P4 pressure
TANK	Tank Temperature at start of run (°C)
AMBIENT	Ambient Temperature at start of run (°C)
MINAMB	Minimum Ambient Temperature during run
MAT	Minimum Temperature reported either at field site or Kapuscasing weather station
MINCOOL	Minimum Temperature during cool down
CLDP	Cloud Point (°C)
LTFT	LTFT (°C)
CFPP	CFPP (°C)
POUR	Pour Point (°C)
MINFTEM	Minimum of Fuel Temperature in fuel system at any point in time
FUELFAIL	Fuel Temperature at point of failure. Minimum Fuel Temperature upstream of failure point (°C)
RATING	Operability Rating 1, 2, 3 or 4
FAILLOC	Failure Location T = Tank, O = Tank Outlet, P = Primary Filter, S = Secondary Filter
FAILTIME	Time to Failure of vehicle (minutes)

FAILMILE	Distance to Failure of vehicles (miles)
RESTRICT	Fuel Restriction 0 = No Plugging 1 = Primary or Tank Filter 2 = Secondary 3 = Both 4 = Other 5 = Unknown
COMMENT	Comments on test run

FIELD DATA BASES COMBINED
MINUS VEHICLE 122, RUNS 42 AND 76

VEHICLE=121

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL	RATING	FAILLOC
1	101	15	Y	N	.	.	.	-14.9	-17.7	-18	-18.0	.	-17.9	-17.9	1	S
2	101	40	N	Y	.	.	.	-26.2	-30.1	-21	-30.1	.	-26.2	-26.2	4	T
3	101	42	N	Y	.	.	.	-21.1	-23.8	-1[illegible]	-23.8	.	-21.1	-21.1	4	T
4	101	62	Y	Y	1.4	1.0	3.7	-16.0	-15.3	-19	-19.0	-15	-16.0	-13.6	1	O
5	101	63	Y	Y	0.9	0.9	3.2	-17.0	-14.6	-21	-21.0	-17	-17.9	-17.9	1	T
6	101	75	Y	Y	4.7	1.0	2.2	-21.6	-13.3	-28	-28.0	-23	-23.4	-23.4	2	T
7	102	17	Y	N	.	.	.	-11.9	-17.2	-19	-19.0	-12	-17.2	-17.2	4	S
8	102	19	Y	N	.	.	.	-9.0	-14.0	-14	-14.0	-9	-14.7	-14.7	4	S
9	102	24	Y	N	3.3	11.8	-6.9	-10.0	-14.0	-14	-14.4	-10	-10.0	-10.0	2	S
10	102	37	N	N	.	6.6	-1.9	-7.0	-13.5	-13	-13.5	.	-11.8	-11.8	2	S
11	102	84	Y	N	1.1	0.7	3.1	-2.5	-5.2	-6	-6.0	-2	-5.2	-5.2	1	O
12	103	87	Y	N	1.3	0.8	3.5	0.2	-0.2	.	-0.2	.	-0.6	-0.6	1	T
13	103	92	Y	N	1.5	0.7	3.9	-1.4	-2.3	-3	-3.1	-1	-1.6	-1.6	1	O
14	103	94	Y	N	.	.	.	-4.1	-7.5	-7	-7.5	-4	-4.1	.	4	
15	103	106	N	N	.	.	.	-4.1	-1.8	0	-8.6	.	-5.3	-5.3	4	
16	104	16	Y	Y	.	.	.	-16.6	-16.1	.	-24.8	-19	-19.0	-18.2	1	T
17	104	27	Y	Y	2.9	6.5	-1.8	-21.0	-24.3	-26	-26.0	-21	-21.1	-21.1	2	S
18	104	30	Y	Y	2.3	1.2	3.5	-21.3	-17.1	-25	-25.0	-21	-21.3	-20.8	1	T
19	104	34	N	Y	12.0	4.1	-12.4	-26.5	-33.1	.	-33.1	.	-28.4	-28.4	4	P
20	104	41	N	Y	.	.	.	-22.2	-16.7	-19	-24.2	.	-22.2	-21.7	4	S
21	105	23	Y	N	1.6	0.9	3.2	-4.5	-8.4	-10	-10.0	-8	-8.0	-7.2	1	S
22	105	26	Y	N	2.6	18.7	-13.1	-8.0	-14.7	-13	-14.7	-8	-13.8	-13.8	4	S
23	105	64	Y	Y	1.7	2.2	2.7	-9.9	-11.5	-11	-11.5	-10	-10.9	-10.9	1	O
24	105	65	Y	N	1.5	14.2	-9.2	-11.7	-11.6	-14	-14.0	-11	-12.2	-12.2	2	S
25	105	77	Y	Y	1.5	4.1	1.0	-14.0	-13.2	-16	-16.3	-14	-14.8	-14.8	2	S

OBS	FAILTIME	FAILMILE	RESTRICT	COMMENT
1	2	.	.	NO PRESSURE DATA
2	10	2	5	ENGINE STARTED BUT DIED AFTER 10 MINS . NO DATA PRINTOUT
3	3	0	5	ENGINE STARTED BUT WOULD NOT RUN. NO DATA PRINTOUT
4	0	.	0	
5	0	.	0	
6	.	.	1	
7	3	0	5	ENGINE STARTED BUT WOULD NOT RUN. NO PRESSURE DATA.
8	10	4	5	ENGINE STARTED.LOST POWER AT 7 MINS AND STALLED AT 10 MINS. NO PRESSURE DATA.
9	.	.	3	
10	.	.	2	ONLY 10 MINS OF DATA. NO P2 READINGS. LARGE TEMP DISCREPANCIES.
11	0	.	0	
12	0	.	0	
13	0	.	0	
14	0	0	5	ENGINE WOULD NOT START.
15	2	0	5	ENGINE STALLED AND WOULD NOT RESTART. RAN ONLY 1 MIN.
16	0	.	.	NO PRESSURE DATA.
17	.	.	3	
18	0	.	0	
19	5	2	3	ENGINE FAILED AT 5 MINS.
20	14	9	5	ENGINE FAILED AT 14 MINS. NO PRESSURE DATA.
21	7	.	0	
22	55	30	3	ENGINE FAILED AT 55 MINS AT 30 MILES. LARGE TEMPERATURE DISCREPANCIES.
23	0	.	0	
24	.	.	2	
25	.	.	2	

FIELD DATA BASES COMBINED
MINUS VEHICLE 122, RUNS 42 AND 76

------------------------------ VEHICLE=121 ------------------------------

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL	RATING
26	106	20	Y	Y	.	.	.	-19.0	-27.8	-27	-27.8	-19	-29.0	-29.0	4
27	106	31	Y	N	.	.	.	-17.0	-17.5	-19	-19.0	-16	-17.0	.	2
28	106	33	Y	Y	.	.	.	-23.5	-29.9	-27	-29.9	-23	-23.5	.	4
29	106	105	Y	N	7.4	1.5	2.8	-10.5	-9.0	-13	-17.5	.	-12.2	-12.2	2
30	107	28	N	Y	1.2	4.8	-0.5	-21.7	-24.7	.	-24.7	.	-21.7	-19.4	4
31	107	38	N	N	1.2	6.8	-3.8	-16.5	-21.2	.	-21.2	.	-21.4	-21.4	4
32	107	45	Y	Y	.	.	.	-12.7	-18.7	-17	-18.7	-13	-13.0	.	4
33	107	57	Y	N	1.3	1.3	2.9	-6.2	-7.0	-8	-8.0	-6	-6.2	-5.7	1
34	107	58	Y	N	1.2	1.8	2.5	-8.6	-1.8	-13	-13.0	-9	-9.0	-7.5	1
35	107	61	Y	N	1.5	18.5	-13.5	-14.8	-15.7	-17	-17.0	-13	-14.8	-13.6	4
36	108	86	Y	N	1.2	18.5	-13.0	-5.2	-5.0	-10	-10.1	-5	-5.8	-5.8	2
37	108	104	N	N	0.6	18.9	-13.3	-6.7	-11.9	.	-11.9	.	-9.6	-9.6	4

OBS	FAILLOC	FAILTIME	FAILMILE	RESTRICT	COMMENT
26	T	10	3	5	ENGINE FAILED AT 10 MINS. NO PRESSURE DATA.
27		.	.	.	NO DATA PRINTOUT.
28		7	1	5	ENGINE FAILED AT 7 MINS. NO DATA PRINTOUT.
29	T	.	.	1	
30	S	5	0	2	ENGINE FAILED AT 5 MINS. P2 AND P4 APPEAR TO BE REVERSED.
31	S	22	0	2	P2 AND P4 APPEAR TO BE REVERSED. ENGINE STARTED BUT WOULD NOT RUN.
32		7	3	5	ENGINE STARTED BUT WOULD NOT IDLE. NO DATA PRINTOUT.
33	O	0	.	0	
34	T	0	.	0	
35	S	10	1	2	ENGINE FAILED AT 10 MINS.
36	S	.	.	2	
37	S	3	0	2	ENGINE STARTED BUT WOULD NOT IDLE.

------------------------------ VEHICLE=122 ------------------------------

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL	RATING	FAILLOC
38	101	15	Y	N	.	.	.	-16.2	-15.0	-18	-18.0	.	-16.2	-16.2	1	
39	101	36	N	Y	2.0	0.7	1.5	-20.0	-15.7	-19	-24.9	.	-20.0	-20.0	1	
40	101	40	N	Y	.	.	.	-23.5	-31.0	-21	-31.0	.	-23.5	-23.5	4	
41	102	19	Y	N	.	.	.	-9.0	-14.3	-14	-14.3	-9	-9.0	-9.0	4	S
42	102	24	Y	N	1.7	.	-5.1	-10.0	-14.2	-14	-14.4	-10	-10.0	-10.0	1	
43	102	72	Y	N	-2.4	11.8	-6.7	-11.6	-17.1	-17	-17.2	-11	-11.6	-10.9	1	
44	102	77	Y	Y	1.2	2.7	0.9	-12.6	-15.2	-16	-16.3	-12	-14.9	-14.9	2	S
45	103	86	Y	N	-12.7	.	-12.4	-4.0	3.7	-10	-10.1	-4	-5.9	-5.9	4	S

OBS	FAILTIME	FAILMILE	RESTRICT	COMMENT
38	.	.	0	NO PRESSURE DATA OBTAINED
39	.	.	0	
40	45	42	5	NO TEMPERATURE OR PRESSURE DATA. FAILED AFTER 42 MILES
41	.	.	0	NO TEMPERATURE OR PRESSURE DATA.
42	.	.	0	NO DATA ON PRESSURE TO SECONDARY FILTER.
43	55	48	2	INCREASE IN PRESSURE DROP ACROSS SECOND FILTER. RECOVERED BY END OF TEST
44	.	.	0	
45	9	6	2	NO DATA ON INLET PRESSURE TO SECONDARY FILTER.

FIELD DATA BASES COMBINED
MINUS VEHICLE 122, RUNS 42 AND 76

VEHICLE=122

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL	RATING	FAILLOC
46	103	90	Y	N	-0.8	0.6	3.0	-2.6	-4.4	-5	-5.2	.	-2.6	-2.6	1	
47	104	16	Y	Y	.	.	.	-16.6	-16.1	.	-24.8	-19	-19.0	-16.6	1	
48	104	27	Y	Y	-1.3	8.0	-3.5	-21.0	-26.3	-26	-26.3	-22	-22.0	-19.6	2	S
49	104	30	Y	Y	.	.	.	-20.0	-25.0	-25	-25.0	-21	-23.0	-23.0	1	
50	104	34	N	Y	2.4	13.5	-13.4	-26.0	-30.0	.	-30.0	.	-32.2	-32.2	4	S
51	105	23	N	N	1.2	0.5	1.1	-4.5	-8.5	-10	-10.0	-10	-11.0	-11.0	1	
52	105	26	Y	N	2.2	1.5	3.0	-7.0	-12.4	-13	-13.0	-8	-11.7	-11.7	1	
53	105	58	Y	N	1.0	0.4	3.2	-9.0	-2.8	-13	-13.0	-9	-9.0	-9.0	1	
54	105	61	Y	N	2.6	0.7	1.7	-14.1	-18.7	-17	-18.7	-13	-15.0	-15.0	3	
55	105	105	N	N	.	.	.	-13.2	-7.7	-13	-17.5	-5	-13.2	-13.2	1	
56	106	20	Y	N	.	.	.	-18.0	-27.9	-27	-27.9	-18	-18.0	-17.2	3	S
57	106	31	Y	N	.	.	.	-17.0	-17.5	-19	-19.0	-16	-17.0	.	1	
58	106	33	Y	Y	.	6.2	-2.1	-24.0	-29.9	-27	-29.9	-23	-24.0	-22.3	4	S
59	106	62	Y	Y	3.1	1.8	1.8	-15.4	-15.3	-19	-19.0	-15	-16.4	-16.4	1	
60	106	63	Y	Y	1.1	1.8	2.8	-17.9	-13.3	-21	-21.0	-17	-17.9	-17.9	1	
61	106	75	Y	Y	2.0	1.5	1.6	-22.1	-14.5	-28	-28.0	-22	-22.1	-22.1	1	
62	107	28	N	Y	1.3	6.9	-2.7	-21.1	-23.8	.	-23.8	.	-25.5	-25.5	4	S
63	107	38	N	N	.	.	.	-15.7	-21.2	.	-21.2	.	-19.3	-19.3	4	S
64	107	45	Y	Y	1.5	3.9	-0.3	-12.3	-18.4	-17	-18.5	-13	-17.7	-17.7	4	S
65	107	57	Y	N	0.9	1.0	2.3	-6.3	-7.0	-8	-8.0	-6	-6.7	-6.7	1	
66	107	65	Y	N	1.3	12.2	-7.3	-11.4	-11.4	-14	-14.0	-11	-11.7	-11.7	2	S
67	108	87	Y	N	.	.	.	0.4	3.0	.	3.0	.	-0.9	-0.9	1	
68	108	92	Y	N	1.0	0.6	2.3	-1.4	-0.2	-3	-3.1	-1	-1.4	1.4	1	
69	108	94	Y	N	.	.	.	-5.0	-7.5	-7	-7.5	-5	-5.0	-5.0	4	
70	108	106	N	N	1.1	1.6	2.7	-4.5	-1.8	0	-8.6	.	-4.5	-4.5	1	

OBS	FAILTIME	FAILMILE	RESTRICT	COMMENT
46	.	.	0	
47	.	.	0	NO PRESSURE DATA OBTAINED. LARGE DROP INAMBIENT TEMPERATURE AT 3AM.
48	40	35	2	PRESSURE DROP AT SECONDARY FILTER LARGE AT 40MIN. DECREASED BY END OF TEST.
49	.	.	0	NO PRESSURE DATA OBTAINED
50	10	5	2	TOP SPEED 20MPH
51	.	.	0	
52	.	.	0	
53	.	.	0	
54	55	45	2	INCOMPLETE PRESSURE DATA. NO DATA AFTER 15 MINUTES.
55	.	.	0	NO TEMPERATURE OR PRESSURE DATA.
56	10	6	5	NO PRESSURE DATA OBTAINED.
57	.	.	1	
58	6	0	2	DATA ON PRIMARY FILTER PRESSURE NO GOOD
59	.	.	0	FUEL LINE HEATER MAY HAVE BEEN ON DURINGPART OF TEST.
60	.	.	0	
61	.	.	0	
62	5	0	2	VEHICLE COULD ONLY BE IDLED.
63	0	0	5	VEHICLE WOULD NOT START.
64	10	2	2	SEVERAL STALLS AFTER 2MILES
65	.	.	0	
66	5	3	2	PRESSURE DROP ACROSS SECONDARY FILTER INCREASED AT 15MIN BUT LATER DROPPED OFF
67	.	.	0	PARTIAL COOLDOWN DATA ONLY. PRESSURE DATA FOULED UP ALSO.
68	.	.	0	
69	18	11	5	STALLED AFTER 11MILES. NO TEMPERATURE OR PRESSURE DATA
70	.	.	0	

FIELD DATA BASES COMBINED
MINUS VEHICLE 122, RUNS 42 AND 76

VEHICLE=123

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL	RATING	FAILLOC
71	101	15	N	N	.	.	.	-14.7	-17.7	-18	-18.0	.	-16.1	-16.1	1	O
72	101	36	N	Y	.	.	.	-19.0	-15.6	-19	-24.9	.	-19.0	-19.0	1	
73	101	40	N	Y	.	.	.	-25.0	-30.9	-21	-30.9	.	-25.0	-25.0	4	
74	101	42	N	Y	8.0	4.7	-5.1	-20.9	-23.8	-16	-23.8	.	-20.9	-20.9	4	P
75	102	17	N	N	.	.	.	-12.2	-17.2	-19	-19.0	-14	-16.7	-16.7	4	
76	102	19	Y	N	.	.	.	-9.0	-14.3	-14	-14.3	-9	-9.0	-7.3	3	T
77	102	24	Y	N	1.3	21.4	-6.5	-10.0	-14.7	-14	-14.7	-10	-10.9	-10.9	4	S
78	102	65	Y	N	2.1	18.2	-6.2	-11.7	-11.6	-14	-14.0	-11	-13.2	-13.2	4	S
79	103	87	Y	N	0.6	0.9	7.5	0.1	3.0	.	3.0	.	-0.8	-0.8	1	T
80	103	92	Y	N	0.5	1.6	9.5	-1.4	-0.2	-3	-3.1	-1	-1.4	-0.9	1	P
81	103	94	Y	N	7.7	2.1	-3.2	-3.9	-7.5	-7	-7.5	-4	-6.0	-6.0	4	P
82	104	16	Y	Y	.	.	.	-15.9	-16.1	.	-24.8	-19	-19.0	-17.2	1	T
83	104	27	Y	Y	.	.	.	-22.0	-26.3	-26	-26.3	-22	-22.0	-21.3	1	O
84	104	30	Y	Y	.	.	.	-20.0	-18.2	-25	-25.0	-21	-21.0	-19.2	1	T
85	104	35	N	Y	2.5	5.9	-6.0	-18.0	.	-28	-35.3	.	-25.0	-25.0	4	P
86	105	22	Y	N	.	.	.	-2.0	-2.2	-2	-2.2	-1	-2.3	-2.3	1	O
87	105	23	Y	N	.	.	.	-4.5	-8.4	-10	-10.0	-7	-7.0	-4.5	1	
88	105	26	Y	N	0.6	4.3	6.7	-7.0	-12.1	-13	-13.0	-8	-10.2	-10.2	1	O
89	105	64	Y	Y	0.5	1.3	7.4	-9.6	-11.5	-11	-11.5	-9	-11.6	-11.6	1	O
90	105	72	Y	N	0.4	6.4	4.3	-15.0	-14.7	-17	-17.2	-15	-16.1	-16.1	1	O
91	105	75	Y	Y	7.7	13.7	-7.7	-23.1	-19.8	-28	-28.0	-27	-27.0	-24.4	3	T
92	105	76	Y	Y	8.6	0.8	-8.1	-21.8	-27.3	-28	-28.0	-22	-25.2	-25.2	4	T
93	106	20	Y	Y	.	.	.	-17.0	-27.9	-27	-27.9	-17	-21.2	-21.2	1	O
94	106	31	Y	N	1.6	2.3	7.6	-17.0	-12.5	-19	-19.0	-16	-17.0	-13.8	1	T
95	106	33	Y	Y	0.3	4.7	2.2	-24.0	-29.4	-27	-29.5	-23	-24.4	-24.4	1	O

OBS	FAILTIME	FAILMILE	RESTRICT	COMMENT
71		.	5	
72	.	.	5	
73	10	2	5	
74	20	13	.	
75	0	1	5	
76	.	.	5	LOSS OF POWER FOR FIRST FIVE MILES
77	20	3	2	PRESSURE DATA LOOK SUSPICIOUS
78	.	.	2	
79	.	.	0	
80	.	.	0	
81	2	1	1	TWO NIGHTS IN VEHICLE
82	.	.	5	
83	.	.	5	
84	.	.	5	TWO NIGHTS IN VEHICLE - TEMP PLOT' ERRONEOUS
85	7	1	2	
86	.	.	5	
87	.	.	5	
88	.	.	.	
89	.	.	0	
90	.	.	2	LOW (49.5) AVG SPEED
91	.	.	3	
92	8	2	1	25 MPH,STOP AND IDLE
93	.	.	5	BIG DELTA T (T-A)
94	.	.	0	
95		.	2	HIGH DELTA P (T--FI)

FIELD DATA BASES COMBINED
MINUS VEHICLE 122, RUNS 42 AND 76

--- VEHICLE=123 ---

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL	RATING	FAILLOC
96	106	34	N	Y	.	.	.	-24.8	-33.0	.	-33.0	.	-24.8	.	4	
97	106	42	N	Y	.	.	.	-19.0	-23.8	-16	-23.8	.	-19.0	.	1	
98	107	28	N	Y	.	.	.	-20.7	-24.7	.	-24.7	.	-20.7	-20.7	4	P
99	107	38	N	N	.	.	.	-14.7	-21.1	.	-21.1	.	-14.7	-14.7	1	
100	107	45	Y	Y	7.0	5.2	-4.5	-12.3	-17.9	-17	-18.5	-13	-13.0	-12.3	4	P
101	107	57	Y	N	0.9	1.0	8.8	-5.9	-7.0	-8	-8.0	-5	-6.3	-6.3	1	T
102	107	58	Y	N	0.3	1.0	8.2	-8.4	-2.3	-13	-13.0	.	-8.4	-8.1	1	T
103	107	61	Y	N	0.4	3.9	6.4	-13.8	-15.6	-17	-17.0	-13	-15.5	-15.5	2	O
104	107	62	Y	Y	0.6	19.3	-5.3	-15.4	-15.3	-19	-19.0	-19	-19.0	-16.2	4	O
105	107	63	Y	Y	0.5	6.9	4.1	-18.1	-16.3	-21	-21.0	-20	-20.0	-15.4	1	T
106	108	86	Y	N	0.6	11.5	2.5	-5.2	-5.0	-10	-10.1	-5	-8.2	-8.2	4	P
107	108	90	Y	N	0.8	1.8	8.8	-2.8	-0.6	-5	-5.2	.	-2.8	-2.1	1	T
108	108	104	N	N	8.6	2.1	-8.0	-9.6	-11.4	.	-11.4	.	-9.6	-9.6	4	P
109	108	106	N	N	8.7	0.8	-4.5	-4.3	2.3	0	-8.6	.	-4.3	-2.1	4	P

OBS	FAILTIME	FAILMILE	RESTRICT	COMMENT
96	10	3	5	
97	.	.	5	NO DATA
98	10	5	5	LESS THAN 30 MPH
99	.	.	5	
100	11	5	3	
101	.	.	0	
102	.	.	0	
103	.	.	2	STALLED 3 TIMES IN YARD
104	9	3	2	
105	.	.	.	
106	12	6	2	
107	.	.	0	EITHER INLET LINE (TANK TO FILTER 1 PLUGGED OR DATA LOGGER DID NOT WORK FOR 10M
108	3	0	1	
109	11	1	1	

FIELD DATA BASES COMBINED
MINUS VEHICLE 122, RUNS 42 AND 76

VEHICLE=124

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL	RATING	FAILLOC
110	101	36		Y	3.5	0.5	1.5	-19.0	-15.0	-19	-24.9	.	-21.0	-21.0	3	P
111	101	40		Y	.	.	.	-25.0	-30.0	-21	-30.0	.	-25.0	-25.0	4	
112	101	42		Y	4.0	0.2	3.8	-21.0	-20.0	-16	-23.2	.	-21.0	-18.7	4	P
113	102	19		N	.	.	.	-10.0	-14.3	-14	-14.3	-10	-10.0	.	1	
114	102	24		N	.	.	.	-12.0	-14.0	-14	-14.4	-11	-12.0	-12.0	3	
115	103	86		N	5.8	0.5	6.2	-5.0	-5.0	-10	-10.1	-4	-6.0	-6.0	4	P
116	103	90		N	0.5	1.0	1.0	-2.7	-0.7	-5	-5.2	.	-2.7	2.5	1	
117	103	106		N	9.0	1.0	9.0	-4.0	-0.1	0	-8.6	.	-4.0	-4.0	4	P
118	104	28		Y	1.5	0.8	1.5	-24.5	-14.0	.	-23.6	.	-25.0	-25.0	1	
119	104	30	Y	Y	.	.	.	-21.0	-25.0	-25	-25.0	-22	-22.0	-21.0	1	
120	104	34		Y	4.8	0.5	4.8	-24.0	-30.0	.	-30.0	.	-24.0	-24.0	4	P
121	104	41		Y	1.0	1.0	2.0	-23.0	-26.7	-19	-26.7	.	-23.0	-20.0	1	
122	105	22		N	0.5	0.5	0.5	-1.0	-2.7	-2	-2.7	-2	-4.0	-4.0	1	
123	105	23		N	1.0	0.5	1.5	-4.0	-8.4	-10	-10.0	-8	-8.0	-6.0	1	
124	105	26		N	.	.	.	-8.0	-12.6	-13	-13.0	.	-8.0	-8.0	3	
125	105	37		N	2.5	0.5	2.5	-7.0	-10.0	-13	-13.3	.	-15.0	-15.0	3	P
126	105	58		N	1.0	0.2	1.0	-9.1	-2.1	-13	-13.0	-10	-10.0	-7.0	1	
127	105	61		N	5.5	0.3	5.5	-13.9	-15.8	-17	-17.0	.	-13.9	-13.9	4	P
128	105	64		Y	.	.	.	-11.0	-10.0	-11	-11.3	-10	-11.0	-11.0	2	
129	106	20		Y	.	.	.	-18.0	-27.9	-27	-27.9	-17	-18.0	-18.0	4	P
130	106	31	N	N	.	.	.	-17.0	-12.3	-19	-19.0	.	-17.0	-17.0	1	
131	106	33		Y	3.5	2.1	3.5	-24.0	-28.0	-27	-29.5	-24	-24.0	-24.0	4	S
132	106	62		Y	1.5	1.5	3.0	-14.0	-15.3	-19	-19.0	-16	-16.0	-10.0	3	S
133	106	63		Y	.	.	.	-17.0	-14.7	-21	-21.0	-17	-17.0	-17.0	4	P
134	106	105		N	1.0	8.0	9.0	-14.0	-11.5	-13	-17.5	-5	-14.0	-11.0	4	S

OBS	FAILTIME	FAILMILE	RESTRICT	COMMENT
110	3	3	1	STALLED WHEN DOWN SHIFTED
111	.	.	5	STALLED IN YARD
112	1	.	1	STALLED IN YARD COULD NOT BE STARTED
113	.	.	5	
114	.	.	5	FAILED TO START INITIALLY BLOCK HEATER PLUGGED IN TO GET START
115	1	.	1	STARTED BUT NO POWER AT FULL THROTTLE
116	.	.	0	
117	2	.	1	STARTED STALLED WOULD NOT IDLE AT FULL THROTTLE
118	.	.	0	
119	.	.	1	
120	1	.	1	
121	.	.	0	
122	.	.	0	
123	.	.	0	
124	.	.	5	SEVERAL START ATTEMPTS MAX SPEED OF 45 AT START STALLED WHEN SHIFTED
125	7	5	1	STARTED OK BUT NO POWER WHEN DOWN SHIFTED DECREASING AMBIENT TEMP.
126	.	.	0	
127	2	.	1	
128	.	.	5	STARTED ON 6TH ATTEMPT
129	.	.	5	STALLED IN YARD COULD NOT BE RESTARTED
130	.	.	1	
131	10	8	3	HARD TO START MAX. SPEED OF 30MPH DID NOT COMPLETE COURSE
132	3	25	2	LOSS OF POWER ON COURSE MAX SPEED 10MPH DID CLEARED UP QUICKLY AMBIENT DEC.
133	.	.	5	FOUR START ATTEMPTS COULD NOT IDLE IN YARD NO PRESSURE DATA POSSIBLE PUMP PROB
134	1	.	2	WOULD NOT RUN IN YARD

FIELD DATA BASES COMBINED
MINUS VEHICLE 122, RUNS 42 AND 76

VEHICLE=124

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL
135	107	38		N	9.0	1.0	9.0	-15.0	-21.1	.	-21.1	.	-15.0	-15.0
136	107	45		Y	2.3	2.0	3.8	-11.0	.	-17	-18.5	-13	-14.0	-14.0
137	107	57		N	.	.	.	-6.4	-7.0	-8	-8.0	-6	-6.4	-6.4
138	107	65		N	.	.	.	-12.0	-11.4	-14	-14.0	-11	-12.0	-12.0
139	107	83		N	.	.	.	-0.6	3.8	-3	-3.0	.	-0.6	-0.6
140	108	87		N	.	.	.	0.0	3.0	.	3.0	.	0.0	0.0
141	108	92		N	.	.	.	-1.7	-2.3	-3	-3.1	-2	-2.0	-1.7
142	108	94		N	2.0	0.2	2.5	-4.0	-7.5	-7	-7.5	-4	-4.0	-4.0
143	108	104		N	9.0	0.7	9.0	-5.0	-11.4	.	-11.4	.	-6.0	-6.0

OBS	RATING	FAILLOC	FAILTIME	FAILMILE	RESTRICT	COMMENT
135	4	P	2	.	1	HARD TO START NO POWER TO MOVE IN YARD
136	4	S	3	1	3	
137	1		.	.	0	
138	4		.	.	5	STARTED BUT STALLED WOULD NOT IDLE WITHOUT THROTTLE ADVANCE
139	1		.	.	0	
140	1		.	.	0	
141	1		.	.	0	
142	4	P	1	.	1	STARTED BUT NO POWER CONTINUED TO STALL
143	4	P	1	.	1	STARTED BUT CONTINUED TO STALL

VEHICLE=125

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL	RATING	FAILLOC
144	101	40	N	Y	-5.8	.	.	-24.5	-29.0	-21	-29.2	.	-24.5	-23.7	4	P
145	101	62	Y	Y	1.6	.	.	-17.6	-18.5	-19	-19.0	-17.0	-17.6	-17.6	1	
146	101	63	Y	Y	1.3	.	.	-18.1	-21.0	-21	-21.0	-17.0	-18.1	-18.1	1	
147	102	24	Y	N	1.0	.	.	-10.0	-12.2	-14	-14.4	-10.0	-10.7	-10.7	1	
148	102	64	Y	Y	1.5	.	.	-9.1	-11.4	-11	-11.4	-9.0	-9.1	-9.1	1	
149	102	72	Y	N	1.6	.	.	-13.5	-17.1	-17	-17.2	-13.0	-15.2	-15.2	1	
150	102	75	Y	Y	3.6	.	.	-20.4	-19.7	-28	-28.0	-21.0	-21.1	-21.1	4	P
151	102	76	Y	Y	0.9	.	.	-16.4	-24.6	-28	-28.0	-17.0	-21.7	-21.7	4	P
152	103	86	Y	N	.	.	.	-3.8	-5.0	-10	-10.1	-0.4	-3.8	-3.8	4	P
153	103	90	Y	N	1.5	1.0	26.6	-2.6	-3.9	-5	-5.2	.	-2.6	-2.6	1	
154	104	23	Y	N	-0.2	0.2	.	-4.5	-7.3	-10	-10.0	-5.0	-6.9	-6.9	1	

OBS	FAILTIME	FAILMILE	RESTRICT	COMMENT
144	10.	1	5	WOULD NOT IDLE ONE MILE TRIP
145	.	.	0	
146	.	.	0	
147	.	.	0	EXCELLENT START SECONDARY FILTER IN ANDOUT TRANSDUCERS WORKED INTERMITTENTLY
148	.	.	0	
149	.	.	0	HARD TO START TWO LONG ATTEMPTS
150	6	5	5	LOSS OF POWER 5 MILES 14MILES TOTALTRIP
151	7	19	5	LOSS OF POWER 19 MILES TOTAL TRIP 30MILE
152	12	16	.	LOSS OF POWER 16 MILES TOTAL TRIP 38MILE
153	.	.	0	
154	.	.	0	EXCELLENT START SECONDARY FILTER IN AND OUT WORKED INTERMITTENTLY

FIELD DATA BASES COMBINED
MINUS VEHICLE 122, RUNS 42 AND 76

VEHICLE=125

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL	RATING	FAILLOC
155	104	28	Y	Y	0.4	.	0.2	-23.0	-22.1	.	-23.6	.	-23.0	-23.0	1	
156	104	30	Y	Y	0.4	.	.	-23.0	-25.7	-25	-25.7	-23	-23.0	-23.0	1	
157	104	34	N	Y	2.0	.	.	-24.8	-32.7	.	-32.7	.	-25.9	-25.9	4	S
158	105	26	Y	N	.	.	.	-9.0	-12.1	-13	-13.0	.	-9.0	-9.0	1	
159	105	65	Y	N	.	.	.	-10.0	-12.7	-14	-14.0	-10	-10.0	-10.0	1	
160	105	73	Y	Y	1.6	.	.	-21.0	-20.3	-25	-25.0	-21	-21.0	-21.0	1	
161	105	77	Y	Y	1.4	.	.	-12.9	-15.0	-16	-16.3	-14	-14.9	-14.9	1	
162	106	31	N	N	1.0	.	.	-17.0	-17.5	-19	-19.0	.	-17.0	-17.0	1	
163	106	33	N	Y	0.2	13.8	1.0	-24.0	-29.9	-27	-29.9	.	-24.0	-22.2	4	S
164	106	42	N	Y	0.3	4.8	-3.5	-21.5	-24.8	-16	-24.8	.	-21.5	-21.4	4	S
165	107	38	N	N	.	.	.	-17.3	-21.2	.	-21.2	.	-17.3	-17.3	4	U
166	107	58	Y	N	1.4	.	9.9	-11.8	-12.1	-13	-13.0	-11	-11.8	-11.8	2	
167	107	61	Y	N	.	.	.	-15.0	-16.7	-17	-17.0	.	-15.0	-15.0	4	U
168	108	87	Y	N	.	.	.	0.2	0.0	.	0.0	.	0.2	0.2	1	
169	108	92	Y	N	1.4	.	.	-1.0	-2.3	-3	-3.1	-1	-1.0	-1.0	1	

OBS	FAILTIME	FAILMILE	RESTRICT	COMMENT
155	.	.	0	GOOD START SECONDARY FILTER IN AND OUT TRANSDUCERS WORKED INTERMITTENTLY
156	.	.	0	SECONDARY FILTER IN AND OUT TRANSDUCERS WORKED INTERMITTENTLY
157	15	4	5	15 MILE TRIP NO POWER USED 2+3 GEARS ON RETURN STARTED WELL STALLED ONCE
158	.	.	0	EXCELLENT START
159	.	.	5	
160	.	.	5	
161	.	.	0	
162	.	.	0	START AID-ETHER SEC FILTER IN/OUT TRANSDUCERS WORKED INTEMITTENTLY
163	2	1	2	STARTED WELL STALLED TWICE
164	20	12	5	RPM LOWERED UNTIL FORCED TO GO TO SHOULDER WOULD IDLE 46 MILE TRIP
165	20	5	5	5 MILE TRIP PULLED OFF ROAD TWICE CLEARED UP ON THE WAY BACK
166	41	52	5	LOSS OF POWER 52 MILES START AID AT START-ETHER
167	9	11	5	START AID-ETHER LOSS OF POWER-8 MILES TOTAL MILES-25 REGAIN POWER LAST 5 MILES
168	.	.	0	
169	.	.	0	

FIELD DATA BASES COMBINED
MINUS VEHICLE 122, RUNS 42 AND 76

-- VEHICLE=126 --

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL
170	101	40	N	Y	.	.	.	-21.1	-25.4	-21	-29.2	.	-25.1	-25.1
171	101	62	Y	Y	.	3.7	-5.6	-16.9	-19.3	-19	-19.3	-16	-16.9	-15.9
172	101	63	Y	Y	.	3.7	-5.0	-18.2	-21.0	-21	-21.0	-18	-19.3	-19.3
173	102	19	N	N	.	.	.	-9.0	-14.2	-14	-14.2	.	-9.0	.
174	102	24	N	N	.	.	.	-13.3	-13.8	-14	-14.4	.	-13.3	-10.3
175	102	37	N	Y	.	.	.	-7.0	-13.5	-13	-13.5	.	-9.7	-9.7
176	102	57	Y	N	.	3.3	-11.4	-6.0	-7.6	-8	-8.0	-6	-6.0	-5.6
177	102	65	Y	N	.	14.9	-16.0	-11.0	-12.7	-14	-14.0	-11	-12.3	-12.3
178	102	71	N	Y	.	4.8	-5.9	-3.7	-2.3	-6	-6.0	-3	-4.2	-4.2
179	102	80	Y	Y	.	.	-5.8	-4.2	-5.8	-9	-9.0	-4	-4.3	-4.3
180	102	83	Y	N	.	4.3	-5.4	-1.6	-3.0	-3	-3.0	-2	-2.7	-2.7
181	103	87	Y	Y	.	4.6	-5.7	0.6	3.0	.	3.0	.	-0.8	-0.8
182	103	92	Y	N	.	4.1	-5.2	-1.0	-2.3	-3	-3.1	-1	-2.0	-2.0
183	103	94	N	N	.	.	.	-3.9	-7.5	-7	-7.5	-4	-4.0	.
184	103	106	N	Y	.	.	.	-5.7	-1.8	0	-8.6	.	-5.7	-4.8
185	104	20	Y	Y	.	.	.	-18.0	-25.0	-27	-27.0	-17	-22.4	-22.4
186	104	28	N	Y	.	.	.	-22.8	-18.7	.	-23.6	.	-22.8	-20.4
187	104	29	N	Y	.	.	.	-18.2	-20.0	-23	-23.0	.	-18.6	-18.6
188	104	30	N	Y	.	.	.	-23.3	-25.7	-25	-25.7	.	-23.6	-23.6
189	105	22	Y	N	.	.	.	-2.0	-2.2	-2	-2.2	-2	-2.8	-2.8
190	105	23	N	Y	.	.	.	-5.0	-6.4	-10	-10.0	.	-5.0	.
191	105	26	Y	N	.	.	.	-9.0	-14.7	-13	-14.7	-9	-10.6	-10.6
192	105	58	Y	N	.	4.8	-6.7	-11.9	-12.1	-13	-13.0	-11	-11.9	-9.3
193	105	61	N	N	.	.	.	-16.0	-16.7	-17	-17.0	-16	-16.0	.
194	105	76		Y	.	.	.	-23.1	-27.3	-28	-28.0	-23	-26.4	-26.4

OBS	RATING	FAILLOC	FAILTIME	FAILMILE	RESTRICT	COMMENT
17C	4		0	0	.	NO START
171	1		.	.	0	
172	1		.	.	0	
173	4		15	1	.	LOST POWER-NO STALL. DRIVER DECISION TORETURN TO YARD
174	4		35	4	.	NO STALL. DRIVER DECISION TO RETURN TO YARD
175	4		5	1	.	NO STALL. DRIVER DECISION TO RETURN TO YARD
176	4	O	23	8	4	LOST POWER-STALLED
177	4	S	14	21	2	LOST POWER-NO STALL. DRIVER DECISION TORETURN TO YARD
178	1		.	.	0	
179	1		.	.	0	ERRATIC P3
180	1		.	.	0	
181	1		.	.	0	TRIP TIME-121 MIN. SNOW/RAIN IN A.M.
182	1		.	.	0	
183	4		0	0	.	NO START
184	4		0	0	.	NO START
185	1		.	.	.	TRIP TIME-100 MIN.
186	1		.	.	.	TRIP TIME-70 MIN.
187	1		.	.	.	
188	1		.	.	.	TRIP TIME-92 MIN.
189	1		.	.	.	TRIP TIME-98 MIN.
190	1		.	.	.	TRIP TIME-75 MIN.
191	1		.	.	.	TRIP TIME-105 MIN.
192	1		.	.	0	
193	4		16	4	.	LOST POWER-NO STALL. DRIVER DECISION TORETURN TO YARD
194	4		0	0	.	NO START

FIELD DATA BASES COMBINED
MINUS VEHICLE 122, RUNS 42 AND 76

VEHICLE=126

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL	RATING	FAILLOC	FAILTIME	FAILMILE	RESTRICT	COMMENT
195	105	105	N	Y	.	.	.	-13.3	-10.9	-13	-17.5	-8	-13.3	.	4		12	2	.	LOST.POWER-NO STALL. *DRIVER DECISION TORETURN TO YARD.*
196	106	31	N	N	.	.	.	-17.0	-13.0	-19	-19.0	.	-17.0	-15.1	1		.	.	.	
197	106	42	N	Y	.	.	.	-21.2	-23.8	-16	-23.8	.	-21.2	-20.6	4		15	0	.	LOST POWER-STALLED
198	107	38	N	N	.	.	.	-16.7	-18.0	.	-18.0	.	-16.7	.	1		.	.	.	
199	107	75	Y	Y	.	7.8	-8.8	-21.6	-19.7	-28	-28.0	-24	-24.0	-23.7	4	S	16	0	2	LOST POWER-STALLED
200	108	86	Y	N	.	5.0	-5.9	-5.1	-4.1	-10	-10.1	-5	-7.2	-7.2	4		15	2	4	LOST POWER-NO STALL. DRIVER DECISION TORETURN TO YARD.
201	108	90	Y	N	.	4.1	-4.1	-2.1	-4.4	-5	-5.2	.	-2.1	0.1	1		.	.	0	
202	108	104	N	N	.	2.7	-3.2	-5.0	-11.4	.	-11.4	.	-6.5	-6.5	4		22	1	4	LOST POWER-STALLED

VEHICLE=128

OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL	RATING	FAILLOC
203	101	62	Y	Y	1.5	0.4	.	-15.1	-19.3	-19	-19.3	-14	-16.8	-16.8	1	O
204	101	63	Y	Y	3.1	0.8	.	-17.9	-21.0	-21	-21.0	-17	-18.6	-18.6	1	O
205	102	57	Y	N	-3.0	-0.6	.	-5.0	-7.6	-8	-8.0	-4	-5.0	-4.4	1	T
206	102	58	Y	Y	8.6	1.1	.	-9.4	-12.1	-13	-13.0	-8	-9.4	-8.7	2	O
207	102	61	Y	Y	11.6	1.0	.	-10.0	-16.7	-17	-17.0	-10	-12.4	-12.4	2	P
208	102	73	Y	Y	12.2	1.3	.	-16.0	-20.3	-25	-25.0	-15	-17.7	-17.7	2	P
209	103	87	Y	Y	3.8	57.4	2.7	0.2	-0.2	.	-0.2	.	-2.4	-2.4	1	O
210	103	92	Y	N	3.2	2.4	59.8	-1.0	-0.3	-3	-3.1	-1	-1.3	-1.3	1	T
211	103	94	N	N	12.0	0.9	-0.5	-3.6	-7.5	-7	-7.5	-4	-6.4	-6.4	2	P
212	103	104	N	N	12.5	0.7	10.0	-4.5	-11.4	.	-11.4	.	-4.5	-2.8	2	P
213	103	110	N	N	.	.	.	-6.8	-13.1	-17	-17.0	.	-6.8	-6.8	4	
214	105	30	N	Y	.	.	.	-23.0	-24.2	-25	-25.0	.	-23.7	-23.7	1	O
215	105	64	Y	Y	.	.	.	-8.8	-11.5	-11	-11.5	-8	-8.8	-8.8	1	
216	105	72	Y	Y	12.0	1.0	.	-10.1	-17.1	-17	-17.2	-9	-12.6	-12.6	2	P

OBS	FAILTIME	FAILMILE	RESTRICT	COMMENT
203	.	.	0	DATA FOR FIRST 15 MIN ONLY
204	.	.	0	
205	.	.	0	
206	.	.	1	MAY HAVE BEEN PASS-PROBLEM WAS BRAKES
207	0	.	1	
208	1	.	1	COULD NOT ATTAIN MORE THAN 48 MPH FIRST 10 MILES
209	.	.	.	
210	.	.	0	
211	10	.	1	
212	5	.	1	NO OPERABILITY PROBLEMS OBSERVED
213	0	0	5	NO DATA,WOULD NOT RUN!
214	.	.	0	8 NIGHTS IN VEHICLE *** TEMP AMB MAY BE OFF BY 10 DEG C
215	.	.	0	
216	0	.	1	

FIELD DATA BASES COMBINED
MINUS VEHICLE 122, RUNS 42 AND 76

-- VEHICLE=128 --

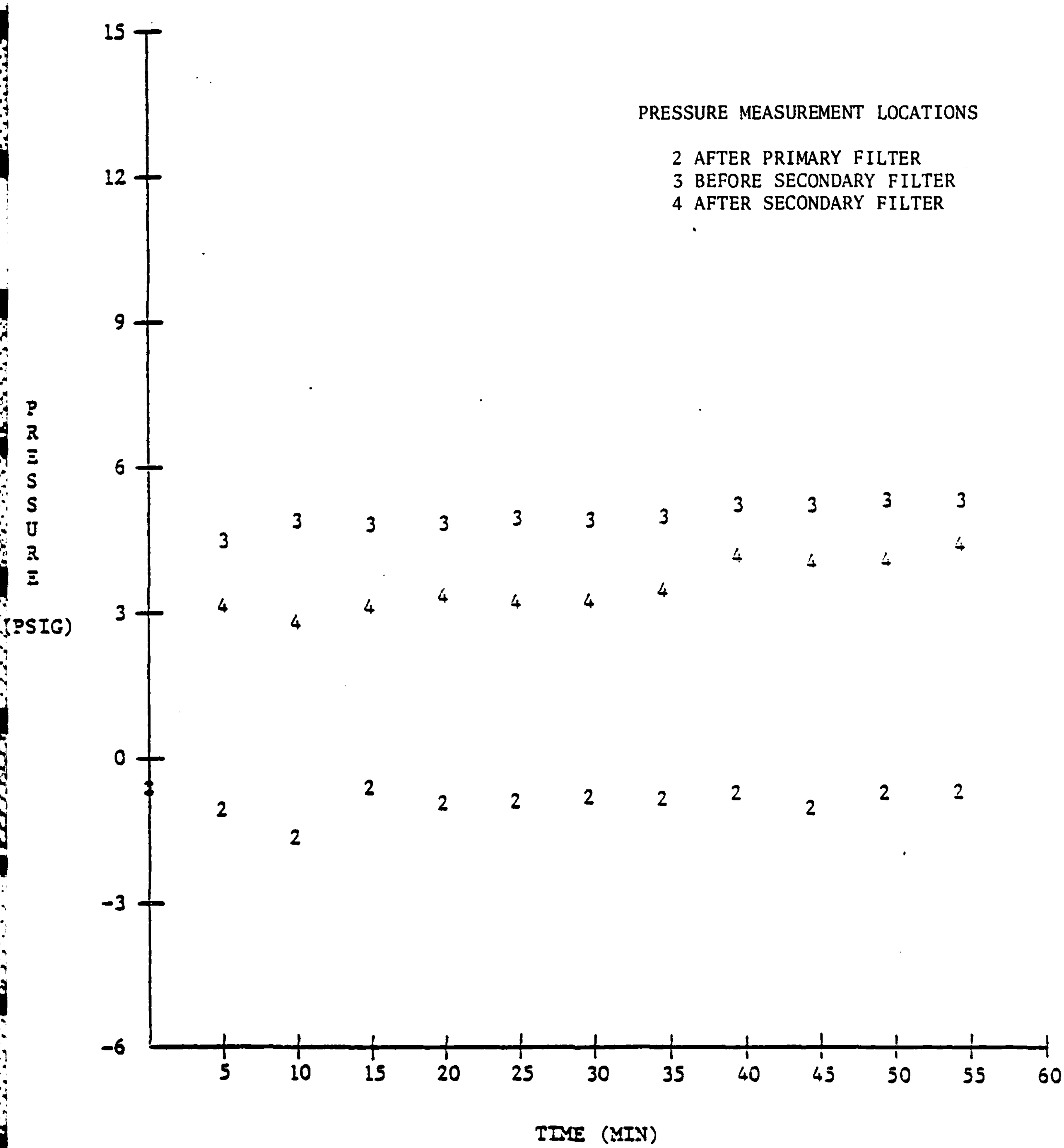
OBS	FUEL	RUN	COOLDOWN	HEATER	DELTA1	DELTA2	MINP4	TANK	AMBIENT	MINAMB	MAT	MINCOOL	MINFTEM	FUELFAIL	RATING	FAILLOC
217	105	74	Y	Y	11.3	1.0	.	-11.2	-16.1	-16	-16.4	-11	-14.5	-14.5	2	P
218	105	76	Y	Y	12.8	1.3	.	-23.2	-27.3	-28	-28.0	-24	-25.5	-25.5	4	P
219	105	77	Y	Y	7.7	1.5	.	-12.9	-15.2	-16	-16.3	-14	-15.3	-15.3	1	O
220	106	31		Y	.	.	.	-17.0	-13.0	-19	-19.0	.	-18.6	-18.6	3	S
221	106	42		Y	.	.	.	-19.0	-23.8	-16	-23.8	.	-19.0	-19.0	1	
222	107	65	Y	N	.	.	.	-10.0	-12.7	-14	-14.0	-10	-12.4	-12.4	1	O
223	107	75	Y	Y	.	.	.	-23.4	-19.7	-28	-28.0	-21	-23.4	-18.2	1	T
224	108	86	Y	N	.	5.1	8.4	-4.4	-5.0	-10	-10.1	-4	-6.2	-6.2	1	P
225	108	105	N	Y	.	.	.	-13.2	-10.1	-13	-17.5	-9	-13.2	-10.7	4	
226	108	106	N	Y	.	.	.	-6.4	-1.8	0	-8.6	4	-6.4	-6.4	3	

OBS	FAILTIME	FAILMILE	RESTRICT	COMMENT
217	0	.	1	7 NIGHTS IN VEHICLE
218	0	.	1	
219	.	.	1	P BASED ON DPI < 8 PSI
220	0	.	1	EXTREME STARTING DIFFICULTY - 1.5 HRS TO START - COMPLETED TEST ONCE STARTED
221	.	.	1	
222	0	.	0	
223	.	.	0	
224	.	.	0	
225	16	0	5	
226	.	.	5	

APPENDIX E

TYPICAL PRESSURE AND TEMPERATURE TRACES CORRESPONDING TO VARIOUS VEHICLE OPERATING CONDITIONS

FIGURE E-1. PRESSURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 121
(Run No. C121064)



Note: 1 psig = 6.89 kPa

FIGURE E-2. TEMPERATURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 121
(Run No. C121064)

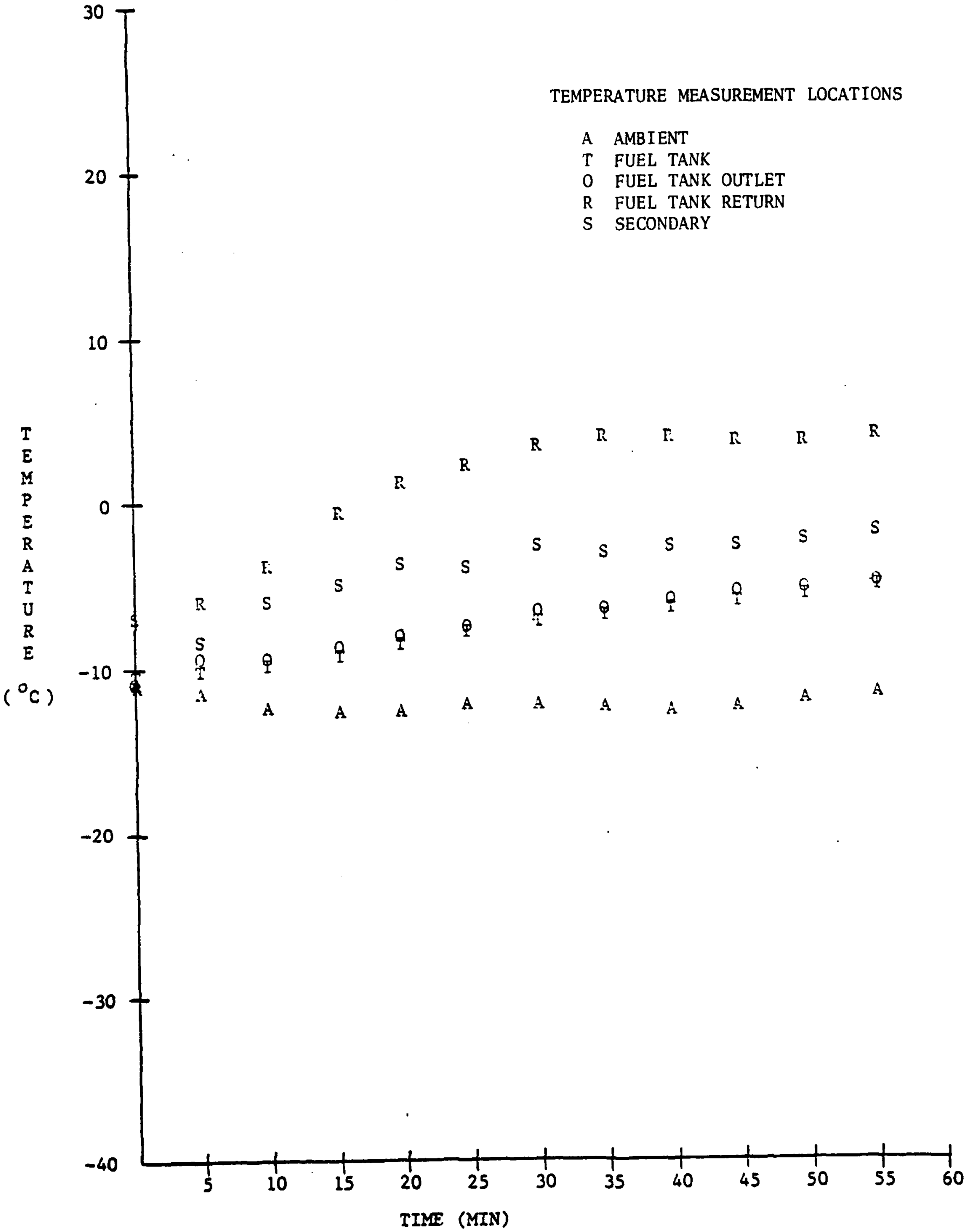
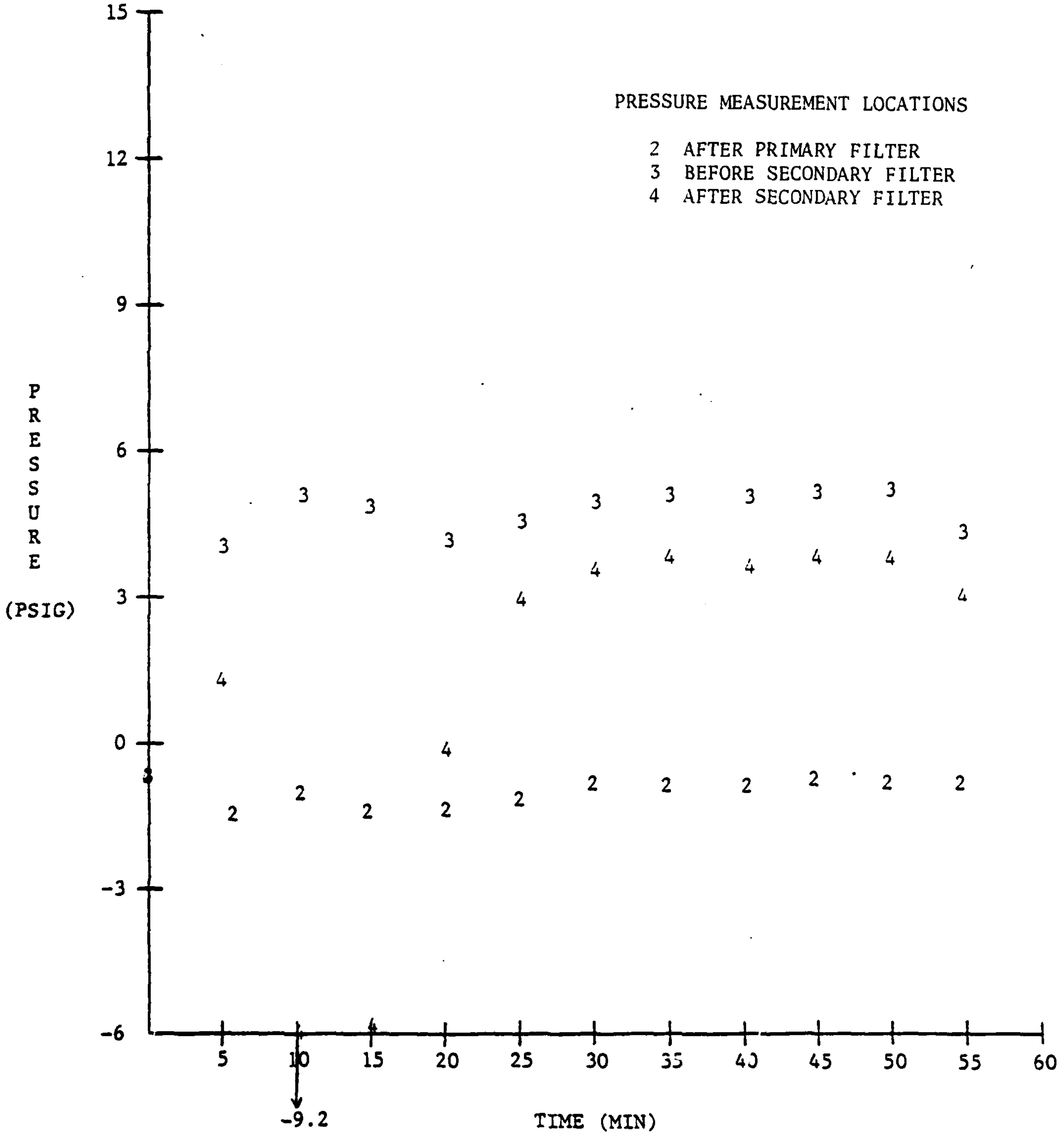
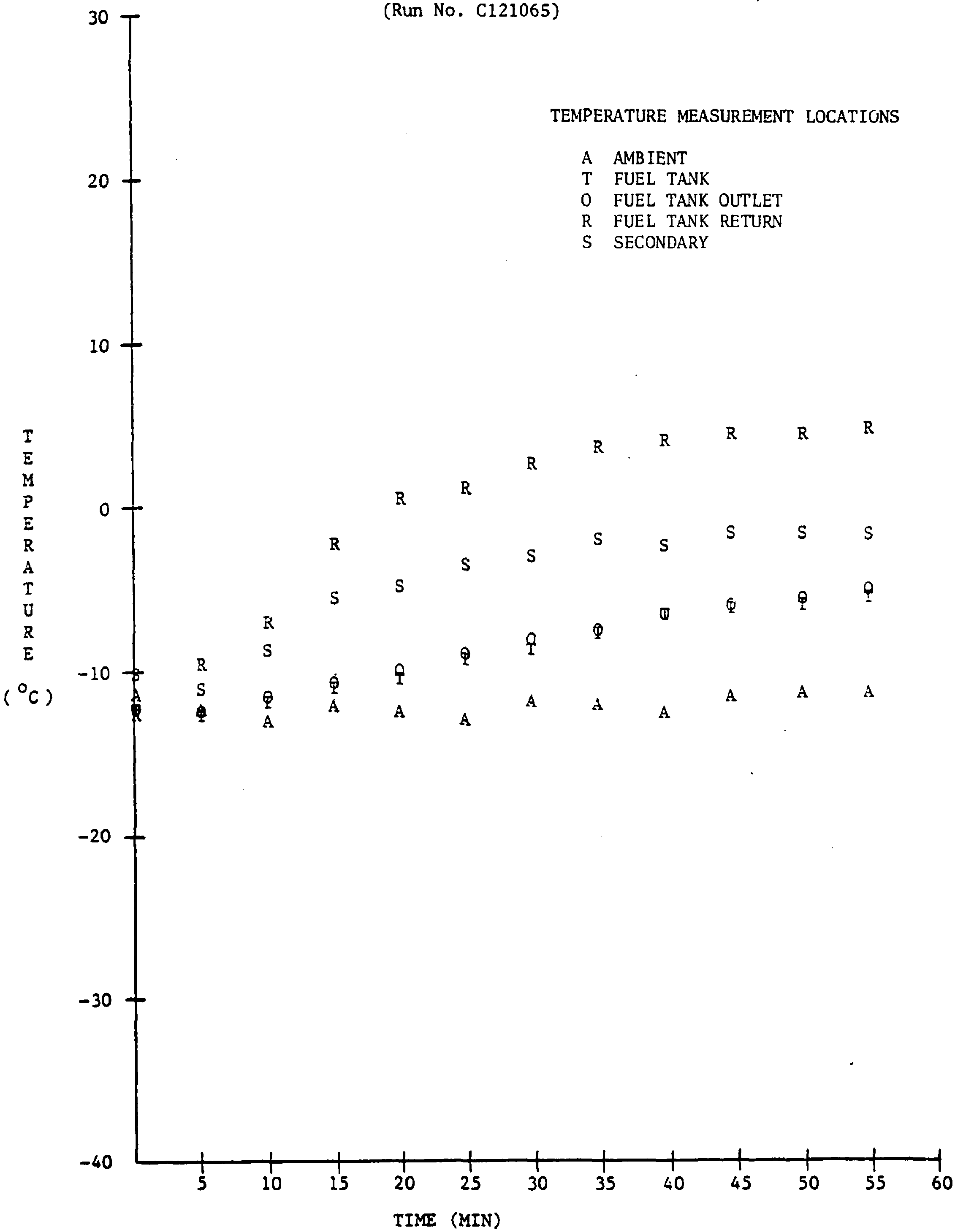


FIGURE E-3. PRESSURE DATA CORRESPONDING TO A BORDERLINE PASS CONDITION IN VEHICLE 121 (Run No. C121065)



Note: 1 psig = 6.89 kPa

FIGURE E-4. TEMPERATURE DATA CORRESPONDING TO A BORDERLINE PASS CONDITION IN VEHICLE 121 (Run No. C121065)



AD-A133 543 1981 CRC (COORDINATING RESEARCH COUNCIL) DIESEL FUEL LOW-TEMPERATURE OPERABILITY FIELD TEST(U) COORDINATING RESEARCH COUNCIL INC ATLANTA GA SEP 83 CRC-528 3/3

UNCLASSIFIED DAAK70-81-C-0128 F/G 21/4 NL

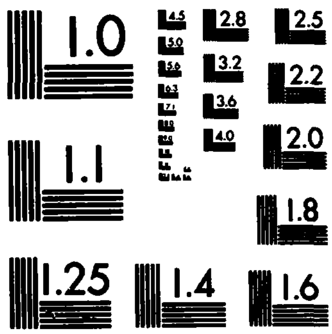


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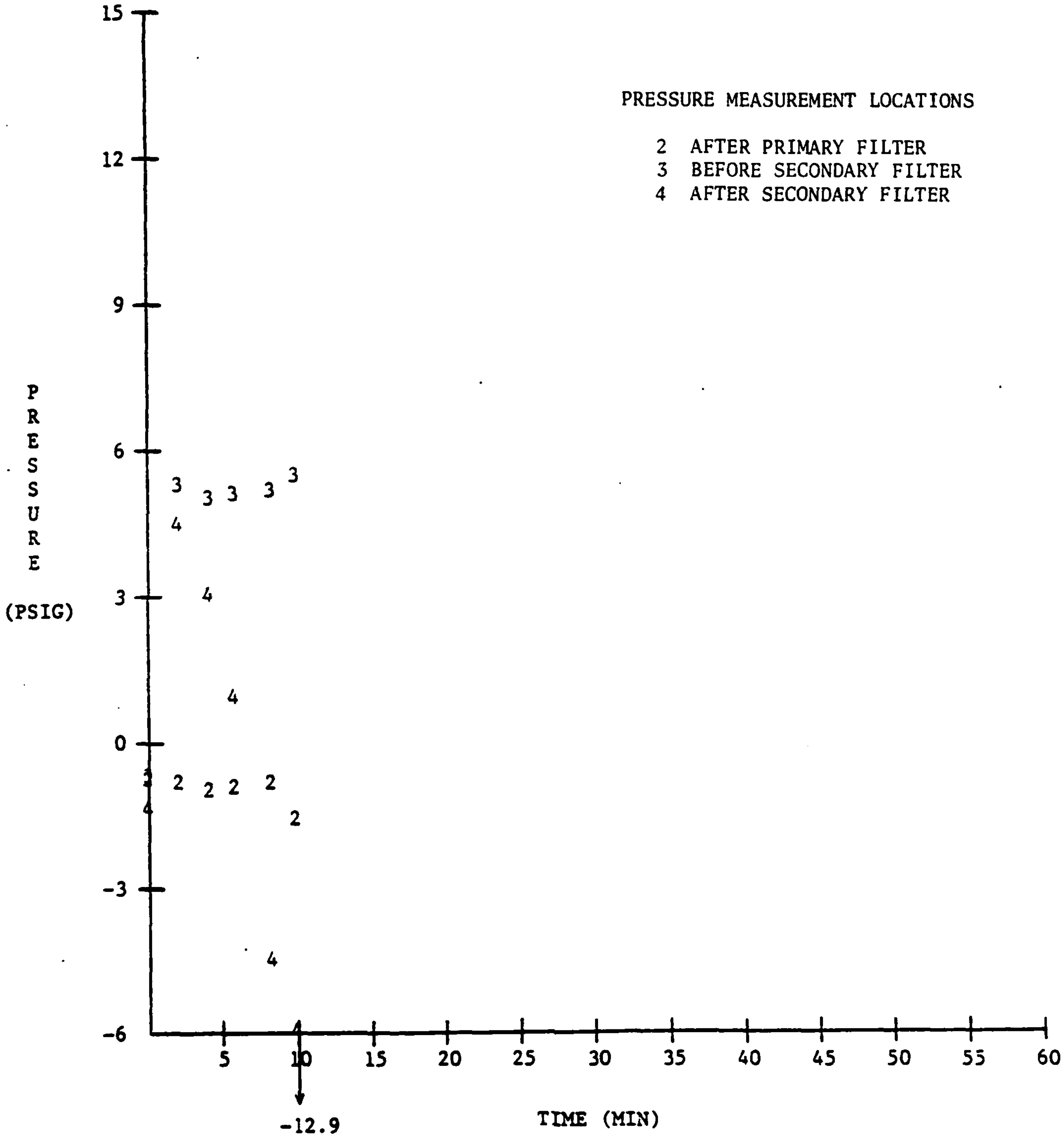
FIGURE E-5. PRESSURE DATA CORRESPONDING TO A FAIL CONDITION IN VEHICLE 121 (Run No. C121061)



Note: 1 psig = 6.89 kPa

FIGURE E-6. TEMPERATURE DATA CORRESPONDING TO A FAIL CONDITION IN VEHICLE 121 (Run No. C121061)

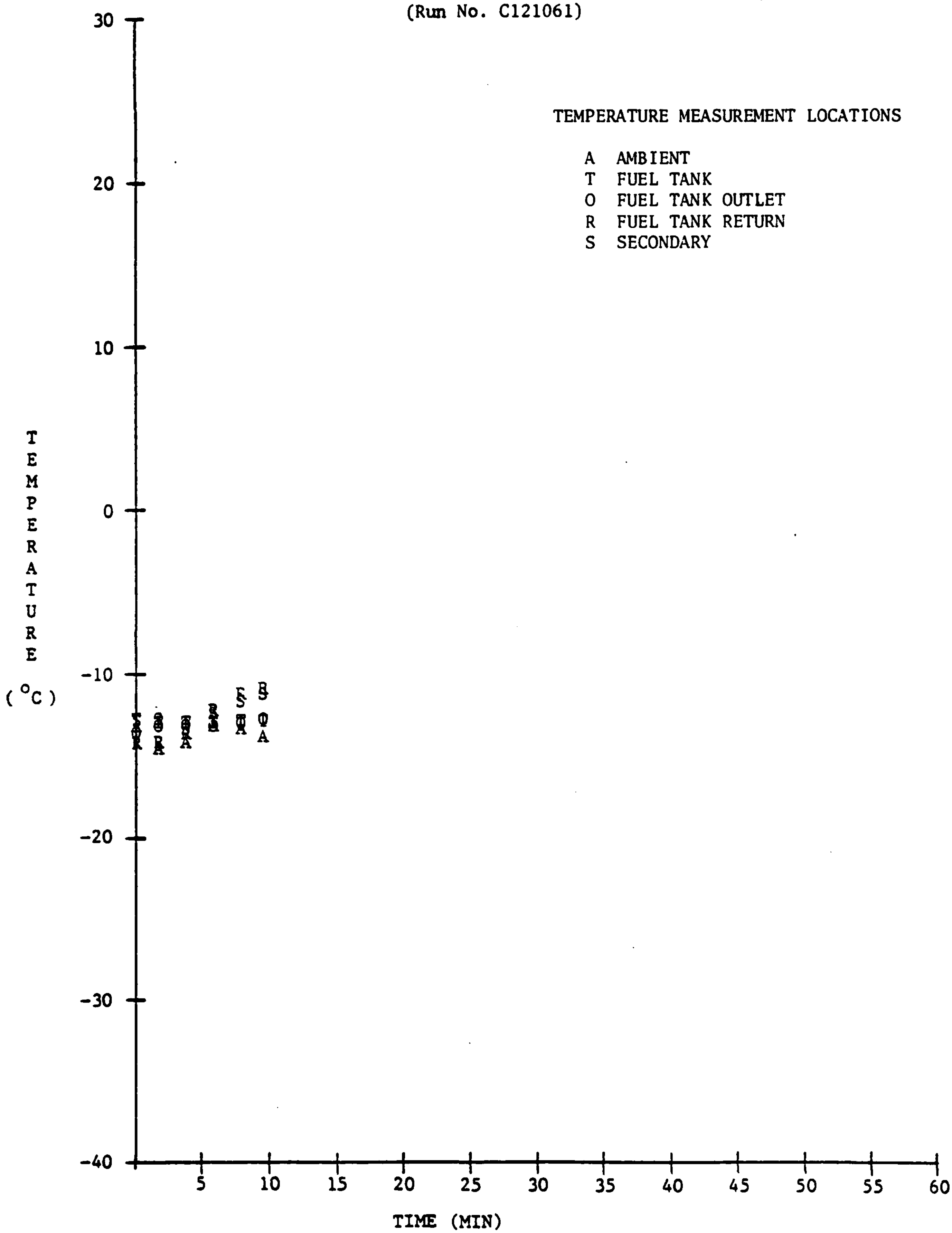
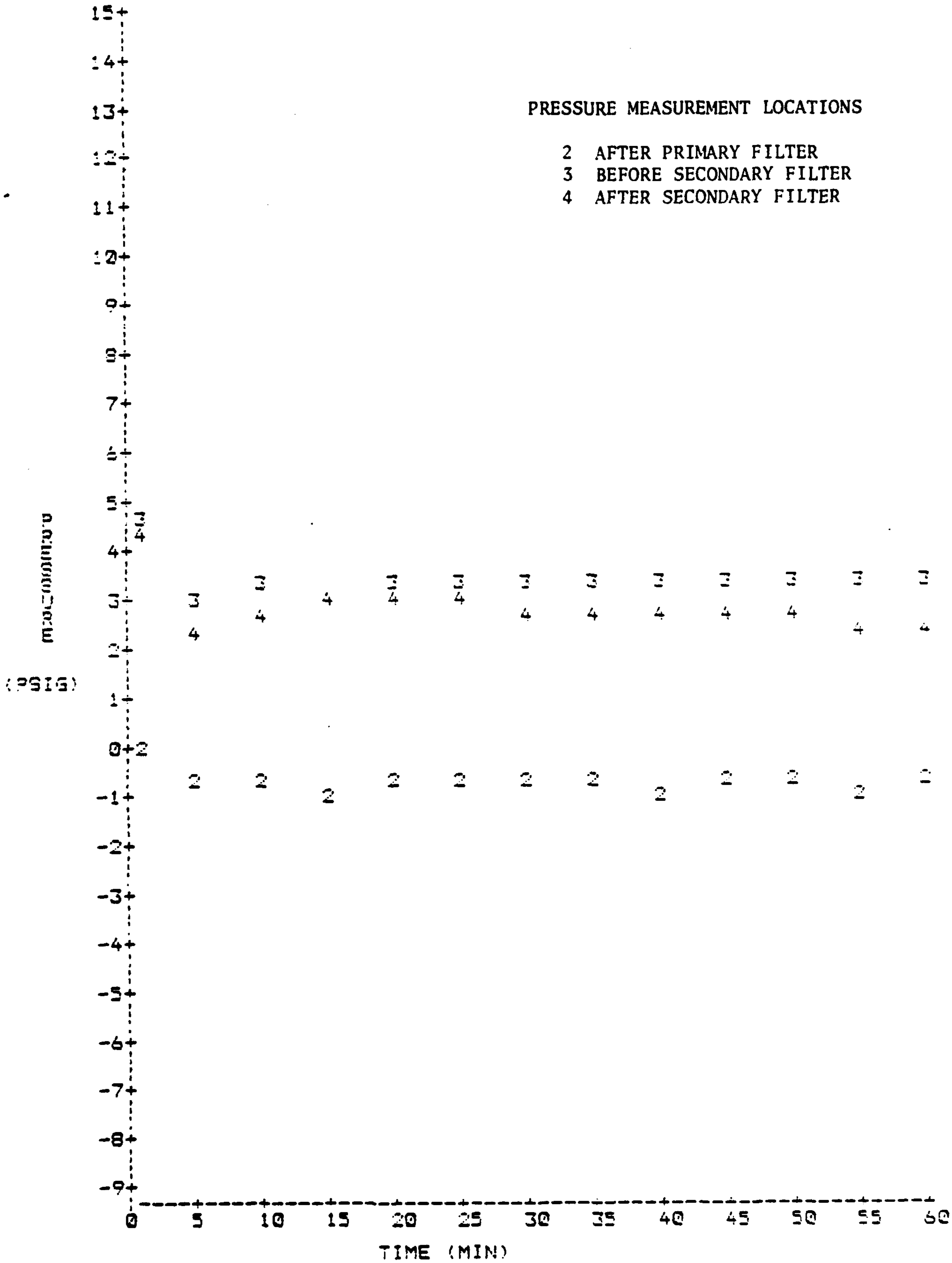


FIGURE E-7. PRESSURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 122 (Run No. C122057)



Note: 1 psig = 6.89 kPa

FIGURE E-8. TEMPERATURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 122
(Run No. C122057)

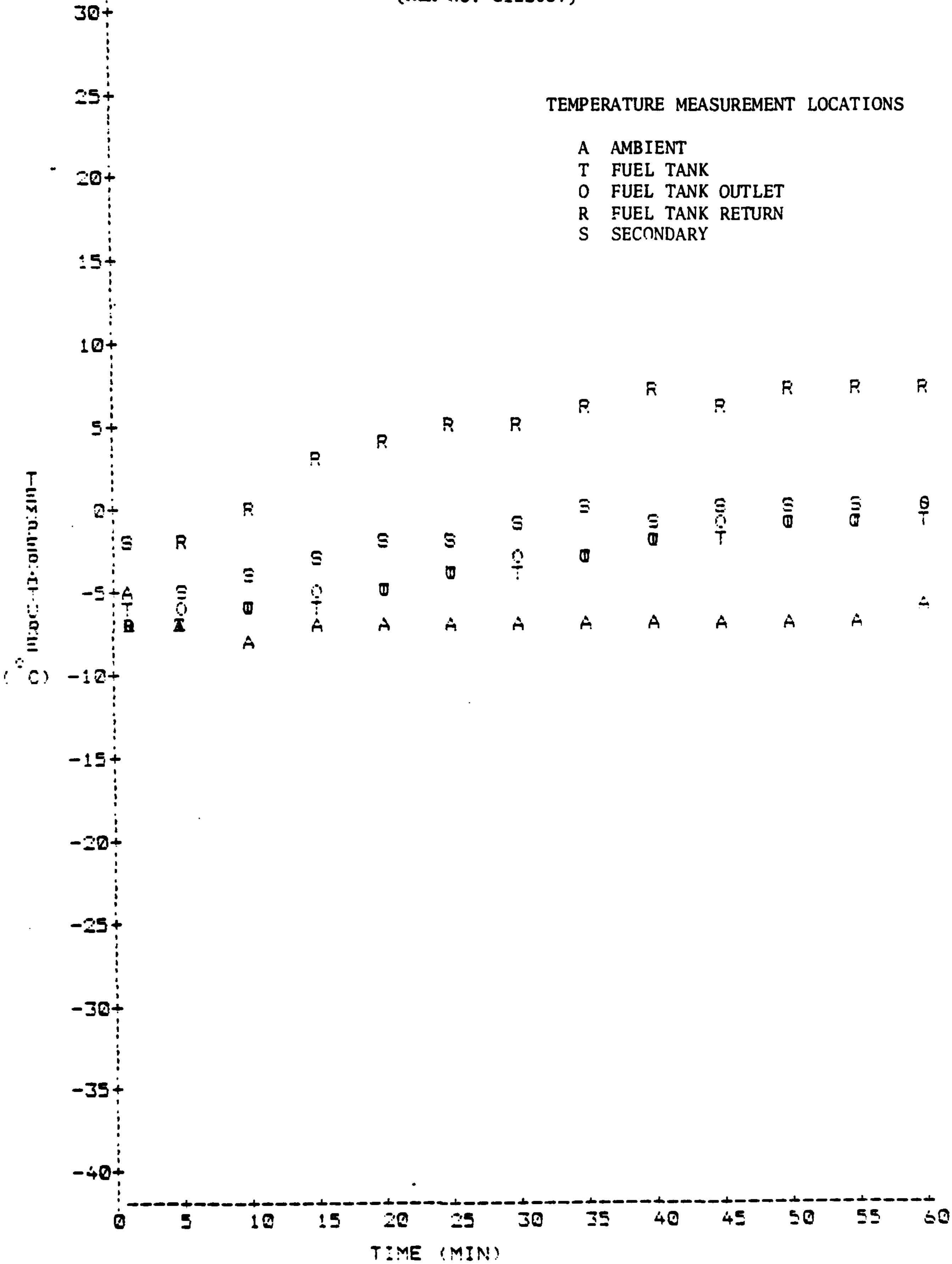
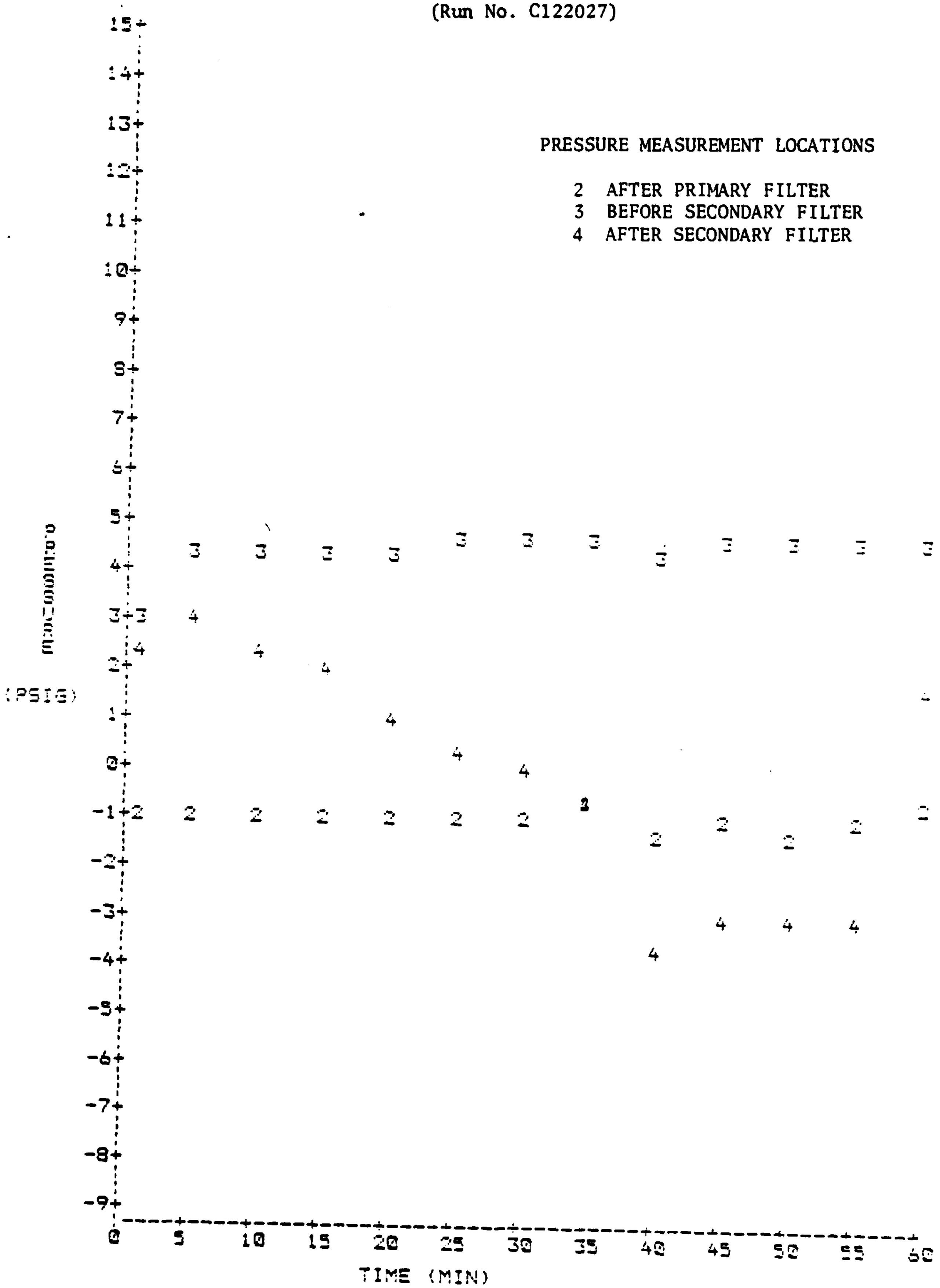


FIGURE E-9. PRESSURE DATA CORRESPONDING TO A BORDERLINE PASS CONDITION IN VEHICLE 122 (Run No. C122027)



Note: 1 psig = 6.89 kPa

FIGURE E-10. TEMPERATURE DATA CORRESPONDING TO A BORDERLINE PASS CONDITION IN VEHICLE 12;
(Run No. C122027)

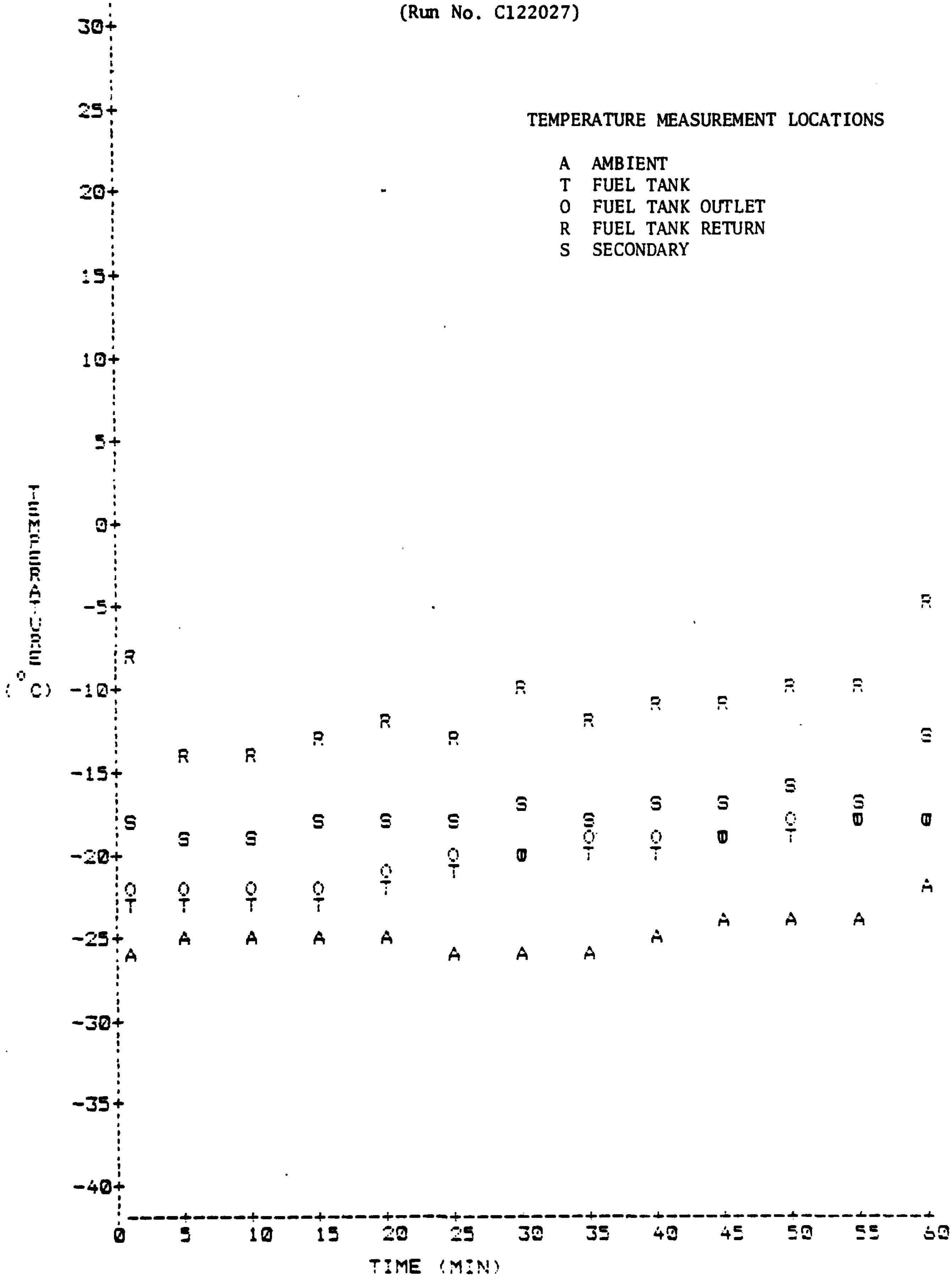
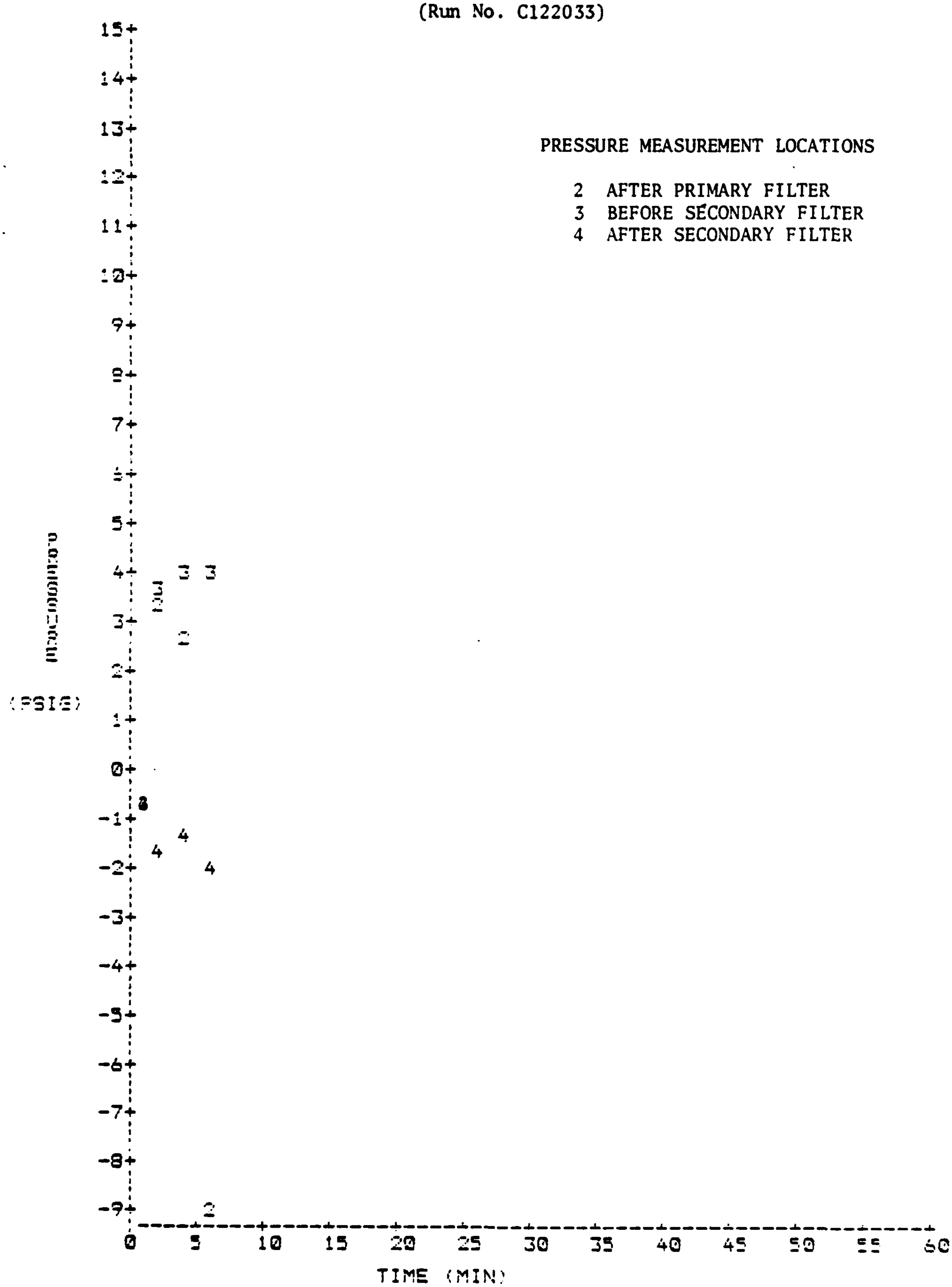


FIGURE E-11. PRESSURE DATA CORRESPONDING TO A FAIL CONDITION IN VEHICLE 122
(Run No. C122033)



Note: 1 psig = 6.89 kPa

FIGURE E-12. TEMPERATURE DATA CORRESPONDING TO A FAIL CONDITION IN VEHICLE 122
(Run No. C122033)

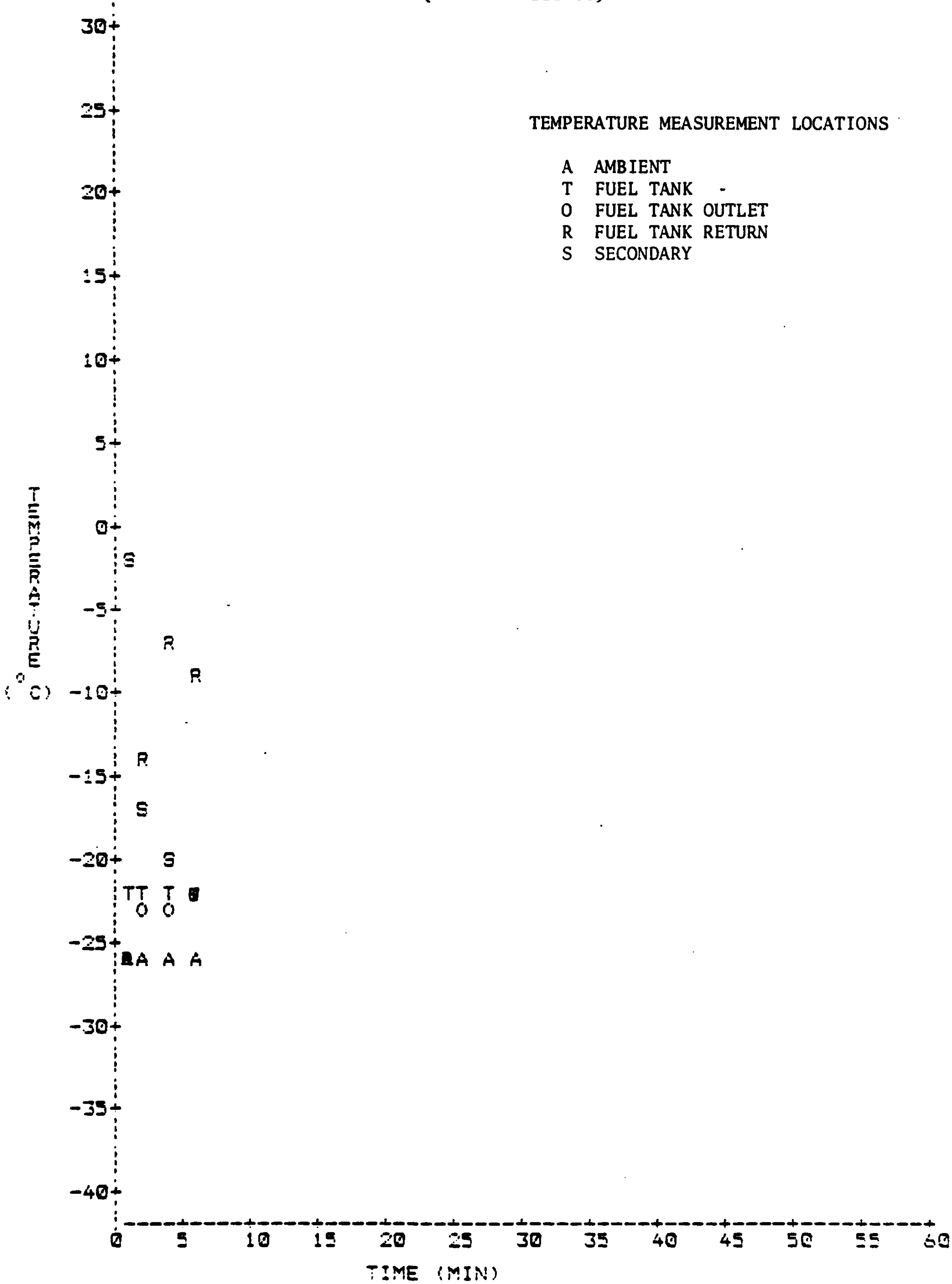
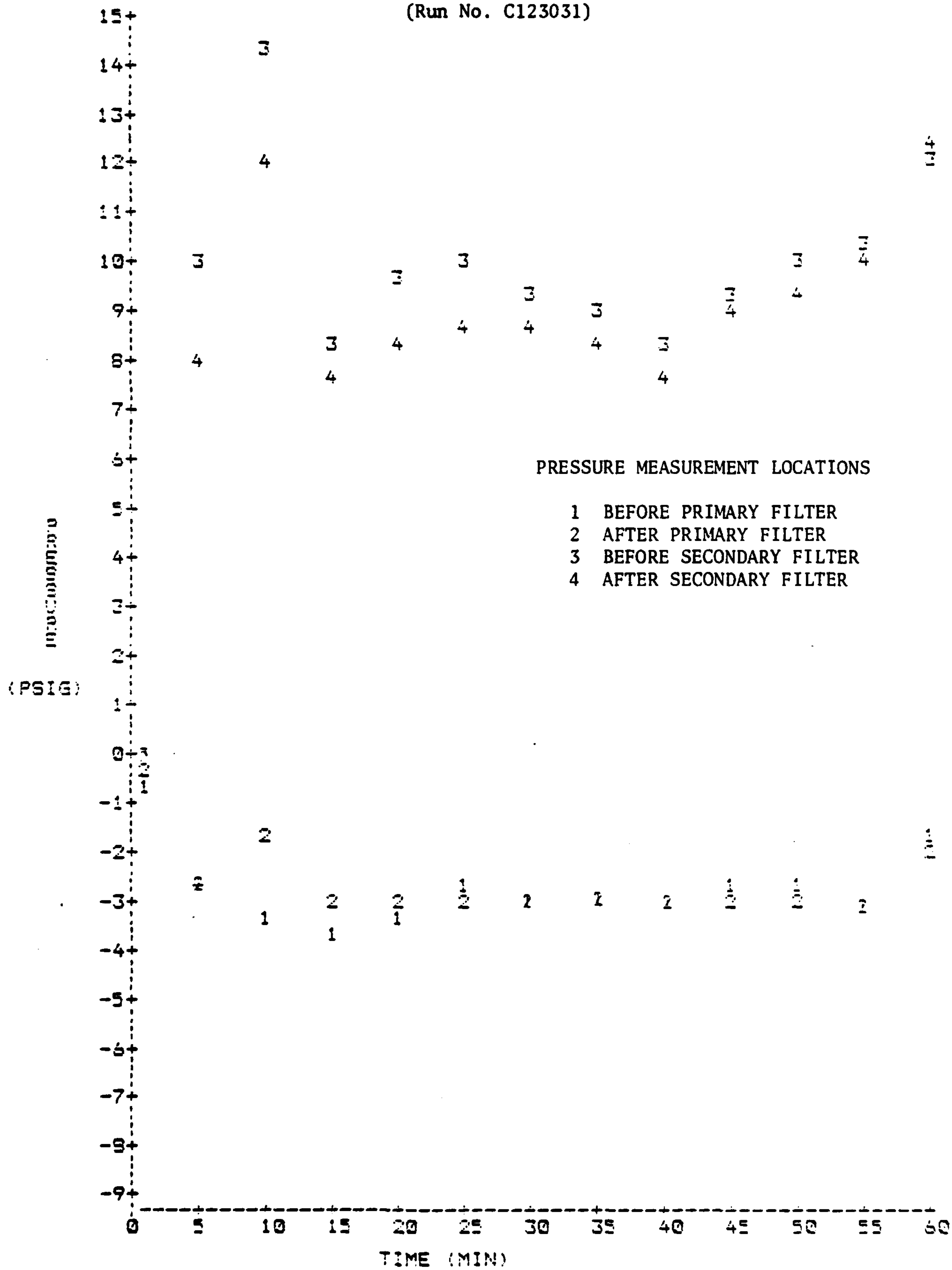


FIGURE E-13. PRESSURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 123
(Run No. C123031)



Note: 1 psig = 6.89 kPa

FIGURE E-14. TEMPERATURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 123 (Run No. C123031)

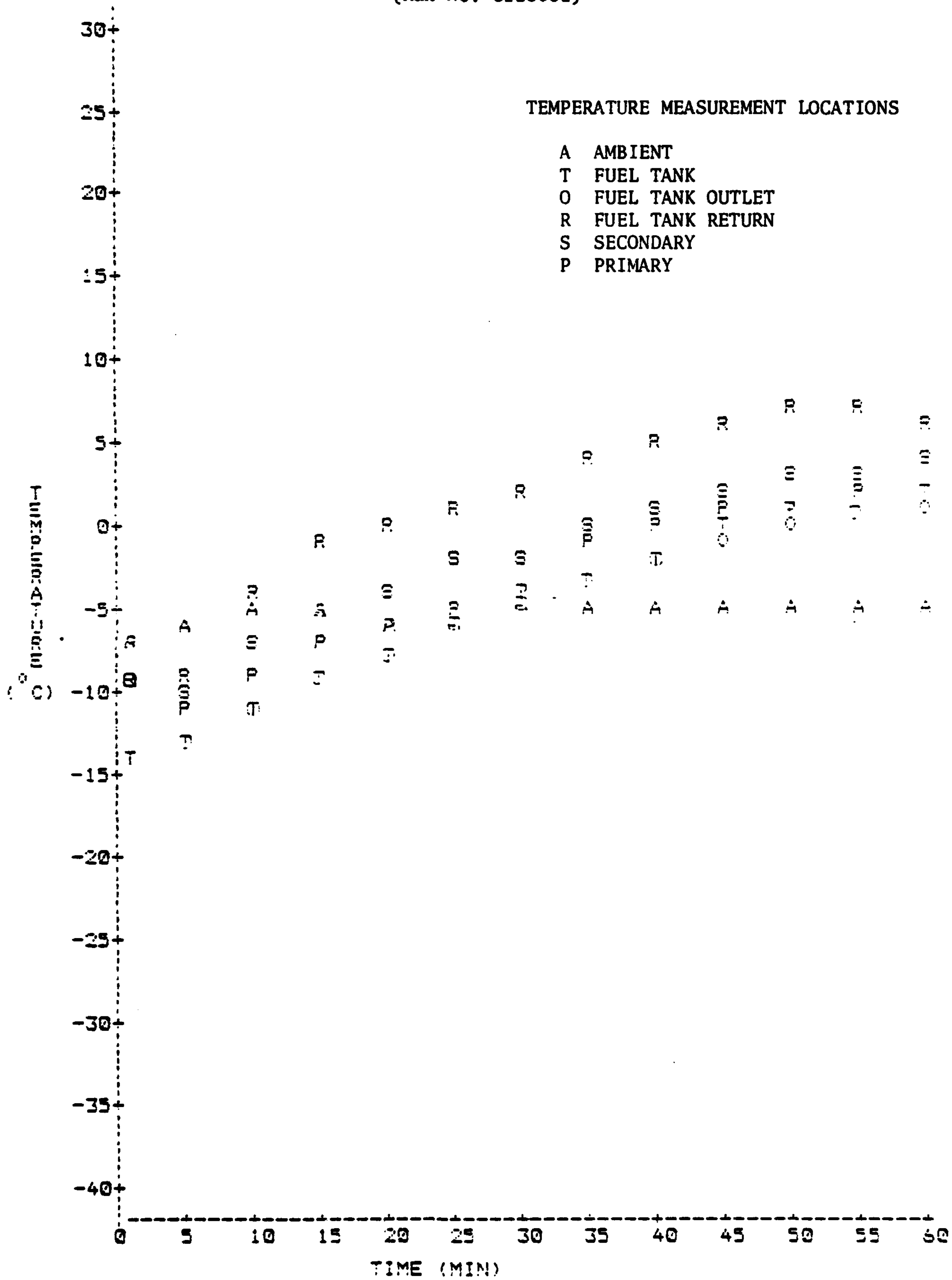
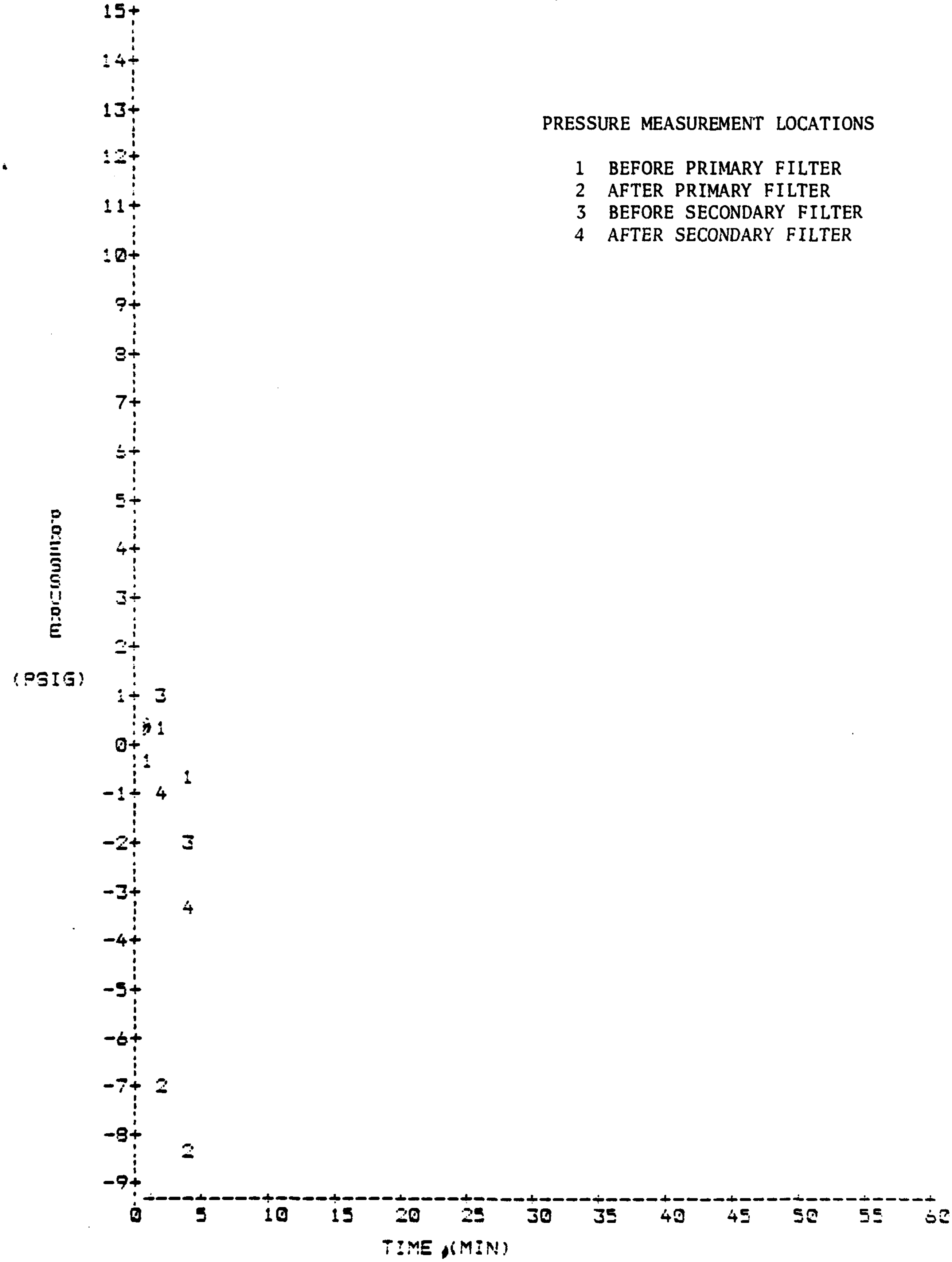


FIGURE E-15. PRESSURE DATA CORRESPONDING TO A FAIL CONDITION IN VEHICLE 123 (Run No. C123094)



Note: 1 psig = 6.89 kPa

FIGURE E-16. TEMPERATURE DATA CORRESPONDING TO A FAIL CONDITION IN VEHICLE 123 (Run No. C123094)

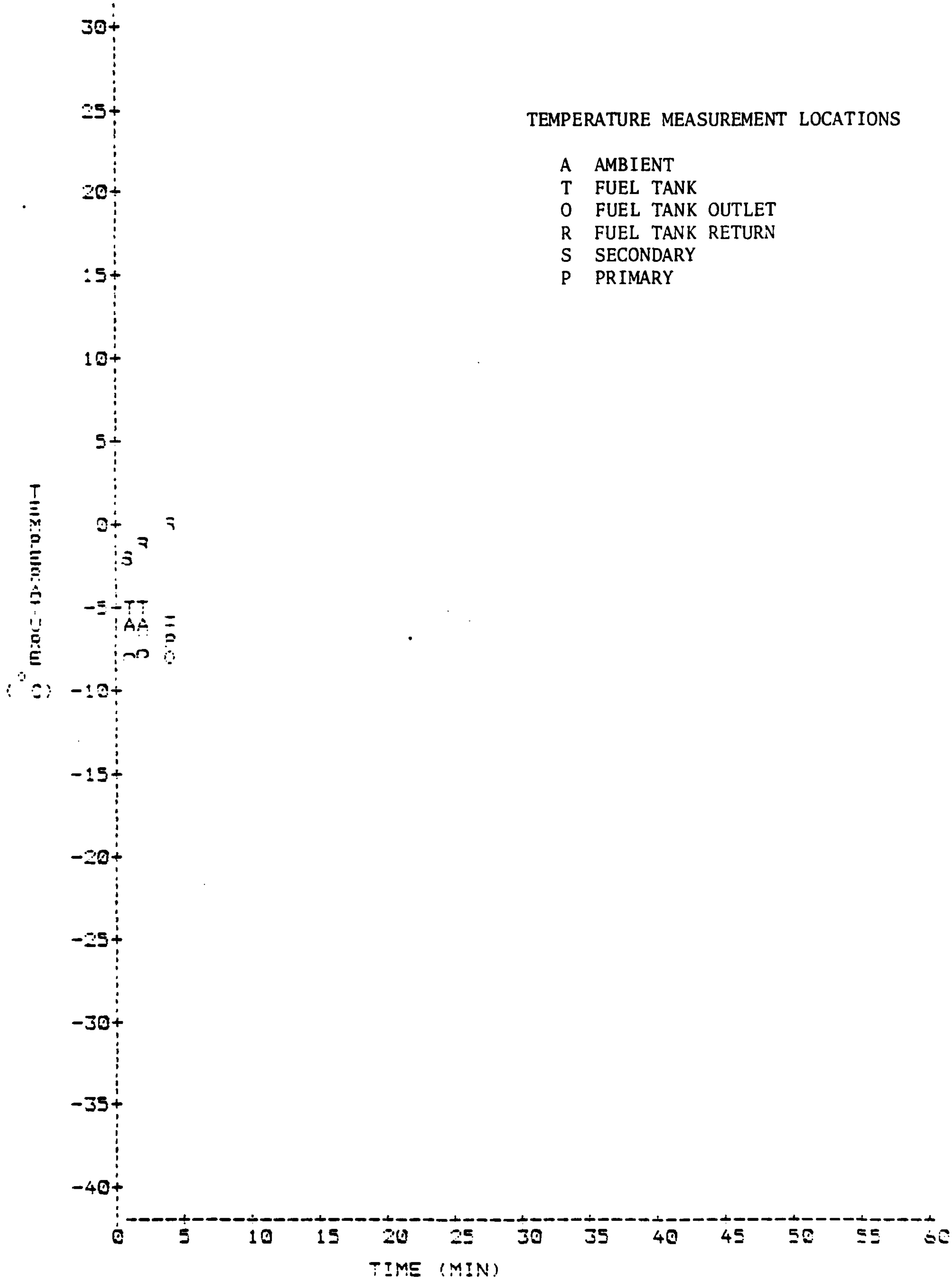
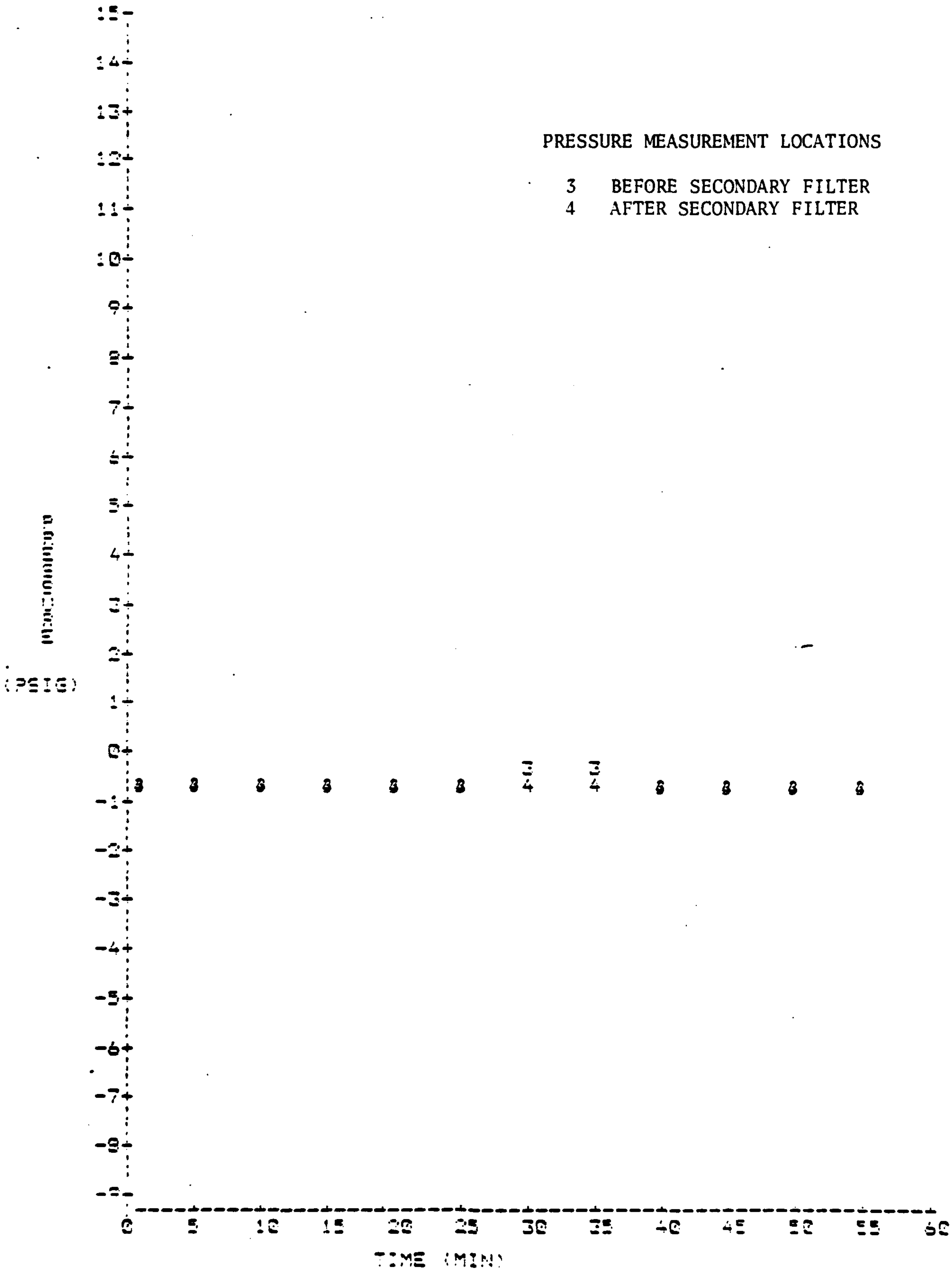


FIGURE E-17. PRESSURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 124
(Run No. C124023)



Note: 1 psig = 6.89 kPa

FIGURE E-18. TEMPERATURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 124 (Run No. C124023)

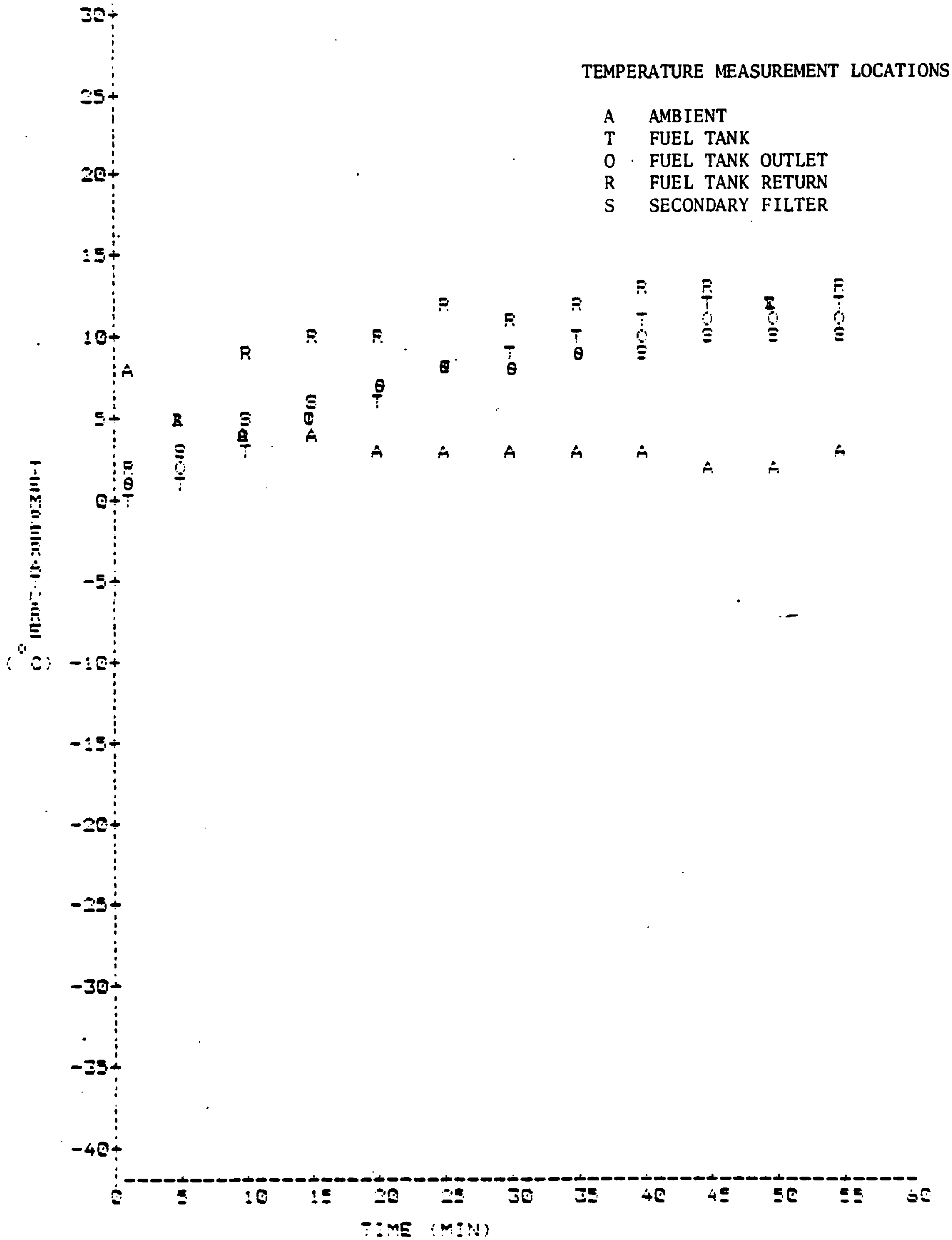
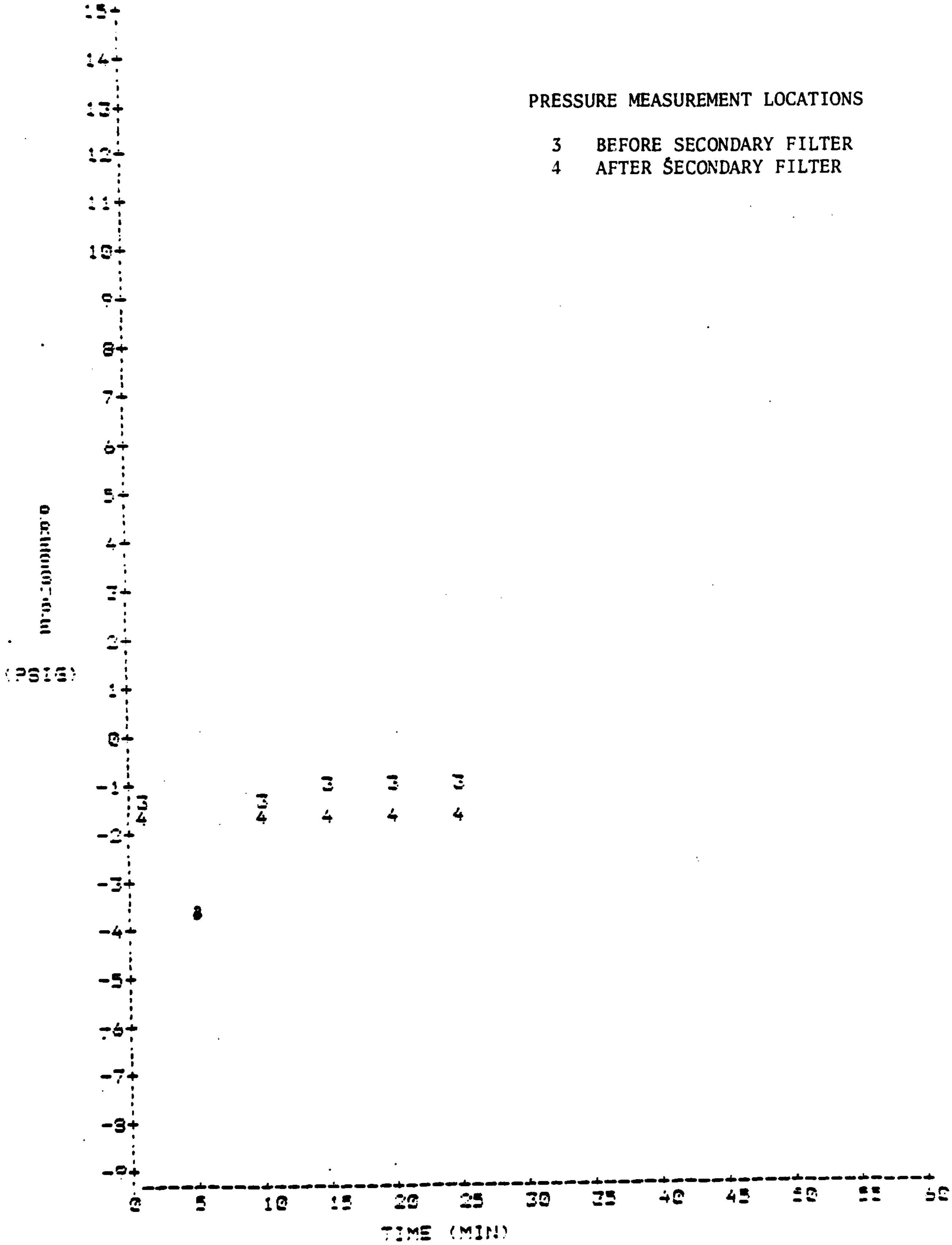


FIGURE E-19. PRESSURE DATA CORRESPONDING TO A BORDERLINE CONDITION IN VEHICLE 124 (Run No. C124036)



Note: 1 psig = 6.89 kPa

FIGURE E-20. TEMPERATURE DATA CORRESPONDING TO A BORDERLINE CONDITION IN VEHICLE 124 (Run No. C124036)

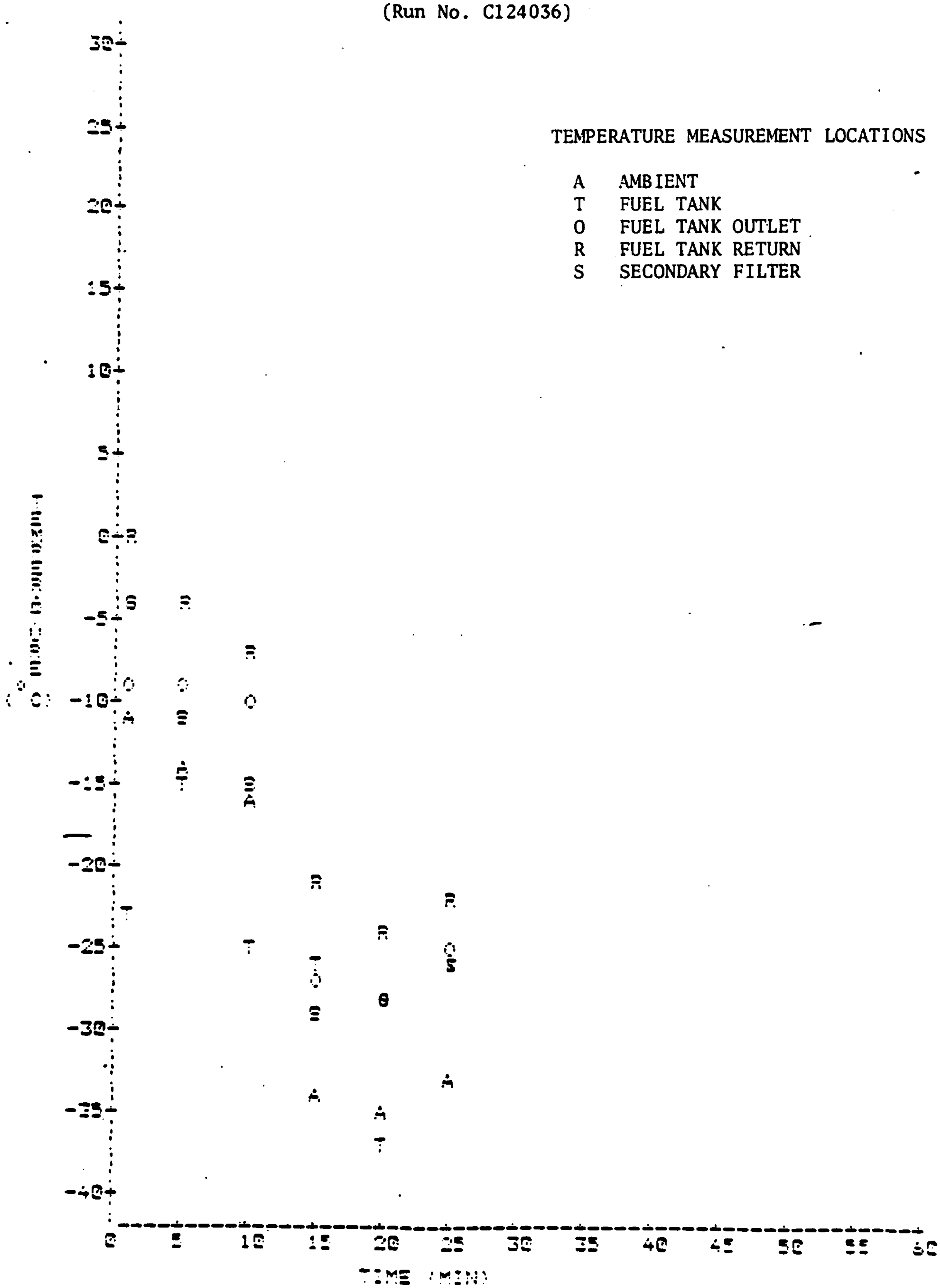
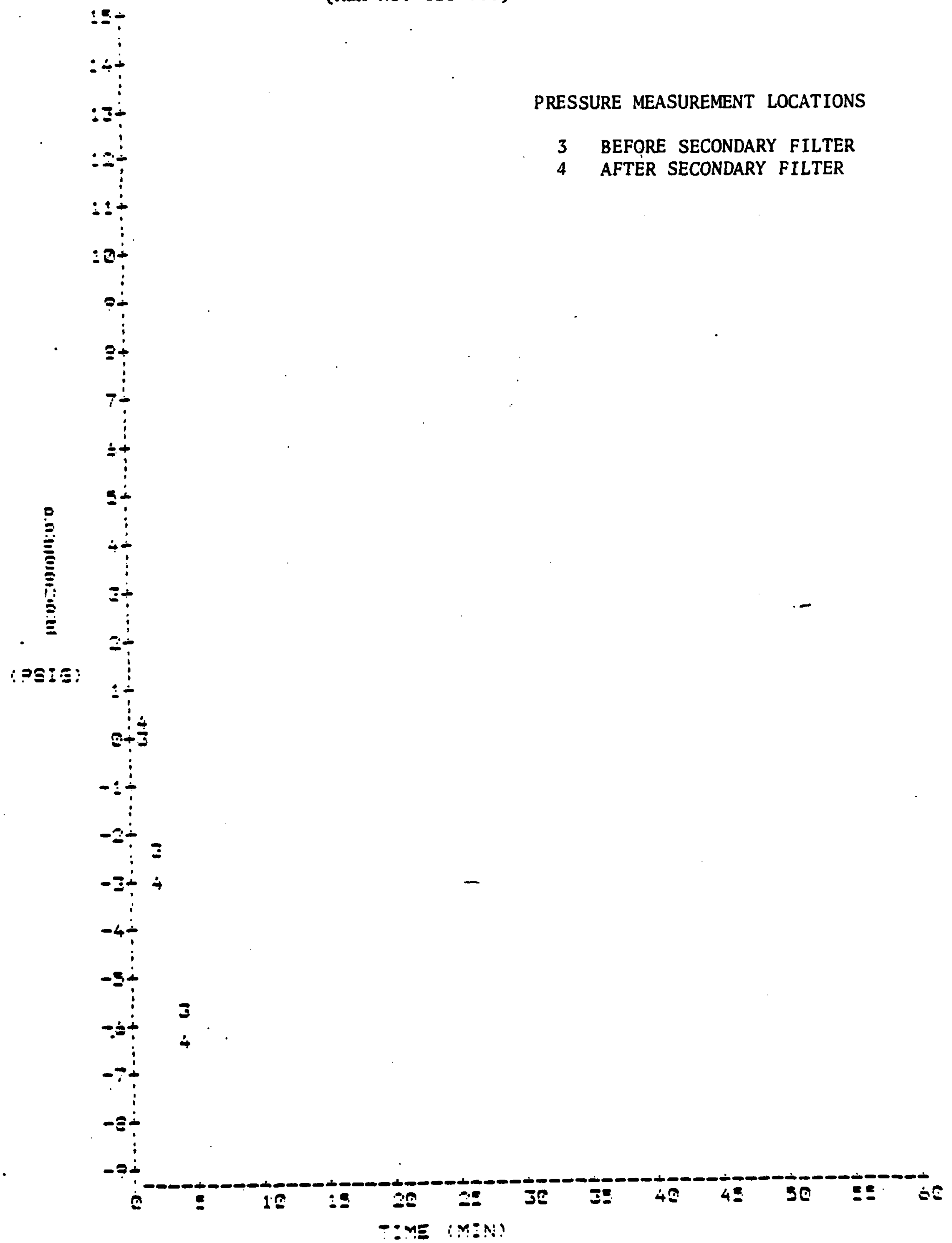


FIGURE E-21. PRESSURE DATA CORRESPONDING TO A FAIL CONDITION IN VEHICLE 124 (Run No. C124086)



Note: 1 psig = 6.89 kPa

FIGURE E-22. TEMPERATURE DATA CORRESPONDING TO A FAIL CONDITION IN VEHICLE 124
(Run No. 124086)

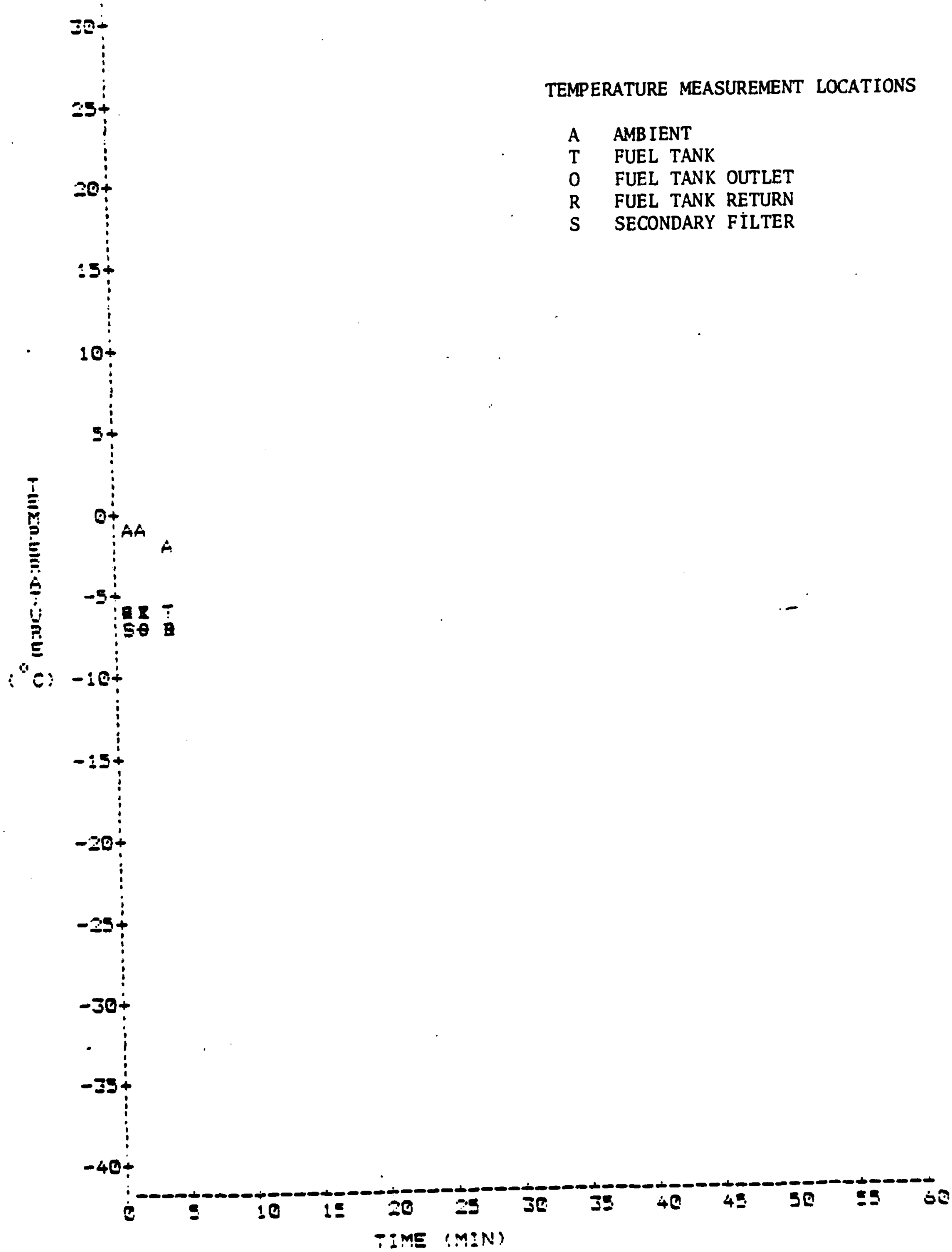
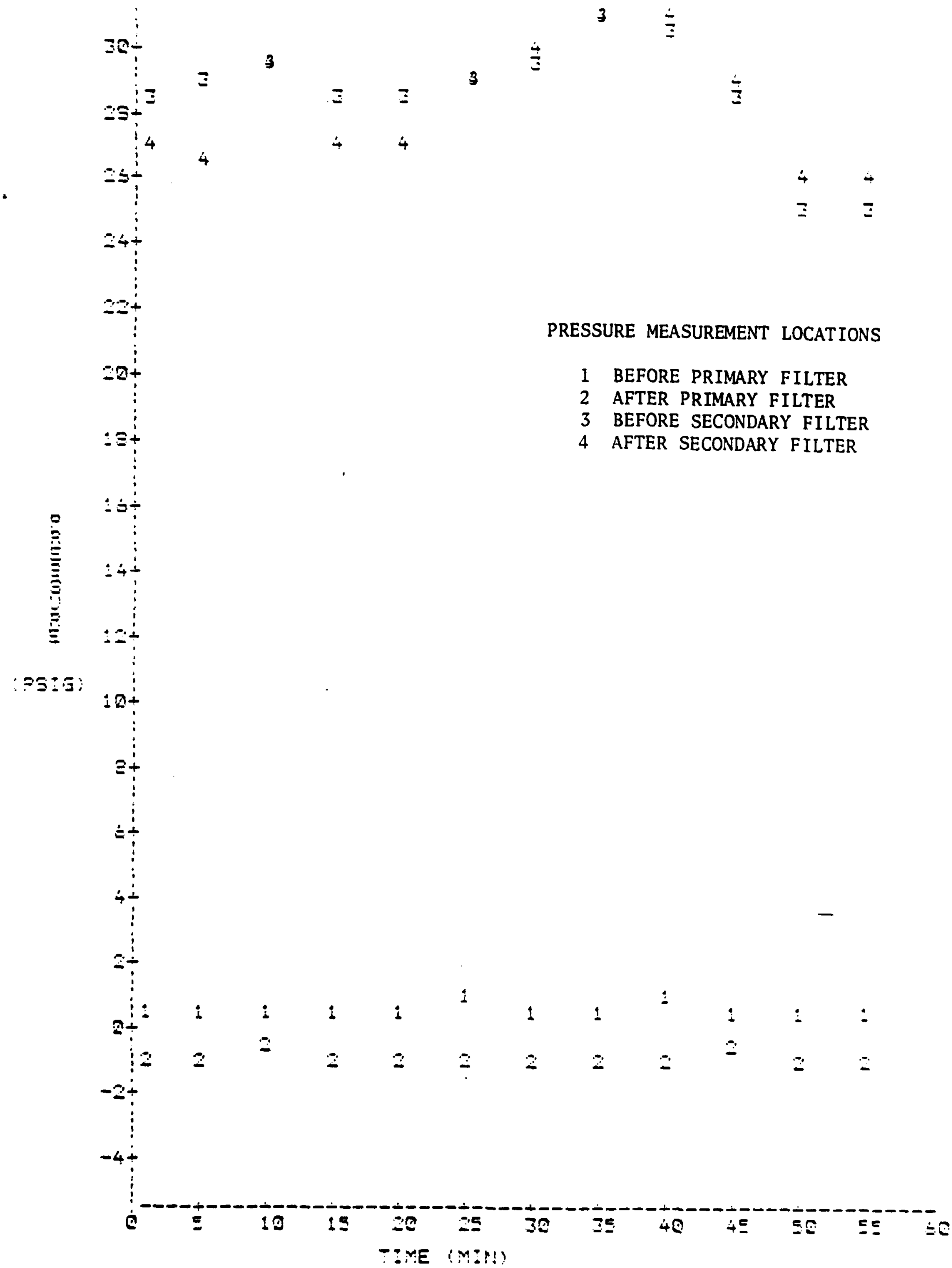


FIGURE E-23. PRESSURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 125 (Run No. C125092)



Note: 1 psig = 6.89 kPa

FIGURE E-24. TEMPERATURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 125 (Run No. C125092)

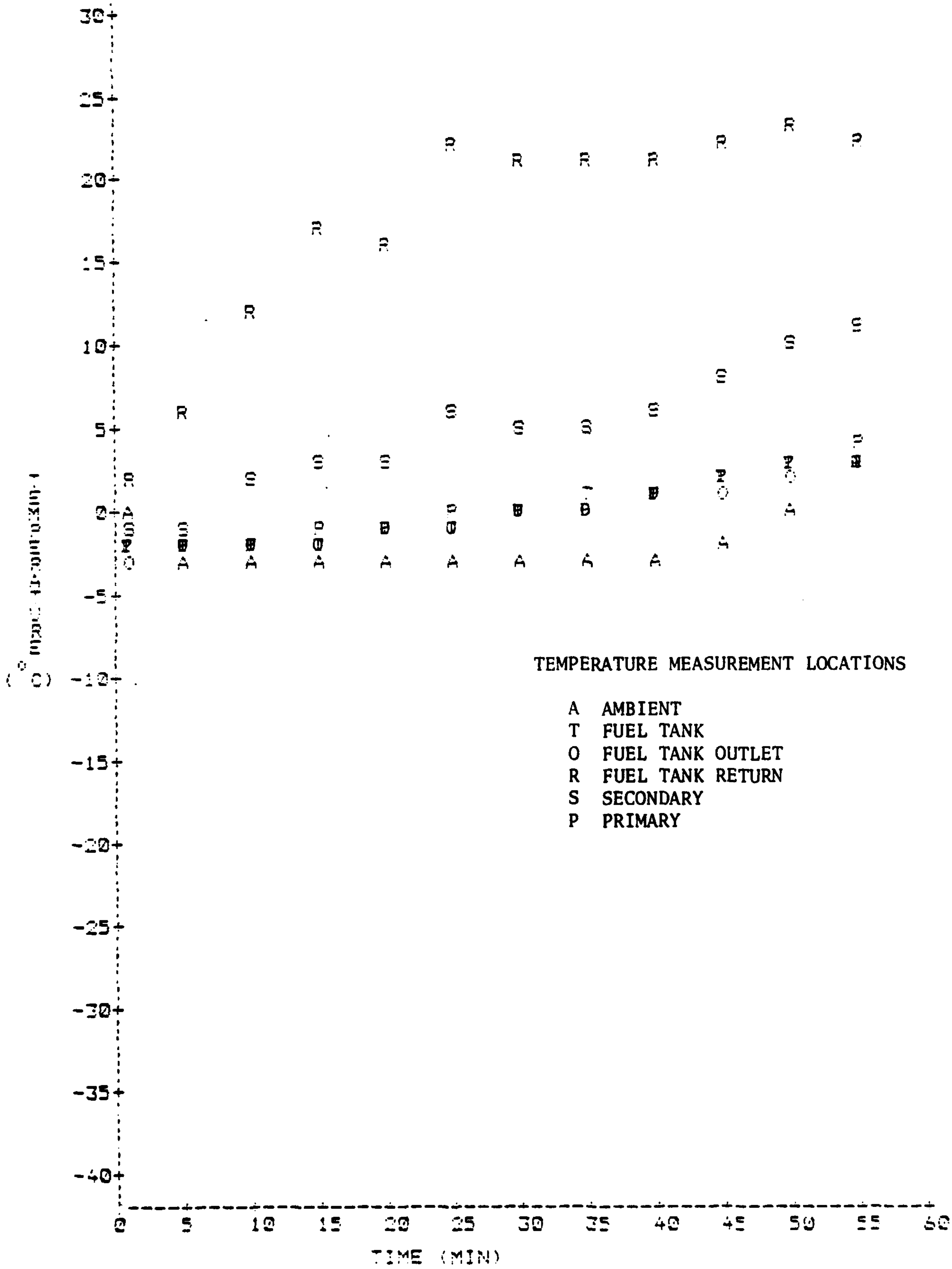
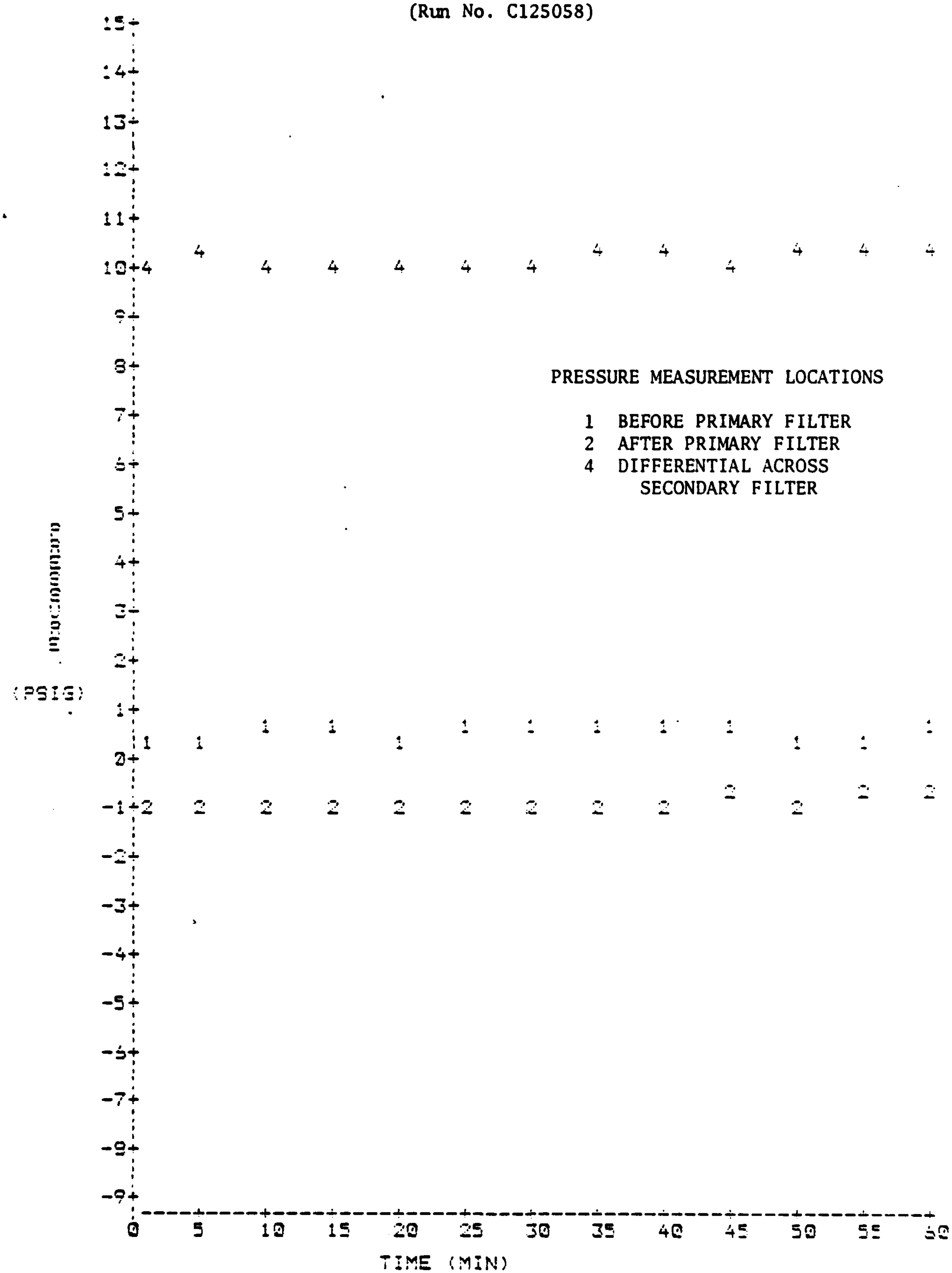


FIGURE E-25. PRESSURE DATA CORRESPONDING TO A BORDERLINE PASS CONDITION IN VEHICLE 125 (Run No. C125058)



Note: 1 psig = 6.89 kPa

FIGURE E-26. TEMPERATURE DATA CORRESPONDING TO A BORDERLINE PASS CONDITION IN VEHICLE 125 (Run No. C125058)

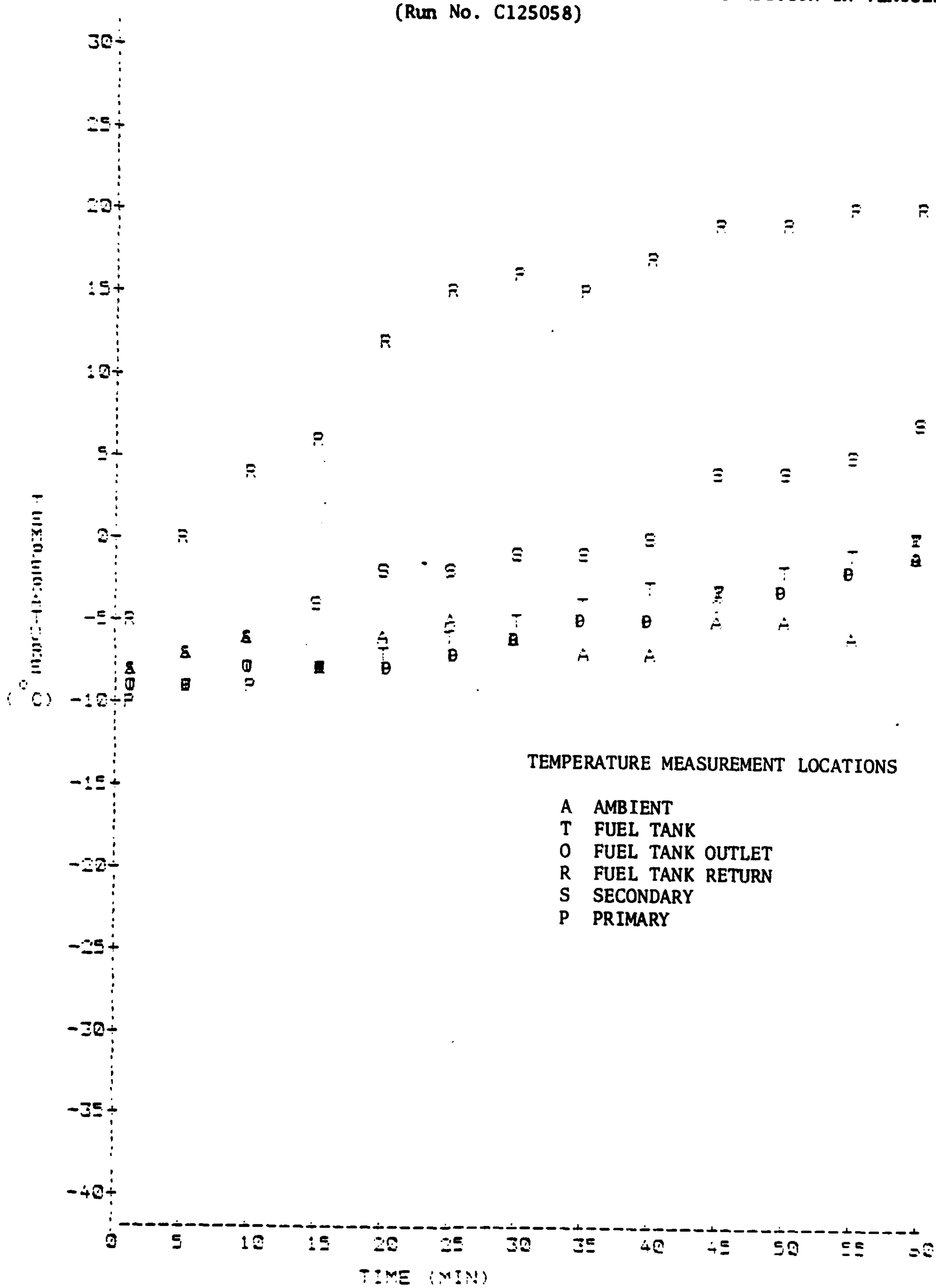
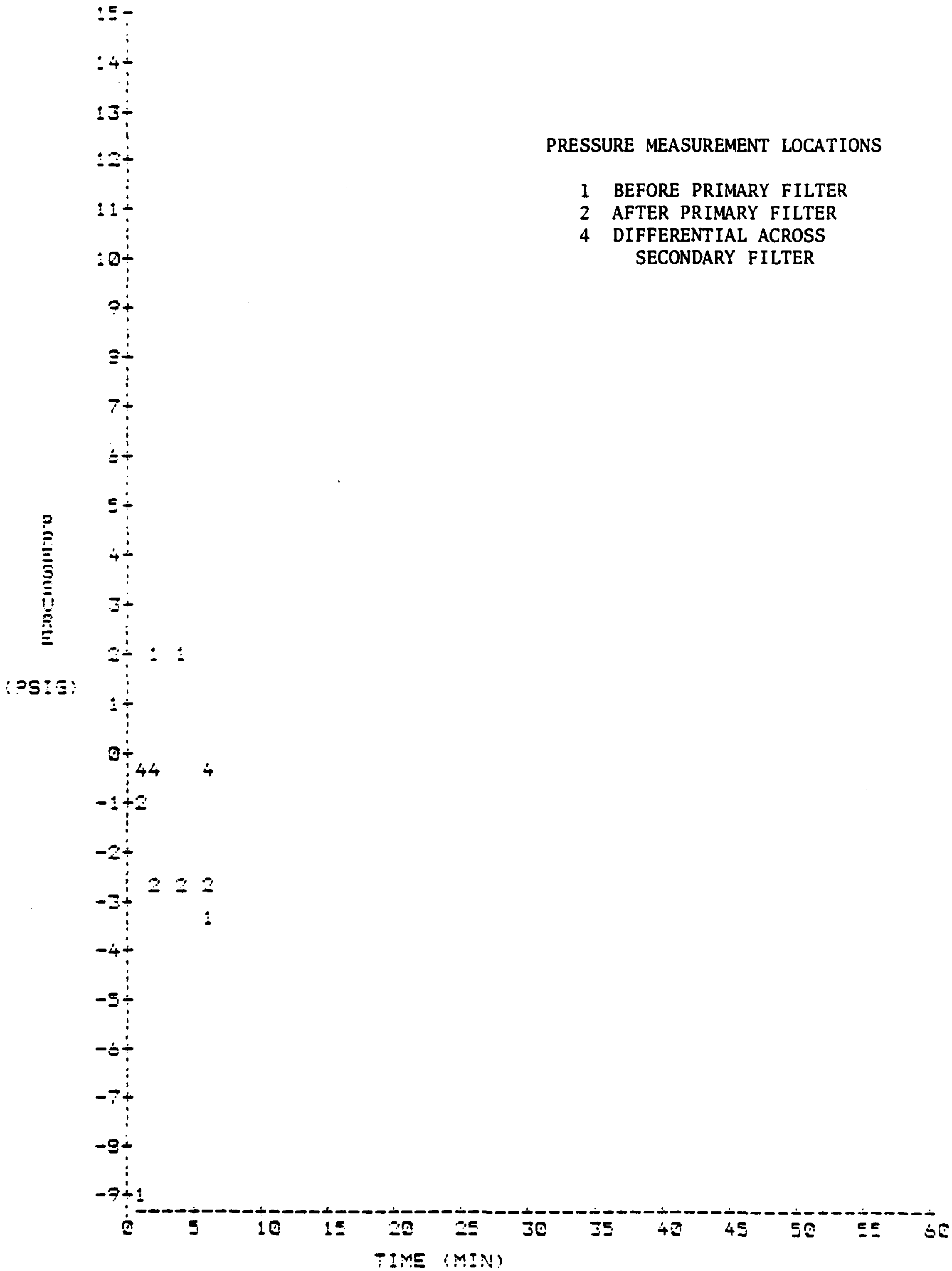


FIGURE E-27. PRESSURE DATA CORRESPONDING TO A FAIL CONDITION IN VEHICLE 125
(Run No. C125076)



Note: 1 psig = 6.89 kPa

FIGURE E-28. TEMPERATURE DATA CORRESPONDING TO A FAIL CONDITION IN VEHICLE 125 (Run No. C125076)

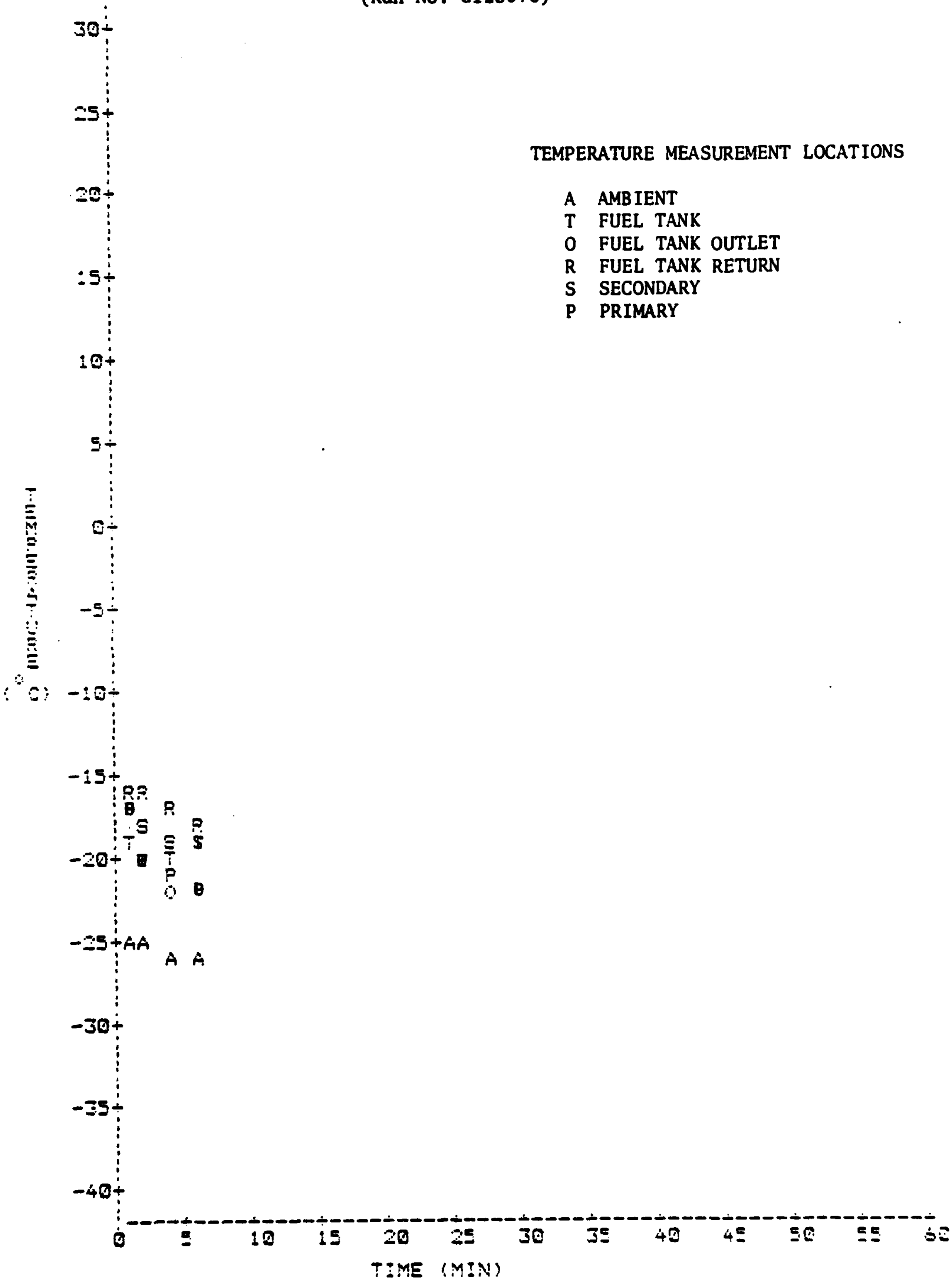
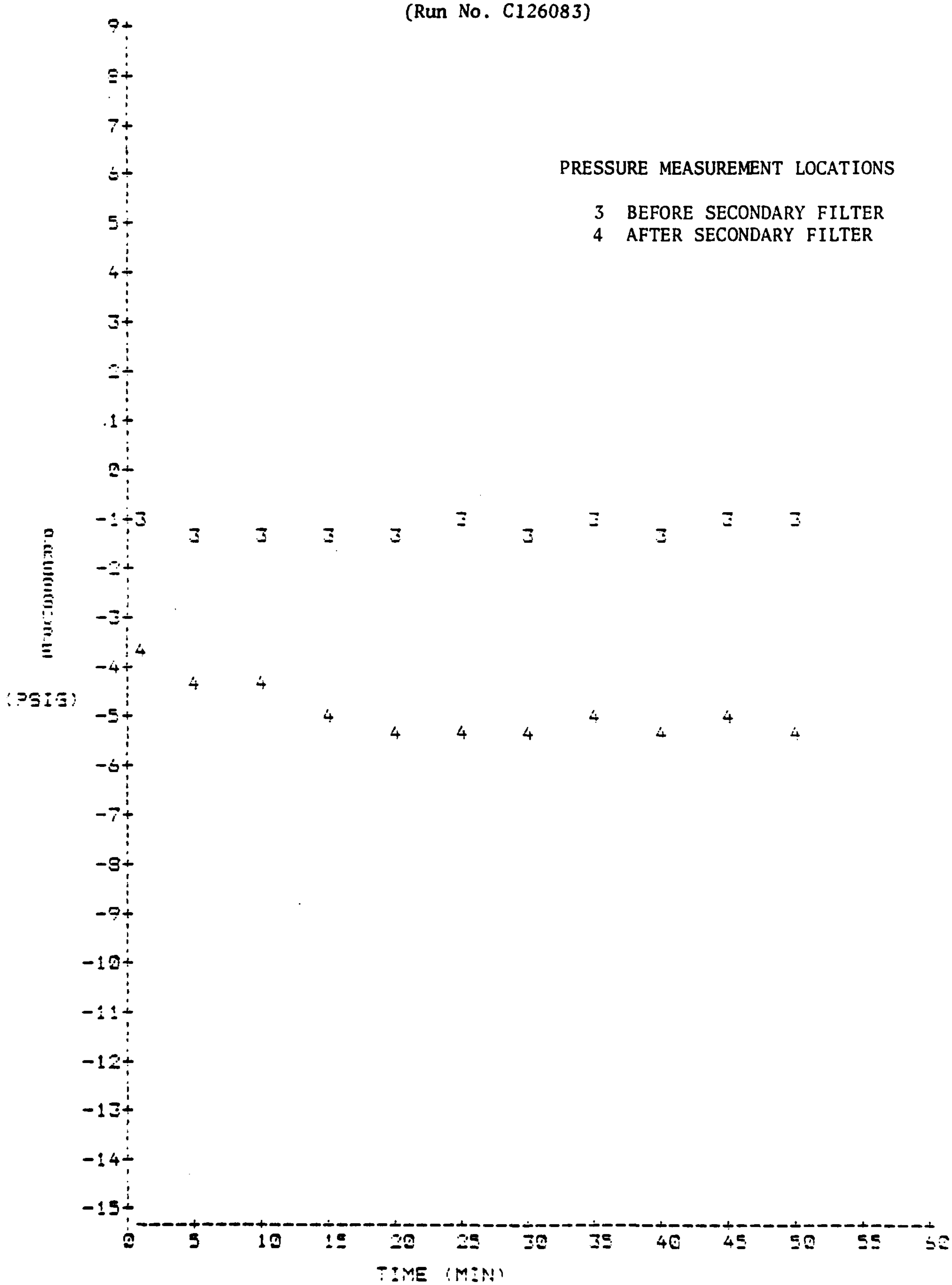


FIGURE E-29. PRESSURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 126 (Run No. C126083)



Note: 1 psig = 6.89 kPa

FIGURE E-30. TEMPERATURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 126 (Run No. C126083)

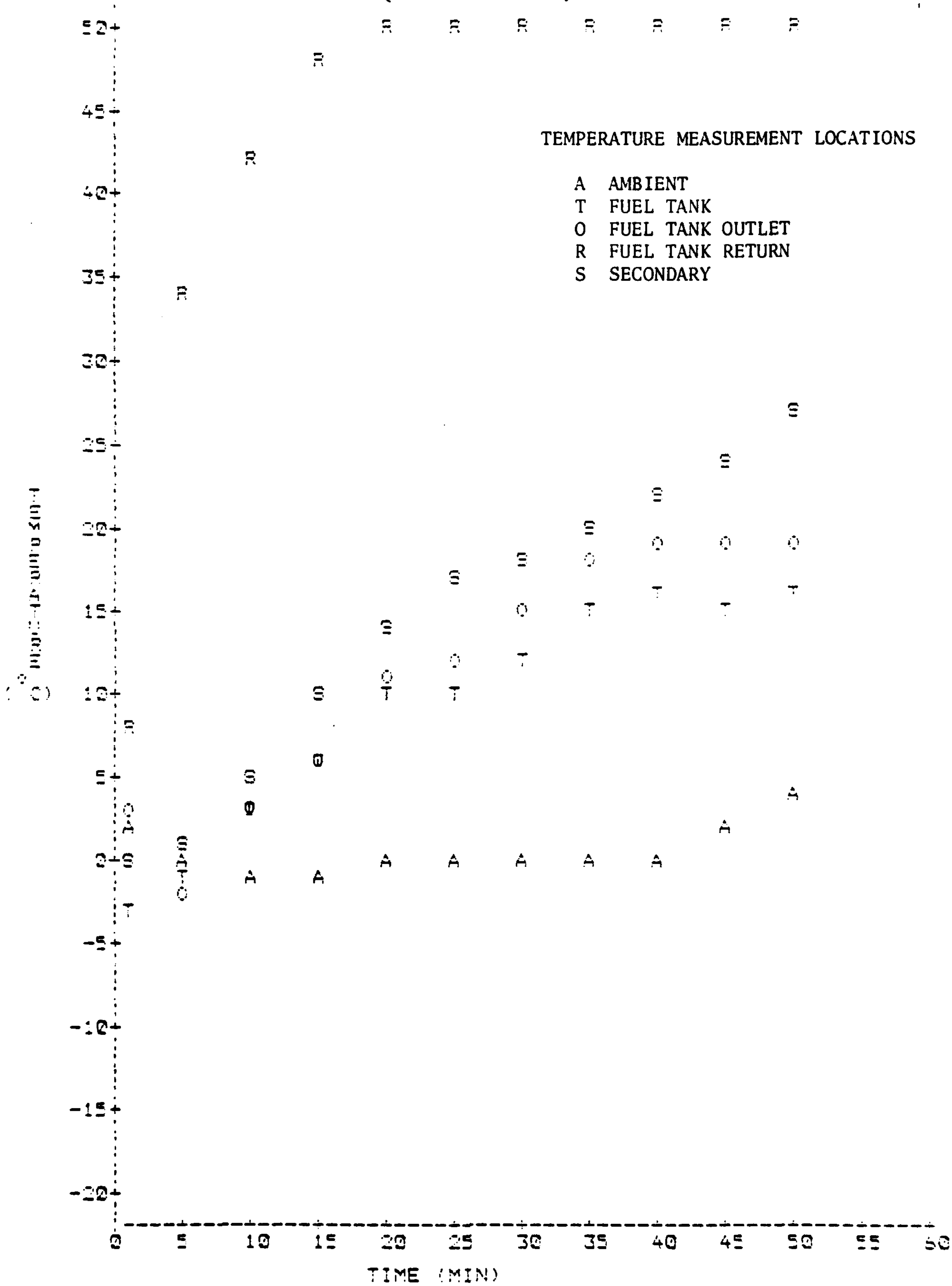
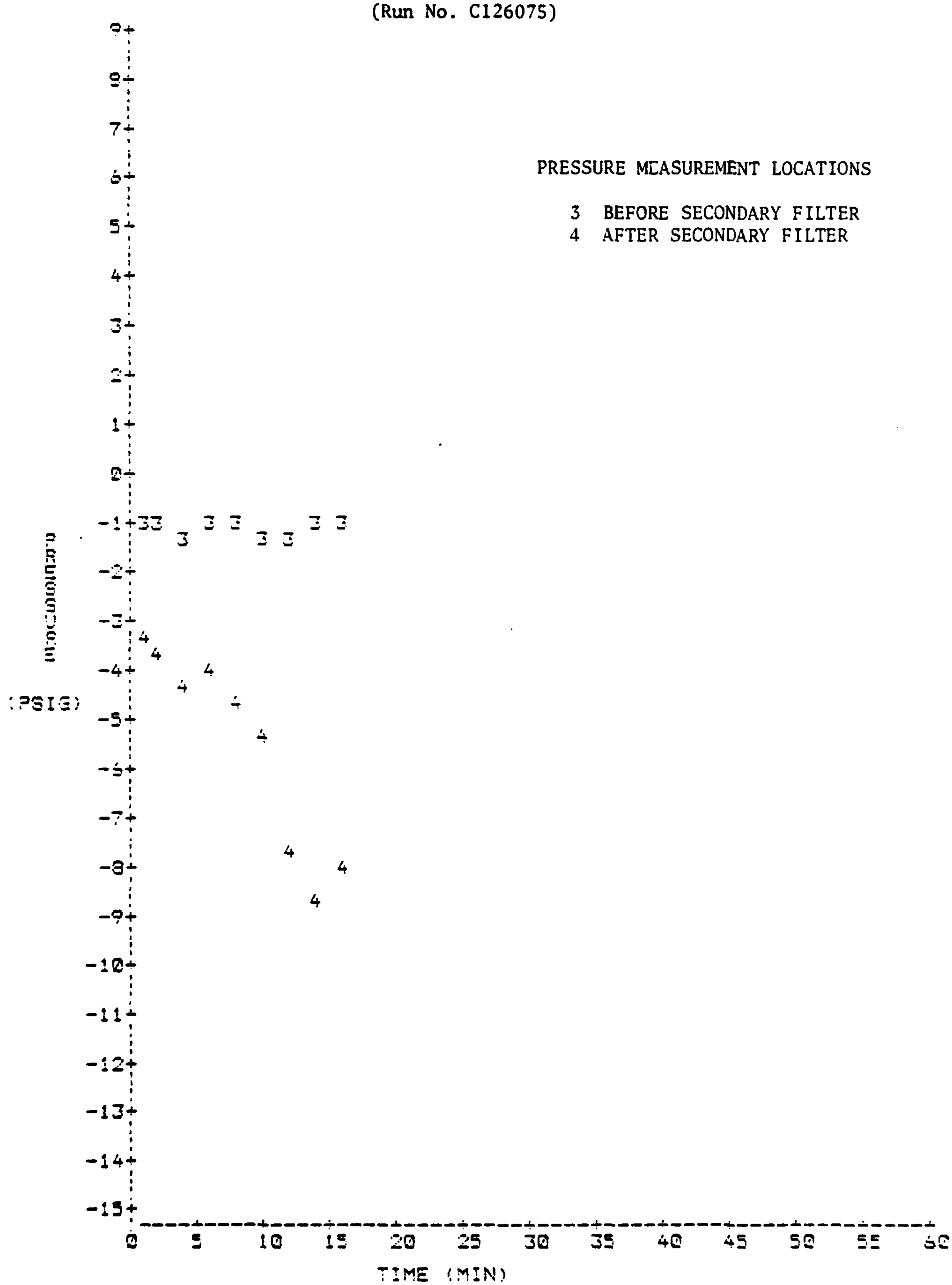


FIGURE E-31. PRESSURE DATA CORRESPONDING TO ONE TYPE OF FAIL CONDITION IN VEHICLE 126 (Run No. C126075)



Note: 1 psig = 6.89 kPa

FIGURE E-32. TEMPERATURE DATA CORRESPONDING TO ONE TYPE OF FAIL CONDITION IN VEHICLE 126
(Run No. C12607S)

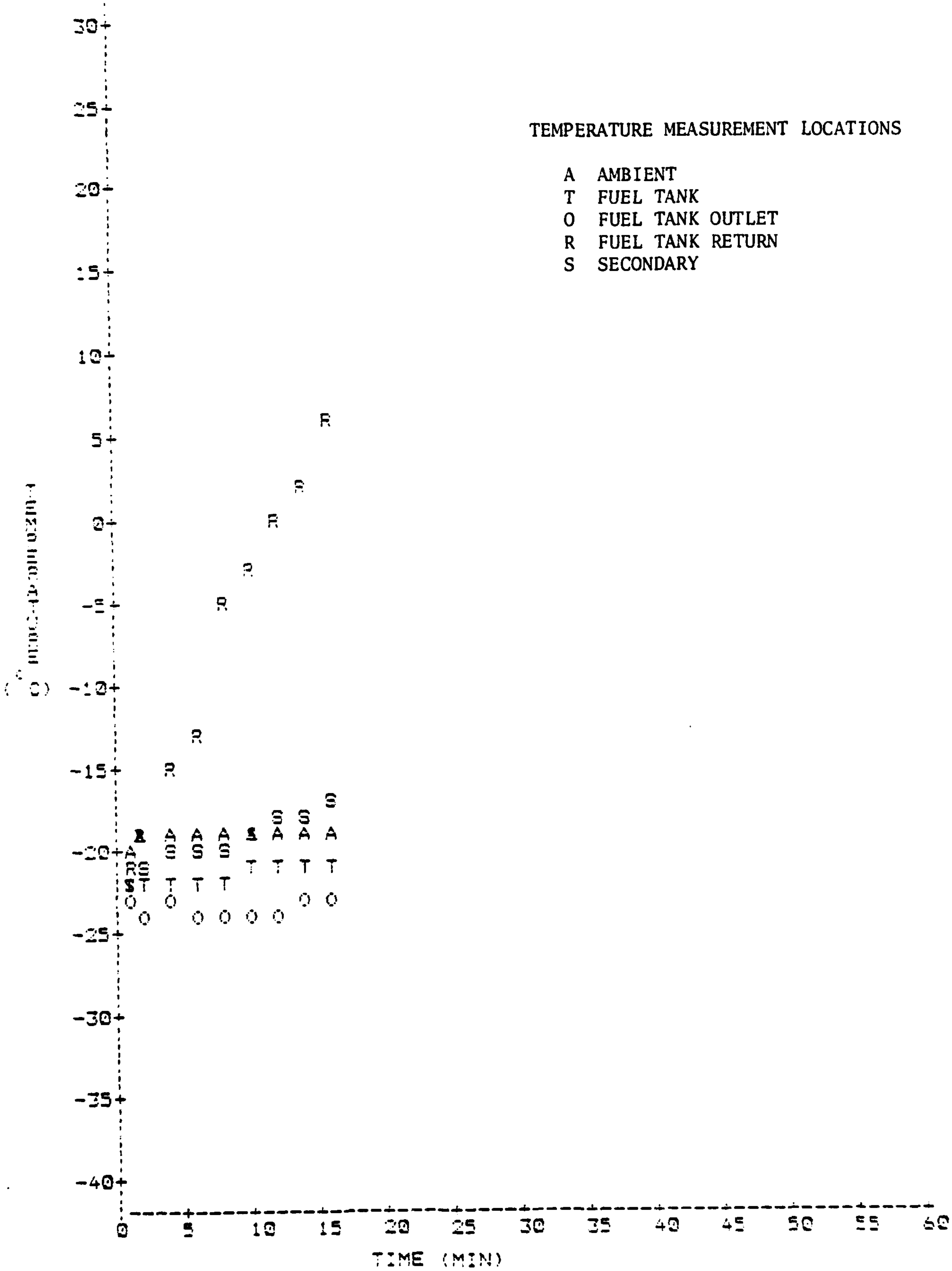
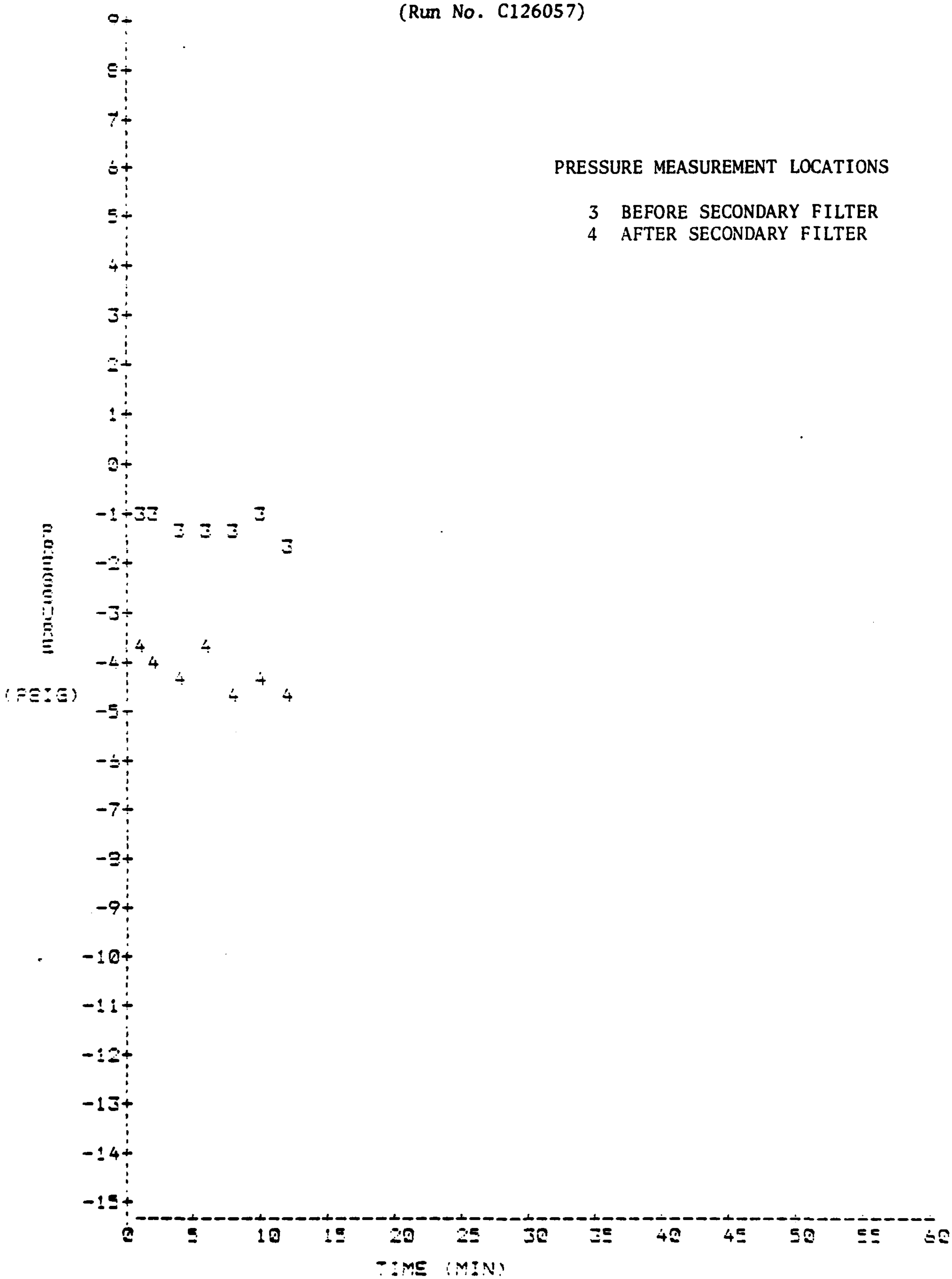


FIGURE E-33. PRESSURE DATA CORRESPONDING TO A SECOND TYPE OF FAIL CONDITION IN VEHICLE 126 (Run No. C126057)



Note: 1 psig = 6.89 kPa

FIGURE E-34. TEMPERATURE DATA CORRESPONDING TO A SECOND TYPE OF FAIL CONDITION IN VEHICLE 126 (Run No. C126057)

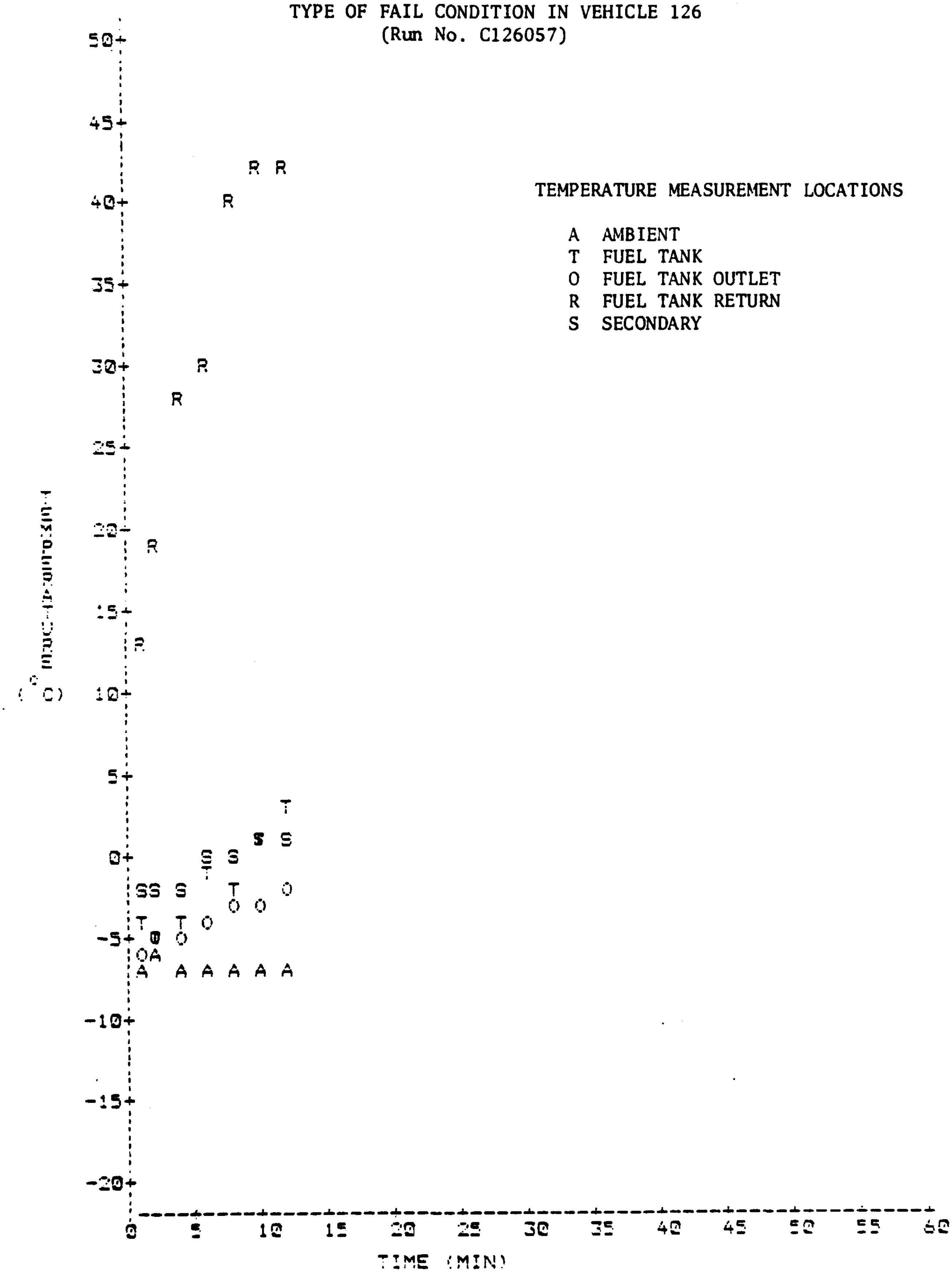
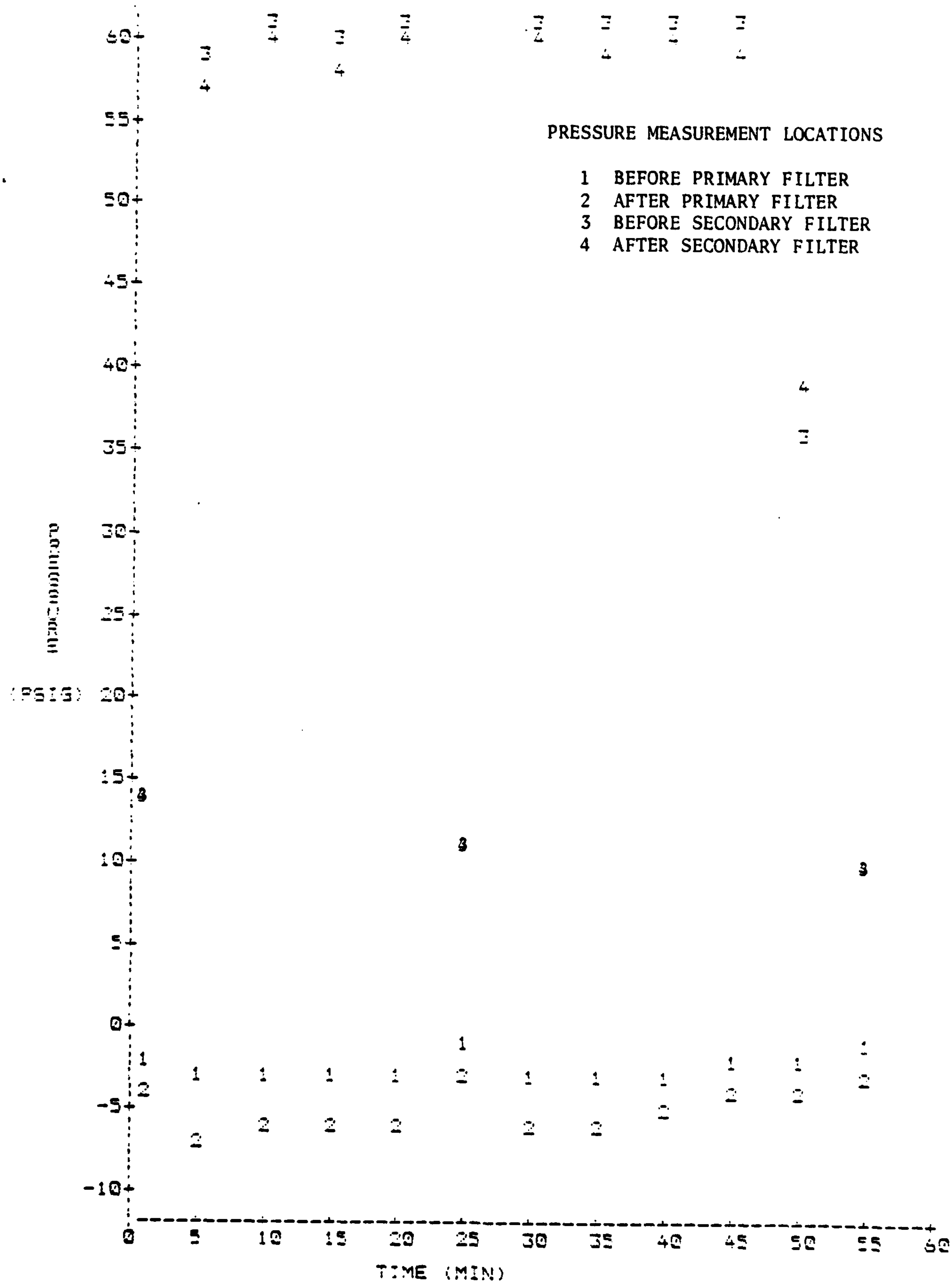


FIGURE E-35. PRESSURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 128
(Run No. C128087)



Note: 1 psig = 6.89 kPa

FIGURE E-36. TEMPERATURE DATA CORRESPONDING TO A PASS CONDITION IN VEHICLE 128 (Run No. C128087)

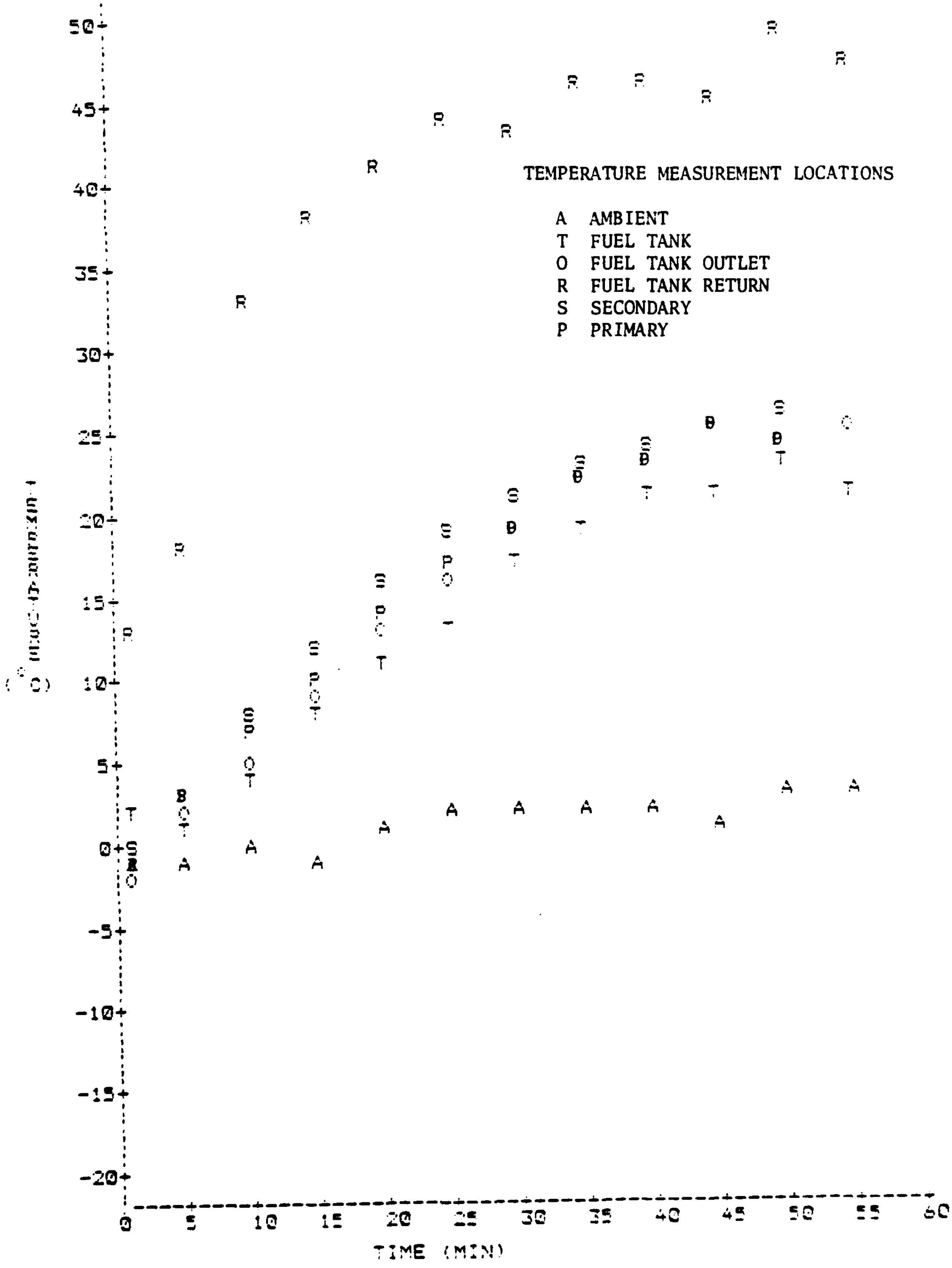
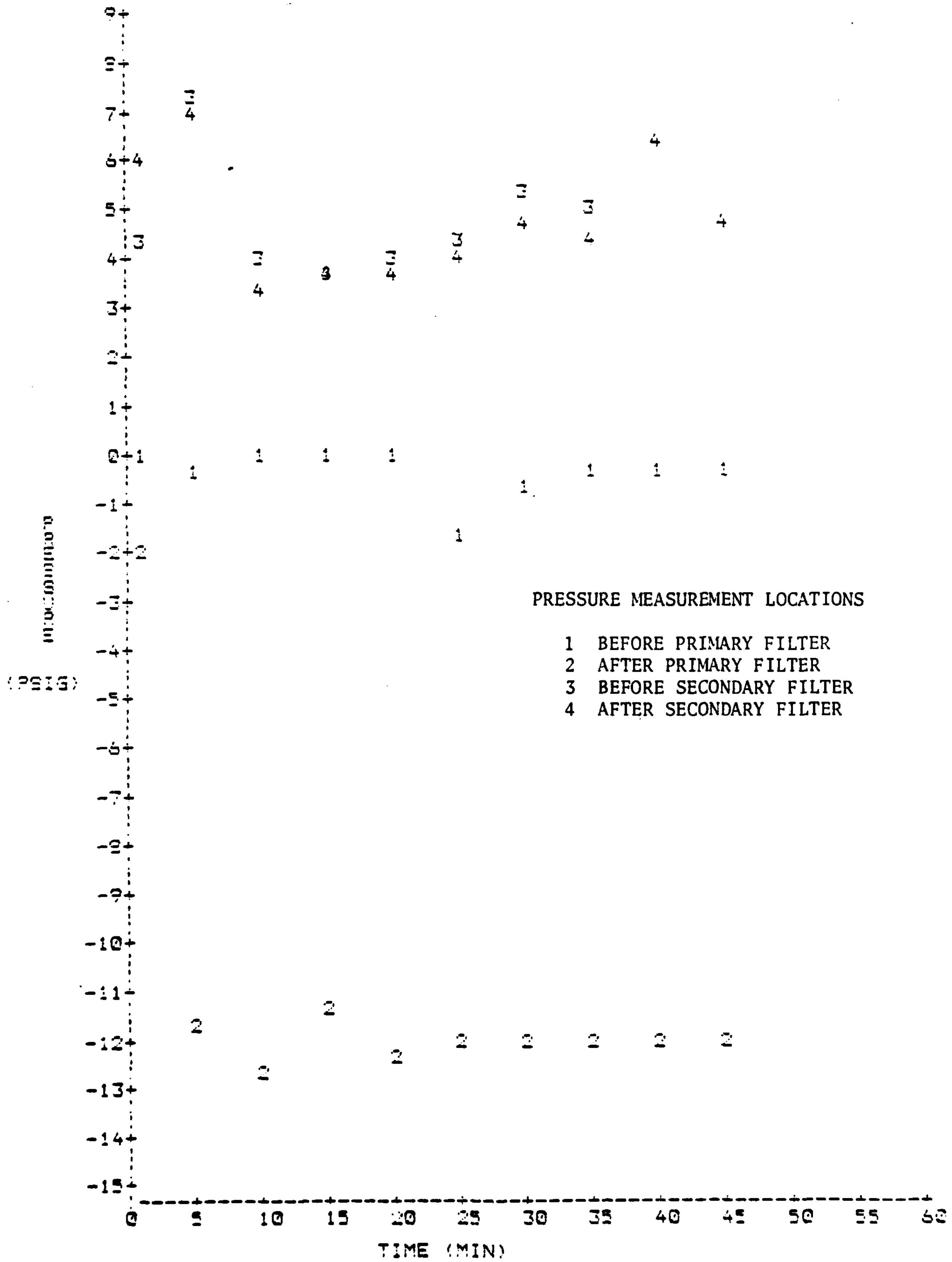


FIGURE E-37. PRESSURE DATA CORRESPONDING TO A BORDERLINE PASS CONDITION IN VEHICLE 128 (Run No. C128104)



Note: 1 psig = 6.89 kPa

FIGURE E-38. TEMPERATURE DATA CORRESPONDING TO A BORDERLINE PASS CONDITION IN VEHICLE 128 (Run No. C128104)

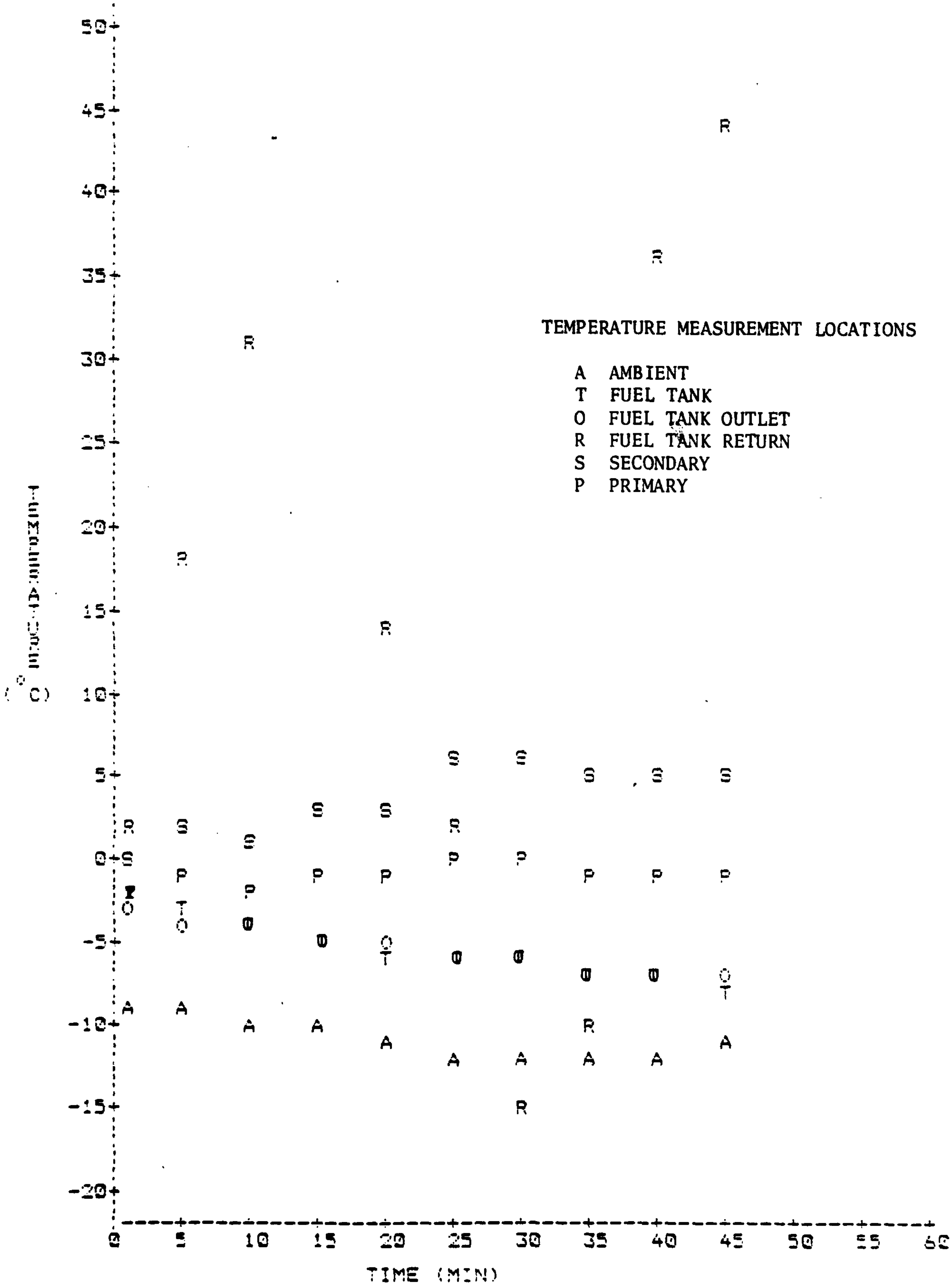
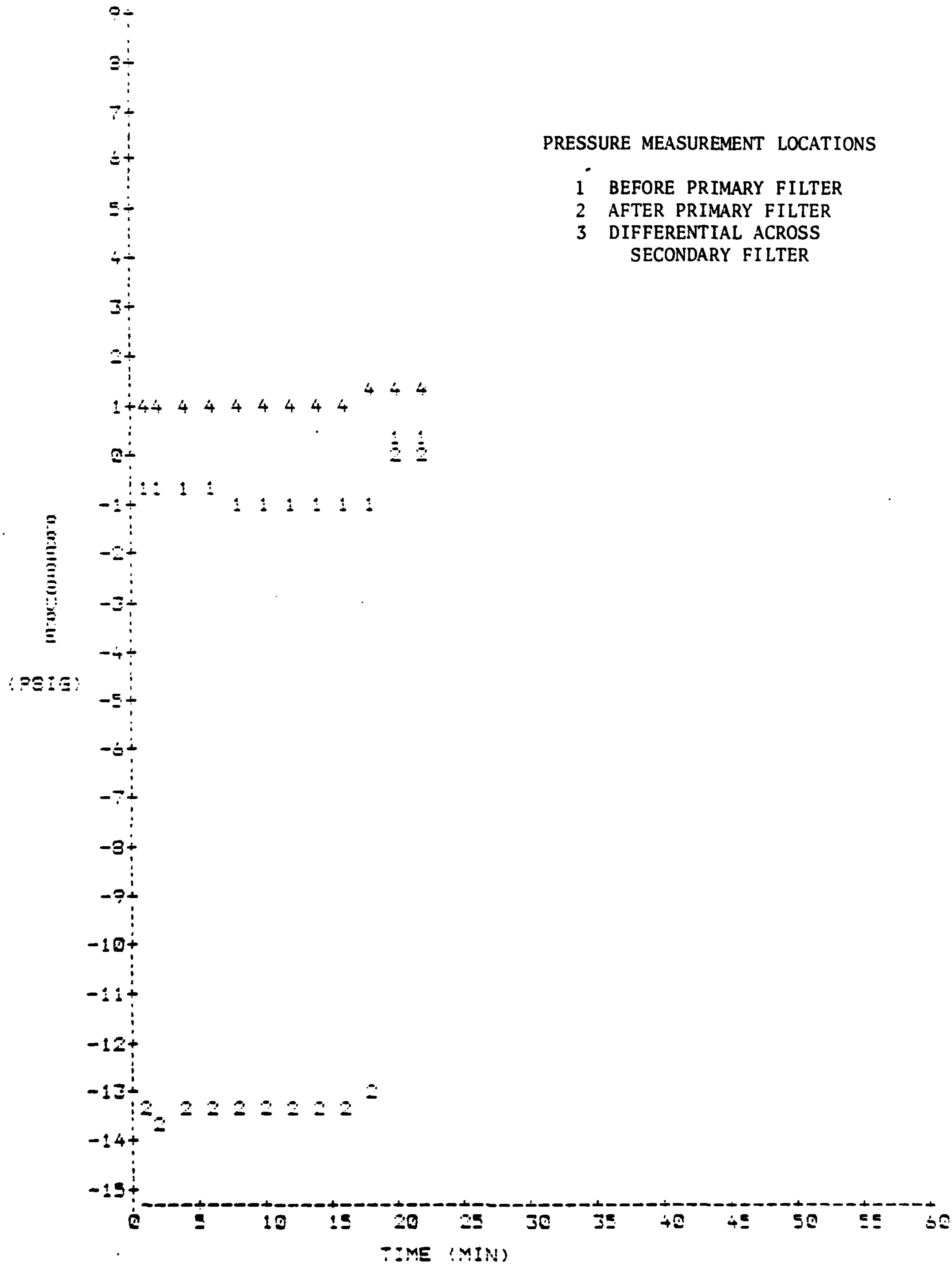
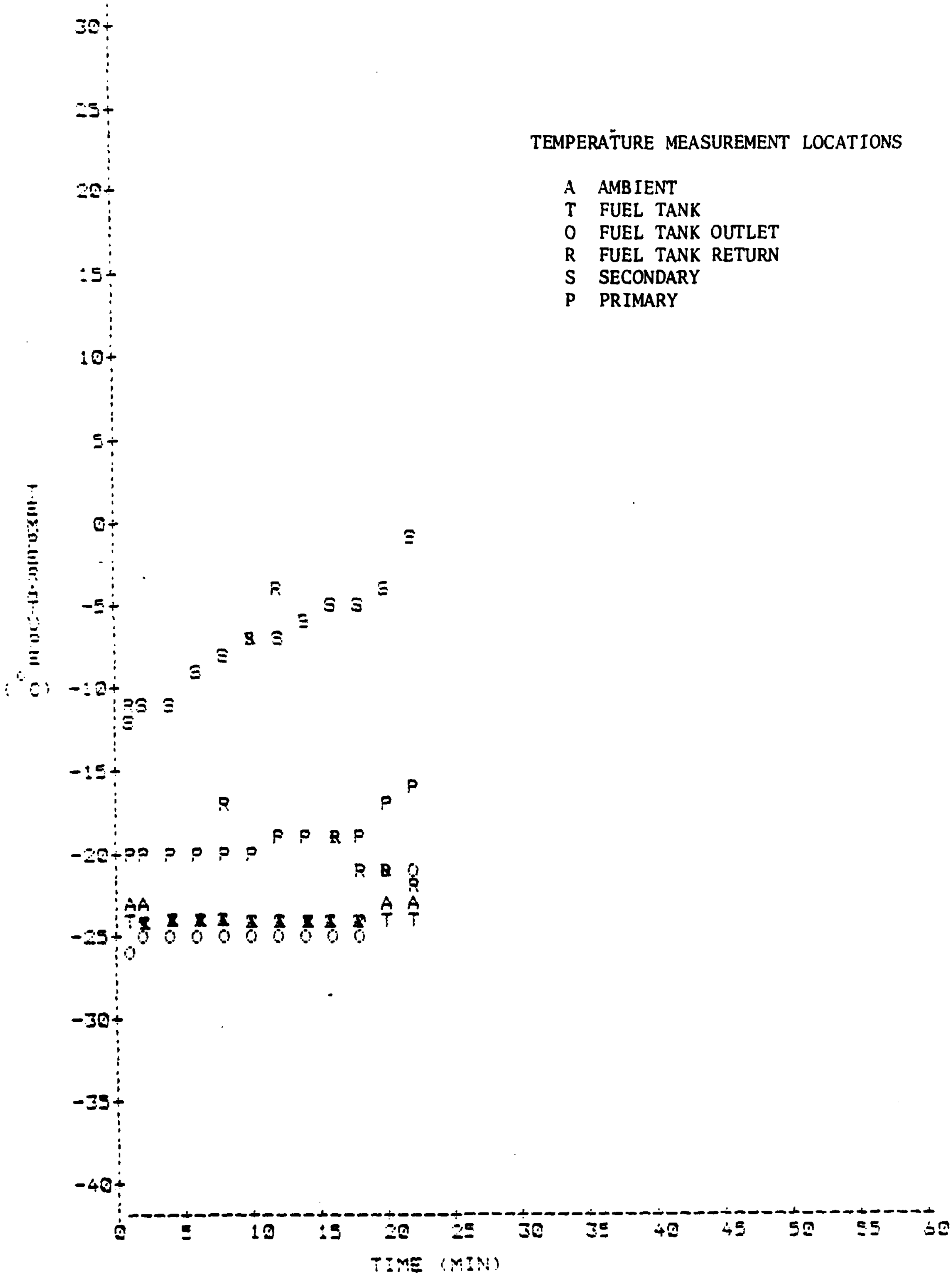


FIGURE E-39. PRESSURE DATA CORRESPONDING TO A FAIL CONDITION IN VEHICLE 128
(Run No. C128076)



Note: 1 psig = 6.89 kPa

FIGURE E-40. TEMPERATURE DATA CORRESPONDING TO A FAIL CONDITION IN VEHICLE 128 (Run No. C128076)



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