data to be
catalyst problems
during the
test.

REPORT OF EMISSION LEVELS AND FUEL ECONOMIES FOR EIGHT WAUKESHA 12V-AT25GL UNITS LOCATED AT THE JOHNSTON, RHODE ISLAND CENTRAL LANDFILL

REPORT PREPARED FOR: WAUKESHA PEARCE INDUSTRIES, INC.
HOUSTON, TEXAS

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TEST DATES: OCTOBER 9 THRU OCTOBER 16, 1990
SUPPLEMENTAL TEST DATE: NOVEMBER 6, 1990

REPORT DATE: NOVEMBER 30, 1990

EXECUTIVE SUMMARY

During the periods October 9-16, 1990 and November 6, 1990 the Waukesha Engine Division of Dresser Industries, Inc. performed emission tests on eight 12V-AT25GL Waukesha engines located at the Johnston, Rhode Island Central Landfill powerhouse.

Permit requirements for emission certification of the units are:

Nitrogen oxides (as NO_2) - 1.25 gr/BHP-HR or 6.6 Lb/HR maximum, whichever is more stringent.

Carbon monoxide - 1.125 gr/BHP-HR or 5.9 Lb/HR maximum, whichever is more stringent.

Nonmethane hydrocarbons - 0.5 gr/BHP-HR or 2.6 Lb/HR maximum, whichever is more stringent.

Initial testing yielded average stack emission rates from the eight units at rated conditions of .50 gr/BHP-HR NO_x, 1.70 gr/BHP-HR CO, and .08 gr/BHP-HR NMHC. All units failed permit requirements for CO emission due to a low average oxidizing catalyst efficiency of 9%. NO_x and NMHC emission levels were well below permit requirements.

The low catalyst CO conversion efficiency was traced to silicon contamination. A mechanical cleaning of the #1 unit catalyst raised its efficiency to 21.5% and lowered the stack CO level to 1.66 gr/BHP-HR. A thorough chemical cleaning of the #8 unit catalyst raised its efficiency to 78.6% and lowered the stack CO level to .36 gr/BHP-HR.

Average fuel consumption at rated conditions was found to be 6917 BTU/BHP-HR.

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1.0: INTRODUCTION

The Johnston, Rhode Island Central Landfill powerhouse contains eight (8) engine/generator units whose purpose is to convert the gas generated by the landfill into useful electrical energy. The engines are Waukesha 12V-AT25GL lean combustion, low emission models.

The State of Rhode Island, Department of Environmental Management (RIDEM) approval #999-1014 requires performance testing be conducted for nitrogen oxides ($NO_x = NO + NO_2$ as NO_2), carbon monoxide (CO), and total non-methane hydrocarbons (NMHC). As part of the conditions of sale of these engines, the Waukesha Engine Division of Dresser Industries, Inc. (WED) was contracted to perform this testing utilizing the capabilities of our mobile emissions testing laboratory.

The emission limitations per permit #999-1014 are:

1. NO_x: the emission rate from each engine shall not exceed 1.25 gr/BHP-HR or a maximum of 6.6 Lb/HR, whichever is more stringent.
2. CO: the emission rate from each engine shall not exceed 1.125 gr/BHP-HR or a maximum of 5.9 Lb/HR, whichever is more stringent.
3. NMHC: the emission rate from each engine shall not exceed 0.5 gr/BHP-HR or a maximum of 2.6 Lb/HR, whichever is more stringent.

Additional permit requirements are:

1. Visible emissions from each engine exhaust shall not exceed 10% opacity except for a period or periods aggregating no more than three minutes in any one hour.
2. Only landfill gas shall be used as an engine fuel.
3. The oxygen content of the exhaust gas entering the CO oxidation catalyst shall not be less than 7.0% by volume.
4. The CO oxidation catalyst exit temperature shall not exceed 1350°F.
5. The CO oxidation catalyst inlet temperature shall be a minimum of 750°F.

Factory engine-out emission guarantees were 1.25 gr/BHP-HR NO_x, 2.25 gr/BHP-HR CO, and 0.5 gr/BHP-HR NMHC. The low CO permit limitation required the addition of a Johnson-Matthey model CO 1750-20 oxidation catalyst to each exhaust system. Engine-out and permit CO levels indicate a required minimum catalyst CO conversion efficiency of 50%.

The required emissions performance testing was performed during the period October 9, 1990 to October 16, 1990. Mr. Richard Evans of RIDEM was present during three days of this testing. A supplemental test was performed on November 6, 1990.

2.0: EQUIPMENT DESCRIPTION

The Central Landfill powerhouse contains eight identical engine/generator units. The engines are Waukesha 12V-AT25GL lean combustion, low emission units of 9.84" bore x 11.81" stroke with 10784 cubic inches displacement. Each engine is rated at 1700 KWe at 900 RPM. At 96% generator efficiency this is 2375 BHP. The engines are adjusted to run on landfill gas. Specified engine settings are 17° BTDC spark timing and 8.6% ± .2% exhaust oxygen level pre-catalyst. Crankcase breather gases are injected into the exhaust stream downstream of the catalyst using compressor bleed air.

Each engine drives a Kato model A24862001 generator rated at 1700 kilowatts at 4160 volts. Switchgear was manufactured by Point Eight and voltage regulators by Basler.

The exhaust stream from each engine passes through a Johnson Matthey oxidizing catalytic converter model CO 1750-20. After leaving the building each exhaust stream is directed upward through a 60" O.D. silencer.

Figure 1 shows powerhouse unit arrangement.

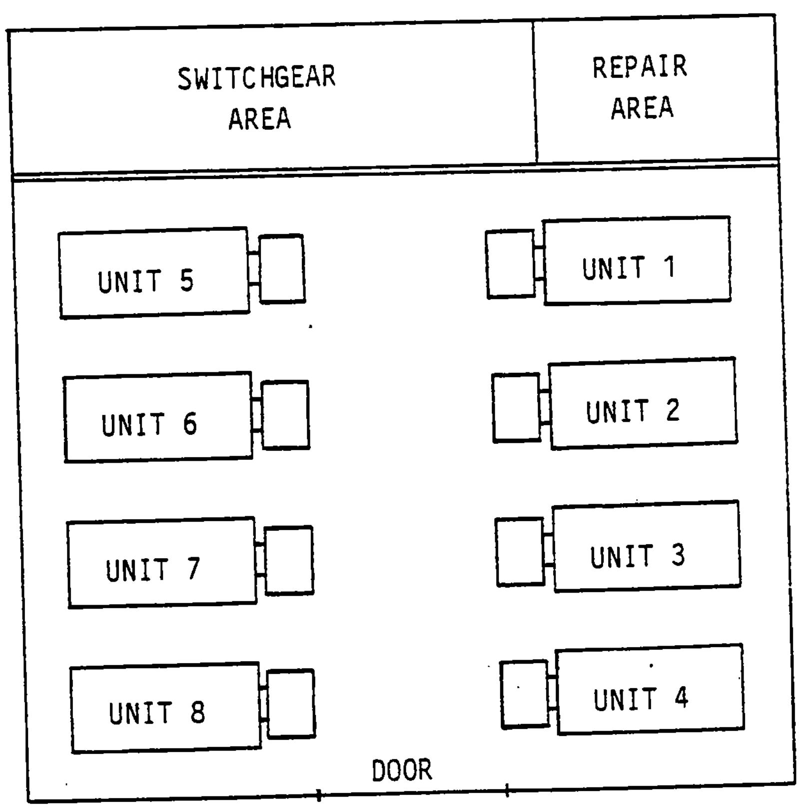

FIGURE 1

Fuel gas treatment is accomplished with a Bio Gas Development (BGD) of Atlanta, Georgia system.

3.0: TEST PROCEDURES

The test procedures used for both fuel economy and gaseous emissions testing followed the test protocol (and supplement) approved by the RIDEM. See Appendix A. Further elaboration is provided below.

3.1: FUEL ECONOMY

During the emission test sequence, five separate measurements were made of the volumetric fuel gas flow rate using a calibrated positive displacement Rootsmeter. See Appendix C for calibration data. Temperature and pressure of the fuel gas were measured at the meter itself to enhance accuracy.

The high and low readings were discarded and an average of the remaining readings was used for all calculations. See Appendix E for raw data sheets.

3.2: GASEOUS EMISSIONS

Procedures outlined in the approved protocol were followed exactly. Analyzers used are described in Appendix A and calibration data is given in Appendix C. A basic schematic of the sample train used is shown in Appendix B. Probes used in all three test locations conformed to 40 CFR 86 section 86.310-79 (b) as presented in Appendix B.

Raw data is presented in Appendix E.

4.0: FUEL ANALYSES

During the original test program, three fuel samples were taken at intervals. Samples were taken on October 9, 11, and 15 during the certification testing. In addition, a fourth sample was taken during the supplemental test on November 6.

These samples were analyzed by IGT Analytical Laboratory of Chicago. Further fuel properties, to allow emission calculation, were calculated at Waukesha from IGT component analyses. These data are given in Appendix D.

Since samples 1 and 2 of October 9 and 11 were nearly identical, an average of these fuel properties was used for calculations spanning that time period. Table I summarizes the three sets of fuel properties used for final fuel consumption and emission calculations. Their applicability is given in Table II.

5.0: RESULTS

Calculated results are detailed in Appendix G. A sample calculation is given in Appendix H. Significant results are summarized in Tables II, III, and IV. Table II summarizes engine test conditions. Table III summarizes the results of the fuel consumption testing. Table IV summarizes the results of the emission testing.

5.1: FUEL ECONOMY

Average engine loads for fuel economy (and emission) calculations were obtained from the raw data computer printouts presented in Appendix E. The mean brake specific fuel consumption (BSFC) is 6917 BTU/BHP-HR with a low of 6648 BTU/BHP-HR and a high of 7145 BTU/BHP-HR. Note that these values are not all directly comparable because of small load differences between the eight engines.

5.2: GASEOUS EMISSIONS

In order to calculate brake specific or mass emission rates, the total exhaust mass flow rate must be known. The general exhaust system layout and large exhaust silencers do not allow a pitot tube measurement of exhaust flow without significant modification. Instead, fuel flow rate was precisely measured as previously noted. Then air-fuel ratio was calculated using the Spindt method, see Appendix F, as modified for the large CO_2 concentration in the fuel gas. See Appendix H, sample calculation, for further elaboration on this point. The air flow rate is calculated as the product of the fuel flow rate and the air-fuel ratio. The total exhaust mass flow rate is the sum of the fuel and air flow rates.

5.2.1: ORIGINAL TESTING

Emission test results are presented in Tables IV-a, -b, and -c for pre-catalyst, post-catalyst, and stack (certification) locations, respectively.

Mean stack emission rates from the eight units as originally tested at rated conditions were found to be .50 gr/BHP-HR NO_x, 1.70 gr/BHP-HR CO, and .08 gr/BHP-HR NMHC. These NO_x and NMHC levels are well below the permit requirements of 1.25 gr/BHP-HR NO_x and 0.5 gr/BHP-HR NMHC. All units failed the 1.125 gr/BHP-HR CO permit requirement due to a low average oxidizing catalyst efficiency of 9%.

5.2.2: SUPPLEMENTAL TESTING

The catalyst from unit #1 was removed and examined. It was found to be covered with a grey/black crusty material. Core samples were removed and forwarded to Johnson Matthey for analysis. In the meantime, the catalyst was mechanically cleaned using high pressure air and replaced. A retest of this unit showed a lowered CO level of 1.66 gr/BHP-HR and a catalyst efficiency of 21.5%.

Analysis by Johnson Matthey of the core samples from unit #1, and additional core samples from unit #8, indicated that by far the major contaminant was silicon. This silicon was almost certainly entering the combustion chamber in some form with the fuel gas.

The #8 catalyst was then chemically cleaned using a sodium hydroxide solution following a procedure recommended by Johnson Matthey. The cleaned catalyst was replaced and the unit retested on November 6. This time the catalyst efficiency was found to be 78.6% and the stack CO level of .36 gr/BHP-HR was well under the permit maximum of 1.125 gr/BHP-HR.

6.0: CONCLUSIONS

As found, all eight units at the Central Landfill powerhouse easily met operating permit requirements for NO_x and NMHC emission levels. However, none of the units was able to meet the permit required CO level. The high CO level was determined to be due to low oxidizing catalyst efficiency which was, in turn, caused by silicon contamination of the catalyst material.

A supplemental test on a unit with a chemically cleaned catalyst yielded a CO level well under the permit maximum.

With properly functioning oxidizing catalysts, the Central Landfill units should easily pass operating permit #999-1014 emission requirements.

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Approved by: J.M. Derra
J.M. Derra
Manager/Engineering Support

TABLE I

FUEL PARAMETERS

FUEL DESIGNATION	SAMPLE DATE(S)	CHARACTERISTICS	
A	10-09-90 10-11-90 (AVERAGE)	SLHV	502 BTU/FT^3
		SPECIFIC GRAVITY	.980
		DENSITY	.07477 LB/FT^3
		F_C	.23742
		F_{H2}	.07975
		F_{O2}	0
		F_{N2}	.00213
		F_{CO2}	.68115
		F_{IN}	0
B	10-15-90	SLHV	473 BTU/FT^3
		SPECIFIC GRAVITY	.977
		DENSITY	.07455 LB/FT^3
		F_C	.22371
		F_{H2}	.07517
		F_{O2}	.01054
		F_{N2}	.05476
		F_{CO2}	.63550
		F_{IN}	0
C	11-06-90	SLHV	480 BTU/FT^3
		SPECIFIC GRAVITY	.994
		DENSITY	.07584 LB/FT^3
		F_C	.22318
		F_{H2}	.07504
		F_{O2}	.00078
		F_{N2}	.01647
		F_{CO2}	.68480
		F_{IN}	0

NOTE: REFERENCE APPENDIX D - F_i TERMS ARE MASS FRACTION VALUES.

TABLE II

ENGINE TEST CONDITIONS

UNIT	DATE	AVERAGE LOAD KWe	AVERAGE LOAD BHP[1]	TEST BAROMETER IN. Hg	TEST HUMIDITY gr/Lb	FUEL PARAMETERS[2]	SPARK TIMING °BTDC	CARBURETOR ADJUSTMENT[3] AIR/FUEL RATIO	CARBURETOR ADJUSTMENT[3] EXCESS AIR (%)
1	10-09-90	1725	2410	29.87	75	A	17°	8.935	64.0
2	10-09-90	1806	2523	29.79	103	A	17°	9.230	69.0
3	10-16-90	1693	2365	29.86	43	B	17°	8.445	65.5
4	10-12-90	1692	2363	29.89	111	A	17°	9.200	68.5
5	10-14-90	1598	2232	29.40	95	B	17°	8.655	69.5
6	10-11-90	1675	2340	30.04	97	A	17°	9.145	67.5
7	10-11-90	1693	2365	30.12	71	A	17°	9.135	67.5
8	10-10-90	1707	2385	30.06	67	A	17°	9.305	71.0
MEAN		1700	2373					9.006	67.8
STANDARD DEVIATION		54	75					.288	2.2
1 RERUN	10-13-90	1665	2326	29.70	102	A	17°	9.210	69.0
8 RERUN	11-06-90	1718	2400	29.28	44	C	17°	8.480	65.5

NOTES: 1) BHP FIGURES ASSUME 96% GENERATOR EFFICIENCY
2) SEE TABLE I FOR FUEL PARAMETERS
3) TWO RUN AVERAGE - REFERENCE TEST PROTOCOL

TABLE III

FUEL CONSUMPTION

UNIT	AVERAGE LOAD KWe	AVERAGE LOAD BHP	FUEL SLHV BTU/FT^3	AVERAGE BSFC BTU/BHP-HR	AVERAGE FUEL RATE LB/MIN
1	1725	2410	502	6829	40.855
2	1806	2523	502	6753	42.295
3	1693	2365	473	6648	41.301
4	1692	2363	502	7145	41.912
5	1598	2232	473	6857	40.203
6	1675	2340	502	7124	41.382
7	1693	2365	502	7073	41.525
8	1707	2385	502	6908	40.899
			MEAN	6917	
			STANDARD DEVIATION	170	
1 RERUN	1665	2326	502	7236	41.781
8 RERUN	1718	2400	480	6888	43.532

TABLE IV-a

PRE-CATALYST EMISSION SUMMARY

UNIT	BRAKE SPECIFIC EMISSIONS - g/BHP-HR NOx	CO	NMHC
1	.485	1.835	.080
2	.435	1.960	.095
3	.660	1.790	.060
4	.400	1.940	.080
5	.390	1.915	.070
6	.570	2.005	.080
7	.515	1.830	.070
8	.475	1.825	.070
MEAN	.491	1.888	.076
STANDARD DEVIATION	.090	.073	.010
1 RERUN	.355	2.070	.090
8 RERUN	.680	1.890	.050

NOTES: 1) TWO RUN AVERAGE - REFERENCE TEST PROTOCOL
2) NO_x AS NO_2

TABLE IV-b

POST-CATALYST EMISSION SUMMARY

UNIT	BRAKE SPECIFIC EMISSIONS - g/BHP-HR NOx	CO	NMHC	CO CATALYST EFFICIENCY-%
1	.500	1.610	.070	12.3
2	.450	1.840	.090	6.1
3	.650	1.510	.060	15.6
4	.410	1.660	.080	14.4
5	.375	1.780	.080	7.0
6	.565	2.015	.090	0
7	.510	1.680	.070	8.2
8	.475	1.660	.060	9.0
MEAN	.492	1.719	.075	9.08
STANDARD DEVIATION	.084	.146	.012	4.71
1 RERUN	.365	1.625	.080	21.5
8 RERUN	.695	.405	.050	78.6

NOTES: 1) TWO RUN AVERAGE - REFERENCE TEST PROTOCOL
2) NO_x AS NO_2

TABLE IV-C

STACK (CERTIFICATION) EMISSION SUMMARY

UNIT	BRAKE SPECIFIC EMISSIONS - g/BHP-HR		
	NOx	CO	NMHC
1	.51	1.57	.07
2	.49	1.84	.08
3	.67	1.39	.06
4	.41	1.66	.09
5	.38	1.80	.09
6	.57	2.00	.09
7	.52	1.67	.08
8	.47	1.64	.06
MEAN	.503	1.696	.078
STANDARD DEVIATION	.085	.173	.012
1 RERUN	.34	1.66	.06
8 RERUN	.70	.36	.05

NOTE: NO_x AS NO_2

PROPOSED TEST PROTOCOL FOR EMISSIONS CERTIFICATION TESTING AT THE JOHNSTON, RHODE ISLAND CENTRAL LANDFILL SITE

Site Equipment

Eight (8) Waukesha 12V-AT25GL lean combustion, low emission reciprocating internal combustion engines driving Kato electric generators. Each unit is rated at 1700 KW_e at 900 RPM. Exhaust from the engines is passed through an oxidizing catalyst for further reduction of carbon monoxide and unburned hydrocarbons. These engines are fueled solely with landfill gas.

Emission Requirements (Reference permit conditions and emissions limitations approvals 999-1014)

1. Nitrogen Oxides (NO_x as NO_2)

   The emission rate of nitrogen oxides from each engine exhaust shall not exceed 1.25 grams per brake horsepower - hour (gm/BHP-HR) or a maximum of 6.6 lbs. per hour, whichever is more stringent.

2. Carbon Monoxide (CO)

   The emission rate of carbon monoxide from each engine exhaust shall not exceed 1.125 gm/BHP-HR or a maximum of 5.9 lbs. per hour, whichever is more stringent.

3. Total Nonmethane Hydrocarbons (NMHC)

   The emission rate of total nonmethane hydrocarbons from each engine exhaust shall not exceed 0.5 gm/BHP-HR or a maximum of 2.6 lbs. per hour, whichever is more stringent.

NOTE: These emission limits apply to the post-catalytic converter exhaust.

Test Methods

Waukesha proposes to use U. S. Environmental Protection Agency (EPA) test methods to demonstrate compliance with the specified emission requirements. These methods are detailed in Title 40 of the Code of Federal Regulations, Part 86, Subpart D (40CFR86, Subpart D).

Waukesha also specifies the following additions and exceptions to 40CFR86, Subpart D:

1. Section 86.301-79. Waukesha extends the applicability of this Subpart to gaseous fuels including landfill gas.

2. For heavy duty stationary engines the test cycles outlined in sections 86.335-79 and 86.336-79 are not used. Instead, all testing is done at steady state conditions at discrete, specified points.

3. Specified dynamometer runs, e.g. sections 86.340-79 and 86.341-79, do not apply literally to this field test. The outlined procedure will be followed as far as practical for the specified test points.

4. Section 86.345-79 - Emission Calculations. Waukesha does not calculate the dry fuel/air ratio (f/a) using the formula in (d). Instead dry (f/a) is calculated using the Spindt method. Reference Society of Automotive Engineers paper #650507, "Air-Fuel Ratios from Exhaust Gas Analysis".

5. Total nonmethane hydrocarbons will be measured with a Byron gas chromatograph.

Test Instrumentation

The instruments and systems in the Waukesha Mobile Engine Exhaust Emission measurement Laboratory (MEEEML) van were selected and designed to comply with USEPA 40CFR86, Subpart D and the gas sampling and analytical train given in figure D79-1, section 86.309-79.

The MEEEML instrumentation is further detailed in Appendix I.

Instrument Calibration

All analyzer calibrations comply with the applicable procedures of 40CFR86, Subpart D. All analyzers will be calibrated at the factory no more than thirty (30) days prior to the scheduled start test date. A copy of all calibration sheets will be provided to the Rhode Island DEM as part of the final report.

Fuel Composition

An average fuel composition based on data taken by Waukesha between 2/4/90 and 2/11/90 will be used for any preliminary calculations performed on site. This fuel composition and analysis is given in Appendix II.

During the test program three fuel samples will be taken at intervals by Waukesha. These samples will provide the fuel characteristics to be used for final emission certification and fuel consumption calculations.

Sample Locations

Emissions entering the catalyst will be sampled at the position marked "A" in photograph "A" in Appendix III. Stack emissions for compliance will be sampled at the position marked "B" in photograph "B" in Appendix III.

Test Procedure

The test procedure followed for each engine will be:

- Engines will be tested fully warmed and stabilized at rated conditions of 1700 KW_e at 900 RPM (about 2375 BHP). Engines will be adjusted at rated conditions to 8.6% ± .2% exhaust oxygen level pre-catalyst, 17° BTDC ignition timing and 9" Hg ± 1" Hg prechamber gas pressure.

- Each stack certification test will consist of a 15 minute run at rated conditions of 1700 KW_e at 900 RPM. During this time NO_x, CO, CO_2, THC, CH_4, NMHC, and O_2 levels will be measured and permanently recorded. Maximum, minimum and average values will be determined for each specie and recorded. LB/HR and gm/BHP-HR emittant rates will be calculated from the average specie values.

  Pre-catalyst emission levels will also be measured to determine compliance with WED and catalyst manufacturer performance warranties. NO_x, CO, CO_2, THC and O_2 emissions will be measured and permanently recorded for a minimum of three minutes both before and after the 15 minute stack compliance test. These emission levels will be averaged for all calculation purposes.

  All analyzers will be zeroed and spanned before and after sampling in accordance with 40CFR86, Subpart D procedures.

- During the emission test sequence, five separate measurements will be made of the volumetric fuel flow rate using a positive displacement Rootsmeter. The high and low readings will be discarded. The remaining three readings will be averaged to yield the fuel flow rate for calculation purposes. The ideal, saturated low heat value of the gas will be used to calculate final brake specific fuel consumption rates.

Repeat Data

A decision to repeat any test run may be made by either Waukesha or Rhode Island DEM representatives after the test run is completed. The Waukesha representative may elect to repeat a run if the data are found to be inaccurate or technically deficient. The Rhode Island DEM representative may elect to repeat a run for any valid reason.

After the test instrumentation has been removed from a unit, testing on that unit will be deemed complete. Such a unit will only be retested if agreement is reached between Waukesha and Rhode Island DEM personnel that existing data are significantly deficient in some manner.

Final Report

A final report on the results of the stack testing will be submitted to the Rhode Island DEM no later than sixty (60) days following completion of the testing.

Certification by Concentration

To save time and expense, yet provide high quality certification data, Waukesha proposes the following:

Units 1, 2 and 3 would be tested for emissions and fuel rate to determine preliminary figures in LB/HR and gm/BHP-HR units. These values and significant operating parameters such as intake manifold pressure, intake manifold temperature and exhaust stack temperature will be compared. If sufficiently similar, a correlation based on these three tests would be used to certify the remaining five units using specie concentration measurements only.

The decision to accept concentration measurements for certification will rest solely with the Rhode Island DEM representative on site observing the test program.

March 22, 1990

APPENDIX I

EMISSION MEASUREMENT INSTRUMENTATION

<u>Waukesha Mobile Engine Exhaust Emission Measurement Laboratory (MEEEML)</u>

The instruments and systems in Waukesha's MEEEML van were selected and designed to comply with the Environmental Protection Agency (EPA) heavy duty engine test requirements - reference 40CFR86 and 42FR45132 - and EPA test method 20, reference 44FR52798, as modified for use in internal combustion engines, reference 44FR43169.

<u>ANALYZERS:</u>

- $NO/NO_2/NO_x$
  Thermo-Electron model 10 chemiluminescent
  S/N 10AR-13640-140
  Ranges 0-2½, 10, 25, 100, 250, 1000, 2500, 10000 ppm

- CO
  Horiba model AIA-23 Non-dispersive infrared
  S/N 4824705
  Ranges 0-.25, 1.0, 5.0%

- THC
  Horiba model FIA-22A Flame ionization detector
  S/N 4812908
  Ranges 0-10, 30, 100, 300, 1000, 3000, 10000, 30000 ppm

- CO_2
  Horiba model AIA-23 Non-dispersive infrared
  S/N 48498112
  Range 0-16%

- O_2
  Teledyne model 326AX Electrochemical
  S/N 38817
  Ranges 0-2, 5, 25%

- M/NMHC
  Byron model 304 Gas chromatograph
  S/N 0317
  Ranges (methane and non-methane)
  0-2, 5, 10, 20, 50, 100, 200, 500, 1000, 2000, 5000, 10000 ppm

- Standard Gas Divider model 75

APPENDIX II

FUEL COMPOSITION

FUEL GAS ANALYSIS WITH ASTM CORRECTION

METHANE	52.60 %	HYDROGEN	0.17 %
ETHANE	0.00 %	HYDROGEN SULFIDE	0.00 %
ETHENE	0.00 %	CARBON MONOXIDE	0.00 %
PROPANE	0.00 %		
PROPYLENE	0.00 %	NITROGEN	3.01 %
ISO BUTANE	0.00 %	OXYGEN	0.11 %
NORMAL BUTANE	0.00 %	AIR	0.00 %
ISO PENTANE	0.00 %	CARBON DIOXIDE	44.10 %
NORNAL PENTANE	0.00 %	WATER	0.00 %
HEXANE	0.00 %	HELIUM	0.00 %
HEPTANE	0.00 %	ARGON	0.00 %

SUM OF THE FUEL PERCENTAGES 99.99%

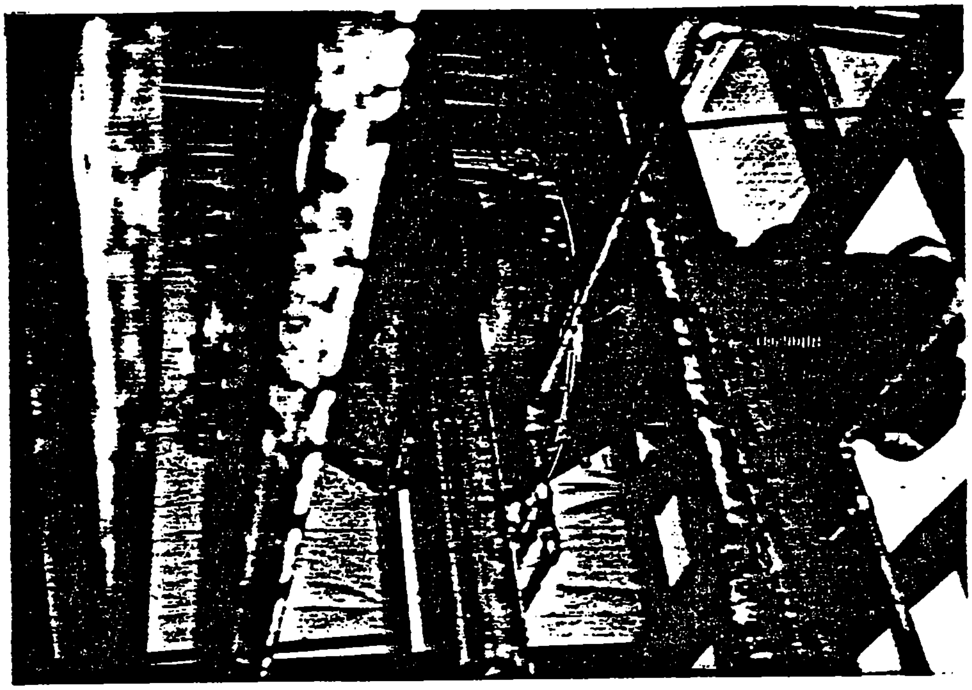
SATURATED LHV	472.05 BTU/CU.FT	SPECIFIC GRAVITY	0.99422
OCTANE RATING	119.61	DENSITY	0.07606

MOLECULAR WEIGHT 28.73180

STOICHIOMETRIC SPINDT AFR IS 5.06:1 BY MASS

THE ATOMIC H/C RATIO FOR THIS FUEL IS 4.006

APPENDIX III
EMISSIONS SAMPLING LOCATIONS



Photograph "A"

PRE-CATALYST SAMPLE LOCATION

Photograph "B"

STACK SAMPLE LOCATION

Waukesha DRESSER
WAUKESHA ENGINE DIVISION
DRESSER INDUSTRIES, INC.
1000 WEST ST. PAUL AVENUE • WAUKESHA, WISCONSIN 53188

August 10, 1990

Mr. Richard Evans
State of Rhode Island and Providence Plantations
Division of Air and Hazardous Materials
291 Promenade Street
Providence, RI 02908-5767

Dear Mr. Evans:

I have received your letter of July 23 requesting additional information for our proposed test protocol for the engines at the Central Landfill in Johnston, RI.

Attachment I (two pages) summarizes Waukesha's and the test team's qualification and experience with regard to engine emission sources and test methodology.

Attachment II (four sheets) is a partial response to your second query. I am attaching sketches and blueprints which describe the engine exhaust system and our two (2) proposed test locations. Note that the upstream location, before catalyst, is different from my March proposal in the protocol. This is caused by expected difficulty in placing the probe port in the original location.

You will note that neither test port is in an ideal location regarding flow obstructions. The overall layout of the exhaust system severely limits the available options for port placement. Since Waukesha does not plan to measure flow with a pitot tube (See Protocol, Test Methods, Item #4) we do not feel this is a major concern. We will use a multi-hole probe extending across the exhaust pipe for emissions measurement. This will result in a representative sample for analysis.

The plan showing location of source and the floor plan of the facility (2 sheets) will be provided by Waukesha-Pearce to you directly.

Since particulate matter in a gas engine exhaust is nil, exhaust opacity is negligible. Waukesha does not feel Method 9 readings are needed. Also, we do not have a technician certified to perform that test. Should a Method 9 test be mandatory, it would be ideal if the Rhode Island observer were certified and could run that test. If this is not feasible, arrangements will have to be made for a separate party to run the Method 9 test.

We currently have no plans for a factory representative to attend the near future site visit. However, Waukesha-Pearce may elect to have a representative present. I suggest that Rhode Island personnel present at this visit observe the clarity of the exhaust from the engines. This may lead to a determination that the Method 9 test is unnecessary unless mandated by statute.

Finally, Waukesha proposes an eight day block of time for the testing. Our first choice would be October 1-October 8, inclusive. If Columbus Day, October 8, is an observed holiday, the last day of testing would be October 9. If this is unacceptable, other alternatives, in order of preference are:

October 9-October ~~17~~ 15
November 5-November 12

For the time being, I have assumed that the October 1-8 period will be acceptable and have begun planning accordingly.

If you need to discuss any part of this, or our earlier submission, please contact me at (414) 549-2753.

Sincerely,

WAUKESHA ENGINE DIVISION
DRESSER INDUSTRIES, INC.

R.W. Stachowicz

R.W. Stachowicz
Senior Project Engineer

RWS/bes

cc: C. Hoefflin - W.E.D.
R. Kakoczki - W.E.D.
J. Derra - W.E.D.
W. Briggs - W.E.D.
E. Brumbaugh - W.P.I.
R. Pollock - W.P.I.

Attachments

ATTACHMENT I

The Waukesha Engine Division of Dresser Industries, Inc., located in Waukesha, Wisconsin, is a leading manufacturer of gaseous fueled internal combustion engines. Since its founding in 1906, the Company has always strived to be at the leading edge of industry technology. For example, we currently offer, or are developing, several electronic controls to make our products more fuel efficient and environmentally acceptable.

The Company recognized early that emissions control and reduction would be an important design parameter and began testing and control programs in 1972. Over the years we have tested, developed, and marketed catalyst, exhaust gas recirculation, and lean combustion (both prechamber and open chamber) systems for emission control of our products. We hold one U.S. patent in emission control technology and currently market a lean burn combustion control with a proprietary oxygen sensor which can function in the 26-32:1 air/fuel ratio regime.

Our understanding of our product line and our long history of involvement with emission measurement has resulted in Waukesha periodically being asked to critique or troubleshoot emissions tests run by independent testing firms. This was particularly true in the early period of stationary source testing in California when local testing firms had little or no internal combustion engine experience.

Waukesha currently operates five full function emissions test benches in our development laboratory. Any research or development work now includes emissions measurement.

Our mobile engine exhaust emission measurement laboratory (test van) includes a full function emissions test bench. It was built for the purposes of offering a testing service to our customers, allowing us to personally monitor the emissions of field test engines, and as a means of troubleshooting emissions problems with field engines if necessary. It has been in service since 1982.

Using this van, Waukesha has performed emissions tests in California, Texas, Iowa, Rhode Island, and other states. We have always employed 40CFR86, heavy duty engine test requirements, methodology as opposed to Method 20 because the former was designed specifically for reciprocating internal combustion engines.

The test team will be composed of three participants:

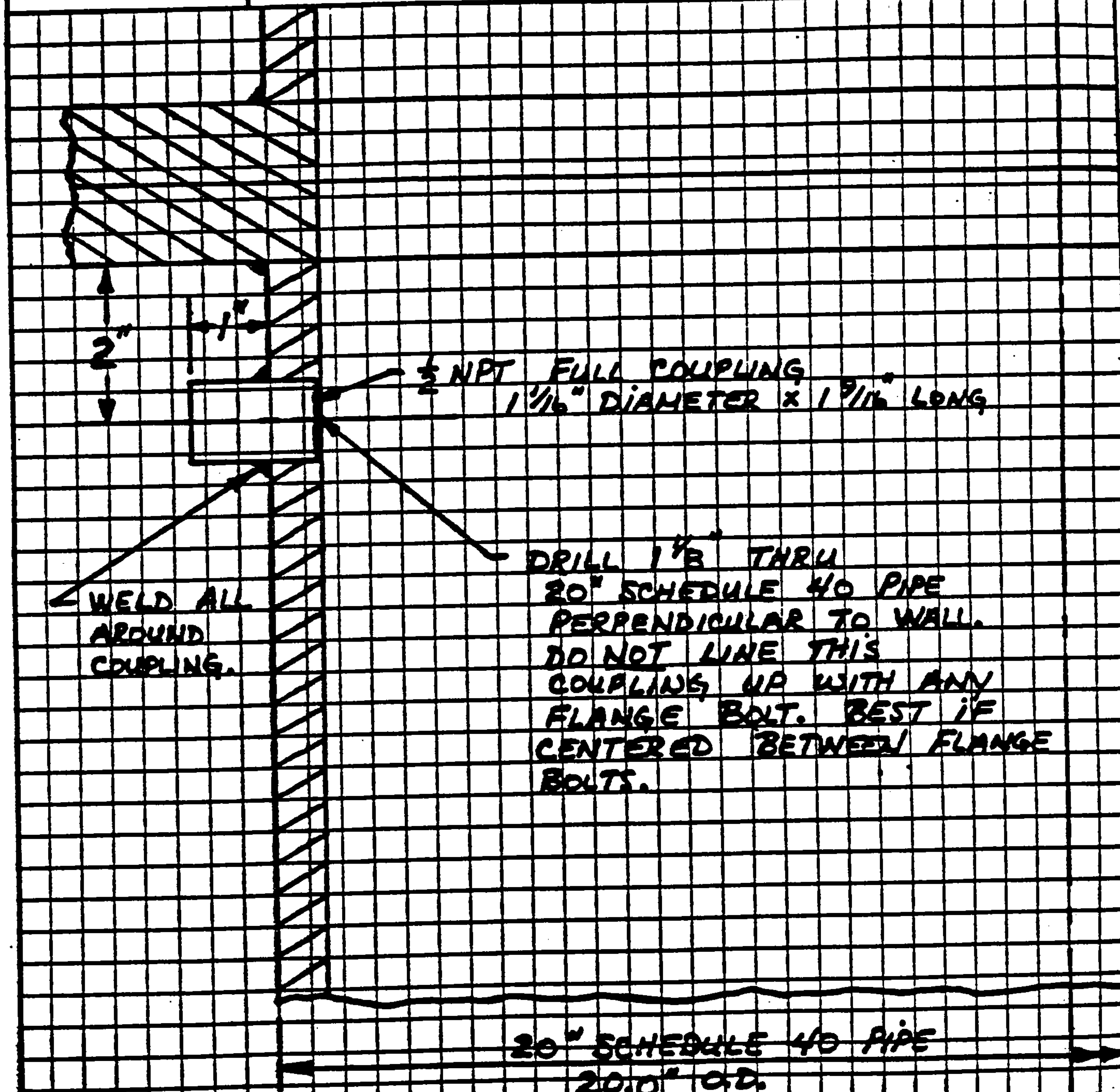
- Engineer: Robert Stachowicz - Senior Project Engineer. BSME and MSME from the University of Wisconsin system. Nineteen years of engine experience; the last ten of which have been in the emissions legislation, measurement, and reduction areas.

- Technician: Dennis Perkins - Experimental Technician II. Associate degree in engine technology. Eleven years of engine experience; the last 6 1/2 of which have been in the emissions measurement area.

- Serviceman: A factory serviceman will be part of the team. His main functions will be to assist with hardware operation, particularly installation and movement of the fuel meter, and to ascertain that each engine is properly adjusted and in good operating condition prior to certification testing.

ATTACHMENT II

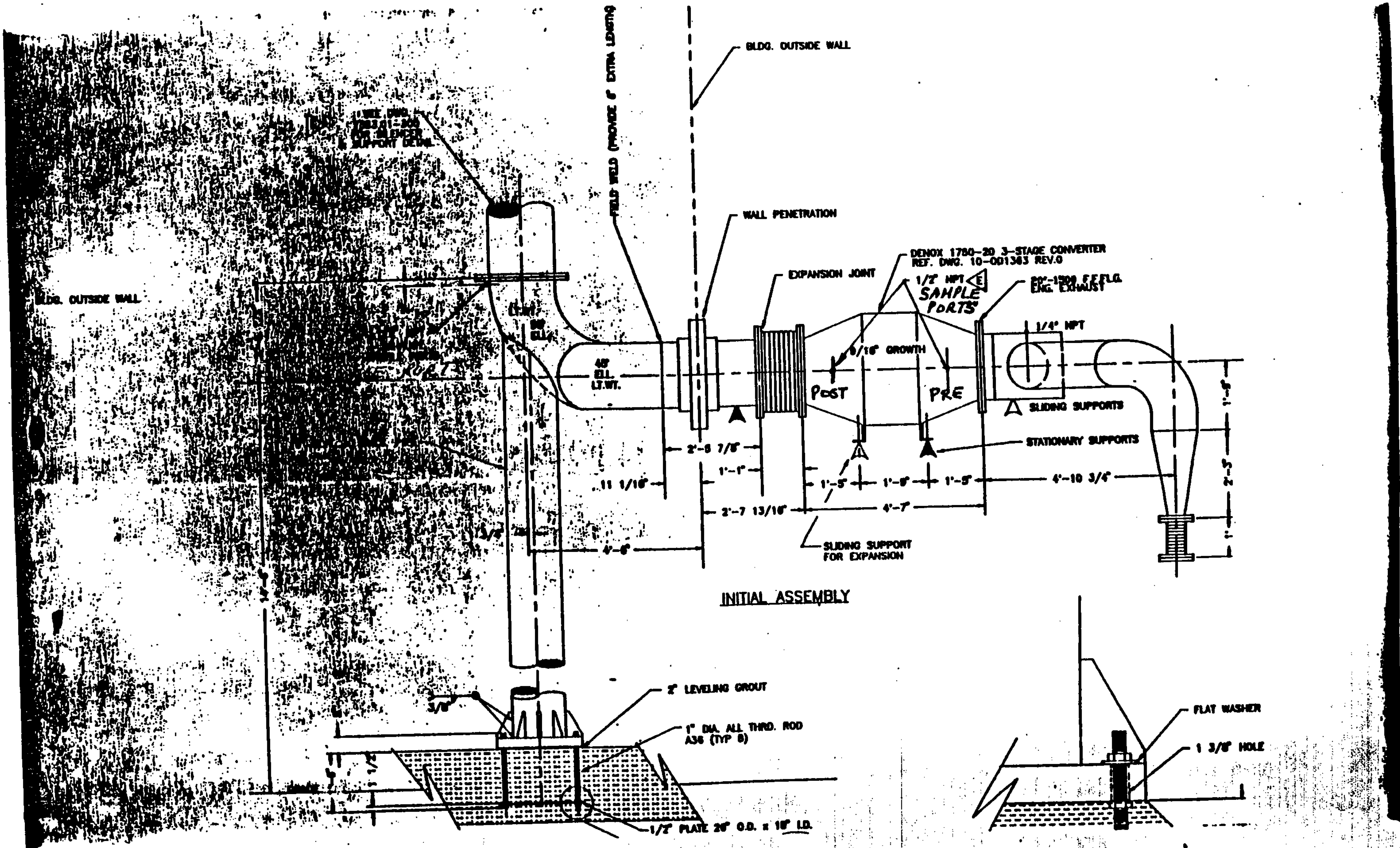
PREPARED BY	Waukesha DRESSER	PAGE 1 OF 4
STACHOWICZ	**ENGINEERING CALCULATION FORM**	PROGRAM & PROJECT NO. JOHNSTON
CHECKED BY		
TERMATREX NO.	SUBJECT EMISSIONS TEST PORT	DATE APRIL 9, 1990



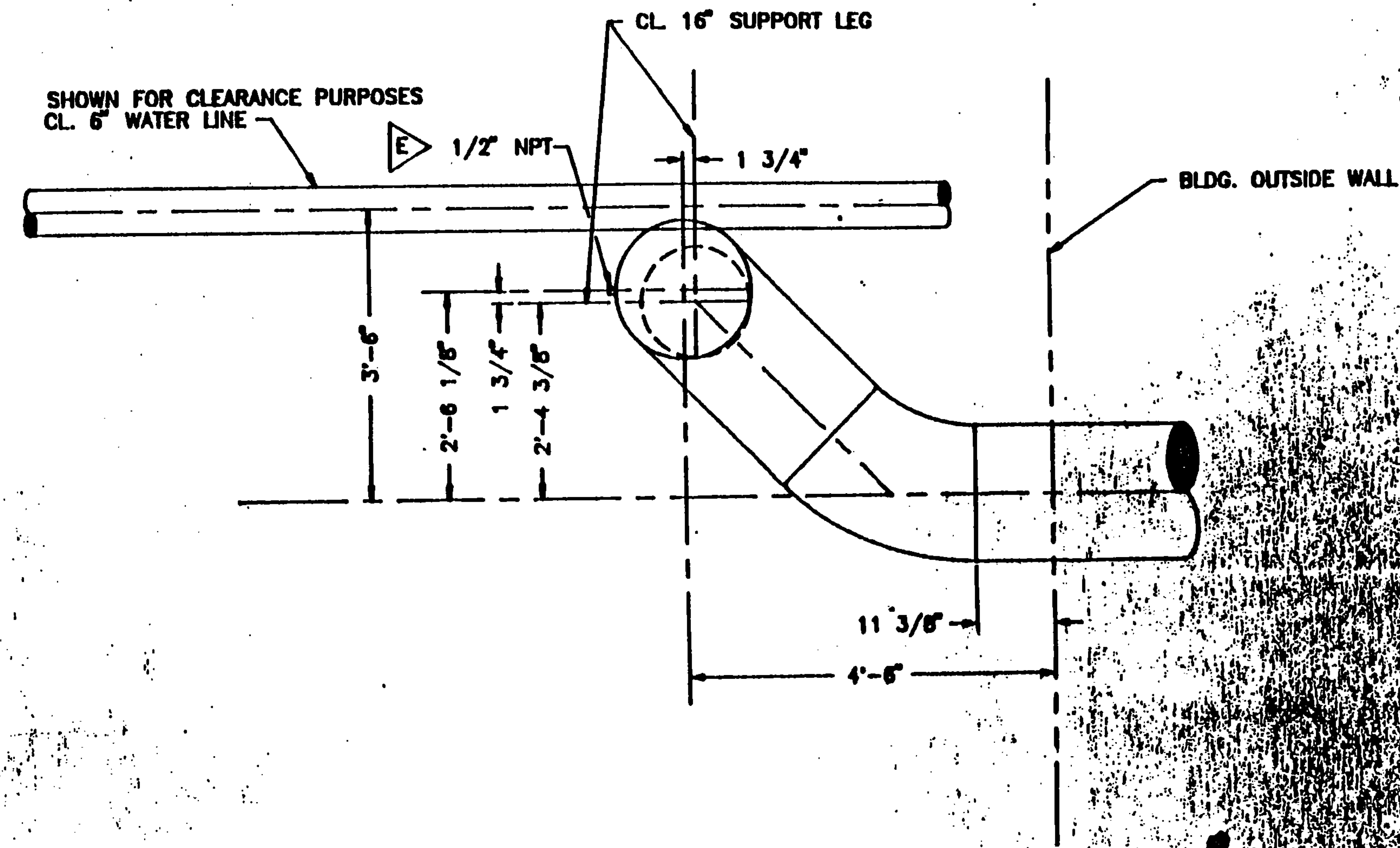
INSTALL 1/2" NPT FULL PIPE COUPLING FOR EMISSIONS TEST PORT. TWO LOCATIONS IN EACH EXHAUST SYSTEM. SEE ATTACHED DRAWINGS FOR LOCATIONS.

INSTALL PIPE PLUG WITH "NEVER SEIZE" (OR EQUIVALENT) WHEN NOT IN USE.

SCALE : HALF

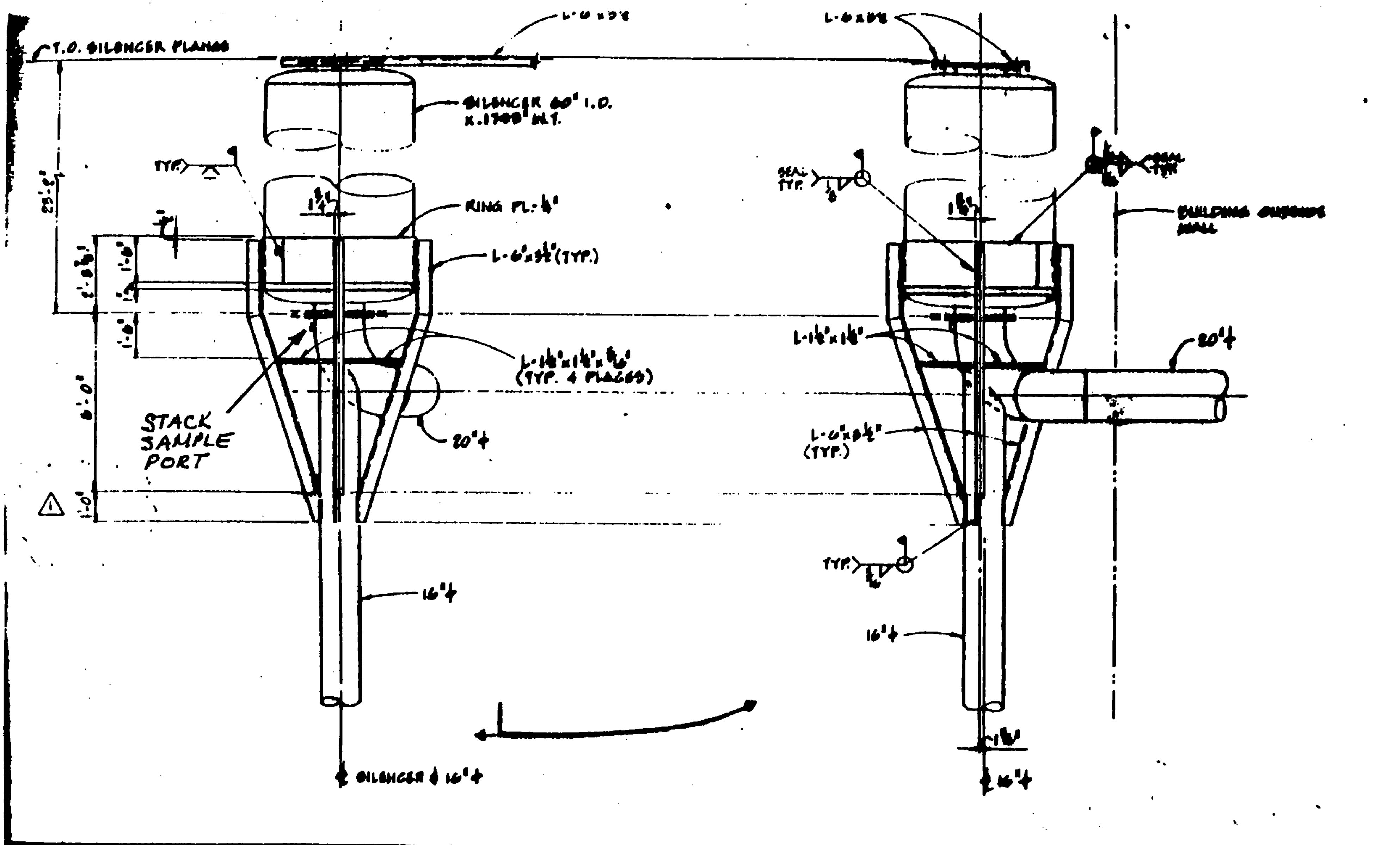

BLDG. OUTSIDE WALL
FIELD WELD (PROVIDE 6" EXTRA LENGTH)
WALL PENETRATION
EXPANSION JOINT
DENOX 1780-20 3-STAGE CONVERTER
REF. DWG. 10-001363 REV.0
1/2" NPT
SAMPLE PORTS
ENG. EXHAUST
1/4" NPT
9/16" GROWTH
POST
PRE
45° ELL. LT.WT.
SLIDING SUPPORTS
STATIONARY SUPPORTS
2'-5 7/8"
1'-1"
11 1/16"
1'-5"
1'-9"
1'-5"
4'-10 3/4"
2'-7 13/16"
4'-7"
4'-6"
1'-5"
2'-5"
1'
SLIDING SUPPORT
FOR EXPANSION
BLDG. OUTSIDE WALL
INITIAL ASSEMBLY
2" LEVELING GROUT
1" DIA. ALL THRD. ROD
A36 (TYP 8)
1/2" PLATE 26" O.D. x 18" I.D.
3/8"
FLAT WASHER
1 3/8" HOLE

ATTACHMENT II
PAGE 2 OF 4



PLAN VIEW

TYP. WEST SIDE OF BLDG.
OPPOSITE HAND FOR EAST
SIDE OF BLDG.



...ERAL NOTES | REFERENCE DRAWINGS | REVISIONS

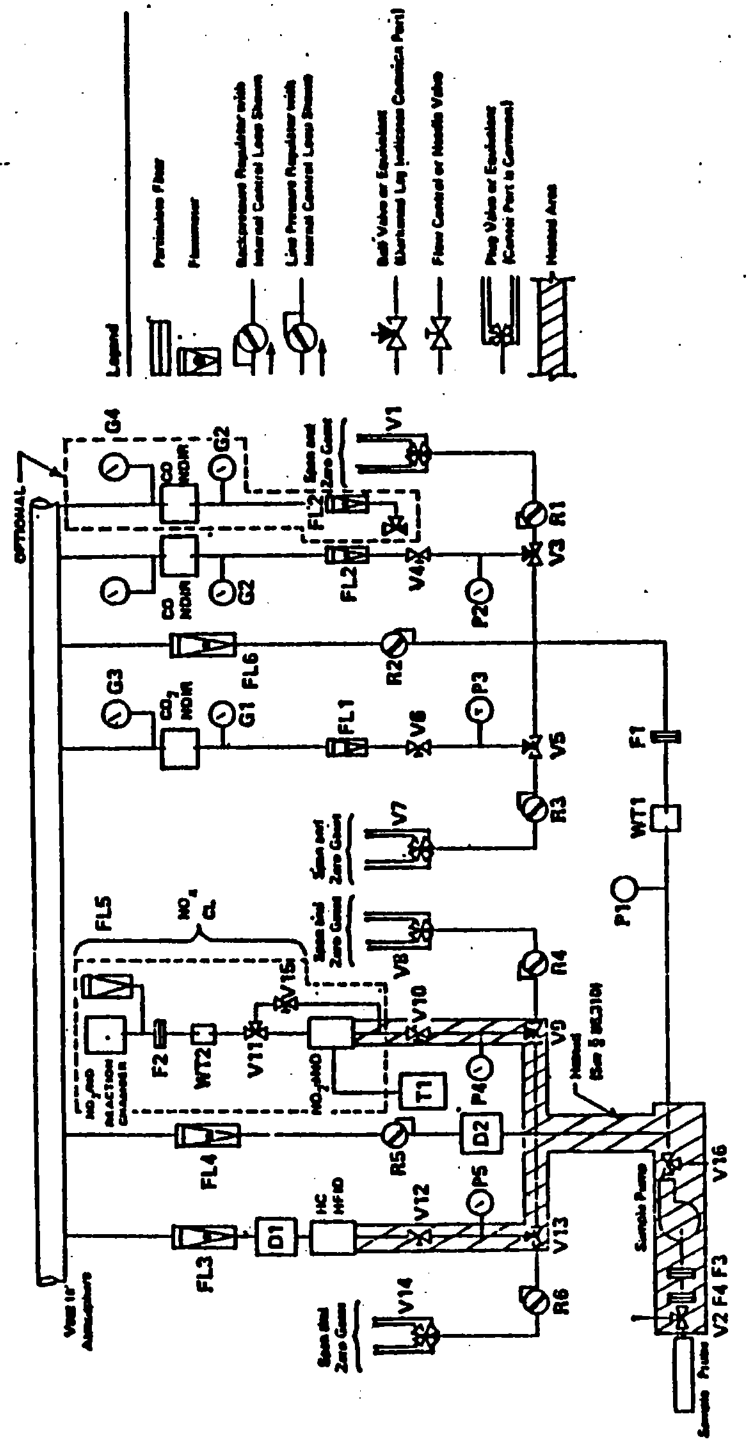


Figure D79-1 HEAVY-DUTY EXHAUST GAS SAMPLING AND ANALYTICAL TRAIN

(c) *System components list.* The following is a list of components shown in Fig. D79-1 by numeric identifier.

(1) *Filters.* Glass fiber filter paper is permitted for F1, F2, and F3. Optional filter F4 is a coarse filter for large particulates.

(i) F1—Fine particulate filter.

(ii) F2—Fine particulate filter.

(iii) F3—Fine heated particulate filter.

(iv) F4—Coarse heated particulate filter.

(2) *Flowmeters.* (i) Flowmeters FL 1 and FL 2 indicate sample flow rates through the CO and CO_2 analyzers.

(ii) Flowmeters FL 3, FL 4, FL 5, and FL 6 indicate bypass flow rates.

(3) *Gauges.* Downstream gauges are required for any system used for testing under this subpart. Upstream gauges may be required under this subpart per § 86.309(b)(2)(v).

(i) Upstream gauges G1 and G2 measure the input to the CO and CO_2 analyzers.

(ii) Downstream gauges G3 and G4 measure the exit pressure of the CO and CO_2 analyzers. If the normal operating range of the downstream gauges is less than 3 inches of water, then the downstream gauges must be capable of reading both pressure and vacuum.

(4) *Pressure gauges.* (i) P1—bypass pressure.

(ii) P2, P3, P4 and P5—sample or span pressure at inlet to flow control valves.

(5) *Water traps.* Water traps WT1, and WT2 to remove water from the sample. A water trap performing the function of WT1 and meeting the specifications in § 86.311(e) is required for any system used for testing under this subpart. Chemical dryers are not an acceptable method of removing the water. Water removal by condensation is acceptable. Means other than condensation may be used only with prior approval from the Administrator.

(6) *Regulators.* (i) R1, R3, R4, and R6—linepressure regulators to control span pressure at inlet to flow control valves.

(ii) R2 and R5—back pressure regulators to control sample pressure at inlet to flow control valves.

(7) *Valves.* (i) V1, V7, V8, and V14—selector valves to select zero or calibration gases.

(ii) V2—optional heated selector valve to purge the sample probe, perform leak checks, or to perform hang-up checks.

(iii) V3 and V5—Selector valves to select sample or span gases.

(iv) V4, V6, and V15—flow control valves.

(v) V9 and V13—heated selector valve to select sample or span gases.

(vi) V10 and V12—heated flow control valves.

(vii) V11—Selector valve to select NO_x or bypass mode in the chemiluminescence analyzer.

(viii) V16—heated selector valve to perform leak checks.

(8) *Pump.* Sample transfer pump to transport sample to analyzers.

(9) *Temperature sensor.* A temperature sensor (T1) to measure the NO_2 to NO converter temperature is required for any system used for testing under this subpart.

(10) *Dryer.* Dryers D1 and D2 to remove the water from the bypass flows to prevent condensation in flowmeters FL3, FL4, and FL6.

§ 86.310–79 Sampling and analytical system; component specifications.

(a) *Temperature.* (1) *For gasoline-fueled engines any heated component;*

(i) In the HC sample path must be maintained above 110°C (230°F) and shall not exceed 230°C (446°F).

(ii) In the NO_x sample path must be maintained above 60°C (140°F) and shall not exceed 230°C (446°F).

(2) *For Diesel engines any heated component;*

(i) In the HC sample path must be maintained above 180°C (356°F) and shall not exceed 230°C (446°F).

(ii) In the NO_x sample path must be maintained above 60°C (140°F) and shall not exceed 230°C (446°F).

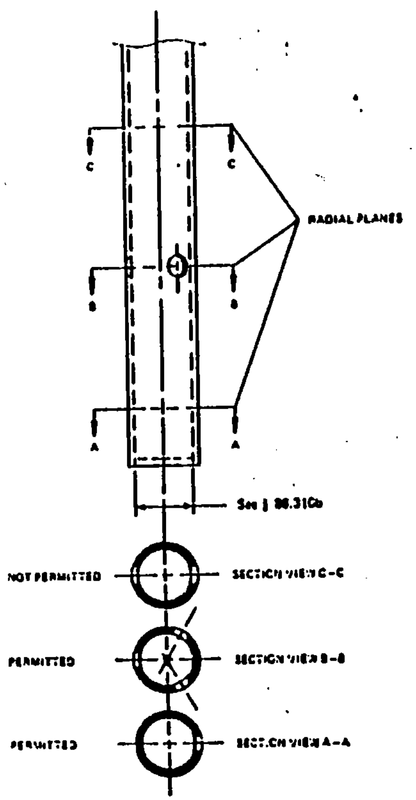


Figure D79-2 SAMPLE PROBE AND TYPICAL HOLE SPACINGS

(3) The sample line outside wall temperature must be maintained at the temperature specified in this paragraph. An exception is made for the first 4 feet of sample line from the exhaust duct. The upper temperature tolerance for this 4 foot section is waived and only the minimum temperature specification applies.

(b) *Sample probe.* (1) The sample probe shall be a straight, closed end, stainless steel, multi-hole probe. The Inside Diameter (I.D.) shall not be greater than the I.D. of the sample line (+.010 in.). The wall thickness of the probe shall not be greater than .040 inch. The fitting that attaches the probe to the exhaust pipe shall be as small as practical in order to minimize heat loss from the probe.

(2) There shall be a minimum of three holes in the probe. The spacing of the radial planes for each hole in the probe must be such that they cover approximately equal cross-sectional areas of the exhause duct. The angular spacing of the holes must be approximately equal. The angular spacing of any two holes in one plane may not be 180° ±20° (i.e., section C-C of Figure D79-2). The holes should be sized such that each has approximately the same flow. If only three holes are used, they may not all be in the same radial plane. See Figure D79-2.

(3) The probe shall extend radially across the exhaust duct. The probe must pass through the approximate center and must extend across at least 80 percent of the diameter of the duct.

(c) *Sample transfer.* (1) The maximum I.D. of the sample line shall not exceed 0.52 inch.

(2) If valve V2 is used, the sample probe must connect directly to valve V2. The location of optional valve V2 may not be greater than 4 feet from the exhaust duct.

(3) The location of optional valve V16 may not be greater than 24 inches from the sample pump. The leakage rate for this section on the pressure side of the sample pump may not exceed the leakage rate specification for the vacuum side of the pump.

(d) *Venting.* All vents including analyzer vents, bypass flow, and pressure relief vents of regulators should be vented in such a manner to avoid endangering personnel in the immediate area.

[42 FR 45154, Sept. 8, 1977, as amended at 46 FR 50495, Oct. 13, 1981, and 47 FR 49807, Nov. 2, 1982]

§ 86.311-79 Miscellaneous equipment; specifications.

(a) *Chart recorders.* (1) The minimum chart speed allowed is 3 inches per minute for gasoline-fueled engines and 0.5 inches per minute for Diesel engines.

(2) When testing gasoline-fueled engines all chart recorders (analyzers, torque, rpm, etc.) shall be provided with Automatic markers which indicate one second intervals. Preprinted chart paper (one second intervals) may be used in lieu of the automatic markers provided the correct chart speed is used.

(b) *Accuracy of temperature measurements.* (1) The following temperature measurements shall be accurate to within 1.2° C:

(i) Temperature measurements used in calculating the engine intake humidity:

(ii) The temperature of the fuel in volume measuring flow rate devices;

(iii) The temperature of the sample within the water trap(s).

(2) All other temperature measurements shall be accurate within 2.5° C.

(c) *Intake air humidity and temperature measurements.* (1) Humidity conditioned air supply. Air that has had its absolute humidity altered is considered humidity-conditioned air. For this type of intake air supply, the humidity measurements must be made within the intake air supply system, and after the humidity conditioning has taken place.

(2) Nonconditioned air supply. Humidity measurements in non-conditioned intake air supply systems must be made in the intake air stream entering the supply system. Alternatively, the humidity measurements can be measured within the intake air supply stream.

(3) Engine intake air temperature measurement must be made within 48 inches of the engine. The measurement location must be made either in the supply system or in the air stream entering the supply system.

(d) *Sample component surface temperature.* For each component (pump, sample line section, filters, etc.) in the heated portion of the sampling system that has a separate source of power or heating element, use engineering judgment to locate the coolest portion of that component and monitor the temperature at that location. If several components are within an oven, then only the surface temperature of the component with the largest thermal mass and the oven temperature need be measured.

(e) If water is removed by condensation, the sample gas temperature or sample dew point must be monitored either within the water trap or downstream. It may not exceed 7°C (45°F).

[42 FR 45154, Sept. 8, 1977, as amended at 46 FR 50495, Oct. 13, 1981; 47 FR 49807, Nov. 2, 1982]

§ 86.312-79 Dynamometer and engine equipment specifications.

(a) *Dynamometer.* (1) The dynamometer test stand and other instruments for measurement of power output shall be accurate to within 2 percent of point at all power settings above 10 percent of full-scale. Below 10 percent of full-scale the accuracy shall be within 5 percent of point. The dynamometer must be capable of performing the test cycle described in § 86.335 or § 86.336. Dynamometers used for testing gasoline-fueled engines must have sufficient motoring capability to meet the test requirements. A 60-tooth wheel in combination with a frequency counter shall be considered an absolute standard for engine speed.

(2) *Dynamometer calibration weights.* A minimum of 6 calibration weights for each range used are required. The weights must be equally spaced and traceable to within 0.5 percent of NBS weights. Laboratories located in foreign countries may certify calibration weights to local government bureau standards.

(b) *Engine cooling.* Means of engine cooling which will maintain the engine operating temperatures (e.g., intake air, oil, water, etc.) at approximately the same temperature as specified by the manufacturer shall be used. Auxiliary fan(s) may be used to maintain engine cooling during operation on the dynamometer.

(c) *Exhaust system.* (1) When testing gasoline-fueled engines:

(i) A chassis-type exhaust system including muffler(s) shall be used. The exhaust system must have a single tail pipe. For engines designed for a dual exhaust system, a standard or specially fabricated "Y" pipe may be used. The "Y" pipe may be located upstream of a single muffler or downstream of a single muffler or downstream of dual mufflers. The potential increase in backpressure due to the use of a single tail pipe instead of dual pipes may be compensated for by using larger than standard exhaust system components downstream of the

ANALYZER NOISE CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315.79)

Date: 9-26-90 Analysis Bench: 4

Operator: D.A.P.

Analyzer: NO

Analyzer Serial No. 10AR-13640-140

Analyzer Range: 250 PPM	Analyzer Range: 1000 PPM
Span Gas Conc.: 236 PPM	Span Gas Conc.: 963 PPM
Bottle No.: CC17410	Bottle No.: CC 49793
Analyzer PTP Response with Zero Gas. Chart Deflection: 0	Analyzer PTP Response with Zero Gas. Chart Deflection: 0
Analyzer PTP Response with Span Gas. Chart Deflection: 94.2 to 94.7	Analyzer PTP Response with Span Gas. Chart Deflection: 96.2 to 96.6
Noise: .53 % FSCD	Noise: .415 % FSCD
Analyzer Range: 2,500 PPM	Analyzer Range: 10,000 PPM
Span Gas Conc.: 2409 PPM	Span Gas Conc.: 9539 PPM
Bottle No.: CC 49806	Bottle No.: CC 49803
Analyzer PTP Response with Zero Gas. Chart Deflection: 0	Analyzer PTP Response with Zero Gas. Chart Deflection: 0
Analyzer PTP Response with Span Gas. Chart Deflection: 96.0 to 96.4	Analyzer PTP Response with Span Gas. Chart Deflection: 95.2 to 95.8
Noise: .415 % FSCD	Noise: .629 % FSCD

1. Zero and span analyzer on all analyzer ranges.
2. Note analyzer peak-to-peak (PTP) response to zero and span gas over a ten second interval.
3. Noise shall not exceed 2% of full scale chart deflection (FSCD) on all ranges used.

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ANALYZER RESPONSE TIME CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315-79)

Date: 9-27-90

Analysis Bench: 4

Operator: D.A.P

Analyzer: NO

Analyzer Serial No.: 10AR-13640-140

Analyzer Range: 250 PPM	Analyzer Range: 1000 PPM
Step Gas Conc.: 236	Step Gas Conc.: 963
Chart Deflection for 95% of Step Gas: 89.7	Chart Deflection for 95% of Step Gas: 91.5
Time to Respond to 95% of Step Gas: 11.8 sec.	Time to Respond to 95% of Step Gas: 11.9 sec.
Analyzer Gas Flow: 2 scfh	Analyzer Gas Flow: 2 scfh
Analyzer Range: 2500 PPM	Analyzer Range:
Step Gas Conc.: 2409	Step Gas Conc.:
Chart Deflection for 95% of Step Gas: 91.5	Chart Deflection for 95% of Step Gas:
Time to Respond to 95% of Step Gas: 16.2 sec.	Time to Respond to 95% of Step Gas: sec.
Analyzer Gas Flow: 2 scfh	Analyzer Gas Flow: scfh

1. Set chart speed at 60 cm/min. to record the following data:
2. Zero/span analyzer on respective range.
3. Introduce to inlet, step change gas of at least 60% of full scale chart deflection. (Step gas in W.E.D. lab is equivalent to span gas.)
4. Begin timing moment analyzer begins to respond to gas and stop timing when analyzer has responded to 95% of step gas concentration. (Chart recorder may be used as a timer, i.e. each cm division = 1 sec.)
5. Analyzer response time may not exceed 6.0 seconds for any analyzer range used.
6. Condensate bath may be by-passed when performing NO analyzer response time.

"Rev. 4/85"

ANALYZER ZERO AND SPAN DRIFT

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315-79)

Date: 10-1-90 Analysis Bench: 4

Operator: D.A.P.

Analyzer: NO

Analyzer Serial No.: 10AR-13640-140

Analyzer Range: 250 PPM

Zero Gas: X N_2 ___ Zero Air

Span Gas Bottle No.: CC17410

Zero Gas Response: 0 (% FSCD/30 SEC.)

Span Gas Response: .015 (% FSCD/30 SEC.)

Zero Drift: 0 % FSCD/HR.

Span Drift: 1.801 % FSCD/HR.

1. Zero and span analyzer on lowest range used.
2. Set chart speed at 10 cm/~~min.~~ hr.
3. Offset zero reading on chart, introduce zero gas over a 1 hour time period.
4. Determine average zero gas response over a 30 second time interval. Evaluate average zero gas response for 1 hour time period to determine drift.
5. Zero gas drift must be not more than 2% of full scale chart deflection (FSCD) over a 1 hour time period.
6. Rezero analyzer, check zero and span points.
7. Introduce span gas over a 1 hour time period.
8. Continue with steps 3 and 4 for span gas.
9. Retain chart paper to file with this page.

"Rev. 4/85"

CHEMILUMINESCENT ANALYZER QUENCH CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.327-79)

Date: 9-28-90 Analysis Bench: 4

Operator: D.A.P. Barometer: 29.19 In. Hg.

Wet Bulb: 62 °F. Dry Bulb: 74 °F.

Analyzer Serial No.: 10AR-13640-140

Analyzer Range: 250 PPM

CO_2 Cal. Gas Conc.: 15.20 NO Cal. Gas Conc.: 236

Bottle No.: 421806 Bottle No.: CC17410

CO_2 Anal. Response: 9.16 ppm

Blend Ratio = $\frac{CO_2 \text{ AR}}{CO_2 \text{ Gas Conc.}}$ = .602

Calculated NO Conc. = NO Calc. Gas Conc. X (1 - Blend Ratio) = 93.9 ppm

Chemi. Anal. Response: 97.0 ppm

% Response Difference = $\frac{\text{Calculated NO Conc. - Chemi AR}}{\text{Full Scale NO Conc.}}$ X 100 = -1.24 %

1. Zero and span analyzer on lowest range used.
2. Blend CO_2 cal. gas and NO cal. gas using divider.
3. Analyze CO_2/NO mixture for CO_2 conc.
4. Determine true NO concentration.
5. CO_2 concentration of blended mixture should equal approximately 12%.
6. Record Chemi. analyzer response.
7. Recheck zero and span if changed more than ± 1% of full scale, repeat Steps 1-7.
8. Determine % response difference.
9. % response difference must not be greater than 3%.

"Rev. 4/85"

NO_X CONVERTER EFFICIENCY DATA

(F.R. VOL. 42, NO. 174, 10/8/77 86.332-79)

Date: 10-1-90 Bench No.: 4

Operator: D.A.P.

NO Analyzer Range: 1000 PPM Converter Temp: 391

NO Bottle Conc: 963 PPM O_2 Bottle Conc.: 99.9%

NO Bottle No.: CC 49793

1. Supply 100% O_2 to "DRY AIR" input on NO_X generator.
2. Select most common NO analyzer range not over 1000 ppm. Supply zero and span gas to rear of the bench (span port).
3. Set up as follows:
   - A. Bench switched to "COND BYPASS" ("BATH BYPASS").
   - B. Bench switched to "BYPASS CONVERTER".
   - C. Bench "NO_X Generator" solenoid switch on.
   - D. Bench NO analyzer main and bypass flow controls full open.
   - E. Adjust zero and span flowrates to 8 scfh using the NO generator "NITRIC OXIDE" flowmeter. Switch between "NO_X". and "NO" mode (converter bypassed) balancing flows with bypass needle valve.
   - F. Set NO_X generator "DRY AIR" and "OZONE BYPASS" flowmeters to 0 (off).
   - G. Verify that the "OZONE & AIR SHUTOFF" valve is closed.
   - H. Turn on temp controller for converter and NO_X sample lines.

	DVM	PPM
4. With NO_X generator "POWER" switch OFF, zero and span the analyzer (analyzer is now in "NO" mode). Record NO reading.	96.3	963
5. Open the "OZONE & AIR SHUTOFF" valve.		
6. Adjust "DRY AIR" flowrate so that the NO indicated by the analyzer is about 10% less than that in Step 4. Record the concentration of this NO + O_2 mixture.	86.5	865
7. Turn on the NO_X generator "POWER" switch.		
8. Adjust "OZONE BYPASS" to about 1 scfh.		

"Rev. 5/85"

9. Adjust "OZONE FLOW" needle valve so that the NO measured by the analyzer is about 20% of that in Step 4. There must be at least 10% unreacted NO at this point. Record the concentration of NO. 19.3 193

10. Switch the bench to the "NO_X" mode (NO_X converter NOT bypassed), and measure total NO_X; record this value. 80.0 800

11. Turn off the NO_X generator "POWER". The analyzer will now indicate the Total NO_X in the NO + O_2 mixture. Record this value. 82.2 822

12. Close the "OZONE & AIR SHUTOFF" valve. The analyzer will now indicate the NO_X in the original NO/N_2 mixture (span gas). This value should be no more than 5% above the value in Step 4.

13. Calculate the efficiency by substituting the appropriate concentrations (ppm) into the following equation:

$$\text{efficiency} = 1 + \frac{10 - 11}{6 - 9} \times 100 \quad = \quad 96.73\ \%$$

The efficiency must be at least 90%. If not recheck and/or adjust converter temperature.

See HORIBA NO_X generator manual.

ANALYZER LINEARITY CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.330, 331, 332-79)

DATE: 9-27-90 ANALYSIS BENCH: 4 OPERATOR: D.A.P. BAROMETER: 29.13 IN.HG.

ANALYZER: NO ANALYZER SERIAL NO.: 10AR-13640-140 WET BULB: 66 °F DRY BULB: 78 °F.

PRESSURES: FID FUEL: ______ KG/CM^2 FID AIR: ______ KG/CM^2 FID REG. AIR: ______ KG/CM^2

REGULATOR AIR: ______ PSI FID BYPASS: ______ BENCH MANIFOLD: ______

Analyzer Range: 250 PPM		Analyzer Range: 1000 PPM		Analyzer Range: 2500 PPM		Analyzer Range:	
Bottle No.: CC17410		Bottle No.: CC49793		Bottle No.: CC49806		Bottle No.:	
Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)
236	94.4	963	96.3	2409	96.4		
188.8	75.9	770.4	77.3	1927.2	78.2		
141.6	56.9	577.8	58.4	1445.4	59.1		
94.4	38.0	385.2	39.3	963.6	39.7		
47.2	19.1	192.6	19.9	481.8	20.3		
0	.3	0	.4	0	.6		

1. Zero and span analyzer via calibration port.
2. Introduce N_2 and span gas to divider inlets at specified pressures.
3. Introduce divider output to analyzer via calibration port, verifying previously set span point (divider set at 100%). If span readings do not agree, adjust divider bypass flow.
4. Record analyzer mv output above, save chart paper for files.
5. Repeat Steps 1-4 for each range used.

"Rev. 7/85"

ANALYZER PRECISION CHECK

(F.R. VOL. 44, NO. 174, 3/29/79, 86.315.79)

: 9-26-90 ANALYSIS BENCH: 4 OPERATOR: D.A.P.

YZER: NO ANALYZER SERIAL NO.: 10AR-13640-140

yzer Range: 250PPM		Analyzer Range: 1000 PPM		Analyzer Range: 2500		Analyzer Range: ~~10,000~~	
Gas Conc.: 236 PPM		Span Gas Conc.: 963 PPM		Span Gas Conc.: 2409		Span Gas Conc.: ~~9539~~	
Point: 94.4 mv		Span Point: 96.3 mv		Span Point: 96.4 mv		Span Point: ~~95.4~~ mv	
le No.: CC17410		Bottle No.: CC49793		Bottle No.: CC49806		Bottle No.: ~~CC49803~~	
No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)
1	94.4	1	96.3	1	96.4	1	
2	94.4	2	96.3	2	96.5	2	
3	94.4	3	96.2	3	96.4	3	
4	94.4	4	96.1	4	96.5	4	
5	94.2	5	96.4	5	96.3	5	
6	94.3	6	96.3	6	96.2	6	
7	94.4	7	96.3	7	96.4	7	
8	94.5	8	96.1	8	96.4	8	
9	94.5	9	96.2	9	96.5	9	
10	94.4	10	96.1	10	96.5	10	

Zero and span analyzer 10 times. (Do not readjust zero and span after intial adjustments.)
Record span response (mv), also retain chart paper for files.
Repeat steps 1 and 2 for each range used.
Input data into computer program to determine precision of analyzer.

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EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:9/27/90

BENCH: 4
OPERATOR'S INITIALS: DAP
BAROMETER: 29.13 IN HG
DRY BULB: 78 F
WET BULB: 66 F

ANALYZER: CHEMI
RANGE: 250 PPM
CONCENTRATION & CYLINDER NUMBER: 236/CC17410

PRECISION CHECK ANALYZER RESPONSES: 94.4 94.4 94.4
94.4 94.2 94.3 94.4 94.5 94.5 94.4

ANALYZER RANGE PRECISION IS : +.22% OF FULL SCALE

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	PERCENT LINEARITY
94.4	236.00	235.32	.27
75.9	188.80	189.20	-.16
56.9	141.60	141.84	-.10
38.0	94.40	94.73	-.13
19.1	47.20	47.61	-.17
.3	0.00	.75	-.30

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:9/27/90

BENCH: 4
OPERATOR'S INITIALS: DAP
BAROMETER: 29.13 IN HG
DRY BULB: 78 F
WET BULB: 66 F

ANALYZER: CHEMI
RANGE: 1000 PPM
CONCENTRATION & CYLINDER NUMBER: 963/CC49793

RECISION CHECK ANALYZER RESPONSES: 96.3 96.3 96.2
6.1 96.4 96.3 96.3 96.1 96.2 96.1

NALYZER RANGE PRECISION IS : +.26% OF FULL SCALE

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	PERCENT LINEARITY
96.3	963.00	958.33	.47
77.3	770.40	769.25	.12
58.4	577.80	581.17	-.34
39.3	385.20	391.09	-.59
19.9	192.60	198.04	-.55
.4	0.00	3.98	-.40

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:9/27/90

BENCH: 4
OPERATOR'S INITIALS: DAP
BAROMETER: 29.13 IN HG
DRY BULB: 78 F
WET BULB: 66 F

ANALYZER: CHEMI
RANGE: 2500 PPM
CONCENTRATION & CYLINDER NUMBER: 2409/CC49806

PRECISION CHECK ANALYZER RESPONSES: 96.4 96.5 96.4
96.5 96.3 96.2 96.4 96.4 96.5 96.5

ANALYZER RANGE PRECISION IS : +.25% OF FULL SCALE

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	PERCENT LINEARITY
96.4	2409.00	2383.02	1.05
78.2	1927.20	1933.12	-.24
59.1	1445.40	1460.96	-.63
39.7	963.60	981.39	-.72
20.3	481.80	501.82	-.81
.6	0.00	14.83	-.60

ANALYZER NOISE CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315.79)

Date: 9-24-90

Analysis Bench: 4

Operator: D.A.P.

Analyzer: CO

Analyzer Serial No. 4824705

Analyzer Range: 2500 PPM
Span Gas Conc.: 2200
Bottle No.: 527884
Analyzer PTP Response with Zero Gas.
Chart Deflection: -.2 to 0
Analyzer PTP Response with Span Gas.
Chart Deflection: 88.6 to 88.9
Noise: .56 % FSCD

Analyzer Range: 1%
Span Gas Conc.: .95%
Bottle No.: J03007
Analyzer PTP Response with Zero Gas.
Chart Deflection: 0 TO .1
Analyzer PTP Response with Span Gas.
Chart Deflection: 96.8 TO 96.9
Noise: .207 % FSCD

Analyzer Range: 5%
Span Gas Conc.: 4.5%
Bottle No.: 58150
Analyzer PTP Response with Zero Gas.
Chart Deflection: 0
Analyzer PTP Response with Span Gas.
Chart Deflection: 95.6 to 95.7
Noise: .104 % FSCD

Analyzer Range: ______
Span Gas Conc.: ______
Bottle No.: ______
Analyzer PTP Response with Zero Gas.
Chart Deflection: ______
Analyzer PTP Response with Span Gas.
Chart Deflection: ______
Noise: ______ % FSCD

1. Zero and span analyzer on all analyzer ranges.
2. Note analyzer peak-to-peak (PTP) response to zero and span gas over a ten second interval.
3. Noise shall not exceed 2% of full scale chart deflection (FSCD) on all ranges used.

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ANALYZER RESPONSE TIME CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315-79)

Date: 9-25-90 Analysis Bench: 4

Operator: D.A.P.

Analyzer: CO Analyzer Serial No.: 4824705

Analyzer Range: 2500 PPM	Analyzer Range: 5%
Step Gas Conc.: 2200	Step Gas Conc.: 4.5%
Chart Deflection for 95% of Step Gas: 84.7	Chart Deflection for 95% of Step Gas: 93.5
Time to Respond to 95% of Step Gas: 4.1 sec.	Time to Respond to 95% of Step Gas: 3.7 sec.
Analyzer Gas Flow: 3 scfh	Analyzer Gas Flow: 3 scfh
Analyzer Range: 1%	Analyzer Range:
Step Gas Conc.: .95%	Step Gas Conc.:
Chart Deflection for 95% of Step Gas: 93.2	Chart Deflection for 95% of Step Gas:
Time to Respond to 95% of Step Gas: 3.9 sec.	Time to Respond to 95% of Step Gas: sec.
Analyzer Gas Flow: 3 scfh	Analyzer Gas Flow: scfh

1. Set chart speed at 60 cm/min. to record the following data:
2. Zero/span analyzer on respective range.
3. Introduce to inlet, step change gas of at least 60% of full scale chart deflection. (Step gas in W.E.D. lab is equivalent to span gas.)
4. Begin timing moment analyzer begins to respond to gas and stop timing when analyzer has responded to 95% of step gas concentration. (Chart recorder may be used as a timer, i.e. each cm division = 1 sec.)
5. Analyzer response time may not exceed 6.0 seconds for any analyzer range used.
6. Condensate bath may be by-passed when performing NO analyzer response time.

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ANALYZER ZERO AND SPAN DRIFT

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315-79)

Date: 10-1-90 Analysis Bench: 4

Operator: D.A.P.

Analyzer: CO

Analyzer Serial No.: 4824705

Analyzer Range: 2500 PPM

Zero Gas: X N_2 ____ Zero Air

Span Gas Bottle No.: 527884

Zero Gas Response: .002 (% FSCD/30 SEC.)

Span Gas Response: .003 (% FSCD/30 SEC.)

Zero Drift: -.2 % FSCD/HR.

Span Drift: .338 % FSCD/HR.

1. Zero and span analyzer on lowest range used.
2. Set chart speed at 10 cm/~~min.~~ hr.
3. Offset zero reading on chart, introduce zero gas over a 1 hour time period.
4. Determine average zero gas response over a 30 second time interval. Evaluate average zero gas response for 1 hour time period to determine drift.
5. Zero gas drift must be not more than 2% of full scale chart deflection (FSCD) over a 1 hour time period.
6. Rezero analyzer, check zero and span points.
7. Introduce span gas over a 1 hour time period.
8. Continue with steps 3 and 4 for span gas.
9. Retain chart paper to file with this page.

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NDIR WATER REJECTION RATIO CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.316, 86.318, 86.331-79

Date: 9-24-90 Analysis Bench: 4

Operator: D.A.P. Barometer: 29.17

Analyzer: CO

Analyzer Range: 2500

Analyzer Serial No.: 4824705

1. Zero/span on lowest range used.
2. Bubble zero gas through distilled water and introduce water/gas mixture directly to analyzer inlet.
3. Record water/gas mixture temperature: 74 °F.
4. Record analyzer operating pressure: 3 In. H_2O, .10839 PSI (gage).
5. Record analyzer response to water/gas mixture: 4.85 ppm.
6. Determine the water concentration using:

$$W.C. = \frac{\text{Saturation Vapor Pressure (SVP, psi)}}{\text{Absolute Gage Pressure (AGP, psi)}} \times 10^6$$

SVP is found from saturation vapor pressure table @ water/gas mixture temperature: .4155 psi.

AGP is the gage pressure (psi) + the barometer (psi): 14.436694 psi.

(0.03613 psi/in H_2O, 0.4912 psi/in. Hg)

W.C. 28780.82752 .

7. Determine water rejection ratio using:

$$WRR = \frac{\text{Water Concentration}}{\text{Anal. Response in ppm}} = 5934.191242$$

8. Minimum WRR CO Analyzer - 1000:1.
9. Minimum WRR CO_2 Analyzer - 100:1.
10. Minimum WRR NO Analyzer - 5000:1.

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NDIR CO_2 REJECTION RATIO CHECK

F.R. VOL. 42, NO. 174, 10/8/79, 86.316, 86.318, 86.332-79)

Date: 9-24-90 Analysis Bench: 4

Operator: D.A.P.

Analyzer: CO Serial No.: 4824705

Analyzer Range: 2500

CO_2 Concentration: 14.89

1. Zero/span on lowest range used.

2. Introduce a CO_2 calibration gas of at least 10% CO_2 to the analyzer.

3. Record analyzer response to CO_2: 24 ppm.

4. Calculate CO_2 rejection ratio using:

$$CO_2RR = \frac{CO_2 \text{ Conc. in ppm}}{\text{Anal. Resp. in ppm}} = 6204.166667$$

5. Minimum CO_2RR CO analyzer - 5000.

6. Minimum CO_2RR NO analyzer - 30,000.

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NDIR ANALYZER CALIBRATION

(F.R. VOL. 42, NO. 174, 10/8/77, 86.330-79)

DATE: 9-25-90 ANALYSIS BENCH: 4 OPERATOR: D.A.P. BAROMETER: 28.79 IN.HG

ANALYZER: CO ANALYZER SERIAL NO.: 4824705 WET BULB: 59 °F DRY BULB: 74 °F

Bottle No.: 527884		Bottle No.: J03007		Bottle No.: 58150		Bottle No.:	
Analyzer Range: 2500 PPM		Analyzer Range: 1%		Analyzer Range: 5%		Analyzer Range:	
Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)
2200	88.7	9500 PPM	96.8	4.50	95.7		
1760	72.3	7600	81.8	3.60	86.0		
1320	55.1	5700	64.8	2.70	74.0		
880	37.3	3800	45.8	1.80	58.3		
440	18.9	1900	24.4	.90	35.9		
0	0	0	0	0	0		

1. Zero and span analyzer via calibration port.
2. Introduce N_2 and span gas to divider inlets at specified pressures.
3. Introduce divider output to analyzer via calibration port, verifying previously set span point (divider set at 100%). If span readings do not agree, adjust divider bypass flow.
4. Record analyzer mv output* above, save chart paper for files.
5. Repeat Steps 1-4 for each range used.

* Correct CO_2 values per gas divider CO_2 correction chart.

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ANALYZER PRECISION CHECK

(F.R. VOL. 44, NO. 174, 3/29/79, 86.315.79)

: 9-24-90 ANALYSIS BENCH: 4 OPERATOR: D.A.P.

YZER: CO ANALYZER SERIAL NO.: 4824705

yzer Range:	2500 PPM	Analyzer Range:	1%	Analyzer Range:	5%	Analyzer Range:	
Gas Conc.:	2200 PPM	Span Gas Conc.:	.95%	Span Gas Conc.:	4.5%	Span Gas Conc.:	
Point:	88.7 mv	Span Point:	96.8 mv	Span Point:	95.7 mv	Span Point:	mv
le No.:	527884	Bottle No.:	J 03007	Bottle No.:	58150	Bottle No.:	
No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)
1	88.7	1	96.8	1	95.7	1	
2	88.7	2	96.8	2	95.7	2	
3	88.7	3	96.8	3	95.7	3	
4	88.6	4	96.8	4	95.7	4	
5	88.7	5	96.8	5	95.6	5	
6	88.8	6	96.8	6	95.6	6	
7	88.8	7	96.9	7	95.6	7	
8	88.7	8	96.8	8	95.6	8	
9	88.8	9	96.8	9	95.6	9	
10	88.9	10	96.9	10	95.7	10	

Zero and span analyzer 10 times. (Do not readjust zero and span after intial adjustments.)
Record span response (mv), also retain chart paper for files.
Repeat steps 1 and 2 for each range used.
Input data into computer program to determine precision of analyzer.

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EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:9/25/90

BENCH: 4
OPERATOR'S INITIALS: DAF
BAROMETER: 28.79 IN HG
DRY BULB: 74 F
WET BULB: 59 F

ANALYZER: NDIR CO
RANGE: 2500 PPM
CONCENTRATION & CYLINDER NUMBER: 2200/527884

ANALYZER PERFORMANCE BASED UPON OLD REGRESSION DATA OF 8/22/88

OLD REGRESSION COEFFICIENTS

+1.98645E-001 +2.38793E+001 -1.50581E-002 +3.58099E-004 -8.07689E-007

ANALYZER ERROR TABLE
OLD REGRESSION DATA OF: 8/22/88

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	% ERROR OF POINT	% ERROR OF FULL SCALE
88.7	2200.00	2199.73	-.01	-.01
72.3	1760.00	1761.23	.07	.05
55.1	1320.00	1322.69	.20	.11
37.3	880.00	886.97	.79	.28
18.9	440.00	448.45	1.92	.34
0.0	0.00	.20	0.00	.01

NEW REGRESSION MODEL DATE: 9/25/90

PPM NDIR CO = +2.86387E-002 +(+2.29295E+001)*(AR)+(+1.87880E-002)*(AR^2)+
(-5.60854E-005)*(AR^3)+(+9.27330E-007)*(AR^4)

ANALYZER ERROR TABLE
NEW REGRESSION DATA OF: 9/25/90

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	% ERROR OR POINT	% ERROR OF FULL SCALE
88.7	2200.00	2199.96	-.00	-.00
72.3	1760.00	1760.19	.01	.01
55.1	1320.00	1319.65	-.03	-.01
37.3	880.00	880.32	.04	.01
18.9	440.00	439.85	-.03	-.01
0.0	0.00	.03	0.00	.00

PRECISION CHECK ANALYZER RESPONSES: 88.7 88.7 88.7
88.6 88.7 88.8 88.8 88.7 88.8 88.9

ANALYZER RANGE PRECISION IS : +.23% OF FULL SCALE

EMISSION INSTRUMENT CALIBRATION CHART

ANALYZER: NDIR CO 2500 PPM
DATE OF CALIBRATION REGRESSION: 9/25/90
DATE OF LATEST CALIBRATION CHECK: 9/25/90

ANALYZER RESPONSE VERSUS CONCENTRATION

.5	11.50	25.5	596.41	50.5	1204.69	75.5	1844.30
1.0	22.98	26.0	608.34	51.0	1217.14	76.0	1857.51
1.5	34.47	26.5	620.27	51.5	1229.59	76.5	1870.74
2.0	45.96	27.0	632.21	52.0	1242.06	77.0	1883.99
2.5	57.47	27.5	644.16	52.5	1254.54	77.5	1897.26
3.0	68.98	28.0	656.12	53.0	1267.04	78.0	1910.55
3.5	80.51	28.5	668.09	53.5	1279.54	78.5	1923.86
4.0	92.04	29.0	680.07	54.0	1292.06	79.0	1937.19
4.5	103.59	29.5	692.06	54.5	1304.60	79.5	1950.53
5.0	115.14	30.0	704.06	55.0	1317.14	80.0	1963.90
5.5	126.70	30.5	716.07	55.5	1329.70	80.5	1977.29
6.0	138.27	31.0	728.09	56.0	1342.27	81.0	1990.70
6.5	149.85	31.5	740.11	56.5	1354.86	81.5	2004.13
7.0	161.44	32.0	752.15	57.0	1367.46	82.0	2017.58
7.5	173.04	32.5	764.19	57.5	1380.07	82.5	2031.06
8.0	184.64	33.0	776.25	58.0	1392.70	83.0	2044.55
8.5	196.26	33.5	788.31	58.5	1405.34	83.5	2058.07
9.0	207.88	34.0	800.39	59.0	1417.99	84.0	2071.61
9.5	219.51	34.5	812.47	59.5	1430.66	84.5	2085.16
10.0	231.16	35.0	824.56	60.0	1443.34	85.0	2098.75
10.5	242.81	35.5	836.67	60.5	1456.04	85.5	2112.35
11.0	254.47	36.0	848.78	61.0	1468.75	86.0	2125.98
11.5	266.13	36.5	860.91	61.5	1481.48	86.5	2139.63
12.0	277.81	37.0	873.04	62.0	1494.22	87.0	2153.30
12.5	289.50	37.5	885.18	62.5	1506.97	87.5	2166.99
13.0	301.19	38.0	897.34	63.0	1519.74	88.0	2180.71
13.5	312.89	38.5	909.50	63.5	1532.53	88.5	2194.46
14.0	324.61	39.0	921.68	64.0	1545.33	89.0	2208.22
14.5	336.33	39.5	933.86	64.5	1558.15	89.5	2222.01
15.0	348.06	40.0	946.06	65.0	1570.98	90.0	2235.83
15.5	359.80	40.5	958.26	65.5	1583.83	90.5	2249.66
16.0	371.54	41.0	970.48	66.0	1596.69	91.0	2263.53
16.5	383.30	41.5	982.70	66.5	1609.57	91.5	2277.42
17.0	395.06	42.0	994.94	67.0	1622.47	92.0	2291.33
17.5	406.84	42.5	1007.19	67.5	1635.38	92.5	2305.27
18.0	418.62	43.0	1019.45	68.0	1648.31	93.0	2319.23
18.5	430.41	43.5	1031.72	68.5	1661.25	93.5	2333.22
19.0	442.21	44.0	1044.00	69.0	1674.21	94.0	2347.23
19.5	454.02	44.5	1056.29	69.5	1687.19	94.5	2361.27
20.0	465.83	45.0	1068.60	70.0	1700.19	95.0	2375.34
20.5	477.66	45.5	1080.91	70.5	1713.20	95.5	2389.44
21.0	489.50	46.0	1093.24	71.0	1726.23	96.0	2403.56
21.5	501.34	46.5	1105.57	71.5	1739.28	96.5	2417.70
22.0	513.19	47.0	1117.92	72.0	1752.34	97.0	2431.88
22.5	525.05	47.5	1130.28	72.5	1765.42	97.5	2446.08
23.0	536.92	48.0	1142.65	73.0	1778.52	98.0	2460.31
23.5	548.80	48.5	1155.04	73.5	1791.64	98.5	2474.57
24.0	560.69	49.0	1167.43	74.0	1804.78	99.0	2488.85
24.5	572.59	49.5	1179.84	74.5	1817.93	99.5	2503.17
25.0	584.50	50.0	1192.26	75.0	1831.11	100.0	2517.51

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:9/25/90

BENCH: 4
OPERATOR'S INITIALS: DAP
BAROMETER: 28.79 IN HG
DRY BULB: 74 F
WET BULB: F

ANALYZER: NDIR CO
RANGE: 1%
CONCENTRATION & CYLINDER NUMBER: .95%/J03007

ANALYZER PERFORMANCE BASED UPON OLD REGRESSION DATA OF 11/17/89

OLD REGRESSION COEFFICIENTS

+2.42000E-002 +7.14846E+001 +2.61365E-001 -9.61423E-004 +1.14716E-005

ANALYZER ERROR TABLE
OLD REGRESSION DATA OF: 11/17/89

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	% ERROR OF POINT	% ERROR OF FULL SCALE
96.8	9500.00	9503.96	.04	.04
81.8	7600.00	7583.71	-.21	-.16
64.8	5700.00	5670.37	-.52	-.30
45.8	3800.00	3780.38	-.52	-.20
24.4	1900.00	1889.95	-.53	-.10
0.0	0.00	.02	0.00	.00

PRECISION CHECK ANALYZER RESPONSES: 96.8 96.8 96.8
96.8 96.8 96.8 96.9 96.8 96.8 96.9

ANALYZER RANGE PRECISION IS : +.14% OF FULL SCALE

EMISSION INSTRUMENT CALIBRATION CHART

ANALYZER: NDIR CO 1%
DATE OF CALIBRATION REGRESSION: 11/17/89
DATE OF LATEST CALIBRATION CHECK: 9/25/90

ANALYZER RESPONSE VERSUS CONCENTRATION

.5	35.83	25.5	1981.74	50.5	4227.33	75.5	6845.94
1.0	71.77	26.0	2023.65	51.0	4275.62	76.0	6903.17
1.5	107.84	26.5	2065.68	51.5	4324.06	76.5	6960.63
2.0	144.03	27.0	2107.82	52.0	4372.65	77.0	7018.31
2.5	180.35	27.5	2150.07	52.5	4421.38	77.5	7076.22
3.0	216.81	28.0	2192.45	53.0	4470.26	78.0	7134.34
3.5	253.38	28.5	2234.94	53.5	4519.30	78.5	7192.70
4.0	290.09	29.0	2277.55	54.0	4568.49	79.0	7251.29
4.5	326.91	29.5	2320.28	54.5	4617.83	79.5	7310.11
5.0	363.87	30.0	2363.12	55.0	4667.32	80.0	7369.16
5.5	400.95	30.5	2406.09	55.5	4716.97	80.5	7428.44
6.0	438.15	31.0	2449.17	56.0	4766.78	81.0	7487.97
6.5	475.47	31.5	2492.37	56.5	4816.74	81.5	7547.73
7.0	512.92	32.0	2535.69	57.0	4866.87	82.0	7607.74
7.5	550.49	32.5	2579.14	57.5	4917.15	82.5	7667.99
8.0	588.18	33.0	2622.70	58.0	4967.60	83.0	7728.48
8.5	626.00	33.5	2666.38	58.5	5018.20	83.5	7789.23
9.0	663.93	34.0	2710.18	59.0	5068.98	84.0	7850.22
9.5	701.99	34.5	2754.10	59.5	5119.91	84.5	7911.47
10.0	740.16	35.0	2798.15	60.0	5171.02	85.0	7972.97
10.5	778.45	35.5	2842.32	60.5	5222.29	85.5	8034.73
11.0	816.87	36.0	2886.61	61.0	5273.73	86.0	8096.74
11.5	855.40	36.5	2931.03	61.5	5325.35	86.5	8159.02
12.0	894.05	37.0	2975.56	62.0	5377.13	87.0	8221.56
12.5	932.82	37.5	3020.23	62.5	5429.09	87.5	8284.37
13.0	971.71	38.0	3065.01	63.0	5481.22	88.0	8347.44
13.5	1010.72	38.5	3109.93	63.5	5533.53	88.5	8410.79
14.0	1049.84	39.0	3154.97	64.0	5586.02	89.0	8474.41
14.5	1089.08	39.5	3200.13	64.5	5638.69	89.5	8538.30
15.0	1128.44	40.0	3245.43	65.0	5691.53	90.0	8602.47
15.5	1167.91	40.5	3290.85	65.5	5744.56	90.5	8666.92
16.0	1207.50	41.0	3336.40	66.0	5797.78	91.0	8731.65
16.5	1247.21	41.5	3382.08	66.5	5851.18	91.5	8796.67
17.0	1287.03	42.0	3427.89	67.0	5904.77	92.0	8861.97
17.5	1326.97	42.5	3473.83	67.5	5958.54	92.5	8927.56
18.0	1367.03	43.0	3519.91	68.0	6012.51	93.0	8993.45
18.5	1407.20	43.5	3566.11	68.5	6066.66	93.5	9059.62
19.0	1447.48	44.0	3612.45	69.0	6121.01	94.0	9126.10
19.5	1487.89	44.5	3658.92	69.5	6175.56	94.5	9192.87
20.0	1528.41	45.0	3705.53	70.0	6230.30	95.0	9259.95
20.5	1569.04	45.5	3752.27	70.5	6285.24	95.5	9327.33
21.0	1609.79	46.0	3799.15	71.0	6340.38	96.0	9395.02
21.5	1650.66	46.5	3846.16	71.5	6395.72	96.5	9463.01
22.0	1691.64	47.0	3893.32	72.0	6451.27	97.0	9531.32
22.5	1732.73	47.5	3940.61	72.5	6507.02	97.5	9599.94
23.0	1773.94	48.0	3988.04	73.0	6562.98	98.0	9668.88
23.5	1815.27	48.5	4035.61	73.5	6619.14	98.5	9738.14
24.0	1856.72	49.0	4083.33	74.0	6675.52	99.0	9807.73
24.5	1898.28	49.5	4131.19	74.5	6732.11	99.5	9877.64
25.0	1939.95	50.0	4179.19	75.0	6788.92	100.0	9947.87

PPM NDIR CO = +2.42000E-002 +(+7.14846E+001)*(AR)+(+2.61365E-001)*(AR^2)+
(-9.61423E-004)*(AR^3)+(+1.14716E-005)*(AR^4)

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:9/25/90

BENCH: 4
OPERATOR'S INITIALS: DAP
BAROMETER: 28.79 IN HG
DRY BULB: 74 F
WET BULB: F

ANALYZER: NDIR CO
RANGE: 5%
CONCENTRATION & CYLINDER NUMBER: 4.5%/58150

ANALYZER PERFORMANCE BASED UPON OLD REGRESSION DATA OF 11/17/89

OLD REGRESSION COEFFICIENTS

+2.18004E-005 +1.63868E-002 +2.79306E-004 -1.93603E-006 +2.46785E-008

ANALYZER ERROR TABLE
OLD REGRESSION DATA OF: 11/17/89

ANALYZER RESPONSE	ACTUAL %	PREDICTED %	% ERROR OF POINT	% ERROR OF FULL SCALE
95.7	4.50	4.50	-.01	-.01
86.0	3.60	3.59	-.18	-.13
74.0	2.70	2.70	-.09	-.05
58.3	1.80	1.81	.34	.12
35.9	.90	.90	-.03	-.01
0.0	0.00	.00	0.00	.00

PRECISION CHECK ANALYZER RESPONSES: 95.7 95.7 95.7
95.7 95.6 95.6 95.6 95.6 95.6 95.7

ANALYZER RANGE PRECISION IS : +.27% OF FULL SCALE

EMISSION INSTRUMENT CALIBRATION CHART

ANALYZER: NDIR CO 5%
DATE OF CALIBRATION REGRESSION: 11/17/89
DATE OF LATEST CALIBRATION CHECK: 9/25/90

ANALYZER RESPONSE VERSUS CONCENTRATION

.5	.01	25.5	.58	50.5	1.45	75.5	2.80
1.0	.02	26.0	.59	51.0	1.47	76.0	2.83
1.5	.03	26.5	.61	51.5	1.49	76.5	2.87
2.0	.03	27.0	.62	52.0	1.52	77.0	2.90
2.5	.04	27.5	.64	52.5	1.54	77.5	2.94
3.0	.05	28.0	.65	53.0	1.56	78.0	2.97
3.5	.06	28.5	.67	53.5	1.58	78.5	3.01
4.0	.07	29.0	.68	54.0	1.60	79.0	3.04
4.5	.08	29.5	.70	54.5	1.63	79.5	3.08
5.0	.09	30.0	.71	55.0	1.65	80.0	3.12
5.5	.10	30.5	.73	55.5	1.67	80.5	3.16
6.0	.11	31.0	.74	56.0	1.70	81.0	3.19
6.5	.12	31.5	.76	56.5	1.72	81.5	3.23
7.0	.13	32.0	.77	57.0	1.74	82.0	3.27
7.5	.14	32.5	.79	57.5	1.77	82.5	3.31
8.0	.15	33.0	.80	58.0	1.79	83.0	3.35
8.5	.16	33.5	.82	58.5	1.82	83.5	3.39
9.0	.17	34.0	.84	59.0	1.84	84.0	3.43
9.5	.18	34.5	.85	59.5	1.87	84.5	3.47
10.0	.19	35.0	.87	60.0	1.89	85.0	3.51
10.5	.20	35.5	.89	60.5	1.92	85.5	3.55
11.0	.21	36.0	.90	61.0	1.94	86.0	3.59
11.5	.22	36.5	.92	61.5	1.97	86.5	3.64
12.0	.23	37.0	.94	62.0	1.99	87.0	3.68
12.5	.25	37.5	.95	62.5	2.02	87.5	3.72
13.0	.26	38.0	.97	63.0	2.05	88.0	3.77
13.5	.27	38.5	.99	63.5	2.07	88.5	3.81
14.0	.28	39.0	1.01	64.0	2.10	89.0	3.85
14.5	.29	39.5	1.02	64.5	2.13	89.5	3.90
15.0	.30	40.0	1.04	65.0	2.15	90.0	3.95
15.5	.32	40.5	1.06	65.5	2.18	90.5	3.99
16.0	.33	41.0	1.08	66.0	2.21	91.0	4.04
16.5	.34	41.5	1.10	66.5	2.24	91.5	4.08
17.0	.35	42.0	1.11	67.0	2.27	92.0	4.13
17.5	.36	42.5	1.13	67.5	2.30	92.5	4.18
18.0	.38	43.0	1.15	68.0	2.32	93.0	4.23
18.5	.39	43.5	1.17	68.5	2.35	93.5	4.28
19.0	.40	44.0	1.19	69.0	2.38	94.0	4.33
19.5	.41	44.5	1.21	69.5	2.41	94.5	4.38
20.0	.43	45.0	1.23	70.0	2.44	95.0	4.43
20.5	.44	45.5	1.25	70.5	2.47	95.5	4.48
21.0	.45	46.0	1.27	71.0	2.51	96.0	4.53
21.5	.47	46.5	1.29	71.5	2.54	96.5	4.58
22.0	.48	47.0	1.31	72.0	2.57	97.0	4.64
22.5	.49	47.5	1.33	72.5	2.60	97.5	4.69
23.0	.51	48.0	1.35	73.0	2.63	98.0	4.74
23.5	.52	48.5	1.37	73.5	2.66	98.5	4.80
24.0	.54	49.0	1.39	74.0	2.70	99.0	4.85
24.5	.55	49.5	1.41	74.5	2.73	99.5	4.91
25.0	.56	50.0	1.43	75.0	2.76	100.0	4.96

% NDIR CO = +2.18004E-005 +(+1.63868E-002)*(AR)+(+2.79306E-004)*(AR^2)+
(-1.93603E-006)*(AR^3)+(+2.46785E-008)*(AR^4)

ANALYZER NOISE CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315.79)

Date: 1-29-90

Operat... : D.A.P.

Analyz... : HC

Analyz... Serial No. 4812908

Analysis Bench: 4

Analyz... Range: 1000

Span Gas Conc.: 909 PPMC

Bottle No.: N-340880

Analyz... PTP Response with Zero Gas. Chart Deflection: 0

Analyz... PTP Response with Span Gas. Chart Deflection: 90.9

Noise: 0 % FSCD

Analyzer Range: 3000

Span Gas Conc.: 2661 PPMC

Bottle No.: 72131

Analyzer PTP Response with Zero Gas. Chart Deflection: 0

Analyzer PTP Response with Span Gas. Chart Deflection: 88.7

Noise: 0 % FSCD

Analyz... Range: ________

Span Gas Conc.: ________

Bottle No.: ________

Analyz... PTP Response with Zero Gas. Chart Deflection: ________

Analyz... PTP Response with Span Gas. Chart Deflection: ________

Noise: ________ % FSCD

Analyzer Range: ________

Span Gas Conc.: ________

Bottle No.: ________

Analyzer PTP Response with Zero Gas. Chart Deflection: ________

Analyzer PTP Response with Span Gas. Chart Deflection: ________

Noise: ________ % FSCD

1. Zero ... span analyzer on all analyzer ranges.
2. Note ... analyzer peak-to-peak (PTP) response to zero and span gas over a ten second interval.
3. Noise ... shall not exceed 2% of full scale chart deflection (FSCD) on all ranges used.

"Rev. 4/85"

ANALYZER RESPONSE TIME CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315-79)

Date: 9-29-90

Analysis Bench: 4

Operator: D.A.P.

Analyzer: HC

Analyzer Serial No.: 4812908

Analyzer Range: 1000	Analyzer Range: 3000
Step Gas Conc.: 909 PPMC	Step Gas Conc.: 2661
Chart Deflection for 95% of Step Gas: 86.4	Chart Deflection for 95% of Step Gas: 84.3
Time to Respond to 95% of Step Gas: 3.1 sec.	Time to Respond to 95% of Step Gas: 3.1 sec.
Analyzer Gas Flow: 5 scfh	Analyzer Gas Flow: 5 scfh
Analyzer Range:	Analyzer Range:
Step Gas Conc.:	Step Gas Conc.:
Chart Deflection for 95% of Step Gas:	Chart Deflection for 95% of Step Gas:
Time to Respond to 95% of Step Gas: ______ sec.	Time to Respond to 95% of Step Gas: ______ sec.
Analyzer Gas Flow: ______ scfh	Analyzer Gas Flow: ______ scfh

1. Set chart speed at 60 cm/min. to record the following data:
2. Zero/span analyzer on respective range.
3. Introduce to inlet, step change gas of at least 60% of full scale chart deflection. (Step gas in W.E.D. lab is equivalent to span gas.)
4. Begin timing moment analyzer begins to respond to gas and stop timing when analyzer has responded to 95% of step gas concentration. (Chart recorder may be used as a timer, i.e. each cm division = 1 sec.)
5. Analyzer response time may not exceed 6.0 seconds for any analyzer range used.
6. Condensate bath may be by-passed when performing NO analyzer response time.

"Rev. 4/85"

ANALYZER ZERO AND SPAN DRIFT

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315-79)

Date: 10-1-90 Analysis Bench: 4

Operator: D.A.P.

Analyzer: HC

Analyzer Serial No.: 4812908

Analyzer Range: 1000 PPMC

Zero Gas: ___ N_2 X Zero Air

Span Gas Bottle No.: N-340880

Zero Gas Response: 0 (% FSCD/30 SEC.)

Span Gas Response: .005 (% FSCD/30 SEC.)

Zero Drift: 0 % FSCD/HR.

Span Drift: .55 % FSCD/HR.

1. Zero and span analyzer on lowest range used.
2. Set chart speed at 10 cm/~~min.~~ 4 hr.
3. Offset zero reading on chart, introduce zero gas over a 1 hour time period.
4. Determine average zero gas response over a 30 second time interval. Evaluate average zero gas response for 1 hour time period to determine drift.
5. Zero gas drift must be not more than 2% of full scale chart deflection (FSCD) over a 1 hour time period.
6. Rezero analyzer, check zero and span points.
7. Introduce span gas over a 1 hour time period.
8. Continue with steps 3 and 4 for span gas.
9. Retain chart paper to file with this page.

"Rev. 4/85"

HYDROCARBON ANALYZER O_2 INTERFERENCE

(F.R. VOL. 42, NO. 174, 10/8/77 86.331-79)

Date: 9-29-90 Analyzer Bench: 4

Operator: D.A.P.

Analyzer Serial No.: 4812908

Type of Sampling: ___ Diesel ___ Gasoline X Gaseous

FID Temperature: 369 Fuel Bottle No.: SA 1431

Regulator Air Press: 6 psi Burner Air Bottle No.: CC56178

O_2 Conc. (%)	HC Conc. (PPMC)	Bottle No.
20.99	943.2	CAL-8565
10.15	880.2	CAL-2976
5.03	887.55	CAL-4435

A = HC conc., PPMC of span gas used in Step 3.

B = HC conc., PPMC of O_2 interference gases used in Step 5.

$$\text{Analyzer Response (ARPPM)} = \frac{A}{\text{\% of FSCD due to A}} \times \text{\% OF FSCD due to B.}$$

(FSCD = Full Scale Chart Deflection)

$$\%\ O_2\ \text{Interference}\ (\%O_2I) = \frac{\text{B-ARPPM}}{\text{B}} \times 100.$$

FUEL PRESS. (kg/cm^2)	AIR PRESS. (kg/cm^2)	BY-PASS PRESS.	FSCD A	FSCD B_5	FSCD B_{10}	$ARPPM_5$	$ARPPM_{10}$	$\%O_2I_5$	$\%O_2I_{10}$
.75	.75	6	94.3	87.9	87.7	879.19	877.19	.942	.342

1. Connect "Shop Air" to bench sample inlet (to simulate sample flow).
2. Zero analyzer.
3. Span analyzer with 21% O_2/propane blend for diesel, gaseous; 0% O_2 for gasoline.
4. Record mv output for 21% O_2 or 0% O_2 span gas.
5. Introduce 5 and 10% O_2 interference gases.
6. Record Full Scale Chart Deflection for 5 and 10% O_2 interference gases.
7. Determine analyzer response in PPM (ARPPM) for each gas, 5 and 10%.
8. Determine oxygen interference (%O_2I) for each gas, 5 and 10%.
9. % O_2I must be less than ± 3.0% for all gases.
10. If %O_2I is not within specification, vary air flow, then fuel flow, and thereafter sample by-pass flow, repeating Steps 1 through 7 for each flow.

"Rev. 4/85"

ANALYZER LINEARITY CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.330, 331, 332-79)

DATE: 9-29-90 ANALYSIS BENCH: 4 OPERATOR: D.A.P. BAROMETER: 29.44 IN.HG.

ANALYZER: HC ANALYZER SERIAL NO.: 4812908 WET BULB: 63 °F DRY BULB: 75 °F.

PRESSURES: FID FUEL: .75 KG/CM^2 FID AIR: .75 KG/CM^2 FID REG. AIR: ____ KG/CM^2

REGULATOR AIR: 6 PSI FID BYPASS: 6 BENCH MANIFOLD: 6

Analyzer Range: 1000		Analyzer Range: 3000		Analyzer Range:		Analyzer Range:	
Bottle No.: N-340880		Bottle No.: 72131		Bottle No.:		Bottle No.:	
Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)
909	90.9	2661	88.7				
727.2	72.8	2128.8	71.2				
545.4	54.8	1596.6	53.4				
363.6	36.4	1064.4	35.6				
181.8	18.2	532.2	17.8				
0	0	0	.1				

1. Zero and span analyzer via calibration port.
2. Introduce N_2 and span gas to divider inlets at specified pressures.
3. Introduce divider output to analyzer via calibration port, verifying previously set span point (divider set at 100%). If span readings do not agree, adjust divider bypass flow.
4. Record analyzer mv output above, save chart paper for files.
5. Repeat Steps 1-4 for each range used.

"Rev. 7/85"

ANALYZER PRECISION CHECK

(F.R. VOL. 44, NO. 174, 3/29/79, 86.315.79)

DATE: 9-29-90 ANALYSIS BENCH: 4 OPERATOR: D.A.P.

ANALYZER: HC ANALYZER SERIAL NO.: 4812908

Analyzer Range:	1000 PPMC	Analyzer Range:	3000	Analyzer Range:		Analyzer Range:	
Span Gas Conc.:	909 PPMC	Span Gas Conc.:	2661 PPMC	Span Gas Conc.:		Span Gas Conc.:	
Span Point:	90.9 mv	Span Point:	88.7 mv	Span Point:	mv	Span Point:	mv
Bottle No.:	N-340880	Bottle No.:	72131	Bottle No.:		Bottle No.:	
Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)
1	90.9	1	88.7	1		1	
2	90.8	2	88.7	2		2	
3	90.9	3	88.8	3		3	
4	90.8	4	88.7	4		4	
5	90.9	5	88.8	5		5	
6	90.8	6	88.7	6		6	
7	90.8	7	88.7	7		7	
8	90.9	8	88.8	8		8	
9	90.9	9	88.8	9		9	
10	90.9	10	88.7	10		10	

1. Zero and span analyzer 10 times. (Do not readjust zero and span after intial adjustments.)
2. Record span response (mv), also retain chart paper for files.
3. Repeat steps 1 and 2 for each range used.
4. Input data into computer program to determine precision of analyzer.

"Rev. 4/85"

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:9/29/90

BENCH: 4
OPERATOR'S INITIALS: DAP
BAROMETER: 29.44 IN HG
DRY BULB: 75 F
WET BULB: 63 F

ANALYZER: FID
RANGE: 1000 PPM
CONCENTRATION & CYLINDER NUMBER: 909/N-340880

PRECISION CHECK ANALYZER RESPONSES: 90.9 90.8 90.9
90.8 90.9 90.8 90.8 90.9 90.9 90.9

ANALYZER RANGE PRECISION IS : +.13% OF FULL SCALE

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	PERCENT LINEARITY
90.9	909.00	907.91	.11
72.8	727.20	727.13	.01
54.8	545.40	547.34	-.19
36.4	363.60	363.56	.00
18.2	181.80	181.78	.00
0.0	0.00	0.00	0.00

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:9/29/90

BENCH: 4
OPERATOR'S INITIALS: DAP
BAROMETER: 29.44 IN HG
DRY BULB: 75 F
WET BULB: 63 F

ANALYZER: FID
RANGE: 3000 PPM
CONCENTRATION & CYLINDER NUMBER: 2661/72131

PRECISION CHECK ANALYZER RESPONSES: 88.7 88.7 88.8
88.7 88.8 88.7 88.7 88.8 88.8 88.7

ANALYZER RANGE PRECISION IS : +.13% OF FULL SCALE

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	PERCENT LINEARITY
88.7	2661.00	2656.09	.16
71.2	2128.80	2132.06	-.11
53.4	1596.60	1599.04	-.08
35.6	1064.40	1066.03	-.05
17.8	532.20	533.01	-.03
.1	0.00	2.99	-.10

ANALYZER NOISE CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315.79)

Date: 9-25-90

Analysis Bench: 4

Operator: D.A.P.

Analyzer: CO_2

Analyzer Serial No. 48498112

Analyzer Range: 16%

Span Gas Conc.: 15.2%

Bottle No.: 42 1806

Analyzer PTP Response with Zero Gas.
Chart Deflection: 0

Analyzer PTP Response with Span Gas.
Chart Deflection: 97.0

Noise: 0 % FSCD

Analyzer Range: ______

Span Gas Conc.: ______

Bottle No.: ______

Analyzer PTP Response with Zero Gas.
Chart Deflection: ______

Analyzer PTP Response with Span Gas.
Chart Deflection: ______

Noise: ______ % FSCD

Analyzer Range: ______

Span Gas Conc.: ______

Bottle No.: ______

Analyzer PTP Response with Zero Gas.
Chart Deflection: ______

Analyzer PTP Response with Span Gas.
Chart Deflection: ______

Noise: ______ % FSCD

Analyzer Range: ______

Span Gas Conc.: ______

Bottle No.: ______

Analyzer PTP Response with Zero Gas.
Chart Deflection: ______

Analyzer PTP Response with Span Gas.
Chart Deflection: ______

Noise: ______ % FSCD

1. Zero and span analyzer on all analyzer ranges.
2. Note analyzer peak-to-peak (PTP) response to zero and span gas over a ten second interval.
3. Noise shall not exceed 2% of full scale chart deflection (FSCD) on all ranges used.

"Rev. 4/85"

ANALYZER RESPONSE TIME CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315-79)

Date: 9-25-90 Analysis Bench: 4

Operator: D.A.P.

Analyzer: CO_2 Analyzer Serial No.: 48498112

Analyzer Range: 16%	Analyzer Range: ________
Step Gas Conc.: 15.2%	Step Gas Conc.: ________
Chart Deflection for 95% of Step Gas: 93.2	Chart Deflection for 95% of Step Gas: ________
Time to Respond to 95% of Step Gas: 2.6 sec.	Time to Respond to 95% of Step Gas: ________ sec.
Analyzer Gas Flow: 3 scfh	Analyzer Gas Flow: ________ scfh
Analyzer Range: ________	Analyzer Range: ________
Step Gas Conc.: ________	Step Gas Conc.: ________
Chart Deflection for 95% of Step Gas: ________	Chart Deflection for 95% of Step Gas: ________
Time to Respond to 95% of Step Gas: ________ sec.	Time to Respond to 95% of Step Gas: ________ sec.
Analyzer Gas Flow: ________ scfh	Analyzer Gas Flow: ________ scfh

1. Set chart speed at 60 cm/min. to record the following data:
2. Zero/span analyzer on respective range.
3. Introduce to inlet, step change gas of at least 60% of full scale chart deflection. (Step gas in W.E.D. lab is equivalent to span gas.)
4. Begin timing moment analyzer begins to respond to gas and stop timing when analyzer has responded to 95% of step gas concentration. (Chart recorder may be used as a timer, i.e. each cm division = 1 sec.)
5. Analyzer response time may not exceed 6.0 seconds for any analyzer range used.
6. Condensate bath may be by-passed when performing NO analyzer response time.

"Rev. 4/85"

ANALYZER ZERO AND SPAN DRIFT

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315-79)

Date: 10-1-90 Analysis Bench: 4

Operator: D.A.P.

Analyzer: CO_2

Analyzer Serial No.: 48498112

Analyzer Range: 16%

Zero Gas: X N_2 ___ Zero Air

Span Gas Bottle No.: 421806

Zero Gas Response: 0 (% FSCD/30 SEC.)

Span Gas Response: 0 (% FSCD/30 SEC.)

Zero Drift: -.1 % FSCD/HR.

Span Drift: +.1 % FSCD/HR.

1. Zero and span analyzer on lowest range used.
2. Set chart speed at 10 cm/~~min.~~ hr.
3. Offset zero reading on chart, introduce zero gas over a 1 hour time period.
4. Determine average zero gas response over a 30 second time interval. Evaluate average zero gas response for 1 hour time period to determine drift.
5. Zero gas drift must be not more than 2% of full scale chart deflection (FSCD) over a 1 hour time period.
6. Rezero analyzer, check zero and span points.
7. Introduce span gas over a 1 hour time period.
8. Continue with steps 3 and 4 for span gas.
9. Retain chart paper to file with this page.

"Rev. 4/85"

NDIR WATER REJECTION RATIO CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.316, 86.318, 86.331-79

Date: 9-25-90 Analysis Bench: 4

Operator: V.A.P. Barometer: 28.80

Analyzer: CO_2

Analyzer Range: 16%

Analyzer Serial No.: 48498112

1. Zero/span on lowest range used.
2. Bubble zero gas through distilled water and introduce water/gas mixture directly to analyzer inlet.
3. Record water/gas mixture temperature: 78 °F.
4. Record analyzer operating pressure: 3 In. H_2O, .10839 PSI (gage).
5. Record analyzer response to water/gas mixture: 3.6 ppm.
6. Determine the water concentration using:

$$\text{W.C.} = \frac{\text{Saturation Vapor Pressure (SVP, psi)}}{\text{Absolute Gage Pressure (AGP, psi)}} \times 10^6$$

SVP is found from saturation vapor pressure table @ water/gas mixture temperature: .47461 psi.

AGP is the gage pressure (psi) + the barometer (psi): 14.25495 psi.

(0.03613 psi/in H_2O, 0.4912 psi/in. Hg)

W.C. 13294.39949.

7. Determine water rejection ratio using:

$$\text{WRR} = \frac{\text{Water Concentration}}{\text{Anal. Response in ppm}} = 9248.444303$$

8. Minimum WRR CO Analyzer - 1000:1.
9. Minimum WRR CO_2 Analyzer - 100:1.
10. Minimum WRR NO Analyzer - 5000:1.

"Rev. 7/85"

NDIR ANALYZER CALIBRATION

(F.R. VOL. 42, NO. 174, 10/8/77, 86.330-79)

DATE: 9-26-90 ANALYSIS BENCH: 4 OPERATOR: D.A.P. BAROMETER: 29.02 IN.HG

ANALYZER: CO_2 ANALYZER SERIAL NO.: 4849 8112 WET BULB: 62 °F DRY BULB: 75 °F

Bottle No.: 421806		Bottle No.:		Bottle No.:		Bottle No.:	
Analyzer Range: 16%		Analyzer Range:		Analyzer Range:		Analyzer Range:	
Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)
15.2	97.0						
12.16	81.3						
9.12	63.9						
6.08	44.7						
3.04	23.4						
0	0						

1. Zero and span analyzer via calibration port.
2. Introduce N_2 and span gas to divider inlets at specified pressures.
3. Introduce divider output to analyzer via calibration port, verifying previously set span point (divider set at 100%). If span readings do not agree, adjust divider bypass flow.
4. Record analyzer mv output* above, save chart paper for files.
5. Repeat Steps 1-4 for each range used.

* Correct CO_2 values per gas divider CO_2 correction chart.

"Rev. 7/85"

EMISSION INSTRUMENT CALIBRATION CHART

ANALYZER: NDIR CO2 16%
DATE OF CALIBRATION REGRESSION: 11/17/89
DATE OF LATEST CALIBRATION CHECK: 9/26/90

ANALYZER RESPONSE VERSUS CONCENTRATION

.5	.06	25.5	3.33	50.5	6.97	75.5	11.12
1.0	.13	26.0	3.40	51.0	7.05	76.0	11.21
1.5	.19	26.5	3.47	51.5	7.13	76.5	11.30
2.0	.25	27.0	3.54	52.0	7.21	77.0	11.39
2.5	.31	27.5	3.61	52.5	7.28	77.5	11.48
3.0	.38	28.0	3.68	53.0	7.36	78.0	11.57
3.5	.44	28.5	3.75	53.5	7.44	78.5	11.66
4.0	.50	29.0	3.82	54.0	7.52	79.0	11.75
4.5	.57	29.5	3.89	54.5	7.60	79.5	11.84
5.0	.63	30.0	3.96	55.0	7.68	80.0	11.93
5.5	.69	30.5	4.03	55.5	7.76	80.5	12.02
6.0	.76	31.0	4.10	56.0	7.84	81.0	12.11
6.5	.82	31.5	4.17	56.5	7.92	81.5	12.21
7.0	.89	32.0	4.24	57.0	8.00	82.0	12.30
7.5	.95	32.5	4.31	57.5	8.08	82.5	12.39
8.0	1.01	33.0	4.38	58.0	8.16	83.0	12.48
8.5	1.08	33.5	4.45	58.5	8.24	83.5	12.58
9.0	1.14	34.0	4.52	59.0	8.32	84.0	12.67
9.5	1.21	34.5	4.59	59.5	8.40	84.5	12.76
10.0	1.27	35.0	4.67	60.0	8.48	85.0	12.86
10.5	1.34	35.5	4.74	60.5	8.56	85.5	12.95
11.0	1.40	36.0	4.81	61.0	8.64	86.0	13.05
11.5	1.47	36.5	4.88	61.5	8.73	86.5	13.14
12.0	1.53	37.0	4.95	62.0	8.81	87.0	13.24
12.5	1.60	37.5	5.03	62.5	8.89	87.5	13.33
13.0	1.66	38.0	5.10	63.0	8.97	88.0	13.43
13.5	1.73	38.5	5.17	63.5	9.06	88.5	13.52
14.0	1.79	39.0	5.24	64.0	9.14	89.0	13.62
14.5	1.86	39.5	5.32	64.5	9.22	89.5	13.72
15.0	1.92	40.0	5.39	65.0	9.31	90.0	13.81
15.5	1.99	40.5	5.46	65.5	9.39	90.5	13.91
16.0	2.06	41.0	5.54	66.0	9.48	91.0	14.01
16.5	2.12	41.5	5.61	66.5	9.56	91.5	14.11
17.0	2.19	42.0	5.69	67.0	9.64	92.0	14.20
17.5	2.25	42.5	5.76	67.5	9.73	92.5	14.30
18.0	2.32	43.0	5.83	68.0	9.81	93.0	14.40
18.5	2.39	43.5	5.91	68.5	9.90	93.5	14.50
19.0	2.45	44.0	5.98	69.0	9.98	94.0	14.60
19.5	2.52	44.5	6.06	69.5	10.07	94.5	14.70
20.0	2.59	45.0	6.13	70.0	10.16	95.0	14.80
20.5	2.66	45.5	6.21	70.5	10.24	95.5	14.90
21.0	2.72	46.0	6.28	71.0	10.33	96.0	15.00
21.5	2.79	46.5	6.36	71.5	10.42	96.5	15.10
22.0	2.86	47.0	6.44	72.0	10.50	97.0	15.20
22.5	2.93	47.5	6.51	72.5	10.59	97.5	15.30
23.0	2.99	48.0	6.59	73.0	10.68	98.0	15.40
23.5	3.06	48.5	6.67	73.5	10.77	98.5	15.51
24.0	3.13	49.0	6.74	74.0	10.85	99.0	15.61
24.5	3.20	49.5	6.82	74.5	10.94	99.5	15.71
25.0	3.27	50.0	6.90	75.0	11.03	100.0	15.81

% NDIR CO2 = +3.40841E-004 +(+1.25141E-001)*(AR)+(+1.83049E-004)*(AR^2)+
(+1.42858E-006)*(AR^3)+(+3.94499E-010)*(AR^4)

ANALYZER PRECISION CHECK

(F.R. VOL. 44, NO. 174, 3/29/79, 86.315.79)

DATE: 9-25-90 ANALYSIS BENCH: 4 OPERATOR: D.A.P.

ANALYZER: CO2 ANALYZER SERIAL NO.: 48498112

Analyzer Range: 16%		Analyzer Range:		Analyzer Range:		Analyzer Range:	
Span Gas Conc.: 15.2%		Span Gas Conc.:		Span Gas Conc.:		Span Gas Conc.:	
Span Point: 97.0 mv		Span Point: mv		Span Point: mv		Span Point: mv	
Bottle No.: 421806		Bottle No.:		Bottle No.:		Bottle No.:	
Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)
1	97.0	1		1		1	
2	97.0	2		2		2	
3	97.0	3		3		3	
4	97.0	4		4		4	
5	97.0	5		5		5	
6	97.0	6		6		6	
7	97.0	7		7		7	
8	97.0	8		8		8	
9	97.0	9		9		9	
10	97.0	10		10		10	

1. Zero and span analyzer 10 times. (Do not readjust zero and span after intial adjustments.)
2. Record span response (mv), also retain chart paper for files.
3. Repeat steps 1 and 2 for each range used.
4. Input data into computer program to determine precision of analyzer.

"Rev. 4/85"

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:9/26/90

BENCH: 4
OPERATOR'S INITIALS: DAP
BAROMETER: 29.02 IN HG
DRY BULB: 75 F
WET BULB: 62 F

ANALYZER: NDIR CO2
RANGE: 16%
CONCENTRATION & CYLINDER NUMBER: 15.2%/421806

ANALYZER PERFORMANCE BASED UPON OLD REGRESSION DATA OF 11/17/89

OLD REGRESSION COEFFICIENTS

+3.40841E-004 +1.25141E-001 +1.83049E-004 +1.42858E-006 +3.94499E-010

ANALYZER ERROR TABLE
OLD REGRESSION DATA OF: 11/17/89

ANALYZER RESPONSE	ACTUAL %	PREDICTED %	% ERROR OF POINT	% ERROR OF FULL SCALE
97.0	15.20	15.20	.00	.00
81.3	12.16	12.17	.07	.06
63.9	9.12	9.12	.04	.02
44.7	6.08	6.09	.15	.06
23.4	3.04	3.05	.24	.05
0.0	0.00	.00	0.00	.00

PRECISION CHECK ANALYZER RESPONSES: 97.0 97.0 97.0
97.0 97.0 97.0 97.0 97.0 97.0 97.0

ANALYZER RANGE PRECISION IS : +0.00% OF FULL SCALE

ANALYZER NOISE CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315.79)

Date: 9-28-90 Analysis Bench: 4

Operator: D.A.P.

Analyzer: O2

Analyzer Serial No. 38817

Analyzer Range: 2%
Span Gas Conc.: 1.9%
Bottle No.: 487291
Analyzer PTP Response with Zero Gas. Chart Deflection: .8
Analyzer PTP Response with Span Gas. Chart Deflection: 95.0
Noise: 0 % FSCD

Analyzer Range: 5%
Span Gas Conc.: 4.75%
Bottle No.: 634241
Analyzer PTP Response with Zero Gas. Chart Deflection: .4
Analyzer PTP Response with Span Gas. Chart Deflection: 95.0
Noise: 0 % FSCD

Analyzer Range: 25%
Span Gas Conc.: 24.97%
Bottle No.: 5398
Analyzer PTP Response with Zero Gas. Chart Deflection: .3 to .4
Analyzer PTP Response with Span Gas. Chart Deflection: 99.9
Noise: .1 % FSCD

Analyzer Range:
Span Gas Conc.:
Bottle No.:
Analyzer PTP Response with Zero Gas. Chart Deflection:
Analyzer PTP Response with Span Gas. Chart Deflection:
Noise: % FSCD

1. Zero and span analyzer on all analyzer ranges.
2. Note analyzer peak-to-peak (PTP) response to zero and span gas over a ten second interval.
3. Noise shall not exceed 2% of full scale chart deflection (FSCD) on all ranges used.

"Rev. 4/85"

ANALYZER RESPONSE TIME CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315-79)

Date: 9-28-90 Analysis Bench: 4

Operator: D.A.P.

Analyzer: O2 Analyzer Serial No.: 38817

Analyzer Range: 2%	Analyzer Range: 5%
Step Gas Conc.: 1.9%	Step Gas Conc.: 4.75%
Chart Deflection for 95% of Step Gas: 90.3	Chart Deflection for 95% of Step Gas: 90.3
Time to Respond to 95% of Step Gas: 3.4 sec.	Time to Respond to 95% of Step Gas: 9.0 sec.
Analyzer Gas Flow: 4 scfh	Analyzer Gas Flow: 4 scfh
Analyzer Range: 25%	Analyzer Range:
Step Gas Conc.: 24.97	Step Gas Conc.:
Chart Deflection for 95% of Step Gas: 94.9	Chart Deflection for 95% of Step Gas:
Time to Respond to 95% of Step Gas: 9.2 sec.	Time to Respond to 95% of Step Gas: sec.
Analyzer Gas Flow: 4 scfh	Analyzer Gas Flow: scfh

1. Set chart speed at 60 cm/min. to record the following data:
2. Zero/span analyzer on respective range.
3. Introduce to inlet, step change gas of at least 60% of full scale chart deflection. (Step gas in W.E.D. lab is equivalent to span gas.)
4. Begin timing moment analyzer begins to respond to gas and stop timing when analyzer has responded to 95% of step gas concentration. (Chart recorder may be used as a timer, i.e. each cm division = 1 sec.)
5. Analyzer response time may not exceed 6.0 seconds for any analyzer range used.
6. Condensate bath may be by-passed when performing NO analyzer response time.

"Rev. 4/85"

ANALYZER ZERO AND SPAN DRIFT

(F.R. VOL. 42, NO. 174, 10/8/77, 86.315-79)

Date: 10-1-90 Analysis Bench: 4

Operator: D.A.P.

Analyzer: O_2

Analyzer Serial No.: 38817

Analyzer Range: 25%

Zero Gas: X N_2 ___ Zero Air

Span Gas Bottle No.: 5398

Zero Gas Response: 0 (% FSCD/30 SEC.)

Span Gas Response: .004 (% FSCD/30 SEC.)

Zero Drift: 0 % FSCD/HR.

Span Drift: .501 % FSCD/HR.

1. Zero and span analyzer on lowest range used.
2. Set chart speed at 10 cm/~~min.~~ hr.
3. Offset zero reading on chart, introduce zero gas over a 1 hour time period.
4. Determine average zero gas response over a 30 second time interval. Evaluate average zero gas response for 1 hour time period to determine drift.
5. Zero gas drift must be not more than 2% of full scale chart deflection (FSCD) over a 1 hour time period.
6. Rezero analyzer, check zero and span points.
7. Introduce span gas over a 1 hour time period.
8. Continue with steps 3 and 4 for span gas.
9. Retain chart paper to file with this page.

"Rev. 4/85"

ANALYZER LINEARITY CHECK

(F.R. VOL. 42, NO. 174, 10/8/77, 86.330, 331, 332-79)

ATE: 9-28-90 ANALYSIS BENCH: 4 OPERATOR: D.A.P. BAROMETER: 29.25 IN.HG.

NALYZER: O_2 ANALYZER SERIAL NO.: 38817 WET BULB: 62 °F DRY BULB: 74 °F.

PRESSURES: FID FUEL: ______ KG/CM^2 FID AIR: ______ KG/CM^2 FID REG. AIR: ______ KG/CM^2

REGULATOR AIR: ______ PSI FID BYPASS: ______ BENCH MANIFOLD: ______

Analyzer Range: 2%		Analyzer Range: 5%		Analyzer Range: 25%		Analyzer Range:	
Bottle No.: 487291		Bottle No.: 634241		Bottle No.: 5398		Bottle No.:	
Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)
1.9	95.0	4.75	95.0	24.97	99.9		
1.52	76.8	3.80	76.4	19.976	80.0		
1.14	58.0	2.85	57.6	14.982	59.9		
.76	39.0	1.90	38.8	9.988	39.9		
.38	20.0	.95	19.6	4.994	19.9		
0	.9	0	0	0	.3		

. Zero and span analyzer via calibration port.
. Introduce N_2 and span gas to divider inlets at specified pressures.
. Introduce divider output to analyzer via calibration port, verifying previously set span point (divider set at 100%).
  If span readings do not agree, adjust divider bypass flow.
. Record analyzer mv output above, save chart paper for files.
. Repeat Steps 1-4 for each range used.

ANALYZER PRECISION CHECK

...peat steps 1-4 for each ... above, save chart paper for files. range used. ... set span point (divider set at 100%).

ANALYZER PRECISION CHECK

(F.R. VOL. 44, NO. 174, 3/29/79, 86.315.79)

DATE: 9-28-90 ANALYSIS BENCH: 4 OPERATOR: D.A.P.

ANALYZER: O_2 ANALYZER SERIAL NO.: 38817

Analyzer Range:	2%	Analyzer Range:	5%	Analyzer Range:	25%	Analyzer Range:	
Span Gas Conc.:	1.9%	Span Gas Conc.:	4.75%	Span Gas Conc.:	24.97	Span Gas Conc.:	
Span Point:	95.0 mv	Span Point:	95.0 mv	Span Point:	99.9 mv	Span Point:	mv
Bottle No.:	487291	Bottle No.:	634241	Bottle No.:	5398	Bottle No.:	
Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)
1	95.0	1	95.0	1	99.9	1	
2	95.0	2	95.0	2	99.8	2	
3	95.1	3	95.0	3	99.8	3	
4	95.1	4	95.0	4	99.7	4	
5	95.0	5	95.0	5	99.7	5	
6	95.1	6	95.0	6	99.6	6	
7	95.1	7	95.1	7	99.7	7	
8	95.2	8	95.1	8	99.7	8	
9	95.2	9	95.2	9	99.7	9	
10	95.2	10	95.2	10	99.7	10	

1. Zero and span analyzer 10 times. (Do not readjust zero and span after intial adjustments.)
2. Record span response (mv), also retain chart paper for files.
3. Repeat steps 1 and 2 for each range used.
4. Input data into computer program to determine precision of analyzer.

"Rev. 4/85"

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:9/28/90

BENCH: 4
OPERATOR'S INITIALS: DAP
BAROMETER: 29.25 IN HG
DRY BULB: 74 F
WET BULB: 62 F

ANALYZER: OXYGEN
RANGE: 2%
CONCENTRATION & CYLINDER NUMBER: 1.9%/487291

PRECISION CHECK ANALYZER RESPONSES: 95.0 95.0 95.1
95.1 95.0 95.1 95.1 95.2 95.2 95.2

ANALYZER RANGE PRECISION IS : +.20% OF FULL SCALE

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL %	PREDICTED %	PERCENT LINEARITY
95.0	1.90	1.88	.85
76.8	1.52	1.52	-.12
58.0	1.14	1.15	-.49
39.0	.76	.77	-.66
20.0	.38	.40	-.83
.9	0.00	.02	-.90

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:9/28/90

BENCH: 4
OPERATOR'S INITIALS: DAP
BAROMETER: 29.25 IN HG
DRY BULB: 74 F
WET BULB: 62 F

ANALYZER: OXYGEN
RANGE: 5%
CONCENTRATION & CYLINDER NUMBER: 4.75%/634241

PRECISION CHECK ANALYZER RESPONSES: 95.0 95.0 95.0
95.0 95.0 95.0 95.1 95.1 95.2 95.2

ANALYZER RANGE PRECISION IS : +.21% OF FULL SCALE

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL %	PREDICTED %	PERCENT LINEARITY
95.0	4.75	4.72	.51
76.4	3.80	3.80	.01
57.6	2.85	2.86	-.29
38.8	1.90	1.93	-.59
19.6	.95	.97	-.50
0.0	0.00	0.00	0.00

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:9/28/90

BENCH: 4
OPERATOR'S INITIALS: DAP
BAROMETER: 29.25 IN HG
DRY BULB: 74 F
WET BULB: 62 F

ANALYZER: OXYGEN
RANGE: 25%
CONCENTRATION & CYLINDER NUMBER: 24.97%/5398

PRECISION CHECK ANALYZER RESPONSES: 99.9 99.8 99.8
99.7 99.7 99.6 99.7 99.7 99.7 99.7

ANALYZER RANGE PRECISION IS : +.21% OF FULL SCALE

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL %	PREDICTED %	PERCENT LINEARITY
99.9	24.97	24.97	.00
80.0	19.98	20.00	-.08
59.9	14.98	14.97	.04
39.9	9.99	9.97	.06
19.9	4.99	4.97	.08
.3	0.00	.07	-.30

ROOTS® PROVER DATA SHEET

ROOTS / DRESSER

DMF-184

LOCATION CELL 1D (LAB)
FIELD METER SIZE 11M
FIELD METER SERIAL 8512972

CALIBRATION FOR RHODE
ISLAND, LANDFILL SITE

ROOTS PROVER SERIAL 16M
OPERATOR JSA
DATE 9-25-90

RUN NUMBER	TIME OF DAY	MASTER METER PRESET	INDICATED FLOW RATE CFH	AVERAGE FLOW RATE CFH	% PRESS. CORR.	% TEMP. CORR.	% PROOF. UNCORR.	% PROOF. CORR.	% ACCURACY CORR.	COMMENTS
		22	1000	995	-0.0	-0.1	99.8	99.9	100.1	ROOTS MTR CALIBRATED
		"	"	994	-0.0	0.0	99.8	99.8	100.2	WHILE RUNNING IN THE
		"	"	996	-0.0	-0.1	99.9	99.8	100.2	OPPOSITE DIRECTION
		19	2500	2552	-0.1	-0.1	99.8	99.6	100.4	
		"	"	2543	-0.1	-0.1	99.7	99.5	100.5	
		"	"	2552	-0.1	-0.1	99.8	99.6	100.4	
		18	5000	4995	-0.3	-0.1	99.9	99.5	100.5	
		"	"	4975	-0.3	-0.1	100.0	99.6	100.4	
		"	"	5000	-0.3	-0.1	100.0	99.6	100.4	
		17	7500	7578	-0.6	-0.1	100.8	100.1	99.9	
		"	"	7578	-0.6	-0.1	100.8	100.1	99.9	
		"	"	7586	-0.6	-0.1	100.9	100.2	99.8	
		17	10,000	9941	-1.0	-0.1	101.4	100.3	99.7	
		"	"	10,039	-1.0	-0.1	101.4	100.3	99.7	
		"	"	10,039	-1.0	-0.1	101.4	100.3	99.7	

Page 1 IGT_ANALYTICAL REPORT Work Order # 90-11-026
Received: 11/12/90 11/16/90 09:27:02 Work Not Complete

REPORT TO Waukesha Engine Division
Dresser Industries, Inc.
1000 West Saint Paul Avenue
Waukesha, WI, 53188-4899
ATTEN Mr. Bob Stachowicz Exp. Lab.

PREPARED BY Chemical Research Services
Institute of Gas Technology
3424 S. State Street
Chicago, IL 60616-3896
ATTEN S. S. Chao ;Business Phone
PHONE 312-567-5739 ; 312-567-3650

CERTIFIED BY

CONTACT KONCAR 3815

CLIENT WAUKESHA_ENG SAMPLES 4
COMPANY Waukesha Engine Division
FACILITY Dresser Industries, Inc.
Waukesha, WI, 53188-4999

(For additional information, phone the CONTACT above.)
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WORK ID Landfill gases 10/9 - 11/5/90
TAKEN
TRANS by United Parcel Service
TYPE Landfill Gas Samples
P.O. # 95582-J55 (VR No. 69968)
INVOICE under separate cover

FAX results to Bob Stachowicz at 414-549-2705

SAMPLE IDENTIFICATION
01 Sample #1 56psi, 90F
02 Sample #2 56psi, 93F
03 Sample #3 57psi, 90F
04 Sample #4 55psi, 70F

TEST CODES and NAMES used on this workorder
GAS2 GAS ANALYSIS

 IGT_ANALYTICAL REPORT Work Order # 90-11-026
Received: 11/12/90 Results by Sample

SAMPLE ID Sample #1 56psi, 90F FRACTION 01A TEST CODE GAS2 NAME GAS ANALYSIS
Date & Time Collected 10/09/90 Category

COMPONENT	MOLE%	D. L.	WEIGHT%
Helium	ND		
Hydrogen	0.18	0.01	0.01
Oxygen & Argon	BDL	0.01	
Nitrogen	0.33	0.01	0.33
Carbon Dioxide	43.8	0.01	68.1
Carbon Monoxide	BDL	0.01	
Methane	55.6	0.01	31.5
Ethane	BDL	0.01	
Ethene	BDL	0.01	
Ethyne (Acetylene)	BDL	0.01	
Propane	BDL	0.01	
Propene	BDL	0.01	
Propyne	BDL	0.01	
Propadiene	BDL	0.01	
i-Butane	BDL	0.01	
n-Butane	BDL	0.01	
1-Butene	BDL	0.01	
iso-Butene	BDL	0.01	
trans-2-Butene	BDL	0.01	
cis-2-Butene	BDL	0.01	
Butadiene	BDL	0.01	
neo-Pentane	BDL	0.01	
i-Pentane	BDL	0.01	
n-Pentane	BDL	0.01	
Pentenes	BDL	0.01	
Pentadienes	BDL	0.01	
C-6 & Heavier	0.02	0.01	0.07
Hydrogen sulfide	ND		
Total	100.0		100.0

CALCULATED PROPERTIES at 60 F / 14.73 psia (ASTM 3588)

Specific Gravity : 0.980
Compressibility [z] : 0.9973

Gross Heating Value (BTU/SCF)		Net Heating Value (BTU/SCF)	
-- dry -- :	566	-- dry -- :	510
-- sat.-- :	557	-- sat.-- :	501

Analyst : Robert Sigwood

NOTES: BDL= below detection limit (D.L.): ND= Component not determined

Received: 11/12/90 Results by Sample

SAMPLE ID Sample #2 58psi, 93F FRACTION 02A TEST CODE GAS2 NAME GAS ANALYSIS

Date & Time Collected 10/11/90 Category

COMPONENT	MOLE%	D. L.	WEIGHT%
Helium	ND		
Hydrogen	0.17	0.01	0.01
Oxygen & Argon	BDL	0.01	
Nitrogen	0.10	0.01	0.10
Carbon Dioxide	43.8	0.01	68.1
Carbon Monoxide	BDL	0.01	
Methane	55.9	0.01	31.7
Ethane	BDL	0.01	
Ethene	BDL	0.01	
Ethyne (Acetylene)	BDL	0.01	
Propane	BDL	0.01	
Propene	BDL	0.01	
Propyne	BDL	0.01	
Propadiene	BDL	0.01	
i-Butane	BDL	0.01	
n-Butane	BDL	0.01	
1-Butene	BDL	0.01	
iso-Butene	BDL	0.01	
trans-2-Butene	BDL	0.01	
cis-2-Butene	BDL	0.01	
Butadiene	BDL	0.01	
neo-Pentane	BDL	0.01	
i-Pentane	BDL	0.01	
n-Pentane	BDL	0.01	
Pentenes	BDL	0.01	
Pentadienes	BDL	0.01	
C-6 & Heavier	0.03	0.01	0.09
Hydrogen sulfide	ND		
Total	100.0		100.0

CALCULATED PROPERTIES at 60 F / 14.73 psia (ASTM 3588)

Specific Gravity : 0.980

Compressibility [z] : 0.9972

Gross Heating Value (BTU/SCF)		Net Heating Value (BTU/SCF)	
-- dry -- :	569	-- dry -- :	512
-- sat. -- :	559	-- sat. -- :	503

Analyst : Robert Bigwood

NOTES: BDL= below detection limit (D.L.); ND= Component not determined

Received: 11/12/90 Results by Sample

MPLE ID Sample #3 87psi, 90F FRACTION 03A TEST CODE GAS2 NAME GAS ANALYSIS
Date & Time Collected 10/15/90 Category

COMPONENT	MOLE%	D. L.	WEIGHT%
Helium	ND		
Hydrogen	0.10	0.01	0.01
Oxygen & Argon	0.93	0.01	1.06
Nitrogen	5.52	0.01	5.47
Carbon Dioxide	40.8	0.01	63.6
Carbon Monoxide	BDL	0.01	
Methane	52.6	0.01	29.9
Ethane	BDL	0.01	
Ethene	BDL	0.01	
Ethyne (Acetylene)	BDL	0.01	
Propane	BDL	0.01	
Propene	BDL	0.01	
Propyne	BDL	0.01	
Propadiene	BDL	0.01	
i-Butane	BDL	0.01	
n-Butane	BDL	0.01	
1-Butene	BDL	0.01	
iso-Butene	BDL	0.01	
trans-2-Butene	BDL	0.01	
cis-2-Butene	BDL	0.01	
Butadiene	BDL	0.01	
neo-Pentane	BDL	0.01	
i-Pentane	BDL	0.01	
n-Pentane	BDL	0.01	
Pentenes	BDL	0.01	
Pentadienes	BDL	0.01	
C-6 & Heavier	BDL	0.01	
Hydrogen sulfide	ND		
Total	100.0		100.0

CALCULATED PROPERTIES at 60 F / 14.73 psia (ASTM 3588)

Specific Gravity : 0.977
Compressibility [z] : 0.9975

Gross Heating Value (BTU/SCF)		Net Heating Value (BTU/SCF)	
-- dry -- :	534	-- dry -- :	481
-- sat.-- :	525	-- sat.-- :	473

Analyst : Robert Bigwood

NOTES: BDL= below detection limit (D.L.); ND= Component not determined

IGT_ANALYTICAL REPORT

Work Order # 90-11-[illegible]

Received: 11/12/90

Results by Sample

SAMPLE ID Sample #4 55psi, 70F FRACTION 04A TEST CODE GAS2 NAME GAS ANALYSIS

Date & Time Collected 11/06/90 Category

COMPONENT	MOLE%	D. L.	WEIGHT%
Helium	ND		
Hydrogen	0.18	0.01	0.01
Oxygen & Argon	0.07	0.01	0.07
Nitrogen	1.69	0.01	1.65
Carbon Dioxide	44.7	0.01	68.5
Carbon Monoxide	BDL	0.01	
Methane	53.4	0.01	29.8
Ethane	BDL	0.01	
Ethene	BDL	0.01	
Ethyne (Acetylene)	BDL	0.01	
Propane	BDL	0.01	
Propene	BDL	0.01	
Propyne	BDL	0.01	
Propadiene	BDL	0.01	
i-Butane	BDL	0.01	
n-Butane	BDL	0.01	
1-Butene	BDL	0.01	
iso-Butene	BDL	0.01	
trans-2-Butene	BDL	0.01	
cis-2-Butene	BDL	0.01	
Butadiene	BDL	0.01	
neo-Pentane	BDL	0.01	
i-Pentane	BDL	0.01	
n-Pentane	BDL	0.01	
Pentenes	BDL	0.01	
Pentadienes	BDL	0.01	
C-6 & Heavier	BDL	0.01	
Hydrogen sulfide	ND		
Total	100.0		100.0

CALCULATED PROPERTIES at 60 F / 14.73 psia (ASTM 3588)

Specific Gravity : 0.994
Compressibility [z] : 0.9973

Gross Heating Value (BTU/SCF)		Net Heating Value (BTU/SCF)	
-- dry -- :	542	-- dry -- :	488
-- sat.-- :	533	-- sat.-- :	480

Analyst : Robert Bigwood

NOTES: BDL= below detection limit (D.L.); ND= Component not determined

10-9-90

***** GAS FUEL ANALYSIS *****

FUEL COMPOSITION IN MOLE FRACTIONS:

CH4:	0.5580			N2:	0.0033
C2H6:	0.0000	C2H4:	0.0000	O2:	0.0000
C3H8:	0.0000	C3H6:	0.0000	AIR:	0.0000
IC4H10:	0.0000	H2:	0.0018	CO2:	0.4380
NC4H10:	0.0000	H2S:	0.0000	H2O:	0.0000
IC5H12:	0.0000	CO:	0.0000	He:	0.0000
NC5H12:	0.0002			Ar:	0.0000
C6H14:	0.0000				
C7H16:	0.0000				

THE SUM OF THE FUEL MOLE FRACTIONS IS 1.00130

THE APPARENT FUEL MOLECULAR WEIGHT IS 28.30209

****
THE FOLLOWING MASS PERCENTAGES ARE TO BE USED FOR 'EAP' PROGRAM CALCULATIONS. THEY INCLUDE THE CARBON IN CO2 AND THE HYDROGEN IN H2O IN THE FUEL CARBON AND HYDROGEN VALUES.
****

THE TOTAL FUEL CARBON PERCENTAGE IS 42.257 %
THE TOTAL FUEL HYDROGEN PERCENTAGE IS 7.960 %
THE FUEL OXYGEN PERCENTAGE IS 49.457 %
THE FUEL NITROGEN PERCENTAGE IS .326 %
THE FUEL SULFUR PERCENTAGE IS 0.000 %
IE FUEL He AND Ar INERTS PERCENTAGE IS 0.000 %

HE SUMMATION OF MASS PERCENTAGES IS 100.000 %

****
THE FOLLOWING MASS PERCENTAGES ARE TO BE USED FOR SPINDT AIR/FUEL RATIO CALCULATIONS ONLY. THEY DO NOT INCLUDE THE CARBON IN CO2 OR THE HYDROGEN IN H2O IN THE FUEL CARBON AND HYDROGEN VALUES.
****

THE BURNABLE CARBON PERCENTAGE IS 23.693 %
THE BURNABLE HYDROGEN PERCENTAGE IS 7.960 %

THE ATOMIC HYDROGEN/CARBON RATIO OF THE BURNABLE FUEL FRACTION IS 4.004

THE STOICHIOMETRIC SPINDT AFR IS 5.45:1 BY MASS.

THE UNSATURATED HIGH HEATING VALUE IS 565.5 BTU/FT3
THE UNSATURATED LOW HEATING VALUE IS 509.0 BTU/FT3
THE SATURATED LOW HEATING VALUE IS 500.2 BTU/FT3

THE FUEL SPECIFIC GRAVITY IS .9771
THE FUEL DENSITY IS .0748 LB/FT3
THE MOTOR OCTANE NUMBER OF THE FUEL IS 119.6
THE IDEAL STOICHIOMETRIC FLAME TEMPERATURE IS 3588 DEG F.

10-11-90

***** GAS FUEL ANALYSIS *****

FUEL COMPOSITION IN MOLE FRACTIONS:

CH_4:	0.5590			N_2:	0.0010
C_2H_6:	0.0000	C_2H_4:	0.0000	O_2:	0.0000
C_3H_8:	0.0000	C_3H_6:	0.0000	AIR:	0.0000
IC_4H_{10}:	0.0000	H_2:	0.0017	CO_2:	0.4380
NC_4H_{10}:	0.0000	H_2S:	0.0000	H_2O:	0.0000
IC_5H_{12}:	0.0000	CO:	0.0000	He:	0.0000
NC_5H_{12}:	0.0003			Ar:	0.0000
C_6H_{14}:	0.0000				
C_7H_{16}:	0.0000				

THE SUM OF THE FUEL MOLE FRACTIONS IS 1.00000

THE APPARENT FUEL MOLECULAR WEIGHT IS 28.29750

****
THE FOLLOWING MASS PERCENTAGES ARE TO BE USED FOR 'EAP' PROGRAM CALCULATIONS. THEY INCLUDE THE CARBON IN CO2 AND THE HYDROGEN IN H2O IN THE FUEL CARBON AND HYDROGEN VALUES.
****

THE TOTAL FUEL CARBON PERCENTAGE IS	42.382 %
THE TOTAL FUEL HYDROGEN PERCENTAGE IS	7.990 %
THE FUEL OXYGEN PERCENTAGE IS	49.529 %
THE FUEL NITROGEN PERCENTAGE IS	.099 %
THE FUEL SULFUR PERCENTAGE IS	0.000 %
THE FUEL He AND Ar INERTS PERCENTAGE IS	0.000 %
THE SUMMATION OF MASS PERCENTAGES IS	100.000 %

****
THE FOLLOWING MASS PERCENTAGES ARE TO BE USED FOR SPINDT AIR/FUEL RATIO CALCULATIONS ONLY. THEY DO NOT INCLUDE THE CARBON IN CO2 OR THE HYDROGEN IN H2O IN THE FUEL CARBON AND HYDROGEN VALUES.
****

THE BURNABLE CARBON PERCENTAGE IS 23.791 %
THE BURNABLE HYDROGEN PERCENTAGE IS 7.990 %

THE ATOMIC HYDROGEN/CARBON RATIO OF THE BURNABLE FUEL FRACTION IS 4.002

THE STOICHIOMETRIC SPINDT AFR IS 5.47:1 BY MASS.

THE UNSATURATED HIGH HEATING VALUE IS 566.9 BTU/FT3
THE UNSATURATED LOW HEATING VALUE IS 510.3 BTU/FT3
THE SATURATED LOW HEATING VALUE IS 501.4 BTU/FT3

THE FUEL SPECIFIC GRAVITY IS .9770
THE FUEL DENSITY IS .0747 LB/FT3
THE MOTOR OCTANE NUMBER OF THE FUEL IS 119.6
THE IDEAL STOICHIOMETRIC FLAME TEMPERATURE IS 3590 DEG F.

10-15-90

***** GAS FUEL ANALYSIS *****

FUEL COMPOSITION IN MOLE FRACTIONS:

CH4:	0.5260			N2:	0.0552
C2H6:	0.0000	C2H4:	0.0000	O2:	0.0093
C3H8:	0.0000	C3H6:	0.0000	AIR:	0.0000
IC4H10:	0.0000	H2:	0.0010	CO2:	0.4080
NC4H10:	0.0000	H2S:	0.0000	H2O:	0.0000
IC5H12:	0.0000	CO:	0.0000	He:	0.0000
NC5H12:	0.0000			Ar:	0.0000
C6H14:	0.0000				
C7H16:	0.0000				

THE SUM OF THE FUEL MOLE FRACTIONS IS 0.99950

THE APPARENT FUEL MOLECULAR WEIGHT IS 28.25491

****
THE FOLLOWING MASS PERCENTAGES ARE TO BE USED FOR 'EAP' PROGRAM CALCULATIONS. THEY INCLUDE THE CARBON IN CO2 AND THE HYDROGEN IN H2O IN THE FUEL CARBON AND HYDROGEN VALUES.
****

THE TOTAL FUEL CARBON PERCENTAGE IS 39.724 %
THE TOTAL FUEL HYDROGEN PERCENTAGE IS 7.517 %
THE FUEL OXYGEN PERCENTAGE IS 47.283 %
THE FUEL NITROGEN PERCENTAGE IS 5.476 %
THE FUEL SULFUR PERCENTAGE IS 0.000 %
HE FUEL He AND Ar INERTS PERCENTAGE IS 0.000 %

HE SUMMATION OF MASS PERCENTAGES IS 99.999 %

****
THE FOLLOWING MASS PERCENTAGES ARE TO BE USED FOR SPINDT AIR/FUEL RATIO CALCULATIONS ONLY. THEY DO NOT INCLUDE THE CARBON IN CO2 OR THE HYDROGEN IN H2O IN THE FUEL CARBON AND HYDROGEN VALUES.
****

THE BURNABLE CARBON PERCENTAGE IS 22.371 %
THE BURNABLE HYDROGEN PERCENTAGE IS 7.517 %

THE ATOMIC HYDROGEN/CARBON RATIO OF THE BURNABLE FUEL FRACTION IS 4.004

THE STOICHIOMETRIC SPINDT AFR IS 5.15:1 BY MASS.

THE UNSATURATED HIGH HEATING VALUE IS 532.1 BTU/FT3
THE UNSATURATED LOW HEATING VALUE IS 478.9 BTU/FT3
THE SATURATED LOW HEATING VALUE IS 470.6 BTU/FT3

THE FUEL SPECIFIC GRAVITY IS .9755
THE FUEL DENSITY IS .0746 LB/FT3
THE MOTOR OCTANE NUMBER OF THE FUEL IS 119.8
THE IDEAL STOICHIOMETRIC FLAME TEMPERATURE IS 3584 DEG F.

11-6-90

***** GAS FUEL ANALYSIS *****

FUEL COMPOSITION IN MOLE FRACTIONS:

CH4:	0.5340			N2:	0.0169
C2H6:	0.0000	C2H4:	0.0000	O2:	0.0007
C3H8:	0.0000	C3H6:	0.0000	AIR:	0.0000
IC4H10:	0.0000	H2:	0.0018	CO2:	0.4470
NC4H10:	0.0000	H2S:	0.0000	H2O:	0.0000
IC5H12:	0.0000	CO:	0.0000	He:	0.0000
NC5H12:	0.0000			Ar:	0.0000
C6H14:	0.0000				
C7H16:	0.0000				

THE SUM OF THE FUEL MOLE FRACTIONS IS 1.00040

THE APPARENT FUEL MOLECULAR WEIGHT IS 28.72743

****
THE FOLLOWING MASS PERCENTAGES ARE TO BE USED FOR 'EAP' PROGRAM CALCULATIONS. THEY INCLUDE THE CARBON IN CO2 AND THE HYDROGEN IN H2O IN THE FUEL CARBON AND HYDROGEN VALUES.
****

THE TOTAL FUEL CARBON PERCENTAGE IS 41.000 %
THE TOTAL FUEL HYDROGEN PERCENTAGE IS 7.504 %
THE FUEL OXYGEN PERCENTAGE IS 49.848 %
THE FUEL NITROGEN PERCENTAGE IS 1.647 %
THE FUEL SULFUR PERCENTAGE IS 0.000 %
HE FUEL He AND Ar INERTS PERCENTAGE IS 0.000 %

THE SUMMATION OF MASS PERCENTAGES IS 100.000 %

****
THE FOLLOWING MASS PERCENTAGES ARE TO BE USED FOR SPINDT AIR/FUEL RATIO CALCULATIONS ONLY. THEY DO NOT INCLUDE THE CARBON IN CO2 OR THE HYDROGEN IN H2O IN THE FUEL CARBON AND HYDROGEN VALUES.
****

THE BURNABLE CARBON PERCENTAGE IS 22.318 %
THE BURNABLE HYDROGEN PERCENTAGE IS 7.504 %

THE ATOMIC HYDROGEN/CARBON RATIO OF THE BURNABLE FUEL FRACTION IS 4.007

THE STOICHIOMETRIC SPINDT AFR IS 5.14:1 BY MASS.

THE UNSATURATED HIGH HEATING VALUE IS 540.5 BTU/FT3
THE UNSATURATED LOW HEATING VALUE IS 486.4 BTU/FT3
THE SATURATED LOW HEATING VALUE IS 478.0 BTU/FT3

THE FUEL SPECIFIC GRAVITY IS .9918
THE FUEL DENSITY IS .0759 LB/FT3
THE MOTOR OCTANE NUMBER OF THE FUEL IS 119.6
THE IDEAL STOICHIOMETRIC FLAME TEMPERATURE IS 3560 DEG F.

678-2867

WAUKESHA MOTOR COMPANY

ENGINEERING DEPARTMENT

Engine Spec. 12V-AT25GL
Serial No. 401567
Bore ____ Stroke ____ Disp. ____
Disp. 1 Cyl. ____ BMEP Const ____
Cyl. Head ____
Clear Vol. ____ C.R. ____
Comp. Press ____ @ ____ rpm

Clearance, Int. ____ Ex. ____
Piston Mat'l ____
Carb. or Pump, No. ____
Make ____ Model ____
Fittings ____

Injector Spec. ____
Ignition 17° BTDC
Spark Plug ____ No. ____
Radiator ____
Size ____
Fan No. ____ Blds. ____ D ____ W ____
Pitch ____ Drive Ratio ____

Air Cleaner ____
Manifolds ____
Lub. oil ____ Grade ____
Fuel ____ Oct. ____ Cet. ____
Specials:
WB 60°F
DB 62°F
Hum 75gr/Lb 89% RH

READING	SPEED: RPM	LOAD: KWe	BHP @ 96%	GAS TEMP. °F	GAS PRESS. PSIG	OBS. FT³	OBS. TIME MIN.	SLHV	SCFM	BSFC	EXH. TEMP. °F	FUEL G/A	"H₂O INTAKE MANIF PRESS	OIL PRESS. PSIG	OIL TEMP °F	WATER TEMP °F	AUX WATER TEMP. °F	INTAKE MANIF TEMP. °F	FUEL RATE LB/MIN	TIME	
1	900	1700	2375	77°	55.0	200	1.680	472		6502	940°		16.5	46	180°	222°	117°	123°	41.47	9:33	
2	900	1700	2375	77°	55.0	200	1.680	472		6502	940°		16.5	46	180°	217°	117°	123°	41.47	9:40	
3	900	1700	2375	77°	55.5	200	1.681	472		6545	940°	9.0"	16.5	46	180°	217°	117°	123°	41.75	9:44	
4	900	1700	2375	77.5°	55.5	200	1.678	472		6551	940°		16.5	46	180°	218°	118°	124°	41.79	9:55	out
5	900	1700	2375	78°	55.5	200	1.686	472		646[illegible]	940°		16.5	46	180°	219°	118°	124°	41.26	10:00	out
								Σ		6516									41.57		

ENGINE CLOCK : 2383 HOURS
PANEL CLOCK : 2483

OBSERVERS STACHOWICZ ROOM NO. ____ BAROMETER 29.87 DAT[illegible]
SUBJECT JOHNSTON LANDFILL CERTIFICATION - UNIT #1 SHEET NO. 1 TES[illegible]

WAUKESHA MOTOR COMPANY

ENGINEERING DEPARTMENT

Engine Spec. 12V-AT25GL	Clearance, Int. ____ Ex. ____	Injector Spec. ____	Air Cleaner ____
Serial No. 401568	Piston Mat'l ____	Ignition 17° BTDC	Manifolds ____
Bore ____ Stroke ____ Disp. ____	Carb. or Pump, No. ____	Spark Plug ____ No. ____	Lub. oil ____ Grade ____
Disp. 1 Cyl. ____ BMEP Const ____	Make ____ Model ____	Radiator ____	Fuel ____ Oct. ____ Cet. ____
Cyl. Head ____	Fittings ____	Size ____	Specials:
Clear Vol. ____ C.R. ____		Fan No. ____ Blds. ____ D ____ W ____	WB 71°
Comp. Press ____ @ ____ rpm		Pitch ____ Drive Ratio ____	DB 78°
			HUM 103 gr/lb 71% RH

Reading	Speed: RPM	Load: KWe	BHP @ 96%		Gas Temp °F	Gas Press PSIG	Obs. FT3	Obs. Time Min	SLHV		SCFM	Fuel Rate LB/MIN	BSFC		Exh. Temp °F	Fuel G/A	Intake Manif "Hg	Press: PSIG Oil Press	Oil Temp °F	Water Temp °F	Aux Water Temp: °F	Intake Manif Temp: °F		Time		
1	903	1700	2375		88.5°	57.0	200	1.610	472		43.57	.6830			860°	9.2	19.3	42	186°	224°	125°	132°		2:32		OUT
2	903	1700	2375		90.0°	56.5	200	1.608	472		43.20	.6772			860°		19.5	42	188°	224°	125°	132°		2:40		
3	903	1700	2375		90.5°	55.5	200	1.604	472		42.65	.6687			860°	9.2	19.5	42	188°	224°	125°	133°		2:50		OUT
4	903	1700	2375		91.0°	55.5	200	1.599	472		42.75	.6702			860°		19.5	42	187°	223°	125°	134°		3:00		
5	903	1700	2375		91.5°	56.0	200	1.595	472		43.13	.6761			860°	9.2	19.5	42	185°	224°	117°	130°		3:05		

$\bar{\Sigma}$ = 43.02 .6745

ENGINE CLOCK : 3102
PANEL CLOCK : 3052

OBSERVERS STACHOWICZ ROOM NO. ____ BAROMETER 29.79 DATE 10-9-90 AM

SUBJECT JOHNSTON LANDFILL CERTIFICATION - UNIT #2 SHEET NO. 2 TEST NO. ____ PM

578-2082

WAUKESHA MOTOR COMPANY

ENGINEERING DEPARTMENT

Engine Spec. 12V-AT25GL
Serial No. 401772
Bore ______ Stroke ______ Disp. ______
Disp. 1 Cyl. ______ BMEP Const ______
Cyl. Head ______
Clear Vol. ______ C.R. ______
Comp. Press ______ @ ______ rpm

Clearance, Int. ______ Ex. ______
Piston Mat'l ______
Carb. or Pump, No. ______
Make ______ Model ______
Fittings ______

Injector Spec. ______
Ignition 17° BTDC
Spark Plug ______ No. ______
Radiator ______
Size ______
Fan No. ______ Blds. ______ D ______ W ______
Pitch ______ Drive Ratio ______

Air Cleaner ______
Manifolds ______
Lub. oil ______ Grade ______
Fuel ______ Oct. ______ Cet. ______
Specials:
WB 56°
DB 71°
HUM 43gr/Lb ; 38 % RH

READING	SPEED : RPM	LOAD : KWe	BHP @ 96%		GAS TEMP - °F	GAS PRESS PSIG	OBS. FT³	OBS. TIME MIN	SLHV	SCFM	FUEL RATE Lb/MIN	BSFC		EXH. TEMP - °F	FUEL G/A "Hg	INT. MANIF. PRESS - PSIG	OIL PRESS PSIG	OIL TEMP °F	WATER TEMP °F	AUX WATER TEMP - °F	INT. MANIF. TEMP - °F	CRANKCASE ΔP - "H₂O	TIME		
1	900	1700	2375		75.0°	58.5	200	1.732	472		42.41	6648		835°	9.0	18.5	35	178°	212°	124°	121°	-1.0	9:15		OUT
2	900	1700	2375		77.5°	58.0	200	1.732	472		41.92	6572		840°		18.0	35	178°	212°	125°	122°		9:20		OUT
3	900	1700	2375		77.5°	58.5	200	1.738	472		42.06	6594		840°	9.0	18.5	34.5	178°	212°	125°	124°	-1.0	9:30		
4	900	1700	2375		77.5°	58.5	200	1.742	472		41.97	6579		840°		18.5	34.5	179°	213°	125°	125°		9:35		
5	900	1700	2375		77.5°	59.0	200	1.736	472		42.40	6647		840°	9.0	18.5	34.5	179°	212°	125°	125°	-1.0	9:45		
									$\bar{\Sigma}$ =		42.14	6607													

PANEL HOURS = 1971
ENGINE HOURS = 1718

OBSERVERS STACHOWICZ ROOM NO. ______ BAROMETER 29.86 DATE 10-16-90 AM
SUBJECT JOHNSTON LANDFILL CERTIFICATION - UNIT #3 SHEET NO. 9 TEST NO. ______ PM

WAUKESHA MOTOR COMPANY

ENGINEERING D... ...MENT

Engine Spec. 12V-AT25GL	Clearance, Int. ____ Ex. ____	Injector Spec. ____	Air Cleaner ____
Serial No. 401775	Piston Mat'l ____	Ignition 17° BTDC	Manifolds ____
Bore ____ Stroke ____ Disp. ____	Carb. or Pump, No. ____	Spark Plug ____ No. ____	Lub. oil ____ Grade ____
Disp. 1 Cyl. ____ BMEP Const ____	Make ____ Model ____	Radiator ____	Fuel ____ Oct. ____ Cet. ____
Cyl. Head ____	Fittings ____	Size ____	Specials: ____
Clear Vol. ____ C.R. ____		Fan No. ____ Blds. ____ D ____ W ____	WB 71°
Comp. Press ____ @ ____ rpm		Pitch ____ Drive Ratio ____	DB 73°
			HUM 111 gr/lb ; 90% RH

READING	SPEED : RPM	LOAD : KWe	BHP @ 96%		GAS TEMP - °F	GAS PRESS PSIG	OBS FT 3	OBS. TIME MIN.	SLHV		SCFM	FUEL RATE Lb/MIN	BSFC		EXH. TEMP - °F	FUEL G/A	INTAKE MANIF PRESS "Hg	OIL PRESS - PSIG	OIL TEMP °F	WATER TEMP °F	AUX WATER TEMP °F	INTAKE MANIF TEMP - °F	CRANKCASE ΔP "H_2O	TIME		
1	900	1700	2375		94.0°	55.5	200	1.591	472		42.76	6704			865°	8.9	19.5	40.5	193°	230°	121°	125°	-1.0	2:45		OUT
2	900	1700	2375		96.5°	55.5	200	1.588	472		42.65	6686			865°		19.5	40.5	194°	230°	121°	125°		2:55		
3	900	1700	2375		96.5°	55.5	200	1.591	472		42.27	6627			865°	9.0	19.5	40.5	193°	230°	121°	125°	-1.1	3:00		OUT
4	900	1700	2375		95.0°	55.5	200	1.596	472		42.55	6671			865°		19.5	40.5	193°	229°	120°	125°		3:05		
5	900	1700	2375		94.5°	55.5	200	1.590	472		42.75	6702			865°	9.0	20.0	40.5	193°	229°	120°	125°	-1.0	3:15		
									$\bar{\Sigma}$ =		42.65	6686														

PANEL HOURS = 1820

ENGINE HOURS = 1818

OBSERVERS STACHOWICZ ROOM NO. ____ BAROMETER 29.89 DATE 10-12-90 AM

SUBJECT JOHNSTON LANDFILL CERTIFICATION - UNIT #4 SHEET NO. 6 TEST NO. ____ PM

576-2862

WAUKESHA MOTOR COMPANY — ENGINEERING DEPARTMENT

Engine Spec. 12V-AT25GL	Clearance, Int. ____ Ex. ____	Injector Spec. ____	Air Cleaner ____
Serial No. 401451	Piston Mat'l ____	Ignition 17° BTDC	Manifolds ____
Bore ____ Stroke ____ Disp. ____	Carb. or Pump, No. ____	Spark Plug ____ No. ____	Lub. oil ____ Grade ____
Disp. 1 Cyl. ____ BMEP Const ____	Make ____ Model ____	Radiator ____	Fuel ____ Oct. ____ Cet. ____
Cyl. Head ____	Fittings ____	Size ____	Specials:
Clear Vol. ____ C.R. ____		Fan No. ____ Blds. ____ D ____ W ____	WB 68
Comp. Press ____ @ ____ rpm		Pitch ____ Drive Ratio ____	DB 73
			HUM 95 gr/Lb ; 78% RH

READING	SPEED : RPM	LOAD : KWe	BHP @ 96%		GAS TEMP - °F	GAS PRESS PSIG	OBS FT³	OBS TIME MIN	SLHV		SCFM	FUEL RATE Lb/MIN	BSFC	EXH. TEMP - °F	FUEL G/A	INT. MANIF PRESS "Hg	OIL PRESS - PSIG	OIL TEMP °F	WATER TEMP °F	AUX WATER TEMP - °F	INT. MANIF TEMP - °F	CRANKCASE ΔP - "H₂O	TIME	
1	900	1625	2270		89.0°	56.5	200	1.702	472		40.77	6687		860°	9.0	19.5	43.5	183°	215°	120°	126°	-.1	10:45	out
2	900	1625	2270		91.5°	56.5	200	1.683	472		41.04	6732		845°		19.5	43.5	183°	215°	121°	127°		10:50	
3	900	1625	2270		92.0°	56.5	200	1.671	472		41.30	6774		840°	9.0	20.0	43.5	183°	215°	121°	127°	0	11:00	out
4	900	1625	2270		92.0°	56.5	200	1.682	472		41.03	6730		840°		20.0	43.5	183°	215°	121°	127°		11:10	
5	900	1625	2270		92.0°	56.5	200	1.683	472		41.01	6726		840°	9.0	20.0	43.5	184°	215°	121°	127°	0	11:15	
									Σ =		41.03	6729												

ENGINE HOURS = 3529
PANEL HOURS = 3449

OBSERVERS STACHOWICZ ROOM NO. ____ BAROMETER 29.40 DATE 10-14-90 AM
SUBJECT JOHNSTON LANDFILL CERTIFICATION ; UNIT # 5 SHEET NO. 8 TEST NO. ____ PM

73-2882

WAUKESHA MOTOR COMPANY

ENGINEERING DEPARTMENT

Engine Spec. 12V-AT25GL
Serial No. 401706
Bore ______ Stroke ______ Disp. ______
Disp. 1 Cyl. ______ BMEP Const ______
Cyl. Head ______
Clear Vol. ______ C.R. ______
Comp. Press ______ @ ______ rpm

Clearance, Int. ______ Ex. ______
Piston Mat'l ______
Carb. or Pump, No. ______
Make ______ Model ______
Fittings ______

Injector Spec. ______
Ignition 17° BTDC
Spark Plug ______ No. ______
Radiator ______
Size ______
Fan No. ______ Blds. ______ D ______ W ______
Pitch ______ Drive Ratio ______

Air Cleaner ______
Manifolds ______
Lub. oil ______ Grade ______
Fuel ______ Oct. ______ Cet. ______
Specials:
WB 72°
DB 85°
HUM. 97 gr/Lb ; 54% RH

READING	SPEED : RPM	LOAD : KWe	BHP @ 96%		GAS TEMP - °F	GAS PRESS PSIG	OBS FT3	OBS TIME MIN.	SLHV	SCFM	FUEL RATE Lb/MIN	BSFC		EXH. TEMP - °F	FUEL G/A	INTAKE MANIF. "Hg	PRESS. - PSIG OIL PRESS. PSIG	OIL TEMP. °F	WATER TEMP. °F	AUX. WATER TEMP. - °F	INTAKE MANIF. TEMP. - °F	CRANKCASE ΔP "H2O	TIME	
1	900	1700	2375		91.0°	56.0	200	1.634	472		42.21	6617		880°	9.5	21.5	48.5	181°	229°	123°	135°	-1.3	2:45	OUT
2	900	1700	2375		95.0°	56.0	200	1.640	472		41.75	6545		885°		21.0	48.5	181°	229°	122°	135°		2:55	OUT
3	900	1700	2375		93.5°	56.0	200	1.633	472		42.04	6591		880°	9.6	21.5	48.0	182°	229°	122°	135°	-1.2	3:00	
4	900	1700	2375		93.0°	56.0	200	1.629	472		42.18	6613		880°		21.5	48.0	182°	228°	120°	135°		3:05	
5	900	1700	2375		93.0°	56.0	200	1.633	472		42.08	6597		880°	9.6	21.0	48.0	181°	227°	120°	134°	-1.5	3:15	
								Σ =			42.10	6600												

ENGINE CLOCK = 3752
PANEL CLOCK = 3693

OBSERVERS STACHOWICZ ROOM NO. ______ BAROMETER 30.04 DATE 10-11-90 AM
SUBJECT JOHNSTON LANDFILL CERTIFICATION - UNIT # 6 SHEET NO. 5 TEST NO. ______ PM

676-2862

WAUKESHA MOTOR COMPANY — **ENGINEERING DEPARTMENT**

Engine Spec. 12V-AT25GL	Clearance, Int. ____ Ex. ____	Injector Spec. ____	Air Cleaner ____
Serial No. 401969	Piston Mat'l ____	Ignition 17° BTDC	Manifolds ____
Bore ____ Stroke ____ Disp. ____	Carb. or Pump, No. ____	Spark Plug ____ No. ____	Lub. oil ____ Grade ____
Disp. 1 Cyl. ____ BMEP Const ____	Make ____ Model ____	Radiator ____	Fuel ____ Oct. ____ Cet. ____
Cyl. Head ____	Fittings ____	Size ____	Specials:
Clear Vol. ____ C.R. ____		Fan No. ____ Blds. ____ D ____ W ____	WB 58°
Comp. Press ____ @ ____ rpm		Pitch ____ Drive Ratio ____	DB 58.5°
			HUM 71 gr/Lb 97% RH

READING	SPEED: RPM	LOAD: KWe	BHP @ 96%		GAS TEMP. - °F	GAS PRESS PSIG	OBS. FT3	OBS. TIME MIN.	SLHV	SCFM	FUEL RATE LB/MIN	BSFC	EXH. TEMP - °F	FUEL G/A	INT. MANIF. PRESS - "Hg	OIL PRESS. PSIG	OIL TEMP °F	WATER TEMP °F	AUX. WATER TEMP. - °F	INTAKE MANIF. TEMP. - °F	CRANKCASE VAC. "H2O	TIME		
1	900	1700	2375		87.0°	56.0	200	1.646	472	42.23	6620		865°	9.1	16.5	44	185°	215°	122°	125°	-1.3	9:45		
2	900	1700	2375		87.0°	56.5	200	1.650	472	42.42	6651		865°		16.5	44	185°	215°	122°	125°		9:55		OUT
3	900	1700	2375		87.0°	56.5	200	1.652	472	42.37	6643		865°	9.1	16.5	44	185°	215°	122°	125°	-1.2	10:00		
4	900	1700	2375		86.0°	56.0	200	1.658	472	42.00	6584		865°		16.0	44	185°	215°	121°	125°		10:10		OUT
5	900	1700	2375		85.0°	56.5	200	1.667	472	42.14	6607		865°	9.1	16.3	44	185°	215°	122°	125°	-1.3	10:15		
							$\bar{\Sigma}$ =			42.25	6623													

ENGINE CLOCK = 1040

PANEL CLOCK = 2918

OBSERVERS STACHOWICZ ROOM NO. ____ BAROMETER 30.12 DATE 10-11-90 AM/PM

SUBJECT JOHNSTON LANDFILL CERTIFICATION -- UNIT #7 SHEET NO. 4 TEST NO. ____

76-2862

WAUKESHA MOTOR COMPANY — **ENGINEERING DEPARTMENT**

Engine Spec. 12V-AT25GL	Clearance, Int. ___ Ex. ___	Injector Spec. ___	Air Cleaner ___
Serial No. 401970	Piston Mat'l ___	Ignition 17° BTDC	Manifolds ___
Bore ___ Stroke ___ Disp. ___	Carb. or Pump, No. ___	Spark Plug ___ No. ___	Lub. oil ___ Grade ___
Disp. 1 Cyl. ___ BMEP Const ___	Make ___ Model ___	Radiator ___	Fuel ___ Oct. ___ Cet. ___
Cyl. Head ___	Fittings ___	Size ___	Specials:
Clear Vol. ___ C.R. ___		Fan No. ___ Blds. ___ D ___ W ___	WB 63
Comp. Press ___ @ ___ rpm		Pitch ___ Drive Ratio ___	DB 75
			HUM 67 gr/Lb 51% RH

READING	SPEED: RPM	LOAD: KWe	BHP @ 96%		GAS TEMP - °F	GAS PRESS PSIG	OBS. FT³	OBS. TIME MINUTE	SLHV		SCFM	FUEL RATE LB/MIN	BSFC		EXH TEMP - °F	FUEL G/A	INTAKE MANIF PRESS: "Hg	OIL PRESS PSIG	OIL TEMP °F	WATER TEMP °F	AUX. WATER TEMP - °F	INTAKE MANIF TEMP. - °F		TIME	
1	902	1700	2375		79.0°	56.0	200	1.671	472		42.19	.6614			870°	9.2	19.5	43	197°	229°	118°	120°		4:07	
2	902	1700	2375		81.0°	54.5	200	1.669	472		41.20	.6459			870°		20.0	43	197°	227°	117°	120°		4:15	OUT
3	902	1700	2375		80.5°	54.5	200	1.671	472		41.19	.6457			870°	9.2	19.5	43	197°	226°	117°	119°		4:20	
4	901	1700	2375		80.0°	55.0	200	1.675	472		41.42	.6494			865°		20.0	43	197°	226°	118°	119°		4:25	
5	902	1700	2375		79.0°	56.5	200	1.666	472		42.75	.6702			865		20.0	43	197°	226°	117°	119°		4:35	OUT
								Σ =			41.60	.6522													

ENGINE CLOCK : 1286
PANEL CLOCK : 2625

OBSERVERS STACHOWICZ ROOM NO. ___ BAROMETER 30.06 DATE 10-10-90 AM

SUBJECT JOHNSTON LANDFILL CERTIFICATION - UNIT #8 SHEET NO. 3 TEST NO. ___ PM

WAUKESHA MOTOR COMPANY

ENGINEERING DEPARTMENT

Engine Spec. 12V-AT25GL
Serial No. 401567
Bore ______ Stroke ______ Disp. ______
Disp. 1 Cyl. ______ BMEP Const ______
Cyl. Head ______
Clear Vol. ______ C.R. ______
Comp. Press ______ @ ______ rpm

Clearance, Int. ______ Ex. ______
Piston Mat'l ______
Carb. or Pump, No. ______
Make ______ Model ______
Fittings ______

Injector Spec. ______
Ignition 17° BTDC
Spark Plug ______ No. ______
Radiator ______
Size ______
Fan No. ______ Blds. ______ D ______ W ______
Pitch ______ Drive Ratio ______

Air Cleaner ______
Manifolds ______
Lub. oil ______ Grade ______
Fuel ______ Oct. ______ Cet. ______
Specials:
WB 69
DB 72
HUM 102 gr/Lb ; 86% RH

READING	SPEED: RPM	LOAD: KWe	BHP @ 96%		GAS TEMP-°F	GAS PRESS PSIG	OBS. FT³	OBS. TIME MIN	SLHV	SCFM	FUEL RATE Lb/MIN	BSFC		EXH. TEMP-°F	FUEL G/A	INT. MANIF PRESS. "Hg - PSIG	OIL PRESS PSIG	OIL TEMP °F	WATER TEMP °F	AUX WATER TEMP - °F	INT. MANIF. TEMP - °F	CRANKCASE ΔP - "H₂O	TIME	
1	900	1650	2305		94.0°	57.5	200	1.635	472		42.74	6904		925°	9.0	18.0	46.5	178°	215°	120°	130°	-.5	10:45	OUT
2	900	1650	2305		96.5°	57.0	200	1.632	472		42.33	6838		925°		17.5	46.5	178°	215°	120°	130°		10:50	OUT
3	900	1650	2305		96.0°	57.0	200	1.630	472		42.42	6852		925°	9.0	18.0	46.5	178°	215°	120°	130°	-.1	11:00	
4	900	1650	2305		96.0°	57.5	200	1.637	472		42.53	6871		925°		17.5	46.5	178°	215°	120°	130°		11:05	
5	900	1650	2305		97.0°	57.6	200	1.634	472		42.53	6871		925°	9.0	17.5	46.5	178°	215°	120°	131°	-.2	11:15	
									$\bar{\Sigma}$ =		42.50	6865												

PANEL HOURS = 2485
ENGINE HOURS = 2384

OBSERVERS STACHOWICZ ROOM NO. ______ BAROMETER 29.70 DATE 10-13-90 AM
SUBJECT JOHNSTON LANDFILL CERTIFICATION - UNIT #1 RERUN SHEET NO. 7 TEST NO. ______ PM

676-2862

WAUKESHA MOTOR COMPANY — **ENGINEERING DEPARTMENT**

Engine Spec. 12V-A 5GL	Clearance, Int. ___ Ex. ___	Injector Spec. ___	Air Cleaner ___
Serial No. 401970	Piston Mat'l ___	Ignition 17° BTDC	Manifolds ___
Bore ___ Stroke ___ Disp. ___	Carb. or Pump, No. ___	Spark Plug ___ No. ___	Lub. oil ___ Grade ___
Disp. 1 Cyl. ___ BMEP Const ___	Make ___ Model ___	Radiator ___	Fuel ___ Oct. ___ Cet. ___
Cyl. Head ___	Fittings ___	Size ___	Specials:
Clear Vol. ___ C.R. ___		Fan No. ___ Blds. ___ D ___ W ___	WB 49
Comp. Press ___ @ ___ rpm		Pitch ___ Drive Ratio ___	DB 54
			Hum 44 gr/lb, 70% RH

Reading	Speed: RPM	Load: KWe	BHP @ 96%		Gas Temp - °F	Gas Press PSIG	OBS FT3	OBS Time Min	SLHV	SCFM	Fuel Rate Lb/Min	BSFC		Exh. Temp - °F	Fuel G/A	Int. Manif "Hg	Press - PSIG Oil Press PSIG	Oil Temp °F	Water Temp °F	Aux. Water Temp - °F	Intake Manif Temp - °F	Crankcase ΔP "H_2O	Time		
1	900	1700	2375		71°	55.5	200	1.635	472		43.23	6777		865°	9.3	19.5	44.5	196°	220°	116°	120°	–	10:45		
2	900	1700	2375		70°	55.0	200	1.639	472		42.89	6725		865°	9.3	19.0	44.5	196°	219°	116°	120°	–	10:55		OUT
3	900	1700	2375		71°	56.0	200	1.628	472		43.72	6855		865°	9.3	19.5	44.5	196°	219°	116°	120°	–	11:00		
4	900	1700	2375		71°	56.5	200	1.590	472		45.09	7069		860°	9.3	19.0	44.0	196°	219°	117°	121°	–	11:10		OUT
5	900	1700	2375		71°	56.6	200	1.617	472		44.02	6902		860°	9.3	19.0	44.0	196°	219°	117°	121°	–	11:15		

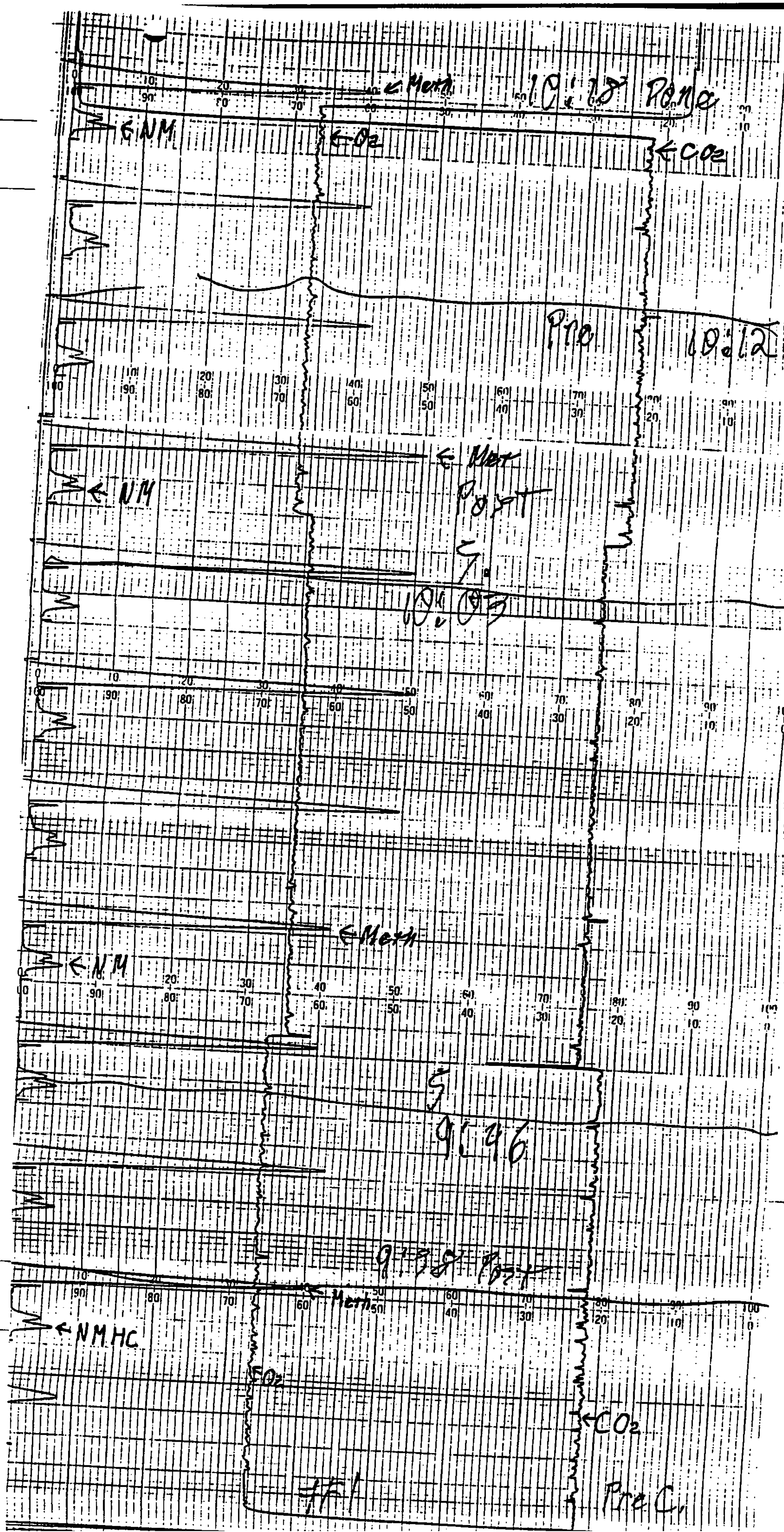
$\bar{\Sigma}$ = 43.66 6845

ENGINE CLOCK = 3.0

PANEL CLOCK = 2767.3

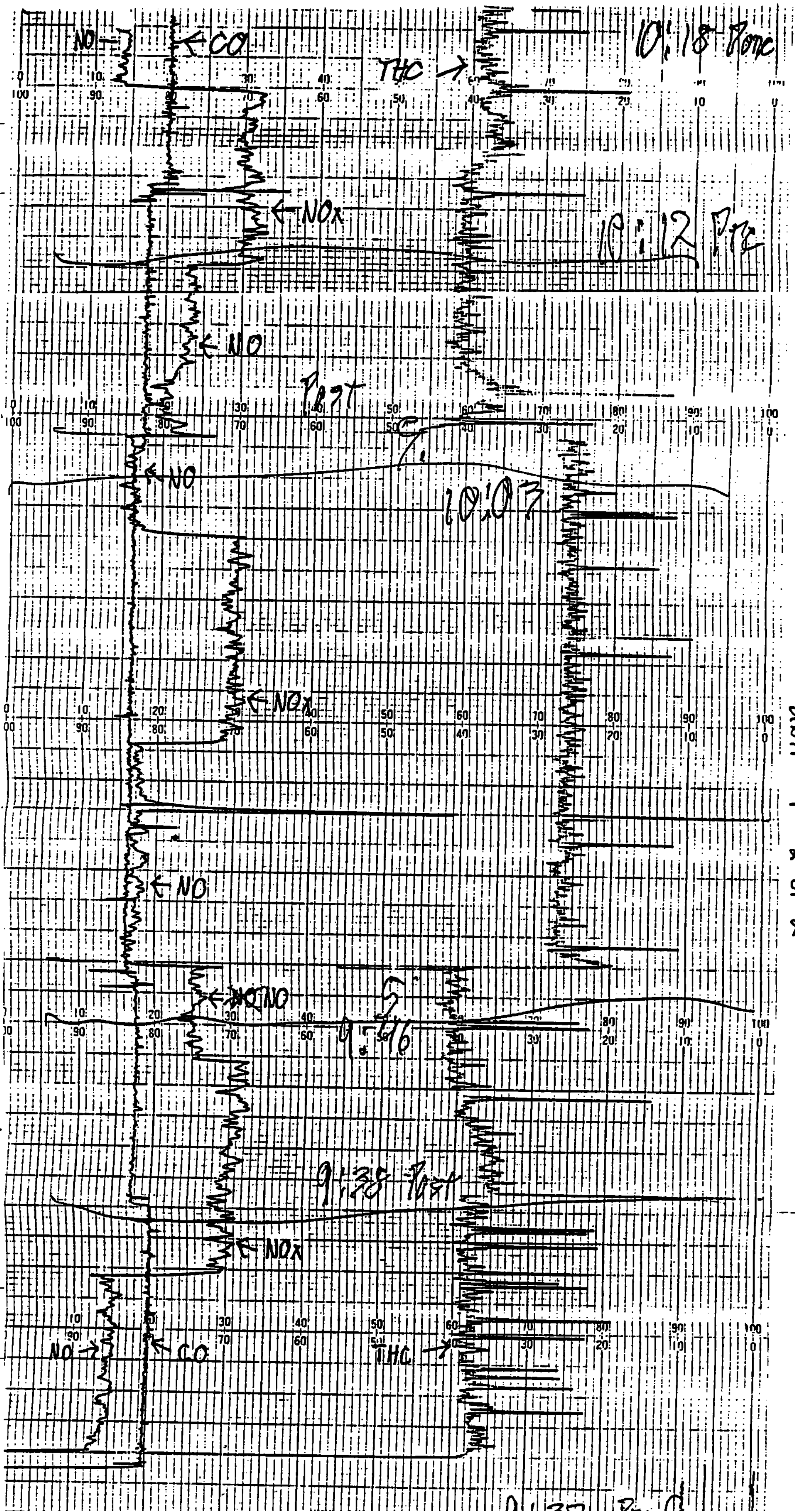
OBSERVERS STACHOWICZ ROOM NO. ___ BAROMETER 29.28 DATE 11-6-90 AM

SUBJECT JOHNSTON LANDFILL - CLEANED CATALYST - UNIT #8 SHEET NO. 10 TEST NO. ___ PM

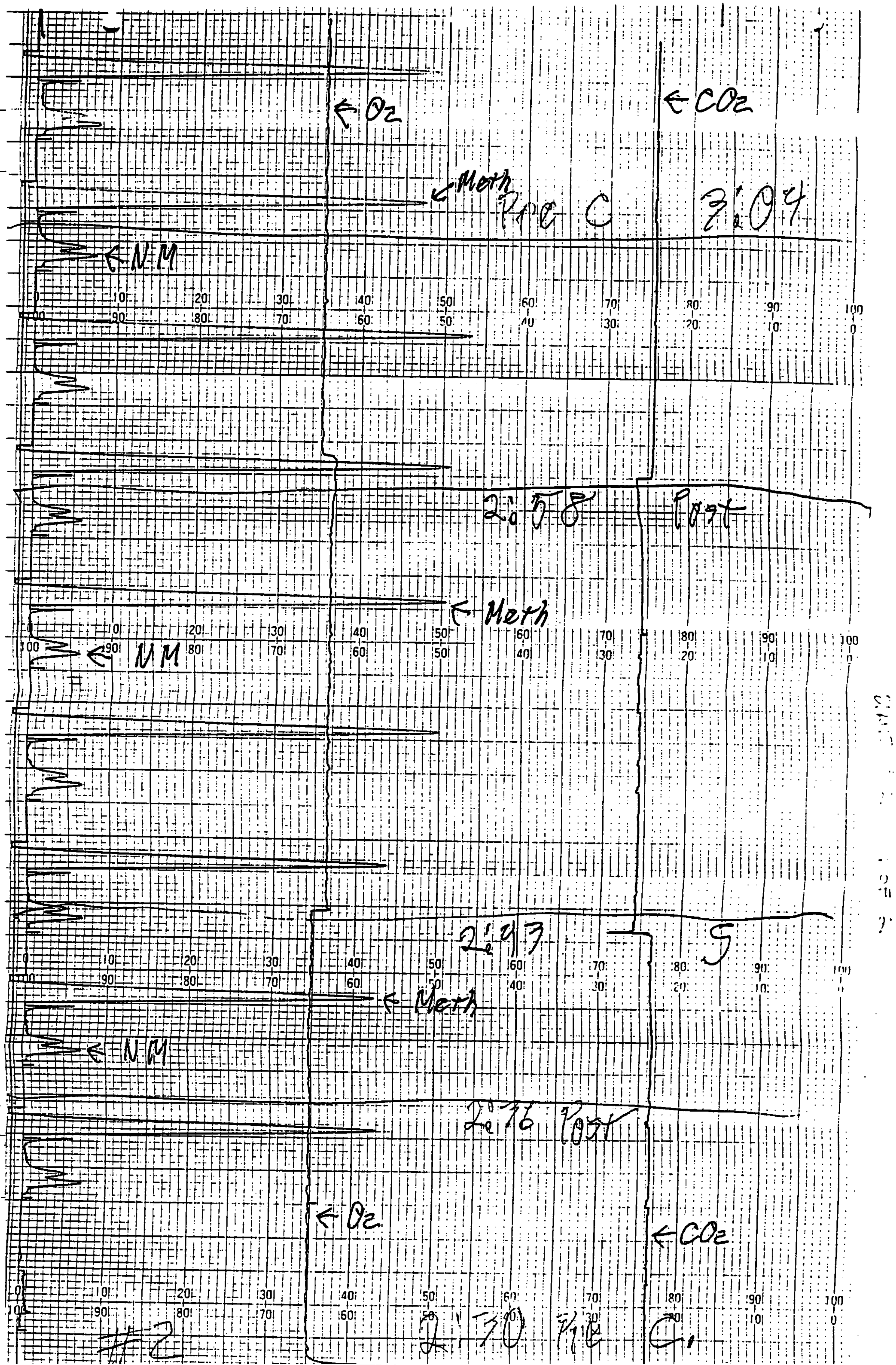


Meth
10:28
NM
O2
CO2
Pre 10:12
Met
NM
Post
5
10:03
Meth
NM
5
9:46
9:38 Post
Meth
NMHC
O2
CO2
#1
Pre C.

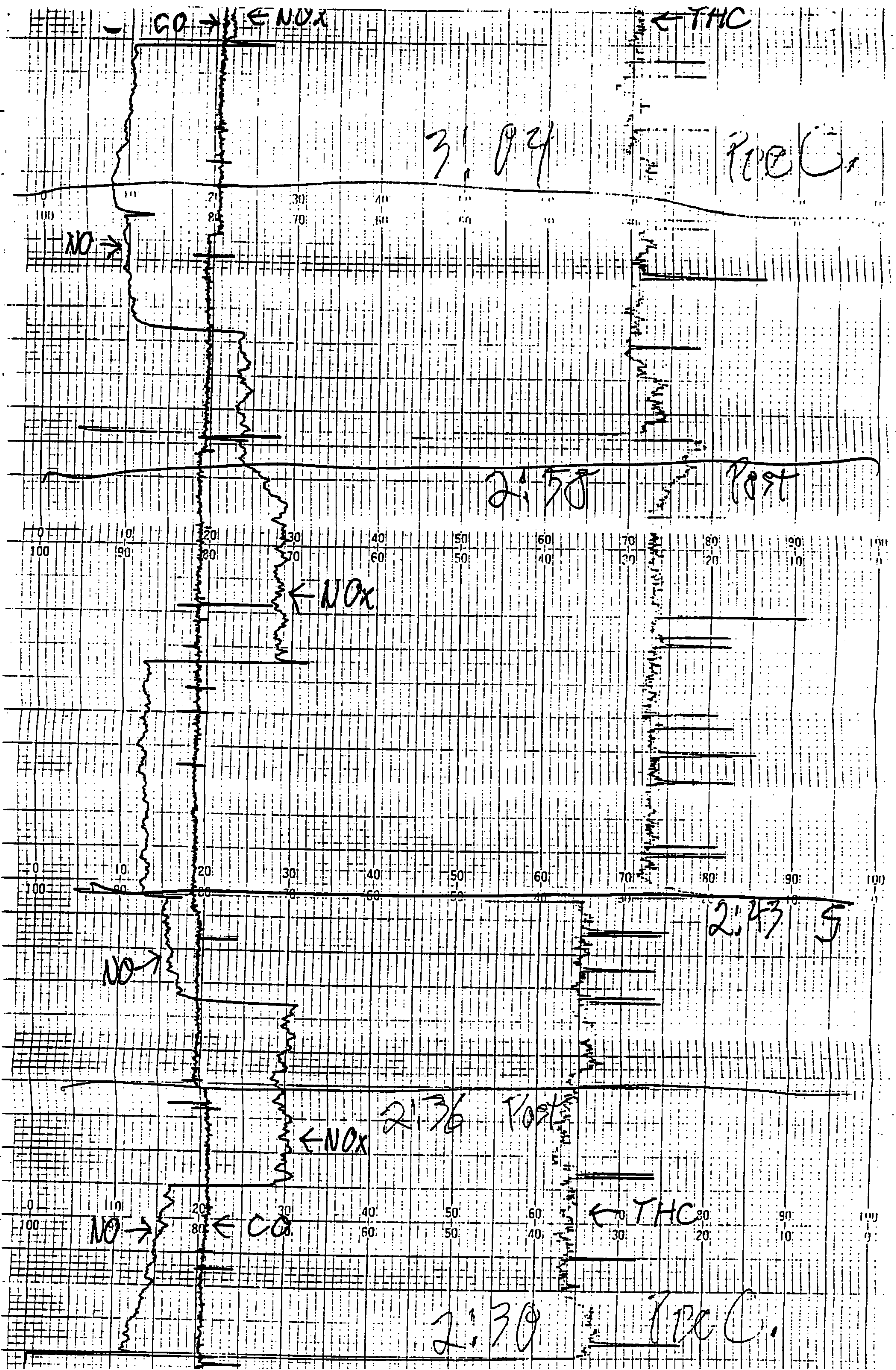
UNIT #1 1 of 2


NO
CO
THC
10:18 Post
NOx
10:12 Pre
NO
Post
NO
10:07
NOx
NO
9:56
9:38 Post
NOx
NO
CO
THC

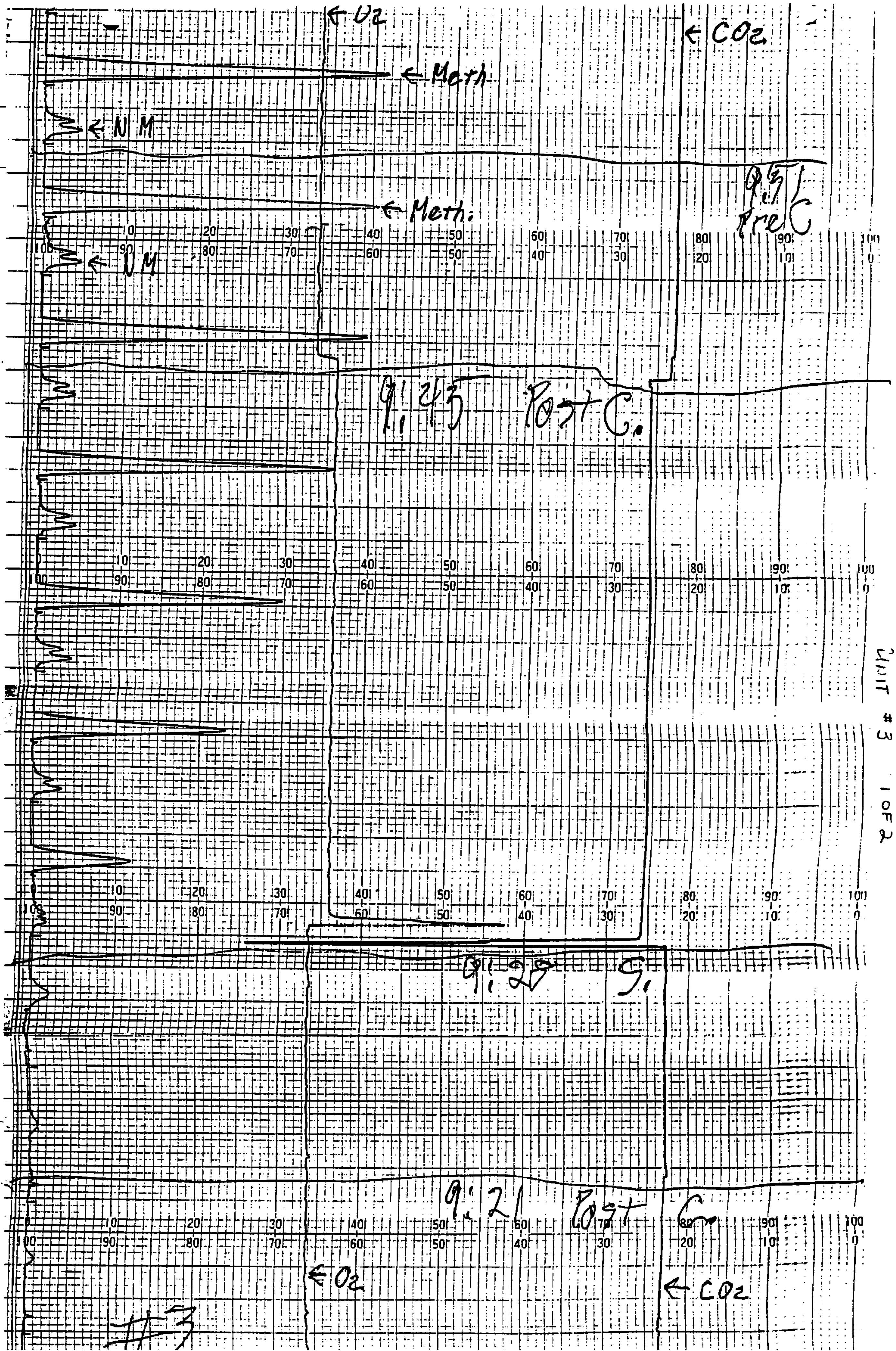
UNIT #1 2 OF 2

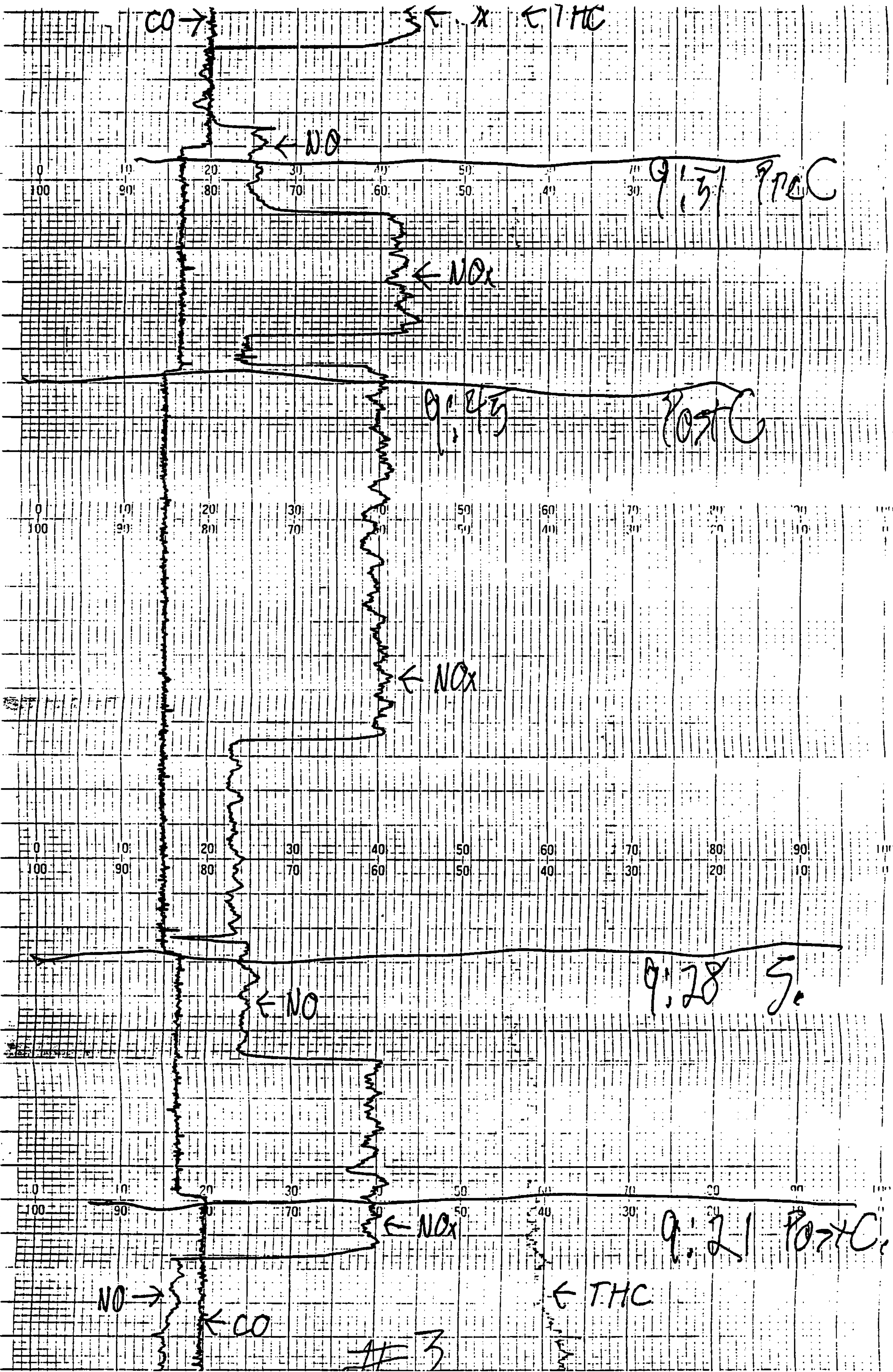


← O2
← CO2
← Meth
Pre C
3:04
← NM
2:58
Post
← Meth
← NM
2:43
S
← Meth
← NM
2:36 Post
← O2
← CO2
2:30 Pre C.
#2

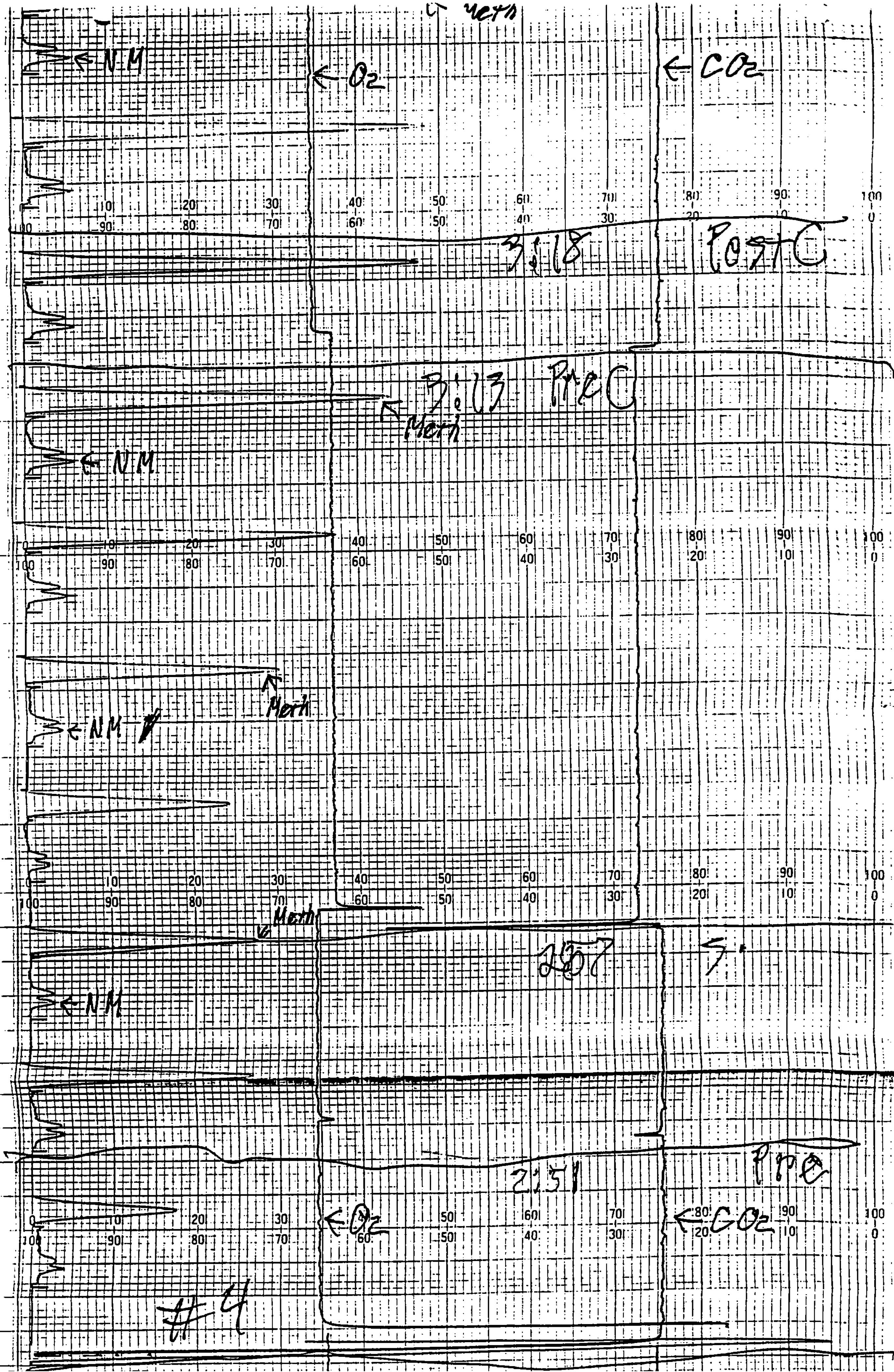

CO
NOx
THC
3:04
PreC
NO
2:58
Post
NOx
2:43
S
NO
2:36
Post
NOx
NO
CO
THC
2:30
PreC

UNIT #2 2 of 2


← O2
← CO2
← Meth
← N M
← Meth.
← NM
9:31 Pre C
9:43 Post C.
9:25 S.
9:21 Post C
← O2
← CO2
#3
UNIT #3 1 OF 2

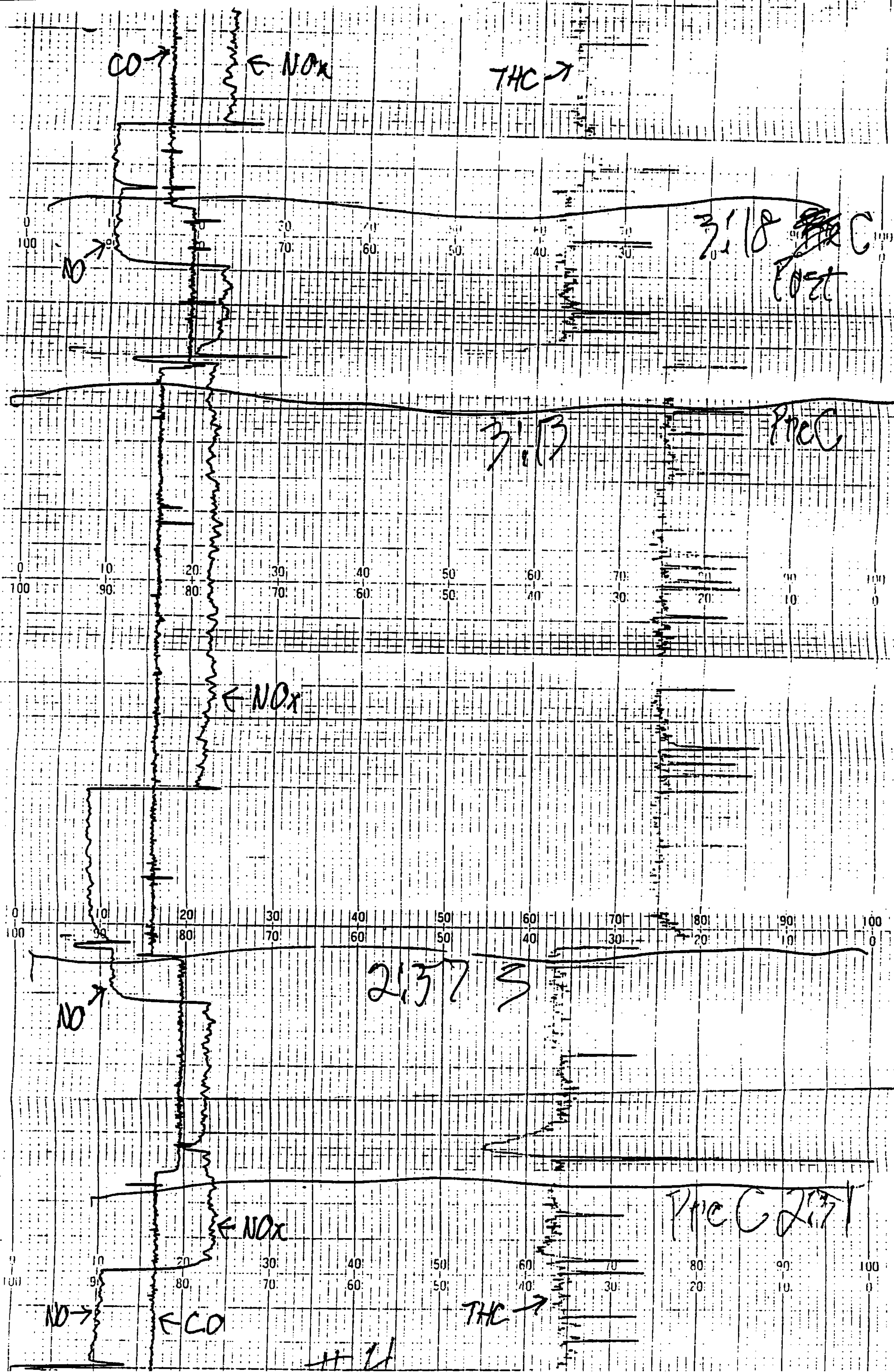


CO →
← THC
← NO
9:37 PreC
← NOx
9:45 PostC
← NOx
9:28 S
← NO
← NOx
9:21 PostC
NO →
← CO
← THC
#3

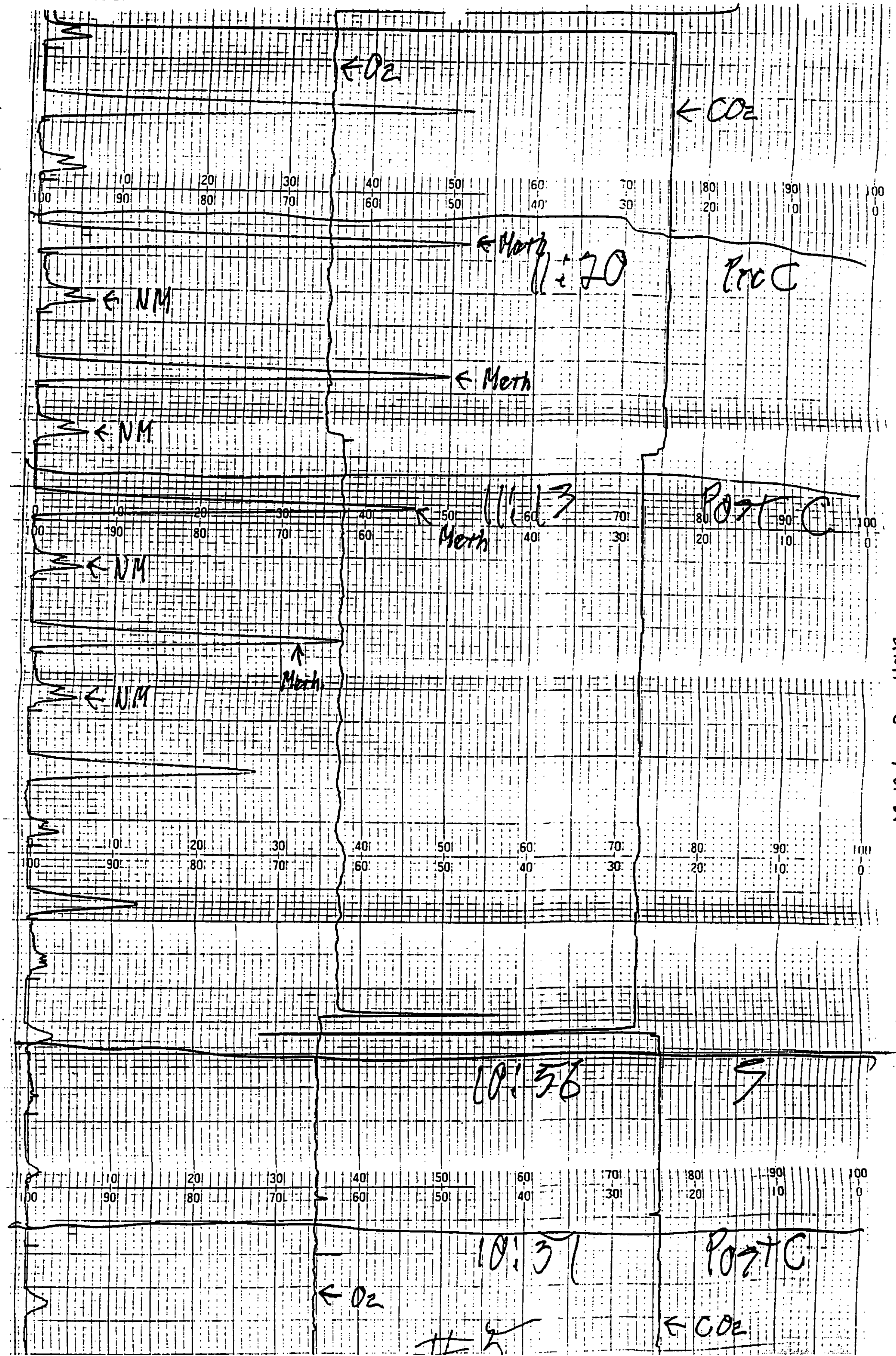


Meth
NM
O_2
CO_2
3:18
PostC
3:13
PreC
Meth
NM
Meth
NM
Meth
287
NM
2:51
Pre
O_2
CO_2
#4

UNIT #4 1 OF 2

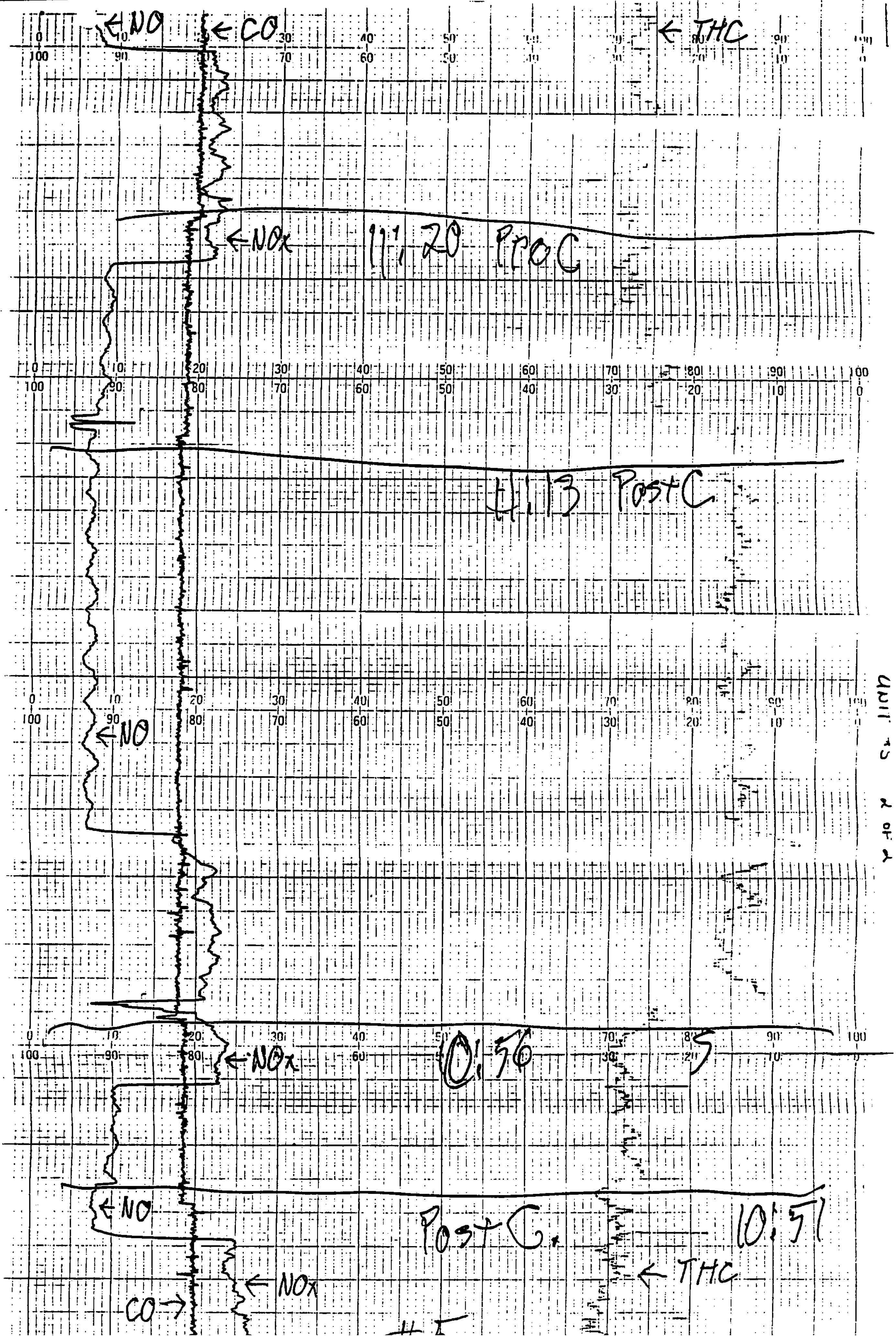

CO
NOx
THC
3:18
Post C
NO
3:13
PreC
NOx
2:37 S
NO
PreC 2:17
NOx
NO
CO
THC

UNIT # 4 2 OF 2

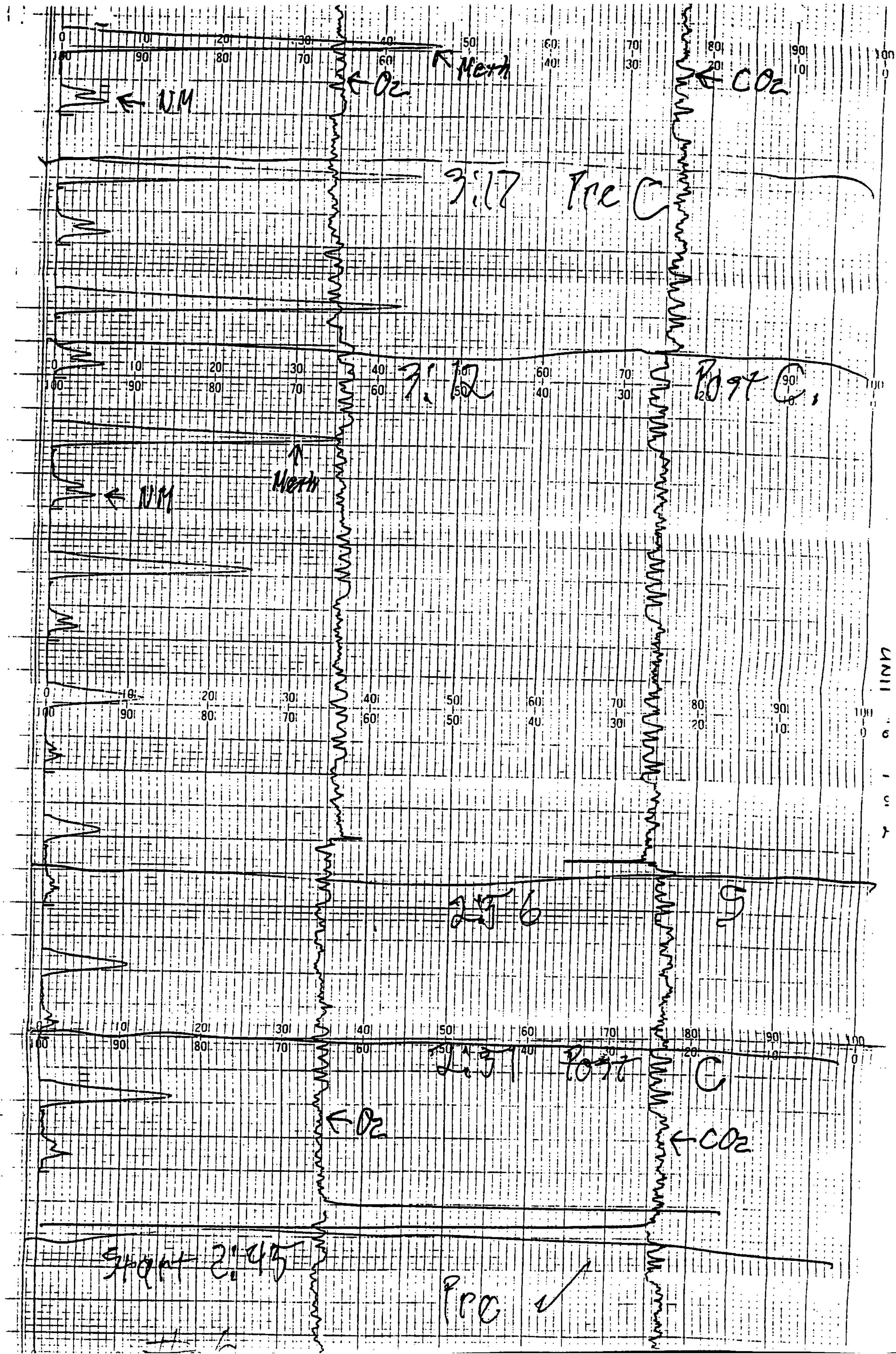


← O2
← CO2
0 10 20 30 40 50 60 70 80 90 100
100 90 80 70 60 50 40 30 20 10 0
← Meth
11:20
Pre C
← NM
← Meth
← NM
11:13
Post C
Meth
← NM
Meth
← NM
10:56
S
10:31
Post C
← O2
← CO2

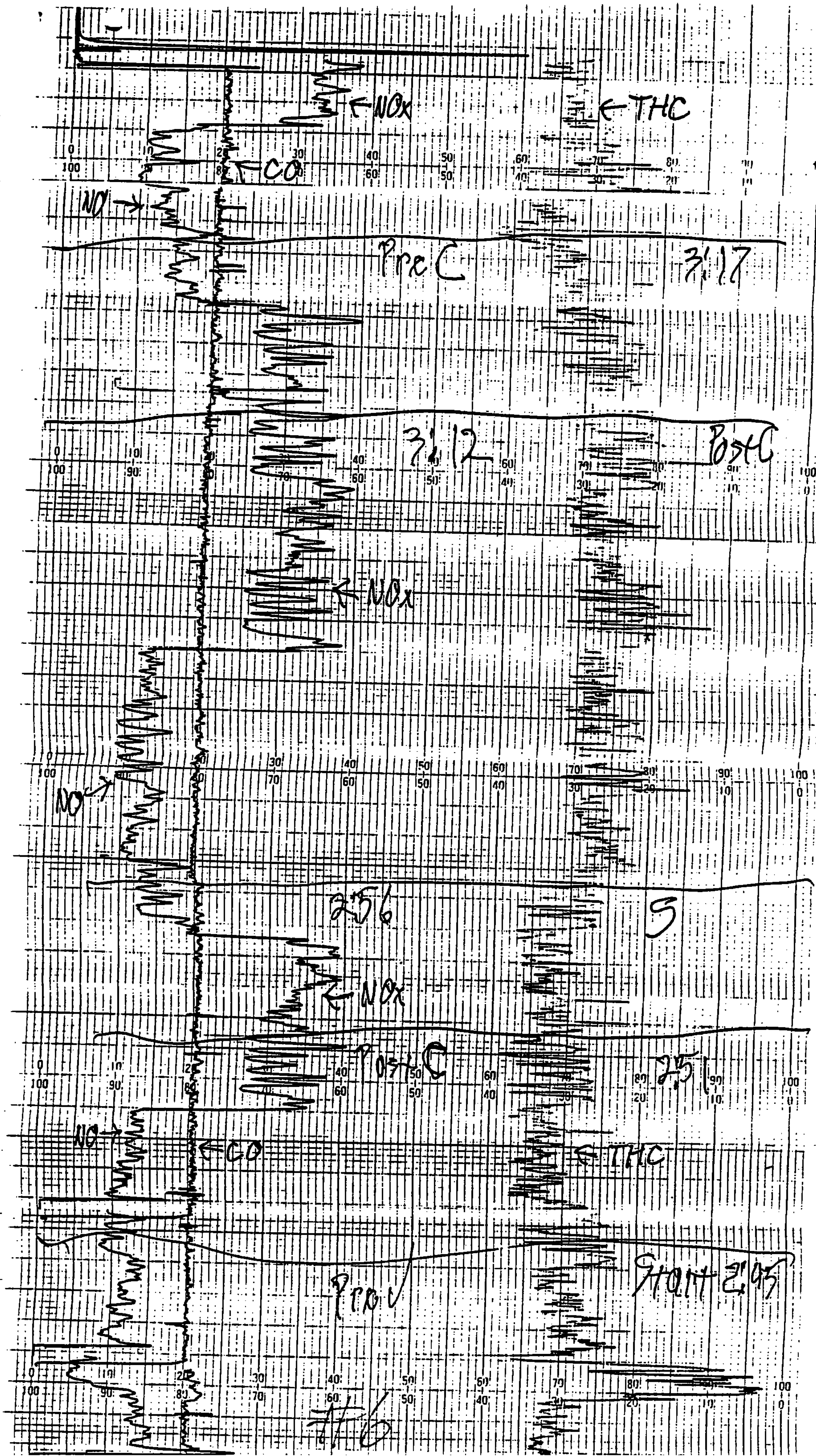
UNIT #5 1 OF 2



← NO
← CO
← THC
← NOx
11:20 PreC
11:13 PostC
← NO
10:56
← NOx
← NO
Post C.
10:51
← THC
← NOx
CO →

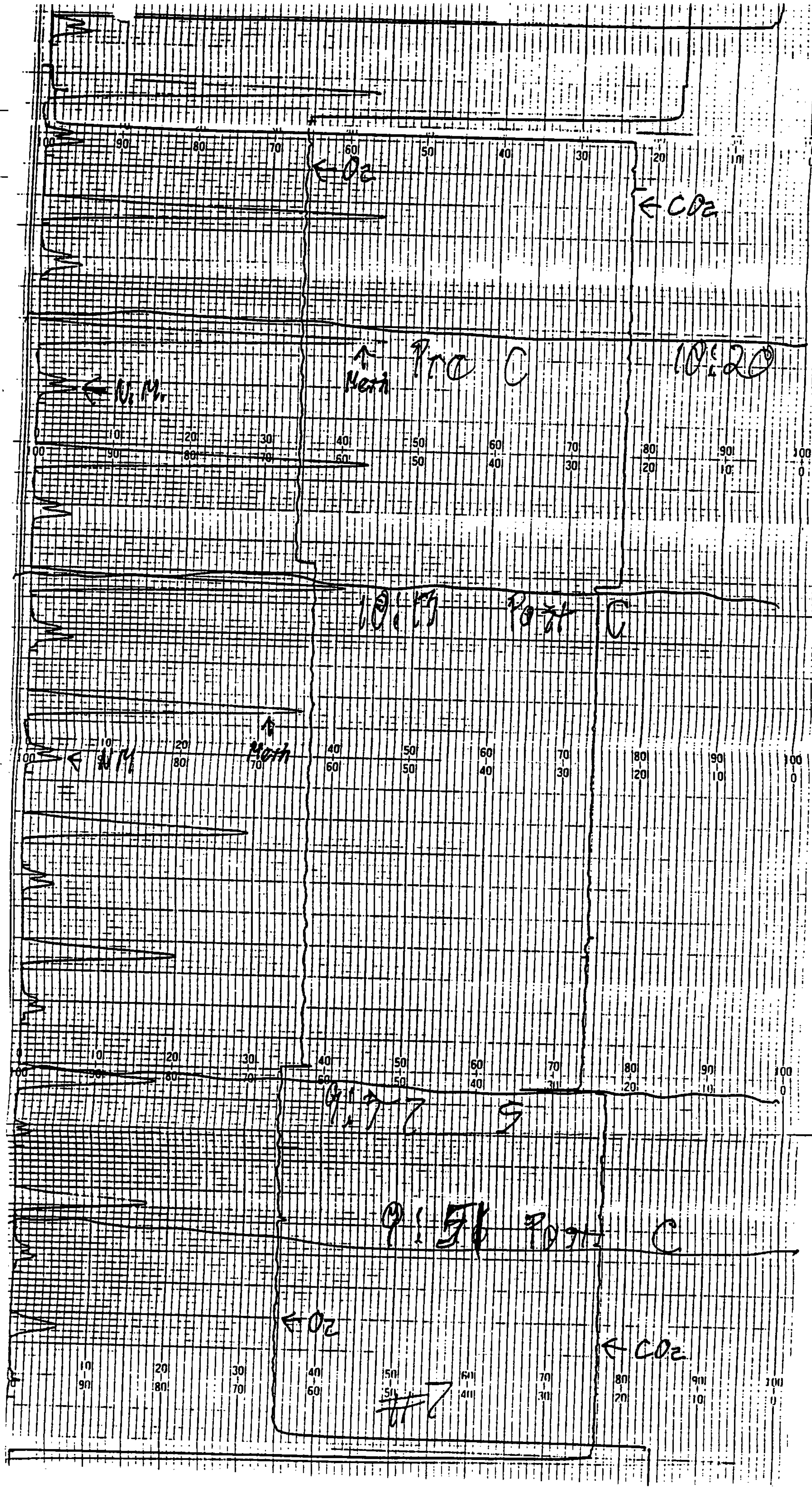


← NM
Meth
← O2
← CO2
3:17 Pre C
3:12 Post C
Meth
← NM
2:56 S
2:31 Post C
← O2
← CO2
Start 2:45
Pre

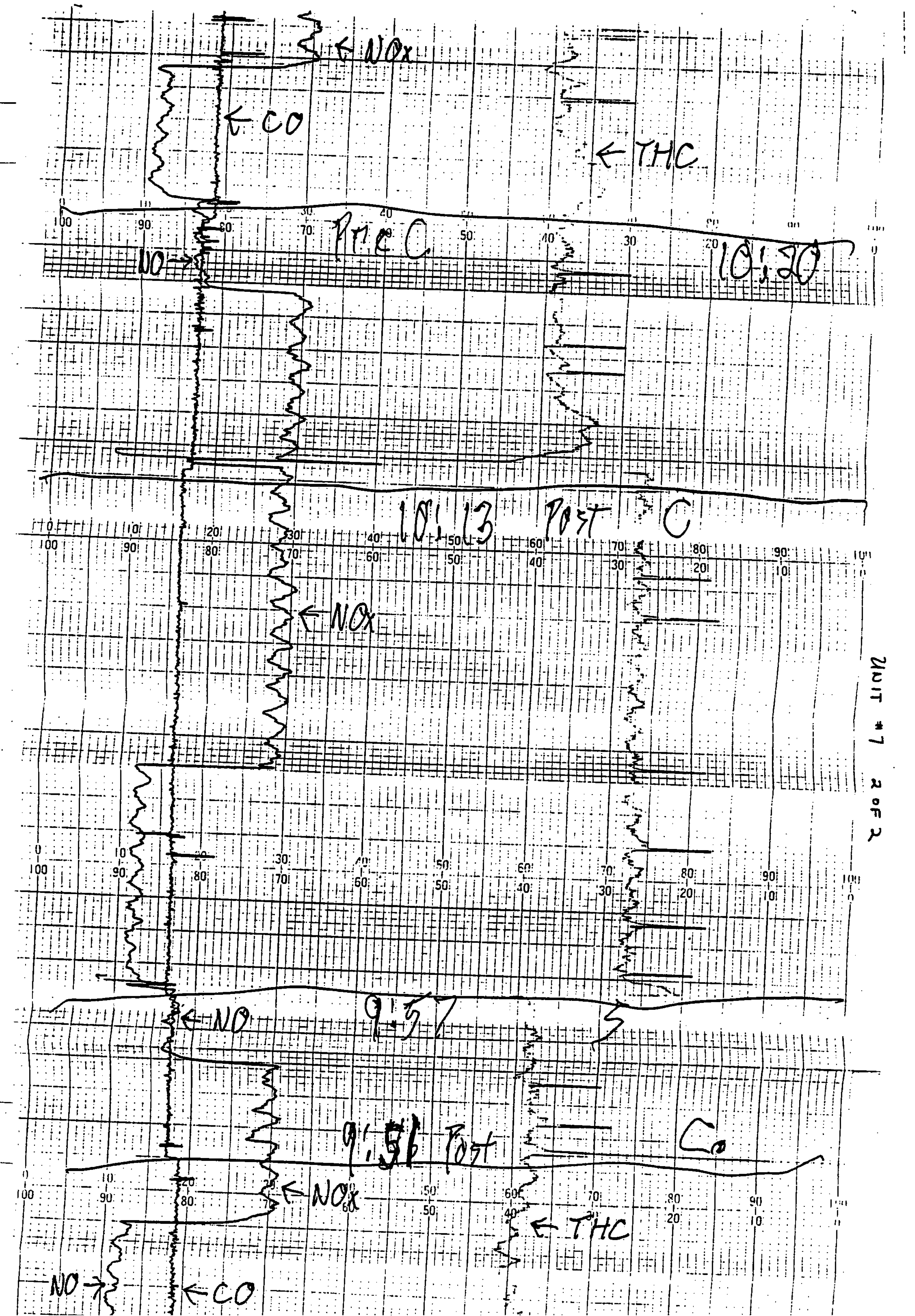


← NOx
← THC
← CO
NO →
PreC
3.17
3.12
PostC
← NOx
NO →
256
S
← NOx
PostC
251
NO →
← CO
← THC
Pre

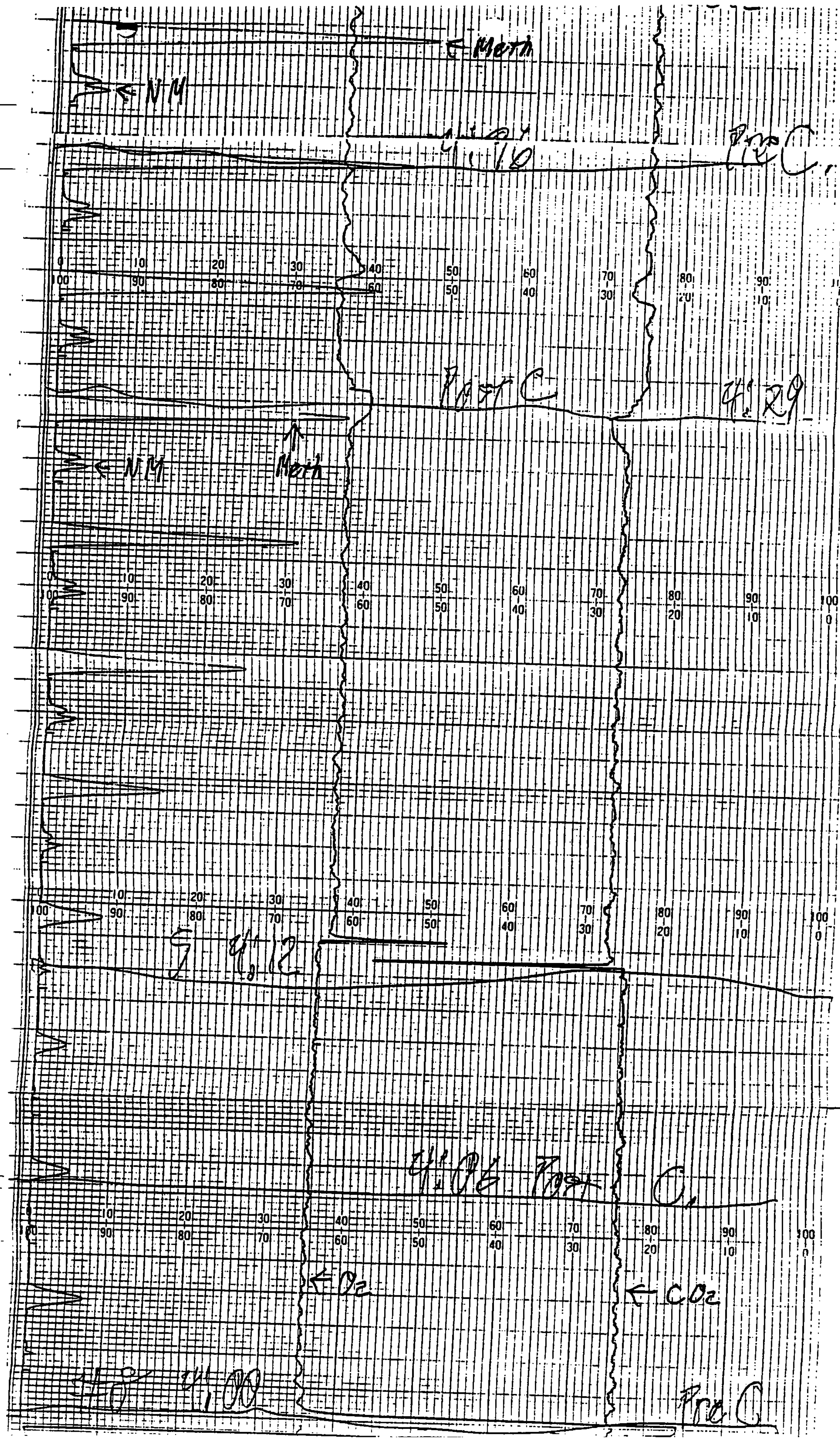
UNIT #6 2 OF 2



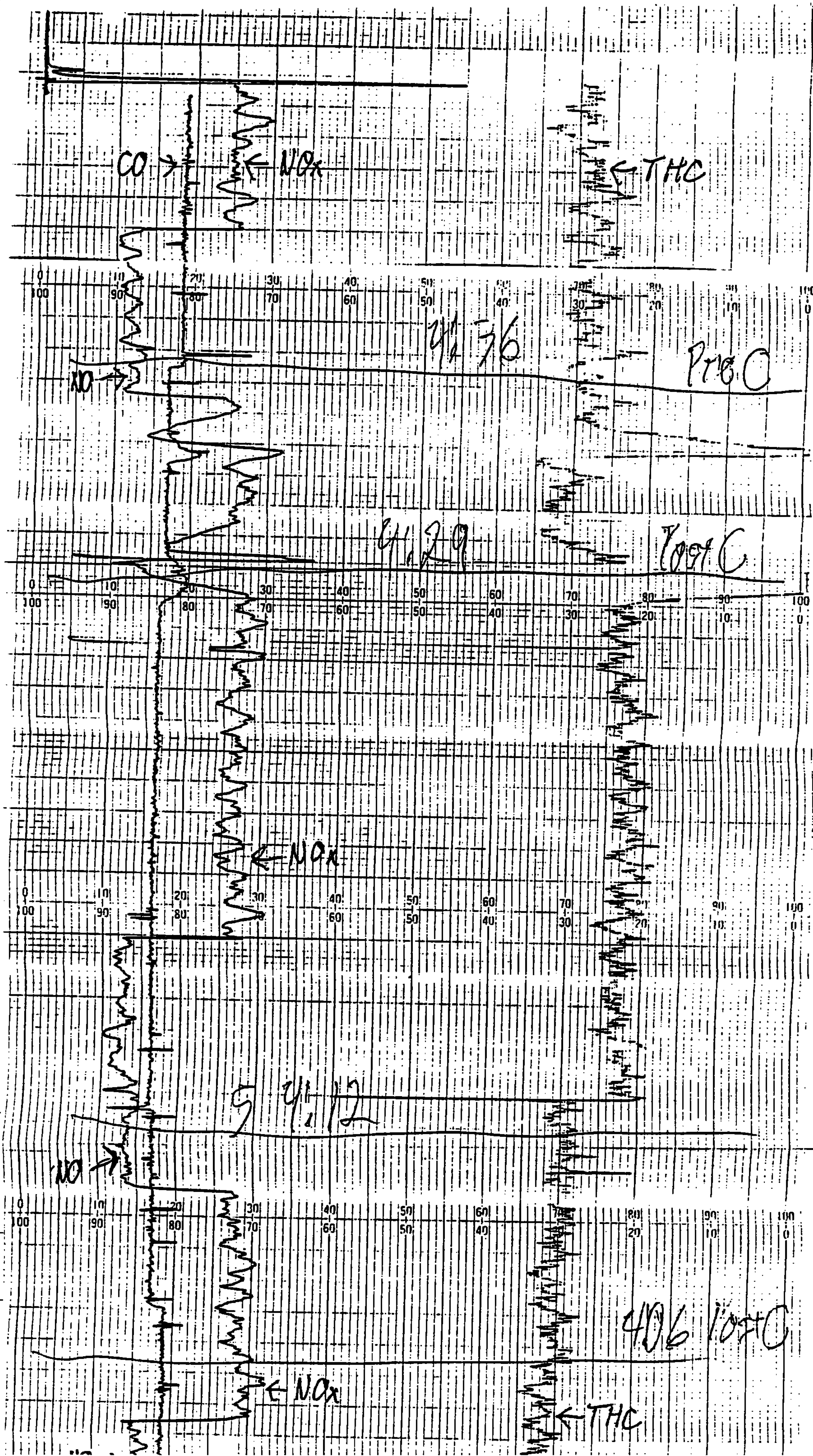
UNIT # 7 1 OF 2



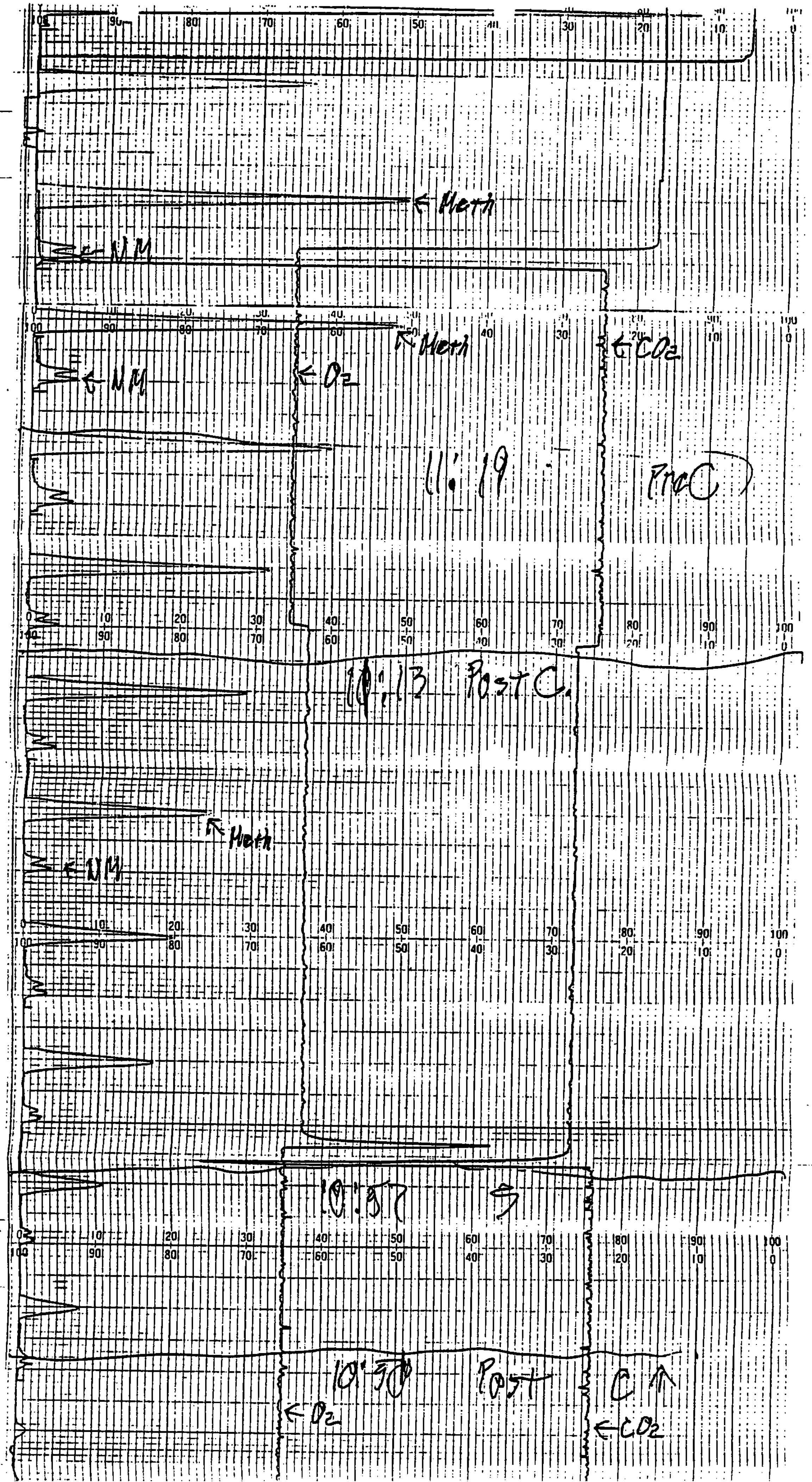
← NOx
← CO
← THC
Pre C
10:20
NO →
10:13 Post C
← NOx
9:57
← NO
9:56 Post Co
← NOx
← THC
NO →
← CO
UNIT #7 2 OF 2


← Meth
← NM
4:16
Pre C
Post C
4:29
← NM
↑ Meth
4:12
4:08 Post C
← O2
← CO2
4:00
Pre C

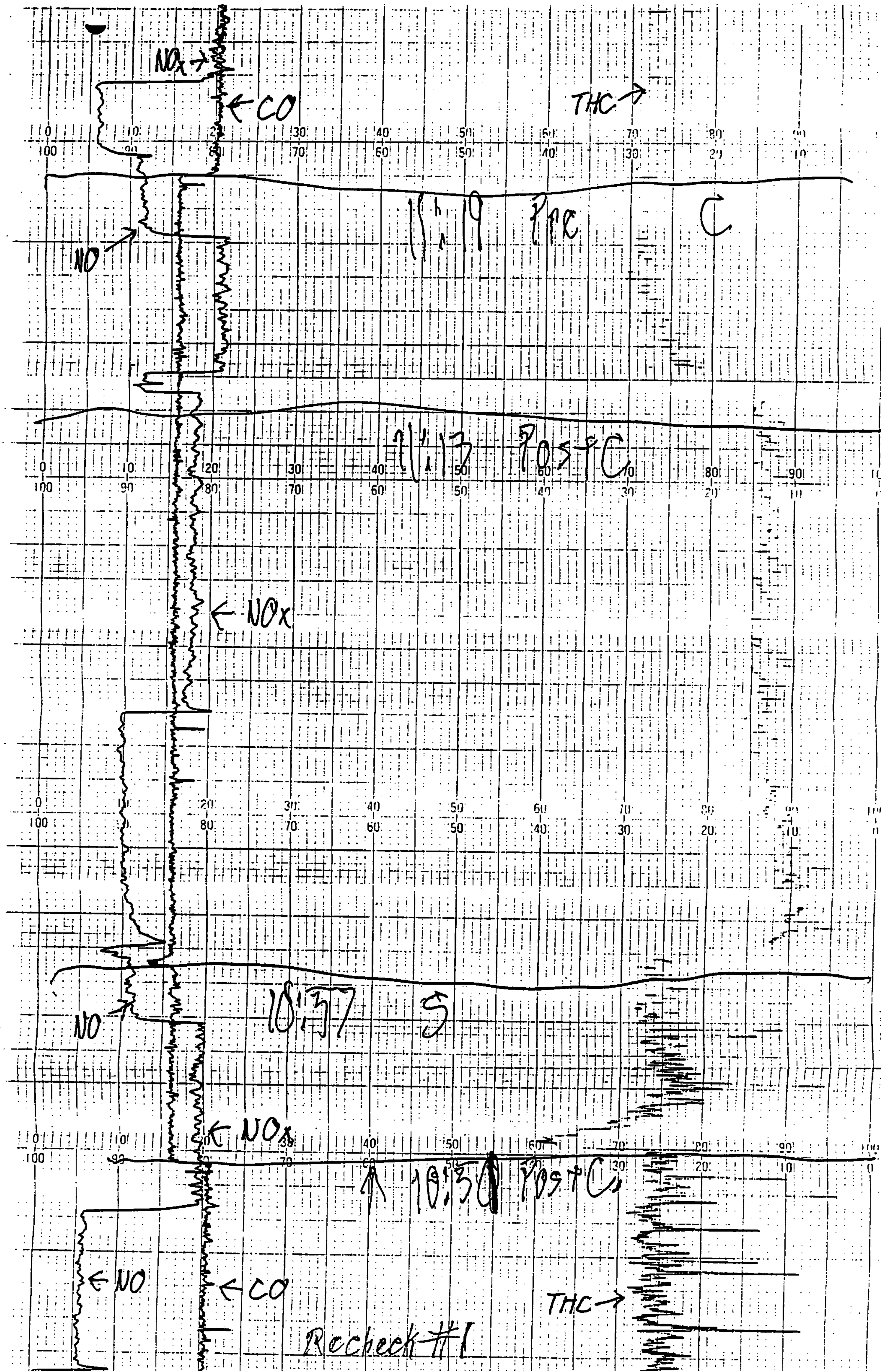
UNIT #8 1 of 2



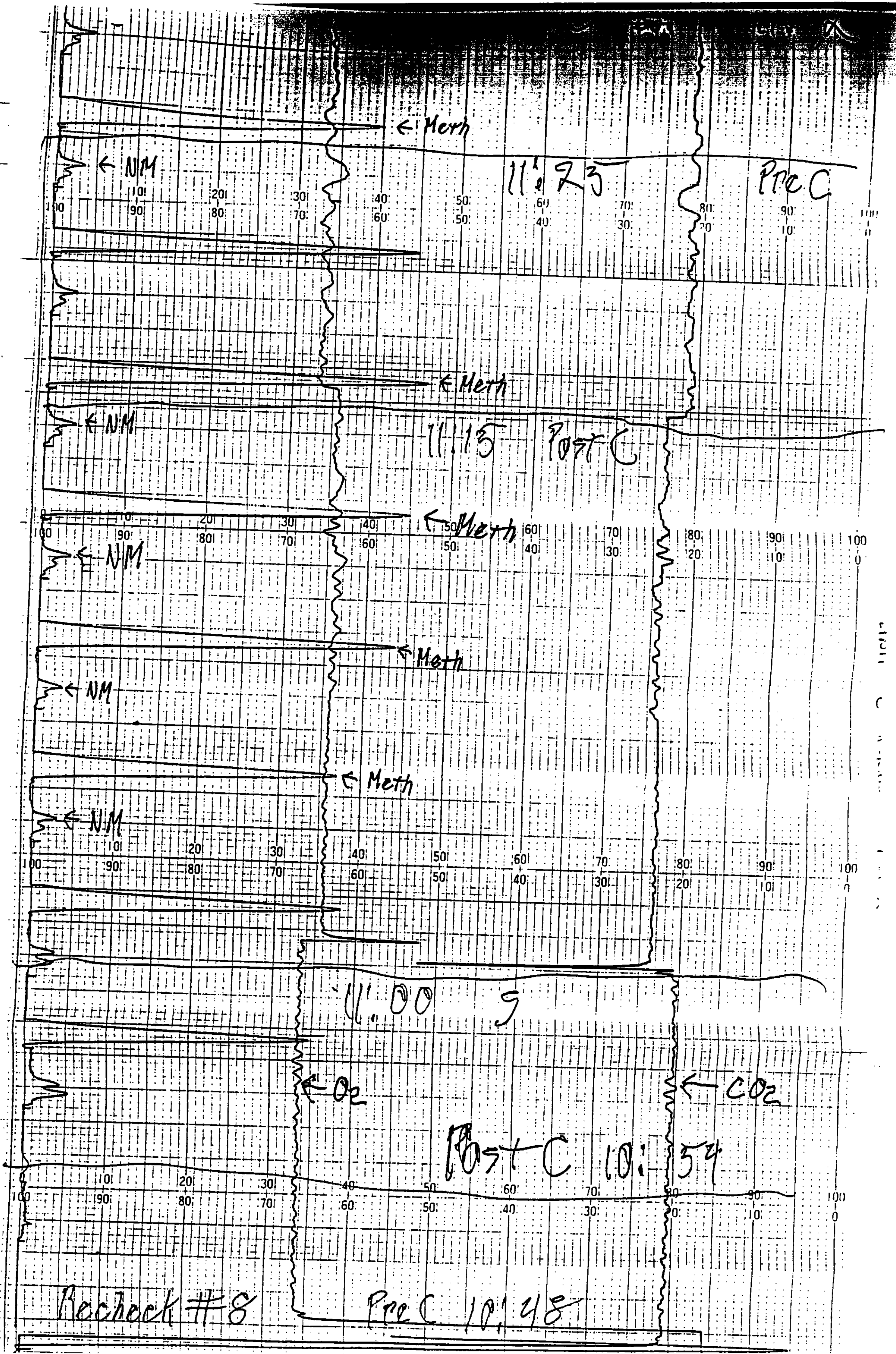
UNIT #8 2 OF 2

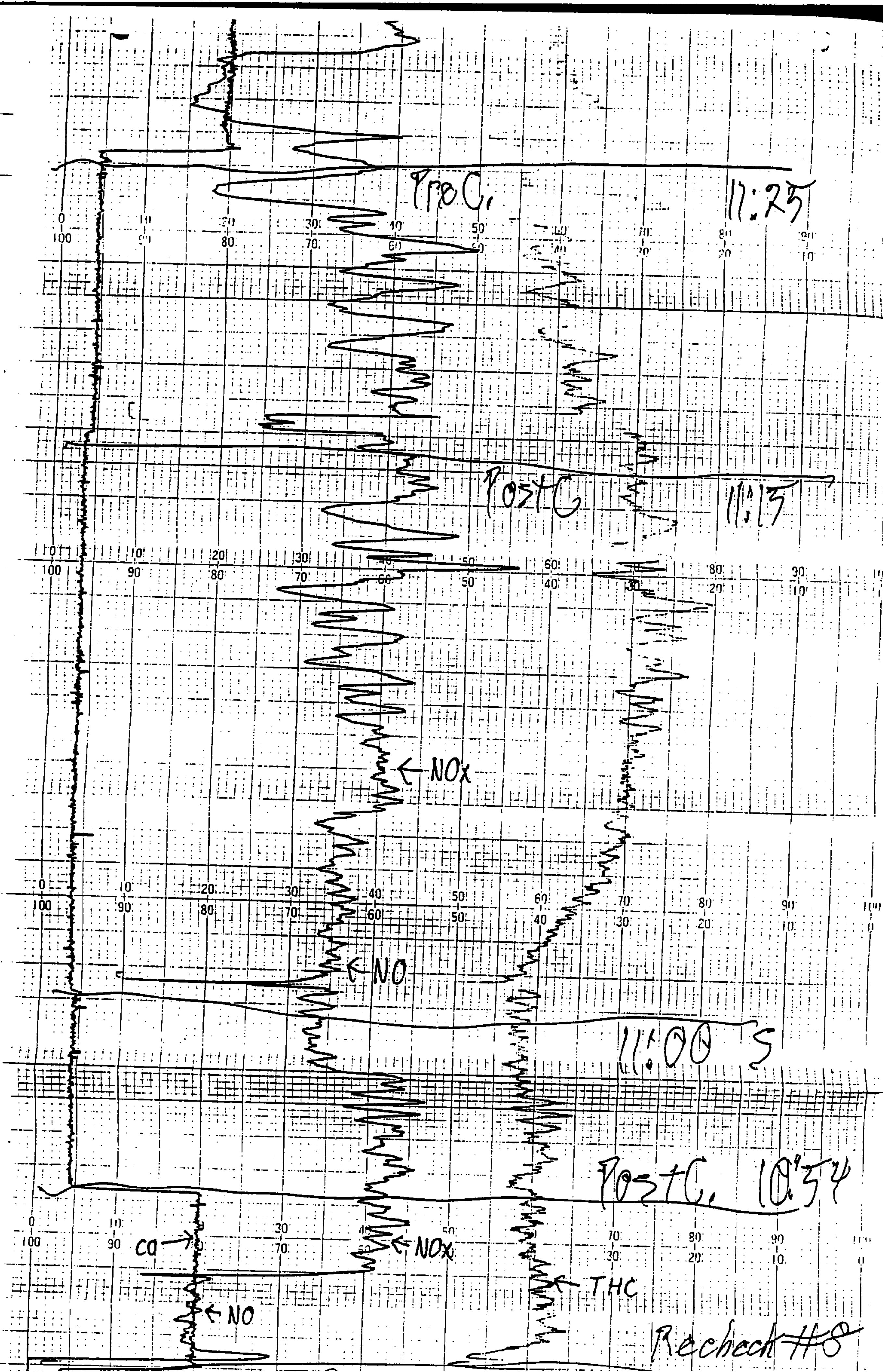


UNIT #1 - RERUN 1 of 2



UNIT #1 - RERUN 2 of 2


← Meth
← NM
11:23
Pre C
← Meth
← NM
11:15 Post C
← Meth
← NM
← Meth
← NM
← Meth
← NM
11:00 S
← O_2
← CO_2
Post C 10:54
Recheck #8
Pre C 10:48



UNIT #8 - RERUN 2 of 2

NM/Meth HC PPM

ENGINE #1

	A/F SPINDT	CO	CO_2 %	O_2 %	PPM HC	PPM NO	PPM NOX	~~NOX GRAMS BHP HR~~
Pre 1.	8.747	460	11.57	8.35	1860	37	74	31/2000
Post 2.	8.731	407	11.59	8.30	1785	63	76	30/2100
S 3.	9.110	377	11.07	8.93	2220	44	75	26/2500
Post 4	8.744	407	11.59	8.33	1785	59	78	25/2080
Pre 5	8.740	466	11.57	8.33	1845	34	76	30/2050

NM/Meth. PPM

#2

	A/F SPINDT	CO	CO_2 %	O_2 %	PPM HC	PPM NO	PPM NOX	~~NOX GRAMS BHP HR~~
Pre 1	8.978	484	11.25	8.70	1920	39	75	35/2140
Post 2	8.976	454	11.25	8.70	1956	39	76	35/2115
S 3	9.227	442	-10.90	9.08	2205	32	71	31/2575
Post 4	9.042	454	11.12	8.80	2130	25	60	33/2665
Pre 5	9.041	484	11.12	8.80	2115	26	55	38/2440

#3

	A/F SPINDT	CO	CO_2 %	O_2 %	PPM HC	PPM NO	PPM NOX	~~NOX GRAMS BHP HR~~ NM/Meth PPM
Pre 1	8.274	460	11.39	8.43	1770	42	99	24/1895
Post 2	8.261	389	11.41	8.38	1680	61	99	23/2030
S 3	8.628	342	10.90	9.00	2025	58	100	21/1975
Post 4	8.276	389	11.39	8.40	1665	63	105	23/2030
Pre 5	8.270	460	11.39	8.40	1680	49	108	24/1895

#4

NM/Meth. PPM

	A/F SPINDT	CO	CO_2 %	O_2 %	PPM HC	PPM NO	PPM NOX	~~NOX GRAMS BHP~~ HR
Pre 1	9.007	454	11.17	8.70	1905	28	56	30/2365
Post 2	9.003	389	11.17	8.68	1905	27	58	29/2410
S 3	9.354	372	10.68	9.20	2265	22	56	30/2190
Post 4	8.960	389	11.19	8.60	1935	26	59	29/2410
Pre 5	8.971	454	11.19	8.63	1905	27	58	30/2365

#5

NM/Meth. PPM

	A/F SPINDT	CO	CO_2 %	O_2 %	PPM HC	PPM NO	PPM NOX	~~NOX GRAMS BHP-HR~~
Pre 1	8.408	466	11.17	8.70	2115	20	61	26/2465
Post 2	8.419	430	11.17	8.73	2145	26	57	29/2600
5 3	8.779	419	10.63	9.30	2565	18	54	31/2490
Post 4	8.472	436	11.08	8.80	2160	23	55	29/2600
Pre 5	8.467	466	11.08	8.80	2190	18	55	26/2465

6

NM/Meth. PPM

	A/F SPINDT	CO	CO_2 %	O_2 %	PPM HC	PPM NO	PPM NOX	~~NOX GRAMS BHP HR~~
Pre 1	8.954	472	11.30	8.70	2025	33	80	30/2275
Post 2	8.924	477	11.30	8.63	2025	35	85	33/2235
5 3	9.156	460	10.99	8.98	2175	33	80	31/2125
Post 4	8.901	477	11.30	8.58	2040	39	78	33/2235
Pre 5	8.904	477	11.30	8.58	2010	31	84	30/2275

7

NM/Meth PPM

	A/F SPINDT	CO	CO_2 %	O_2 %	PPM HC	PPM NO	PPM NOX	~~HSP~~ ~~GRAMS~~ ~~BHP-HR~~
Pre 1	8.954	436	11.35	8.68	1815	30	75	26/2100
Post 2	8.925	401	11.37	8.63	1860	43	74	25/2265
S 3	9.331	378	10.83	9.25	2190	31	72	27/2040
Post 4	8.925	401	11.37	8.63	1860	43	74	25/2265
Pre 5	8.924	436	11.37	8.63	1845	31	74	26/2100

NM/Meth PPM

#8

	A/F SPINOT	CO	CO_2 %	O_2 %	PPM HC	PPM NO	PPM NOX	~~NOX GRAMS BHP-HR~~
Pre 1	9.030	442	11.19	8.80	2040	39	74	26/2350
Post 2	9.115	395	11.08	8.93	2115	34	68	23/2050
S 3	9.410	377	10.72	9.38	2340	31	66	22/1865
Post 4	9.130	395	11.08	8.95	2055	31	69	23/2050
Pre 5	9.125	430	11.12	9.00	2160	30	63	26/2350

Recheck #1

NH/Meth. PPM

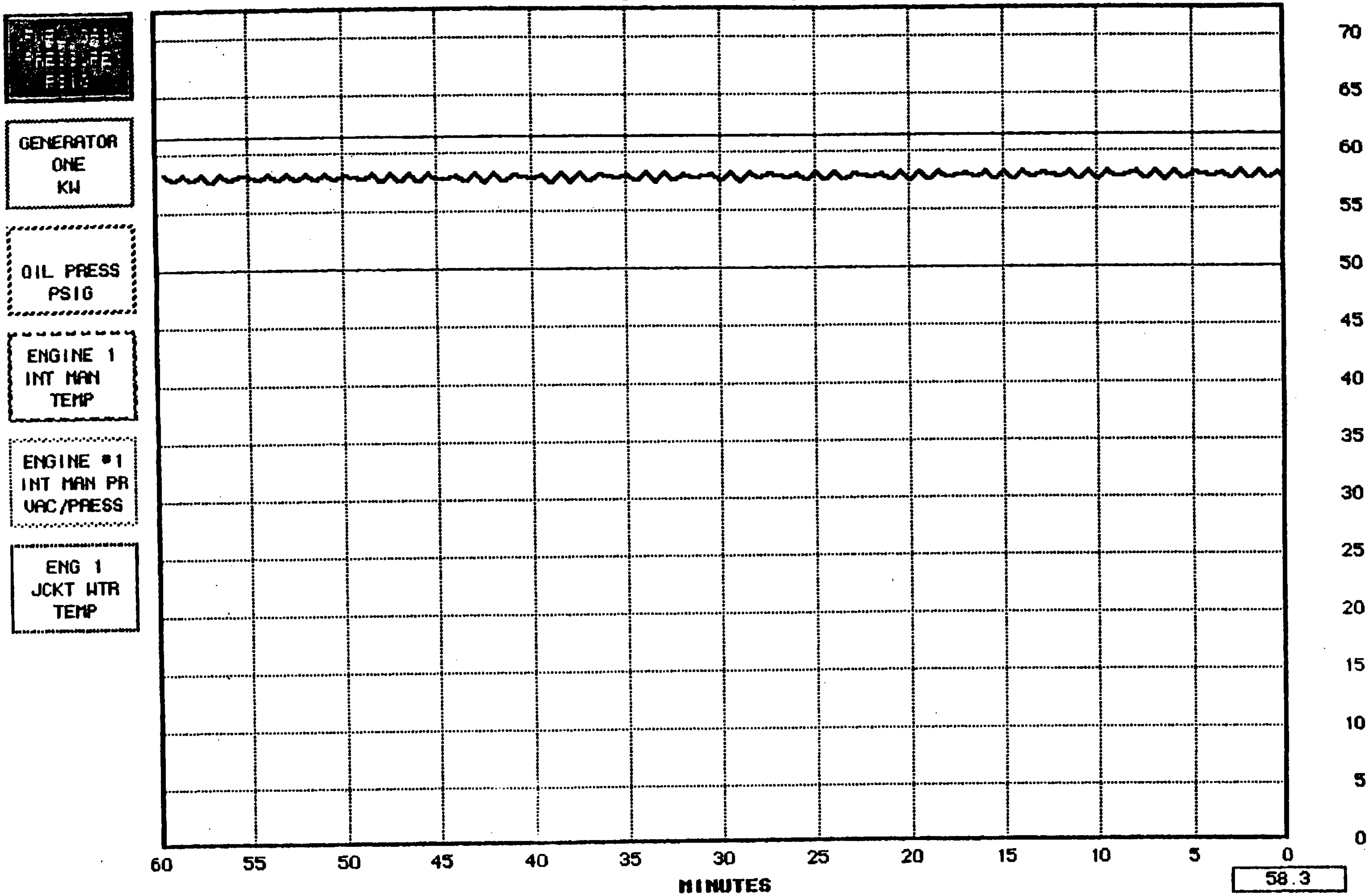
	A/F SPINDT	CO	CO_2 %	O_2 %	PPM HC	PPM NO	PPM NOX	~~NOX GRAMS BHP-HR~~
Pre 1	8.971	478	11.17	8.70	2235	15	49	30/2450
Post 2	8.975	378	11.17	8.70	2250	28	49	28/1990
S 3	9.346	366	10.66	9.25	2595	25	45	20/1580
Post 4	8.976	372	11.17	8.68	2160	29	53	28/1990
Pre 5	8.974	478	11.17	8.70	2205	16	51	30/2450

#8 Recheck

NM/Meth PP

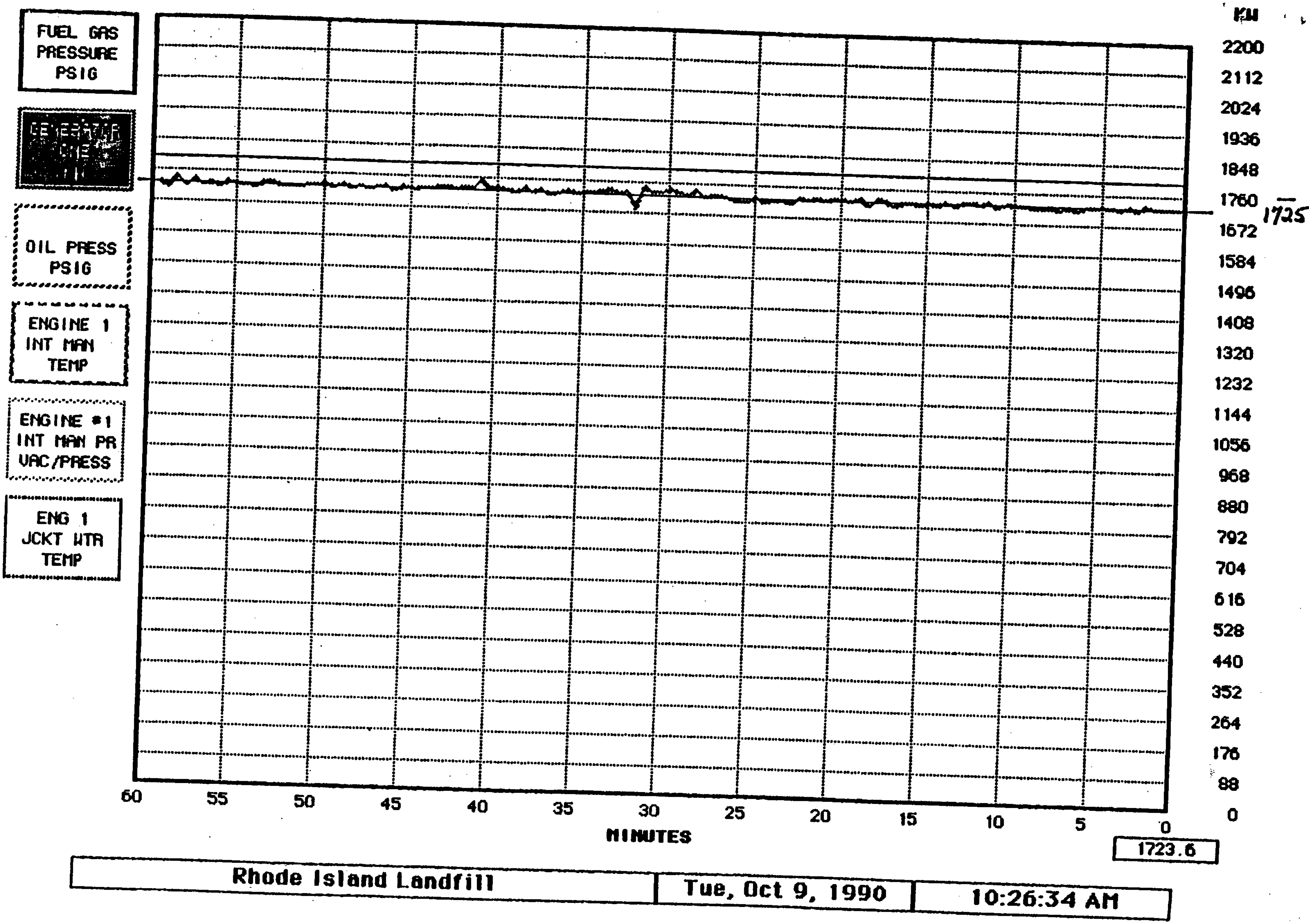
	A/F SPINDT	CO	CO_2 %	O_2 %	PPM HC	PPM NO	PPM NOX	~~NOX GRAMS BHP HR~~
Pre 1	8.265	466	11.79	8.35	1800	49	104	19/2000
Post 2	8.269	98	11.84	8.33	1740	84	105	18/2010
S 3	8.662	86	11.25	8.98	2100	88	101	19/2325
Post 4	8.365	104	11.61	8.43	1785	78	104	18/2010
Pre 5	8.346	466	11.61	8.43	1785	51	100	19/2000

Un #1

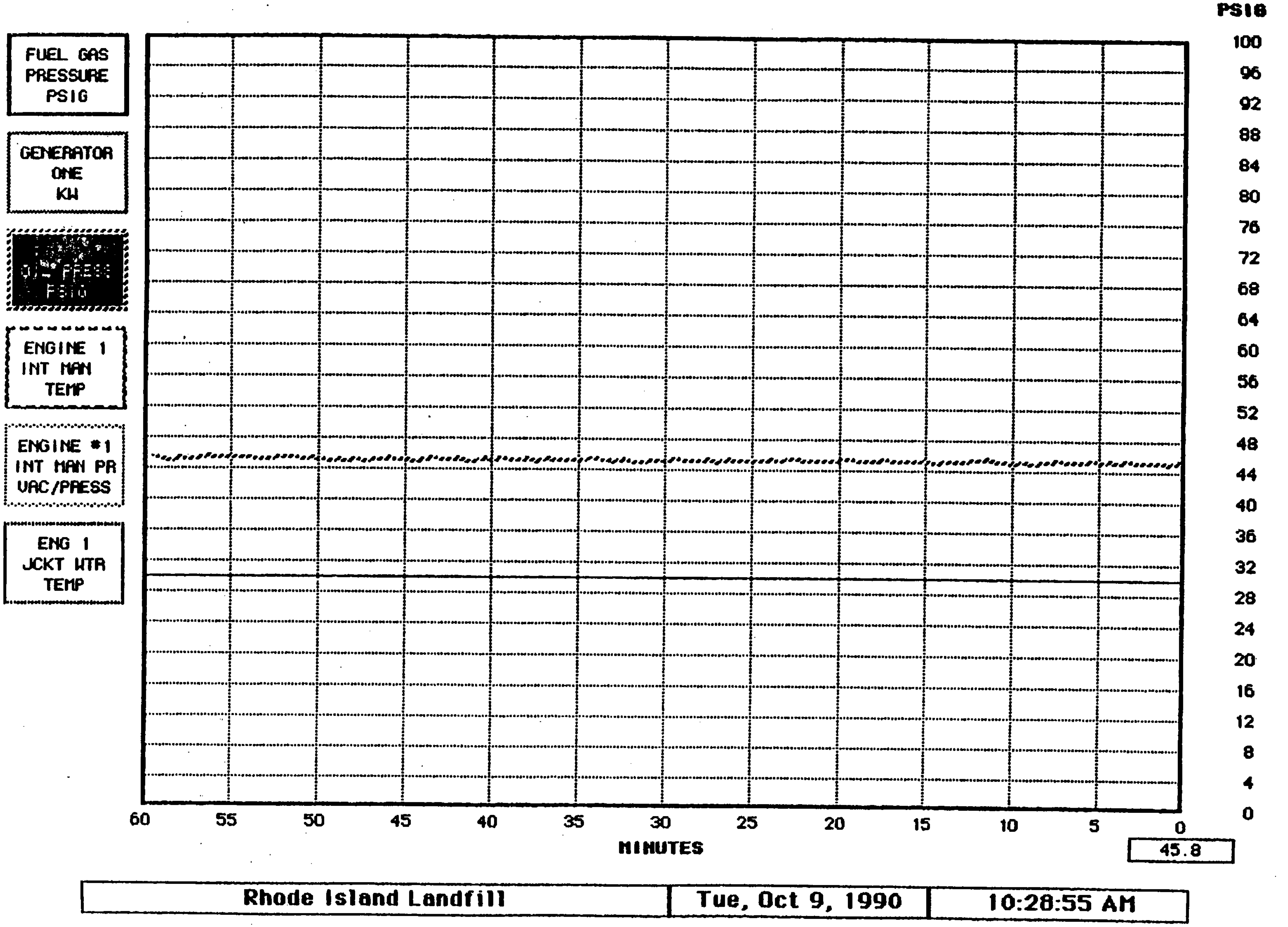


Rhode Island Landfill	Tue, Oct 9, 1990	10:24:12 AM

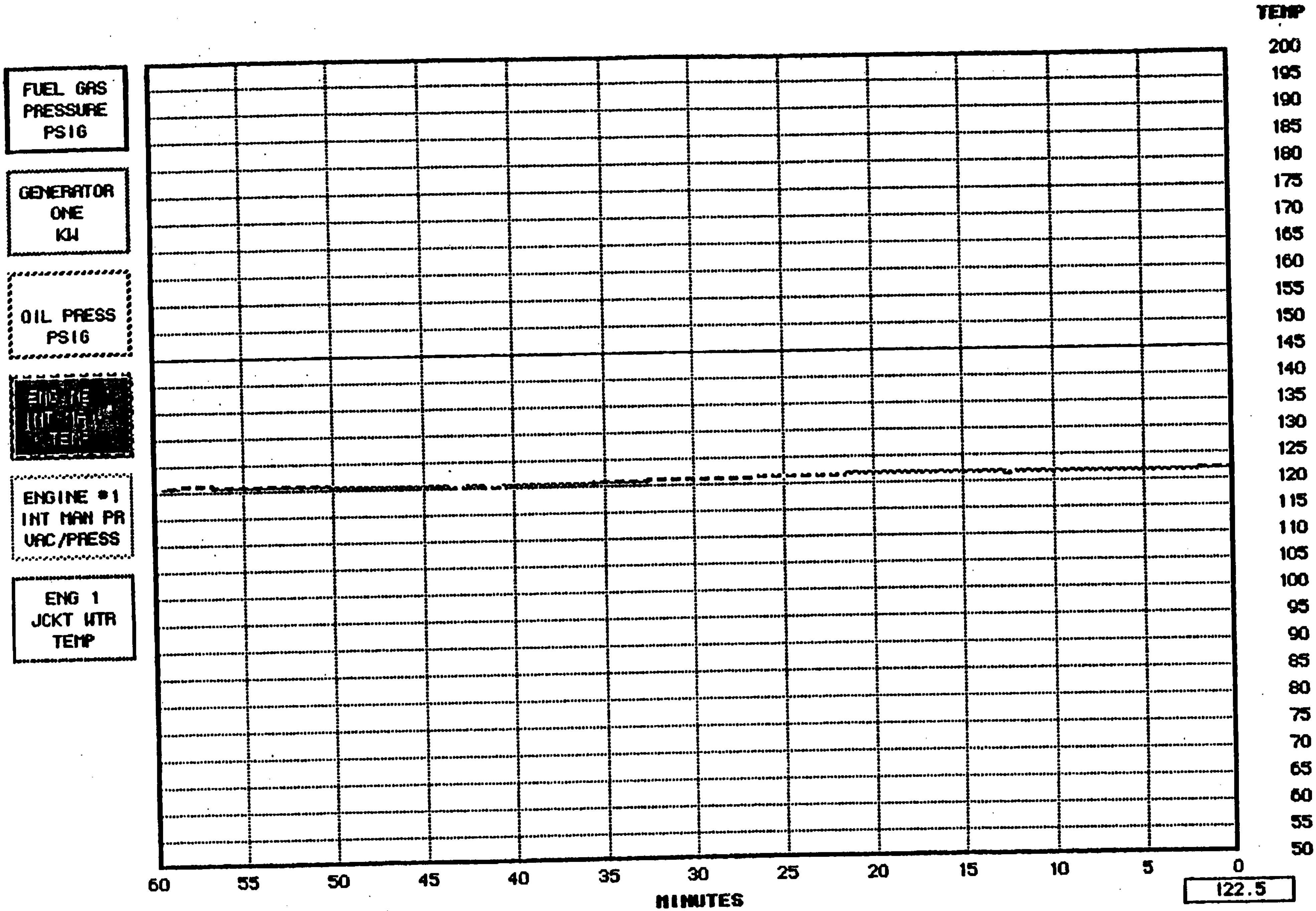
UNIT #1


FUEL GAS PRESSURE PSIG
OIL PRESS PSIG
ENGINE 1 INT MAN TEMP
ENGINE #1 INT MAN PR VAC/PRESS
ENG 1 JCKT WTR TEMP
KW
2200
2112
2024
1936
1848
1760
1672
1584
1496
1408
1320
1232
1144
1056
968
880
792
704
616
528
440
352
264
176
88
0
1725
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
1723.6
Rhode Island Landfill
Tue, Oct 9, 1990
10:26:34 AM

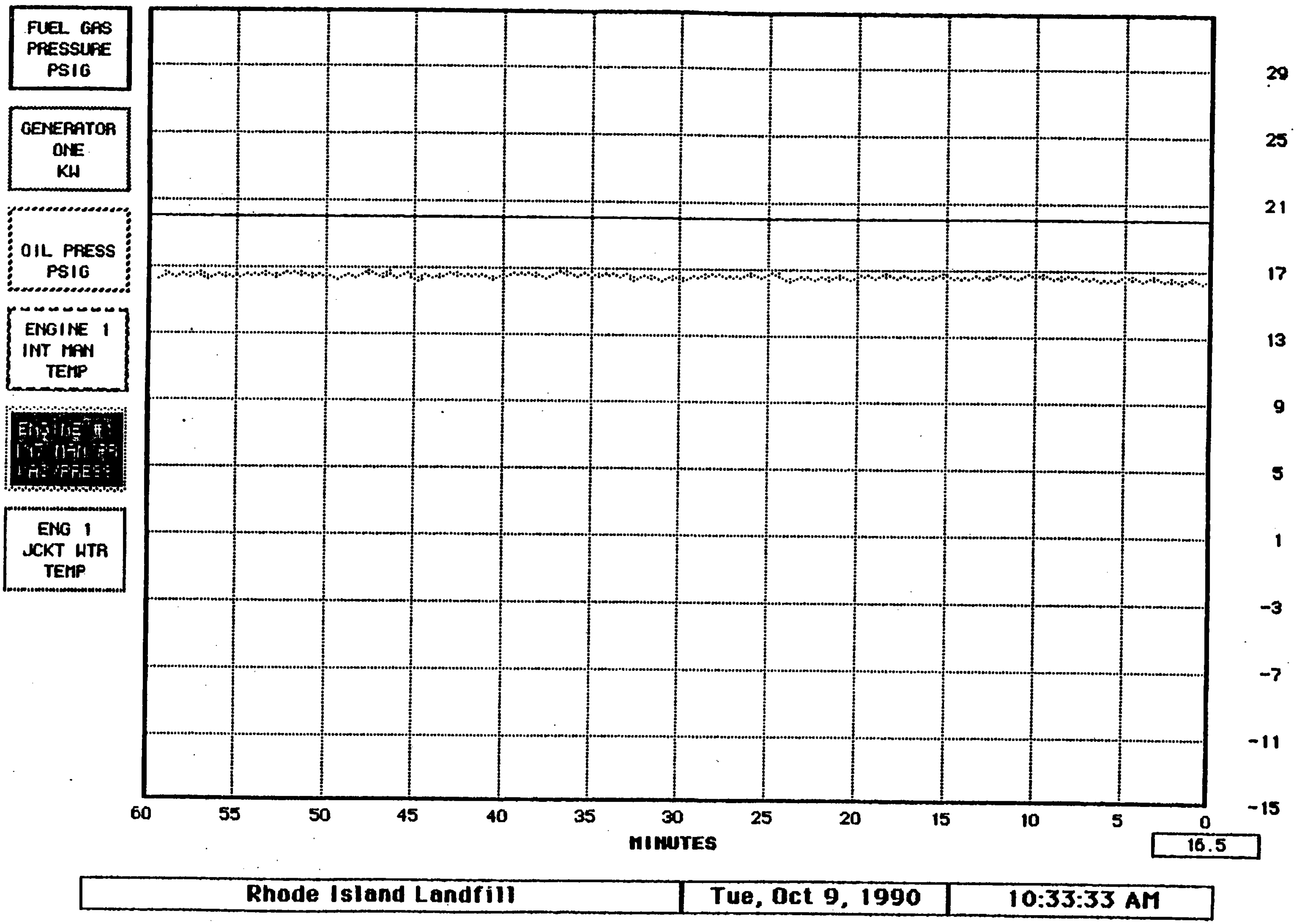
PSIG



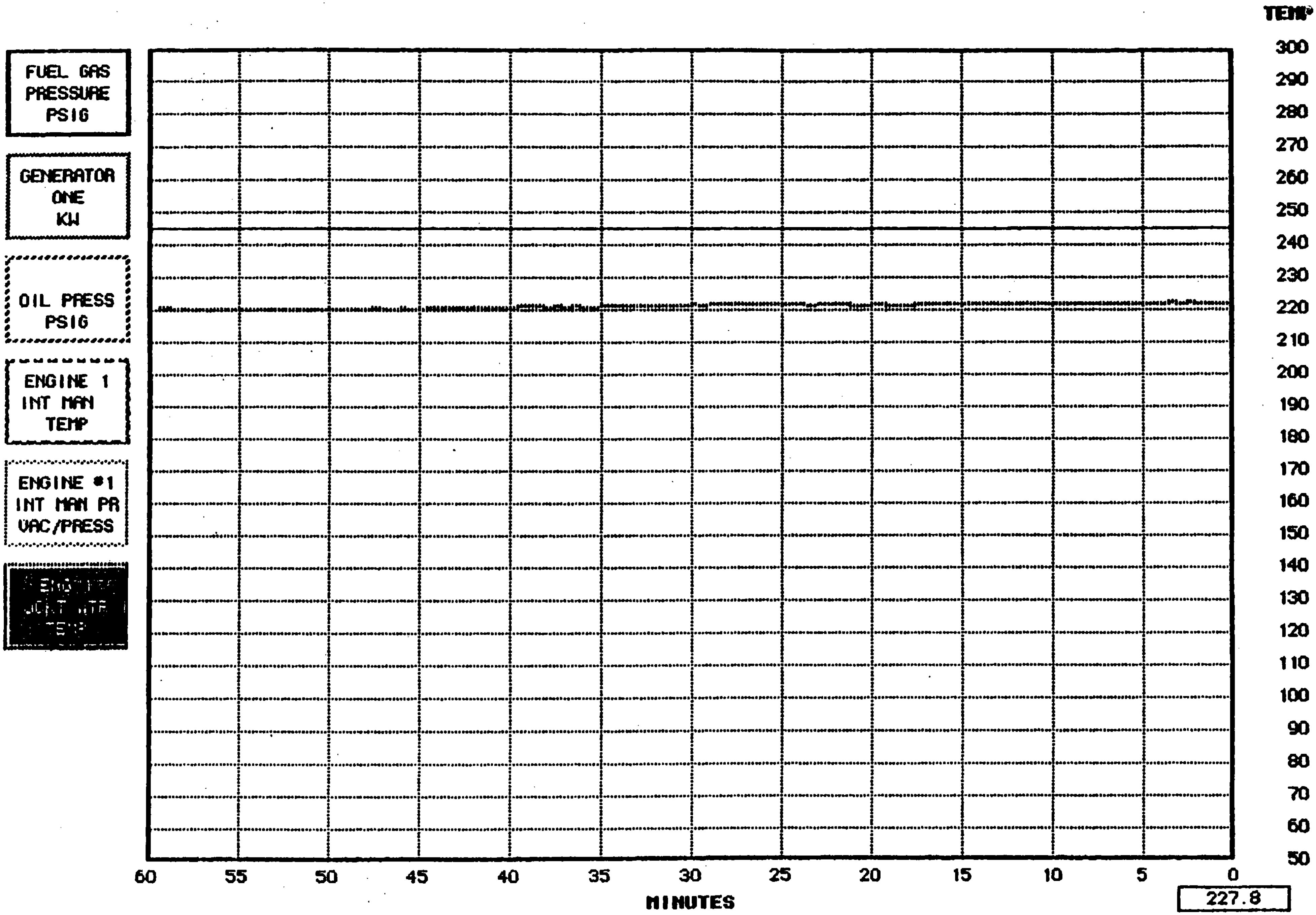
FUEL GAS PRESSURE PSIG
GENERATOR ONE KW
PRESS
ENGINE 1 INT MAN TEMP
ENGINE #1 INT MAN PR VAC/PRESS
ENG 1 JCKT WTR TEMP
PSIG
100
96
92
88
84
80
76
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
45.8
Rhode Island Landfill
Tue, Oct 9, 1990
10:28:55 AM



Rhode Island Landfill	Tue, Oct 9, 1990	10:31:13 AM

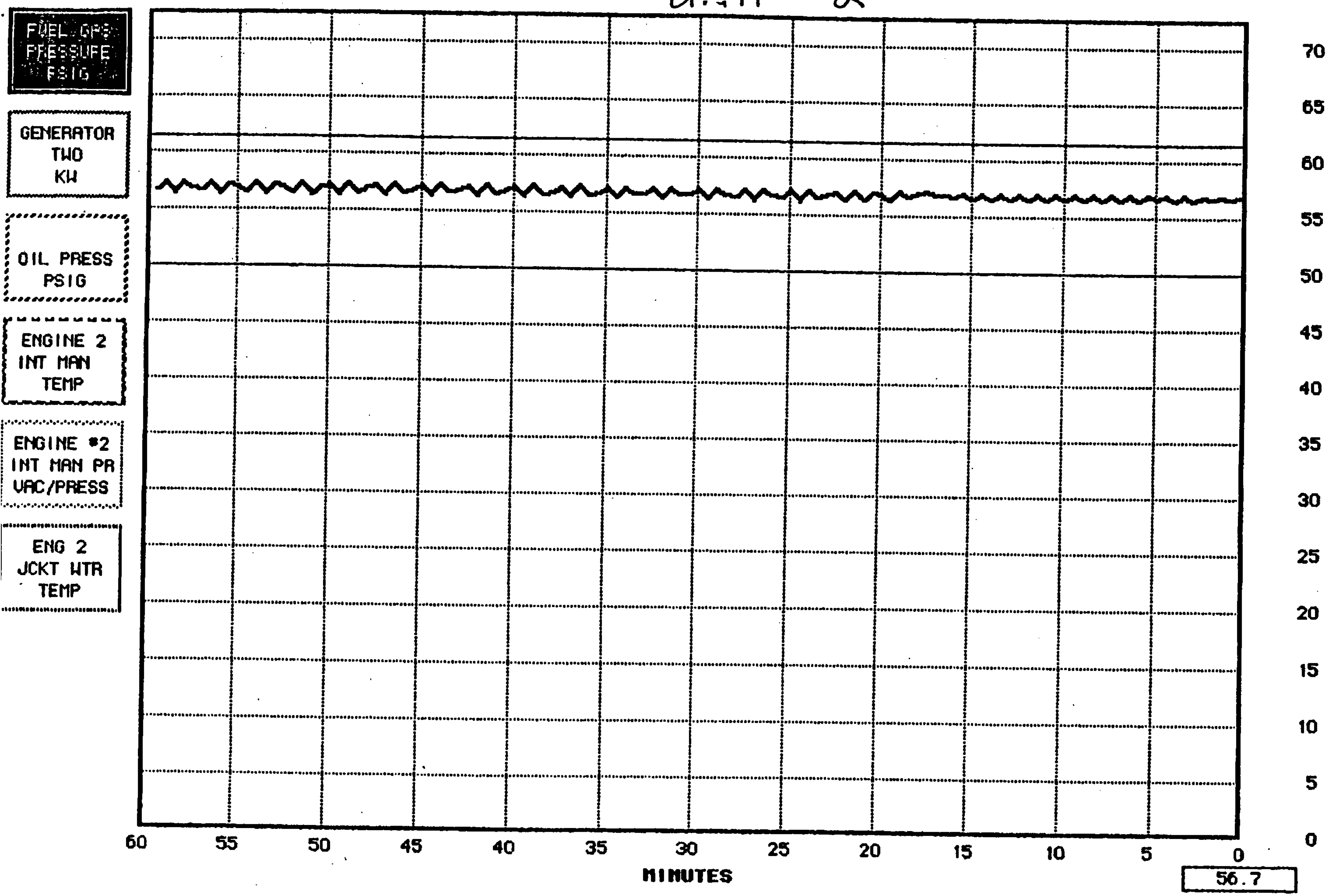


FUEL GAS PRESSURE PSIG
GENERATOR ONE KW
OIL PRESS PSIG
ENGINE 1 INT MAN TEMP
ENG 1 JCKT WTR TEMP
29
25
21
17
13
9
5
1
-3
-7
-11
-15
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
16.5
Rhode Island Landfill
Tue, Oct 9, 1990
10:33:33 AM



Rhode Island Landfill	Tue, Oct 9, 1990	10:35:56 AM

UNIT #2



Rhode Island Landfill	Tue, Oct 9, 1990	3:34:51 PM

UNIT #2

FUEL GAS PRESSURE PSIG

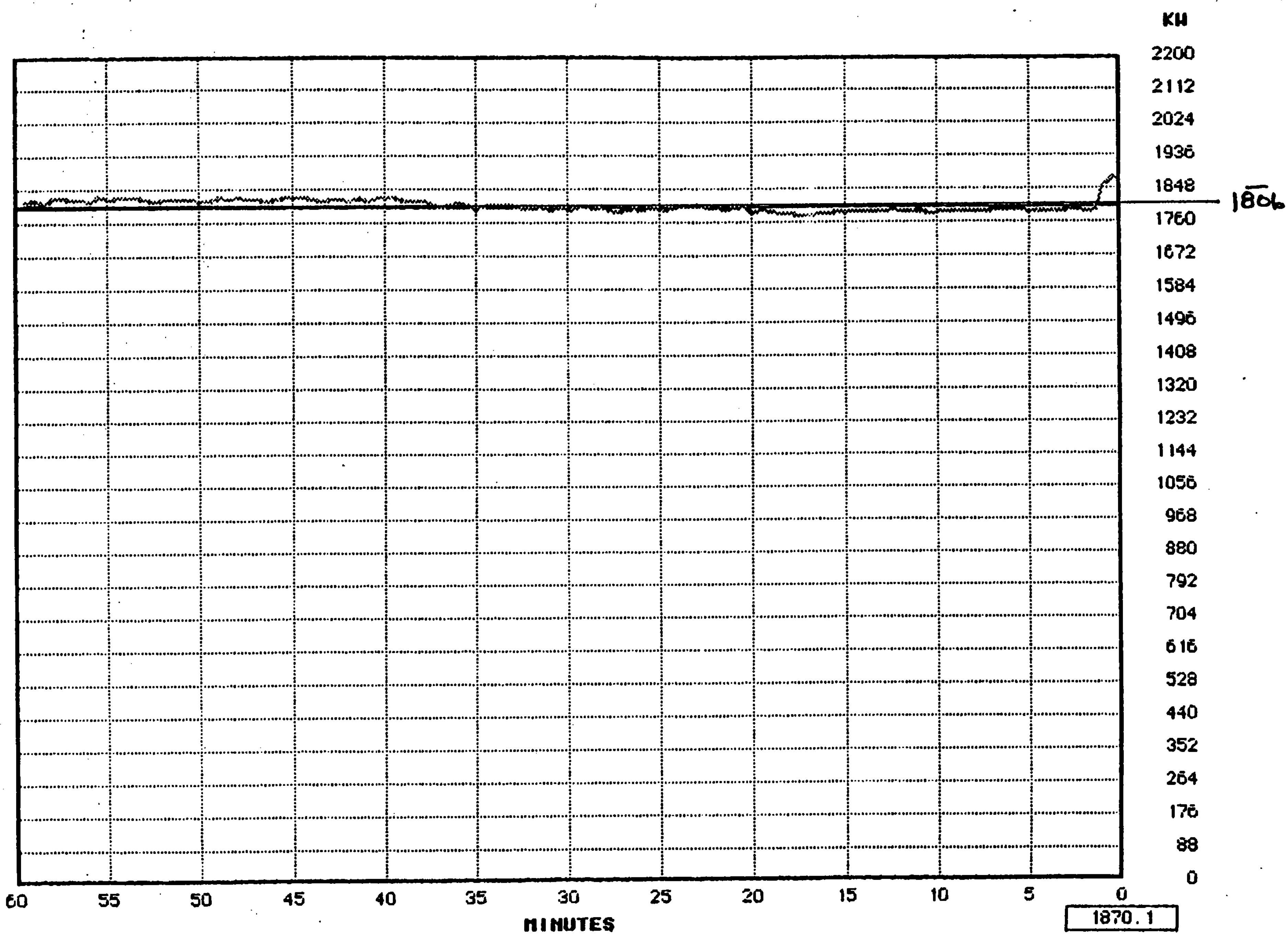
GENERATOR TWQ KW

OIL PRESS PSIG

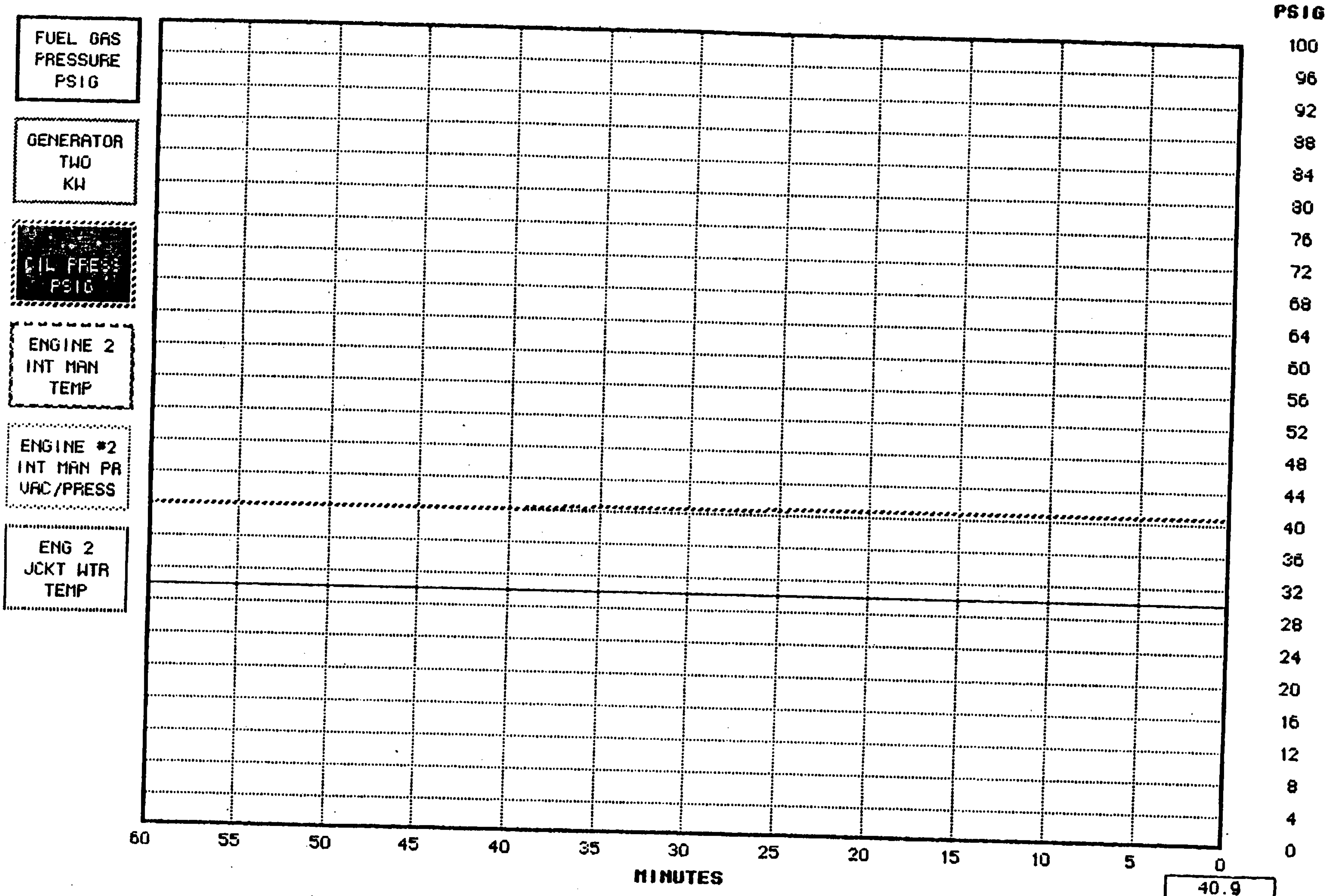
ENGINE 2 INT MAN TEMP

ENGINE #2 INT MAN PR VAC/PRESS

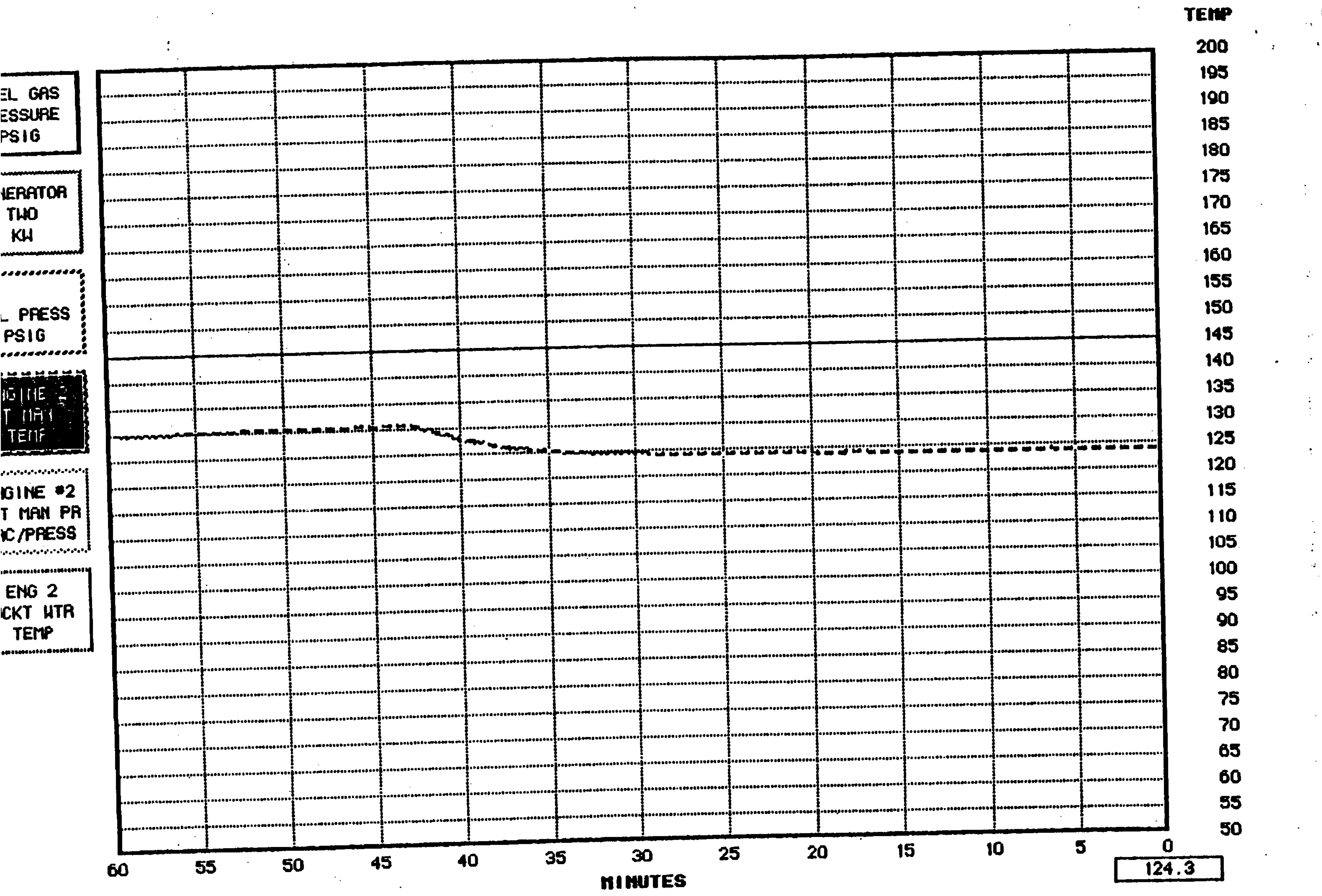
ENG 2 JCKT WTR TEMP



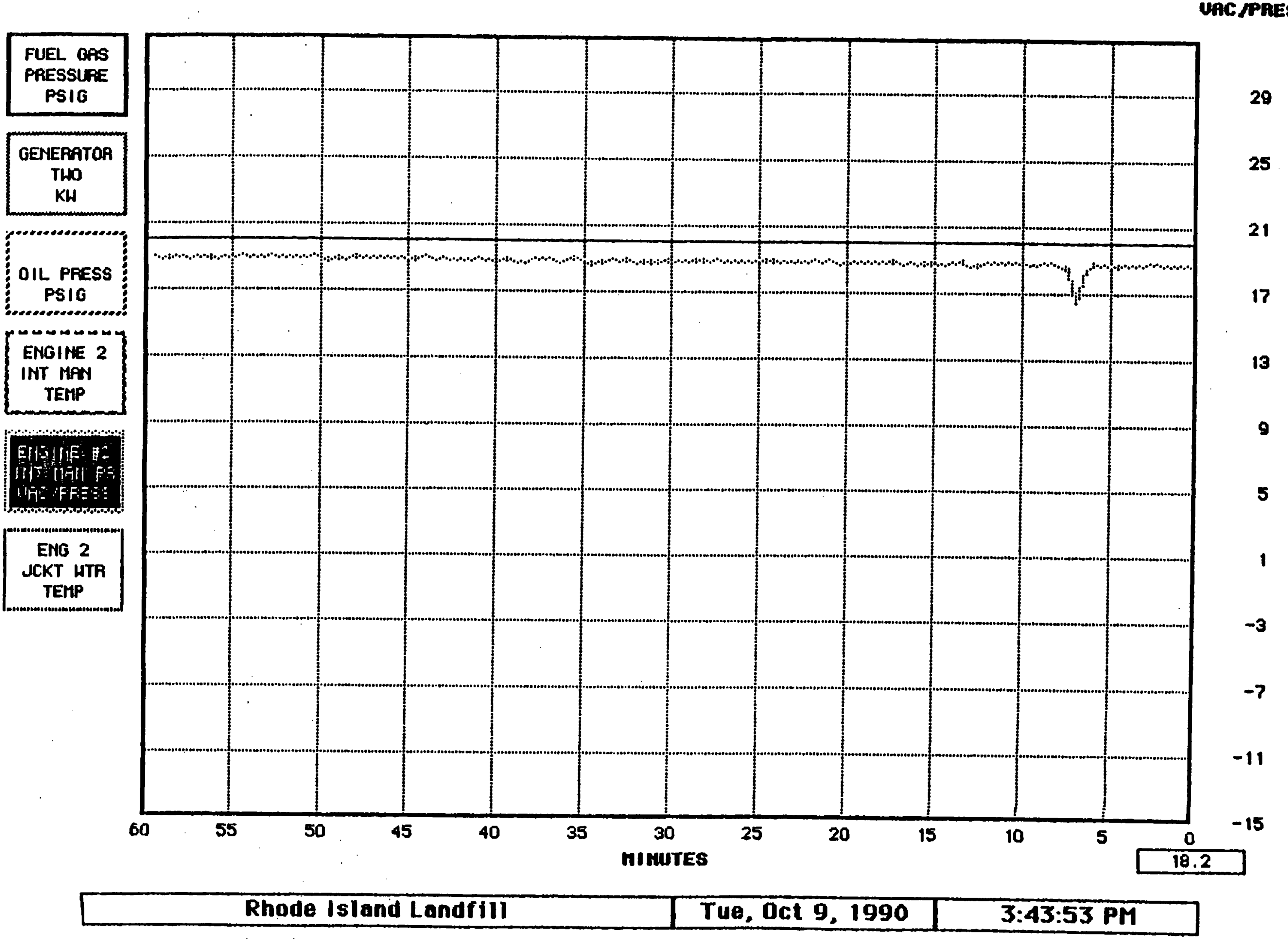
Rhode Island Landfill	Tue, Oct 9, 1990	3:37:10 PM

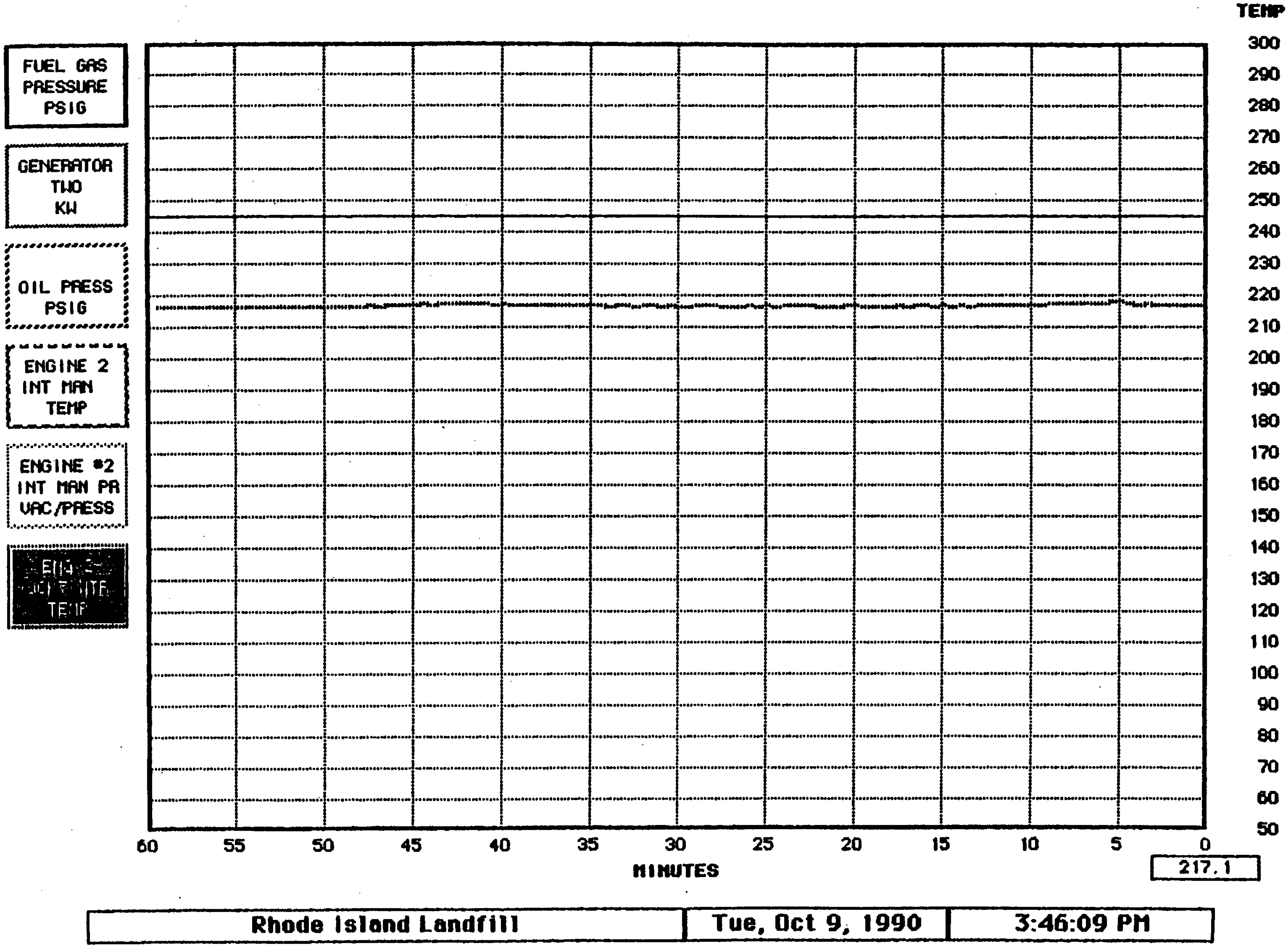


Rhode Island Landfill	Tue, Oct 9, 1990	3:39:24 PM

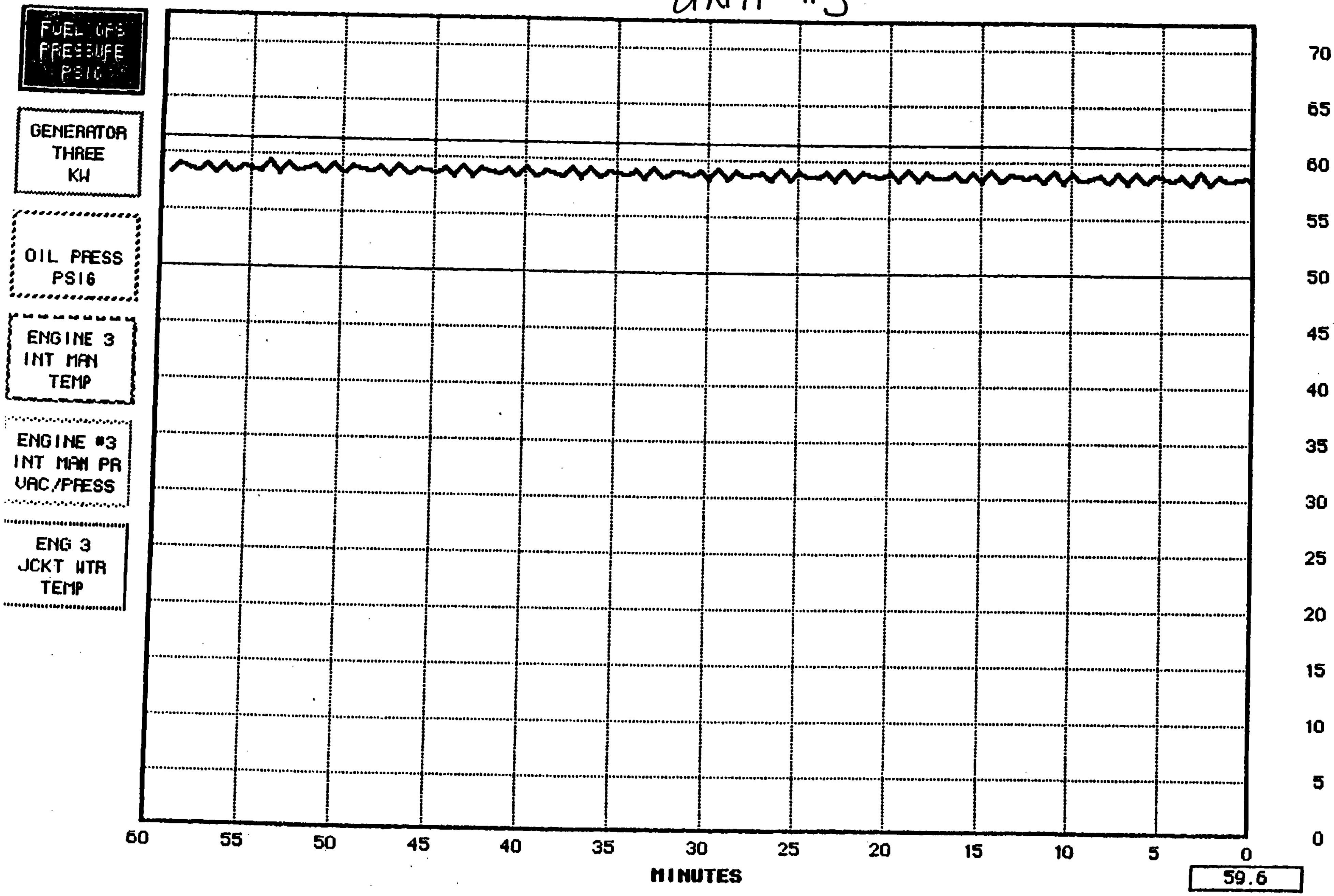


Rhode Island Landfill	Tue, Oct 9, 1990	3:41:37 PM


VAC/PRES
FUEL GAS PRESSURE PSIG
GENERATOR TWO KW
OIL PRESS PSIG
ENGINE 2 INT MAN TEMP
ENGINE #2 INT MAN PR VAC/PRESS
ENG 2 JCKT WTR TEMP
29
25
21
17
13
9
5
1
-3
-7
-11
-15
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
18.2
Rhode Island Landfill
Tue, Oct 9, 1990
3:43:53 PM

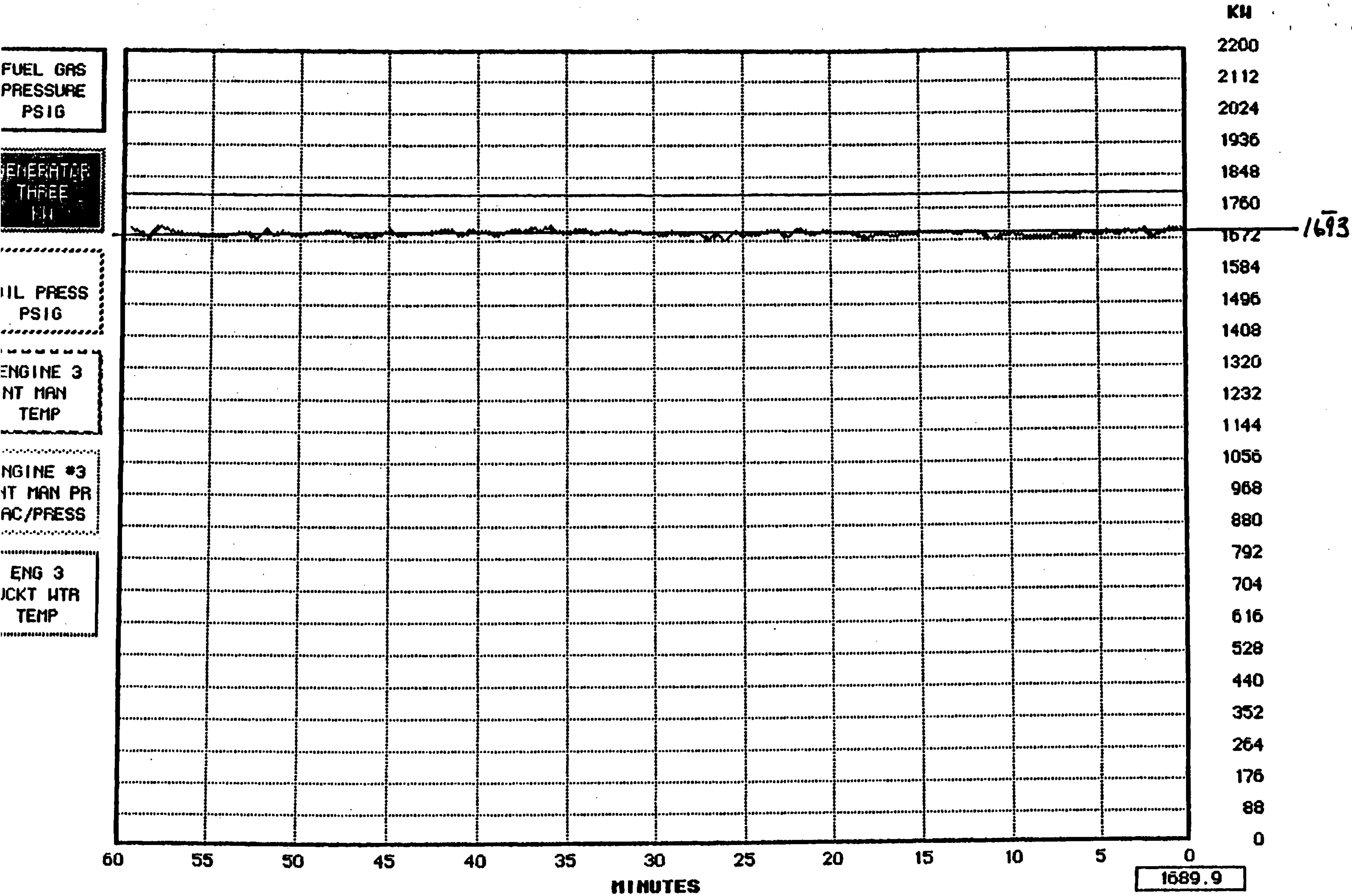

FUEL GAS PRESSURE PSIG
GENERATOR TWO KW
OIL PRESS PSIG
ENGINE 2 INT MAN TEMP
ENGINE #2 INT MAN PR VAC/PRESS
TEMP
TEMP
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
217.1
Rhode Island Landfill
Tue, Oct 9, 1990
3:46:09 PM

UNIT #3



Rhode Island Landfill	Tue, Oct 16, 1990	10:17:24 AM

UNIT #3



Rhode Island Landfill	Tue, Oct 16, 1990	10:19:41 AM

FUEL GAS
PRESSURE
PSIG

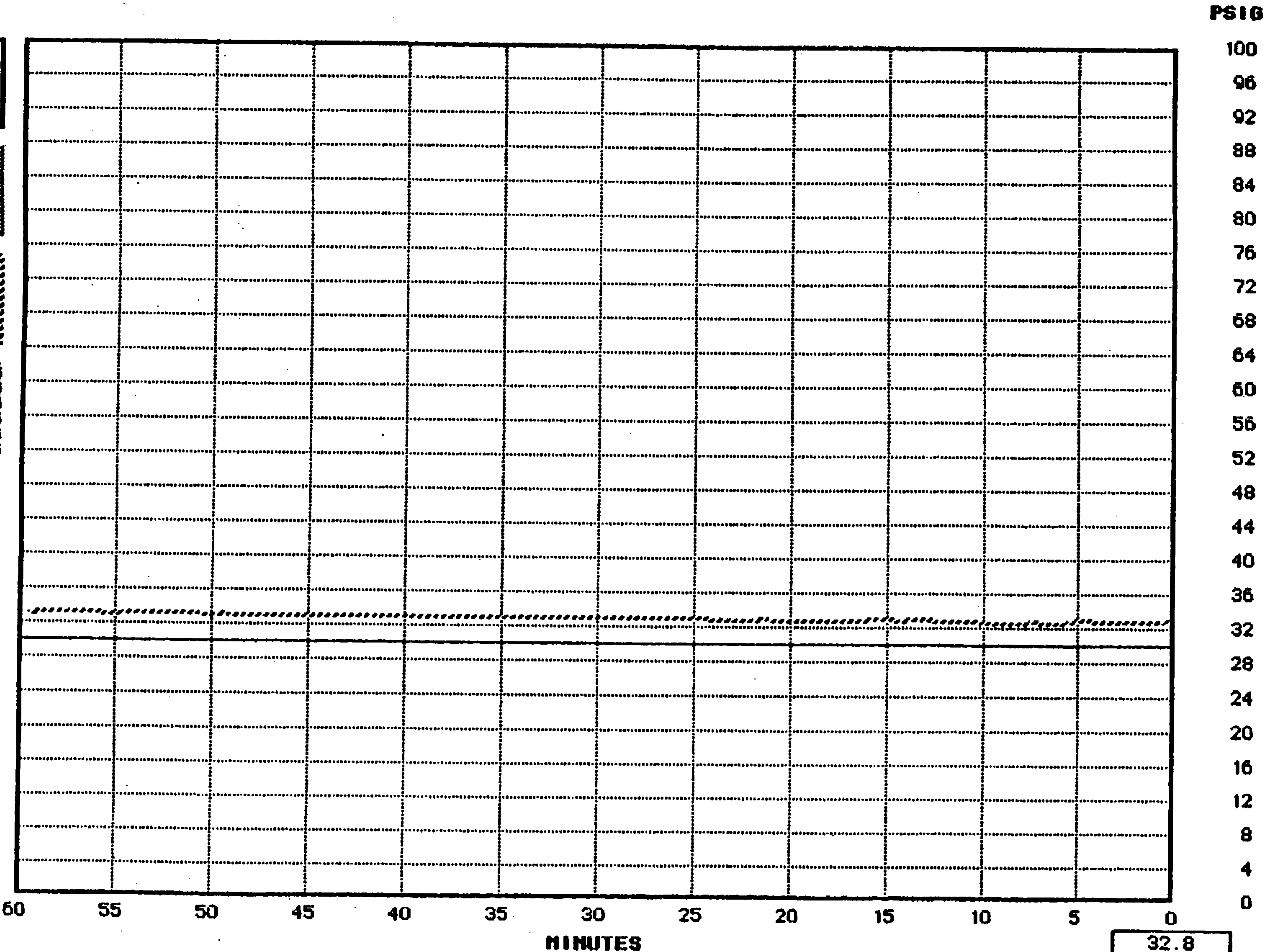
GENERATOR
THREE
KW

OIL PRESS
PSIG

ENGINE 3
INT MAN
TEMP

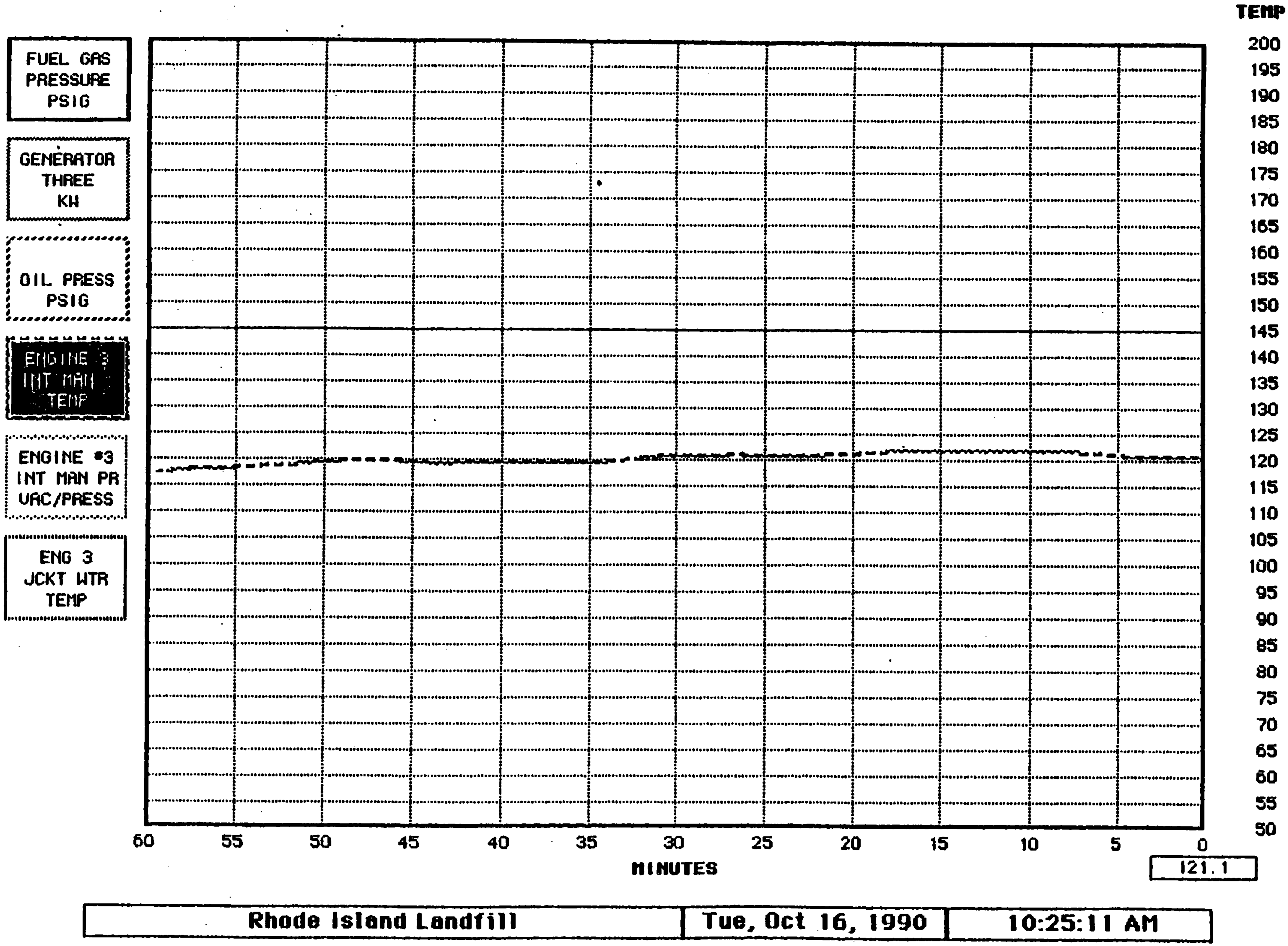
ENGINE #3
INT MAN PR
VAC/PRESS

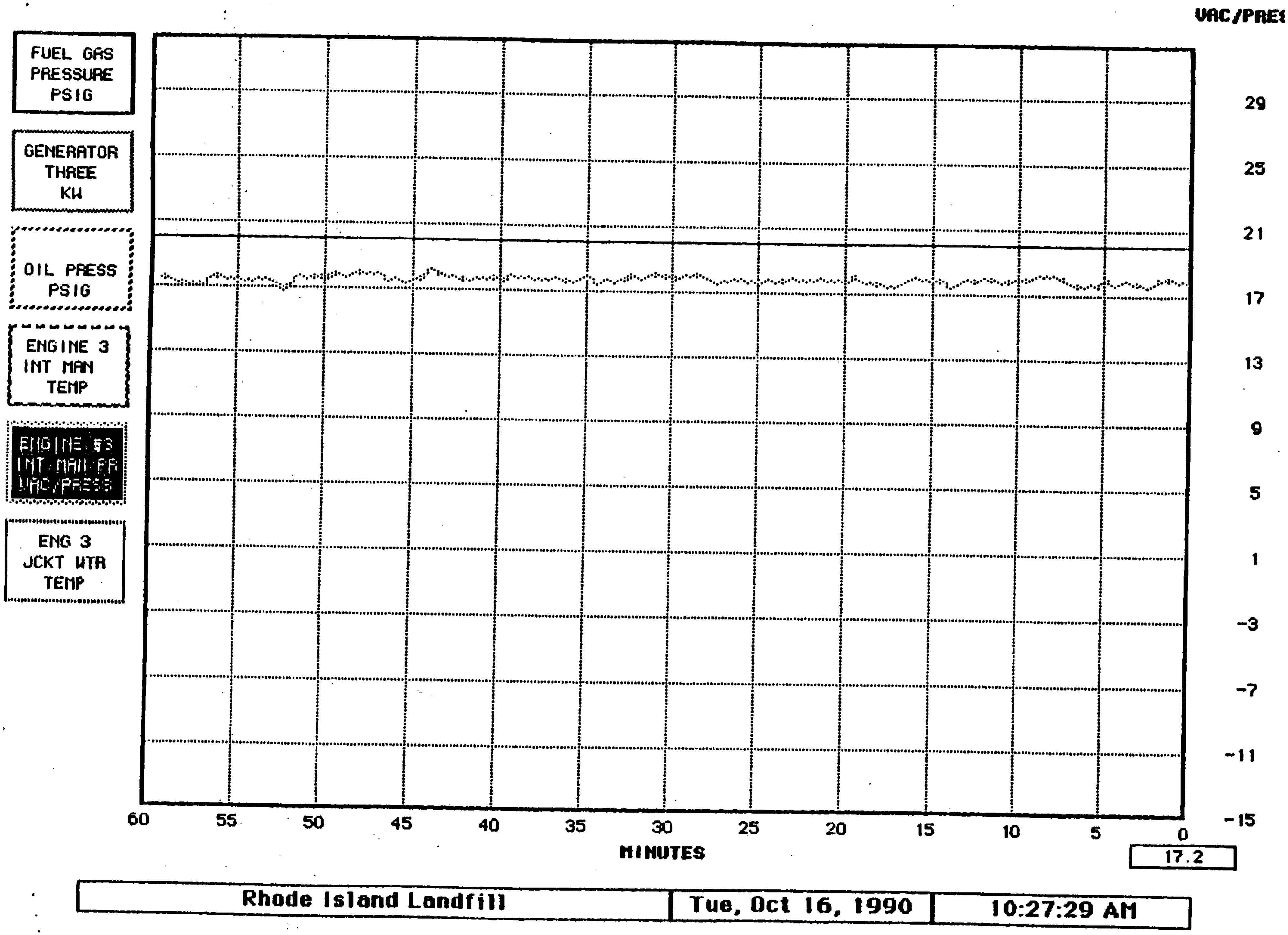
ENG 3
JCKT WTR
TEMP

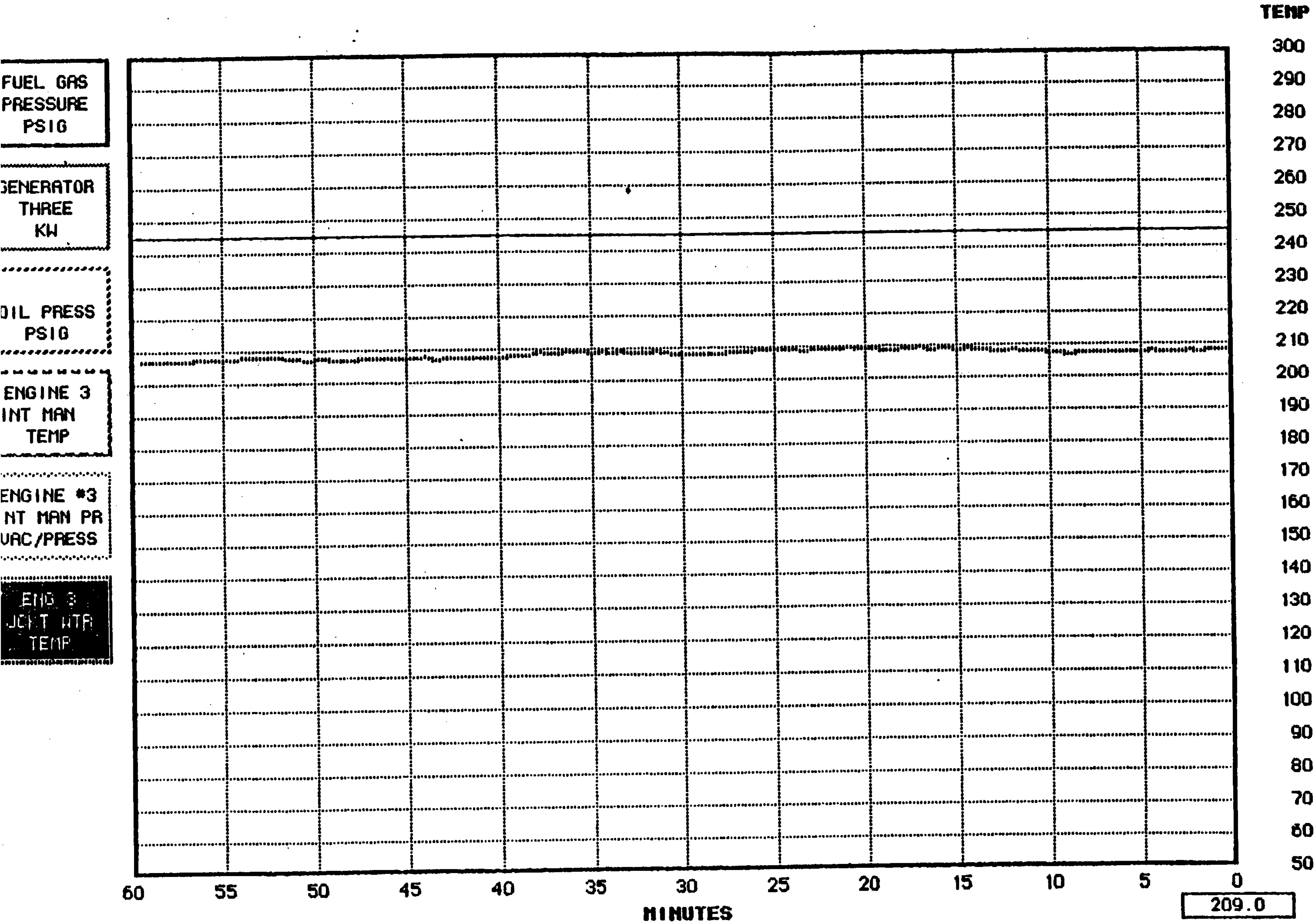


32.8

Rhode Island Landfill	Tue, Oct 16, 1990	10:22:07 AM


FUEL GAS PRESSURE PSIG
GENERATOR THREE KW
OIL PRESS PSIG
ENGINE 3 INT MAN TEMP
ENGINE #3 INT MAN PR VAC/PRESS
ENG 3 JCKT WTR TEMP
TEMP
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
121.1
Rhode Island Landfill
Tue, Oct 16, 1990
10:25:11 AM

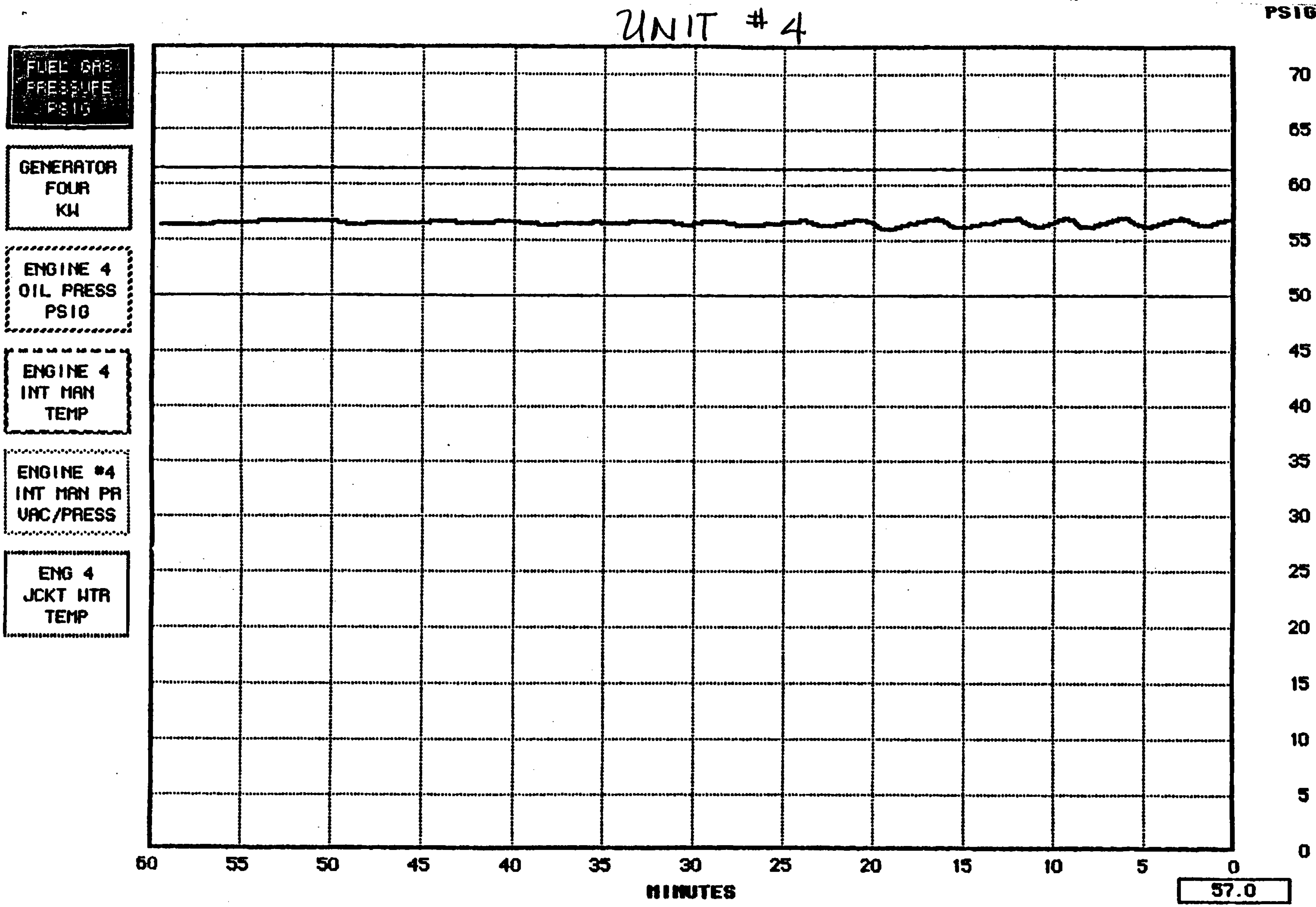

FUEL GAS PRESSURE PSIG
GENERATOR THREE KW
OIL PRESS PSIG
ENGINE 3 INT MAN TEMP
ENGINE #3 INT MAN PR VAC/PRESS
ENG 3 JCKT WTR TEMP
VAC/PRES
29
25
21
17
13
9
5
1
-3
-7
-11
-15
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
17.2
Rhode Island Landfill
Tue, Oct 16, 1990
10:27:29 AM



Rhode Island Landfill	Tue, Oct 16, 1990	10:29:51 AM

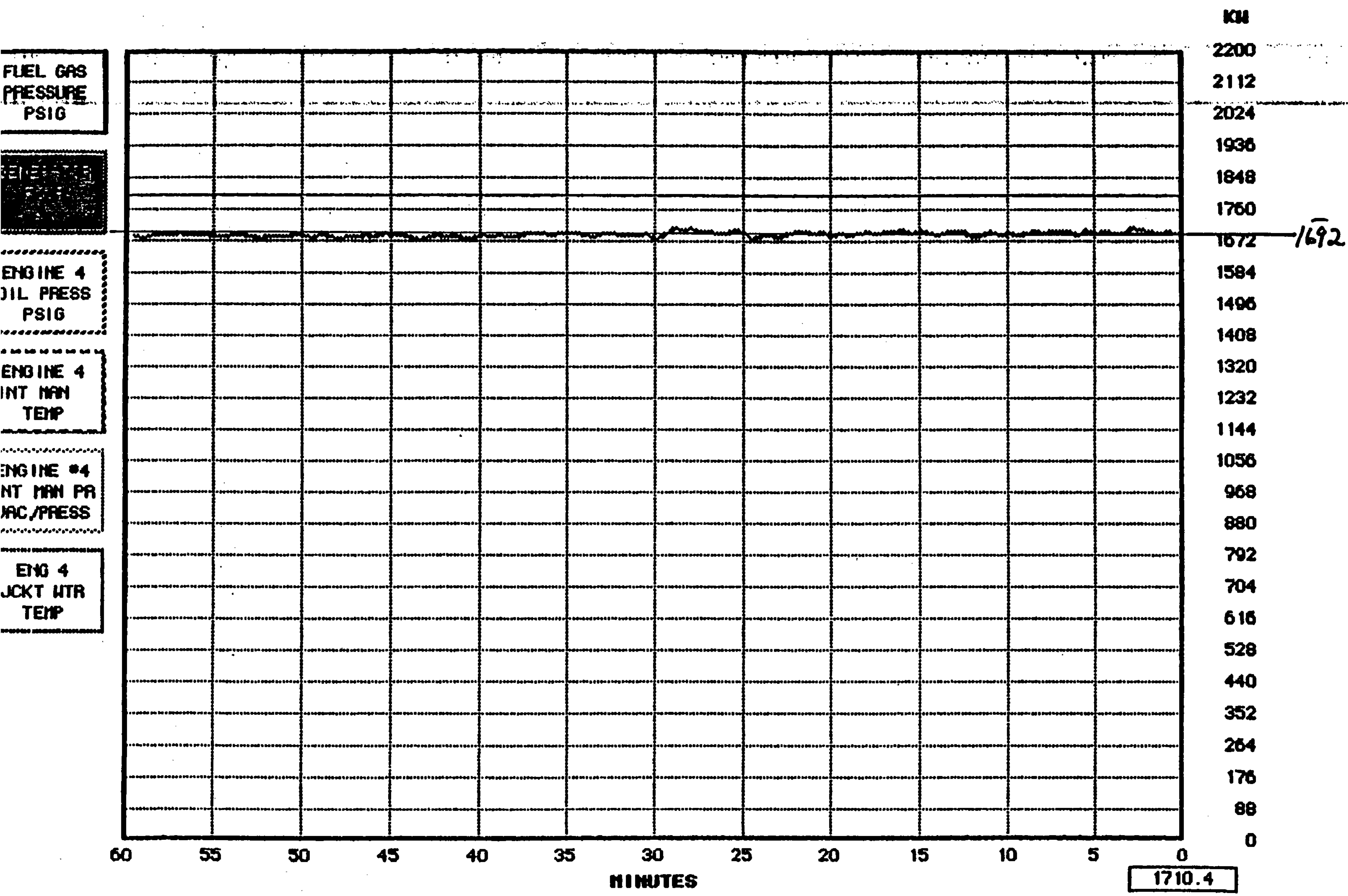
10:29:51 AM

UNIT #4

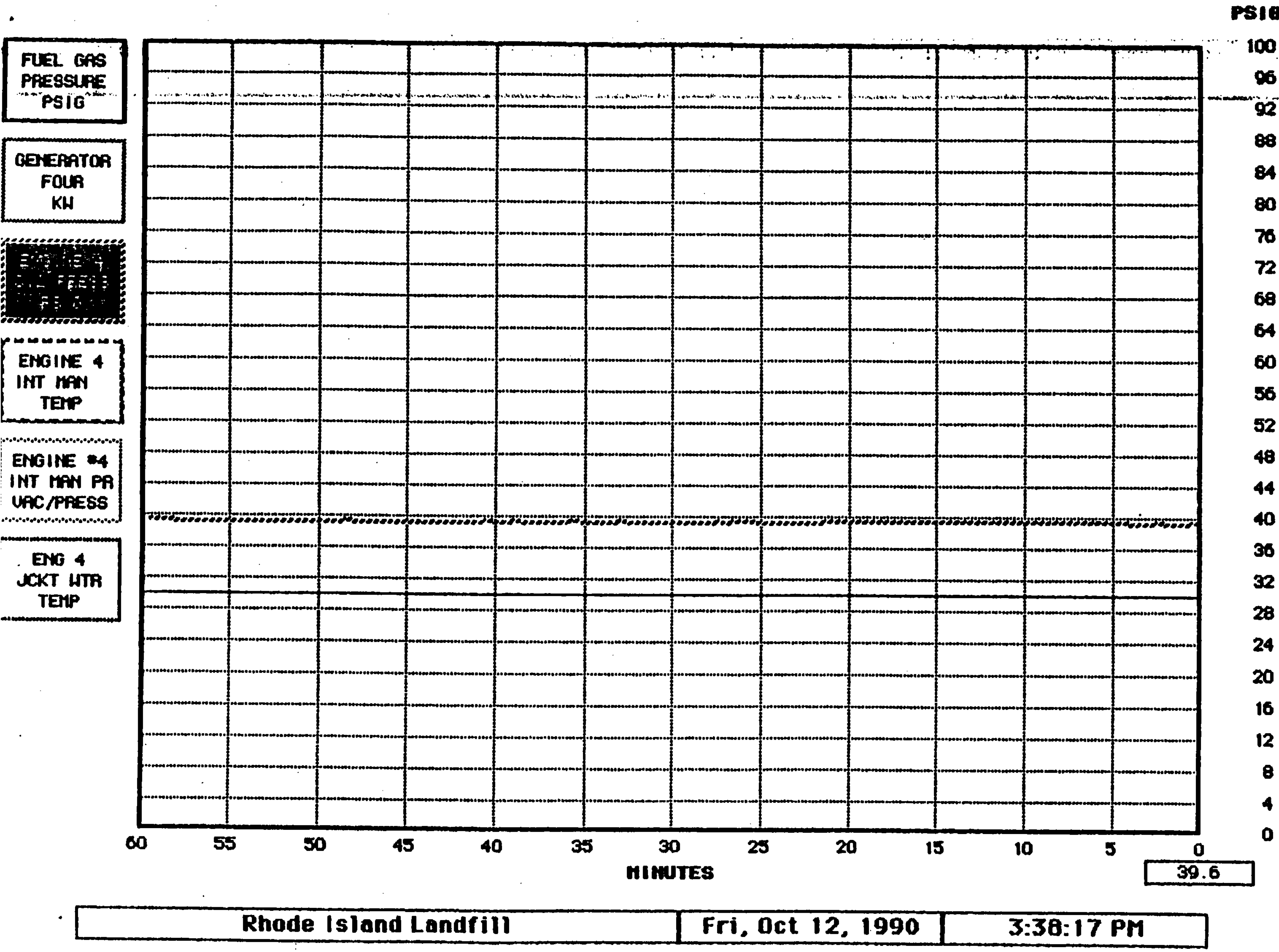


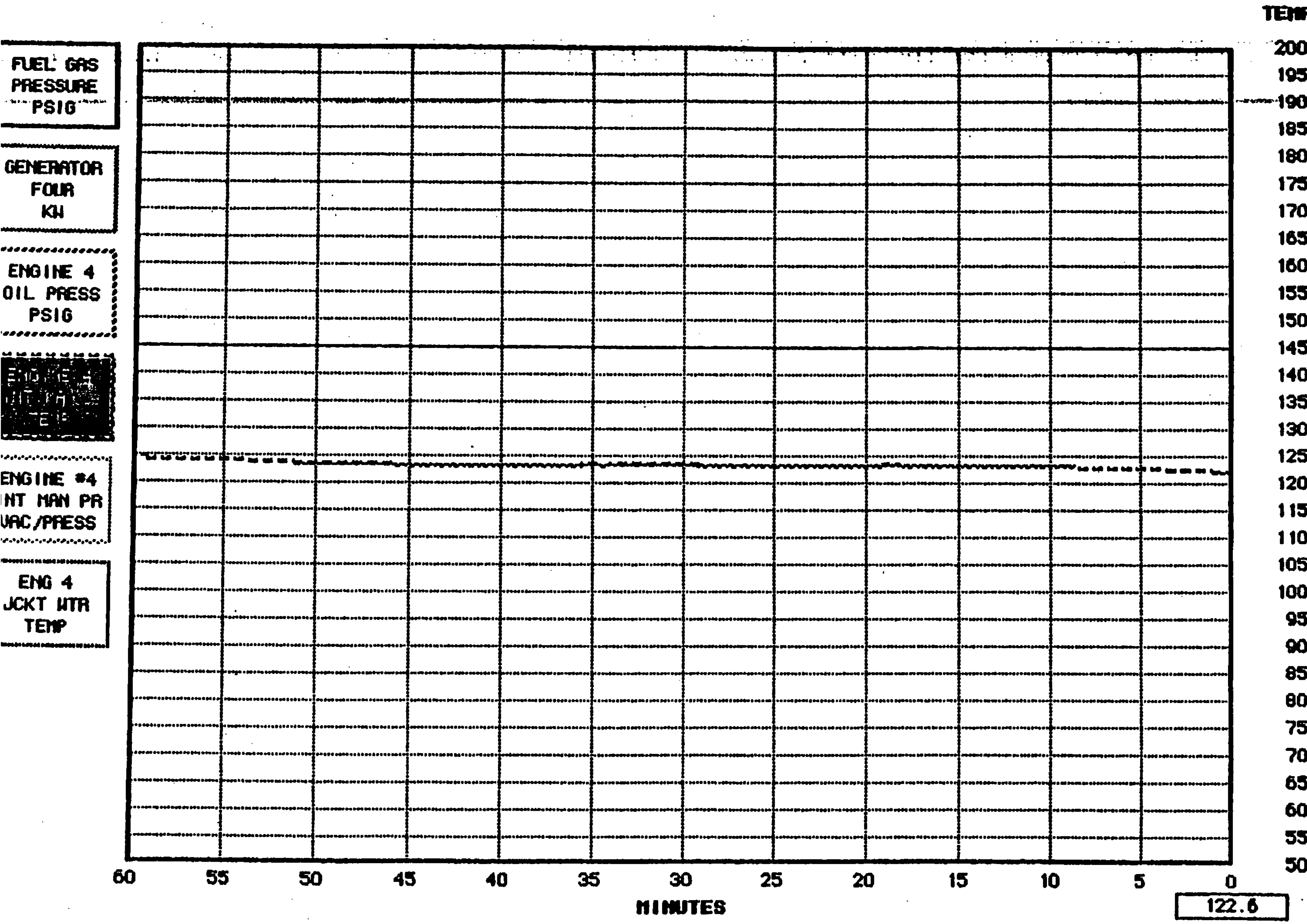
Rhode Island Landfill	Fri, Oct 12, 1990	3:33:32 PM

UNIT #4

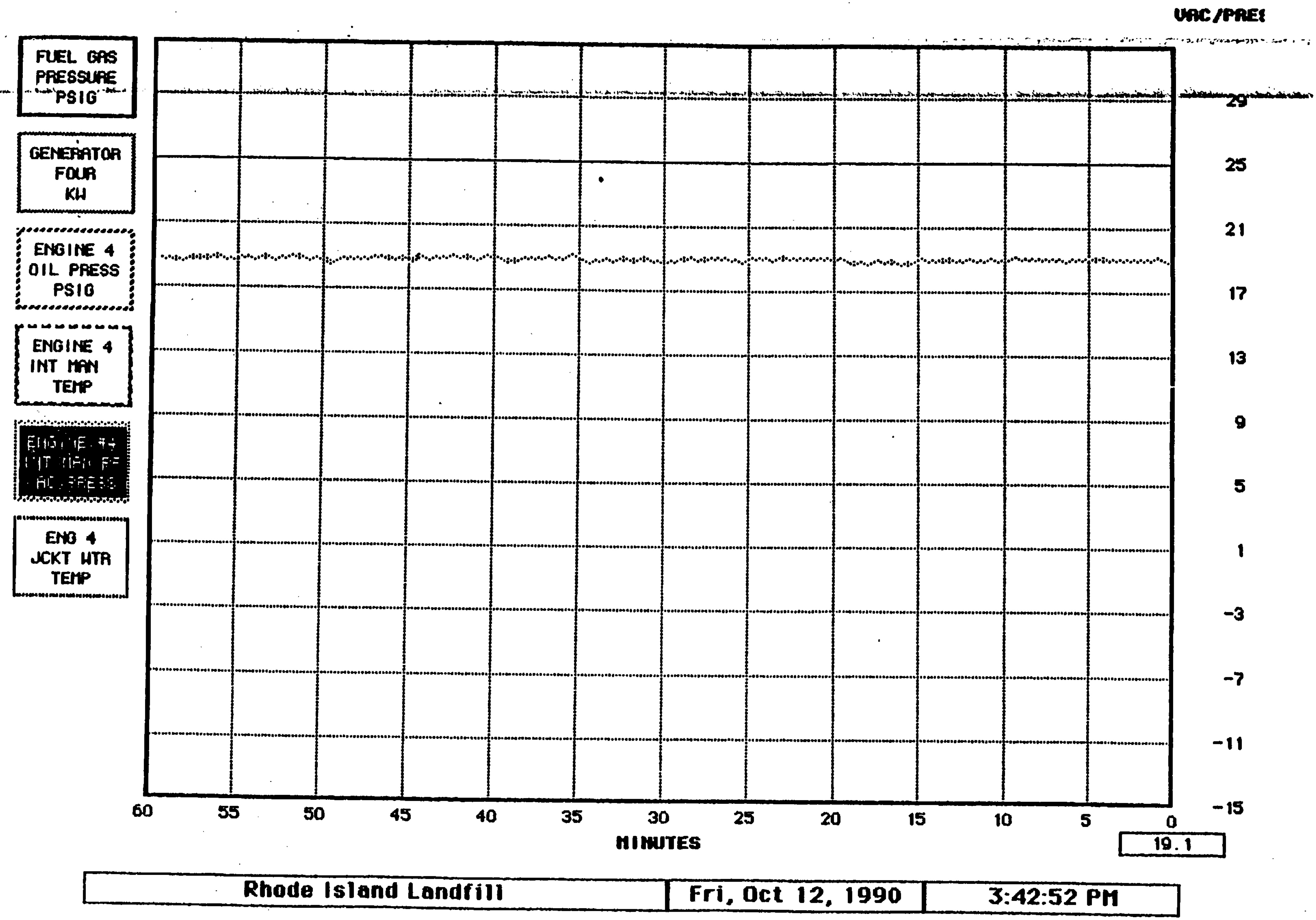


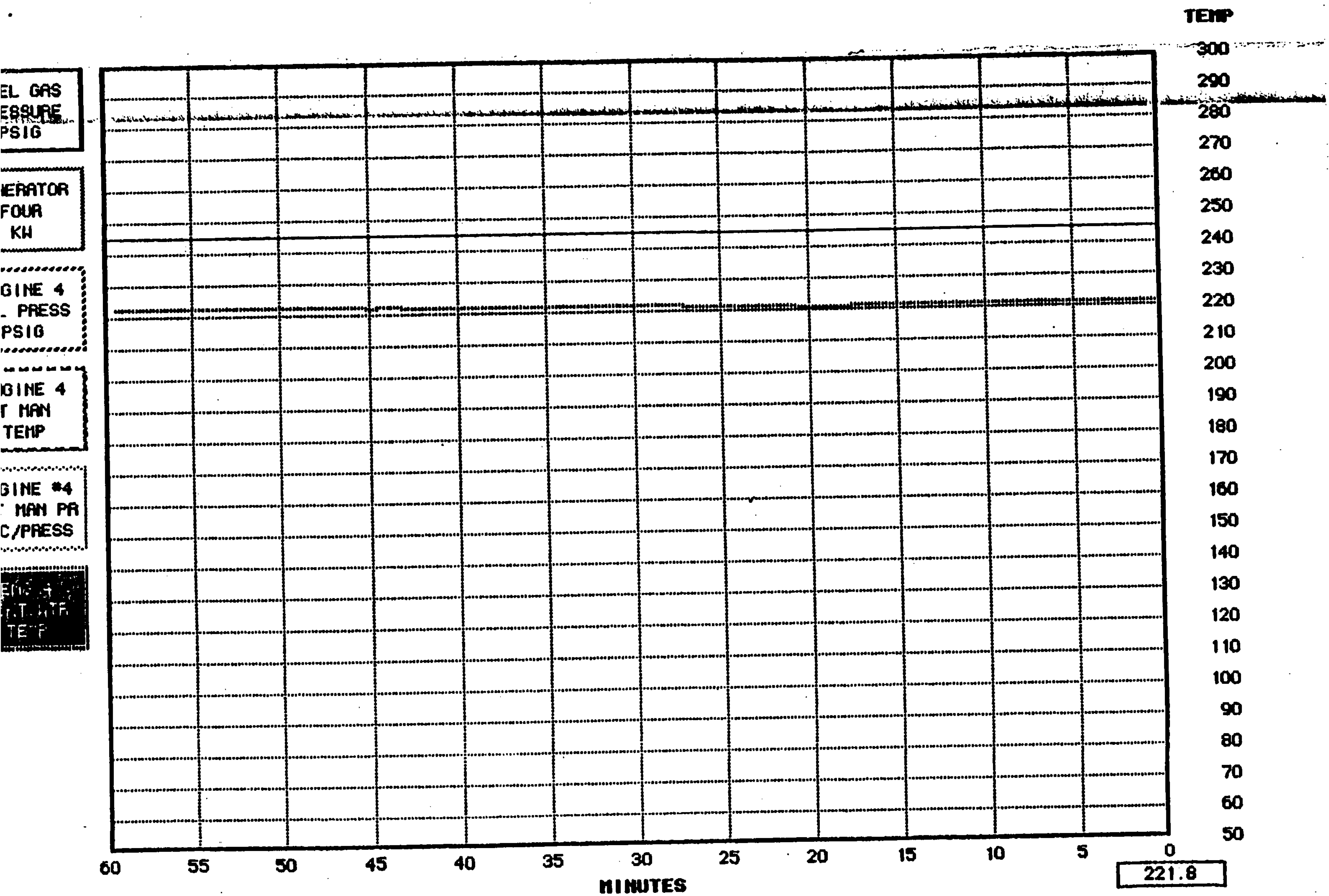
Rhode Island Landfill | Fri Oct 12 | 7:36:00 PM


FUEL GAS PRESSURE PSIG
GENERATOR FOUR KW
ENGINE 4 INT MAN TEMP
ENGINE #4 INT MAN PR VAC/PRESS
ENG 4 JCKT WTR TEMP
PSIG
100
96
92
88
84
80
76
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
39.6
Rhode Island Landfill
Fri, Oct 12, 1990
3:38:17 PM



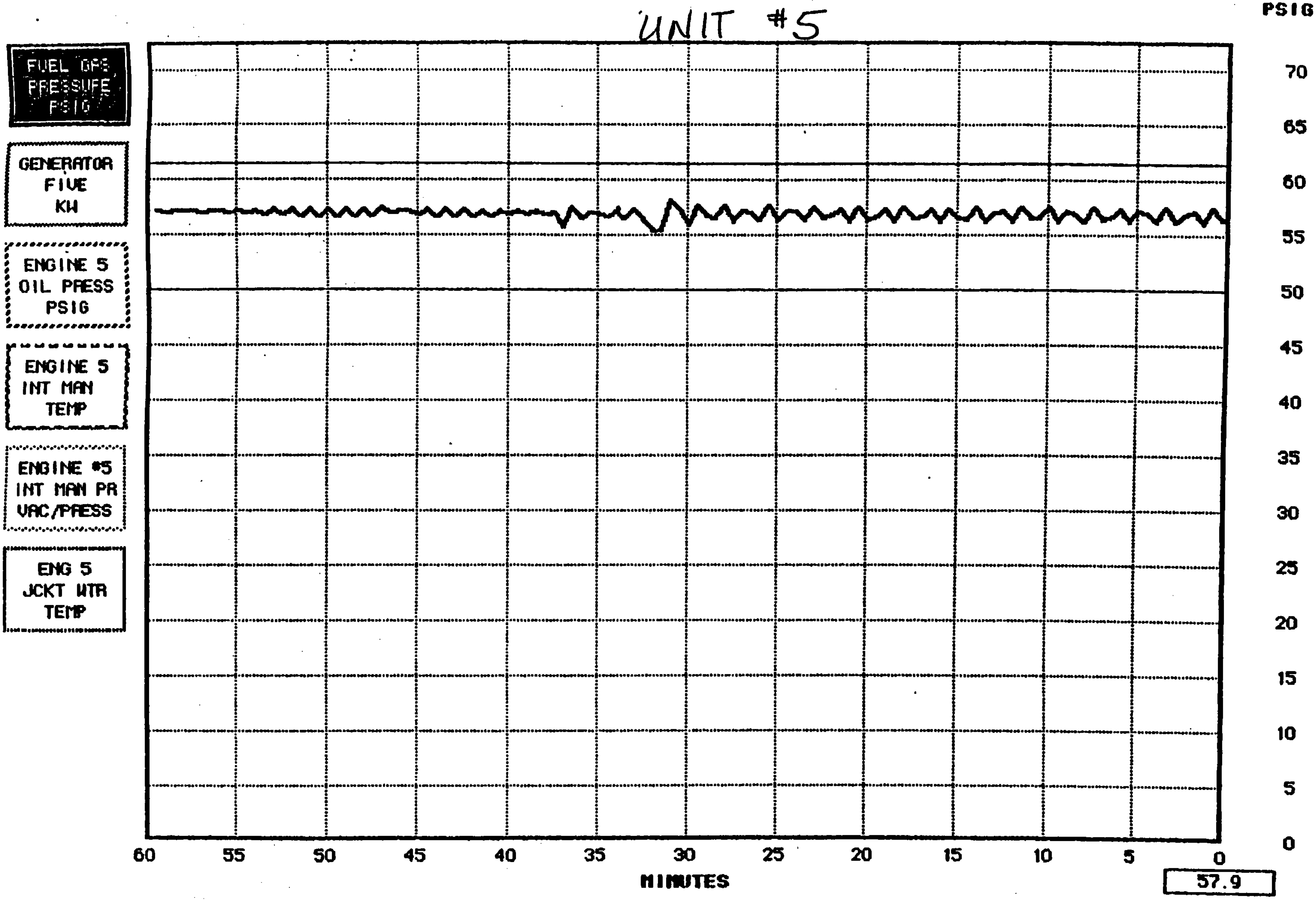
Rhode Island Landfill	Fri, Oct 12, 1990	3:40:34 PM


VAC/PRE
FUEL GAS PRESSURE PSIG
GENERATOR FOUR KW
ENGINE 4 OIL PRESS PSIG
ENGINE 4 INT MAN TEMP
ENG 4 JCKT WTR TEMP
29
25
21
17
13
9
5
1
-3
-7
-11
-15
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
19.1
Rhode Island Landfill
Fri, Oct 12, 1990
3:42:52 PM



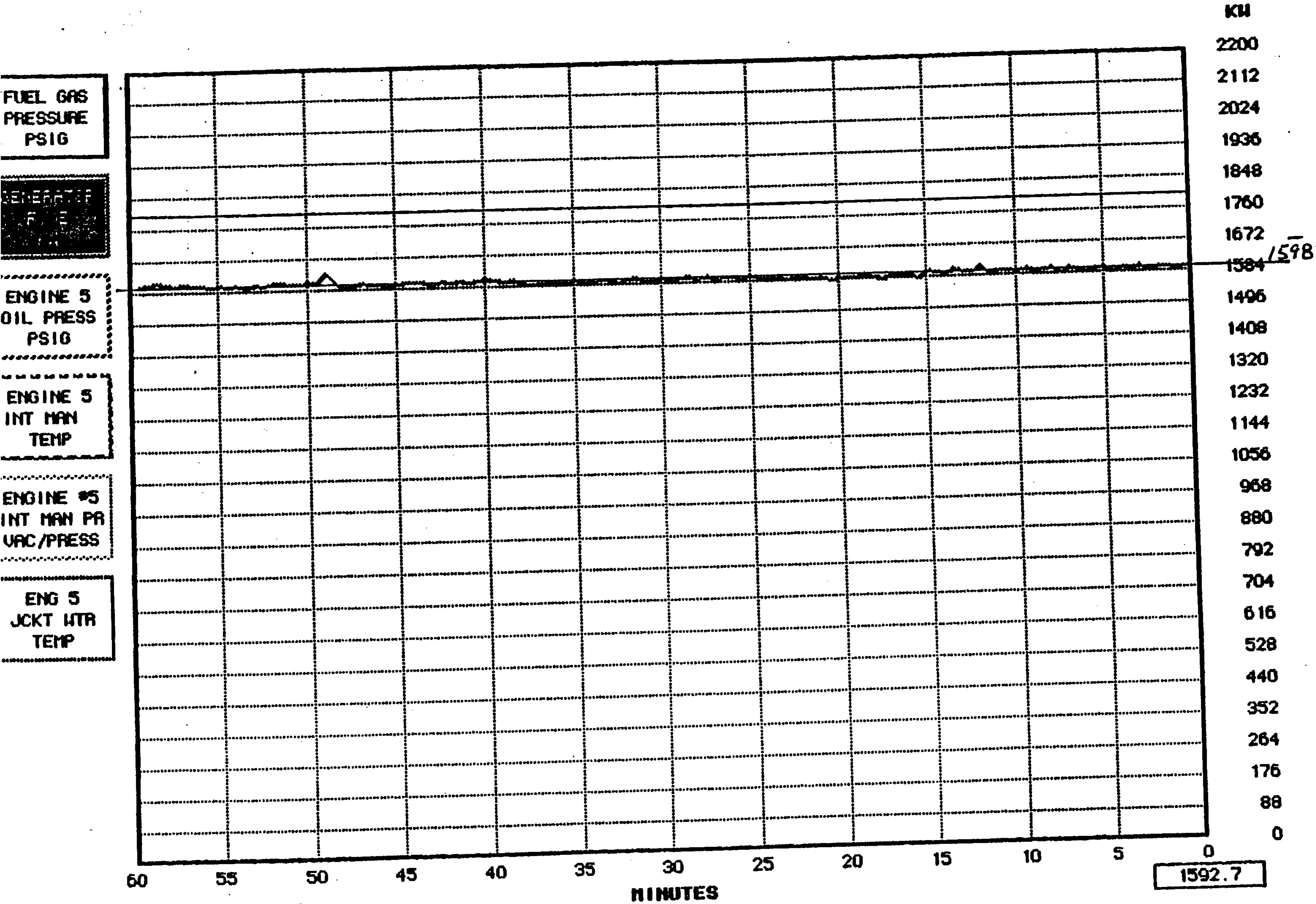
Rhode Island Landfill | Fri, Oct 12, 1990 | 3:45:12 PM

UNIT #5

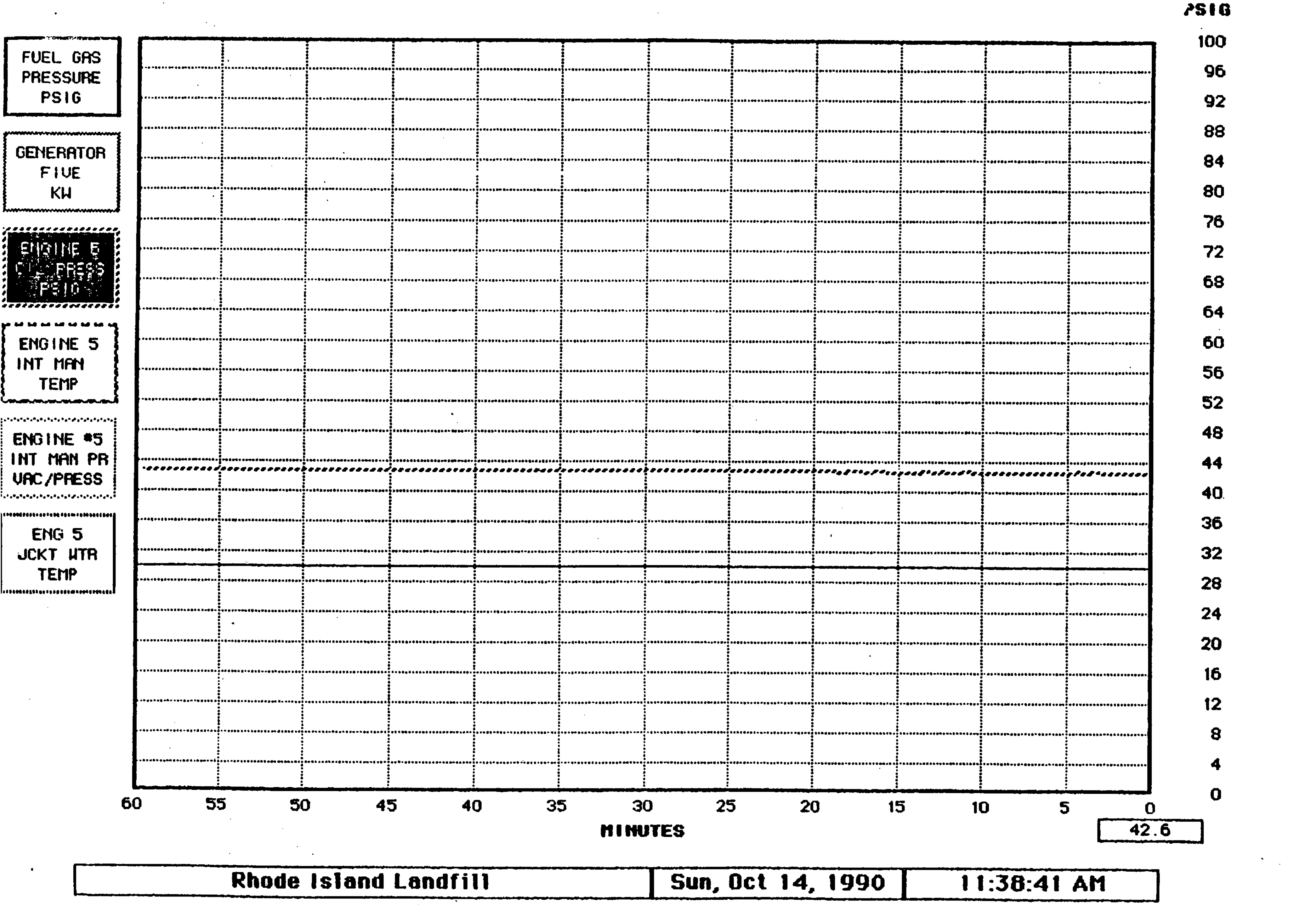


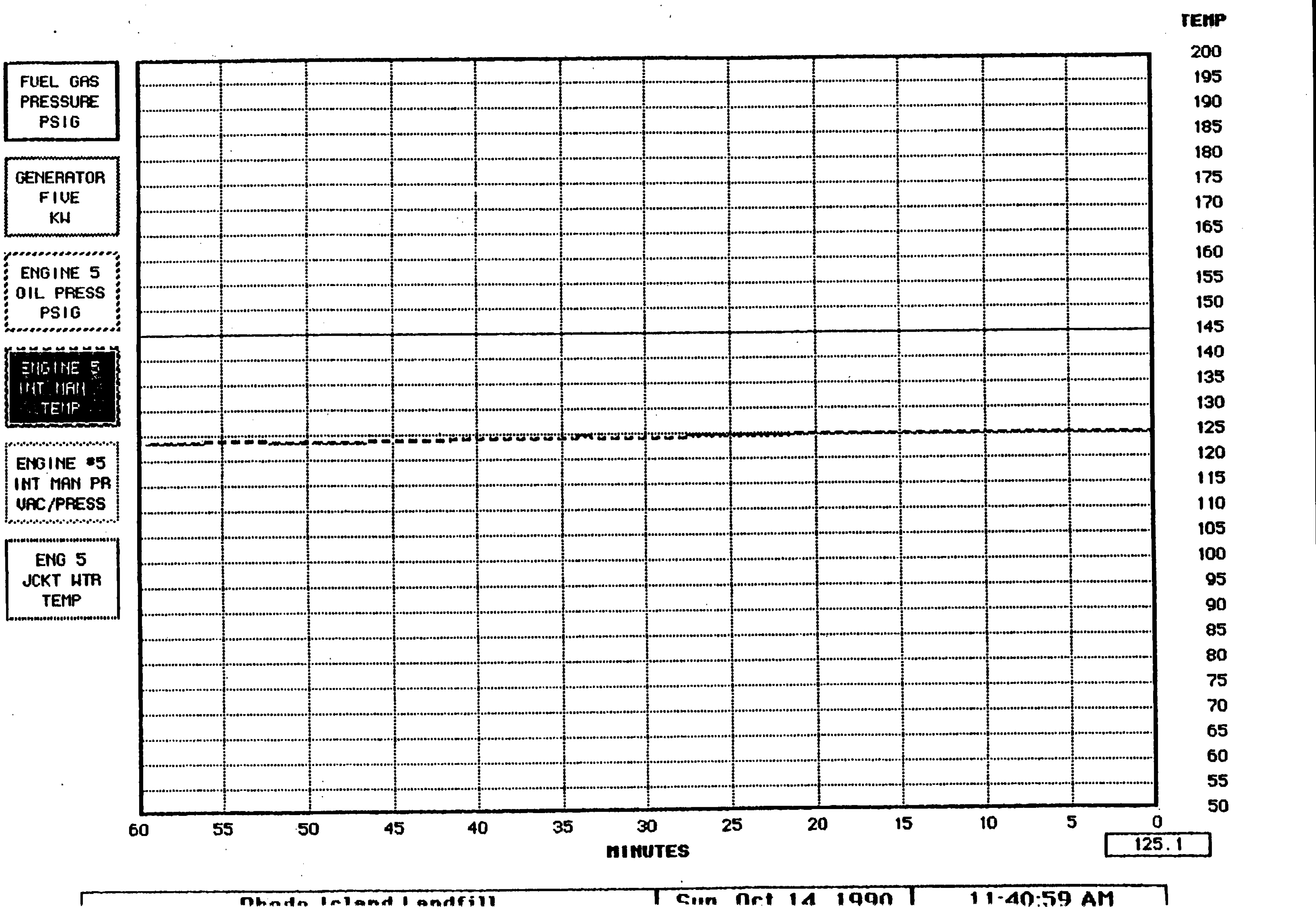
Rhode Island Landfill	Sun, Oct 14, 1990	11:34:09 AM

UNIT #5

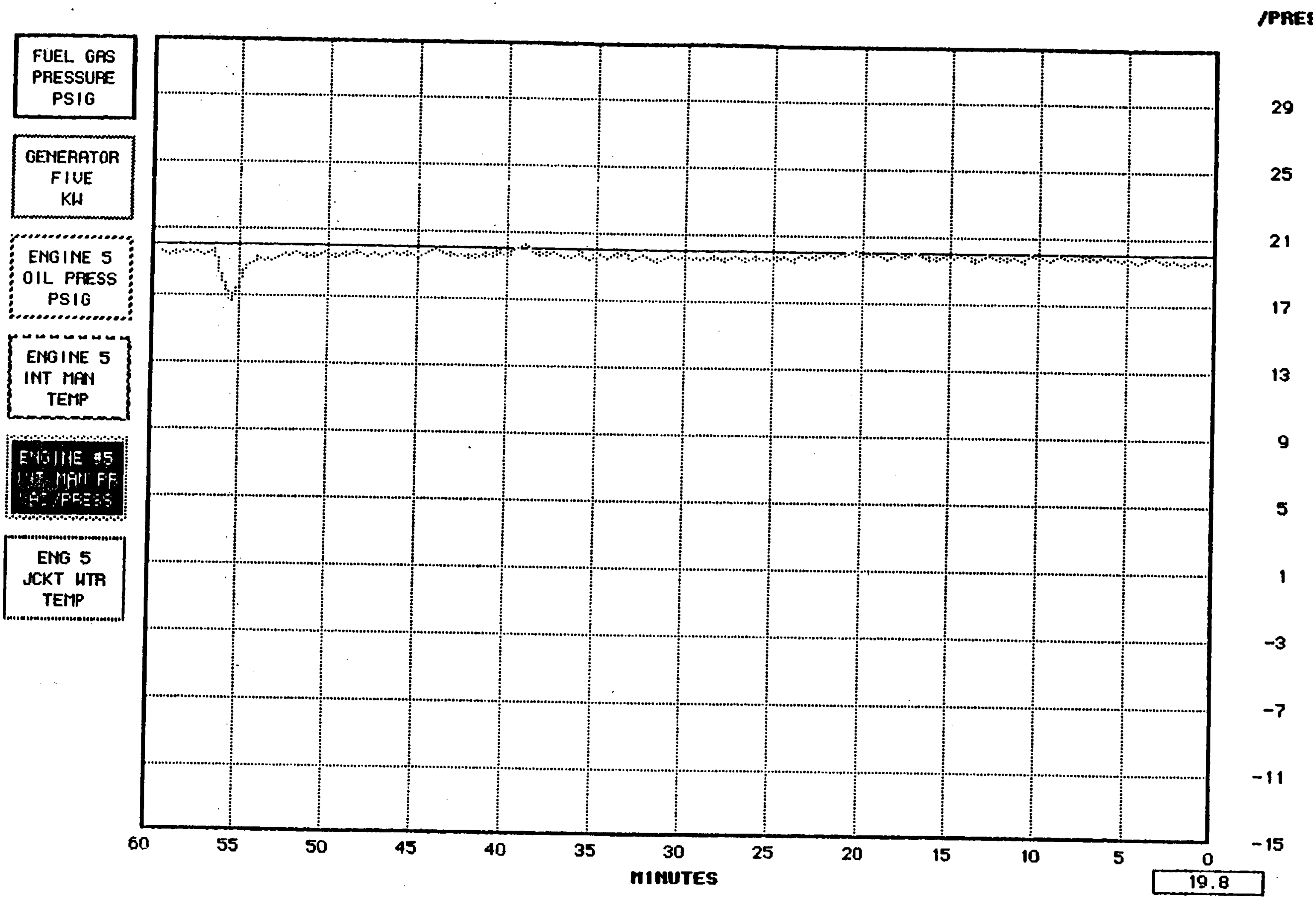


Rhode Island Landfill | Sun, Oct 14, 1990 | 11:36:24 AM

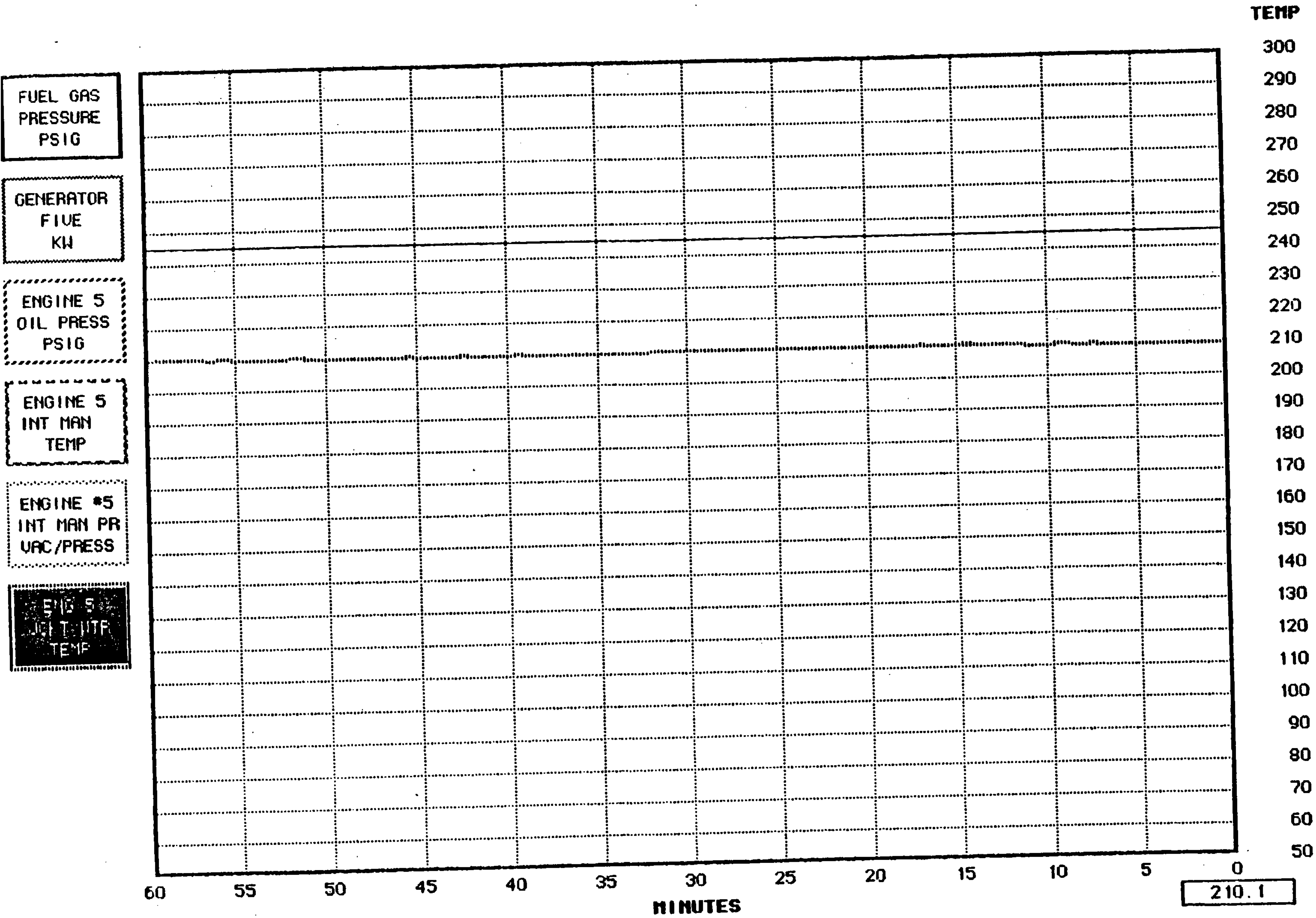

FUEL GAS PRESSURE PSIG
GENERATOR FIVE KW
ENGINE 5 PRESS PSIG
ENGINE 5 INT MAN TEMP
ENGINE #5 INT MAN PR VAC/PRESS
ENG 5 JCKT WTR TEMP
PSIG
100
96
92
88
84
80
76
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
42.6
Rhode Island Landfill
Sun, Oct 14, 1990
11:38:41 AM



FUEL GAS PRESSURE PSIG
GENERATOR FIVE KW
ENGINE 5 OIL PRESS PSIG
ENGINE 5 INT MAN TEMP
ENGINE #5 INT MAN PR VAC/PRESS
ENG 5 JCKT WTR TEMP
TEMP
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
125.1
Sun Oct 14 1990
11:40:59 AM

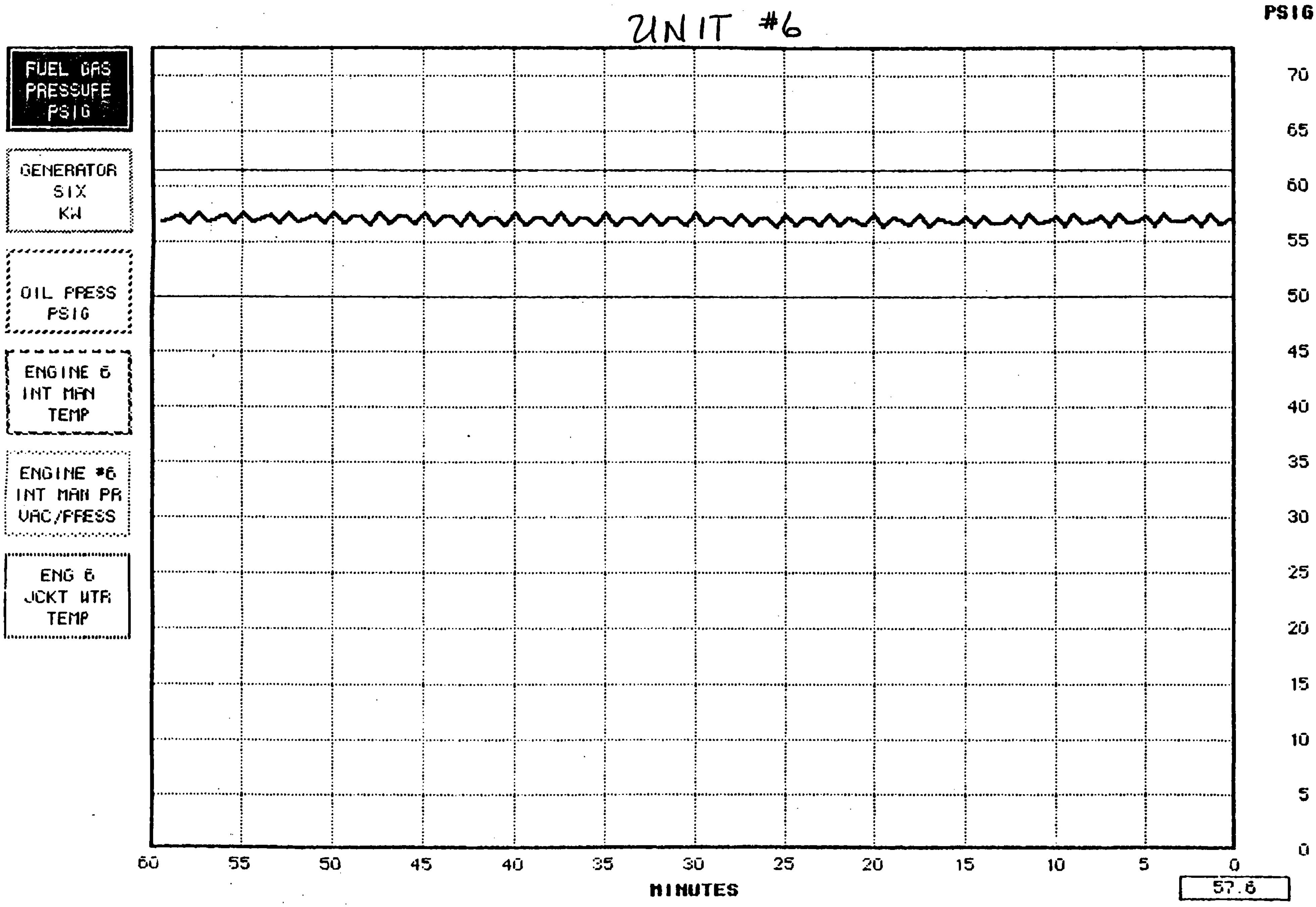


Rhode Island Landfill	Sun, Oct 14, 1990	11:43:21 AM



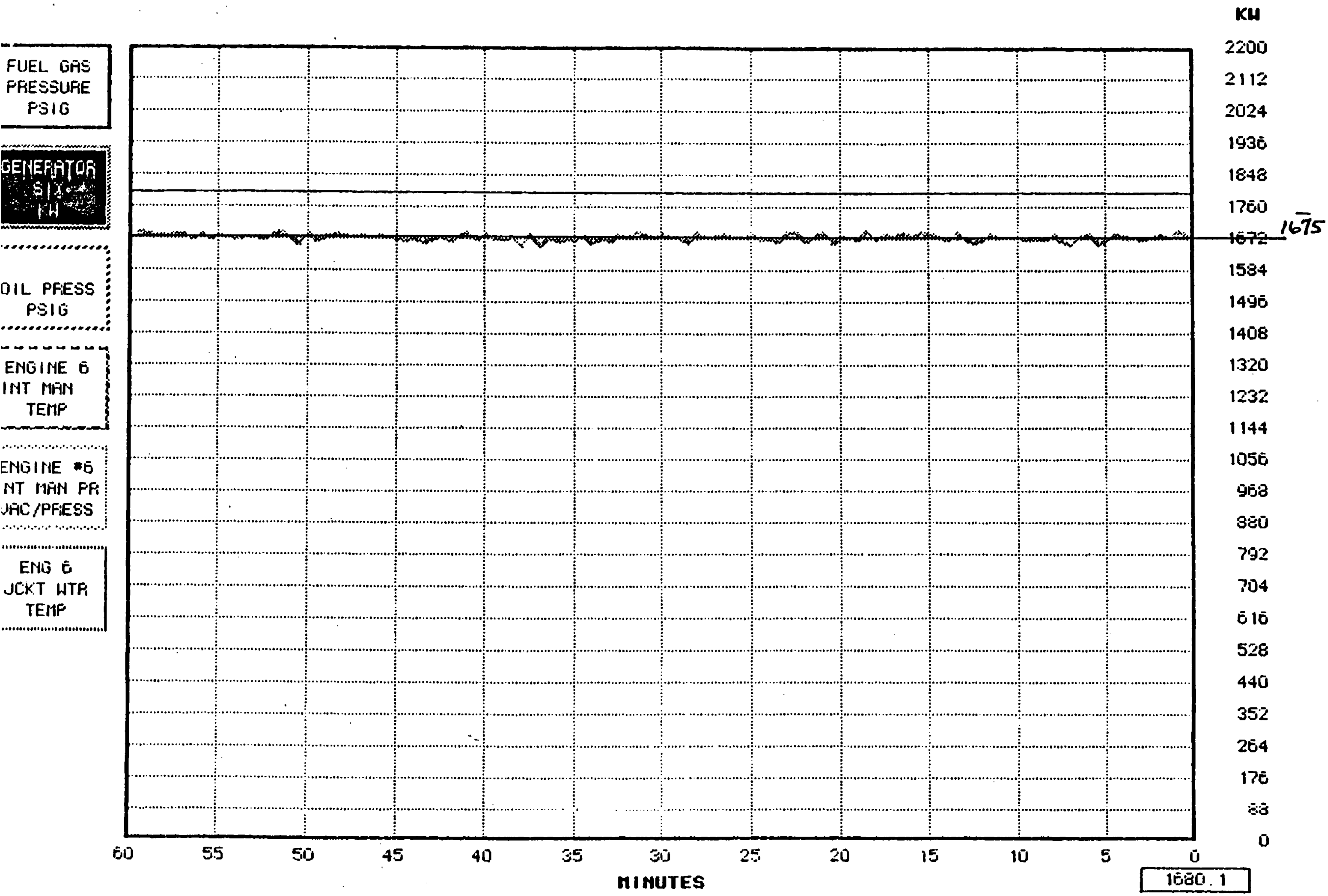
Rhode Island Landfill | Sun, Oct 14, 1990 | 11:45:40 AM

UNIT #6

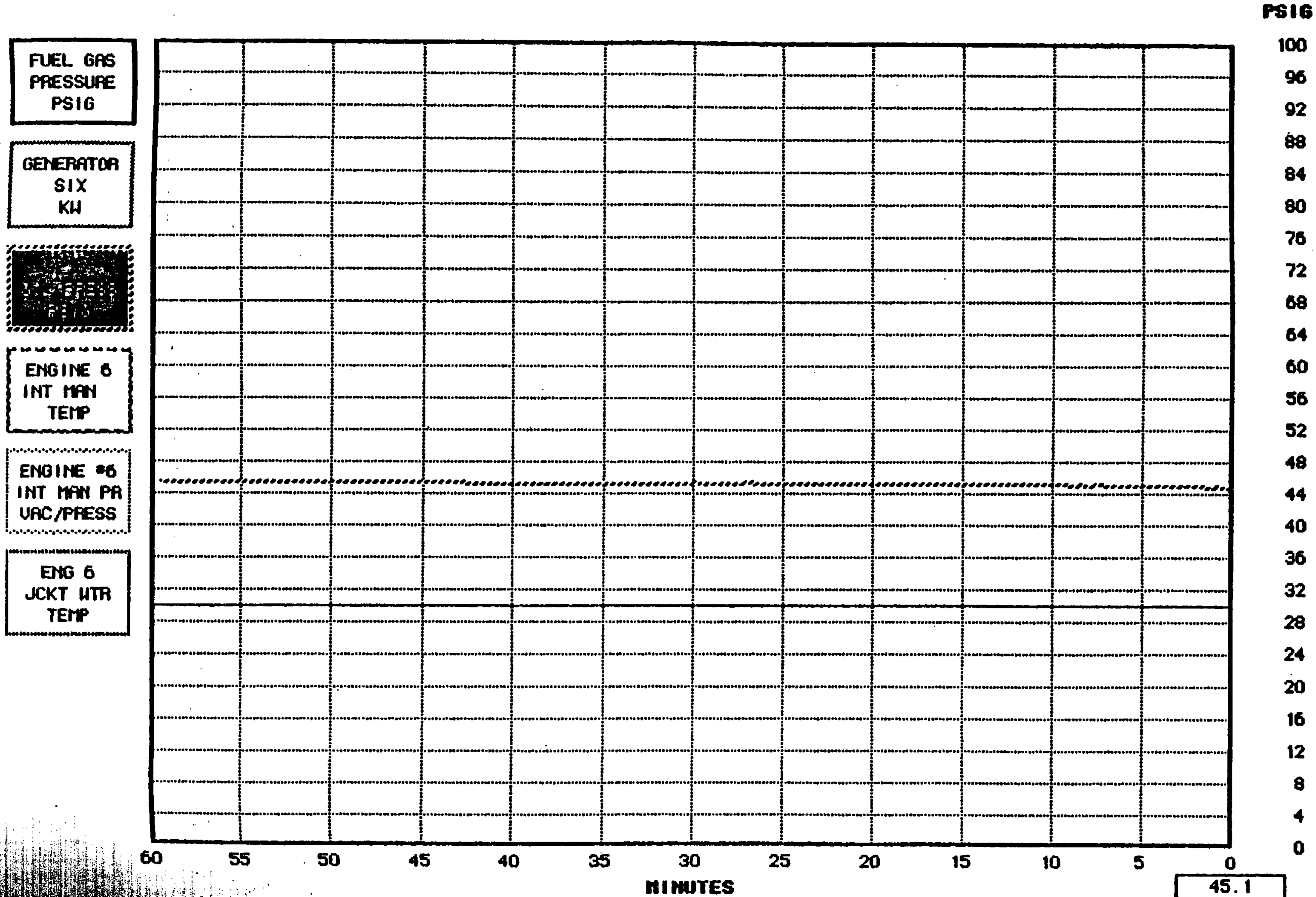


Rhode Island Landfill	Thu, Oct 11, 1990	3:32:33 PM

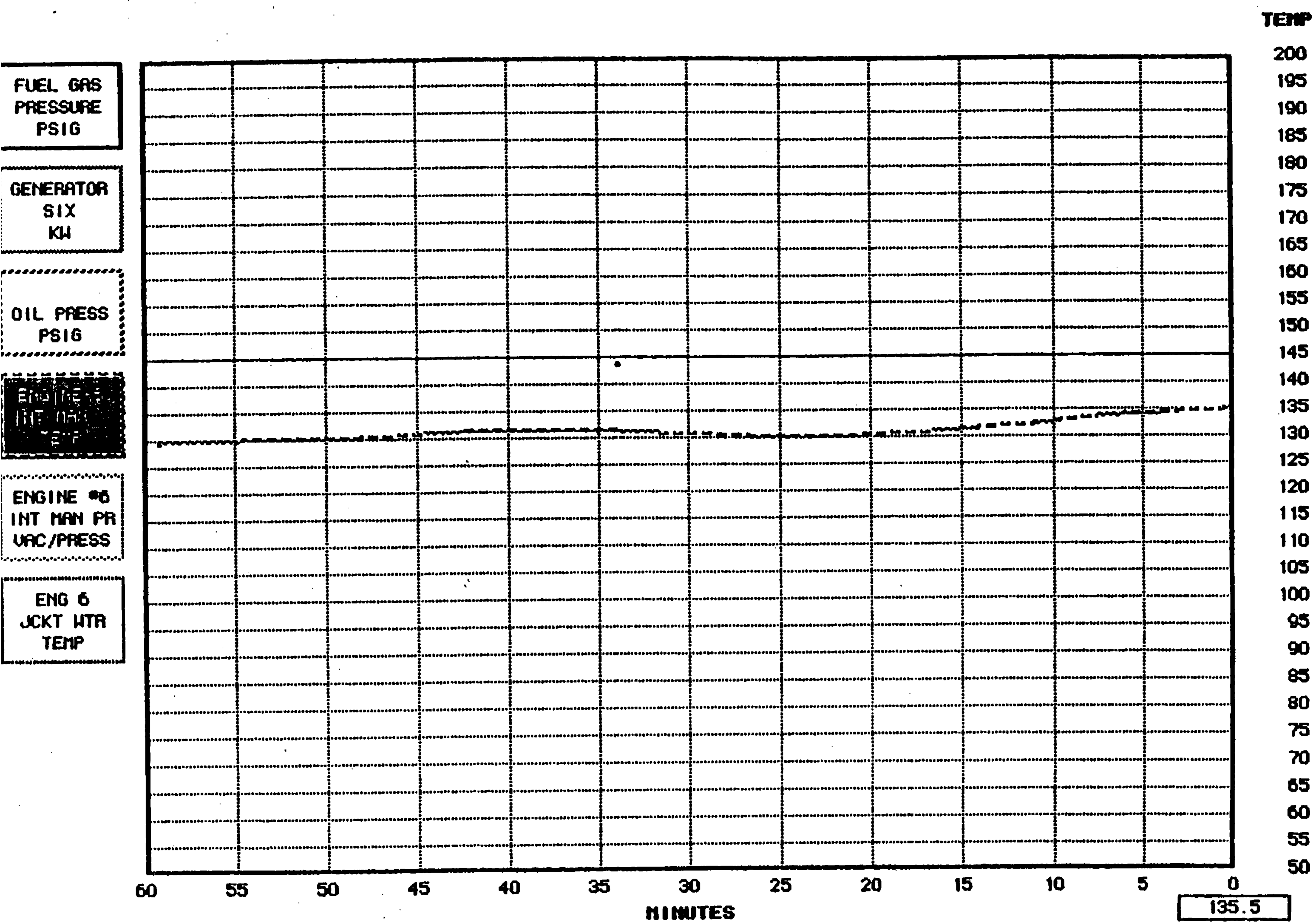
UNIT #6

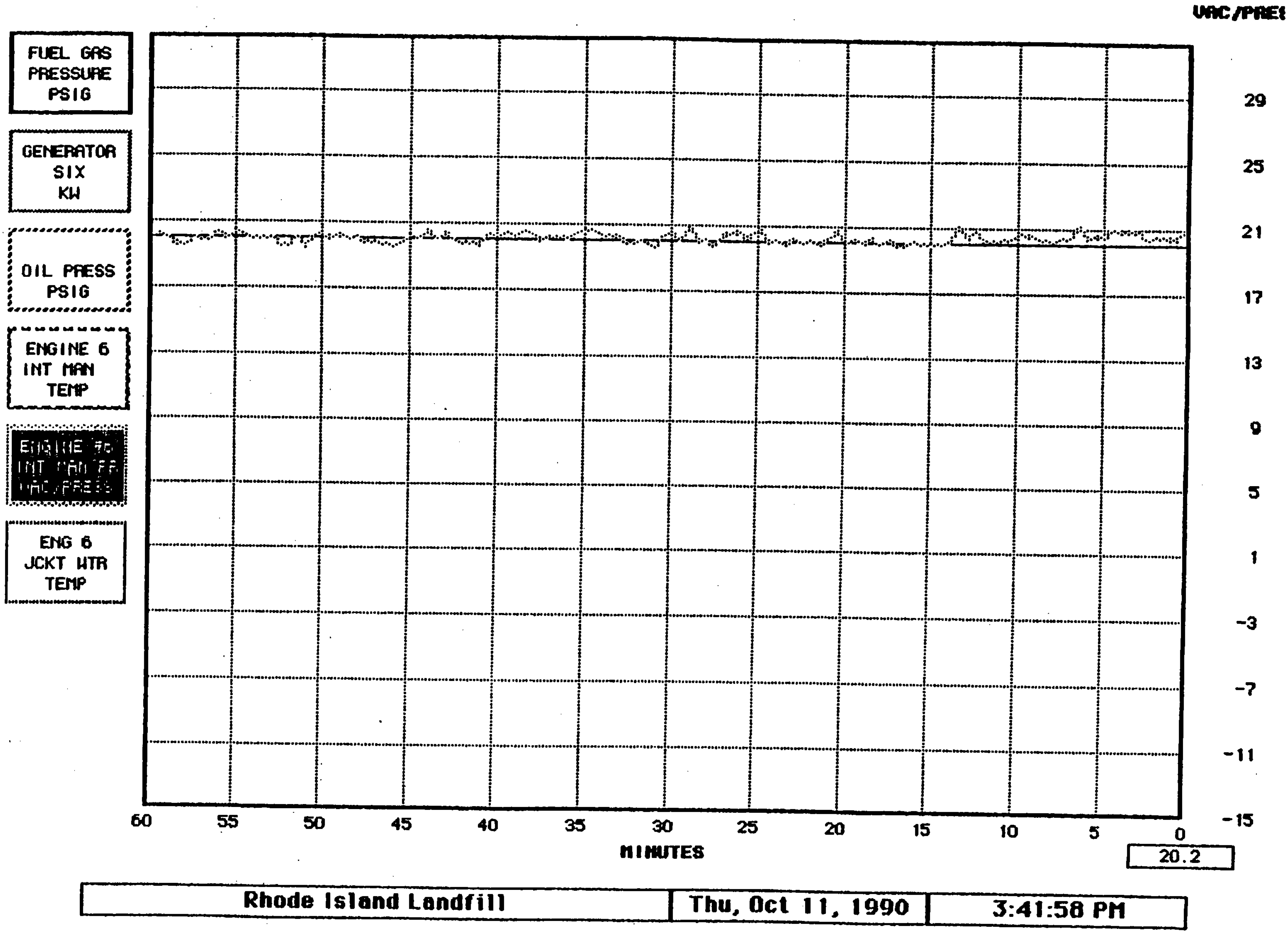


Rhode Island Landfill | Thu Oct 11 1990 | 3:34:55 PM

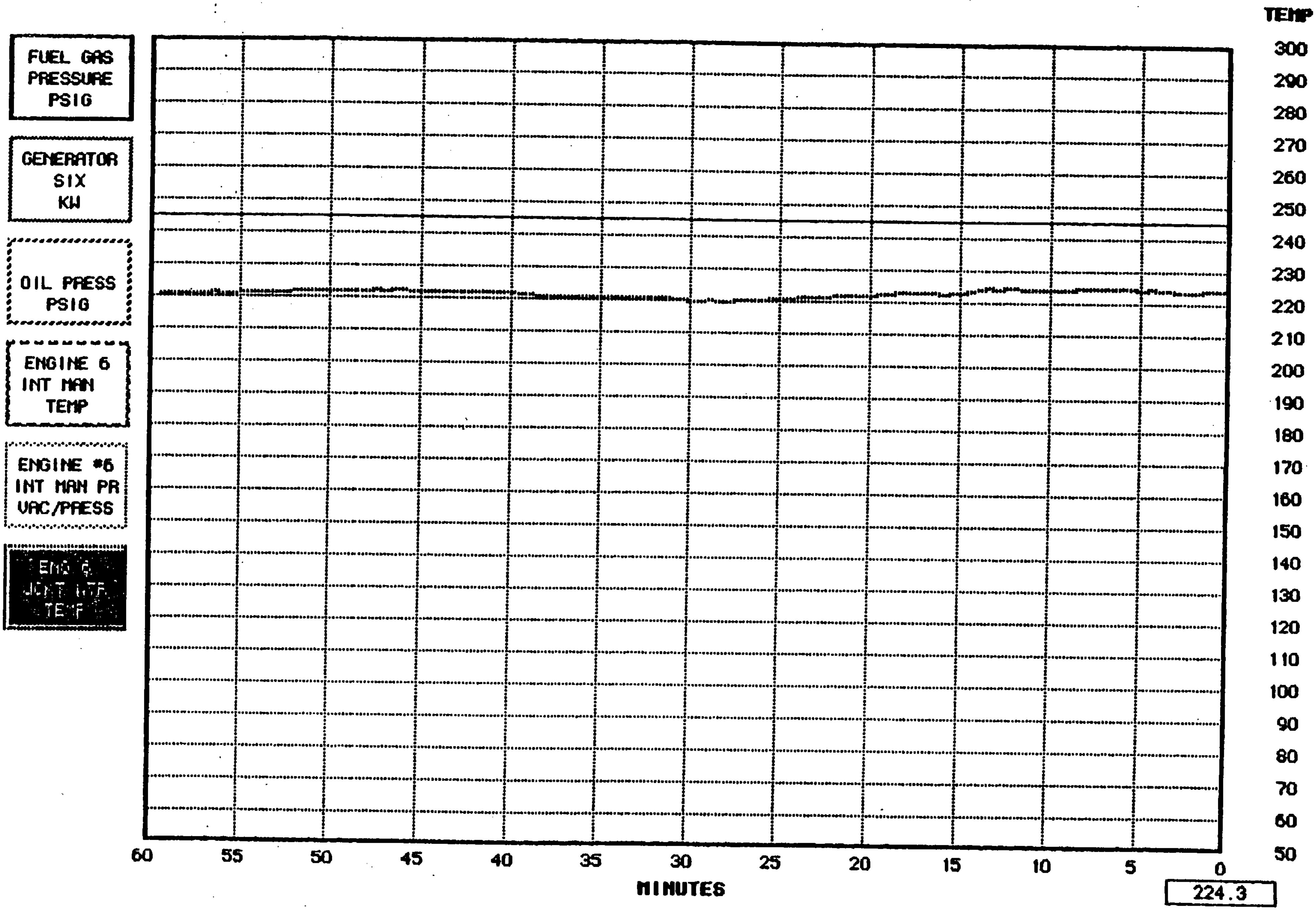


Rhode Island Landfill | Thu, Oct 11, 1990 | 3:37:23 PM

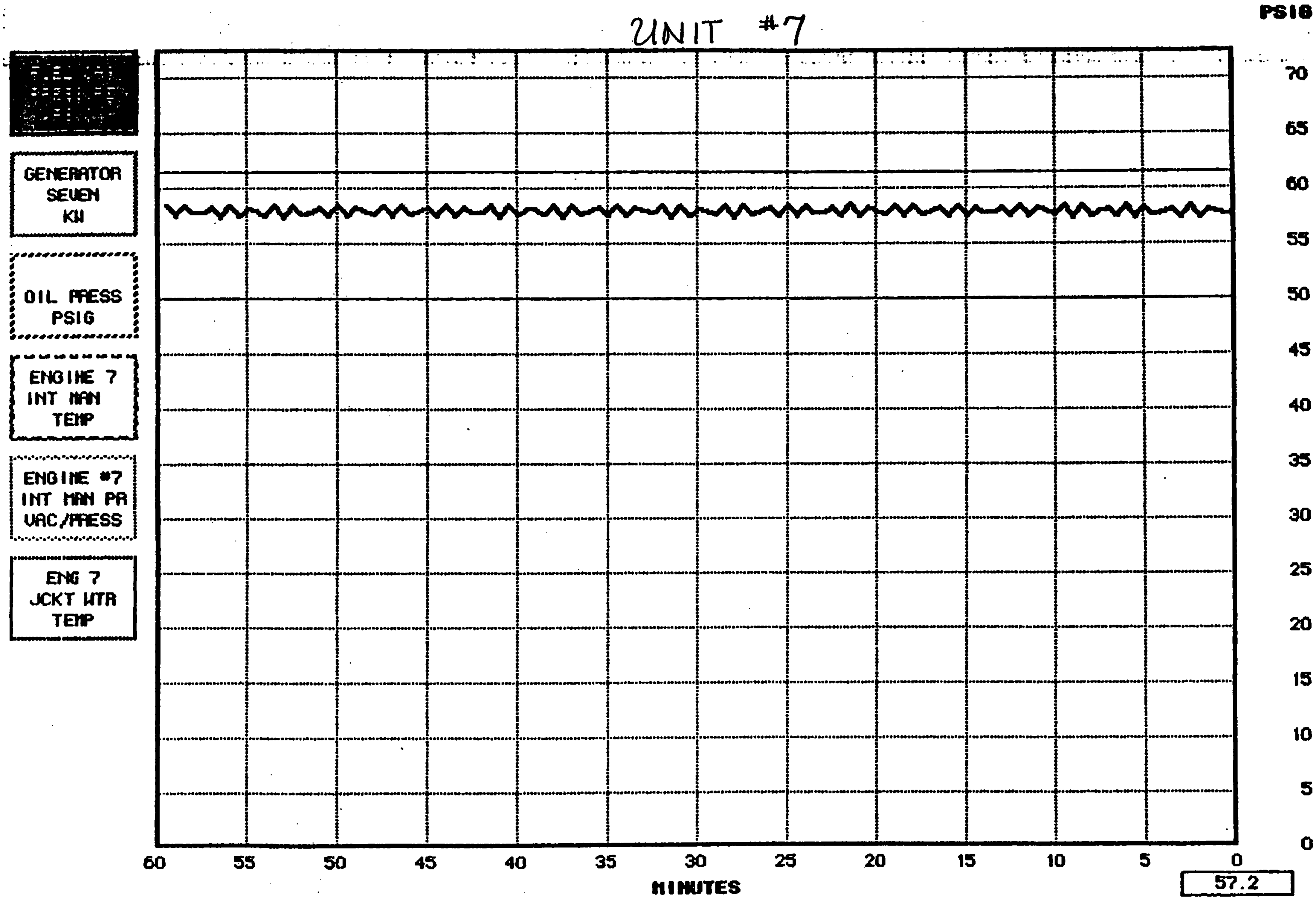

FUEL GAS PRESSURE PSIG
GENERATOR SIX KW
OIL PRESS PSIG
ENGINE #6 INT MAN PR VAC/PRESS
ENG 6 JCKT WTR TEMP
TEMP
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
135.5



VAC/PRE
FUEL GAS PRESSURE PSIG
GENERATOR SIX KW
OIL PRESS PSIG
ENGINE 6 INT MAN TEMP
ENG 6 JCKT WTR TEMP
29
25
21
17
13
9
5
1
-3
-7
-11
-15
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
20.2
Rhode Island Landfill
Thu, Oct 11, 1990
3:41:58 PM

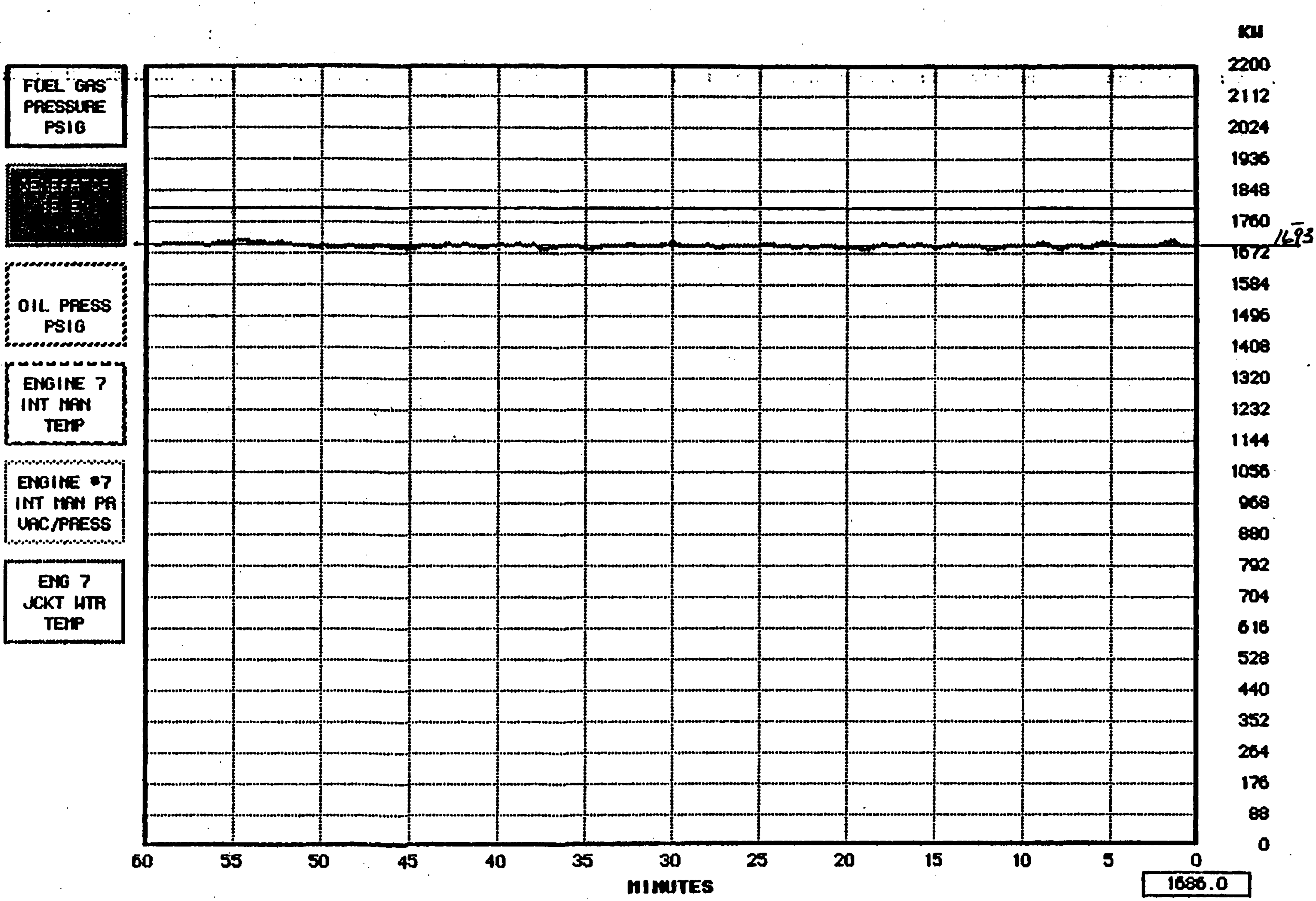

FUEL GAS PRESSURE PSIG
GENERATOR SIX KW
OIL PRESS PSIG
ENGINE 6 INT MAN TEMP
ENGINE #6 INT MAN PR VAC/PRESS
TEMP
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
224.3

UNIT #7



Rhode Island Landfill	Thu, Oct 11, 1990	10:35:56 AM

UNIT #7



FUEL GAS PRESSURE PSIG
OIL PRESS PSIG
ENGINE 7 INT MAN TEMP
ENGINE #7 INT MAN PR VAC/PRESS
ENG 7 JCKT WTR TEMP
KW
2200
2112
2024
1936
1848
1760
1672
1584
1496
1408
1320
1232
1144
1056
968
880
792
704
616
528
440
352
264
176
88
0
1693
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
1686.0

FUEL GAS
PRESSURE
PSIG

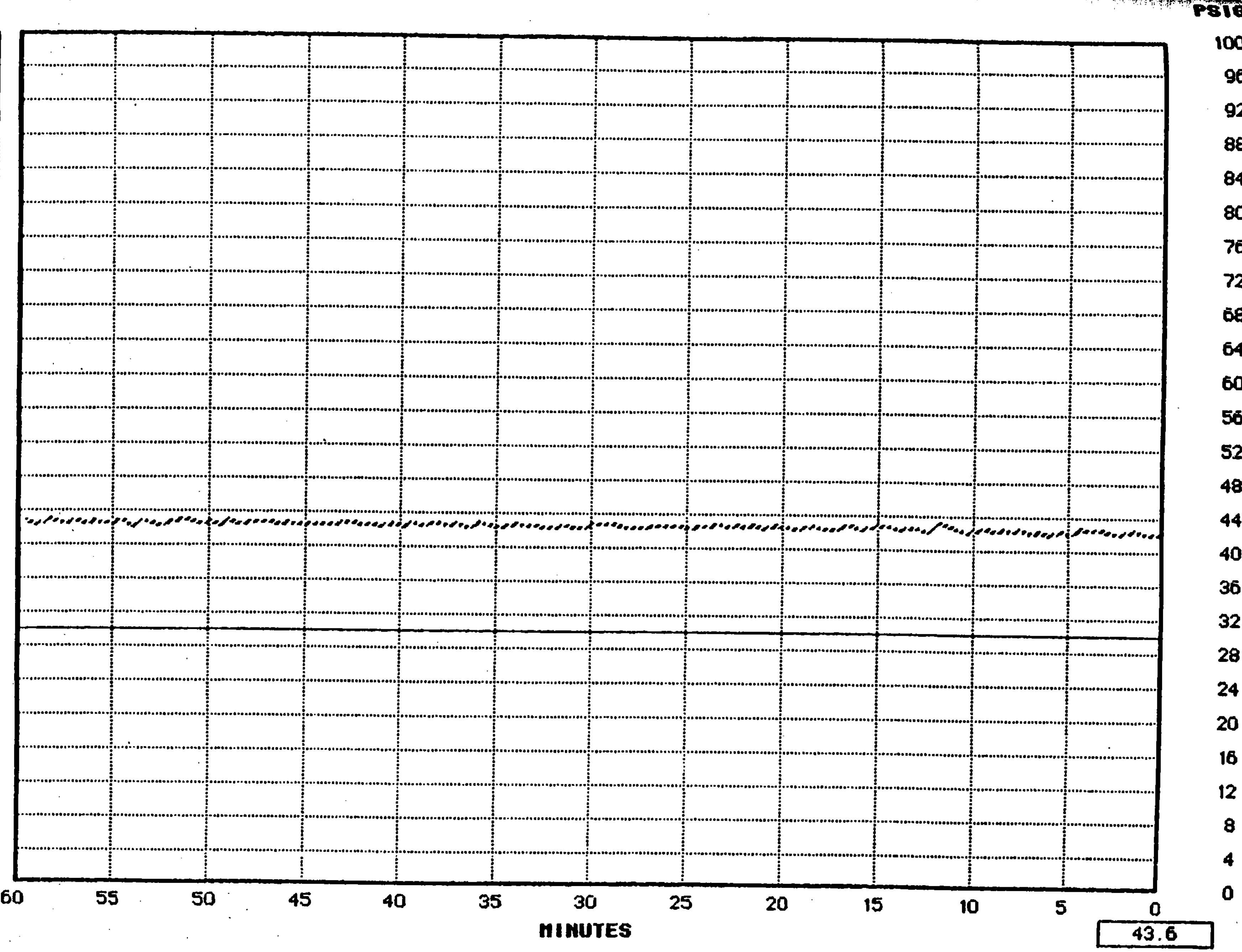
GENERATOR
SEVEN
KW

OIL PRESS
PSIG

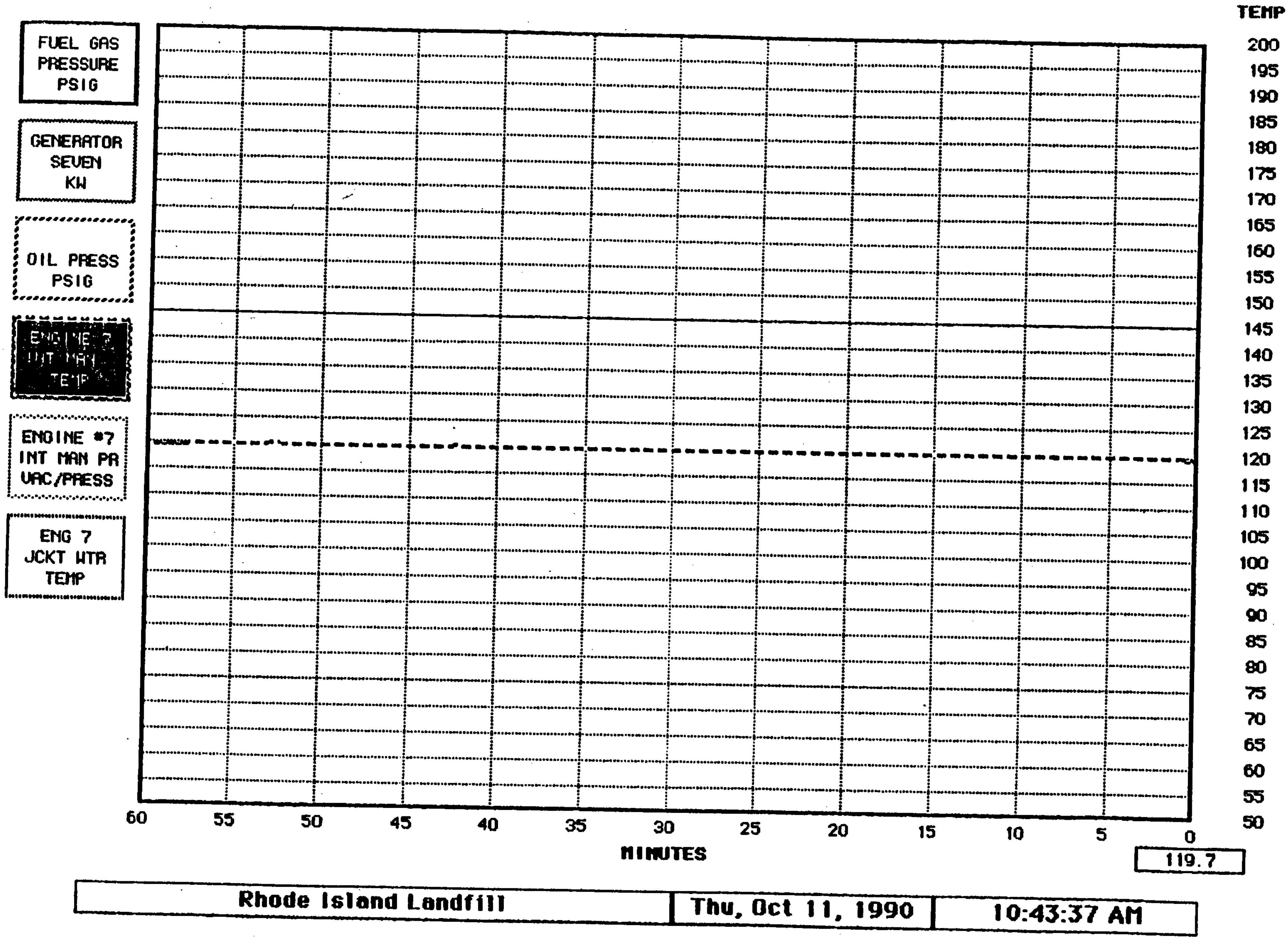
ENGINE 7
INT MAN
TEMP

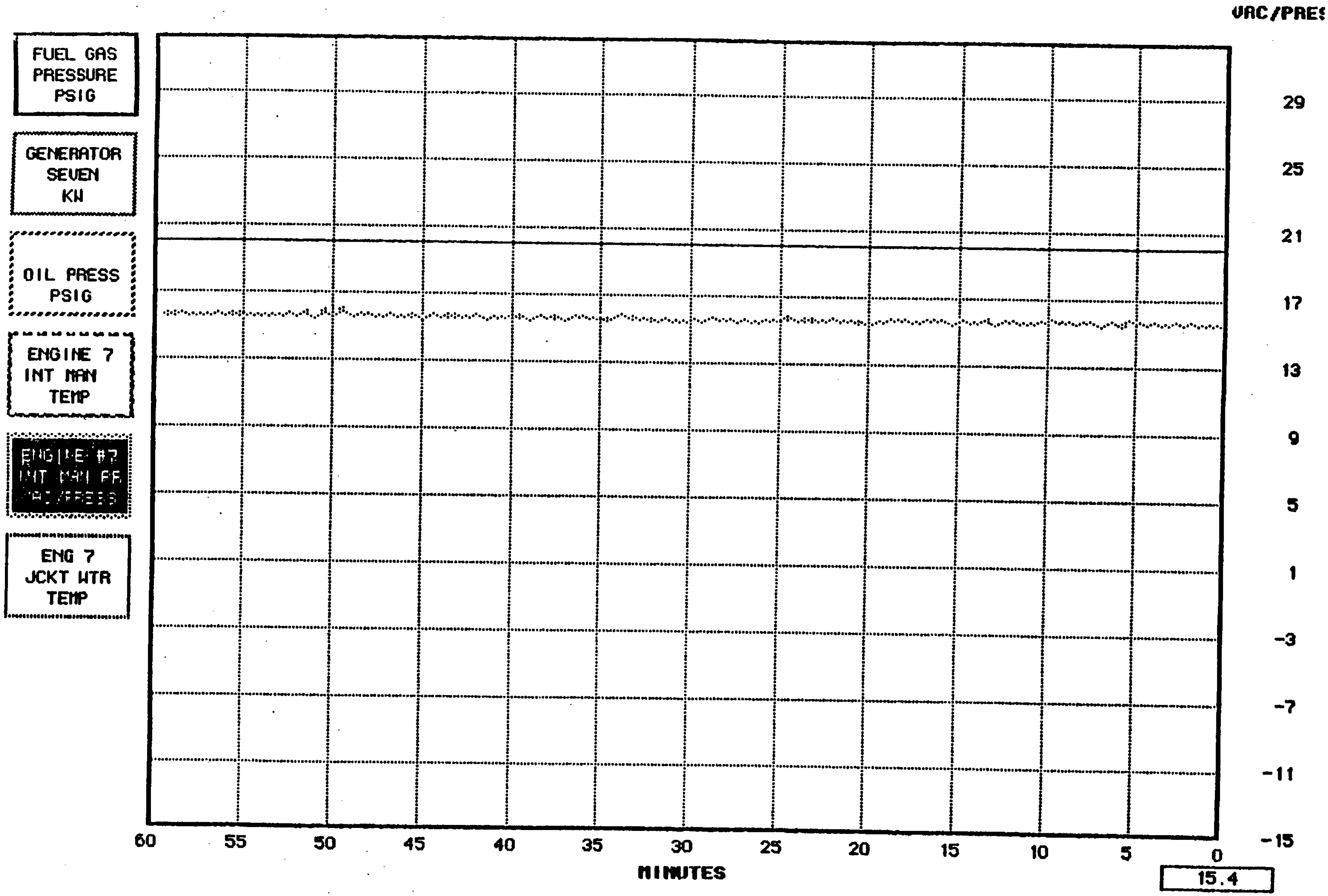
ENGINE #7
INT MAN PR
VAC/PRESS

ENG 7
JCKT WTR
TEMP



Rhode Island Landfill	Thu, Oct 11, 1990	10:41:19 AM


FUEL GAS PRESSURE PSIG
GENERATOR SEVEN KW
OIL PRESS PSIG
ENGINE 7 INT MAN TEMP
ENGINE #7 INT MAN PR VAC/PRESS
ENG 7 JCKT WTR TEMP
TEMP
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
60 55 50 45 40 35 30 25 20 15 10 5 0
MINUTES
119.7
Rhode Island Landfill
Thu, Oct 11, 1990
10:43:37 AM



Rhode Island Landfill	Thu, Oct 11, 1990	10:46:12 AM

FUEL GAS
PRESSURE
PSIG

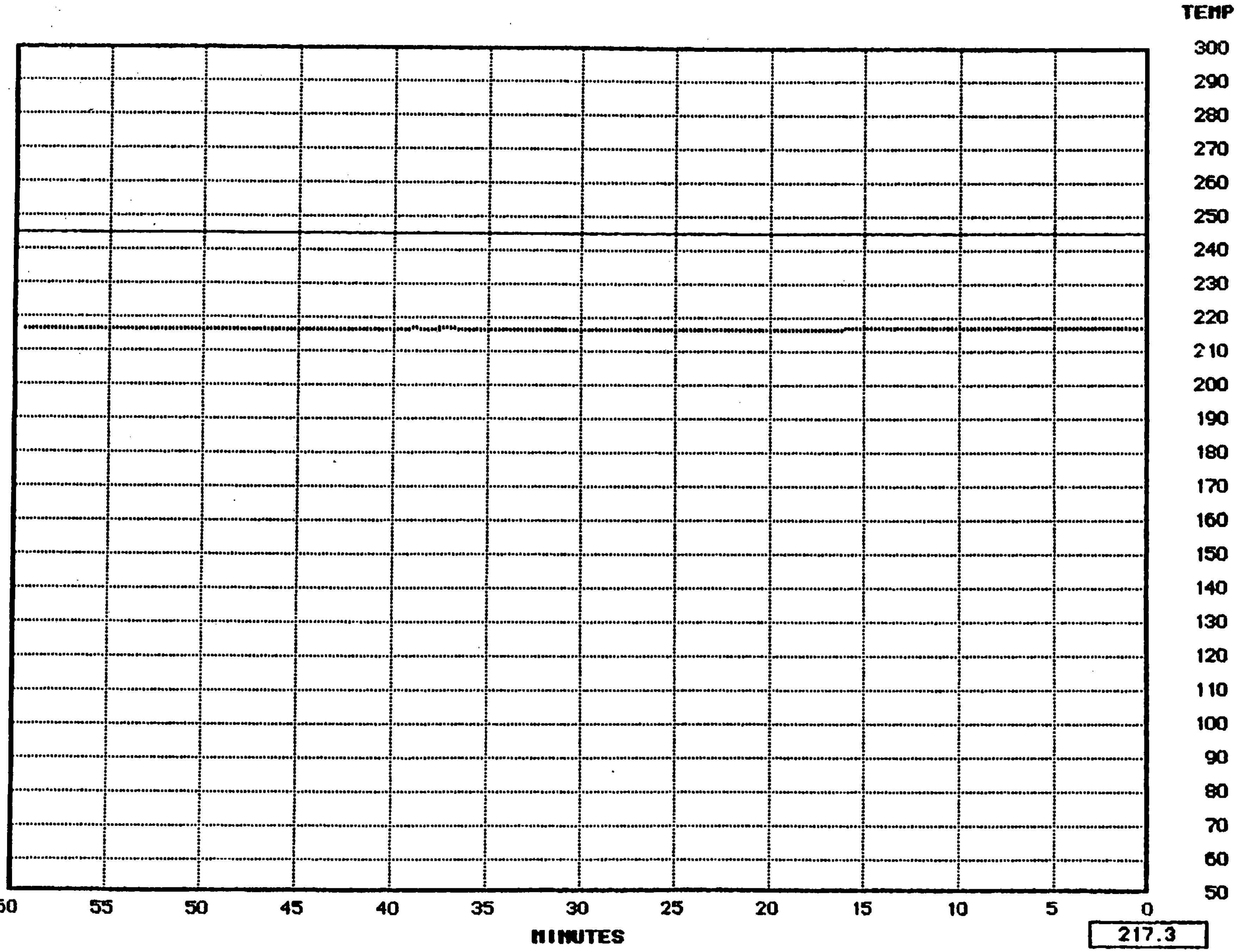
GENERATOR
SEVEN
KW

OIL PRESS
PSIG

ENGINE 7
INT MAN
TEMP

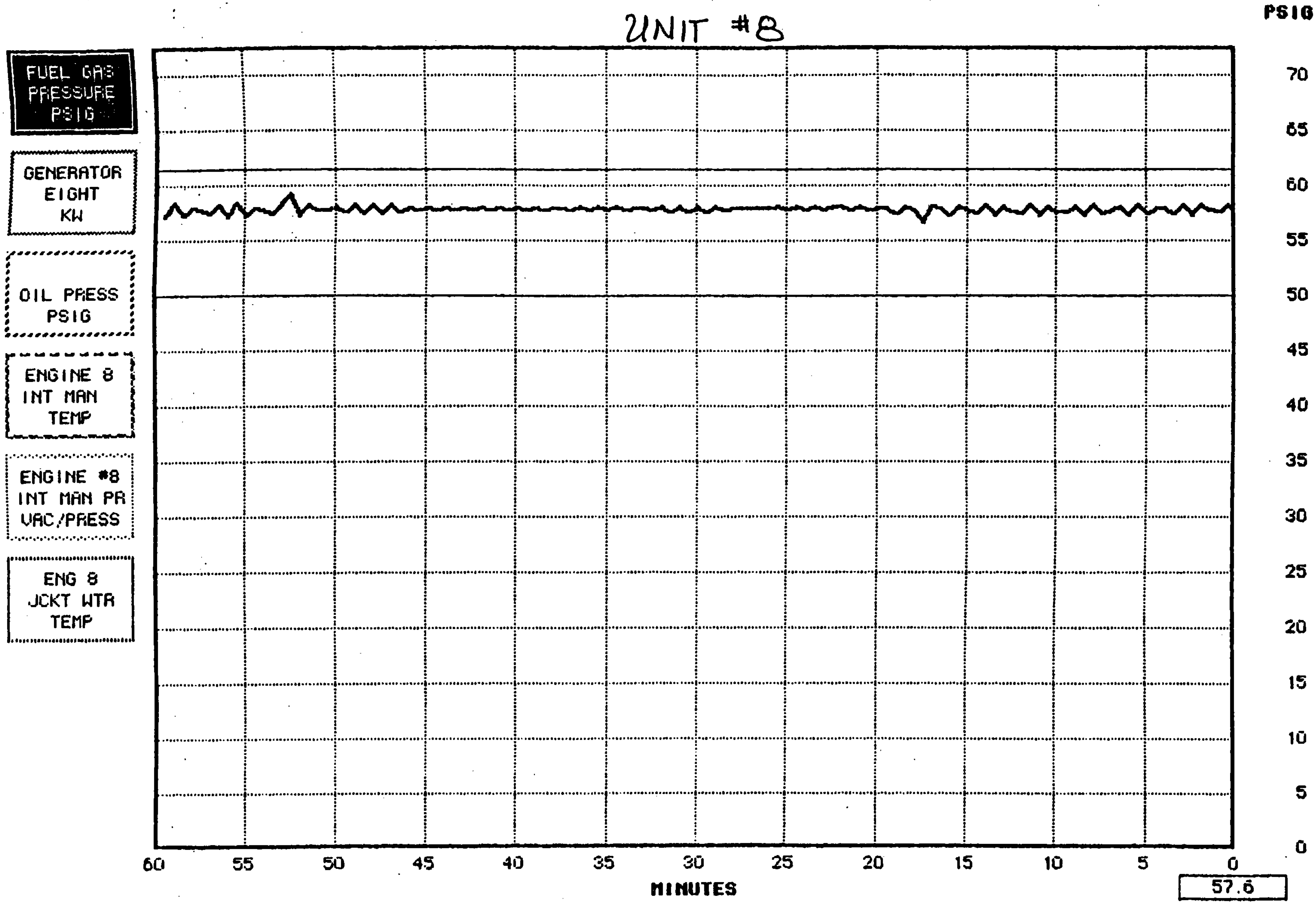
ENGINE #7
INT MAN PR
VAC/PRESS

TEMP



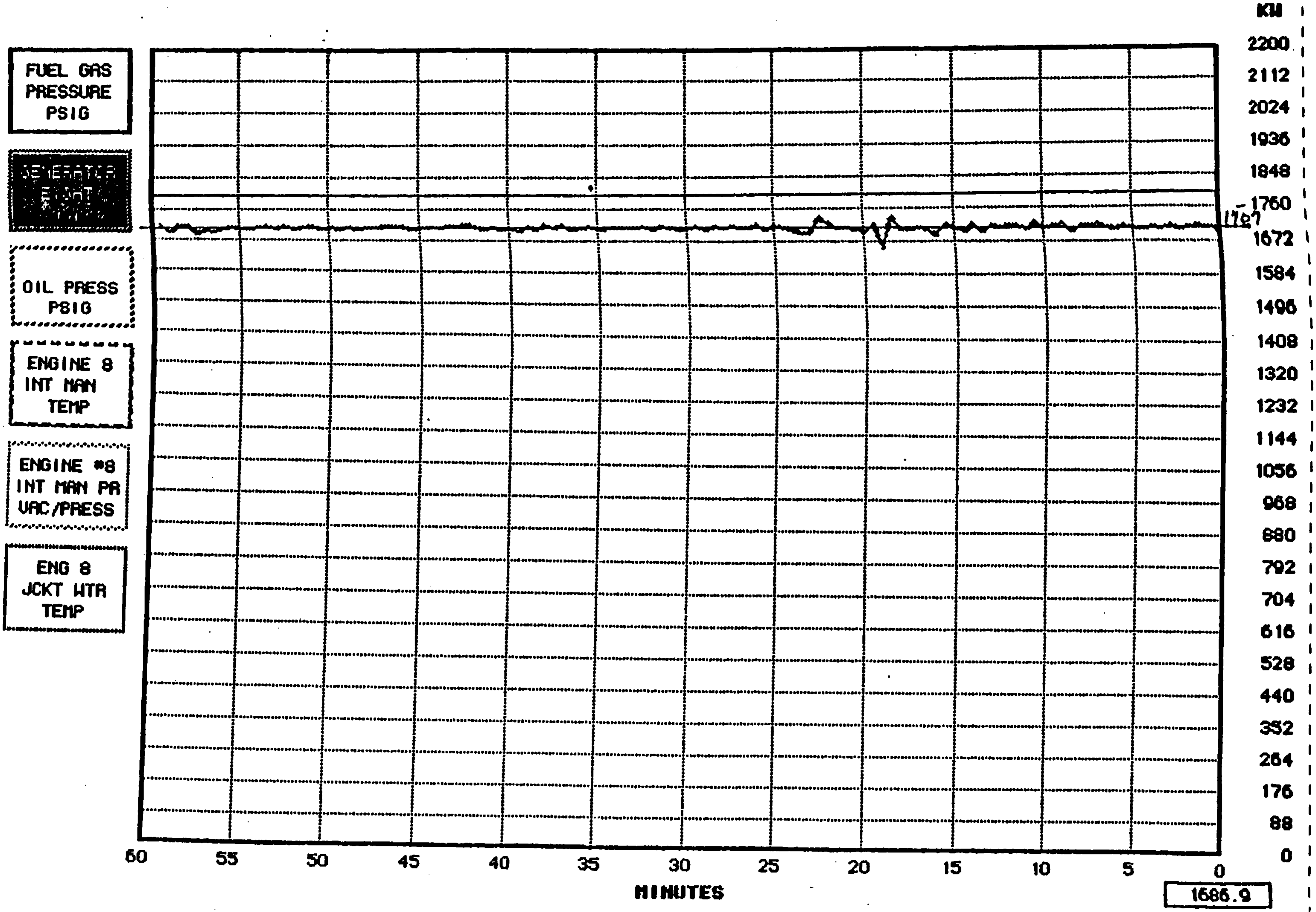
Rhode Island Landfill	Thu, Oct 11, 1990	10:48:33 AM

UNIT #8

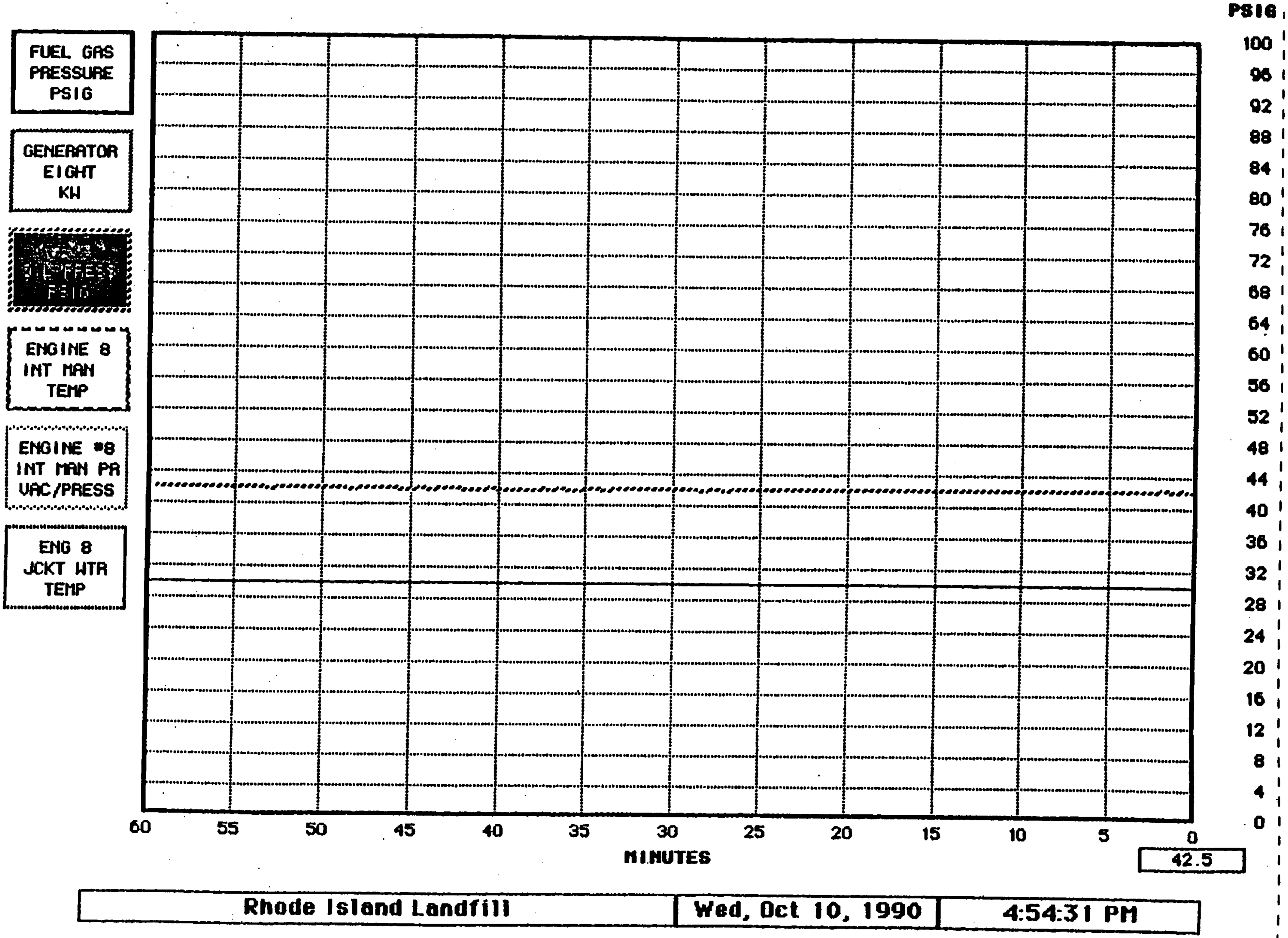


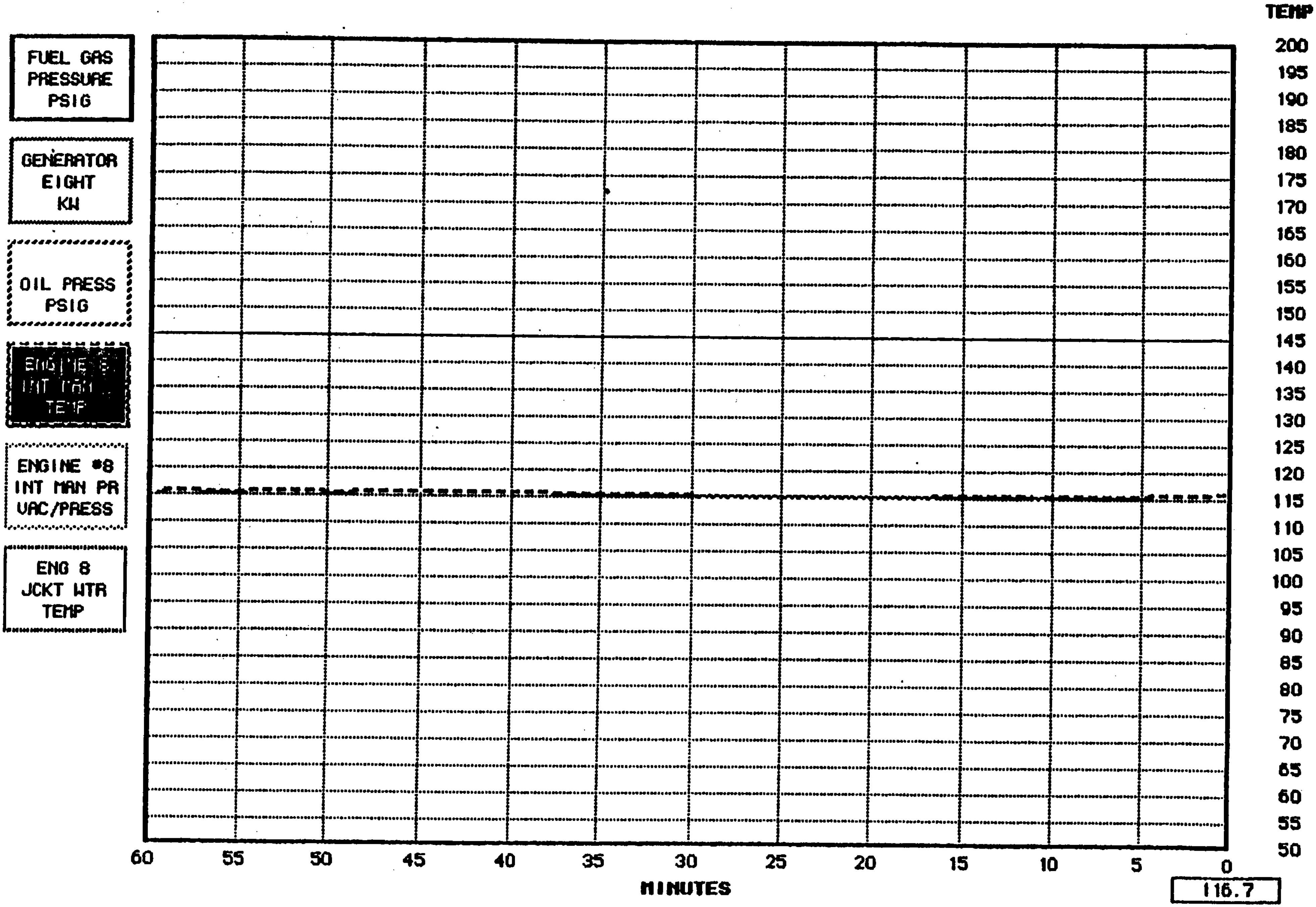
Rhode Island Landfill	Wed, Oct 10, 1990	4:49:59 PM

UNIT #8

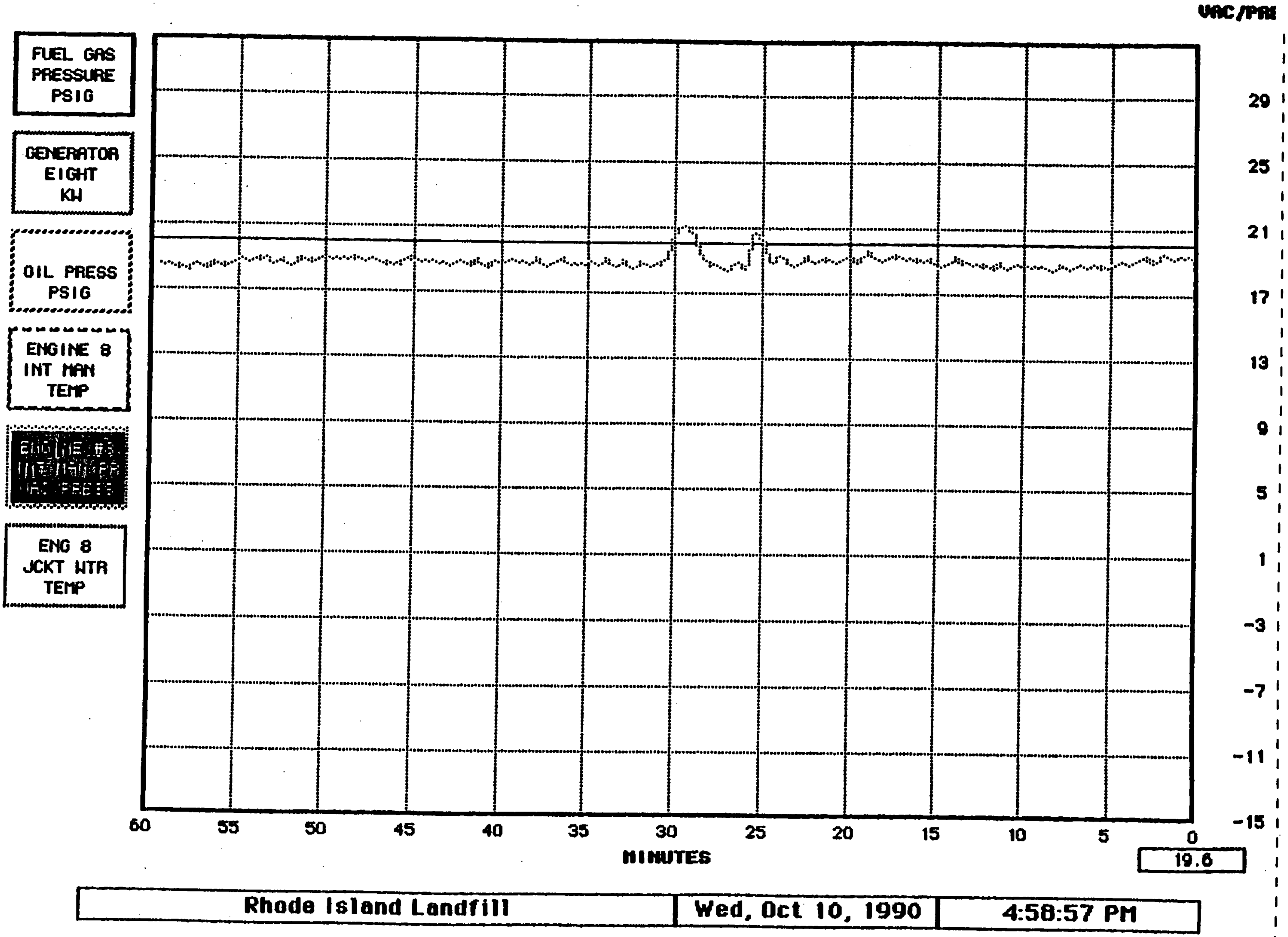


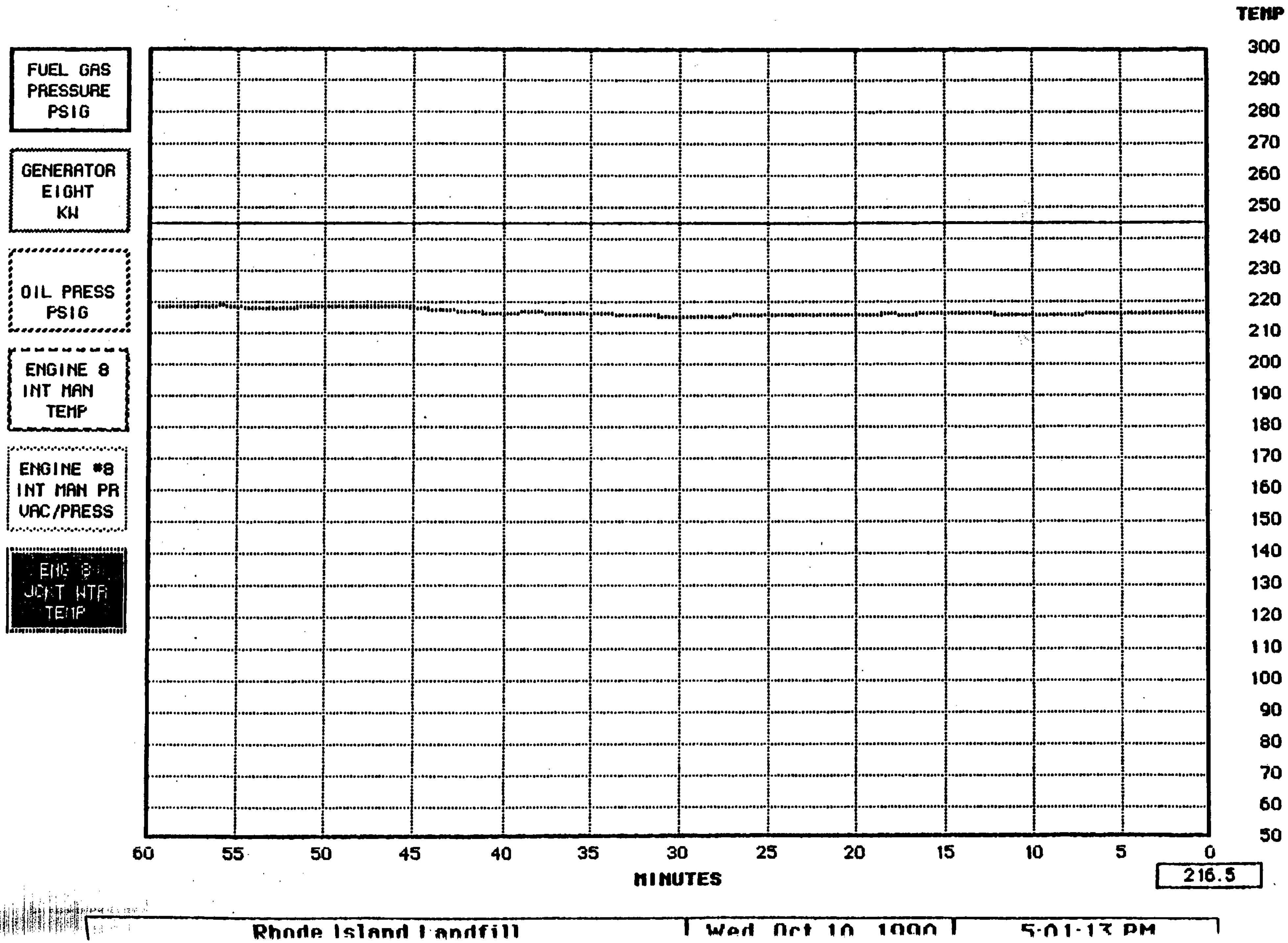
FUEL GAS PRESSURE PSIG
OIL PRESS PSIG
ENGINE 8 INT MAN TEMP
ENGINE #8 INT MAN PR VAC/PRESS
ENG 8 JCKT WTR TEMP
KW
2200
2112
2024
1936
1848
1760
1672
1584
1496
1408
1320
1232
1144
1056
968
880
792
704
616
528
440
352
264
176
88
0
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
1686.9


FUEL GAS PRESSURE PSIG
GENERATOR EIGHT KW
OIL PRESS PSIG
ENGINE 8 INT MAN TEMP
ENGINE #8 INT MAN PR VAC/PRESS
ENG 8 JCKT WTR TEMP
PSIG
100
96
92
88
84
80
76
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
42.5
Rhode Island Landfill
Wed, Oct 10, 1990
4:54:31 PM

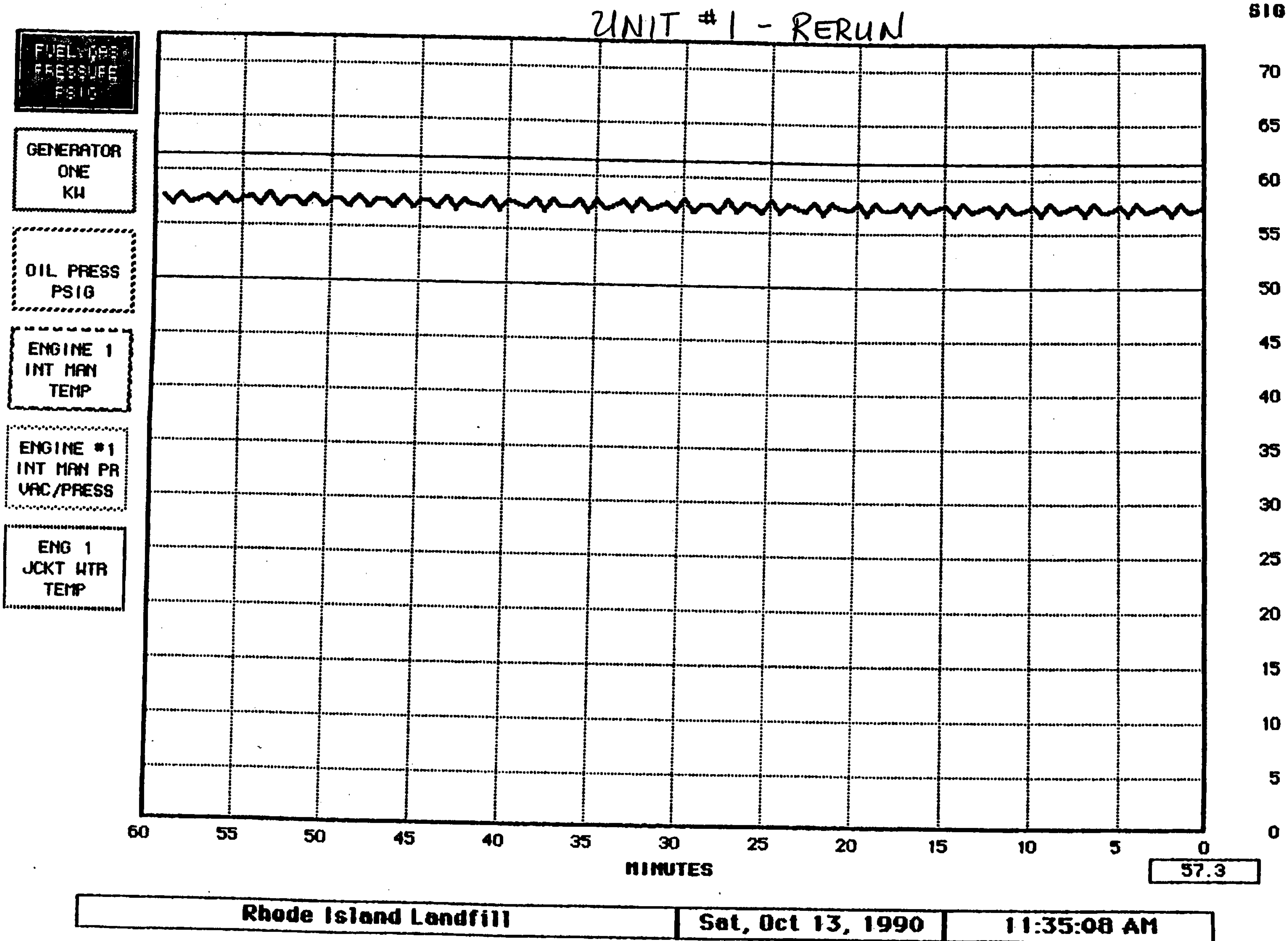


Rhode Island Landfill | Wed, Oct 10, 1990 | 4:56:45 PM

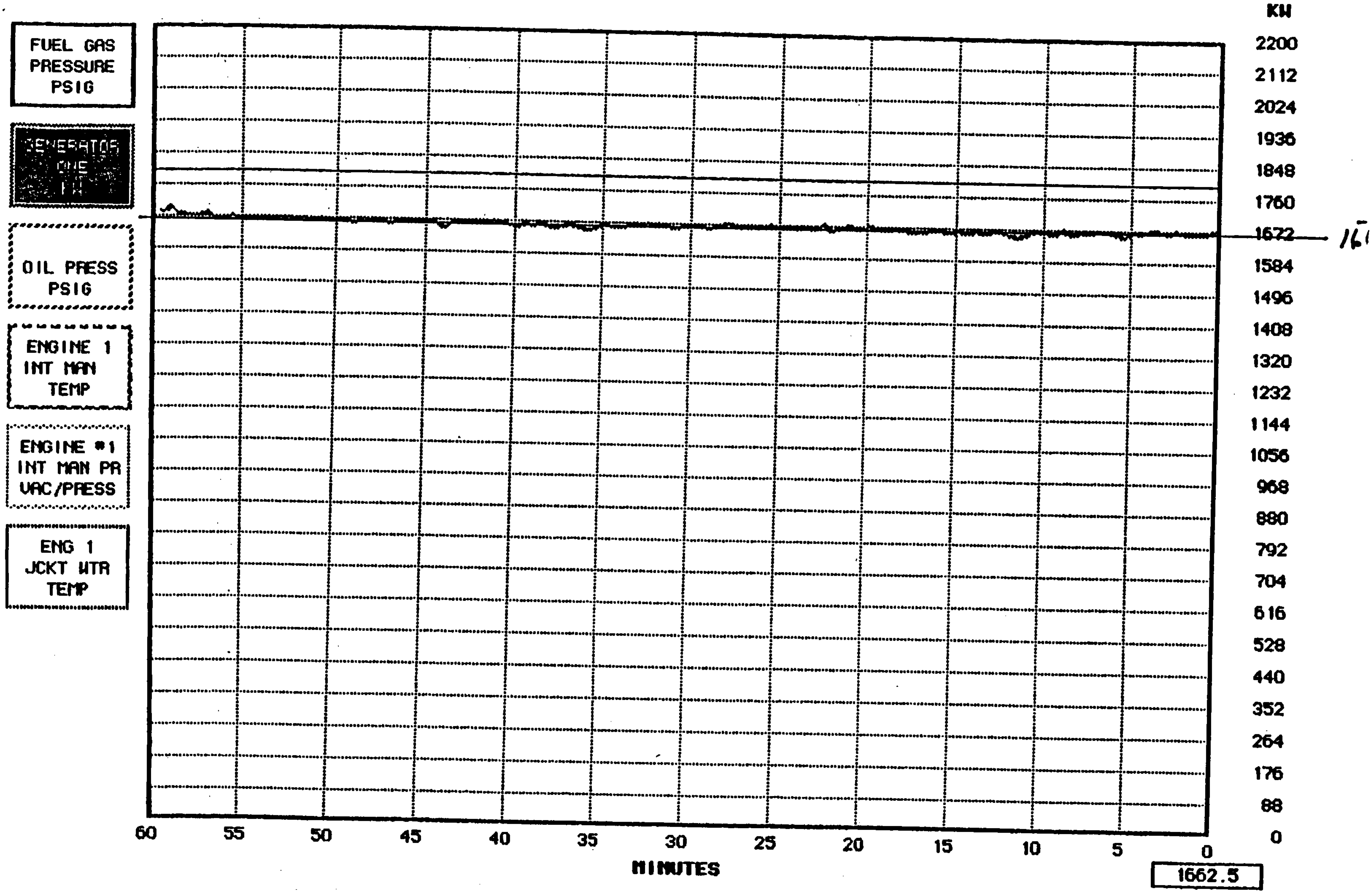

FUEL GAS PRESSURE PSIG
GENERATOR EIGHT KW
OIL PRESS PSIG
ENGINE 8 INT MAN TEMP
ENG 8 JCKT WTR TEMP
VAC/PRE
29
25
21
17
13
9
5
1
-3
-7
-11
-15
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
19.6
Rhode Island Landfill
Wed, Oct 10, 1990
4:58:57 PM


FUEL GAS PRESSURE PSIG
GENERATOR EIGHT KW
OIL PRESS PSIG
ENGINE 8 INT MAN TEMP
ENGINE #8 INT MAN PR VAC/PRESS
ENG 8 JCKT WTR TEMP
TEMP
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
216.5
Rhode Island Landfill
Wed Oct 10 1990
5:01:13 PM

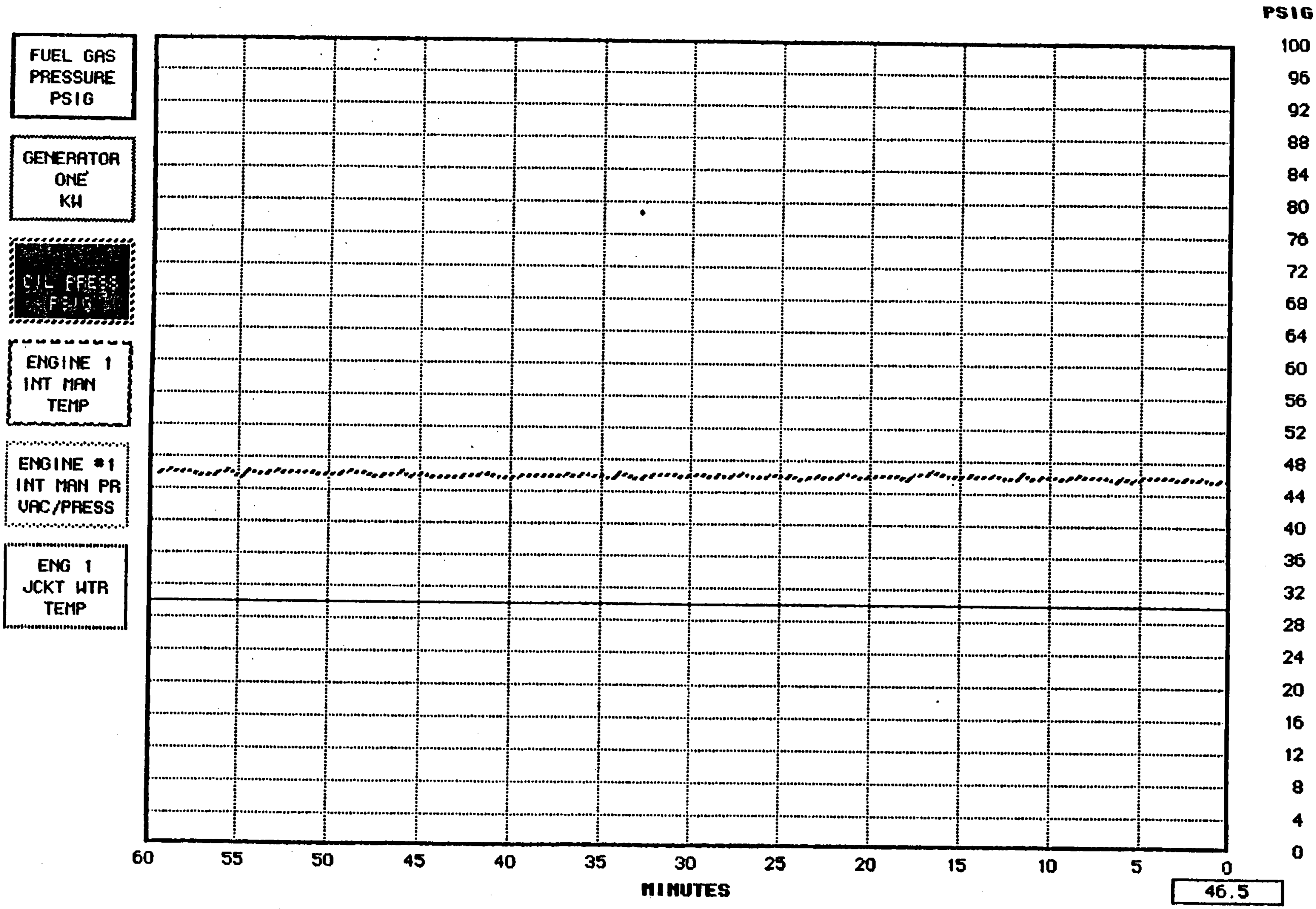
UNIT #1 - RERUN



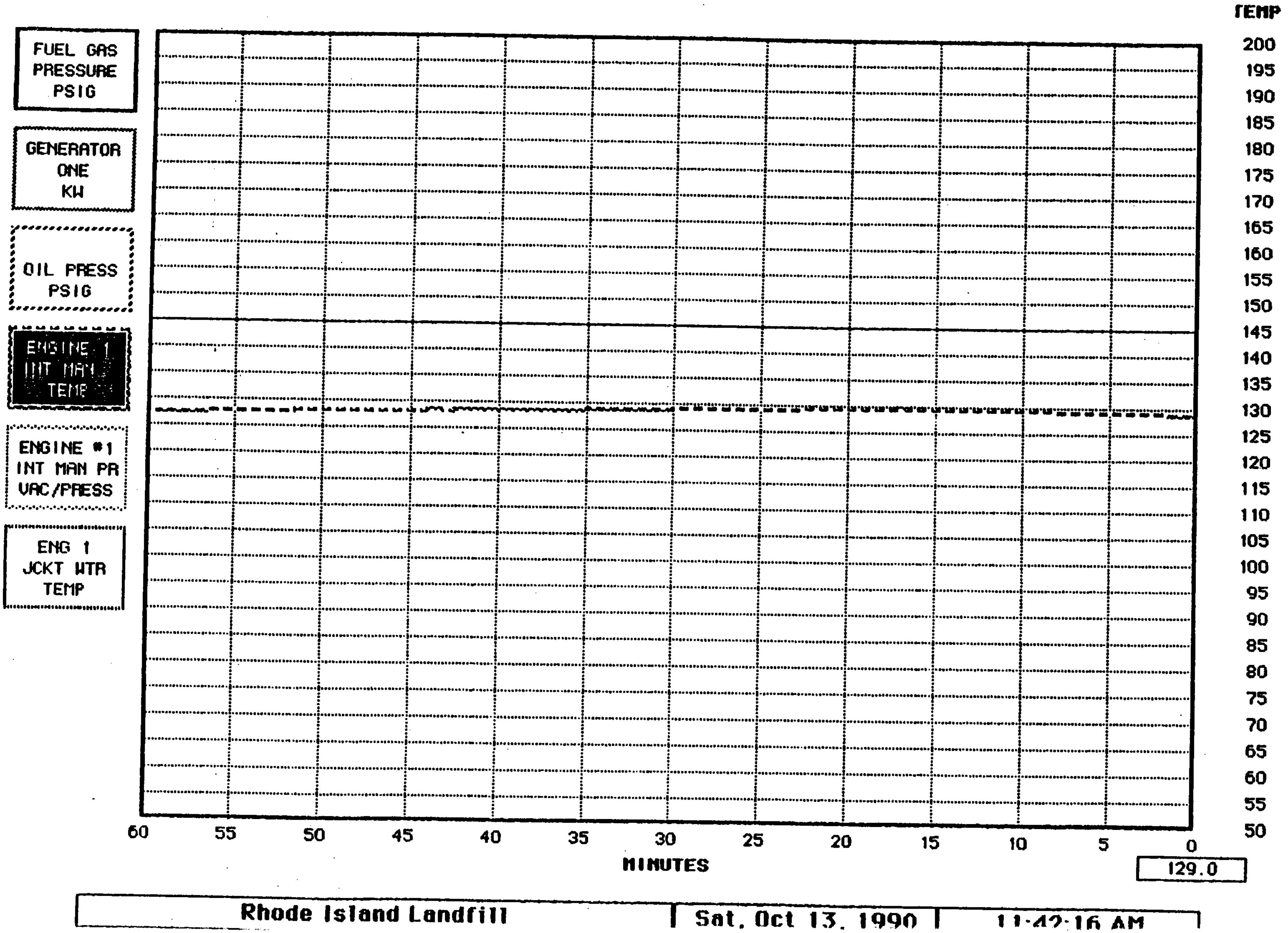
UNIT #1 - RERUN

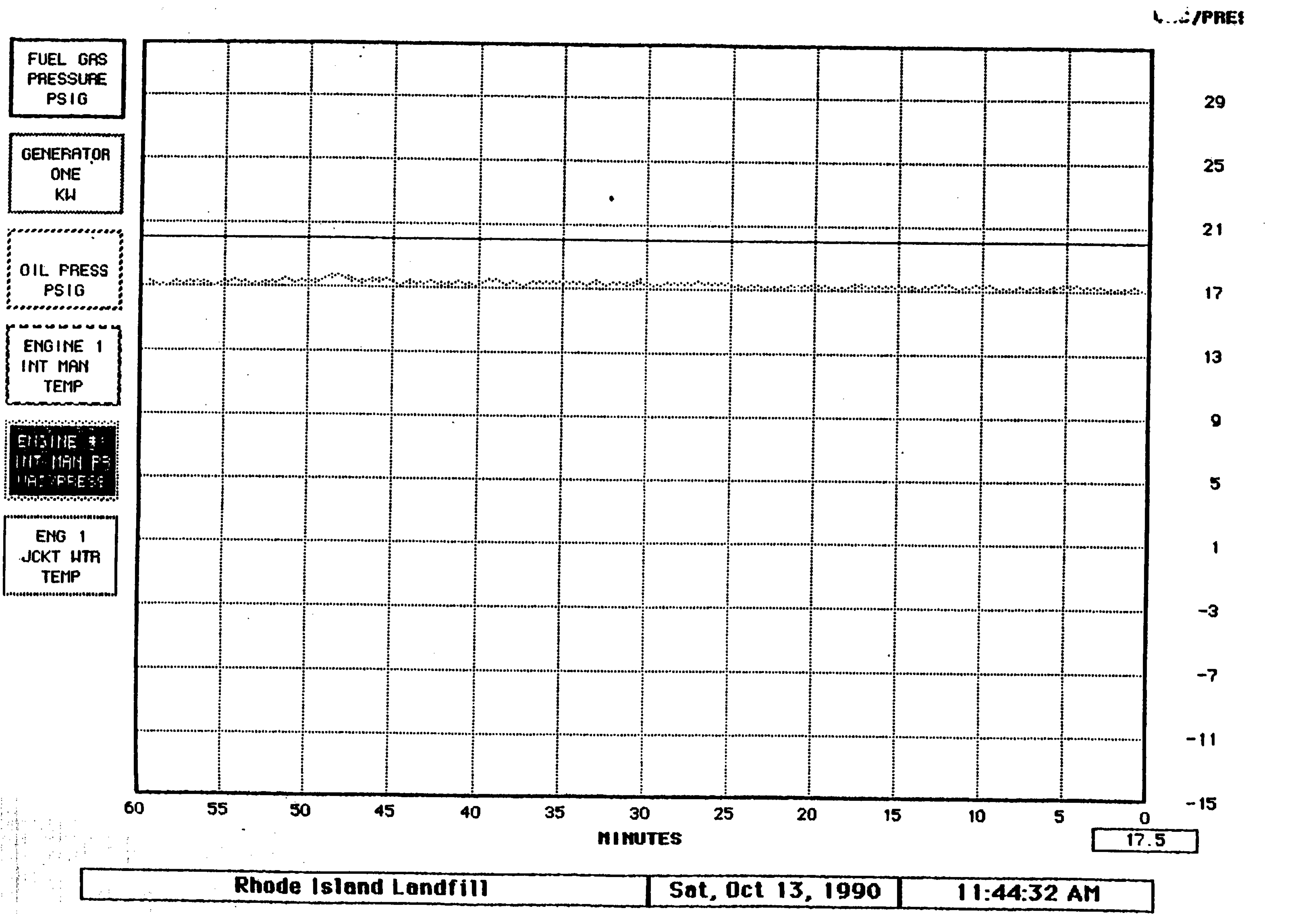


Rhode Island Landfill | Sat, Oct 13, 1990 | 11:37:35 AM



Rhode Island Landfill	Sat, Oct 13, 1990	11:39:58 AM


FUEL GAS PRESSURE PSIG
GENERATOR ONE KW
OIL PRESS PSIG
ENGINE 1 INT MAN TEMP
ENGINE #1 INT MAN PR VAC/PRESS
ENG 1 JCKT WTR TEMP
TEMP
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
129.0
Rhode Island Landfill
Sat, Oct 13, 1990
11:42:16 AM



/PRES
FUEL GAS PRESSURE PSIG
GENERATOR ONE KW
OIL PRESS PSIG
ENGINE 1 INT MAN TEMP
ENGINE # INT MAN PS VAC/PRESS
ENG 1 JCKT WTR TEMP
29
25
21
17
13
9
5
1
-3
-7
-11
-15
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
17.5
Rhode Island Landfill
Sat, Oct 13, 1990
11:44:32 AM

FUEL GAS
PRESSURE
PSIG

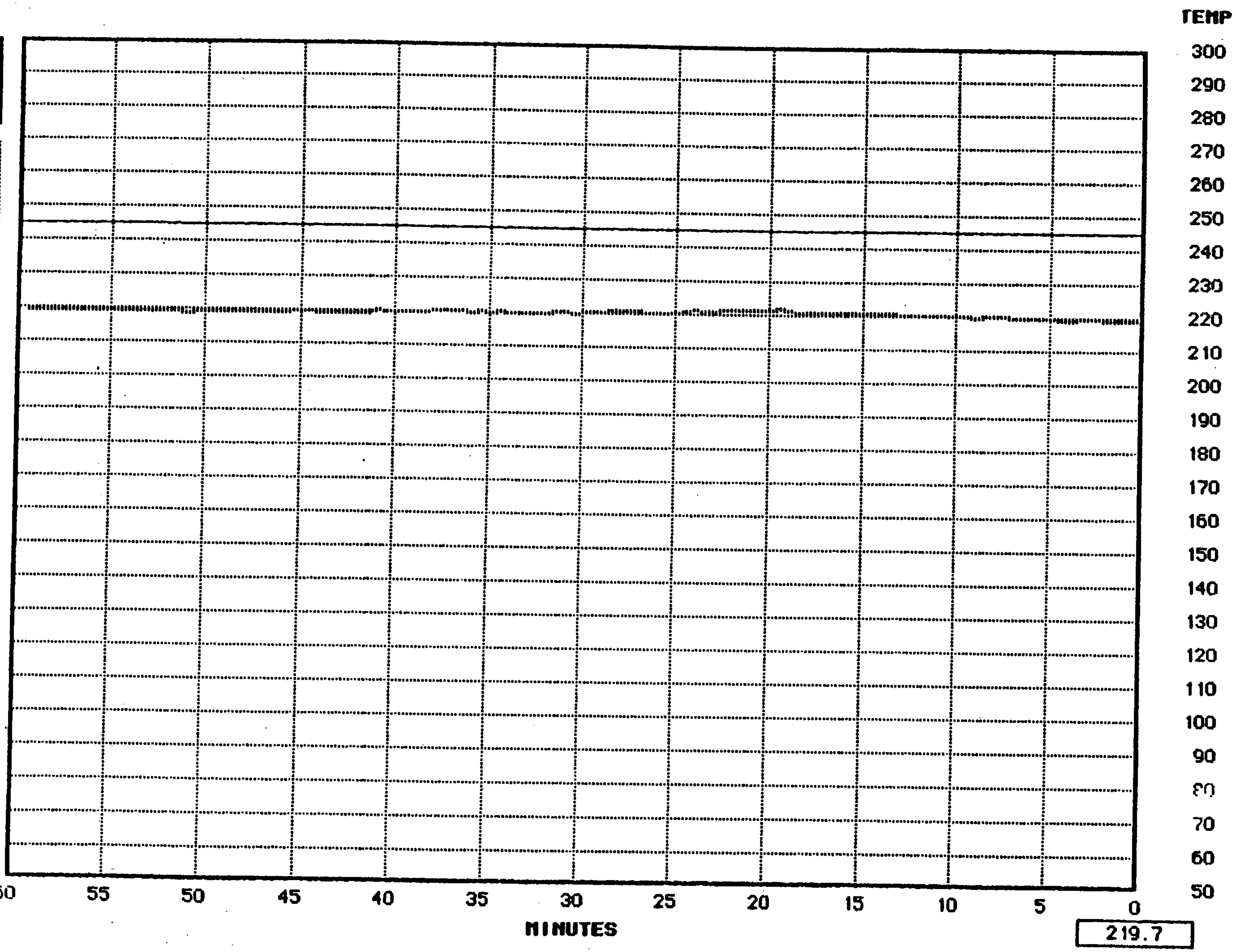
GENERATOR
ONE
KW

OIL PRESS
PSIG

ENGINE 1
INT MAN
TEMP

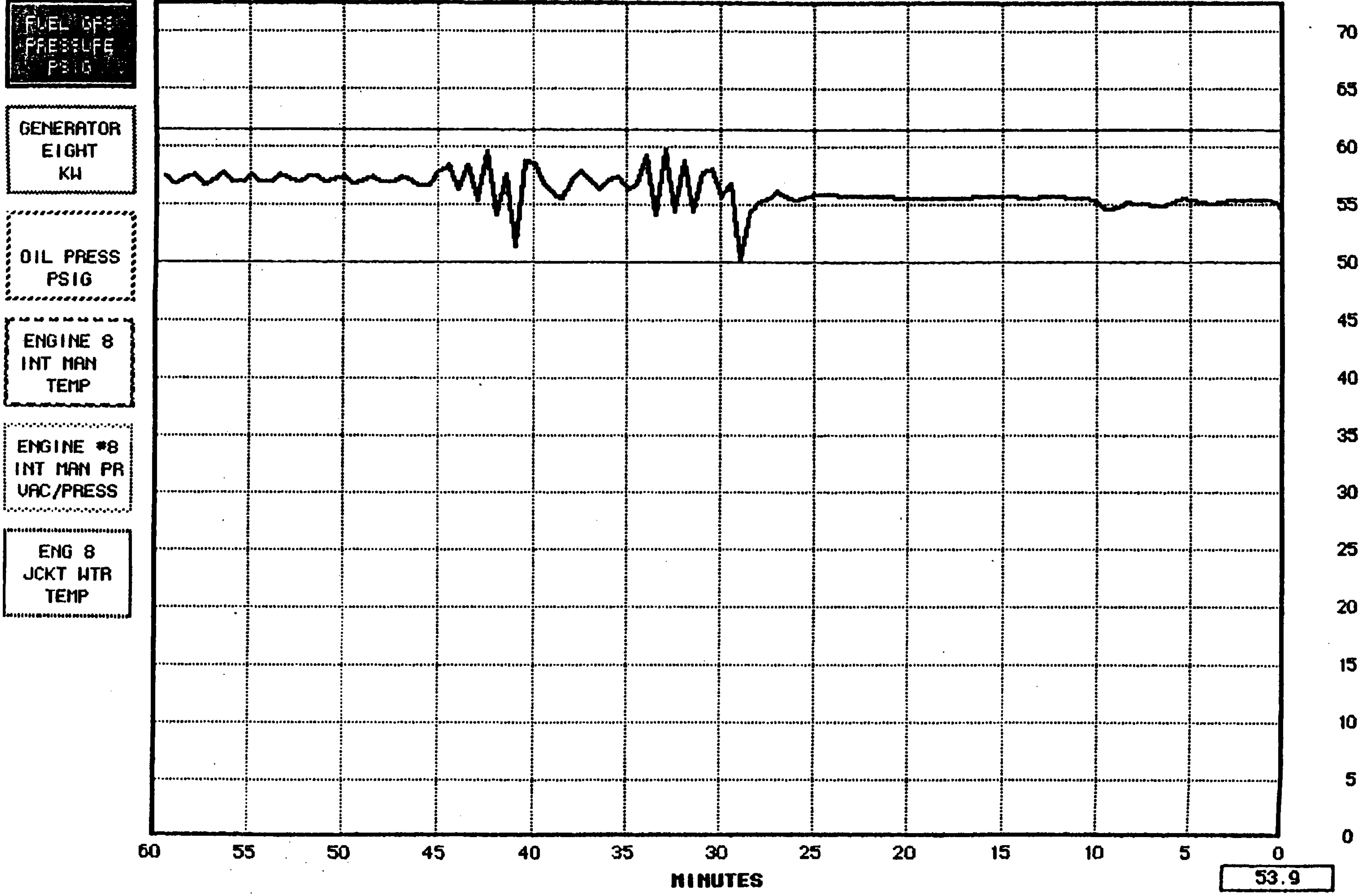
ENGINE #1
INT MAN PR
VAC/PRESS

ENG 1
JCKT WTR
TEMP



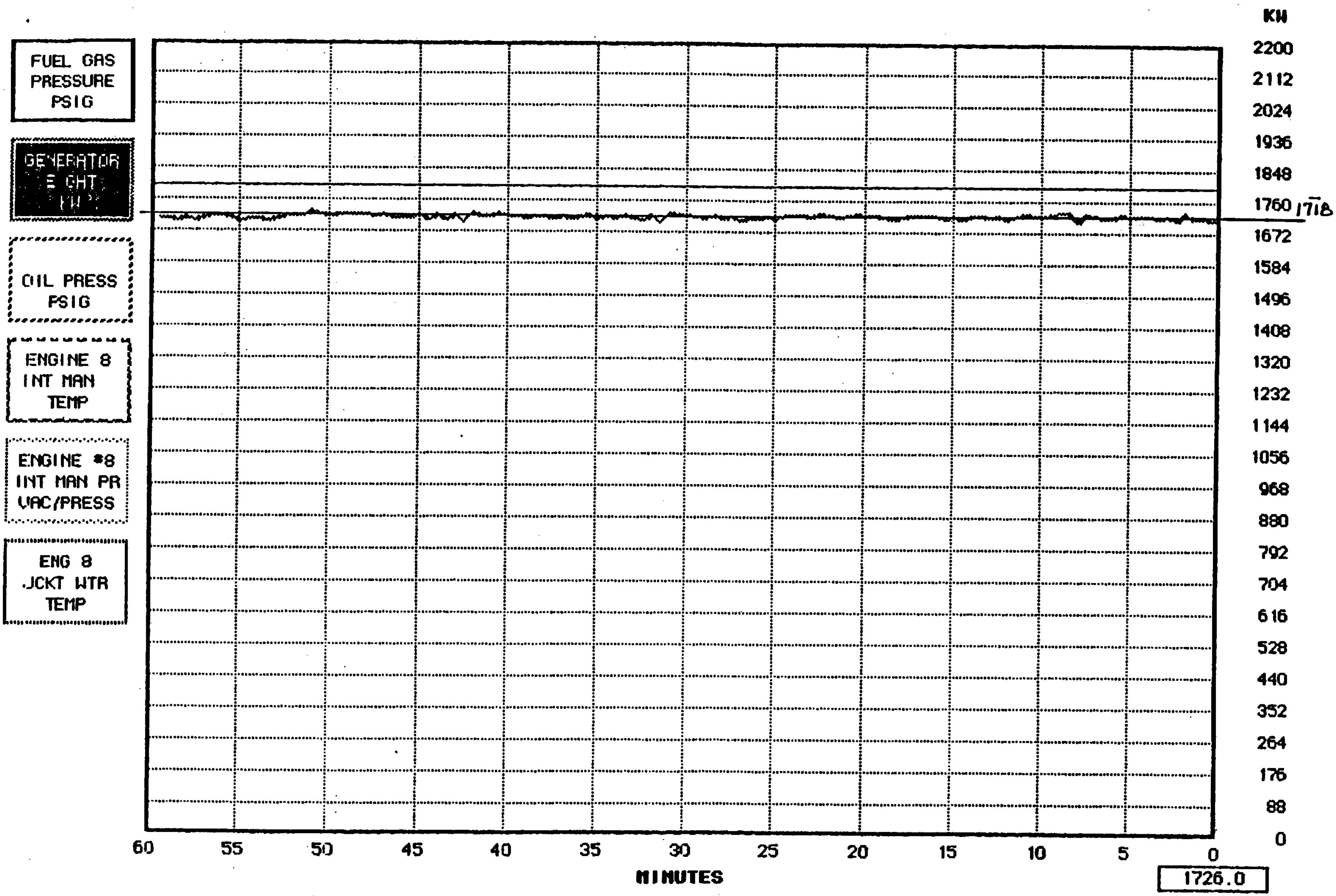
Rhode Island Landfill	Sat, Oct 13, 1990	11:46:54 AM

UNIT #8- RERUN

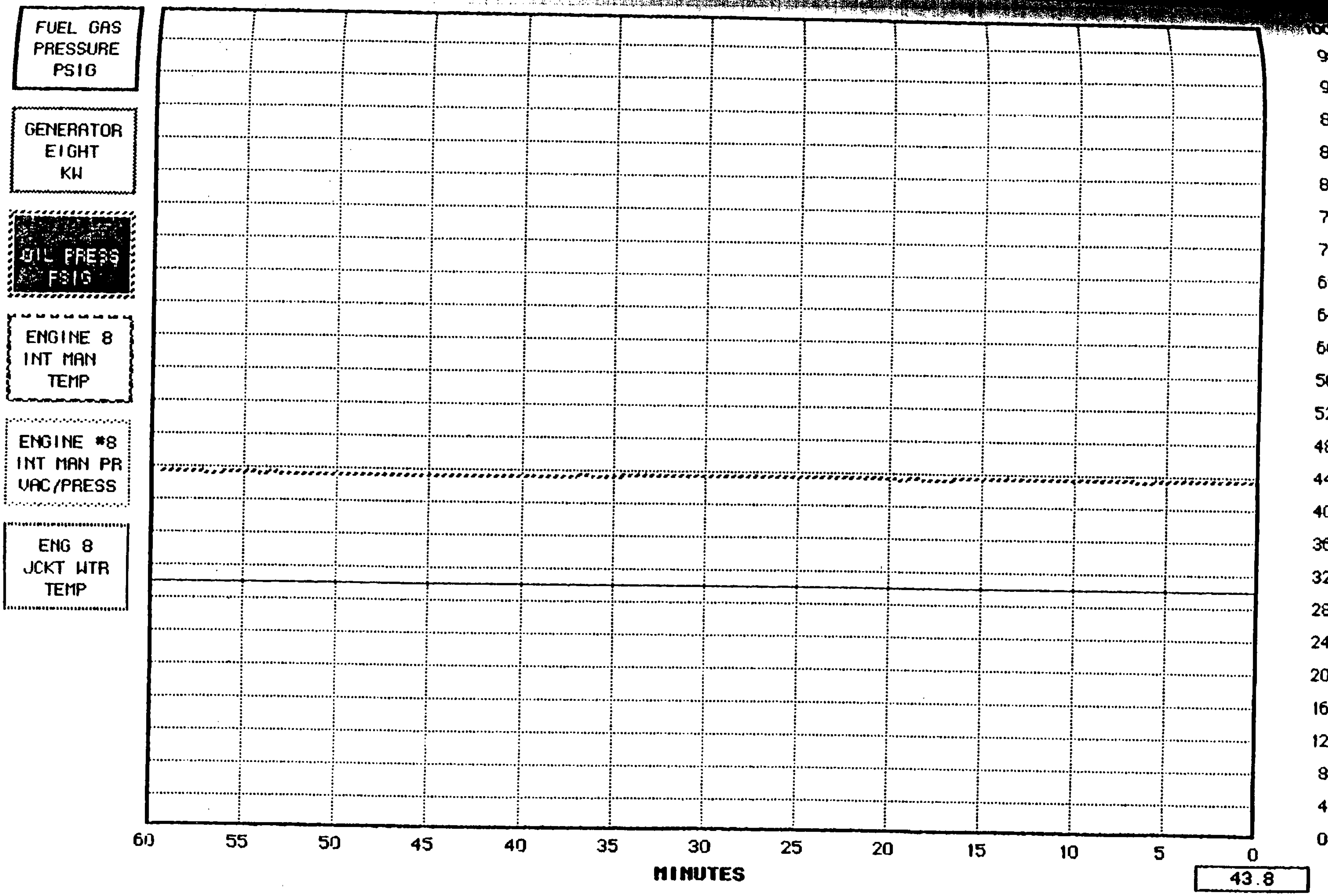


Rhode Island Landfill	Tue, Nov 6, 1990	11:52:55 AM

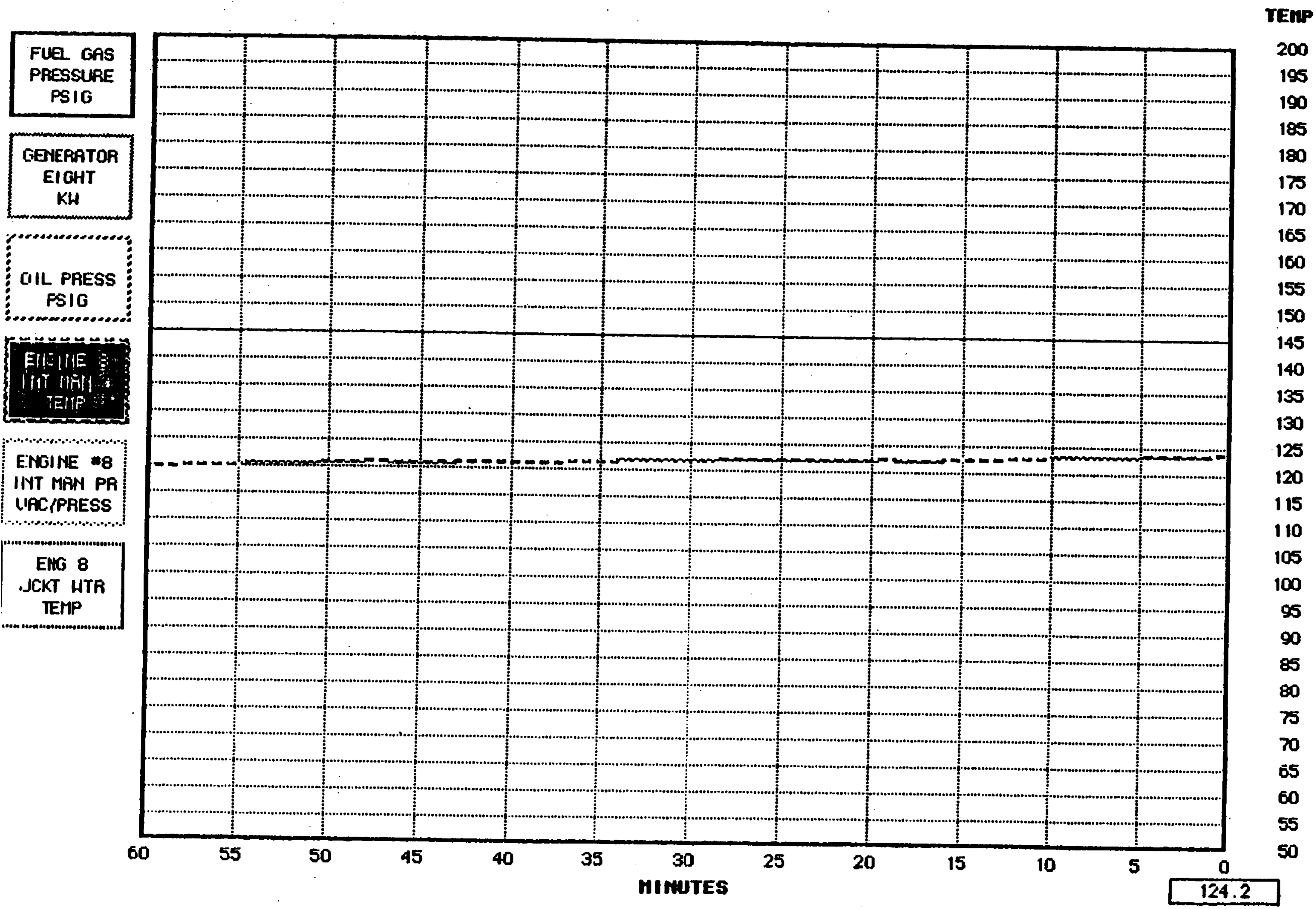
UNIT #8- RERUN

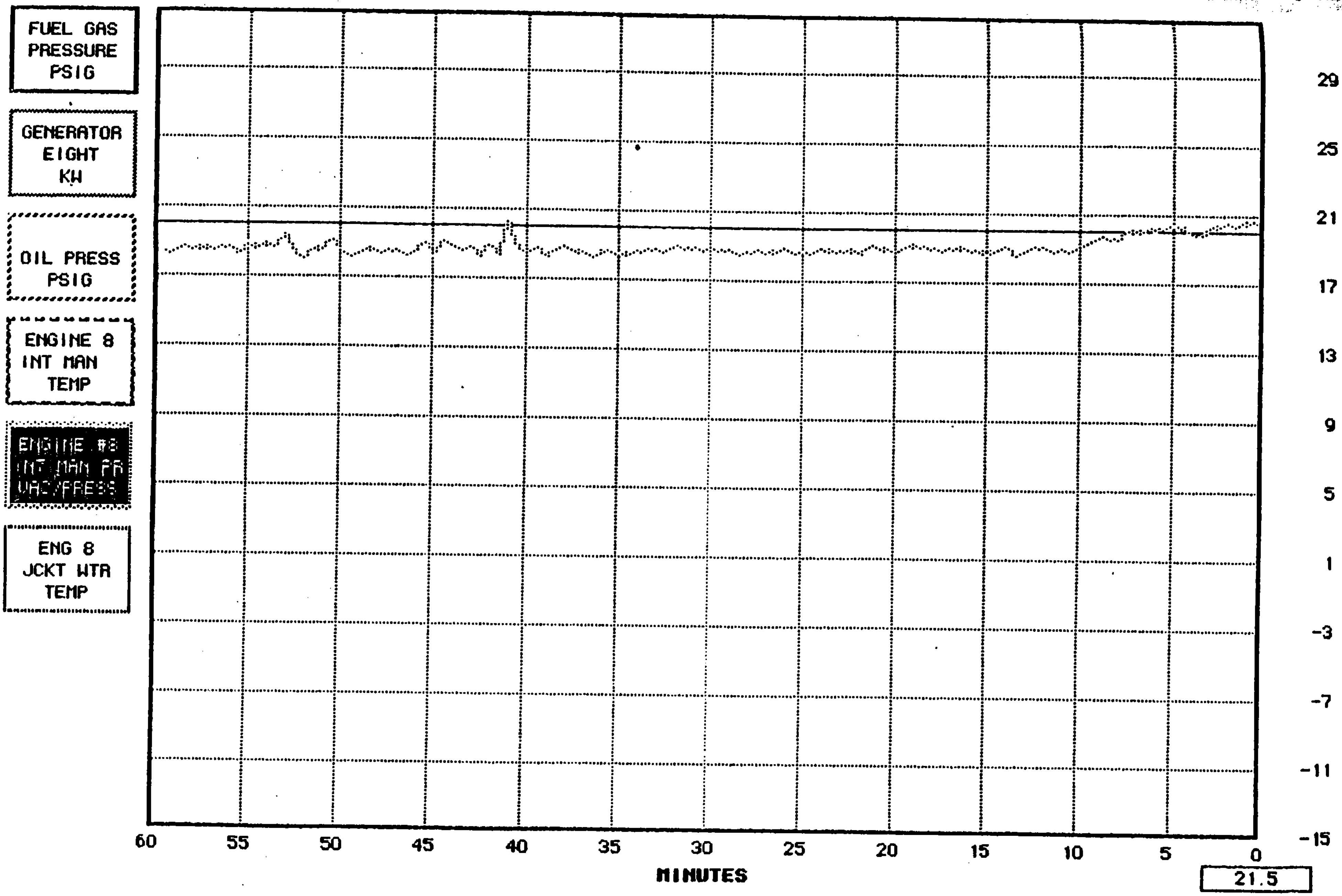


Rhode Island Landfill	Tue, Nov 6, 1990	11:55:24 AM

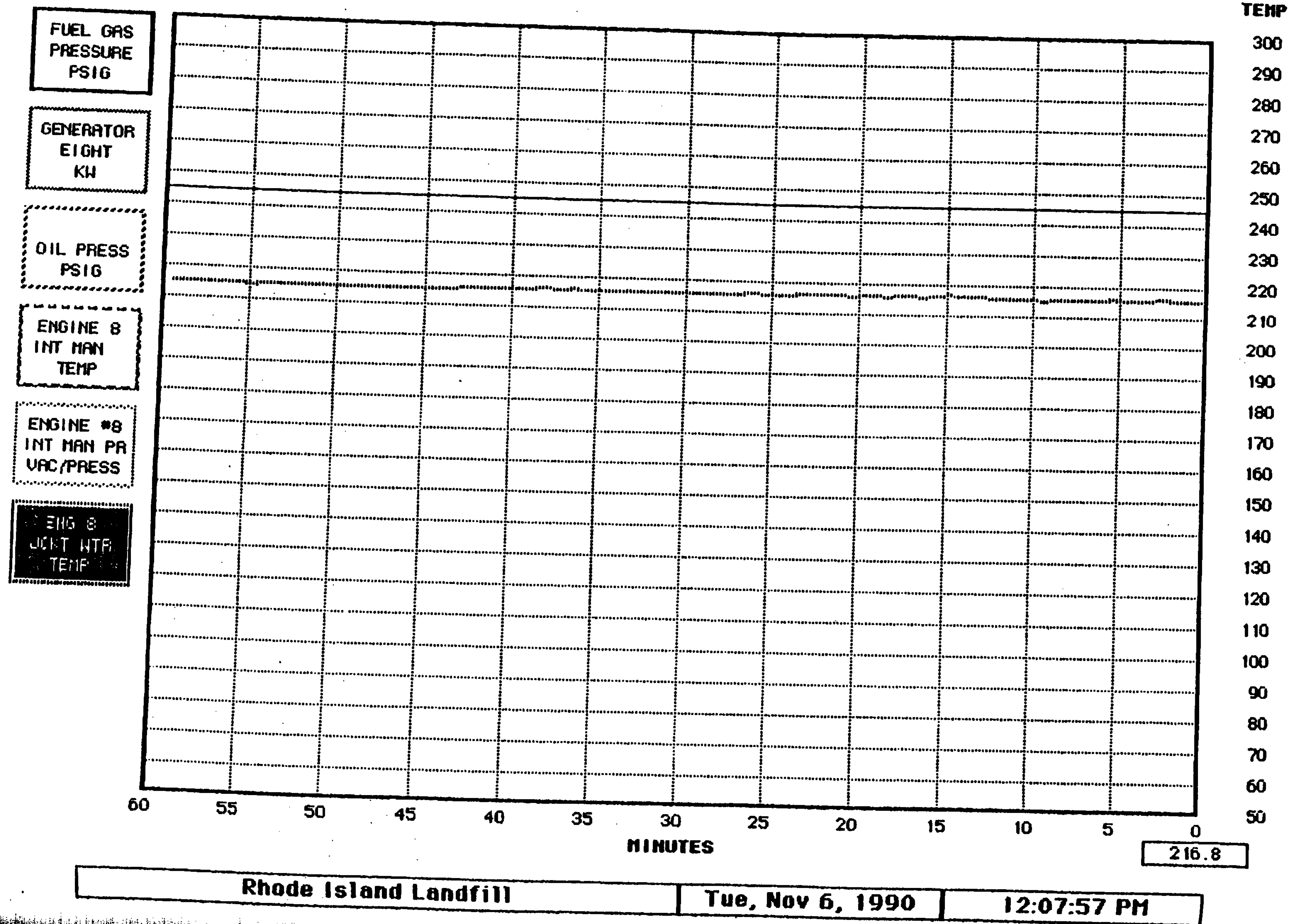


Rhode Island Landfill	Tue, Nov 6, 1990	11:59:57 AM


FUEL GAS PRESSURE PSIG
GENERATOR EIGHT KW
OIL PRESS PSIG
ENGINE 8 INT MAN TEMP
ENGINE #8 INT MAN PR VAC/PRESS
ENG 8 JCKT WTR TEMP
TEMP
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
124.2



Rhode Island Landfill	Tue, Nov 6, 1990	12:04:50 PM


FUEL GAS PRESSURE PSIG
GENERATOR EIGHT KW
OIL PRESS PSIG
ENGINE 8 INT MAN TEMP
ENGINE #8 INT MAN PR VAC/PRESS
ENG 8 JCKT WTR TEMP
TEMP
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
216.8
Rhode Island Landfill
Tue, Nov 6, 1990
12:07:57 PM

Pattison 1002

650507

ABSTRACT

The composition of a burned mixture of air and hydrocarbons must reflect the air-fuel ratio of the original mixture. This paper shows that the air-fuel ratio can be calculated by an equation that involves only fuel composition and exhaust gas composition. For this calculation, the hydrocarbon content of the combusted mixture has been measured with a flame ionization detector as a carbon counter.

Air-Fuel Ratios from Exhaust Gas Analysis

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ENGINEERS HAVE been aware since the days of the first gasoline engine that the composition of the exhaust gas reflects the composition of fuel and air that is inducted into the engine. Since air-fuel ratio is very important to engine performance and exhaust gas analysis is deceptively simple, a correlation of exhaust gas analysis and air-fuel ratio has long been sought. This paper presents yet another way of correlating these compositions. The method is based on ratios of the component concentrations and it is not sensitive to small errors in analysis.

One of the first intensive studies to correlate air-fuel ratio with exhaust gas analysis was reported by D'Alleva and Lovell (1).* In the discussion of this paper, H. C. Dickenson (1) cautioned that the results reported were accurate and usable only when combustion is complete; that is, the fuel is burned to equilibrium products. When misfiring or incomplete combustion occurred, no meaningful results could be obtained. Assumptions made by these authors were that:

1. Combustion was complete.
2. A "water-gas" equilibrium constant of 3.8 was appropriate.
3. 0.15 mole of methane was formed per mole of fuel.

Even at that time, other hydrocarbons were known to be present in the exhaust but their analysis was difficult.

L. S. Leonard (2) has described a system for evaluating air-fuel ratio from exhaust gas analysis. He assumes complete combustion and an empirical correlation of hydrogen and methane concentrations with carbon monoxide concentration. The fuel stoichiometry necessary for a study of fuel distribution problems can be calculated from his charts. However, when combustion is not complete, erroneous results will be obtained. Incomplete combustion occurs under some common conditions.

In recent years the study of exhaust gases for their hydrocarbon content has become very important for understanding their contribution to air pollution. While methane is an important exhaust constituent, almost all the constituents in the original gasoline, as well as light cracked products are also present. Only under good combustion conditions does methane occur at a larger concentration than any other single hydrocarbon. Figs. 1-3 illustrate how the exhaust gas hydrocarbons resemble those of the original fuel. These figures were obtained by gas chromatography using a capillary column coated with squalene.

Fig. 1 is obtained from the original fuel. Fig. 2 is the exhaust from a single-cylinder engine running at 15/1 air-fuel ratio, 1800 rpm, and 10 in. Hg manifold vacuum. Fig. 3 is the exhaust from the same engine under the same conditions except at 20 in. Hg manifold vacuum. Obviously, the exhaust gas contains significant amounts of unburned fuel.

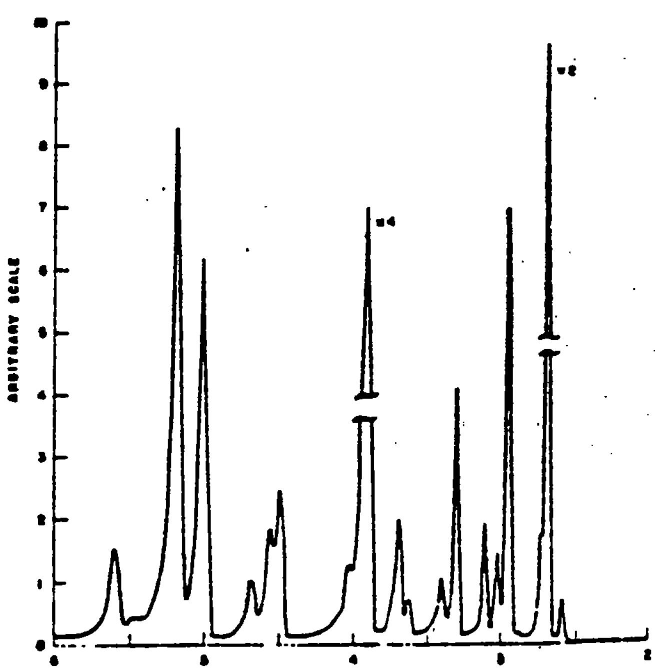
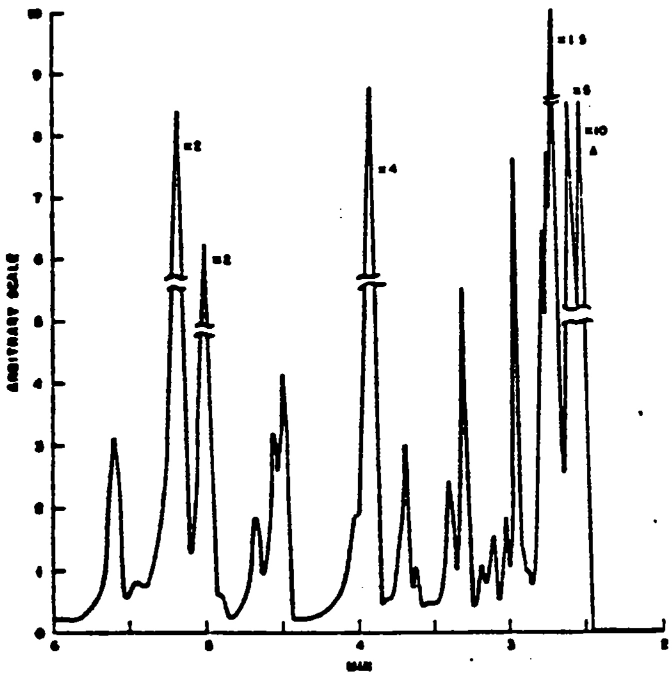


Fig. 1 - Chromatographic record of hydrocarbon components -- original fuel

*Numbers in parentheses designate References at end of paper.



A METHANE, ETHANE AND ETHYLENE.

Fig. 2 - Exhaust gas cruise conditions

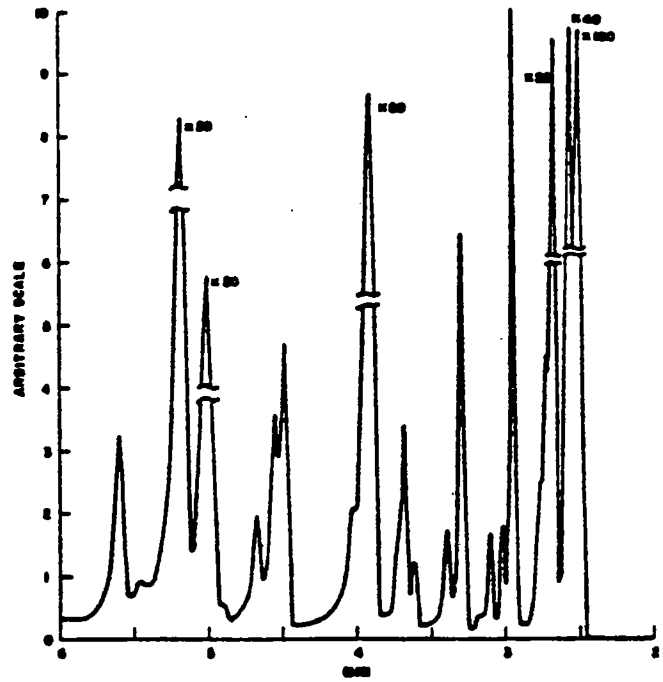


Fig. 3 - Exhaust gas motored conditions (attenuation 10X)

While methane and ethylene (unresolved components of the first peak from the right in Figs. 2 and 3) are major constituents, they represent less than 50% of the total unburned hydrocarbons present under any conditions studied (3). Further, thermodynamic consideration of combustion processes (4) shows that methane should be a minor product of combustion present in concentrations less than 0.01% of the mixture under the most favorable conditions. Under many conditions of use, much more unburned fuel may be present.

The exhaust gas, however, still reflects the input charge to the engine and its analysis should permit air-fuel ratios to be calculated independent of the extent of combustion. This paper supports this hypothesis and maintains that combustion is complete in the flame. All unburned hydrocarbons arise from incomplete passage of the flame through the mixture. Methane and other products are formed from combustion intermediates reacting by undefined processes in the quench zone (5) next to the combustion chamber walls.

The theory shows that air-fuel ratio can be calculated using only ratios of the exhaust component concentrations, that is, per cent of CO, CO_2, O_2, and hydrocarbons. Further, no correction for condensed water is necessary, as long as all components are treated the same. This is true because the ratio measurement cancels out any such correction.

THEORY OF THE CORRELATION OF EXHAUST COMPOSITION WITH AIR-FUEL RATIO

Let 100 moles of air react with X atoms carbon and Y moles of hydrogen from a hydrocarbon C_nH_m. The general combustion equation then will be:

$$20.99\,(O_2) + X\,(C) + Y\,(H_2) \longrightarrow A\,(CO_2) + B\,(CO) + C\,(H_2O) + D\,(H_2) + E\,(O_2) \qquad (1)$$

where A, B, C, D represent moles of product and E represents moles excess oxygen, if any. (Nitrogen from the air (79.01 moles) has been excluded from Eq. 1.)

The following equations give the stoichiometry of the system:

$$X = A + B \qquad \text{Carbon Balance} \qquad (2)$$

$$Y = C + D \qquad \text{Hydrogen Balance} \qquad (3)$$

$$20.99 = A + B/2 + C/2 + E \qquad \text{Oxygen Balance} \qquad (4)$$

Carbon monoxide and water are known to equilibrate wit carbon dioxide and hydrogen in fixed proportions to yield a constant called the water-gas equilibrium constant. This is defined as:

$$K = \frac{C \times B}{A \times D} \qquad (5)$$

This constant is temperature dependent but an average value (3.5) has been deduced that is satisfactory for the pur poses of this correlation.* Quite large variations in value

*The value of the constant K was chosen by treating it as an adjustable parameter and choosing the value that gav the best fit to the data.

of this constant have only a small effect on the calculated air-fuel ratio.

Now, air-fuel ratio is defined as lb air/lb fuel. Therefore,

$$A/F = \frac{28.97 \times 100}{12.01X + 2.016Y} \qquad (6)$$

Also, the fractions of carbon (F_c) and hydrogen (F_h) in a hydrocarbon fuel are defined as:

$$F_c = \frac{12.01X}{12.01X + 2.016Y} \qquad F_h = \frac{2.016Y}{12.01X + 2.016Y} \qquad (7)$$

[redacted]) Eqs. 6 and 7 can be solved for X and Y:

$$X = \frac{2897F_c}{12.01\,(A/F)} = 241.2\,\frac{F_c}{(A/F)} \qquad (8)$$

$$Y = \frac{2897F_h}{2.016\,(A/F)} = 1437.0\,\frac{F_h}{(A/F)} \qquad (9)$$

Now, the moles of exhaust gas is equal to the moles of the original charge times the fraction unburned plus the moles of the combustion products times the fraction burned. Also, if F_b = fraction burned and F_u = fraction unburned

Moles Exh = F_u × Moles Reactants + F_b × Moles Products

$$F_b + F_u = 1 \qquad (10)$$

The total moles of exhaust gas per 100 moles of air are, therefore,

$$T = F_u(100 + X/n) + F_b\,(A + B + C + D + E + 79.01) \qquad (11)$$

where:

X/n = Number of moles of fuel present per 100 moles of air.

T is the total moles of exhaust produced by combustion per 100 moles of air. T is not necessarily equal to the actual number of moles in the exhaust analyzed since water may be condensed from the gases. In any event, it is not necessary to know T, since air-fuel ratio will be calculated by ratio measurements from the relative concentrations usually expressed as a per cent.

By definition the following percentage relations hold:

$$P_{CO_2} = \frac{A \times 100F_b}{T} \qquad (12)$$

$$P_{CO} = \frac{B \times 100F_b}{T} \qquad (13)$$

$$P_{CH} = \frac{X \times 100F_u}{T} \qquad (14)$$

where:

P_{CH} = Per cent carbon in hydrocarbons on a per carbon basis

$$P_{O_2} = \frac{(20.99F_u + E \times F_b)\,100}{T} \qquad (15)$$

$$\text{Let } R = \frac{P_{CO}}{P_{CO_2}} = \cancel{X/B} \quad B/A \qquad (16)$$

$$Q = \frac{P_{O_2}}{P_{CO_2}} = \frac{20.99F_u + E \times F_b}{A \times F_b} \qquad (17)$$

Now from Eqs. 2, 12, 13, and 14:

$$\frac{P_{CH}}{P_{CO_2} + P_{CO}} = \frac{X \times F_u}{(A + B)\,F_b} = \frac{F_u}{F_b} \qquad (18)$$

Therefore, from Eqs. 10 and 18:

$$F_u = \frac{P_{CH}}{P_{CO} + P_{CO_2} + P_{CH}} \qquad (19)$$

$$F_b = \frac{P_{CO} + P_{CO_2}}{P_{CO} + P_{CO_2} + P_{CH}} \qquad (20)$$

Solving Eq. 17 for E gives:

$$E = A \times Q - 20.99F_u/F_b \qquad (21)$$

From Eqs. 2, 3, 5, and 16:

$$A = \frac{X}{1 + R} \qquad (22)$$

$$B = \frac{X \times R}{(1 + R)} \qquad (23)$$

$$C = \frac{K \times Y}{(K + R)} \qquad (24)$$

into
Substituting Eqs. 21, 22, 23, 24, ~~and~~ 4, gives:

$$20.99 = \frac{X}{1+R} + \frac{X \times R/2}{1+R} + \frac{K \times Y/2}{K+R} + \frac{X \times Q}{1+R} - 20.99 F_u / F_b \quad (25)$$

Substituting Eqs. 5, 8, 9, and 10 into Eq. 25 and solving for A/F gives:

$$\boxed{A/F = \frac{F_b 2897}{20.99}\left[\frac{F_c}{12.01}\left(\frac{1+R/2+Q}{1+R}\right) + \frac{K(F_h)}{4.032(K+R)}\right] = F_b\left[11.492 F_c\left(\frac{1+R/2+Q}{1+R}\right) + \left(\frac{120 \times F_h}{3.5+R}\right)\right] \quad (26)}$$

The air-fuel ratio is calculated only from ratios of the percentage components. Therefore, it is not necessary to know the extent of water condensed from the system nor the completeness of combustion as such. F_b is [illegible]

EXPERIMENTAL

Data required to solve Eq. 26 are the percentage concentrations of CO, CO_2, CH (per carbon atom), and O_2. Instruments are available for continuous measurement of each of the components (6). Carbon monoxide and carbon dioxide were measured using Beckman nondispersive infrared analyzers with 1/8 in. thick sample cells and quartz windows. Oxygen was determined using a Beckman F-3 paramagnetic analyzer. Hydrocarbons were determined on a per carbon basis with a hydrogen flame detector.

To verify the use of the proposed equation, data were collected from a modified CFR engine. The engine was run at 1800 rpm, with a variety of air-fuel ratios and manifold pressures and with several fuels. Since fuel composition is very important, four hydrocarbons of widely varying carbon content were used: isooctane, diisobutylene, toluene, and a 50-50 blend of isooctane and toluene. In addition, four experimental commercial type fuels were also tested. Their carbon content varied from 84.55-87.03 weight %. Test parameters are given in Table 1.

Data were recorded on a Visicorder, an optical galvanometer. Chart width was 5-1/2 in. and readings were taken to the closest 0.02 in.

The data were collected at 4-8 different air-fuel ratios for each fuel and manifold pressure. No attempt was made to select any particular air-fuel ratio so long as a range from at least 10/1 to 15/1 was covered. Fuel was measured directly by timing the consumption of 0.1 lb. Airflow was measured by three techniques. Above 20 in. Hg MAP a calibrated orifice was used. For low MAP (11-12 in. Hg) as well as at higher MAP of 28 in. Hg a dry gas meter and a Meriam laminar flow meter were used in series. Since absolute airflow is not an easy thing to measure accurately the three devices used provided a system for self-checking.

Table 1 - Test Parameters

CFR engine with RDH head	8:1 Compression Ratio
Coolant temperature, F	210
Oil temperature, F	180
Speed[a, b]	1800 rpm
Spark advance, deg btc	20, 25, 35
MAP, in. Hg Absolute[c]	12, 20, 28, 30
Air-fuel ratio	Variable
Total number of A/F ratio observations	243
Fuels	Isooctane
	Diisobutylene
	Toluene
	Isooctane, Toluene } Equal Parts
	4 Commercial-type fuels

[a] One set of air-fuel ratios were run at 900 rpm, 12 in. Hg MAP with diisobutylene.

[b] One set of air-fuel ratios were run at 900 rpm, 28.7 in Hg MAP with diisobutylene.

[c] One set of air-fuel ratios were run at 1800 rpm, 11 in. Hg MAP with isooctane.

Experimentally, the engine was run under specified conditions. While the fuel and airflow were being measured, exhaust gas analysis data were obtained. Air-fuel ratios were computed from both the measured air and fuel flow and the exhaust gas analysis. The data were analyzed by taking the difference between calculated and measured air fuel ratio. Table 2 gives some typical results. These data were chosen to show the effect of fuel carbon-hydrogen ratio and operating conditions.

RESULTS

This study, of necessity, compares air-fuel ratios measured directly with those calculated from exhaust gas composition. Fuel flow was measured by one method while airflow was measured by three techniques. All three methods gave very nearly the same results relative to the value calculated from exhaust analysis, with the Meriam meter perhaps most accurate.

Table 3 gives the average deviation between calculated and measured air-fuel ratios for the three methods of air measurement. The Meriam and dry gas meter were used simultaneously while the orifice meter was used with a different set of measurements.

The standard deviation of an observation with the Mer-

Table 2 - Typical Exhaust Gas Analyses Results

Per Cent					Air-Fuel Ratio	
CO_2	CO	Hydro-carbon	O_2	$100F_u$	Calc.	Meas-ured
Fuel: Toluene - MAP 12 in. Hg						
11.06	8.70	0.584	0.73	2.87	10.69	10.46
13.70	4.35	0.421	0.72	2.28	12.10	11.78
14.63	2.98	0.350	0.75	1.95	12.62	12.50
15.10	0.67	0.412	1.40	2.55	13.78	13.68
13.36	0.23	0.68	3.77	4.79	15.50	15.29
Fuel: Toluene - MAP 20 in. Hg						
11.45	8.54	0.518	0.49	2.53	10.69	10.56
12.97	6.27	0.387	0.63	1.97	11.51	11.27
13.85	4.17	0.324	0.90	1.77	12.33	12.02
14.89	0.12	0.126	2.61	0.834	15.12	14.66
13.65	0.37	0.096	3.97	0.683	16.17	16.32
Fuel: Isooctane - MAP 12 in. Hg						
9.44	6.88	0.587	1.22	3.47	12.39	11.61
10.64	6.13	0.408	0.65	2.37	12.62	12.36
13.06	2.26	0.366	1.11	2.33	14.47	14.06
13.06	0.77	0.719	2.17	4.94	15.44	14.82
Fuel: Isooctane - MAP 20 in. Hg						
9.75	7.09	0.250	0.0	1.46	11.94	12.39
11.06	5.13	0.210	0.0	1.28	12.76	13.33
12.87	2.14	0.158	0.15	1.04	14.10	14.41
13.36	0.44	0.116	0.45	0.83	15.07	15.44
11.28	0.16	0.060	3.54	0.53	17.88	17.98
Fuel A - MAP 12 in. Hg						
7.16	10.67	3.208	1.84	15.31	9.49	9.83
9.18	9.75	0.979	0.0	4.92	10.35	10.83
11.54	6.24	0.621	0.41	3.38	11.96	12.07
13.75	1.81	0.438	0.42	2.74	13.64	13.65
13.96	0.30	0.270	1.90	1.86	15.41	15.44
11.94	0.27	0.999	4.70	7.56	16.82	17.22
Fuel A - MAP 28 in. Hg						
8.99	10.36	0.558	0.0	2.80	10.42	10.69
12.78	4.52	0.336	0.18	1.91	12.64	12.88
14.73	1.22	0.230	0.62	1.34	14.20	14.29
14.73	0.21	0.173	1.29	1.14	15.10	15.24
13.36	0.12	0.011	3.00	0.08	16.65	16.82

Per Cent					Air-Fuel Ratio	
CO_2	CO	Hydro-carbon	O_2	$100F_u$	Calc.	Meas-ured
Fuel B - Map 12 in. Hg						
6.15	9.85	2.638	2.82	14.14	10.37	10.39
8.59	8.70	0.760	1.20	4.21	11.56	11.37
10.31	6.54	0.400	0.37	2.32	12.25	12.75
12.73	1.91	0.273	0.72	1.83	14.37	14.37
13.26	0.73	0.400	1.30	2.86	15.15	15.12
Fuel B - MAP 28 in. Hg						
7.82	10.85	0.396	0.0	2.08	10.48	10.83
10.65	5.54	0.232	0.17	1.40	12.63	12.91
12.08	3.52	0.137	0.78	0.87	13.88	13.91
14.11	0.43	0.120	0.49	0.82	15.03	15.31
12.36	0.07	0.075	3.04	0.60	17.25	17.44
Fuel C - MAP 12 in. Hg						
7.72	11.31	1.600	1.50	7.85	10.11	9.90
9.18	9.61	1.004	0.95	5.05	10.80	10.95
12.40	5.36	0.690	0.56	3.75	12.29	12.44
13.26	2.12	0.636	0.86	4.00	13.56	13.47
Fuel C - MAP 28 in. Hg						
9.75	10.71	0.456	0.08	2.18	10.58	10.58
11.59	8.01	0.360	0.22	1.81	11.57	11.55
11.99	5.86	0.258	0.65	1.43	12.44	12.47
15.27	0.15	0.119	1.93	0.77	15.51	15.76
13.96	0.10	0.106	3.51	0.75	16.77	17.06
Fuel D - MAP 12 in. Hg						
6.39	9.35	2.698	2.30	14.62	10.14	10.19
8.37	7.83	0.840	0.84	4.94	11.32	11.17
11.50	3.69	0.390	0.48	2.50	13.18	13.41
12.64	0.85	0.703	0.98	1.48	14.91	15.16
11.63	0.17	0.750	4.00	6.00	16.98	16.75
Fuel D - MAP 28 in. Hg						
6.57	11.56	0.540	0.0	2.89	9.74	9.91
8.52	8.92	0.382	0.0	2.14	10.93	11.20
9.71	6.71	0.310	0.0	1.85	11.77	12.14
11.94	2.76	0.204	0.59	1.37	13.80	13.83
13.16	0.16	0.120	1.26	0.89	15.53	15.75

iam gage and the dry gas meter is ±0.23 air-fuel ratio units. This measure of error, however, contains the error in the analysis of exhaust composition and the error in "true" air and fuel-flow. A brief study of the effect of reading errors was made using some of the experimental results as a base point. In each case the readings of each component were arbitrarily increased or decreased by 0.05 in. In a statistical pattern to give a 2×2×2×2 orthogonal array. The net change in reading of 0.1 in. for any one component gave a maximum deviation in air-fuel ratio of 0.08 and of all com-

Table 3 - Analysis of Data

Air Measurement	Air-Fuel Ratio: Average Deviation Measured-Calculated	Air-Fuel Ratio: Standard Deviation Measured-Calculated
Orifice meter	0.114	0.177
Meriam meter	-0.023	0.228
Dry Gas meter	-0.134	0.231

ponents of 0.21 under the most extreme conditions (each component in the direction of maximum error). Since the readings are not likely to be in error by more than 0.05 in. of chart, air-fuel ratios from exhaust gas analysis are about as accurate as those from direct measurement of air and fuel flow. This analysis shows that small errors in measurement do not significantly affect the air-fuel ratio determination.

The analyses so far discussed are for results obtained with good combustion, 95% complete or better. This equation will give reasonably accurate results even with poor combustion.

Table 4 gives some results of operating the engine at 11 in. Hg. Even under conditions where only 65% of the mixture burns the equation gives a reasonable measure of the air-fuel ratio. While these results do not appear to be as good as those obtained with better combustion, they are better than can be obtained with any other method of calculation. For example, the first result of Table 4 calculates to 20 air-fuel ratio by the Leonard method and is completely ambiguous by the D'Alleva charts.

The principal error in these measurements, and this is true for all of the data, may be in the hydrocarbon results. Hydrocarbons were measured with a flame ionization detector which is a carbon counter, nearly independent of the type of hydrocarbon burned. This detector gives low results in the presence of oxygen. With low hydrocarbon concentrations, this has little influence on the calculated air-fuel ratio since the hydrocarbon concentration enters only in the fraction burned calculation.

In the case of poor combustion with large concentrations of unburned hydrocarbon, there is a consistently large oxygen concentration. The effect of the oxygen is to underestimate the amount of hydrocarbon present which results in a calculated air-fuel ratio leaner than measured.

The use of an equation as complex as the one proposed, does not lend itself readily to hand computation. With the increasing use of computers for the analysis of exhaust gas data, calculation of air-fuel ratio can be simply another computer step to give more complete and meaningful interpretation of the data.

CONCLUSIONS

The analysis of exhaust gases can give a reliable measure of air-fuel ratio. The method can be applied to exhaust gases without regard to the degree of combustion encountered in the engine. It is not sensitive to small errors in analysis.

Table 4 - Exhaust Gas Analysis with Incomplete Combustion

Per Cent: CO_2	Per Cent: CO	Per Cent: Hydrocarbon	Per Cent: O_2	Per Cent: $100F_u$	Air-Fuel Ratio: Calc.	Air-Fuel Ratio: Measured
Fuel: Isooctane - MAP 11 in. Hg						
4.89	6.97	6.40	7.50	35.05	10.91	10.47
7.96	6.85	2.16	3.28	12.75	12.16	11.62
10.23	4.61	1.43	2.56	8.79	13.35	12.90
11.63	1.48	1.47	3.86	10.10	15.46	14.55
7.65	0.17	3.55	9.95	31.32	18.64	16.79

In summary, to calculate air-fuel ratio determine the percentage concentrations of CO, CO_2, O_2, and hydrocarbons (per carbon atom). With these percentages and the known fraction of carbon in the fuel (F_c), calculate the following ratios:

$$R = P_{CO}/P_{CO_2}$$

$$Q = P_{O_2}/P_{CO_2}$$

$$F_b = (P_{CO} + P_{CO_2})/(P_{CO} + P_{CO_2} + P_{CH})$$

Then:

$$A/F = F_b\left[11.492F_c\left(\frac{1 + R/2 + Q}{1 + R}\right) + \frac{120(1 - F_c)^{*}}{3.5 + R}\right]$$

*ONLY IF $F_c + F_h = 1.0$ SEE EQUATION (26) ON PAGE 4.

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4. R. D. Kopa, B. R. Hollander, and H. Kimura, "Combustion Temperature, Pressure, and Products at Chemical Equilibrium." SAE Progress in Technology, Vol. 7, "Digital Calculations of Engine Cycles," 1964.

5. W. A. Daniel and J. T. Wentworth, paper "Exhaust Gas Hydrocarbons - Genesis and Exodus." SAE Progress in Technology, Vol. 6, "Vehicle Emissions," 1964.

6. B. M. Sturgis, W. F. Biller, J. W. Bozek, and S. B. Smith, "The Application of Continuous Infrared Instruments to the Analysis of Exhaust Gas." SAE Progress in Technology, Vol. 6, "Vehicle Emissions," 1964.

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF-1:D700
ENGINE MODEL: 12VAT25GL
REF.LOG.NUMBER: 0001
TEST NUMBER: 0001
LOG SHEET NUMBER: 0001
OPERATOR: D.A.PERKINS
5
DATE: 10-9-90
BENCH NUMBER: TRUCK

TEST NAME: FIRST

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23742 HYDROGEN: .07975
OXYGEN: 0 CARBON DIOXIDE: .6811

NITROGEN: .00213
HYDROGEN TO CARBON RATIO: 4.006
STOICHIOMETRIC A/F: 5.458

RAW DATA PRINT OUT:

DATA POINT	SPEED RPM	BMEP PSI	BHP	HUMIDITY GR/LB	FUEL FLOW LB/MIN	BSFC BTU/BHP-HR	AIR FLOW LB/MIN
1	900	196.7	2410	75	40.855	6829	357.36
2	900	196.7	2410	75	40.855	6829	356.71
3	900	196.7	2410	75	40.855	6829	372.19
4	900	196.7	2410	75	40.855	6829	357.24
5	900	196.7	2410	75	40.855	6829	357.07

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	NMHC PPM
1	460	37	74	11.57	8.35	31
2	407	63	76	11.59	8.30	30
3	377	44	75	11.07	8.93	26
4	407	59	78	11.59	8.33	25
5	466	34	76	11.57	8.33	30

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.017	8.65	8.94	1.64	1.147	.998
2	1.017	8.64	8.92	1.63	1.147	.999
3	1.017	9.01	9.36	1.71	1.141	.999
4	1.017	8.65	8.93	1.64	1.147	.999
5	1.017	8.65	8.93	1.64	1.147	.998

AKE SPECIFIC EMISSIONS FOR DRY EXHAUST GAS
GRAMS/BHP-HR

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL NMHC	METHANE	NON METHANE	NO PPM
1	1.82	.24	.48	.48	.08	0.00	0.00	17
2	1.61	.41	.49	.49	.08	0.00	0.00	30
3	1.57	.30	.51	.51	.07	0.00	0.00	22
4	1.61	.38	.51	.51	.06	0.00	0.00	28
5	1.85	.22	.49	.49	.08	0.00	0.00	16

NOX
PPM

35
36
37
37
36

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF-2:D700
ENGINE MODEL: 12VAT25GL
REF.LOG.NUMBER: 0002
TEST NUMBER: 0002
LOG SHEET NUMBER: 0002
OPERATOR: D.A.PERKINS
5
DATE: 10-9-90
BENCH NUMBER: TRUCK

TEST NAME: ENGINE #2

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23742 HYDROGEN: .07975
OXYGEN: 0 CARBON DIOXIDE: .6811

NITROGEN: .00213
HYDROGEN TO CARBON RATIO: 4.006
STOICHIOMETRIC A/F: 5.458

RAW DATA PRINT OUT:

DATA POINT	SPEED RPM	BMEP PSI	BHP	HUMIDITY GR/LB	FUEL FLOW LB/MIN	BSFC BTU/BHP-HR	AIR FLOW LB/MIN
1	900	205.9	2523	103	42.295	6753	379.72
2	900	205.9	2523	103	42.295	6753	379.64
3	900	205.9	2523	103	42.295	6753	390.26
4	900	205.9	2523	103	42.295	6753	382.43
5	900	205.9	2523	103	42.295	6753	382.39

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	NM HC PPM
1	484	39	75	11.25	8.70	35
2	454	39	76	11.25	8.70	35
3	442	32	71	10.90	9.08	31
4	454	25	60	11.12	8.80	33
5	484	26	55	11.12	8.80	38

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.006	8.85	9.19	1.68	1.150	.998
2	1.006	8.84	9.19	1.68	1.150	.998
3	1.006	9.09	9.48	1.74	1.146	.998
4	1.006	8.91	9.28	1.70	1.149	.998
5	1.006	8.91	9.27	1.70	1.149	.998

'AKE SPECIFIC EMISSIONS FOR DRY EXHAUST GAS
GRAMS/BHP-HR

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL NMHC	METHANE	NON METHANE	NO PPM
1	1.95	.26	.50	.54	.09	0.00	0.00	19
2	1.83	.26	.50	.54	.09	0.00	0.00	19
3	1.84	.22	.49	.52	.08	0.00	0.00	16
4	1.85	.17	.40	.43	.09	0.00	0.00	12
5	1.97	.17	.37	.40	.10	0.00	0.00	13

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF-9:D700
ENGINE MODEL: 12VAT25GL
REF.LOG.NUMBER: 0009
TEST NUMBER: 0009
LOG SHEET NUMBER: 0009
OPERATOR: D.A.PERKINS
0
DATE: 10-16-90
BENCH NUMBER: TRUCK

TEST NAME: ENGINE #3

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .22371 HYDROGEN: .07517
OXYGEN: .01054 CARBON DIOXIDE: .6355

NITROGEN: .05476
HYDROGEN TO CARBON RATIO: 4.006
STOICHIOMETRIC A/F: 5.098

RAW DATA PRINT OUT:

DATA POINT	SPEED RPM	BMEP PSI	BHP	HUMIDITY GR/LB	FUEL FLOW LB/MIN	BSFC BTU/BHP-HR	AIR FLOW LB/MIN
1	900	193.0	2365	43	41.301	6648	341.72
2	900	193.0	2365	43	41.301	6648	341.19
3	900	193.0	2365	43	41.301	6648	356.35
4	900	193.0	2365	43	41.301	6648	341.81
5	900	193.0	2365	43	41.301	6648	341.56

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	NM HC PPM
1	460	42	99	11.39	8.43	24
2	389	61	99	11.41	8.38	23
3	342	58	100	10.90	9.00	21
4	389	63	105	11.39	8.40	23
5	460	49	108	11.39	8.40	24

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.048	8.22	8.45	1.66	1.138	.998
2	1.048	8.21	8.43	1.65	1.139	.999
3	1.048	8.58	8.84	1.73	1.133	.999
4	1.048	8.23	8.44	1.66	1.138	.999
5	1.048	8.22	8.44	1.65	1.139	.998

BRAKE SPECIFIC EMISSIONS FOR DRY EXHAUST GAS
GRAMS/BHP-HR

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL NM HC	METHANE	NON METHANE	NO PPM
1	1.79	.27	.63	.58	.06	0.00	0.00	20
2	1.51	.39	.63	.58	.06	0.00	0.00	29
3	1.39	.39	.67	.62	.06	0.00	0.00	29
4	1.51	.40	.67	.62	.06	0.00	0.00	30
5	1.79	.31	.69	.64	.06	0.00	0.00	23

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF-6:D700
ENGINE MODEL: 12VAT25GL
REF.LOG.NUMBER: 0006
TEST NUMBER: 0006
LOG SHEET NUMBER: 0006
OPERATOR: D.A.PERKINS
5
DATE: 10-12-90
BENCH NUMBER: TRUCK

TEST NAME: ENGINE #4

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23742 HYDROGEN: .07975
OXYGEN: 0 CARBON DIOXIDE: .6811

NITROGEN: .00213
HYDROGEN TO CARBON RATIO: 4.006
STOICHIOMETRIC A/F: 5.458

RAW DATA PRINT OUT:

DATA POINT	SPEED RPM	BMEP PSI	BHP	HUMIDITY GR/LB	FUEL FLOW LB/MIN	BSFC BTU/BHP-HR	AIR FLOW LB/MIN
1	900	192.8	2363	111	41.912	7145	377.50
2	900	192.8	2363	111	41.912	7145	377.33
3	900	192.8	2363	111	41.912	7145	392.04
4	900	192.8	2363	111	41.912	7145	375.53
5	900	192.8	2363	111	41.912	7145	375.99

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	NM HC PPM
1	454	28	56	11.17	8.70	30
2	389	27	58	11.17	8.68	29
3	372	22	56	10.68	9.20	30
4	389	26	59	11.19	8.60	29
5	454	27	58	11.19	8.63	30

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.064	8.86	9.22	1.69	1.151	.998
2	1.064	8.86	9.21	1.69	1.152	.999
3	1.064	9.21	9.62	1.76	1.146	.999
4	1.064	8.82	9.17	1.68	1.152	.999
5	1.064	8.83	9.18	1.68	1.152	.998

AKE SPECIFIC EMISSIONS FOR DRY EXHAUST GAS
GRAMS/BHP-HR

EPA HUM.

CORRECTED
TO 15% OXYGEN

:

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL NM HC	METHANE	NON METHANE	NO PPM
1	1.94	.20	.39	.43	.08	0.00	0.00	14
2	1.66	.19	.41	.45	.08	0.00	0.00	13
3	1.66	.16	.41	.45	.09	0.00	0.00	11
4	1.66	.18	.41	.46	.08	0.00	0.00	12
5	1.94	.19	.41	.45	.08	0.00	0.00	13

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF-8:D700
ENGINE MODEL: 12VAT25GL
REF.LOG.NUMBER: 0008
TEST NUMBER: 0008
LOG SHEET NUMBER: 0008
OPERATOR: D.A.PERKINS
O
DATE: 10-14-90
BENCH NUMBER: TRUCK

TEST NAME: ENGINE #5

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .22371 HYDROGEN: .07517
OXYGEN: .01054 CARBON DIOXIDE: .6355
NITROGEN: .05476
HYDROGEN TO CARBON RATIO: 4.006
STOICHIOMETRIC A/F: 5.098

RAW DATA PRINT OUT:

DATA POINT	SPEED RPM	BMEP PSI	BHP	HUMIDITY GR/LB	FUEL FLOW LB/MIN	BSFC BTU/BHP-HR	AIR FLOW LB/MIN
1	900	182.1	2232	95	40.203	6857	338.03
2	900	182.1	2232	95	40.203	6857	338.47
3	900	182.1	2232	95	40.203	6857	352.94
4	900	182.1	2232	95	40.203	6857	340.60
5	900	182.1	2232	95	40.203	6857	340.40

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	NM HC PPM
1	466	20	61	11.17	8.70	26
2	430	26	57	11.17	8.73	29
3	419	18	54	10.63	9.30	31
4	436	23	55	11.08	8.80	29
5	466	18	55	11.08	8.80	26

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.081	8.29	8.62	1.69	1.148	.998
2	1.081	8.30	8.64	1.69	1.147	.998
3	1.081	8.66	9.06	1.78	1.142	.998
4	1.081	8.36	8.69	1.71	1.147	.998
5	1.081	8.35	8.69	1.70	1.147	.998

.AKE SPECIFIC EMISSIONS FOR DRY EXHAUST GAS
GRAMS/BHP-HR

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL NMHC	METHANE	NON METHANE	NO PPM
1	1.91	.13	.41	.43	.07	0.00	0.00	10
2	1.76	.18	.38	.40	.08	0.00	0.00	13
3	1.80	.13	.38	.40	.09	0.00	0.00	9
4	1.80	.16	.37	.39	.08	0.00	0.00	11
5	1.92	.12	.37	.39	.07	0.00	0.00	9

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF-5:D700
ENGINE MODEL: 12VAT25GL
REF.LOG.NUMBER: 0005
TEST NUMBER: 0005
LOG SHEET NUMBER: 0005
OPERATOR: D.A.PERKINS
5
DATE: 10-11-90
BENCH NUMBER: TRUCK

TEST NAME: ENGINE #6

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23742 HYDROGEN: .07975
OXYGEN: 0 CARBON DIOXIDE: .6811

NITROGEN: .00213
HYDROGEN TO CARBON RATIO: 4.006
STOICHIOMETRIC A/F: 5.458

RAW DATA PRINT OUT:

DATA POINT	SPEED RPM	BMEP PSI	BHP	HUMIDITY GR/LB	FUEL FLOW LB/MIN	BSFC BTU/BHP-HR	AIR FLOW LB/MIN
1	900	190.9	2340	97	41.382	7124	370.53
2	900	190.9	2340	97	41.382	7124	369.29
3	900	190.9	2340	97	41.382	7124	378.89
4	900	190.9	2340	97	41.382	7124	368.34
5	900	190.9	2340	97	41.382	7124	368.47

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	NM HC PPM
1	472	33	80	11.30	8.70	30
2	477	35	85	11.30	8.63	33
3	460	33	80	10.99	8.98	31
4	477	39	78	11.30	8.58	33
5	477	31	84	11.30	8.58	30

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.061	8.83	9.17	1.68	1.149	.998
2	1.061	8.80	9.14	1.67	1.149	.998
3	1.061	9.03	9.40	1.72	1.146	.998
4	1.061	8.78	9.12	1.67	1.150	.998
5	1.061	8.78	9.12	1.67	1.150	.998

:AKE SPECIFIC EMISSIONS FOR DRY EXHAUST GAS
GRAMS/BHP-HR

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL NM HC	METHANE	NON METHANE	NO PPM
1	2.00	.23	.56	.59	.08	0.00	0.00	16
2	2.02	.24	.59	.63	.09	0.00	0.00	17
3	2.00	.24	.57	.61	.09	0.00	0.00	16
4	2.01	.27	.54	.57	.09	0.00	0.00	19
5	2.01	.22	.58	.62	.08	0.00	0.00	15

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF-4:D700
ENGINE MODEL: 12VAT25GL
REF.LOG.NUMBER: 0004
TEST NUMBER: 0004
LOG SHEET NUMBER: 0004
OPERATOR: D.A.PERKINS
5
DATE: 10-11-90
BENCH NUMBER: TRUCK

TEST NAME: ENGINE #7

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23742 HYDROGEN: .07975
OXYGEN: 0 CARBON DIOXIDE: .6811

NITROGEN: .00213
HYDROGEN TO CARBON RATIO: 4.006
STOICHIOMETRIC A/F: 5.458

RAW DATA PRINT OUT:

DATA POINT	SPEED RPM	BMEP PSI	BHP	HUMIDITY GR/LB	FUEL FLOW LB/MIN	BSFC BTU/BHP-HR	AIR FLOW LB/MIN
1	900	193.0	2365	71	41.525	7073	371.81
2	900	193.0	2365	71	41.525	7073	370.61
3	900	193.0	2365	71	41.525	7073	387.47
4	900	193.0	2365	71	41.525	7073	370.61
5	900	193.0	2365	71	41.525	7073	370.57

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	NM HC PPM
1	436	30	75	11.35	8.68	26
2	401	43	74	11.37	8.63	25
3	378	31	72	10.83	9.25	27
4	401	43	74	11.37	8.63	25
5	436	31	74	11.37	8.63	26

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.053	8.86	9.15	1.68	1.143	.998
2	1.053	8.83	9.12	1.67	1.144	.999
3	1.053	9.24	9.58	1.76	1.137	.999
4	1.053	8.83	9.12	1.67	1.144	.999
5	1.053	8.83	9.12	1.67	1.144	.998

AKE SPECIFIC EMISSIONS FOR DRY EXHAUST GAS
GRAMS/BHP-HR

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL NM HC	METHANE	NON METHANE	NO PPM
1	1.83	.21	.52	.51	.07	0.00	0.00	14
2	1.68	.30	.51	.50	.07	0.00	0.00	21
3	1.67	.22	.52	.52	.08	0.00	0.00	16
4	1.68	.30	.51	.50	.07	0.00	0.00	21
5	1.83	.21	.51	.50	.07	0.00	0.00	15

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF-3:D700
ENGINE MODEL: 12VAT25GL
REF.LOG.NUMBER: 0003
TEST NUMBER: 0003
LOG SHEET NUMBER: 0003
OPERATOR: D.A.PERKINS
5
DATE: 10-10-90
BENCH NUMBER: TRUCK

TEST NAME: ENGINE #8

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23742 HYDROGEN: .07975
OXYGEN: 0 CARBON DIOXIDE: .6811

NITROGEN: .00213
HYDROGEN TO CARBON RATIO: 4.006
STOICHIOMETRIC A/F: 5.458

RAW DATA PRINT OUT:

DATA POINT	SPEED RPM	BMEP PSI	BHP	HUMIDITY GR/LB	FUEL FLOW LB/MIN	BSFC BTU/BHP-HR	AIR FLOW LB/MIN
1	900	194.6	2385	67	40.899	6908	369.32
2	900	194.6	2385	67	40.899	6908	372.79
3	900	194.6	2385	67	40.899	6908	384.86
4	900	194.6	2385	67	40.899	6908	373.41
5	900	194.6	2385	67	40.899	6908	373.20

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	NM HC PPM
1	442	39	74	11.19	8.80	26
2	395	34	68	11.08	8.93	23
3	377	31	66	10.72	9.38	22
4	395	31	69	11.08	8.95	23
5	430	30	63	11.12	9.00	26

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.029	8.94	9.25	1.70	1.141	.998
2	1.029	9.03	9.35	1.71	1.139	.999
3	1.029	9.32	9.69	1.77	1.135	.999
4	1.029	9.04	9.36	1.71	1.139	.999
5	1.029	9.04	9.36	1.72	1.139	.998

AKE SPECIFIC EMISSIONS FOR DRY EXHAUST GAS
GRAMS/BHP-HR

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL NM HC	METHANE	NON METHANE	NO PPM	NOX PPM
1	1.84	.27	.51	.49	.07	0.00	0.00	19	36
2	1.66	.23	.47	.46	.06	0.00	0.00	17	34
3	1.64	.22	.47	.46	.06	0.00	0.00	16	34
4	1.66	.21	.48	.47	.06	0.00	0.00	15	34
5	1.81	.21	.44	.43	.07	0.00	0.00	15	31

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF-7:D700
ENGINE MODEL: 12VAT25GL
REF.LOG.NUMBER: 0007
TEST NUMBER: 0007
LOG SHEET NUMBER: 0007
OPERATOR: D.A.PERKINS
5
DATE: 10-13-90
BENCH NUMBER: TRUCK

TEST NAME: ENGINE #1 RECHECK

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23742 HYDROGEN: .07975
OXYGEN: 0 CARBON DIOXIDE: .6811

NITROGEN: .00213
HYDROGEN TO CARBON RATIO: 4.006
STOICHIOMETRIC A/F: 5.458

RAW DATA PRINT OUT:

DATA POINT	SPEED RPM	BMEP PSI	BHP	HUMIDITY GR/LB	FUEL FLOW LB/MIN	BSFC BTU/BHP-HR	AIR FLOW LB/MIN
1	900	189.8	2326	102	41.781	7236	374.82
2	900	189.8	2326	102	41.781	7236	374.98
3	900	189.8	2326	102	41.781	7236	390.49
4	900	189.8	2326	102	41.781	7236	375.03
5	900	189.8	2326	102	41.781	7236	374.94

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	NM HC PPM
1	478	15	49	11.17	8.70	30
2	378	28	49	11.17	8.70	28
3	366	25	45	10.66	9.25	20
4	372	29	53	11.17	8.68	28
5	478	16	51	11.17	8.70	30

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.078	8.84	9.21	1.69	1.149	.998
2	1.078	8.84	9.22	1.69	1.149	.999
3	1.078	9.21	9.65	1.77	1.144	.999
4	1.078	8.85	9.21	1.69	1.149	.999
5	1.078	8.84	9.21	1.69	1.149	.998

'AKE SPECIFIC EMISSIONS FOR DRY EXHAUST GAS
GRAMS/BHP-HR

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL NMHC	METHANE	NON METHANE	NO PPM	NOX PPM
1	2.07	.11	.35	.38	.09	0.00	0.00	7	24
2	1.64	.20	.35	.38	.08	0.00	0.00	14	24
3	1.66	.19	.34	.36	.06	0.00	0.00	13	23
4	1.61	.21	.38	.41	.08	0.00	0.00	14	26
5	2.07	.11	.36	.39	.09	0.00	0.00	8	25

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF-10:D700
ENGINE MODEL: 12VAT25GL
REF.LOG.NUMBER: 0010
TEST NUMBER: 0010
LOG SHEET NUMBER: 0010
OPERATOR: D.A.PERKINS

DATE: 11-6-90
BENCH NUMBER: TRUCK

TEST NAME: ENGINE #8 RECHECK

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .22318 HYDROGEN: .07504
OXYGEN: .00078 CARBON DIOXIDE: .6846
NITROGEN: .01647
HYDROGEN TO CARBON RATIO: 4.006
STOICHIOMETRIC A/F: 5.130

RAW DATA PRINT OUT:

DATA POINT	SPEED RPM	BMEP PSI	BHP	HUMIDITY GR/LB	FUEL FLOW LB/MIN	BSFC BTU/BHP-HR	AIR FLOW LB/MIN
1	900	195.8	2400	44	43.532	6888	359.79
2	900	195.8	2400	44	43.532	6888	359.97
3	900	195.8	2400	44	43.532	6888	377.07
4	900	195.8	2400	44	43.532	6888	364.15
5	900	195.8	2400	44	43.532	6888	363.32

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	NMHC PPM
1	466	49	104	11.79	8.35	19
2	98	84	105	11.84	8.33	18
3	86	88	101	11.25	8.98	19
4	104	78	104	11.61	8.43	18
5	466	51	100	11.61	8.43	19

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.088	8.21	8.44	1.65	1.139	.999
2	1.088	8.22	8.44	1.64	1.139	1.000
3	1.088	8.61	8.88	1.73	1.132	1.000
4	1.088	8.31	8.54	1.67	1.137	1.000
5	1.088	8.29	8.52	1.66	1.137	.998

:AKE SPECIFIC EMISSIONS FOR DRY EXHAUST GAS
GRAMS/BHP-HR

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL NM HC	METHANE	NON METHANE	NO PPM	NOX PPM
1	1.88	.32	.69	.64	.05	0.00	0.00	23	49
2	.39	.56	.69	.64	.05	0.00	0.00	39	49
3	.36	.61	.70	.65	.05	0.00	0.00	44	50
4	.42	.52	.70	.64	.05	0.00	0.00	37	49
5	1.90	.34	.67	.62	.05	0.00	0.00	24	47

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SAMPLE CALCULATION FOR FUEL CONSUMPTION AND BRAKE SPECIFIC EMISSION RATES.
CALCULATION WILL BE FOR UNIT #1, LINE #1 - PRE-CATALYST CONDITION.
SEE APPENDIX E FOR RAW DATA.

NOTE: TO SIMPLIFY THIS EXAMPLE, ITERATIVE CALCULATIONS WILL NOT BE DONE. INSTEAD, FINAL RESULTS FROM COMPUTER PRINTOUT WILL BE USED.

A. BRAKE SPECIFIC FUEL CONSUMPTION (BSFC)

AVERAGE HORSEPOWER 2410 BHP

FUEL PROPERTIES:

SATURATED LOW HEAT VALUE 502 BTU/FT^3

SPECIFIC GRAVITY .980

FUEL GAS DENSITY = .980 x .0763
= .07477 Lb/FT^3

$$BSFC = 1040.0 \left(\frac{SLHV}{BHP}\right)\left(\frac{FT^3}{MIN}\right)\left(\frac{BP + P_{GAS}}{T_{GAS} + 460°F}\right)$$

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WHERE:	1040.0	UNIT CONVERSION FACTOR
	SLHV	SATURATED LOW HEAT VALUE
	BHP	BRAKE HORSEPOWER
	FT^3	CUBIC FEET MEASURED
	MIN	MINUTES TO MEASURE FT^3
	BP	BAROMETRIC PRESSURE in. Hg
	P_{GAS}	MEASURED FUEL GAS PRESSURE
	T_{GAS}	MEASURED FUEL GAS TEMPERATURE

FOR UNIT #1, READINGS 4 AND 5 ARE DISCARDED PER THE TEST PROTOCOL BASED ON PRELIMINARY CALCULATIONS.

READING #1

$$BSFC = \frac{(1040)(502)}{2410}\left(\frac{200}{1.680}\right)\left(\frac{29.87 + \frac{55\text{ psi}}{.491}}{77^\circ + 460^\circ}\right)$$

$= 6814.1$ BTU/BHP-HR

READING #2

$$BSFC = \frac{(1040)(502)}{2410}\left(\frac{200}{1.680}\right)\left(\frac{29.87 + \frac{55\text{ psi}}{.491}}{77^\circ + 460^\circ}\right)$$

$= 6814.1$ BTU/BHP-HR

READING #3

$$BSFC = \frac{(1040)(502)}{2410}\left(\frac{200}{1.681}\right)\left(\frac{29.87 + \frac{55.5\text{ psi}}{.491}}{77^\circ + 460^\circ}\right)$$

$= 6858.9$ BTU/BHP-HR

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$$\text{AVERAGE BSFC} = \frac{6814.1 + 6814.1 + 6858.9}{3}$$

$$= 6829 \text{ BTU/BHP-HR}$$

B. FUEL FLOW

$$\text{FUEL FLOW} = \text{BSFC} \frac{\text{BTU}}{\text{BHP-HR}} \times \frac{1}{60 \frac{\text{HR}}{\text{MIN}}} \times 2410 \text{ BHP} \times \frac{1}{502 \frac{\text{BTU}}{\text{FT}^3}} \times .07477 \frac{\text{LB}}{\text{FT}^3}$$

$$\text{FUEL FLOW} = (6829)\left(\frac{1}{60}\right)(2410)\left(\frac{1}{502}\right)(.07477)$$

$$= 40.855 \text{ LB/MIN} = 2451.3 \text{ LB/HR}$$

C. AIR-FUEL RATIO

FROM APPENDIX F, EQUATION (26) THE AIR-FUEL RATIO IS:

$$AFR = F_b\left[11.492\, F_c\left(\frac{1 + R/2 + Q}{1+R}\right) + \left(\frac{120 \times F_{H2}}{3.5 + R}\right)\right]$$

THIS EQUATION MUST BE MODIFIED FOR FUELS CONTAINING SIGNIFICANT LEVELS OF CO_2 SINCE CO_2 IS A PRODUCT OF COMBUSTION. IF A CORRECTION WERE NOT MADE THE CO_2 ENTERING WITH THE FUEL GAS WOULD BE ASSUMED TO HAVE

BEEN FORMED BY COMBUSTION. THIS WOULD GIVE AN ERRONEOUS AIR-FUEL RATIO VALUE.
SUBTRACTING THE FUEL-BORNE CO_2:

$$AFR = F_b\left[\left(11.492F_c + 3.136F_{CO_2}\right)\left(\frac{1+\frac{R}{2}+Q}{1+R}\right) + \left(\frac{120\times F_{H2}}{3.5+R}\right) - 3.136F_{CO_2}\right]$$

THE EQUATION PARAMETERS ARE DEFINED IN APPENDIX F.

TAKING THE APPROPRIATE VALUES FOR FUEL "A" FROM TABLE I:

CARBON FRACTION $= F_c = .23742$
HYDROGEN FRACTION $= F_{H2} = .07975$
CARBON DIOXIDE FRACTION $= F_{CO2} = .68115$

FROM APPENDIX E FOR LINE #1, UNIT #1:

CO IN EXHAUST $= P_{CO} = 460$ ppm $= .046\%$
CO_2 IN EXHAUST $= P_{CO_2} = 11.57\%$
O_2 IN EXHAUST $= P_{O_2} = 8.35\%$
CH IN EXHAUST $= 1860$ ppm $= .186\%$

THIS LATTER VALUE IS MEASURED "WET". TO CONVERT TO AN EQUIVALENT "DRY" VALUE IT IS MULTIPLIED BY THE WET/DRY RATIO. THIS IS DETERMINED BY AN ITERATIVE PROCESS. TAKING THE VALUE 1.147 FROM APPENDIX G:

$$P_{CH} = (.186\%)(1.147) = .2133\%$$

WE CAN NOW CALCULATE

$$R = P_{CO}/P_{CO_2} = .046/11.57 = .003976$$

$$Q = P_{O_2}/P_{CO_2} = 8.35/11.57 = .72169$$

$$F_b = \frac{P_{CO} + P_{CO_2}}{P_{CO} + P_{CO_2} + P_{CH}} = \frac{.046 + 11.57}{.046 + 11.57 + .2133} = .9820$$

AND

$$AFR = .982\left[\left((11.492)(.23742) + (3.136)(.68115)\right)\left(\frac{1 + \frac{.003976}{2} + .72169}{1 + .003976}\right) + \left(\frac{(120)(.07975)}{3.5 + .003976}\right) - (3.136)(.68115)\right]$$

$$AFR = 8.947 : 1$$

D. AIR FLOW

$$\begin{aligned} \text{AIR FLOW} &= \text{FUEL FLOW} \times \text{AFR} \\ &= (2451.3 \text{ Lb/HR})(8.947) \\ &= 21931.8 \text{ Lb/HR} \end{aligned}$$

E. EXHAUST FLOW

THE TOTAL EXHAUST FLOW IS THE SUM OF THE AIR AND FUEL FLOWS.

EXHAUST FLOW = 2451.3 + 21931.8 = 24,383.1 Lb/HR

F. BRAKE SPECIFIC EMISSION RATES.

FROM APPENDIX E

NO_x	74 ppm	volume	"DRY"	MEASURED
CO	460 ppm	volume	"DRY"	MEASURED
THC	1860 ppm	volume	"WET"	MEASURED
NMHC	31 ppm	volume	"WET"	MEASURED

THE WET/DRY RATIO FROM APPENDIX G IS USED TO CONVERT THE MEASURED NO_x AND CO VALUES TO EQUIVALENT "WET" READINGS.

NO_x = 74 ppm / 1.147 = 64.5 ppm "WET" volume
CO = 460 ppm / 1.147 = 401.0 ppm "WET" volume

WE MUST DETERMINE MASS FRACTIONS AS OPPOSED TO THE MEASURED VOLUME FRACTIONS (ppm).

TO DO THIS WE MUST DETERMINE THE APPARENT MOLECULAR WEIGHT OF THE EXHAUST STREAM.

FROM APPENDIX E THE MEASURED EXHAUST ANALYSIS IS:

NO_x	= 74 ppm	= .0074 %	= .000074	"DRY"
CO	= 460 ppm	= .0460 %	= .000460	"DRY"
THC	= 1860 ppm	= .1860 %	= .001860	"WET"
CO_2	=	11.57 %	= .115700	"DRY"
O_2	=	8.35 %	= .083500	"DRY"

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FROM APPENDIX G THE WET/DRY RATIO IS 1.147

$$\frac{1}{1.147} = .8718$$

THEREFORE $1 - .8718 = .1282$ OR 12.82 % OF THE EXHAUST STREAM IS WATER VAPOR.

CONVERTING TO AN ENTIRE "WET" ANALYSIS:

NO_x = .0000645
CO = .0004010
THC = .001860
CO_2 = .100872
O_2 = .072799
H_2O = .128200
BALANCE N_2 = .695803

THE APPARENT MOLECULAR WEIGHT OF THE EXHAUST STREAM IS CALCULATED AS:

SPECIE	VOLUME FRACTION	SPECIE MOL. WT.	MOLECULAR WEIGHT FRACTION
NO_x (AS NO_2)	.0000645	46.01	.003
CO	.000401	28.01	.011
THC (AS CH_4)	.001860	16.04	.030
CO_2	.100872	44.01	4.439
O_2	.072799	32.00	2.330
H_2O	.128200	18.02	2.310
N_2	.695803	28.02	19.496
SUM =	.9999995		28.619

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TO CONVERT MEASURED VOLUME FRACTIONS TO MASS FRACTIONS MULTIPLY THE VOLUME FRACTION BY THE RATIO OF SPECIE MOLECULAR WEIGHT TO APPARENT EXHAUST MOLECULAR WEIGHT.

SPECIE	VOLUME FRACTION	SPECIE MOL. WT.	$\frac{\text{SPECIE MOL. WT}}{28.619}$	MASS FRACTION
NO_x (AS NO_2)	.0000645	46.01	1.6077	.0001037
CO	.000401	28.01	.9787	.0003925
THC (AS CH_4)	.001860	16.04	.5605	.0010425
CO_2	.100872	44.01	1.5378	.1551199
O_2	.072799	32.00	1.1181	.0813994
H_2O	.128200	18.02	.6296	.0807213
N_2	.695803	28.02	.9791	.6812397
SUM =	.9999995			1.0000190

FINALLY, EACH BRAKE SPECIFIC EMISSION RATE IS CALCULATED AS:

$$E_i = \frac{(\text{TOTAL EXHAUST MASS FLOW RATE}) \times (\text{MASS FRACTION}_i)}{\text{BHP}}$$

$$E_i = 24383.1 \frac{\text{LB}}{\text{HR}} \times 453.6 \frac{\text{gram}}{\text{Lb}} \times \frac{1}{2410 \text{ BHP}} \times MF_i$$

$$E_i = 4589.2839 \times MF_i \quad \text{gr/BHP-HR}$$

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NO_x : 4589.2839 × .0001037 = .476 gr/BHP-HR

CO : 4589.2839 × .0003925 = 1.801 gr/BHP-HR

THC : 4589.2839 × .0010425 = 4.784 gr/BHP-HR

FOR NON-METHANE HYDROCARBONS :

1860 ppm − 31 ppm = 1829 ppm = .001829 (volume)

.001829 × .5605 = .0010252 (MASS)

NMHC = 4.784 − 4589.2839 × .0010252 = 4.784 − 4.705

NMHC = .079 gr/BHP-HR

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