Johnston RI

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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
REPORT PREPARED BY:	ROBERT STACHOWICZ SENIOR PROJECT ENGINEER WAUKESHA ENGINE DIVISION DRESSER INDUSTRIES, INC. WAUKESHA, WISCONSIN 53188
TEST DATES:	JUNE 4 THRU JUNE 7, 1991
REPORT DATE:	JULY 19, 1991

NOx, CO, & NMOC
Pre & Post Catalyst Emissions
fuel composition

97

EXECUTIVE SUMMARY

During the period of June 4-7, 1991 the Waukesha Engine Division of Dresser Industries, Inc. performed an emission certification test 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 (NO_x 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.

Testing yielded average stack emission rates from the eight units of .60 gr/BHP-HR NO_x, .52 gr/BHP-HR CO, and .09 gr/BHP-HR NMHC. These levels are 48%, 46%, and 18% of permit requirements, respectively. Each unit individually passed permit requirements for all three specie. Average oxidizing catalyst efficiency was 74.1%.

Average fuel consumption at rated conditions was found to be 7424 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) approvals #999-1014 require performance testing be conducted for nitrogen oxides (NO_x = NO + NO_2 as NO_2), carbon monoxide (CO), and total non-methane hydrocarbons (NMHC). 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 permits #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 an approximate minimum catalyst CO conversion efficiency of 50%.

Initial certification testing was performed during the period October 9, 1990 to October 16, 1990. This 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 to meet permit requirements for CO emission due to a low average oxidizing catalyst efficiency of 9%. See the November 30, 1990 certification report for details.

The low CO conversion efficiency was traced to silicon contamination of the catalyst material. The silicon was finally proven to be entering the system in the form of siloxane components (silicone bearing hydrocarbons) of the landfill gas fuel.

This second certification test was performed during the period June 4, 1991 to June 7, 1991. All units had cleaned or new catalyst beds installed. Mr. Richard Evans of RIDEM was present as an observer during all four days of this testing.

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 engines 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.

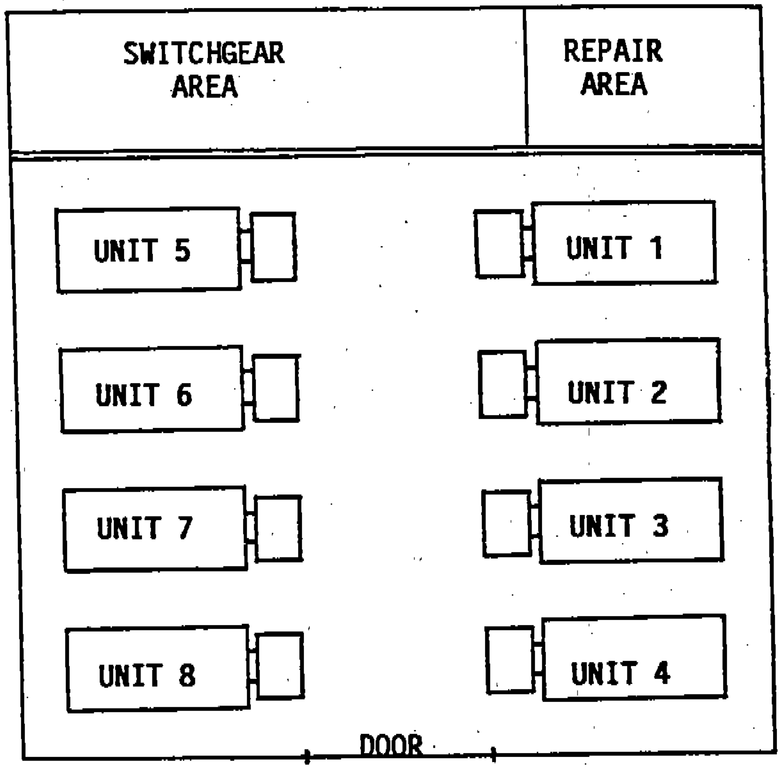


FIGURE 1

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 are 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 are presented in Appendix E.

4.0 FUEL ANALYSES

During the test program three fuel samples were taken at intervals. Samples were taken on June 4,5, and 6 during the certification testing.

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 2 and 3 of June 5 and 6 were nearly identical, an average of these fuel properties was used for calculations spanning that time period. Table I summarizes the two 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 7424 BTU/BHP-HR with a low of 7227 BTU/BHP-HR and a high of 7651 BTU-BHP-HR. Note that these values are not all directly comparable because of small load and carburetor adjustment 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.

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 tested at rated conditions were found to be .60 gr/BHP-HR NO_x, .52 gr/BHP-HR CO, and .09 gr/BHP-HR MNHC. These levels are well below the permit requirements for all three specie for these units. Individually each unit passed permit requirements for emission of each specie. See Table IV-c.

6.0: CONCLUSION

The results of this testing showed that all eight units at the Central Landfill powerhouse easily met operating permit requirements for NO_x, CO, and NMHC emission rates.

Written by: R.W. Stachowicz
R.W. Stachowicz
Senior Project Engineer/Engineering Support

Approved by: J.M. Derra 7/18/91
J.M. Derra
Manager/Engineering Support

TABLE I

FUEL PARAMETERS

FUEL DESIGNATION	SAMPLE DATES(S)	CHARACTERISTICS	
A	6-4-91	SLHV	496 BTU/FT^3
		Specific Gravity	.9686
		Density	.0741 LB/FT
		H/C Ratio	4.001
		F_C	.23740
		F_{H2}	.07971
		F_{O2}	.00057
		F_{N2}	.03293
		F_{CO2}	.64933
		F_{IN}	0
B	6-5-91 6-6-91 (AVERAGE)	SLHV	486 BTU/FT^3
		Specific Gravity	.9713
		Density	.0743 LB/FT^3
		H/C Ratio	3.995
		F_C	.23231
		F_{H2}	.07789
		F_{O2}	.00103
		F_{N2}	.04962
		F_{CO2}	.63886
		F_{IN}	0

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

TABLE II

ENGINE TEST CONDITIONS

UNIT	DATE	AVERAGE LOAD[1] KWe	AVERAGE LOAD[1] BHP	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	6-6-91	1714	2394	29.83	58	B	17°	8.635	61.6
2	6-6-91	1721	2404	29.90	57	B	17°	8.745	63.6
3	6-4-91	1715	2396	29.55	76	A	17°	9.055	65.8
4	6-4-91	1718	2400	29.53	63	A	17°	8.960	64.1
5	6-7-91	1689	2359	29.96	48	B	17°	8.640	61.6
6	6-6-91	1697	2371	30.00	43	B	17°	8.665	62.1
7	6-5-91	1689	2359	29.80	54	B	17°	8.695	62.7
8	6-5-91	1693	2365	29.84	52	B	17°	8.725	63.2
MEAN		1704.5	2381					8.765	63.1
STANDARD DEVIATION		12.9	18.0					.146	1.33

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	1714	2394	486	7354	44.863
2	1721	2404	486	7386	45.240
3	1715	2396	496	7367	43.932
4	1718	2400	496	7331	43.794
5	~~1689~~	~~2359~~	486	7651	45.991
6	1697	2371	486	7542	45.561
7	1689	2359	486	7531	45.268
8	1693	2365	486	7227	43.548
	avg	BHP			
MEAN				7424	44.775
STANDARD DEVIATION				129	.847

NOTE: BHP FIGURES ASSUME 96% GENERATOR EFFICIENCY.

1704.5 2381

ratio

.7159

TABLE IV-a

PRE-CATALYST EMISSION SUMMARY

UNIT	BRAKE SPECIFIC EMISSIONS - g/BHP-HR		
	NOx	CO	NMHC
1	.650	1.995	.095
2	.605	1.930	.085
3	.640	1.940	.080
4	.625	1.830	.065
5	.725	2.245	.080
6	.465	1.960	.070
7	.355	1.865	.095
8	.435	1.735	.095
MEAN	.563	1.938	.083
STANDARD DEVIATION	.120	.140	.011

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	.605	.835	.095	58.1
2	.615	.815	.085	57.9
3	.635	.435	.080	77.6
4	.595	.300	.070	83.8
5	.775	.480	.075	78.6
6	.460	.230	.060	88.0
7	.370	.265	.095	85.9
8	.450	.645	.090	62.8
MEAN	.563	.501	.081	74.1
STANDARD DEVIATION	.121	.225	.012	11.8

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

TABLE IV-c

STACK (CERTIFICATION) EMISSION SUMMARY

UNIT	BRAKE SPECIFIC EMISSION - g/BHP-HR		
	NO_x	CO	NMHC
1	.68	.98	.11
2	.69	.81	.10
3	.63	.44	.09
4	.61	.31	.07
5	.90	.46	.09
6	.47	.24	.07
7	.37	.27	.11
8	.45	.66	.10
MEAN	.60	.52	.09
STANDARD DEVIATION	.16	.25	.015

NOTES: 1) NO_x as NO_2
2) INCLUDES BREATHER GASES

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

Waukesha Mobile Engine Exhaust Emission Measurement Laboratory (MEEEML)

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.

ANALYZERS:

- $NO/NO_2/NO_x$
  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

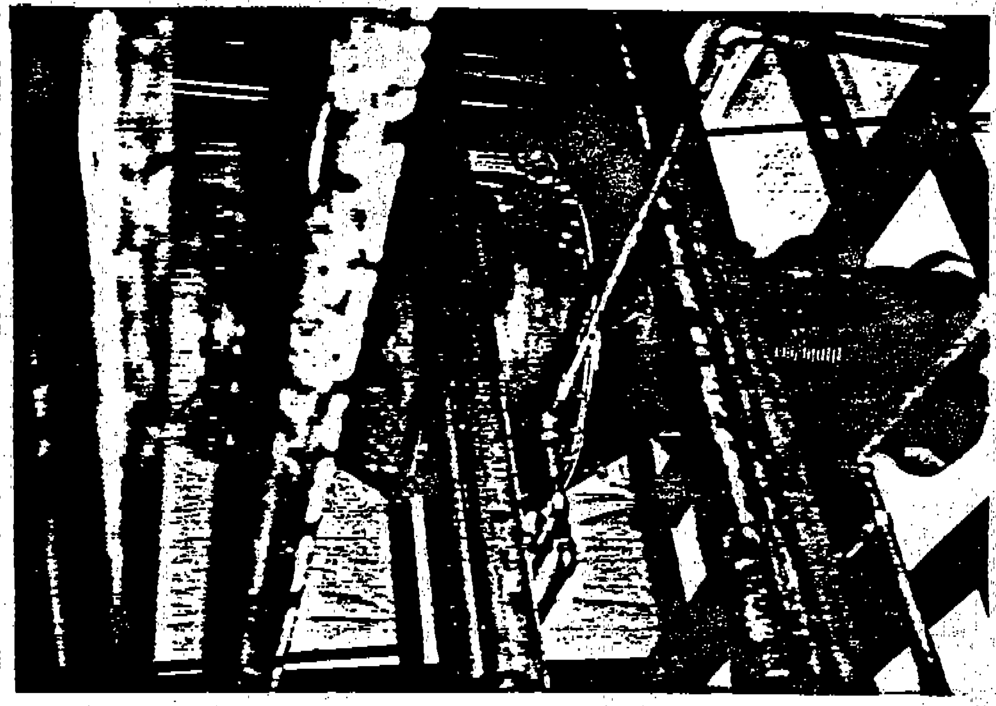
MOLECULAR WEIGHT 28.73180

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.

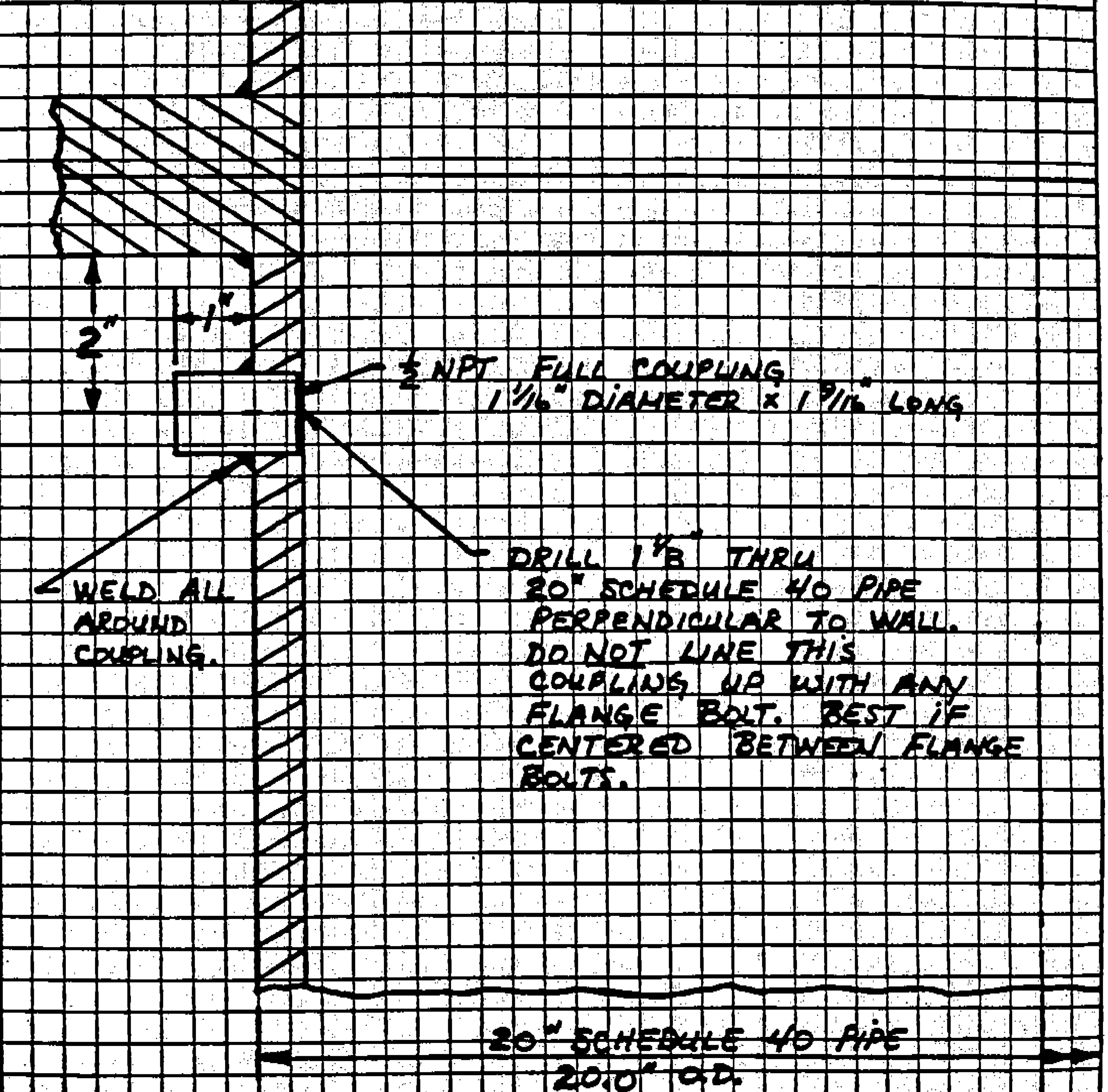
The test team will be composed of three participants:

- 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.

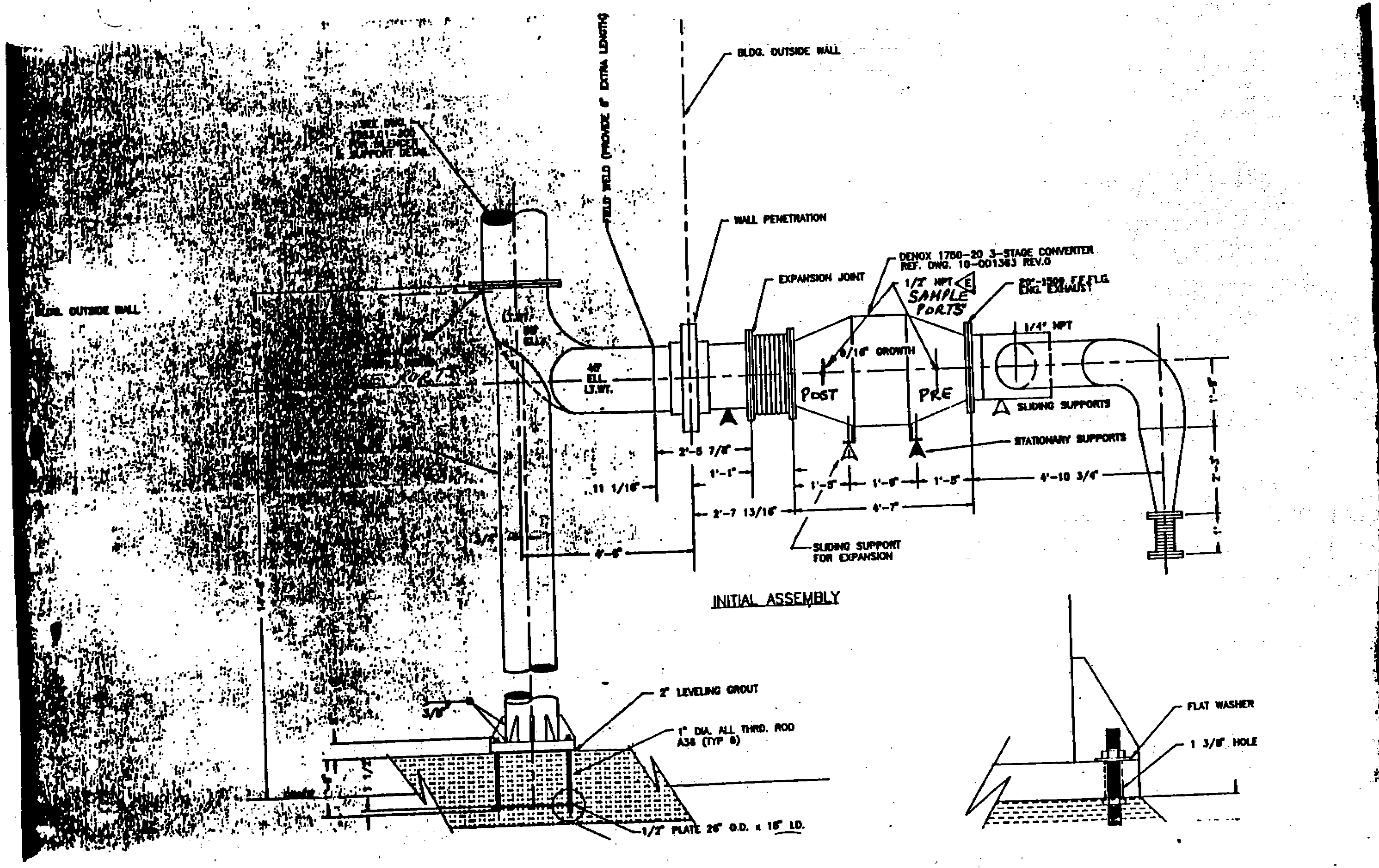
PREPARED BY	Waukesha DRESSER	PAGE 1 OF 4
STACHOWICZ		
CHECKED BY	ENGINEERING CALCULATION FORM	PROGRAM & PROJECT NO. JOHNSTON
TERAMATREX NO.	SUBJECT EMISSIONS TEST PORT	DATE APRIL 9, 1990



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

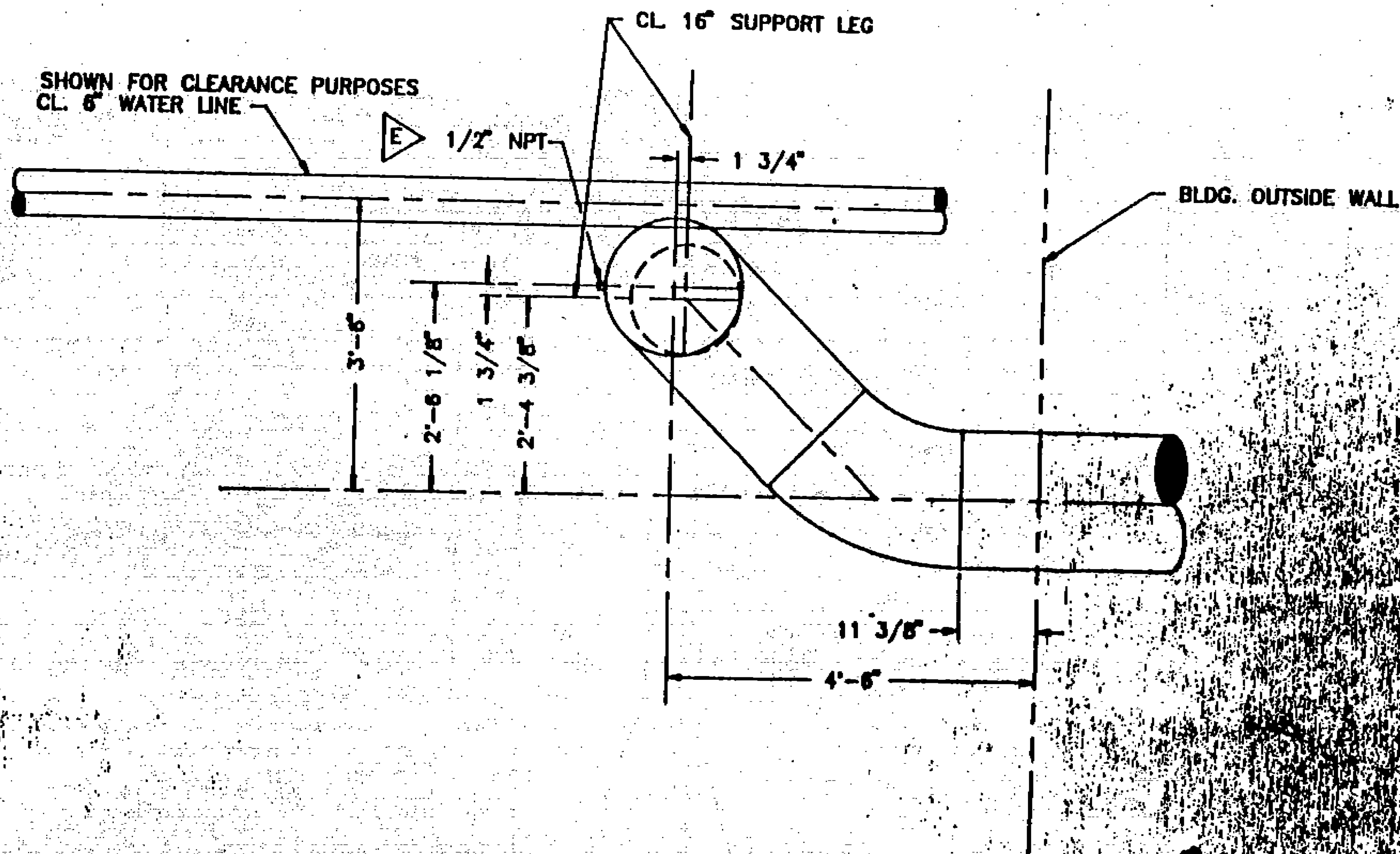
INSTALL PIPE PLUG WITH "NEVER SEIZE" (OR EQUIVALENT) WHEN NOT IN USE.

SCALE: HALF



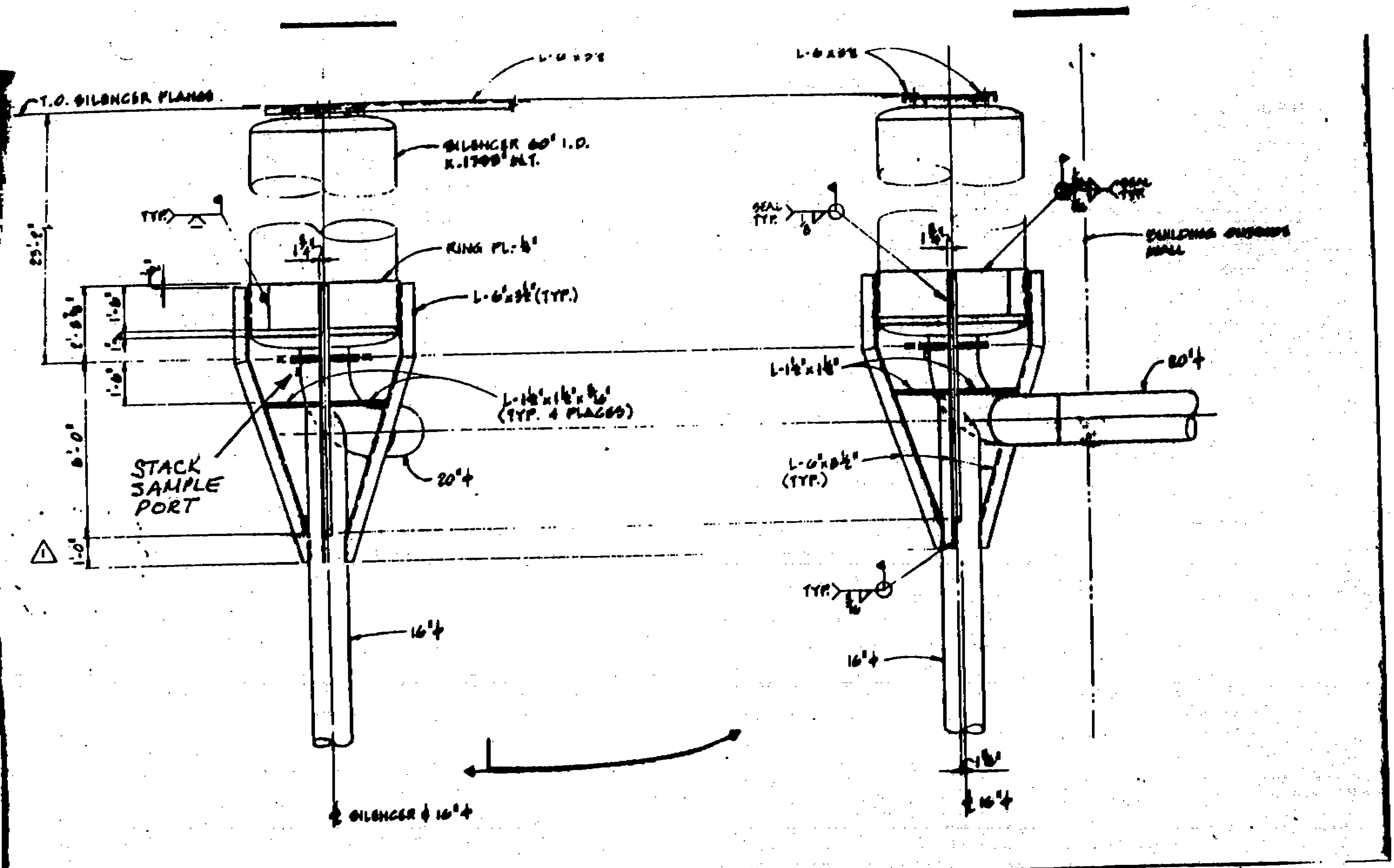
INITIAL ASSEMBLY

ATTACHMENT II
PAGE ? OF 4.



PLAN VIEW

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



GENERAL NOTES	REFERENCE DRAWINGS	REVISIONS

check (%O₂I). If the difference in oxygen concentration is greater than 1 mole percent, then the oxygen interference must be checked and the analyzer adjusted if necessary, to meet the %O₂I requirements. The burner air must contain less than 2 ppmC hydrocarbon.

(f) Oxygen interference check gases shall contain propane with 350 ppmC±75 ppmC hydrocarbon. The concentration value shall be determined to calibration gas tolerances by chromatographic analysis of total hydrocarbons plus impurities or by dynamic blending. Nitrogen shall be the predominant diluent with the balance oxygen. Blends required for gasoline-fueled and Diesel engine testing are as follows:

Applicability	O_2 concentration (percent)	Balance
Diesel	21 (20 to 22)	N_2
Diesel and gasoline	10 (9 to 11)	N_2
Do	5 (4 to 6)	N_2
Gasoline	0 (0 to 1)	N_2

(g) Proportioning and blending devices may be used to obtain required gas concentration.

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

§ 86.309-79 Sampling and analytical system; schematic drawing.

(a) Any variation from the specifications in this subpart including performance specifications and emission detection methods may be used only with prior approval by the Administrator.

(b) Schematic drawing.

(1) An example of a sampling and analytical system which may be used for testing under this subpart is shown in Figure D79-1. All components or parts of components that are wetted by the sample or corrosive calibration gases shall be either chemically cleaned stainless steel or inert material, e.g. polytetrafluoroethylene resin. The use of "gauge savers" or "protectors" with nonreactive diaphragms to reduce dead volumes is permitted. The specific detection methods to be used for each exhaust component can be found in § 86.316 for CO, § 86.317 for HC, and § 86.318 for NO_x. Additional components such as instruments, valves, solenoids, pumps, switches, etc. may be employed to provide additional information and coordinate the functions of the component systems.

(2) The following requirements must be incorporated in each system used for testing under this subpart.

(i) All analyzers must obtain the sample to be analyzed from the same sample line.

(ii) The sample transport system from the engine exhaust pipe to the HC analyzer and the NO_x analyzer must be heated as is indicated in Figure D79-1.

(iii) Carbon monoxide and carbon dioxide measurements must be made on a dry basis. Specific requirements for the means of drying the sample can be found in § 86.309 (b)(5) and § 86.311(e).

(iv) All NDIR analyzers must have a pressure gauge immediately downstream of the analyzer. The gauge tap must be within 2 inches of the analyzer exit port. Gauge specifications can be found in § 86.309(b)(3).

(v) All bypass and analyzer flows exiting the analysis system must be measured. Capillary flows such as in HFID and CL analyzers are excluded. For each ND IR analyzer with a flow meter located upstream of the analyzer, and upstream pressure gauge must be used. The gauge tap must be within 2 inches of the analyzer entrance port.

(vi) Calibration or span gases for the NO_x measurement system must pass through the NO_2 to NO converter.

(vii) The temperature of the NO_2 to NO converter must be displayed continuously.

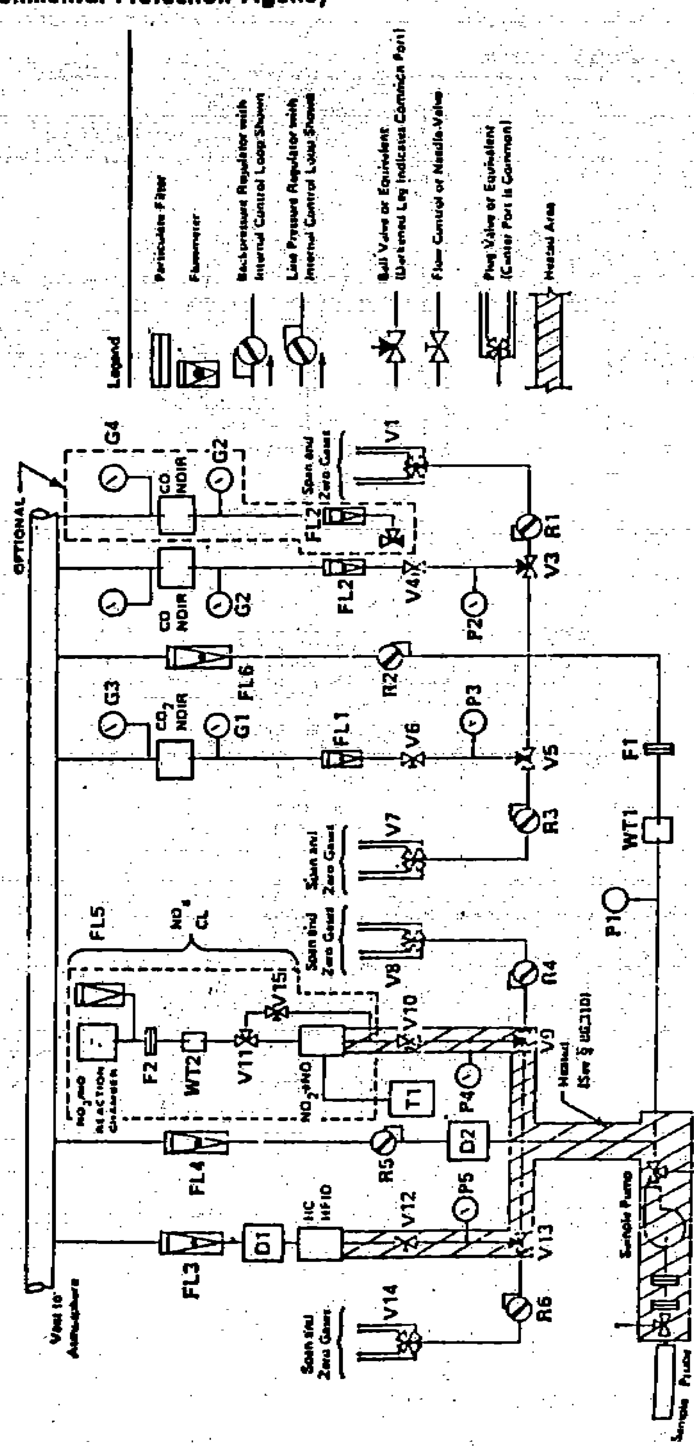


Figure D79-1 HEAVY-DUTY EXHAUST GAS SAMPLING AND ANALYTICAL TRAIN

(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).

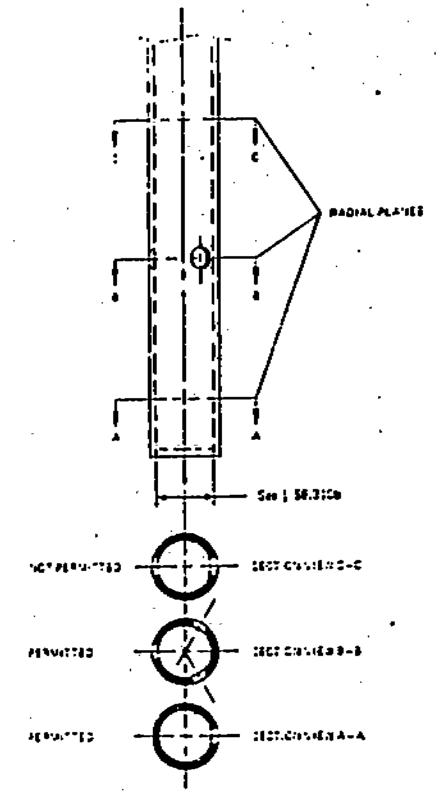


Figure D79-2 Sample probe and typical hole spacings

(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 walved 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 the[y] cover approximately equal cross-sec[-]tional areas of the exhause duct. Th[e] angular spacing of the holes must b[e] approximately equal. The angula[r] spacing of any two holes in one plan[e] may not be 180° ±20° (i.e., section C-[C] of Figure D79-2). The holes should b[e] sized such that each has approximate[-]ly the same flow. If only three hole[s] are used, they may not all be in th[e] same radial plane. See Figure D79-2.

(3) The probe shall extend radiall[y] across the exhaust duct. The prob[e] must pass through the approximat[e] center and must extend across at lea[st] 80 percent of the diameter of the duc[t].

(c) *Sample transfer.* (1) The max[i-]mum I.D. of the sample line shall n[ot] exceed 0.52 inch.

(2) If valve V2 is used, the sampl[e] probe must connect directly to valv[e] V2. The location of optional valve V[2] may not be greater than 4 feet fro[m] the exhaust duct.

(3) The location of optional valv[e] V16 may not be greater than 24 inche[s] from the sample pump. The leakag[e] rate for this section on the pressur[e] side of the sample pump may n[ot] exceed the leakage rate specificatio[n] for the vacuum side of the pump.

(d) *Venting.* All vents including ana[-]lyzer vents, bypass flow, and pressur[e] relief vents of regulators should b[e] vented in such a manner to avoid en[-]dangering personnel in the immediat[e] area.

[42 FR 45154, Sept. 8, 1977, as amended [at] 46 FR 50495, Oct. 13, 1981, and 47 FR 4980[...] Nov. 2, 1982]

§ 86.311-79 Miscellaneous equipmen[t] specifications.

(a) *Chart recorders.* (1) The min[i-]mum chart speed allowed is 3 inche[s] per minute for gasoline-fueled engine[s] and 0.5 inches per minute for Diese[l] engines.

(2) When testing gasoline-fueled en[-]gines all chart recorders (analyzers[,] torque, rpm, etc.) shall be provide[d] with Automatic markers which indi[-]cate one second intervals. Preprinte[d] chart paper (one second intervals[)] may be used in lieu of the automati[c]

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE: 4/29/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 28.80 IN HG
DRY BULB: 75 F
WET BULB: 65 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
81.4	12.16	12.19	.23	.17
64.1	9.12	9.16	.40	.23
44.9	6.08	6.12	.64	.25
23.8	3.04	3.10	2.03	.39
0.0	0.00	.00	0.00	.00

NEW REGRESSION MODEL DATE: 4/29/91

% NDIR CO2 = -2.06169E-004 +(+1.18311E-001)*(AR)+(+4.37820E-004)*(AR^2)+
(-2.05112E-006)*(AR^3)+(+1.66853E-008)*(AR^4)

ANALYZER ERROR TABLE
NEW REGRESSION DATA OF: 4/29/91

ANALYZER RESPONSE	ACTUAL %	PREDICTED %	% ERROR OR POINT	% ERROR OF FULL SCALE
97.0	15.20	15.20	.00	.00
81.4	12.16	12.16	-.02	-.02
64.1	9.12	9.12	.04	.02
44.9	6.08	6.08	-.05	-.02
23.8	3.04	3.04	.04	.01
0.0	0.00	-.00	0.00	-.00

PRECISION CHECK ANALYZER RESPONSES: 97.0 97.0 96.9
96.9 96.9 96.9 96.9 96.9 96.9 96.9

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

EMISSION INSTRUMENT CALIBRATION CHART

ANALYZER: NDIR CO2 16%
DATE OF CALIBRATION REGRESSION: 4/29/91
DATE OF LATEST CALIBRATION CHECK: 4/29/91

ANALYZER RESPONSE VERSUS CONCENTRATION

.5	.06	25.5	3.27	50.5	6.94	75.5	11.09
1.0	.12	26.0	3.34	51.0	7.01	76.0	11.18
1.5	.18	26.5	3.41	51.5	7.09	76.5	11.27
2.0	.24	27.0	3.48	52.0	7.17	77.0	11.36
2.5	.30	27.5	3.55	52.5	7.25	77.5	11.45
3.0	.36	28.0	3.62	53.0	7.33	78.0	11.54
3.5	.42	28.5	3.69	53.5	7.41	78.5	11.63
4.0	.48	29.0	3.76	54.0	7.48	79.0	11.72
4.5	.54	29.5	3.83	54.5	7.56	79.5	11.81
5.0	.60	30.0	3.90	55.0	7.64	80.0	11.90
5.5	.66	30.5	3.97	55.5	7.72	80.5	11.99
6.0	.73	31.0	4.04	56.0	7.80	81.0	12.08
6.5	.79	31.5	4.11	56.5	7.88	81.5	12.18
7.0	.85	32.0	4.18	57.0	7.96	82.0	12.27
7.5	.91	32.5	4.26	57.5	8.04	82.5	12.36
8.0	.97	33.0	4.33	58.0	8.12	83.0	12.45
8.5	1.04	33.5	4.40	58.5	8.20	83.5	12.55
9.0	1.10	34.0	4.47	59.0	8.29	84.0	12.64
9.5	1.16	34.5	4.54	59.5	8.37	84.5	12.74
10.0	1.22	35.0	4.61	60.0	8.45	85.0	12.83
10.5	1.29	35.5	4.69	60.5	8.53	85.5	12.93
11.0	1.35	36.0	4.76	61.0	8.61	86.0	13.02
11.5	1.42	36.5	4.83	61.5	8.69	86.5	13.12
12.0	1.48	37.0	4.90	62.0	8.78	87.0	13.21
12.5	1.54	37.5	4.98	62.5	8.86	87.5	13.31
13.0	1.61	38.0	5.05	63.0	8.94	88.0	13.40
13.5	1.67	38.5	5.12	63.5	9.02	88.5	13.50
14.0	1.74	39.0	5.20	64.0	9.11	89.0	13.60
14.5	1.80	39.5	5.27	64.5	9.19	89.5	13.70
15.0	1.87	40.0	5.34	65.0	9.27	90.0	13.79
15.5	1.93	40.5	5.42	65.5	9.36	90.5	13.89
16.0	2.00	41.0	5.49	66.0	9.44	91.0	13.99
16.5	2.06	41.5	5.57	66.5	9.53	91.5	14.09
17.0	2.13	42.0	5.64	67.0	9.61	92.0	14.19
17.5	2.19	42.5	5.72	67.5	9.70	92.5	14.29
18.0	2.26	43.0	5.79	68.0	9.78	93.0	14.39
18.5	2.33	43.5	5.87	68.5	9.87	93.5	14.49
19.0	2.39	44.0	5.94	69.0	9.95	94.0	14.59
19.5	2.46	44.5	6.02	69.5	10.04	94.5	14.69
20.0	2.53	45.0	6.09	70.0	10.12	95.0	14.79
20.5	2.59	45.5	6.17	70.5	10.21	95.5	14.89
21.0	2.66	46.0	6.24	71.0	10.30	96.0	15.00
21.5	2.73	46.5	6.32	71.5	10.38	96.5	15.10
22.0	2.80	47.0	6.40	72.0	10.47	97.0	15.20
22.5	2.86	47.5	6.47	72.5	10.56	97.5	15.30
23.0	2.93	48.0	6.55	73.0	10.65	98.0	15.41
23.5	3.00	48.5	6.63	73.5	10.73	98.5	15.51
24.0	3.07	49.0	6.70	74.0	10.82	99.0	15.62
24.5	3.14	49.5	6.78	74.5	10.91	99.5	15.72
25.0	3.21	50.0	6.86	75.0	11.00	100.0	15.83

% NDIR CO2 = -[illegible]E-004 +(+1.[illegible]E-001)*(AR)+(+4.37820E-004 * AR^2)-
[illegible]E-0[illegible])*(AR^3)+(+[illegible]E-008)*(AR^4)

ANALYZER PREC ON CHECK

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

DATE: 4-29-91   ANALYSIS BENCH: TRUCK   OPERATOR: Jeff Holmes

ANALYZER: NDIR CO_2 ANALYZER SERIAL NO.: 431198112

Analyzer Range:		Analyzer Range: 16% R3		Analyzer Range:		Analyzer Range:	
Span Gas Conc.:		Span Gas Conc.: 15.2%		Span Gas Conc.:		Span Gas Conc.:	
Span Point: ___ mv		Span Point: 91.0 mv		Span Point: ___ mv		Span Point: ___ mv	
Bottle No.:		Bottle No.: 421806		Bottle No.:		Bottle No.:	
Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)
1		1	97.0	1		1	
2		2	97.0	2		2	
3		3	96.9	3		3	
4		4	96.9	4		4	
5		5	96.9	5		5	
6		6	96.9	6		6	
7		7	96.9	7		7	
8		8	96.9	8		8	
9		9	96.9	9		9	
10		10	96.9	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"

ANALYZER NOISE CHECK

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

Date: 4-15-91

Analysis Bench: TRUCK

Operator: Jeff Holmes

Analyzer: O_2

Analyzer Serial No. 38817

Analyzer Range: 25%
Span Gas Conc.: 20.96%
Bottle No.: Room Air
Analyzer PTP Response with Zero Gas.
Chart Deflection: 0
Analyzer PTP Response with Span Gas.
Chart Deflection: 0
Noise: 0 % FSCD

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

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

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"

4 cm/min

ANALYZER RESPONSE TIME CHECK

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

Date: 4-15-91

Analysis Bench: TRUCK

Operator: Jeff Holmes

Analyzer: O_2

Analyzer Serial No.: 38817

Analyzer Range: 25%

Step Gas Conc.: 20.96%

Chart Deflection for 95% of Step Gas: 19.9 (80)

Time to Respond to 95% of Step Gas: 7 sec.

Analyzer Gas Flow: 4 scfh

Analyzer Range: 2%

Step Gas Conc.: 1.9%

Chart Deflection for 95% of Step Gas: 1.81 (90)

Time to Respond to 95% of Step Gas: 6.8 sec.

Analyzer Gas Flow: 4 scfh

Analyzer Range: 5%

Step Gas Conc.: 4.75%

Chart Deflection for 95% of Step Gas: 4.51 (90.2)

Time to Respond to 95% of Step Gas: 6.8 sec.

Analyzer Gas Flow: 4 scfh

Analyzer Range: _____

Step Gas Conc.: _____

Chart Deflection for 95% of Step Gas: _____

Time to Respond to 95% of Step Gas: _____ sec.

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: 5-1-91 Analysis Bench: 4

Operator: Jeff Holmes

Analyzer: O_2

Analyzer Serial No.: 38817

Analyzer Range: 2%

Zero Gas: X N_2 ___ Zero Air

Span Gas Bottle No.: 487291

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

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

Zero Drift: .2 % FSCD/HR.

Span Drift: .3 % 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)

DATE: 4-11-91 ANALYSIS BENCH: TRUCK OPERATOR: Jess Holmes BAROMETER: 29.71 IN.HG.

ANALYZER: O_2 ANALYZER SERIAL NO.: 38817 WET BULB: 55 °F DRY BULB: 75 °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: 25%		Analyzer Range: 5%		Analyzer Range: 2%		Analyzer Range:	
Bottle No.: Room Air 20.96		Bottle No.: 634241		Bottle No.: 487291		Bottle No.:	
Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)
100% 20.96	83.8	100% 4.75	95	100% 1.9	95		
80% 16.76	67.2	80 3.80	76.5	80 1.52	76.6		
60% 12.58	50.4	60 2.85	57.6	60 1.14	58.0		
40% 8.38	33.6	40 1.9	38.7	40 .76	39.1		
20% 4.19	16.8	20 .95	19.6	20 .38	20.1		
0% 0	.2	0	.6	0	1.1		

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 [illegible]

on each range used.

ANALYZER PRECISION CHECK

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

DATE: 4-15-91 ANALYSIS BENCH: TRUCK OPERATOR: Jeff Holmes

ANALYZER: O_2 ANALYZER SERIAL NO.: 38817

Analyzer Range: 25%	Analyzer Range: 5%	Analyzer Range: 2%	Analyzer Range:
Span Gas Conc.: 20.96%	Span Gas Conc.: 4.75%	Span Gas Conc.: 1.9%	Span Gas Conc.:
Span Point: 83.8 mv	Span Point: 95 mv	Span Point: 95 mv	Span Point: mv
Bottle No.: ROOM AIR 20.96	Bottle No.: 634241	Bottle No.: 487291	Bottle No.:

Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)
1	84.0	1	95.0	1	95.0	1	
2	84.0	2	95.1	2	95.0	2	
3	83.9	3	95.2	3	94.9	3	
4	84.0	4	95.1	4	94.9	4	
5	83.9	5	95.1	5	94.9	5	
6	83.8	6	95.1	6	94.9	6	
7	83.8	7	95.0	7	94.9	7	
8	83.8	8	95.0	8	94.9	8	
9	83.8	9	95.1	9	94.9	9	
10	83.8	10	95.1	10	95.0	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. RECORDER SPEED SET TO 20 cm/hr
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:4/11/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 29.71 IN HG
DRY BULB: 75 F
WET BULB: 55 F

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

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL %	PREDICTED %	PERCENT LINEARITY
95.0	1.90	1.88	.81
76.6	1.52	1.52	.03
58.0	1.14	1.15	-.32
39.1	.76	.78	-.73
20.1	.38	.40	-.94
1.1	0.00	.02	-1.10

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/11/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 29.71 IN HG
DRY BULB: 75 F
WET BULB: 55 F

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/11/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 29.71 IN HG
DRY BULB: 75 F
WET BULB: 55 F

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

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL %	PREDICTED %	PERCENT LINEARITY
95.0	4.75	4.72	.53
76.5	3.80	3.80	-.07
57.6	2.85	2.86	-.28
38.7	1.90	1.92	-.49
19.6	.95	.97	-.49
.6	0.00	.03	-.60

EMISSION ANALYZER CALIBRATION

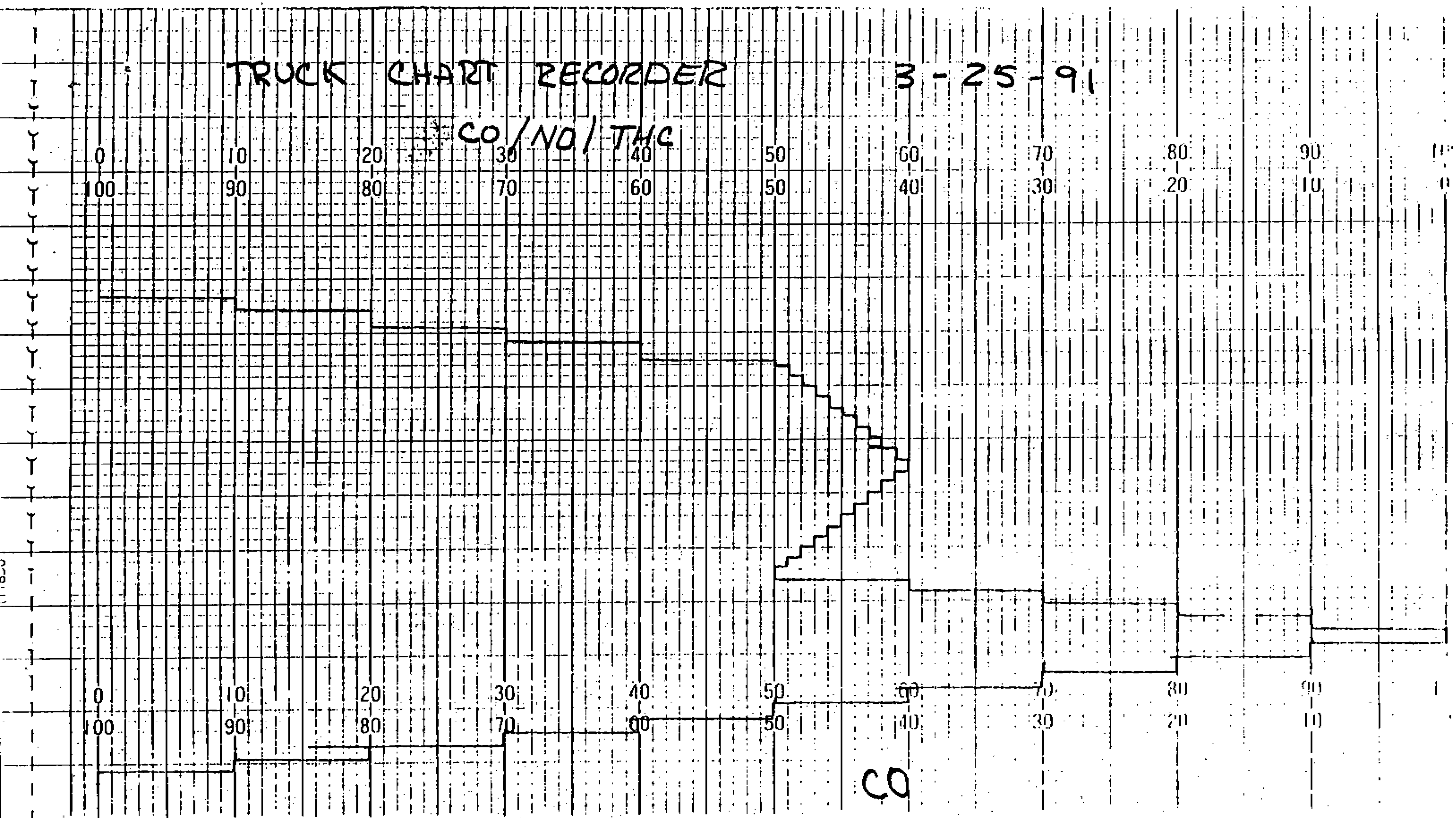
CALIBRATION DATE:4/11/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 29.71 IN HG
DRY BULB: 75 F
WET BULB: 55 F

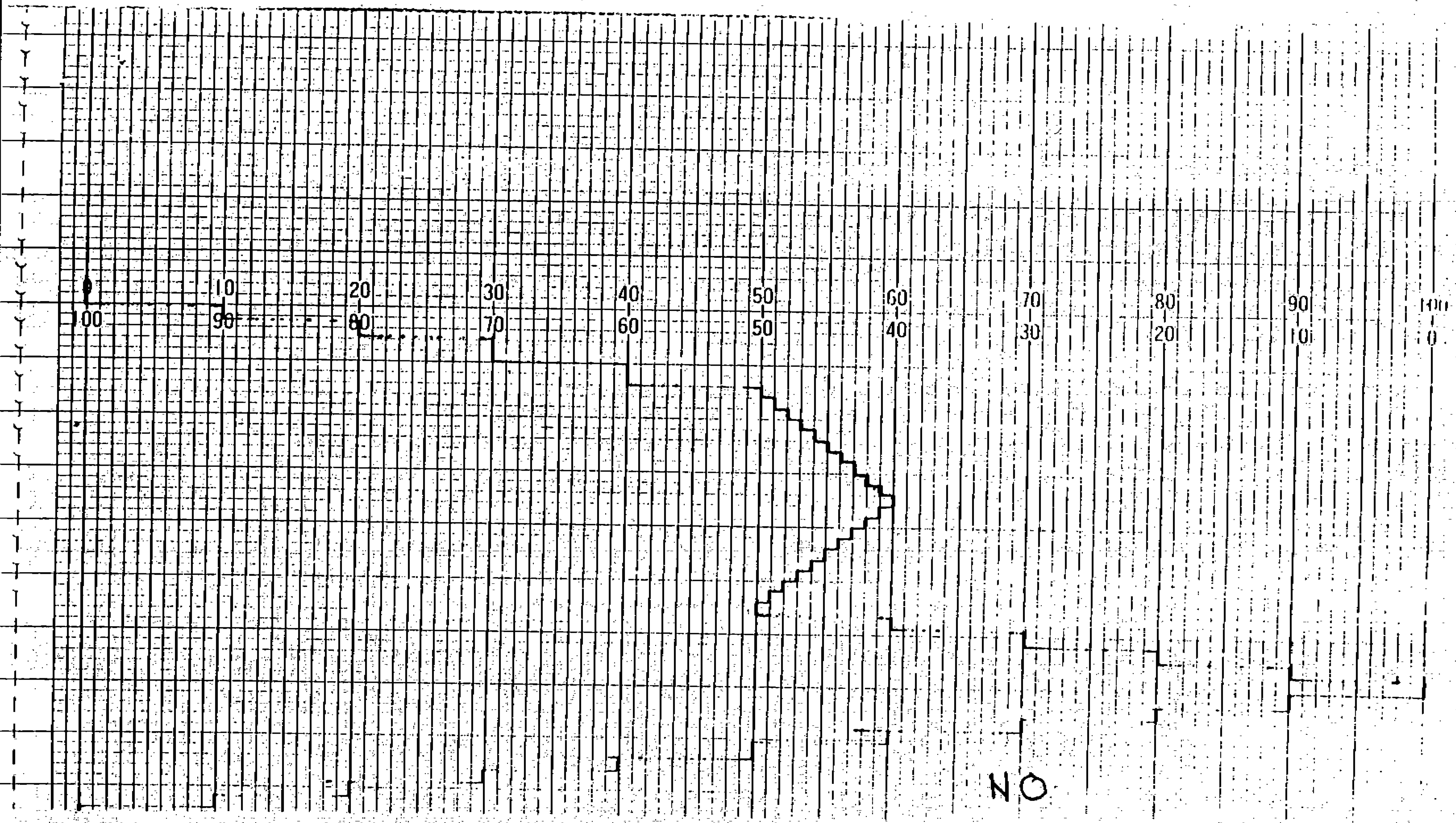
ANALYZER: OXYGEN
RANGE: 25%
CONCENTRATION & CYLINDER NUMBER: 20.96

ANALYZER RANGE LINEARITY CHECK

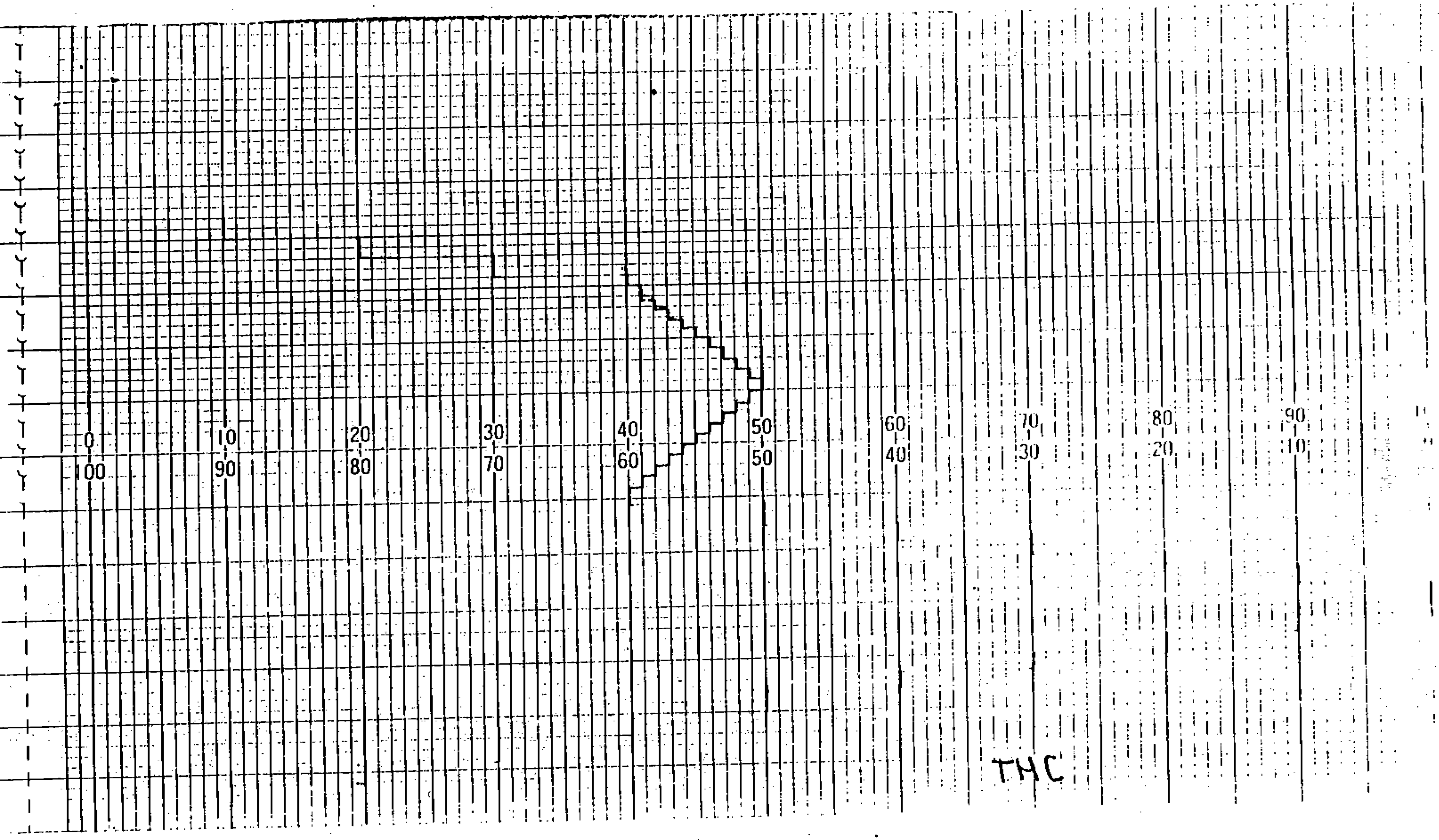
ANALYZER RESPONSE	ACTUAL %	PREDICTED %	PERCENT LINEARITY
83.8	20.96	20.93	.12
67.2	16.76	16.78	-.10
50.4	12.58	12.59	-.03
33.6	8.38	8.39	-.05
16.8	4.19	4.20	-.02
.2	0.00	.05	-.20

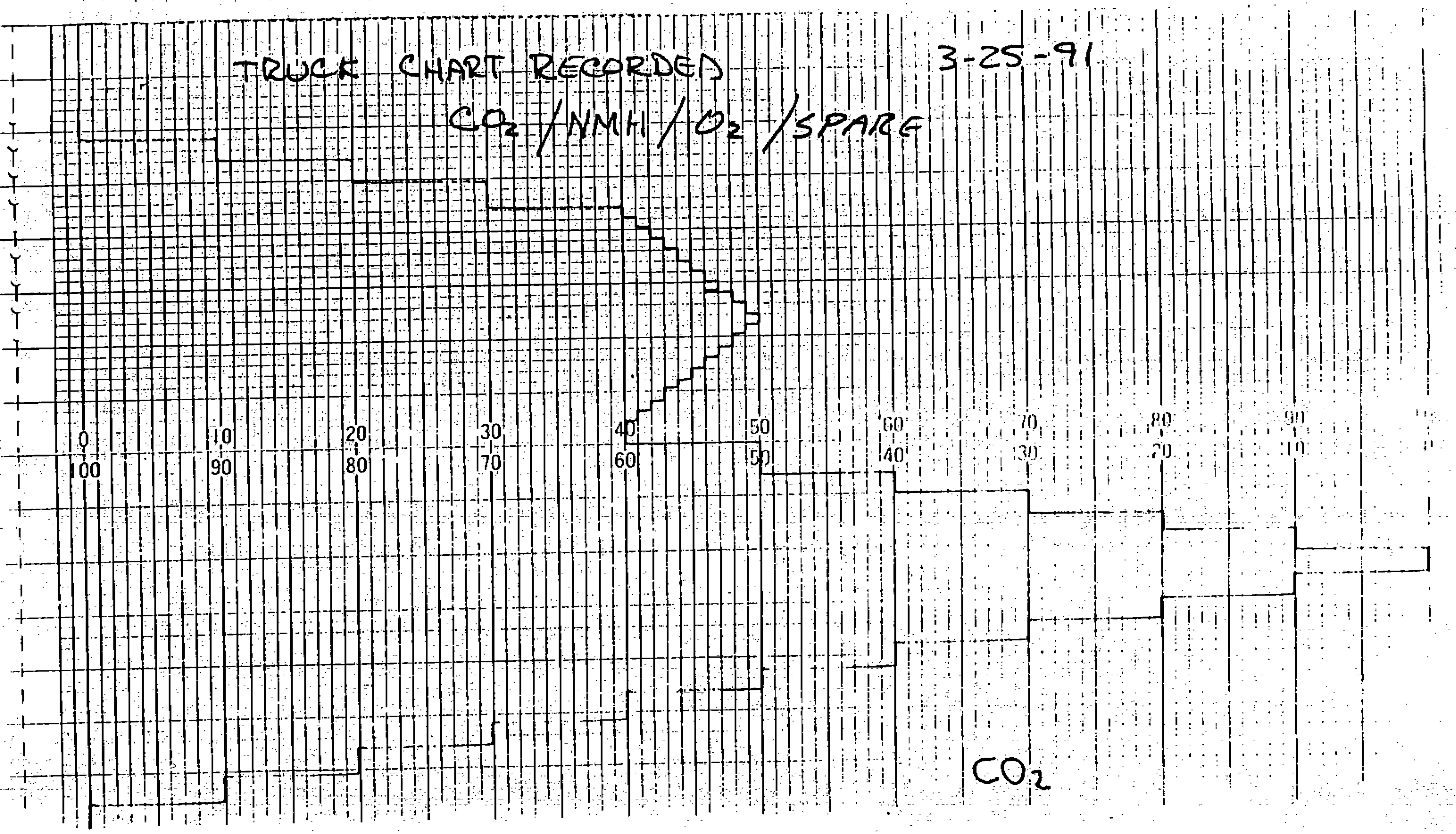


TRUCK CHART RECORDER
3-25-91
CO/NO/THC
CO

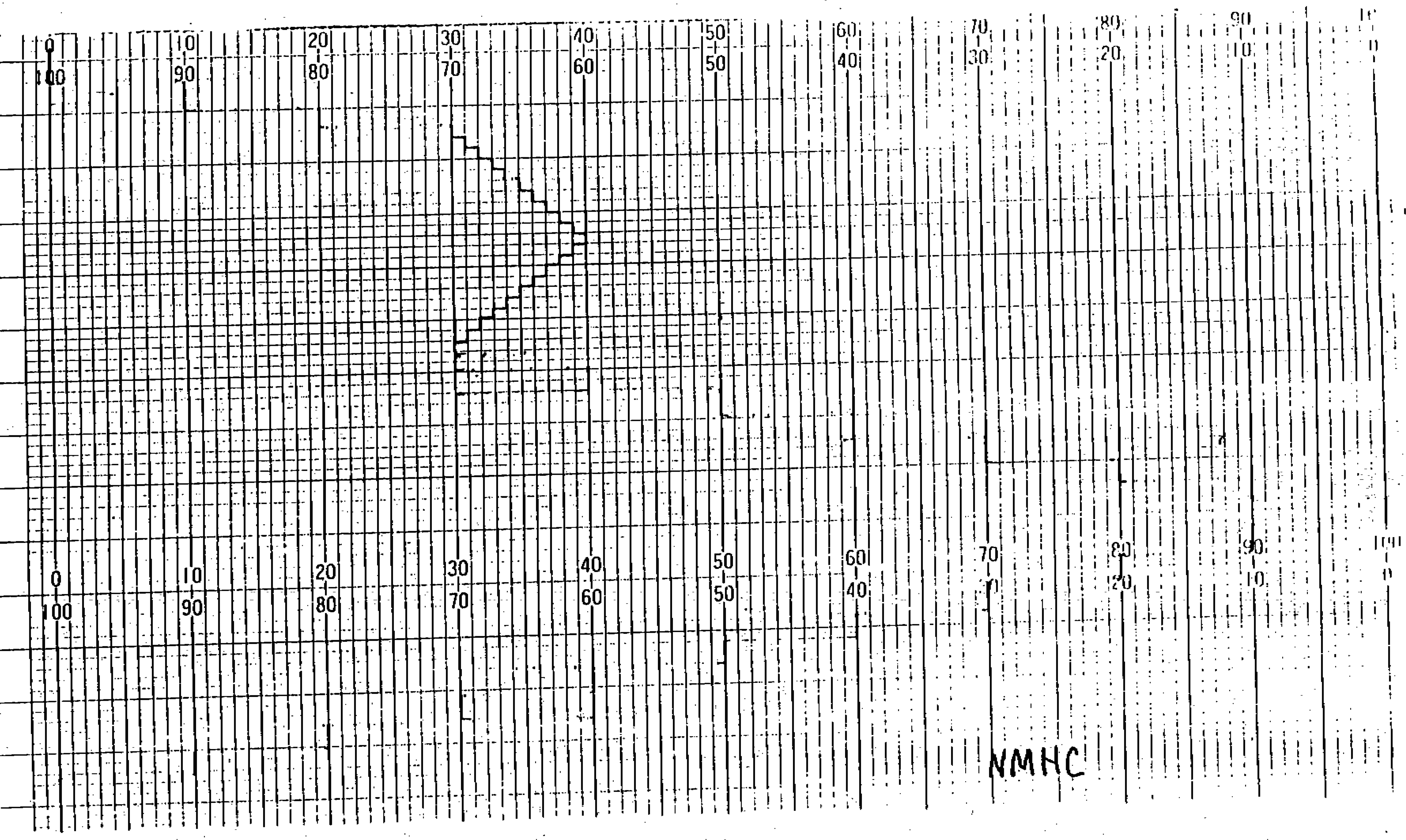


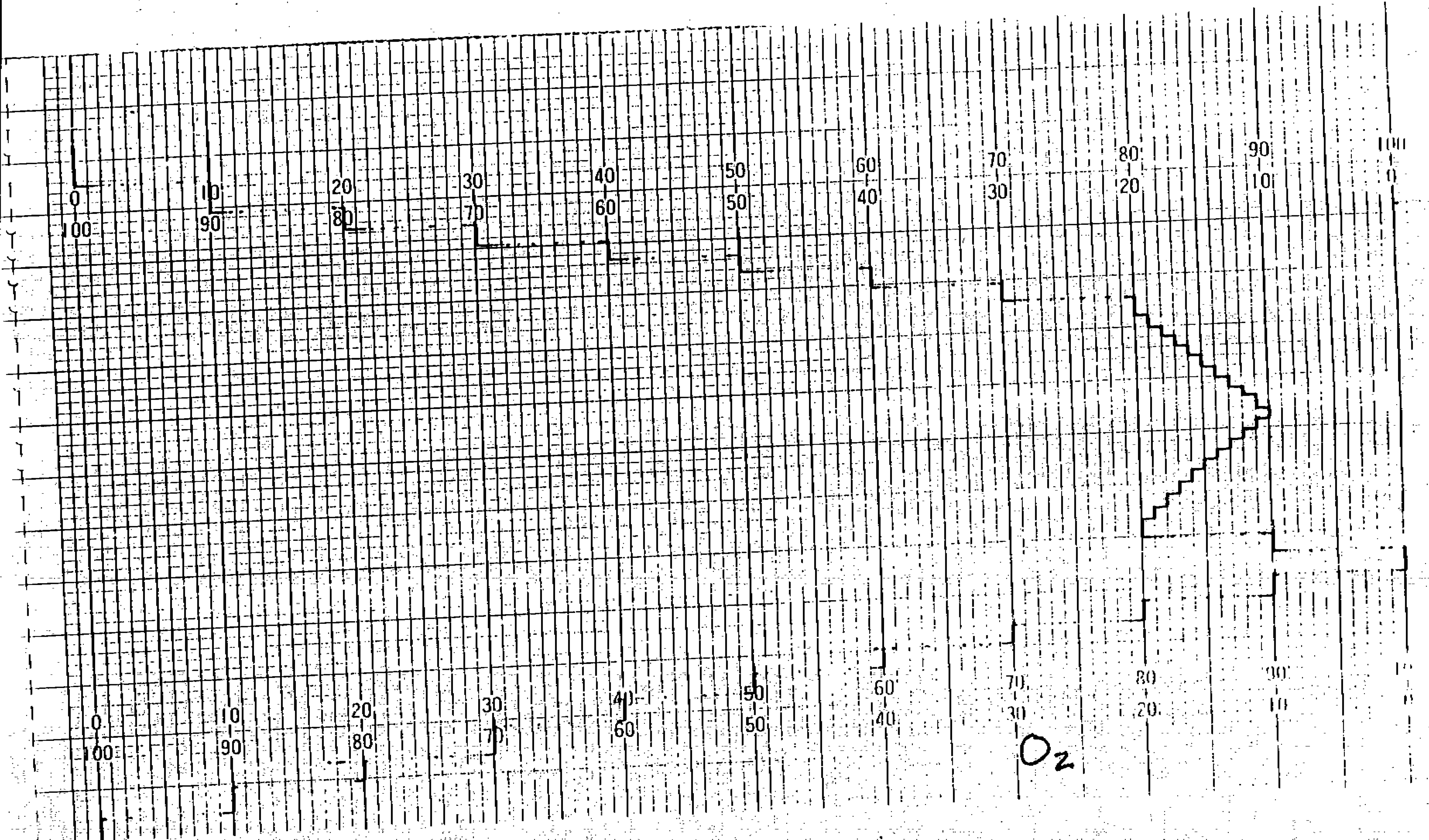
0 10 20 30 40 50 60 70 80 90 100
100 90 80 70 60 50 40 30 20 10 0
NO


0 100
10 90
20 80
30 70
40 60
50 50
60 40
70 30
80 20
90 10
THC

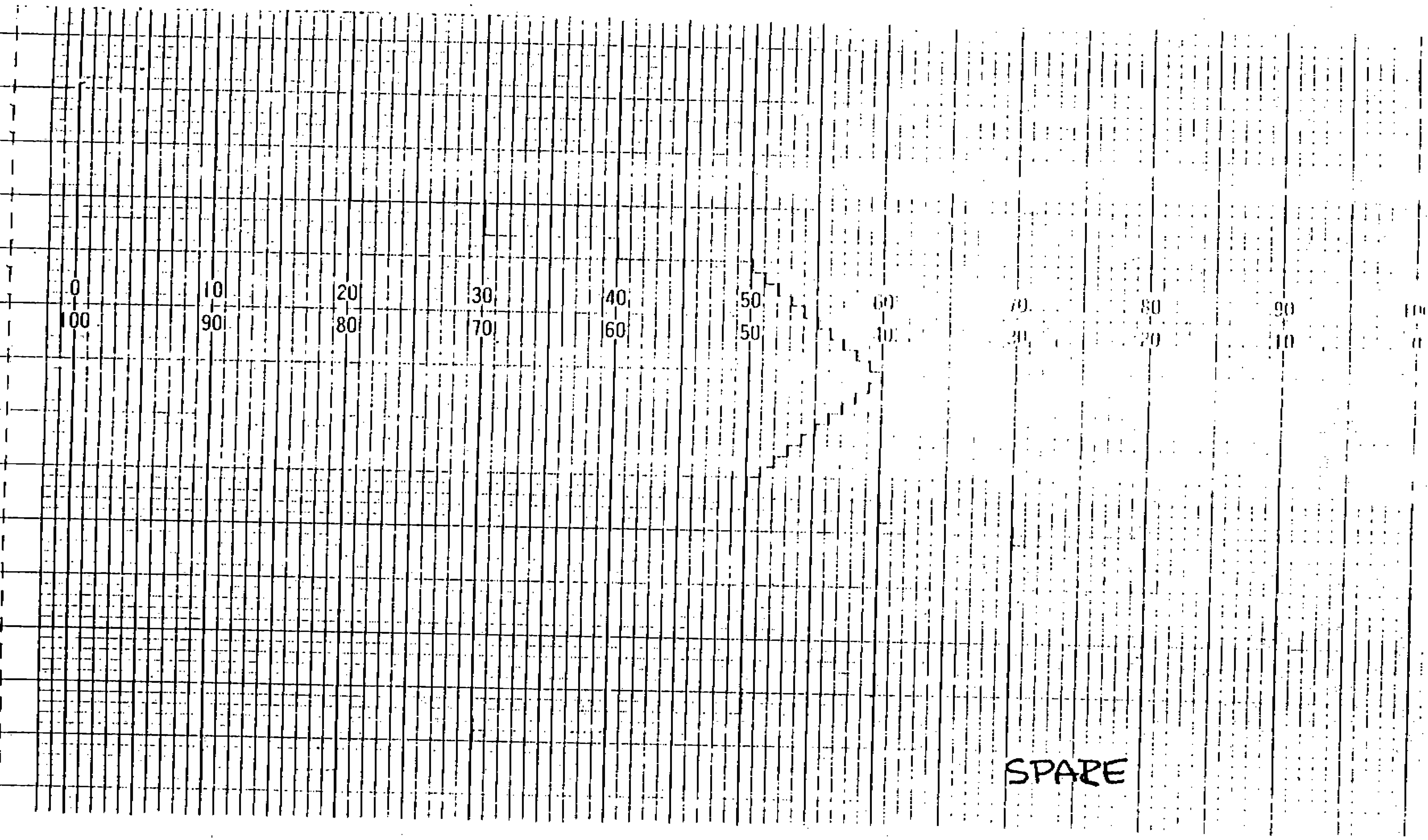


TRUCK CHART RECORDED
CO_2 / NMH / O_2 / SPARE
3-25-91
0
100
10
90
20
80
30
70
40
60
50
50
60
40
70
30
80
20
90
10
CO_2


NMHC



O2



SPARE

ROOTS DRESSER

ROOTS® PROVER DATA SHEET

DMF-184

LOCATION Cell 12 (Lab)
FIELD METER SIZE 11M
FIELD METER SERIAL 8512972

Calibration for trip to Rhode Island

ROOTS PROVER SERIAL 10M
OPERATOR JA
DATE 5-13-91

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	1057	-0.0	+0.4	99.7	100.1	99.9	87.4°F
		"	"	1081	-0.0	+0.5	99.8	100.3	99.7	
		"	"	1108	-0.0	+0.5	99.8	100.3	99.7	
		19	2500	2543	-0.1	+0.5	99.7	100.1	99.9	
		"	"	2524	-0.1	+0.5	99.7	100.1	99.9	
		"	"	2527	-0.1	+0.5	99.6	100.0	100.0	
		18	5000	5015	-0.3	+0.5	99.8	100.0	100.0	
		"	"	4945	-0.3	+0.4	99.9	100.0	100.0	
		"	"	4940	-0.3	+0.4	99.8	99.9	100.1	
		17	7500	7671	-0.6	+0.4	100.5	100.3	99.7	
		"	"	7671	-0.6	+0.3	100.5	100.2	99.8	
		"	"	7671	-0.6	+0.3	100.5	100.2	99.8	
		17	10,000	10009	-1.0	+0.3	101.1	100.4	99.6	
		"	"	10000	-1.0	+0.3	101.0	100.3	99.7	
		"	"	10100	-1.0	+0.3	101.0	100.3	99.7	

ANALYZER NOISE CHECK

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

Date: 4-30-91

Analysis Bench: TRUCK

Operator: Jeff Holmes

Analyzer: Co

Analyzer Serial No. 482W705

Analyzer Range: R-1 2500 PPm	Analyzer Range: R-3 5%
Span Gas Conc.: 2200	Span Gas Conc.: 4.5%
Bottle No.: 527884	Bottle No.: 58150
Analyzer PTP Response with Zero Gas. Chart Deflection: -.3 - -.1	Analyzer PTP Response with Zero Gas. Chart Deflection: 0
Analyzer PTP Response with Span Gas. Chart Deflection: 88.5 - 88.9	Analyzer PTP Response with Span Gas. Chart Deflection: 95.7 - 95.8
Noise: .6 % FSCD	Noise: .1 % FSCD
Analyzer Range: R-2 1%	Analyzer Range:
Span Gas Conc.: .85%	Span Gas Conc.:
Bottle No.: 56-[illegible]	Bottle No.:
Analyzer PTP Response with Zero Gas. Chart Deflection: 0-0	Analyzer PTP Response with Zero Gas. Chart Deflection:
Analyzer PTP Response with Span Gas. Chart Deflection: 84.0-84.1	Analyzer PTP Response with Span Gas. Chart Deflection:
Noise: .1 % FSCD	Noise: % FSCD

[illegible] VALVE O.K.

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: 4-30-91

Analysis Bench: TRUCK

Operator: Jeff Holmes

Analyzer: Co

Analyzer Serial No.: 4824705

Analyzer Range: 2500 PPM	Analyzer Range: 5%
Step Gas Conc.: 88.7 2200PPM	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: 3.2 sec.	Time to Respond to 95% of Step Gas: 3.3 sec.
Analyzer Gas Flow: 4 scfh	Analyzer Gas Flow: 4 scfh
Analyzer Range: 1%	Analyzer Range:
Step Gas Conc.: .85	Step Gas Conc.:
Chart Deflection for 95% of Step Gas: 75.6	Chart Deflection for 95% of Step Gas:
Time to Respond to 95% of Step Gas: 4.6 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: 5-1-91 Analysis Bench: 4

Operator: Jeff Holmes

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: 0 (% FSCD/30 SEC.)

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

Zero Drift: .3 % FSCD/HR.

Span Drift: .3 % FSCD/HR.

1. Zero and span analyzer on lowest range used.
2. Set chart speed at 10 cm/~~min.~~ 4-.
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"

10 cm/hr

NDIR WATER REJECTION RATIO CHECK

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

Date: 4-30-91 Analysis Bench: TRUCK

Operator: Jeff Holmes Barometer: 28.86 56/74

Analyzer: CO

Analyzer Range: 2500 PPM

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: 82.2 °F.
4. Record analyzer operating pressure: 4 In. H_2O, 14452 PSI (gage).
5. Record analyzer response to water/gas mixture: (.4) 9.2 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: .54093 psi.

AGP is the gage pressure (psi) + the barometer (psi): 14.32 psi.

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

W.C. 37,774.

7. Determine water rejection ratio using:

$$WRR = \frac{\text{Water Concentration}}{\text{Anal. Response in ppm}} = 4105$$

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 CO_2 REJECTION RATIO CHECK

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

Date: 5-1-91 Analysis Bench: 4

Operator: Jeff Holmes

Analyzer: CO Serial No.: 4824705

Analyzer Range: 2500 PPM

CO_2 Concentration: 15.2%

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: 25.3 ppm.

4. Calculate CO_2 rejection ratio using:

$$CO_2RR = \frac{CO_2 \text{ Conc. in ppm}}{\text{Anal. Resp. in ppm}} = \frac{152{,}000}{25.3} = 6008$$

5. Minimum CO_2RR CO analyzer - 5000.

6. Minimum CO_2RR NO analyzer - 30,000.

"Rev. 7/85

NDIR ANAL. CALIBRATION

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

DATE: 4-30-91 ANALYSIS BENCH: TRUCK OPERATOR: Jeff Holmes BAROMETER: 28.66 IN.HG

ANALYZER: CO ANALYZER SERIAL NO.: 4824705 WET BULB: 56 °F DRY BULB: 74 °F

Bottle No.:		Bottle No.: 527884		Bottle No.: S-03007		Bottle No.: 58150	
Analyzer Range:		Analyzer Range: 2500 PPM		Analyzer Range: 1%		Analyzer Range:	
Gas Concentration	Response (mv)	Gas Concentration	Response (mv) ovm	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)
		2200	88.7	.9500	96.8	4.5%	95.7
		1760	72.2	.76	81.6	3.6	85.9
		1320	55.0	.57	64.6	2.7	73.7
		880	37.3	.38	45.6	1.8	57.8
		440	18.8	.19	24.2	.9	35.6
		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.

"Rev. 7/85"

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/30/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 28.86 IN HG
DRY BULB: 74 F
WET BULB: 56 F

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

ANALYZER PERFORMANCE BASED UPON OLD REGRESSION DATA OF 9/25/90

OLD REGRESSION COEFFICIENTS

+2.31387E-002 +2.29295E+001 +1.87880E-002 -5.60654E-005 +9.27330E-007

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

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	% ERROR OF POINT	% ERROR OF FULL SCALE
88.7	2200.00	2199.96	-.00	-.00
72.2	1760.00	1757.57	-.14	-.10
55.0	1320.00	1317.14	-.22	-.11
37.3	880.00	880.32	.04	.01
19.8	440.00	437.49	-.57	-.10
0.0	0.00	.03	0.00	.00

PRECISION CHECK ANALYZER RESPONSES: 88.7 88.7 88.7
88.7 88.6 88.6 88.7 88.7 88.7 88.6

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

EMISSION INSTRUMENT CALIBRATION CHART

ANALYZER: NDIR CO 2500 PPM
DATE OF CALIBRATION REGRESSION: 9/25/90
DATE OF LATEST CALIBRATION CHECK: 4/30/91

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	608.33	51.0	1217.13	76.0	1857.51
1.5	34.46	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	1267.03	78.0	1910.55
3.5	80.51	28.5	668.09	53.5	1279.54	78.5	1923.85
4.0	92.04	29.0	680.07	54.0	1292.06	79.0	1937.18
4.5	103.59	29.5	692.06	54.5	1304.59	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	728.08	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	1367.45	82.0	2017.58
7.5	173.04	32.5	764.19	57.5	1380.07	82.5	2031.05
8.0	184.64	33.0	776.25	58.0	1392.69	83.0	2044.55
8.5	196.26	33.5	788.31	58.5	1405.33	83.5	2058.06
9.0	207.88	34.0	800.39	59.0	1417.99	84.0	2071.60
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	2098.74
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	2125.97
11.5	266.13	36.5	860.90	61.5	1481.47	86.5	2139.62
12.0	277.81	37.0	873.04	62.0	1494.21	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	2194.45
14.0	324.61	39.0	921.67	64.0	1545.33	89.0	2208.22
14.5	336.33	39.5	933.86	64.5	1558.14	89.5	2222.01
15.0	348.06	40.0	946.05	65.0	1570.98	90.0	2235.82
15.5	359.79	40.5	958.26	65.5	1583.82	90.5	2249.66
16.0	371.54	41.0	970.48	66.0	1596.69	91.0	2263.52
16.5	383.30	41.5	982.70	66.5	1609.57	91.5	2277.41
17.0	395.06	42.0	994.94	67.0	1622.46	92.0	2291.32
17.5	406.84	42.5	1007.19	67.5	1635.37	92.5	2305.26
18.0	418.62	43.0	1019.45	68.0	1648.30	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	1068.59	70.0	1700.18	95.0	2375.34
20.5	477.66	45.5	1080.91	70.5	1713.20	95.5	2389.43
21.0	489.49	46.0	1093.23	71.0	1726.22	96.0	2403.55
21.5	501.34	46.5	1105.57	71.5	1739.27	96.5	2417.70
22.0	513.19	47.0	1117.92	72.0	1752.34	97.0	2431.87
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	2474.56
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	2503.16
25.0	584.49	50.0	1192.26	75.0	1831.10	100.0	2517.51

M NDIR CO = +2.86387E-002 +(+2.29295E+001)*(AR)+(+1.87880E-002)*(AR^2)+
(-3.60354E-005)*(AR^3)+(+9.27506E-007)*(AR^4)

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/30/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 28.86 IN HG
DRY BULB: 74 F
WET BULB: 56 F

ANALYZER: NDIR CO
RANGE: 1%
CONCENTRATION & CYLINDER NUMBER: 9500 PPM / J-0300

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

OLD REGRESSION COEFFICIENTS

+2.40000E-002 +7.14846E+001 +2.61365E-001 -9.61423E-004 +1.14716E-0(

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
81.6	7600.00	7559.71	-.53	-.40
64.6	5700.00	5649.24	-.89	-.51
45.6	3800.00	3761.63	-1.01	-.39
24.2	1900.00	1873.33	-1.40	-.27
0.0	0.00	.02	0.00	.00

NEW REGRESSION MODEL DATE: 4/30/91

PPM NDIR CO = +6.48528E-002 +(+7.34547E+001)*(AR)+(+2.02937E-001)*(AR^2)+
(+1.09112E-004)*(AR^3)+(+4.42790E-006)*(AR^4)

ANALYZER ERROR TABLE
NEW REGRESSION DATA OF: 4/30/91

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	% ERROR OR POINT	% ERROR OF FULL SCALE
94.8	9500.00	9499.79	-.00	-.00
81.6	7600.00	7600.84	.01	.01
64.6	5700.00	5698.66	-.02	-.01
45.6	3800.00	3801.07	.03	.01
24.2	1900.00	1899.58	-.02	-.00
0.0	0.00	.06	0.00	.00

PRECISION CHECK ANALYZER RESPONSES: 94.2 94.2 94.2
; 94.2 94.2 94.1 94.1 94.1 94.1

NDIR CO RANGE PRECISION IS : +.14% OF FULL SCALE

EMISSION INSTRUMENT CALIBRATION CHART

ANALYZER: NDIR CO 1%
DATE OF CALIBRATION REGRESSION: 4/30/91
DATE OF LATEST CALIBRATION CHECK: 4/30/91

ANALYZER RESPONSE VERSUS CONCENTRATION

.5	36.84	25.5	2008.80	50.5	4269.92	75.5	6893.52
1.0	73.72	26.0	2051.01	51.0	4318.52	76.0	6950.41
1.5	110.70	26.5	2093.34	51.5	4367.27	76.5	7007.49
2.0	147.79	27.0	2135.78	52.0	4416.17	77.0	7064.76
2.5	184.97	27.5	2178.34	52.5	4465.21	77.5	7122.22
3.0	222.26	28.0	2221.02	53.0	4514.40	78.0	7179.88
3.5	259.65	28.5	2263.81	53.5	4563.73	78.5	7237.73
4.0	297.14	29.0	2306.71	54.0	4613.21	79.0	7295.78
4.5	334.73	29.5	2349.74	54.5	4662.85	79.5	7354.03
5.0	372.43	30.0	2392.88	55.0	4712.63	80.0	7412.47
5.5	410.23	30.5	2436.14	55.5	4762.56	80.5	7471.11
6.0	448.13	31.0	2479.52	56.0	4812.65	81.0	7529.96
6.5	486.13	31.5	2523.02	56.5	4862.88	81.5	7589.01
7.0	524.24	32.0	2566.64	57.0	4913.27	82.0	7648.26
7.5	562.45	32.5	2610.38	57.5	4963.82	82.5	7707.71
8.0	600.76	33.0	2654.24	58.0	5014.51	83.0	7767.37
8.5	639.18	33.5	2698.22	58.5	5065.37	83.5	7827.23
9.0	677.70	34.0	2742.33	59.0	5116.38	84.0	7887.31
9.5	716.33	34.5	2786.55	59.5	5167.55	84.5	7947.59
10.0	755.06	35.0	2830.90	60.0	5218.87	85.0	8008.08
10.5	793.89	35.5	2875.37	60.5	5270.36	85.5	8068.79
11.0	832.83	36.0	2919.97	61.0	5322.00	86.0	8129.70
11.5	871.88	36.5	2964.69	61.5	5373.81	86.5	8190.83
12.0	911.02	37.0	3009.53	62.0	5425.78	87.0	8252.18
12.5	950.28	37.5	3054.51	62.5	5477.91	87.5	8313.74
13.0	989.64	38.0	3099.60	63.0	5530.20	88.0	8375.52
13.5	1029.10	38.5	3144.83	63.5	5582.66	88.5	8437.52
14.0	1068.68	39.0	3190.18	64.0	5635.29	89.0	8499.74
14.5	1108.35	39.5	3235.66	64.5	5688.08	89.5	8562.17
15.0	1148.14	40.0	3281.27	65.0	5741.03	90.0	8624.84
15.5	1188.03	40.5	3327.01	65.5	5794.16	90.5	8687.72
16.0	1228.03	41.0	3372.88	66.0	5847.46	91.0	8750.83
16.5	1268.13	41.5	3418.88	66.5	5900.92	91.5	8814.17
17.0	1308.35	42.0	3465.00	67.0	5954.56	92.0	8877.73
17.5	1348.67	42.5	3511.27	67.5	6008.37	92.5	8941.53
18.0	1389.10	43.0	3557.66	68.0	6062.35	93.0	9005.55
18.5	1429.64	43.5	3604.19	68.5	6116.50	93.5	9069.81
19.0	1470.29	44.0	3650.85	69.0	6170.83	94.0	9134.29
19.5	1511.05	44.5	3697.64	69.5	6225.34	94.5	9199.02
20.0	1551.91	45.0	3744.57	70.0	6280.02	95.0	9263.97
20.5	1592.89	45.5	3791.64	70.5	6334.89	95.5	9329.17
21.0	1633.98	46.0	3838.84	71.0	6389.93	96.0	9394.60
21.5	1675.18	46.5	3886.18	71.5	6445.15	96.5	9460.28
22.0	1716.49	47.0	3933.66	72.0	6500.55	97.0	9526.19
22.5	1757.91	47.5	3981.27	72.5	6556.13	97.5	9592.35
23.0	1799.44	48.0	4029.03	73.0	6611.90	98.0	9658.75
23.5	1841.09	48.5	4076.92	73.5	6667.85	98.5	9725.39
24.0	1882.85	49.0	4124.96	74.0	6723.99	99.0	9792.28
24.5	1924.72	49.5	4173.14	74.5	6780.31	99.5	9859.42
25.0	1966.70	50.0	4221.46	75.0	6836.82	100.0	9926.81

NDIR CO = +5.48528E-002 +(+7.34547E+001)*(AR)+(+2.02937E-001)*(AR^2)+
(-1.09112E-004)*(AR^3)+(+4.42790E-006)*(AR^4)

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/30/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 28.86 IN HG
DRY BULB: 74 F
WET BULB: 56 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-00

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
85.9	3.60	3.59	-.41	-.30
73.7	2.70	2.68	-.82	-.45
57.8	1.80	1.78	-1.01	-.36
35.6	.90	.89	-1.15	-.21
0.0	0.00	.00	0.00	.00

NEW REGRESSION MODEL DATE: 4/30/91

% NDIR CO = +6.[illegible]E-006 +(+1.69837E-002)*(AR)+(+2.57204E-004)*(AR^2)+
(-1.43353E-006)*(AR^3)+(+2.11657E-008)*(AR^4)

ANALYZER ERROR TABLE
NEW REGRESSION DATA OF: 4/30/91

ANALYZER RESPONSE	ACTUAL %	PREDICTED %	% ERROR OR POINT	% ERROR OF FULL SCALE
95.7	4.50	4.50	-.00	-.00
85.9	3.60	3.60	.02	.01
73.7	2.70	2.70	-.02	-.01
57.8	1.80	1.80	.02	.01
35.6	.90	.90	-.01	-.00
0.0	0.00	.00	0.00	.00

RECISION CHECK ANALYZER RESPONSES: 95.7 95.7 95.6
3.7 95.7 95.6 95.5 95.7 95.3 95.7

A VZER RANGE PRECISION IS : +.[illegible]% OF FULL SCALE

EMISSION INSTRUMENT CALIBRATION CHART

ANALYZER: NDIR CO 5%

DATE OF CALIBRATION REGRESSION: 4/30/91

DATE OF LATEST CALIBRATION CHECK: 4/30/91

ANALYZER RESPONSE VERSUS CONCENTRATION

.5	.01	25.5	.59	50.5	1.47	75.5	2.82
1.0	.02	26.0	.60	51.0	1.49	76.0	2.85
1.5	.03	26.5	.61	51.5	1.51	76.5	2.89
2.0	.03	27.0	.63	52.0	1.53	77.0	2.92
2.5	.04	27.5	.64	52.5	1.55	77.5	2.96
3.0	.05	28.0	.66	53.0	1.58	78.0	2.99
3.5	.06	28.5	.67	53.5	1.60	78.5	3.03
4.0	.07	29.0	.69	54.0	1.62	79.0	3.06
4.5	.08	29.5	.70	54.5	1.64	79.5	3.10
5.0	.09	30.0	.72	55.0	1.67	80.0	3.14
5.5	.10	30.5	.73	55.5	1.69	80.5	3.17
6.0	.11	31.0	.75	56.0	1.71	81.0	3.21
6.5	.12	31.5	.77	56.5	1.74	81.5	3.25
7.0	.13	32.0	.78	57.0	1.76	82.0	3.29
7.5	.14	32.5	.80	57.5	1.79	82.5	3.33
8.0	.15	33.0	.81	58.0	1.81	83.0	3.37
8.5	.16	33.5	.83	58.5	1.83	83.5	3.41
9.0	.17	34.0	.85	59.0	1.86	84.0	3.45
9.5	.18	34.5	.86	59.5	1.88	84.5	3.49
10.0	.19	35.0	.88	60.0	1.91	85.0	3.53
10.5	.21	35.5	.90	60.5	1.94	85.5	3.57
11.0	.22	36.0	.91	61.0	1.96	86.0	3.61
11.5	.23	36.5	.93	61.5	1.99	86.5	3.65
12.0	.24	37.0	.95	62.0	2.01	87.0	3.69
12.5	.25	37.5	.96	62.5	2.04	87.5	3.74
13.0	.26	38.0	.98	63.0	2.07	88.0	3.78
13.5	.27	38.5	1.00	63.5	2.09	88.5	3.82
14.0	.29	39.0	1.02	64.0	2.12	89.0	3.87
14.5	.30	39.5	1.04	64.5	2.15	89.5	3.91
15.0	.31	40.0	1.05	65.0	2.17	90.0	3.96
15.5	.32	40.5	1.07	65.5	2.20	90.5	4.00
16.0	.33	41.0	1.09	66.0	2.23	91.0	4.05
16.5	.35	41.5	1.11	66.5	2.26	91.5	4.09
17.0	.36	42.0	1.13	67.0	2.29	92.0	4.14
17.5	.37	42.5	1.15	67.5	2.32	92.5	4.19
18.0	.38	43.0	1.16	68.0	2.35	93.0	4.23
18.5	.40	43.5	1.18	68.5	2.38	93.5	4.28
19.0	.41	44.0	1.20	69.0	2.41	94.0	4.33
19.5	.42	44.5	1.22	69.5	2.44	94.5	4.38
20.0	.43	45.0	1.24	70.0	2.47	95.0	4.43
20.5	.45	45.5	1.26	70.5	2.50	95.5	4.48
21.0	.46	46.0	1.28	71.0	2.53	96.0	4.53
21.5	.47	46.5	1.30	71.5	2.56	96.5	4.58
22.0	.49	47.0	1.32	72.0	2.59	97.0	4.63
22.5	.50	47.5	1.34	72.5	2.62	97.5	4.68
23.0	.52	48.0	1.36	73.0	2.65	98.0	4.74
23.5	.53	48.5	1.38	73.5	2.69	98.5	4.79
24.0	.54	49.0	1.40	74.0	2.72	99.0	4.84
24.5	.56	49.5	1.42	74.5	2.75	99.5	4.90
25.0	.57	50.0	1.45	75.0	2.79	100.0	4.95

NDIR CO = +6.27263E-006 +(+1.69837E-002)*(AR)+(+2.57204E-004)*(AR^2)+(-1.43353E-006)*(AR^3)+(+2.11657E-008)*(AR^4)

ANALYZER PRE[illegible]ON CHECK

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

DATE: 4-30-91 ANALYSIS BENCH: TRUCK OPERATOR: Jeff Holmes

ANALYZER: CO ANALYZER SERIAL NO.: 4824705

Analyzer Range:		Analyzer Range: 2500 PPM		Analyzer Range: 1%		USED WRONG SPAN VALUE. PUT O.K. Analyzer Range: 5%	
Span Gas Conc.:		Span Gas Conc.: 2200 PPM		Span Gas Conc.: .85		Span Gas Conc.: 4.5%	
Span Point: mv		Span Point: 88.7 mv		Span Point: 84.2 mv		Span Point: 95.7 mv	
Bottle No.:		Bottle No.: 527884		Bottle No.: SG-1397		Bottle No.: 58150	
Test No.	Response (mv)	Test No.	Response (mv) OFF OF DUM	Test No.	Response (mv)	Test No.	Response (mv)
1		1	88.7	1	84.2	1	95.7
2		2	88.7	2	84.2	2	95.7
3		3	88.7	3	84.2	3	95.6
4		4	88.7	4	84.1	4	95.7
5		5	88.6	5	84.2	5	95.7
6		6	88.6	6	84.2	6	95.6
7		7	88.7	7	84.1	7	95.6
8		8	88.7	8	84.1	8	95.7
9		9	88.7	9	84.1	9	95.8
10		10	88.6	10	84.1	10	95.7

1. Zero and span analyzer 10 times. (Do not readjust zero and span after initial 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"

ANALYZER NOISE CHECK

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

Date: 4-24-91

Analysis Bench: TRUCK

Operator: Jeff Holmes

Analyzer: FID HC

Analyzer Serial No. 4812902

Analyzer Range: 1000 PPM

Span Gas Conc.: 90.9 303 PPM

Bottle No.: N-340880

Analyzer PTP Response with Zero Gas.
Chart Deflection: 90.8 - 90.8

Analyzer PTP Response with Span Gas.
Chart Deflection: 0.0 - 0.0

Noise: 0 % FSCD

Analyzer Range: 3000 PPM

Span Gas Conc.: 88.7 (887 PPM)

Bottle No.: 72131

Analyzer PTP Response with Zero Gas.
Chart Deflection: 88.6 - 88.6

Analyzer PTP Response with Span Gas.
Chart Deflection: 0.0 - 0.0

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

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: 4-24-91 Analysis Bench: TRUCK

Operator: Jeff Holmes

Analyzer: FID HC Analyzer Serial No.: 4812908

Analyzer Range: 1000 PPM | Analyzer Range: 3000 PPM

Step Gas Conc.: 303 | Step Gas Conc.: 887

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: 3.0 sec. | Time to Respond to 95% of Step Gas: 3.0 sec.

Analyzer Gas Flow: 4 scfh | Analyzer Gas Flow: 4 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: 5-1-91 Analysis Bench: 4

Operator: Jeff Holmes

Analyzer: HC

Analyzer Serial No.: 4812908

Analyzer Range: 1000 PPM

Zero Gas: X N_2 ___ Zero Air

Span Gas Bottle No.: N-340886

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

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

Zero Drift: .2 % FSCD/HR.

Span Drift: .2 % 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"

HYDROCARBON ANALYZER O_2 INTERFERENCE

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

Date: 4-24-91 Analyzer Bench: 4 (TRUCK)

Operator: Jeff Holmes

Analyzer Serial No.: 4812908

Type of Sampling: ___ Diesel ___ Gasoline X Gaseous

FID Temperature: 390 °F Fuel Bottle No.: S 92188

Regulator Air Press: 6 psi Burner Air Bottle No.: CC 89030

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.

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

(FSCD = Full Scale Chart Deflection)

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

FUEL PRESS. (kg/cm^2)	AIR PRESS. (kg/cm^2)	BY-PASS PRESS.	FSCD A	FSCD B_5	FSCD B_{10}	$ARPPM_5$	$ARPPM_{10}$	$\%O_2I_5$	$\%O_2I_{10}$
.79	.78	6 PSI	94.3	89.1	90.0	891.2	900.2	-2.27	-.41

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: 4-25-91 ANALYSIS BENCH: TRUCK OPERATOR: Jeff Holmes BAROMETER: 29.22 IN.HG.

ANALYZER: FID ANALYZER SERIAL NO.: 4812908 WET BULB: 55 °F DRY BULB: 77 °F.

PRESSURES: FID FUEL: .79 KG/CM^2 FID AIR: .78 KG/CM^2 FID REG. AIR: .2 KG/CM^2

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

Analyzer Range:		Analyzer Range: 1000 PPM		Analyzer Range: 3000 PPM		Analyzer Range:	
Bottle No.:		Bottle No.: N-340880		Bottle No.: 72131		Bottle No.:	
Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)
	100% →	909	90.9	2661 (88.7)	88.7		
	80% →	727 (72.7)	72.5	2128.8 (70.9)	70.8		
	60% →	545 (54.5)	54.2	1596.6 (53.2)	52.9		
	40% →	363.6 (36.4)	35.9	1064.4 (35.5)	35.2		
	20% →	181.8 (18.2)	17.8	532.2 (17.7)	17.5		
	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

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/25/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 29.22 IN HG
DRY BULB: 77 F
WET BULB: 55 F

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

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

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

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	PERCENT LINEARITY
90.9	909.00	911.72	-.27
72.5	727.00	727.17	-.02
54.2	545.00	543.62	.14
35.9	363.60	360.07	.35
17.8	181.80	178.53	.33
0.0	0.00	0.00	0.00

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE: 4/25/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 29.22 IN HG
DRY BULB: 77 F
WET BULB: 55 F

ANALYZER: FID
RANGE: 3000 PPM
CONCENTRATION & CYLINDER NUMBER: 887/72131

PRECISION CHECK ANALYZER RESPONSES: 88.7 88.7 88.7
88.7 88.6 88.6 88.7 88.6 88.6 88.6

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

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE*	ACTUAL PPM	PREDICTED PPM	PERCENT LINEARITY
88.7	2661.00	2667.54	-.22
70.8	2128.80	2129.22	-.01
52.9	1596.60	1590.90	.19
35.2	1064.40	1058.59	.19
17.5	532.20	526.29	.20
0.0	0.00	0.00	0.00

ANALYZER PRL ION CHECK

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

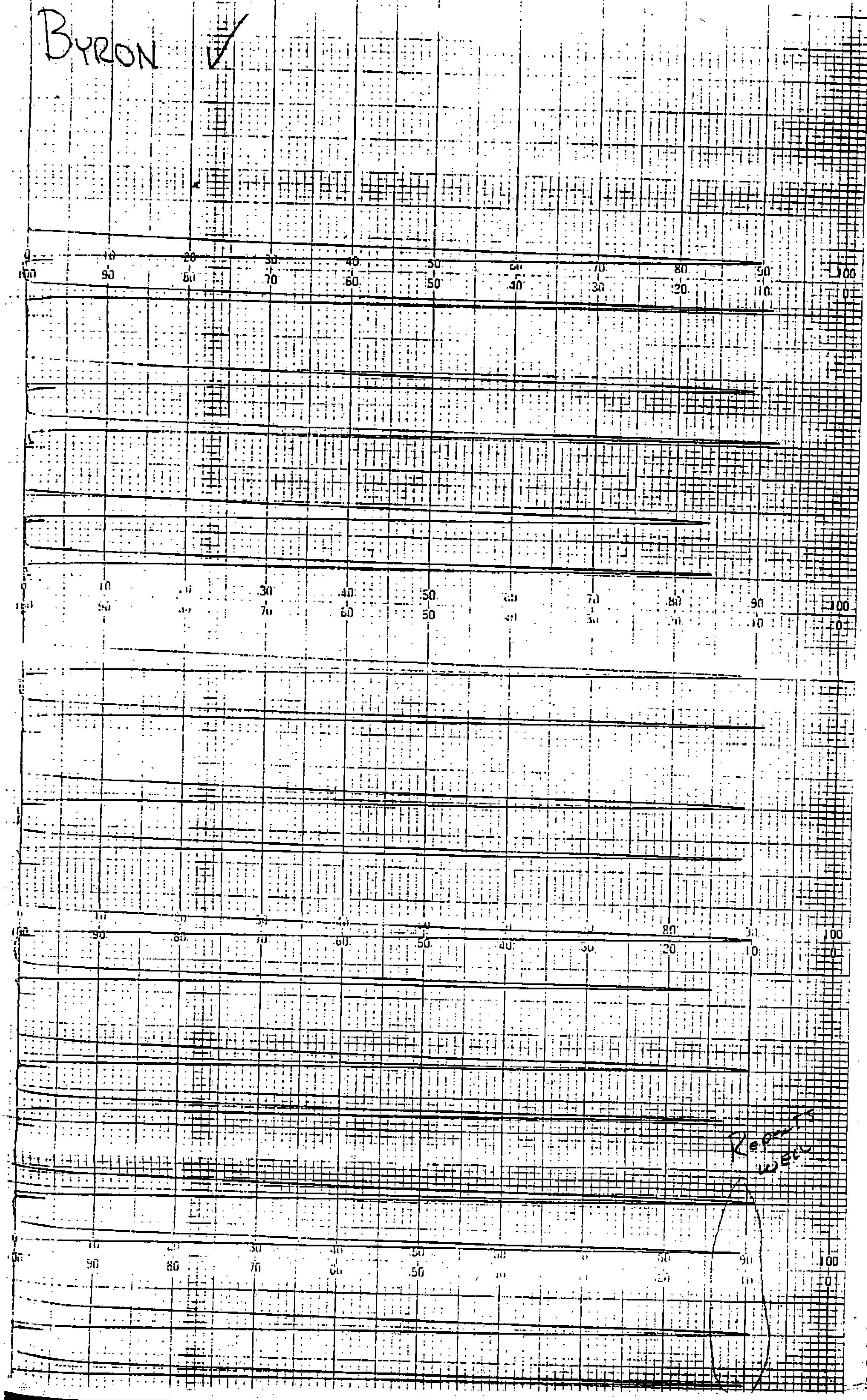
DATE: 4-24-91 ANALYSIS BENCH: TRUCK OPERATOR: Jeff Holmes

ANALYZER: FID ANALYZER SERIAL NO.: 4812908

Analyzer Range:		Analyzer Range: 1000 PPM		Analyzer Range: 3000		Analyzer Range:	
Span Gas Conc.:		Span Gas Conc.: 303		Span Gas Conc.: 887		Span Gas Conc.:	
Span Point: mv		Span Point: 90.9 mv		Span Point: 88.7 mv		Span Point: mv	
Bottle No.:		Bottle No.: N-340880		Bottle No.: 72131		Bottle No.:	
Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)	Test No.	Response (mv)
1		1	90.9	1	88.7	1	
2		2	90.9	2	88.7	2	
3		3	90.9	3	88.7	3	
4		4	90.8	4	88.7	4	
5		5	90.9	5	88.6	5	
6		6	90.9	6	88.6	6	
7		7	90.8	7	88.7	7	
8		8	90.8	8	88.6	8	
9		9	90.8	9	88.6	9	
10		10	90.8	10	88.6	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"


BYRON
Repeats well

ANALYZER NOISE CHECK

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

Date: 4-29-91

Analysis Bench: TRUCK

Operator: Jess Holmes

Analyzer: NDIR - CO_2

Analyzer Serial No. 48498112

Analyzer Range: R-3 11%

Span Gas Conc.: 15.2%

Bottle No.: 421806

Analyzer PTP Response with Zero Gas.
Chart Deflection: 0.0 - 0.0

Analyzer PTP Response with Span Gas.
Chart Deflection: 91.[illegible] - 91.[illegible]

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: 4-29-91

Analysis Bench: TRUCK

Operator: Jeff Holmes

Analyzer: NDIR CO_2

Analyzer Serial No.: 48498112

Analyzer Range: R-3 16%	Analyzer Range:
Step Gas Conc.: 15.2% = 97.0	Step Gas Conc.:
Chart Deflection for 95% of Step Gas: 93.3	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: 4 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.

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ANALYZER ZERO AND SPAN DRIFT

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

Date: 5-1-91 Analysis Bench: 4

Operator: Jeff Holmes

Analyzer: CO_2

Analyzer Serial No.: 48498112

Analyzer Range: 16%

Zero Gas: ✓ 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: .2 % FSCD/HR.

Span Drift: .2 % FSCD/HR.

1. Zero and span analyzer on lowest range used.
2. Set chart speed at 10 ~~cm/min.~~ 4 m.
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: 4-29-91 Analysis Bench: TRUCK

Operator: Jeff Holmes Barometer: 28.80

Analyzer: NDIR CO_2

Analyzer Range: R-3 16% CO_2

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: 72.2 °F.
4. Record analyzer operating pressure: 4 In. H_2O, .14452 PSI (gage).
5. Record analyzer response to water/gas mixture: .2 dum 240 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: .38840 psi.

AGP is the gage pressure (psi) + the barometer (psi): 14.29108 psi.

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

W.C. 27,181.

7. Determine water rejection ratio using:

$$WRR = \frac{\text{Water Concentration}}{\text{Anal. Response in ppm}} = 113.25417$$

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 ANALY[illegible] CALIBRATION

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

DATE: 4-29-91 ANALYSIS BENCH: TRUCK OPERATOR: Jeff Holmes BAROMETER: 28.[illegible] IN.HG

ANALYZER: CO2 ANALYZER SERIAL NO.: [illegible] WET BULB: 65 °F DRY BULB: [illegible] °F

Bottle No.:		Bottle No.: 42/80[illegible]		Bottle No.:		Bottle No.:	
Analyzer Range:		Analyzer Range: 16%		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	81.4				
		9.12	64.1				
		6.08	44.9				
		3.04	23.8				
		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"

ANALYZER NOISE CHECK

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

Date: 4-18-91

Analysis Bench: TRUCH

Operator: Jeff Holmes

Analyzer: CHEMI

Analyzer Serial No. 10AR2-13640-140

Analyzer Range: 250

Span Gas Conc.: 246

Bottle No.: CC-89049

Analyzer PTP Response with Zero Gas.
Chart Deflection: 0

Analyzer PTP Response with Span Gas.
Chart Deflection: .4

Noise: .41% % FSCD

Analyzer Range: 2500

Span Gas Conc.: 2407

Bottle No.: CC-49806

Analyzer PTP Response with Zero Gas.
Chart Deflection: 0

Analyzer PTP Response with Span Gas.
Chart Deflection: .1

Noise: .1 % FSCD

Analyzer Range: 1000

Span Gas Conc.: 963

Bottle No.: CC-49793

Analyzer PTP Response with Zero Gas.
Chart Deflection: 0

Analyzer PTP Response with Span Gas.
Chart Deflection: 933-934

Noise: .10 % FSCD

Analyzer Range: 10000

Span Gas Conc.: 9539

Bottle No.: CC-49803

Analyzer PTP Response with Zero Gas.
Chart Deflection: 0

Analyzer PTP Response with Span Gas.
Chart Deflection: 0

Noise: 0 % 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: 4-18-91

Analysis Bench: TRUCK

Operator: Jeff Holmes

Analyzer: CHEMI

Analyzer Serial No.: 10AR-13640-140

Analyzer Range: 250	Analyzer Range: 2500
Step Gas Conc.: 246	Step Gas Conc.: 2409
Chart Deflection for 95% of Step Gas: 93.5	Chart Deflection for 95% of Step Gas: 91.6
Time to Respond to 95% of Step Gas: 12.2 sec.	Time to Respond to 95% of Step Gas: 11.6 sec.
Analyzer Gas Flow: BY-PASS 2.4 scfh	Analyzer Gas Flow: 2.4 scfh
Analyzer Range: 1000	Analyzer Range: 10000
Step Gas Conc.: 963	Step Gas Conc.: 9539
Chart Deflection for 95% of Step Gas: 91.5	Chart Deflection for 95% of Step Gas: 90.6
Time to Respond to 95% of Step Gas: 11.0 sec.	Time to Respond to 95% of Step Gas: 11.2 sec.
Analyzer Gas Flow: 2.4 scfh	Analyzer Gas Flow: 2.4 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: 5-1-91 Analysis Bench: 4

Operator: Jeff Holmes

Analyzer: NO

Analyzer Serial No.: 10AR-13640-140

Analyzer Range: 250 PPM

Zero Gas: X N_2 ___ Zero Air

Span Gas Bottle No.: CC 89049

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

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

Zero Drift: .2 % FSCD/HR.

Span Drift: .1 % FSCD/HR.

1. Zero and span analyzer on lowest range used.
2. Set chart speed at 10 ~~cm/min.~~ 4-.
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: 4-20-91 Analysis Bench: TRUCK

Operator: Jeff Holmes Barometer: 29.18 In. Hg.

Wet Bulb: 55 °F. Dry Bulb: 75 °F.

Analyzer Serial No.: 10AR-13640-140

Analyzer Range: 250 PPM

CO_2 Cal. Gas Conc.: 15.2% NO Cal. Gas Conc.: 246

Bottle No.: 421806 Bottle No.: CC-89049

CO_2 Anal. Response: 9.12% ppm

Blend Ratio $= \dfrac{CO_2\ AR}{CO_2\ \text{Gas Conc.}} =$ .600

Calculated NO Conc. = NO Cal. Gas Conc. X (1 - Blend Ratio) = 98.4 ppm

Chemi. Anal. Response: 97.5 ppm

% Response Difference $= \dfrac{\text{Calculated NO Conc.} - \text{Chemi AR}}{\text{Full Scale NO Conc.}}$ X 100 = .36 %

$\dfrac{98.4 - 97.5}{250}$

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: 4/22/91 Bench No.: TRUCK

Operator: Jeff Holmes

NO Analyzer Range: 250 Converter Temp: 392°F

NO Bottle Conc: 246 O_2 Bottle Conc.: 99

NO Bottle No.: CC89049

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.

Step	DVM	PPM
4. With NO_X generator "POWER" switch OFF, zero and span the analyzer (analyzer is now in "NO" mode). Record NO reading.	98.4	246
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.	88.6	221.5

7. Turn on the NO_X generator "POWER" switch.
8. Adjust "OZONE BYPASS" to about 1 scfh.

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. 19.7 49.3

10. Switch the bench to the "NO_X" mode (NO_X converter NOT bypassed), and measure total NO_X; record this value. 25.3 213.3

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. 87.6 219

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:

$$\text{efficiency} = 1 + \frac{10 - 11}{6 - 9} \times 100 = \underline{96.7\%}$$

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

See HORIBA NO_X generator manual.

$$1 + \frac{213.3 - 219}{221.5 - 49.3} \times 100 = \boxed{96.7\%}$$

ANALYZER LINEARITY CHECK

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

DATE: 4-20-91 ANALYSIS BENCH: TRUCK OPERATOR: Jeff Holmes BAROMETER: 29.18 IN.HG.

ANALYZER: CHEMI (NO-NOx) ANALYZER SERIAL NO.: 10AR-13640-140 WET BULB: 55 °F DRY BULB: 75 °F.

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

REGULATOR AIR: — PSI [redacted] BYPASS: 2.4 SCFH ~~BENCH MANIFOLD~~: —

Analyzer Range: 250			Analyzer Range: 1000			Analyzer Range: 2500			Analyzer Range: 10,000			
Bottle No.: CC-890419			Bottle No.: CC-49793			Bottle No.: CC-49806			Bottle No.: CC-49803			
Gas Concentration	Response (mv)		Gas Concentration	Response (mv)		Gas Concentration	Response (mv)		Gas Concentration	Response (mv)		Rerun
246	98.4	98.4	963	96.3	96.3	2409	96.4	96.4	9539	95.4	95.4	93.5
196.8	78.7	79.1	770.4	77.0	77.4	1927.2	77.1	77.2	7631.2	76.3	75.9	75.9
147.6	59.0	59.5	577.8	57.8	58.1	1445.4	57.8	57.8	5723.4	57.2	56.3	56.1
98.4	39.4	39.8	385.2	38.5	38.8	963.6	38.5	38.4	3815.6	38.2	37.2	37.2
49.2	19.7	20.0	192.6	19.3	19.4	481.8	19.3	19.0	1907.8	19.1	18.4	11.3
0	0	0	0	0	0	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. 1 cm/min
5. Repeat Steps 1-4 for each range used.

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/18/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 29.18 IN HG
DRY BULB: 75 F
WET BULB: 55 F

ANALYZER: CHEMI
RANGE: 250 PPM
CONCENTRATION & CYLINDER NUMBER: 246 / CC-89049

PRECISION CHECK ANALYZER RESPONSES: 98.5 98.6 98.6
98.5 98.6 98.7 98.7 98.7 98.8 98.8

ANALYZER RANGE PRECISION IS : +.24% OF FULL SCALE

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	PERCENT LINEARITY
98.4	246.00	245.07	.37
79.1	196.80	197.00	-.08
59.5	147.60	148.19	-.24
39.8	98.40	99.12	-.29
20.0	49.20	49.81	-.25
0.0	0.00	0.00	0.00

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/18/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 29.18 IN HG
DRY BULB: 75 F
WET BULB: 55 F

ANALYZER: CHEMI
RANGE: 1000 PPM
CONCENTRATION & CYLINDER NUMBER: 963 / CC-49793

PRECISION CHECK ANALYZER RESPONSES: 96.3 96.3 96.4
96.4 96.5 96.4 96.5 96.6 96.5 96.6

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

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	PERCENT LINEARITY
96.3	963.00	960.18	.28
77.4	770.40	771.74	-.13
58.1	577.80	579.30	-.15
38.8	385.20	386.86	-.17
19.4	192.60	193.43	-.08
0.0	0.00	0.00	0.00

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/18/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 29.18 IN HG
DRY BULB: 75 F
WET BULB: 55 F

ANALYZER: CHEMI
RANGE: 2500 PPM
CONCENTRATION & CYLINDER NUMBER: 2409 / CC-49806

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

ANALYZER RANGE PRECISION IS : +.24% OF FULL SCALE

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	PERCENT LINEARITY
96.4	2409.00	2409.90	-.04
77.2	1927.20	1929.92	-.11
57.8	1445.40	1444.94	.02
38.4	963.60	959.96	.15
19.0	481.80	474.98	.27
0.0	0.00	0.00	0.00

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/18/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 29.18 IN HG
DRY BULB: 75 F
WET BULB: 55 F

ANALYZER: CHEMI
RANGE: 10000 PP
CONCENTRATION & CYLINDER NUMBER: 9539 / CC-49803

PRECISION CHECK ANALYZER RESPONSES: 95.4 95.5 95.5
95.5 95.5 95.4 95.4 95.2 95.2 95.2

ANALYZER RANGE PRECISION IS : +.33% OF FULL SCALE

ANALYZER RANGE LINEARITY CHECK

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	PERCENT LINEARITY
95.4	9539.00	9603.24	-.64
75.9	7631.20	7640.31	-.09
56.3	5723.40	5667.32	.56
37.2	3815.60	3744.66	.70
18.4	1907.80	1852.20	.55
0.0	0.00	0.00	0.00

ANALYZER PRE...ON CHECK

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

DATE: 4-18-91 ANALYSIS BENCH: TRUCK OPERATOR: Jeff Holmes

ANALYZER: CHEMI ANALYZER SERIAL NO.: 10AR-B640-140

Analyzer Range: 250
Span Gas Conc.: 246
Span Point: 98.4 mv
Bottle No.: CC-89049

	Test No.	Response (mv)
	1	98.4
1	2	98.5 reset slightly
2	3	98.6
3	4	98.6
4	5	98.6
5	6	98.6
6	7	98.7
7	8	98.7
8	9	98.7
9	10	98.8
10		98.8

Analyzer Range: 1000
Span Gas Conc.: 963
Span Point: 96.3 mv
Bottle No.: CC-49793

Test No.	Response (mv)
1	96.3
2	96.3
3	96.4
4	96.4
5	96.5
6	96.4
7	96.5
8	96.6
9	96.5
10	96.6

Analyzer Range: 2500
Span Gas Conc.: 2409
Span Point: 96.4 mv
Bottle No.: CC-49806

Test No.	Response (mv)
1	96.4
2	96.4
3	96.4
4	96.4
5	96.3
6	96.3
7	96.2
8	96.2
9	96.2
10	96.2

Analyzer Range: 10000
Span Gas Conc.: 9539
Span Point: 95.4 mv
Bottle No.: CC-49803

Test No.	Response (mv)
1	95.4
2	95.5
3	95.5
4	95.5
5	95.5
6	95.4
7	95.4
8	95.2
9	95.2
10	95.2

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. 20 CM/HR

"Rev. 4/85"

ANALYZER NOISE CHECK

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

Date: 4-30-91

Analysis Bench: TRUCK

Operator: Jeff Holmes

Analyzer: Co

Analyzer Serial No. 482 4705

Analyzer Range: R-1 2500 PPM

Span Gas Conc.: 2200

Bottle No.: 527884

Analyzer PTP Response with Zero Gas.
Chart Deflection: -.3 – -.1

Analyzer PTP Response with Span Gas.
Chart Deflection: 88.5 - 88.9

Noise: .6 % FSCD

Analyzer Range: R-3 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: 95.7 - 95.8

Noise: .1 % FSCD

[illegible]
WRONG
[illegible] VALUE
BUT O.K.

Analyzer Range: R-2 1%

Span Gas Conc.: .85%

Bottle No.: 56-[illegible]

Analyzer PTP Response with Zero Gas.
Chart Deflection: 0-0

Analyzer PTP Response with Span Gas.
Chart Deflection: 84.0-84.1

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: 4-30-91

Analysis Bench: TRUCK

Operator: Jeff Haimes

Analyzer: Co

Analyzer Serial No.: 4824705

Analyzer Range: 2500 PPM	Analyzer Range: 5%
Step Gas Conc.: 88.7 2200PPM	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: 3.2 sec.	Time to Respond to 95% of Step Gas: 3.3 sec.
Analyzer Gas Flow: 4 scfh	Analyzer Gas Flow: 4 scfh
Analyzer Range: 1%	Analyzer Range:
Step Gas Conc.: .85	Step Gas Conc.:
Chart Deflection for 95% of Step Gas: 75.6	Chart Deflection for 95% of Step Gas:
Time to Respond to 95% of Step Gas: 4.6 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: 5-1-91 Analysis Bench: 4

Operator: Jeff Holmes

Analyzer: CO

Analyzer Serial No.: 4824705

Analyzer Range: 2500 PPM

Zero Gas: ✓ N_2 ___ Zero Air

Span Gas Bottle No.: 527884

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

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

Zero Drift: .3 % FSCD/HR.

Span Drift: .3 % 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"

1cm/hr

NDIR WATER REJECTION RATIO CHECK

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

Date: 4-30-91 Analysis Bench: TRUCK

Operator: Jeff Holmes Barometer: 28.86 56/74

Analyzer: CO

Analyzer Range: 2500 PPM

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: 82.2 °F.
4. Record analyzer operating pressure: 4 In. H_2O, 14452 PSI (gage).
5. Record analyzer response to water/gas mixture: (.4) 9.2 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: .54093 psi.

AGP is the gage pressure (psi) + the barometer (psi): 14.32 psi.

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

W.C. 37,774.

7. Determine water rejection ratio using:

$$\text{WRR} = \frac{\text{Water Concentration}}{\text{Anal. Response in ppm}} = 4105$$

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 CO_2 REJECTION RATIO CHECK

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

Date: 5-1-91 Analysis Bench: 4

Operator: Jeff Holmes

Analyzer: CO Serial No.: 4824705

Analyzer Range: 2500 PPM

CO_2 Concentration: 15.2%

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: 25.3 ppm.

4. Calculate CO_2 rejection ratio using:

$$CO_2RR = \frac{CO_2 \text{ Conc. in ppm}}{\text{Anal. Resp. in ppm}} = \frac{152{,}000}{25.3} = 6008$$

5. Minimum CO_2RR CO analyzer - 5000.

6. Minimum CO_2RR NO analyzer - 30,000.

"Rev. 7/85"

[illegible] CALIBRATION

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

DATE: 4-30-91 ANALYSIS BENCH: TRUCK OPERATOR: [illegible] BAROMETER: 28.66 IN.HG

ANALYZER: CO ANALYZER SERIAL NO.: 4824705 WET BULB: 56 °F DRY BULB: 74 °F

Bottle No.:		Bottle No.: 527884		Bottle No.: S-03007		Bottle No.: 58150	
Analyzer Range:		Analyzer Range: 2500 PPM		Analyzer Range: 1%		Analyzer Range: [illegible]	
Gas Concentration	Response (mv)	Gas Concentration	Response (mv) ppm	Gas Concentration	Response (mv)	Gas Concentration	Response (mv)
		2200	88.7	.9500	96.8	4.5%	95.7
		1760	72.2	.76	81.6	3.6	85.9
		1320	55.0	.57	64.6	2.7	73.7
		880	37.3	.38	45.6	1.8	57.8
		440	18.8	.19	24.2	.9	35.6
		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.

"Rev. 7/85"

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/30/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 28.86 IN HG
DRY BULB: 74 F
WET BULB: 56 F

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

ANALYZER PERFORMANCE BASED UPON OLD REGRESSION DATA OF 9/25/90

OLD REGRESSION COEFFICIENTS

+2.86387E-002 +2.29295E+001 +1.87880E-002 -5.60854E-005 +9.27330E-007

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

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	% ERROR OF POINT	% ERROR OF FULL SCALE
88.7	2200.00	2199.96	-.00	-.00
72.2	1760.00	1757.57	-.14	-.10
55.0	1320.00	1317.14	-.22	-.11
37.3	880.00	880.32	.04	.01
18.8	440.00	437.49	-.57	-.10
0.0	0.00	.03	0.00	.00

PRECISION CHECK ANALYZER RESPONSES: 88.7 88.7 88.7
88.7 88.6 88.6 88.7 88.7 88.7 88.6

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

EMISSION INSTRUMENT CALIBRATION CHART

ANALYZER: NDIR CO 2500 PPM
DATE OF CALIBRATION REGRESSION: 9/25/90
DATE OF LATEST CALIBRATION CHECK: 4/30/91

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	608.33	51.0	1217.13	76.0	1857.51
1.5	34.46	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	1267.03	78.0	1910.55
3.5	80.51	28.5	668.09	53.5	1279.54	78.5	1923.85
4.0	92.04	29.0	680.07	54.0	1292.06	79.0	1937.18
4.5	103.59	29.5	692.06	54.5	1304.59	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	728.08	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	1367.45	82.0	2017.58
7.5	173.04	32.5	764.19	57.5	1380.07	82.5	2031.05
8.0	184.64	33.0	776.25	58.0	1392.69	83.0	2044.55
8.5	196.26	33.5	788.31	58.5	1405.33	83.5	2058.06
9.0	207.88	34.0	800.39	59.0	1417.99	84.0	2071.60
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	2098.74
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	2125.97
11.5	266.13	36.5	860.90	61.5	1481.47	86.5	2139.62
12.0	277.81	37.0	873.04	62.0	1494.21	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	2194.45
14.0	324.61	39.0	921.67	64.0	1545.33	89.0	2208.22
14.5	336.33	39.5	933.86	64.5	1558.14	89.5	2222.01
15.0	348.06	40.0	946.05	65.0	1570.98	90.0	2235.82
15.5	359.79	40.5	958.26	65.5	1583.82	90.5	2249.66
16.0	371.54	41.0	970.48	66.0	1596.69	91.0	2263.52
16.5	383.30	41.5	982.70	66.5	1609.57	91.5	2277.41
17.0	395.06	42.0	994.94	67.0	1622.46	92.0	2291.32
17.5	406.84	42.5	1007.19	67.5	1635.37	92.5	2305.26
18.0	418.62	43.0	1019.45	68.0	1648.30	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	1068.59	70.0	1700.18	95.0	2375.34
20.5	477.66	45.5	1080.91	70.5	1713.20	95.5	2389.43
21.0	489.49	46.0	1093.23	71.0	1726.22	96.0	2403.55
21.5	501.34	46.5	1105.57	71.5	1739.27	96.5	2417.70
22.0	513.19	47.0	1117.92	72.0	1752.34	97.0	2431.87
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	2474.56
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	2503.16
25.0	584.49	50.0	1192.26	75.0	1831.10	100.0	2517.51

```
NDIR CO = +2.86387E-002 +(+2.29295E+001)*(AR)+(+1.87380E-003)*(AR^2)+
(-5.60354E-005)*(AR^3)+(+9.27370E-007)*(AR^4)
```

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/30/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 28.86 IN HG
DRY BULB: 74 F
WET BULB: 56 F

ANALYZER: NDIR CO
RANGE: 1%
CONCENTRATION & CYLINDER NUMBER: 9500 PPM / J-0300

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-00

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
81.6	7600.00	7559.71	-.53	-.40
64.6	5700.00	5649.24	-.89	-.51
45.6	3800.00	3761.63	-1.01	-.39
24.2	1900.00	1873.33	-1.40	-.27
0.0	0.00	.02	0.00	.00

NEW REGRESSION MODEL DATE: 4/30/91

PPM NDIR CO = +6.48528E-002 +(+7.34547E+001)*(AR)+(+2.02937E-001)*(AR^2)+
(+1.09112E-004)*(AR^3)+(+4.42790E-006)*(AR^4)

ANALYZER ERROR TABLE
NEW REGRESSION DATA OF: 4/30/91

ANALYZER RESPONSE	ACTUAL PPM	PREDICTED PPM	% ERROR OR POINT	% ERROR OF FULL SCALE
94.8	9500.00	9499.79	-.00	-.00
81.6	7600.00	7600.84	.01	.01
64.6	5700.00	5698.66	-.02	-.01
45.6	3800.00	3801.07	.03	.01
24.2	1900.00	1899.58	-.02	-.00
0.0	0.00	.06	0.00	.00

PRECISION CHECK ANALYZER RESPONSES: 84.2 84.2 84.2
1 84.2 84.2 84.1 84.1 84.1 84.1

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

EMISSION INSTRUMENT CALIBRATION CHART

ANALYZER: NDIR CO 1%
DATE OF CALIBRATION REGRESSION: 4/30/91
DATE OF LATEST CALIBRATION CHECK: 4/30/91

ANALYZER RESPONSE VERSUS CONCENTRATION

.5	36.84	25.5	2008.80	50.5	4269.92	75.5	6893.52
1.0	73.72	26.0	2051.01	51.0	4318.52	76.0	6950.41
1.5	110.70	26.5	2093.34	51.5	4367.27	76.5	7007.49
2.0	147.79	27.0	2135.78	52.0	4416.17	77.0	7064.76
2.5	184.97	27.5	2178.34	52.5	4465.21	77.5	7122.22
3.0	222.26	28.0	2221.02	53.0	4514.40	78.0	7179.88
3.5	259.65	28.5	2263.81	53.5	4563.73	78.5	7237.73
4.0	297.14	29.0	2306.71	54.0	4613.21	79.0	7295.78
4.5	334.73	29.5	2349.74	54.5	4662.85	79.5	7354.03
5.0	372.43	30.0	2392.88	55.0	4712.63	80.0	7412.47
5.5	410.23	30.5	2436.14	55.5	4762.56	80.5	7471.11
6.0	448.13	31.0	2479.52	56.0	4812.65	81.0	7529.96
6.5	486.13	31.5	2523.02	56.5	4862.88	81.5	7589.01
7.0	524.24	32.0	2566.64	57.0	4913.27	82.0	7648.26
7.5	562.45	32.5	2610.38	57.5	4963.82	82.5	7707.71
8.0	600.76	33.0	2654.24	58.0	5014.51	83.0	7767.37
8.5	639.18	33.5	2698.22	58.5	5065.37	83.5	7827.23
9.0	677.70	34.0	2742.33	59.0	5116.38	84.0	7887.31
9.5	716.33	34.5	2786.55	59.5	5167.55	84.5	7947.59
10.0	755.06	35.0	2830.90	60.0	5218.87	85.0	8008.08
10.5	793.89	35.5	2875.37	60.5	5270.36	85.5	8068.79
11.0	832.83	36.0	2919.97	61.0	5322.00	86.0	8129.70
11.5	871.88	36.5	2964.69	61.5	5373.81	86.5	8190.83
12.0	911.02	37.0	3009.53	62.0	5425.78	87.0	8252.18
12.5	950.28	37.5	3054.51	62.5	5477.91	87.5	8313.74
13.0	989.64	38.0	3099.60	63.0	5530.20	88.0	8375.52
13.5	1029.10	38.5	3144.83	63.5	5582.66	88.5	8437.52
14.0	1068.68	39.0	3190.18	64.0	5635.29	89.0	8499.74
14.5	1108.35	39.5	3235.66	64.5	5688.08	89.5	8562.17
15.0	1148.14	40.0	3281.27	65.0	5741.03	90.0	8624.84
15.5	1188.03	40.5	3327.01	65.5	5794.16	90.5	8687.72
16.0	1228.03	41.0	3372.88	66.0	5847.46	91.0	8750.83
16.5	1268.13	41.5	3418.88	66.5	5900.92	91.5	8814.17
17.0	1308.35	42.0	3465.00	67.0	5954.56	92.0	8877.73
17.5	1348.67	42.5	3511.27	67.5	6008.37	92.5	8941.53
18.0	1389.10	43.0	3557.66	68.0	6062.35	93.0	9005.55
18.5	1429.64	43.5	3604.19	68.5	6116.50	93.5	9069.81
19.0	1470.29	44.0	3650.85	69.0	6170.83	94.0	9134.29
19.5	1511.05	44.5	3697.64	69.5	6225.34	94.5	9199.02
20.0	1551.91	45.0	3744.57	70.0	6280.02	95.0	9263.97
20.5	1592.89	45.5	3791.64	70.5	6334.89	95.5	9329.17
21.0	1633.98	46.0	3838.84	71.0	6389.93	96.0	9394.60
21.5	1675.18	46.5	3886.18	71.5	6445.15	96.5	9460.28
22.0	1716.49	47.0	3933.66	72.0	6500.55	97.0	9526.19
22.5	1757.91	47.5	3981.27	72.5	6556.13	97.5	9592.35
23.0	1799.44	48.0	4029.03	73.0	6611.90	98.0	9658.75
23.5	1841.09	48.5	4076.92	73.5	6667.85	98.5	9725.39
24.0	1882.85	49.0	4124.96	74.0	6723.99	99.0	9792.28
24.5	1924.72	49.5	4173.14	74.5	6780.31	99.5	9859.42
25.0	1966.70	50.0	4221.46	75.0	6836.82	100.0	9926.81

NDIR CO = +5.48528E-002 +(+7.34547E+001)*(AR)+(-2.02937E-001)*(AR^2)+
(-[illegible]9112E-004)*(AR^3)+(+4.42790E-006)*(AR^4)

EMISSION ANALYZER CALIBRATION

CALIBRATION DATE:4/30/91

BENCH: 4
OPERATOR'S INITIALS: JEH
BAROMETER: 28.86 IN HG
DRY BULB: 74 F
WET BULB: 56 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 +1.63862E-002 +2.79306E-004 -1.93603E-006 +2.46785E-0

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
85.9	3.60	3.59	-.41	-.30
73.7	2.70	2.68	-.82	-.45
57.8	1.80	1.78	-1.01	-.36
35.6	.90	.89	-1.15	-.21
0.0	0.00	.00	0.00	.00

NEW REGRESSION MODEL DATE: 4/30/91

% NDIR CO = +6.[illegible]7263E-006 +(+1.69837E-002)*(AR)+(+2.57204E-004)*(AR^2)+
(-1.43353E-006)*(AR^3)+(+2.11657E-008)*(AR^4)

ANALYZER ERROR TABLE
NEW REGRESSION DATA OF: 4/30/91

ANALYZER RESPONSE	ACTUAL %	PREDICTED %	% ERROR OR POINT	% ERROR OF FULL SCALE
95.7	4.50	4.50	-.00	-.00
85.9	3.60	3.60	.02	.01
73.7	2.70	2.70	-.02	-.01
57.8	1.80	1.80	.02	.01
35.6	.90	.90	-.01	-.00
0.0	0.00	.00	0.00	.00

PRECISION CHECK ANALYZER RESPONSES: 95.7 95.7 95.6
95.7 95.7 95.6 95.6 95.7 95.3 95.7

A[illegible]YZER RANGE PRECISION IS : +.32% OF FULL SCALE

EMISSION INSTRUMENT CALIBRATION CHART

ANALYZER: NDIR CO 5%
DATE OF CALIBRATION REGRESSION: 4/30/91
DATE OF LATEST CALIBRATION CHECK: 4/30/91

ANALYZER RESPONSE VERSUS CONCENTRATION

.5	.01	25.5	.59	50.5	1.47	75.5	2.82
1.0	.02	26.0	.60	51.0	1.49	76.0	2.85
1.5	.03	26.5	.61	51.5	1.51	76.5	2.89
2.0	.03	27.0	.63	52.0	1.53	77.0	2.92
2.5	.04	27.5	.64	52.5	1.55	77.5	2.96
3.0	.05	28.0	.66	53.0	1.58	78.0	2.99
3.5	.06	28.5	.67	53.5	1.60	78.5	3.03
4.0	.07	29.0	.69	54.0	1.62	79.0	3.06
4.5	.08	29.5	.70	54.5	1.64	79.5	3.10
5.0	.09	30.0	.72	55.0	1.67	80.0	3.14
5.5	.10	30.5	.73	55.5	1.69	80.5	3.17
6.0	.11	31.0	.75	56.0	1.71	81.0	3.21
6.5	.12	31.5	.77	56.5	1.74	81.5	3.25
7.0	.13	32.0	.78	57.0	1.76	82.0	3.29
7.5	.14	32.5	.80	57.5	1.79	82.5	3.33
8.0	.15	33.0	.81	58.0	1.81	83.0	3.37
8.5	.16	33.5	.83	58.5	1.83	83.5	3.41
9.0	.17	34.0	.85	59.0	1.86	84.0	3.45
9.5	.18	34.5	.86	59.5	1.88	84.5	3.49
10.0	.19	35.0	.88	60.0	1.91	85.0	3.53
10.5	.21	35.5	.90	60.5	1.94	85.5	3.57
11.0	.22	36.0	.91	61.0	1.96	86.0	3.61
11.5	.23	36.5	.93	61.5	1.99	86.5	3.65
12.0	.24	37.0	.95	62.0	2.01	87.0	3.69
12.5	.25	37.5	.96	62.5	2.04	87.5	3.74
13.0	.26	38.0	.98	63.0	2.07	88.0	3.78
13.5	.27	38.5	1.00	63.5	2.09	88.5	3.82
14.0	.29	39.0	1.02	64.0	2.12	89.0	3.87
14.5	.30	39.5	1.04	64.5	2.15	89.5	3.91
15.0	.31	40.0	1.05	65.0	2.17	90.0	3.96
15.5	.32	40.5	1.07	65.5	2.20	90.5	4.00
16.0	.33	41.0	1.09	66.0	2.23	91.0	4.05
16.5	.35	41.5	1.11	66.5	2.26	91.5	4.09
17.0	.36	42.0	1.13	67.0	2.29	92.0	4.14
17.5	.37	42.5	1.15	67.5	2.32	92.5	4.19
18.0	.38	43.0	1.16	68.0	2.35	93.0	4.23
18.5	.40	43.5	1.18	68.5	2.38	93.5	4.28
19.0	.41	44.0	1.20	69.0	2.41	94.0	4.33
19.5	.42	44.5	1.22	69.5	2.44	94.5	4.38
20.0	.43	45.0	1.24	70.0	2.47	95.0	4.43
20.5	.45	45.5	1.26	70.5	2.50	95.5	4.48
21.0	.46	46.0	1.28	71.0	2.53	96.0	4.53
21.5	.47	46.5	1.30	71.5	2.56	96.5	4.58
22.0	.49	47.0	1.32	72.0	2.59	97.0	4.63
22.5	.50	47.5	1.34	72.5	2.62	97.5	4.68
23.0	.52	48.0	1.36	73.0	2.65	98.0	4.74
23.5	.53	48.5	1.38	73.5	2.69	98.5	4.79
24.0	.54	49.0	1.40	74.0	2.72	99.0	4.84
24.5	.56	49.5	1.42	74.5	2.75	99.5	4.90
25.0	.57	50.0	1.45	75.0	2.79	100.0	4.95

NDIR CO = +6.27263E-006 +(+1.69837E-002)*(AR)+(+2.57204E-004)*(AR^2)+
(-1.43353E-006)*(AR^3)+(+2.11657E-008)*(AR^4)

ANALYZER PREC...ION CHECK

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

DATE: 4-30-91 ANALYSIS BENCH: TRUCK OPERATOR: Jeff Holmes

ANALYZER: CO ANALYZER SERIAL NO.: 4824705

USED WRONG SPAN VALUE. PUT O.K.

Analyzer Range:		Analyzer Range:	2500 PPM	Analyzer Range:	1%	Analyzer Range:	5%
Span Gas Conc.:		Span Gas Conc.:	2200 PPM	Span Gas Conc.:	.85	Span Gas Conc.:	4.5%
Span Point:	mv	Span Point:	88.7 mv	Span Point:	84.2 mv	Span Point:	95.7 mv
Bottle No.:		Bottle No.:	527884	Bottle No.:	SG-1372	Bottle No.:	58150
Test No.	Response (mv)	Test No.	Response (mv) OFF OF DUM	Test No.	Response (mv)	Test No.	Response (mv)
1		1	88.7	1	84.2	1	95.7
2		2	88.7	2	84.2	2	95.7
3		3	88.7	3	84.2	3	95.6
4		4	88.7	4	84.1	4	95.7
5		5	88.6	5	84.2	5	95.7
6		6	88.6	6	84.2	6	95.6
7		7	88.7	7	84.1	7	95.6
8		8	88.7	8	84.1	8	95.7
9		9	88.7	9	84.1	9	95.8
10		10	88.6	10	84.1	10	95.7

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"

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***** GAS FUEL ANALYSIS *****
*** WITH ASTM CORRECTIONS ***

N MOLE FRACTIONS:

   CH4: 0.5400                                      N2: 0.0510
  C2H6: 0.0000          C2H4: 0.0000                O2: 0.0008
  C3H8: 0.0000          C3H6: 0.0000               AIR: 0.0000
IC4H10: 0.0000            H2: 0.0012               CO2: 0.4060
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: 0.0004
 C7H16: 0.0000

THE SUM OF THE FUEL MOLE FRACTIONS IS 0.99940

THE APPARENT FUEL MOLECULAR WEIGHT IS 28.03941

*******************************************************************
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           40.651 %
THE TOTAL FUEL HYDROGEN PERCENTAGE IS          7.798 %
THE FUEL OXYGEN PERCENTAGE IS                 46.452 %
THE FUEL NITROGEN PERCENTAGE IS                5.098 %
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 23.249 %
THE BURNABLE HYDROGEN PERCENTAGE IS  7.798 %

THE ATOMIC HYDROGEN/CARBON RATIO OF THE BURNABLE FUEL FRACTION IS  3.997

THE STOICHIOMETRIC SPINDT AFR IS  5.35:1 BY MASS.

THE UNSATURATED HIGH HEATING VALUE IS  549.6 BTU/FT3
THE UNSATURATED LOW HEATING VALUE IS  494.8 BTU/FT3
THE SATURATED LOW HEATING VALUE IS  486.1 BTU/FT3

THE FUEL SPECIFIC GRAVITY IS  .9701
THE FUEL DENSITY IS  .0742 LB/FT3
THE MOTOR OCTANE NUMBER OF THE FUEL IS 119.7
THE IDEAL STOICHIOMETRIC FLAME TEMPERATURE IS 3586 DEG F.
```

Received: 06/12/91

IGT_ANALYTICAL REPORT
Results by Sample

Work Order # 91-06-031

"PLE ID Rhode Island Gas Sample #3 FRACTION 03A TEST CODE GAS1 NAME GAS ANALYSIS
Date & Time Collected 06/06/91 Category

COMPONENT	MOLE%	D. L.	WEIGHT%
Helium	ND		
Hydrogen	0.12	0.01	0.01
Oxygen & Argon	0.08	0.01	0.09
Nitrogen	5.10	0.01	5.09
Carbon Dioxide	40.6	0.01	63.8
Methane	54.0	0.03	30.9
Ethane	BDL	0.01	
Propane	BDL	0.01	
i-Butane	BDL	0.01	
n-Butane	BDL	0.01	
neo-Pentane	BDL	0.01	
i-Pentane	BDL	0.01	
n-Pentane	BDL	0.01	
C-6 & Heavier	0.04	0.01	0.11
Hydrogen sulfide	ND		
Total	100.0		100.0

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

Specific Gravity : 0.970
Compressibility [z] : 0.9974

Gross Heating Value (BTU/SCF)		Net Heating Value (BTU/SCF)	
-- dry -- :	550	-- dry -- :	495
-- sat. -- :	541	-- sat. -- :	487

Analyst : Jeff Lander

NOTES: BDL = below detection limit (D.L.) 0.01 mole% if not specified
ND = Component not determined by this analysis

***** GAS FUEL ANALYSIS *****
*** WITH ASTM CORRECTIONS ***

EL COMPOSITION IN MOLE FRACTIONS:

CH4:	0.5400			N2:	0.0484
C2H6:	0.0000	C2H4:	0.0000	O2:	0.0010
C3H8:	0.0000	C3H6:	0.0000	AIR:	0.0000
IC4H10:	0.0000	H2:	0.0008	CO2:	0.4090
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:	0.0005				
C7H16:	0.0000				

THE SUM OF THE FUEL MOLE FRACTIONS IS 0.99970

THE APPARENT FUEL MOLECULAR WEIGHT IS 28.10441

****
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 40.698 %
THE TOTAL FUEL HYDROGEN PERCENTAGE IS 7.780 %
THE FUEL OXYGEN PERCENTAGE IS 46.695 %
THE FUEL NITROGEN PERCENTAGE IS 4.826 %
E FUEL SULFUR PERCENTAGE IS 0.000 %
E 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 23.213 %
THE BURNABLE HYDROGEN PERCENTAGE IS 7.780 %

THE ATOMIC HYDROGEN/CARBON RATIO OF THE BURNABLE FUEL FRACTION IS 3.994

THE STOICHIOMETRIC SPINDT AFR IS 5.34:1 BY MASS.

THE UNSATURATED HIGH HEATING VALUE IS 550.0 BTU/FT3
THE UNSATURATED LOW HEATING VALUE IS 495.1 BTU/FT3
THE SATURATED LOW HEATING VALUE IS 486.5 BTU/FT3

THE FUEL SPECIFIC GRAVITY IS .9724
THE FUEL DENSITY IS .0744 LB/FT3
THE MOTOR OCTANE NUMBER OF THE FUEL IS 119.7
E IDEAL STOICHIOMETRIC FLAME TEMPERATURE IS 3585 DEG F.

Page 3 IGT ANALYTICAL REPORT Work Order # 91-06-031
Received: 06/12/91 Results by Sample

MPLE ID Rhode Island Gas Sample #2 FRACTION 02A TEST CODE GAS1 NAME GAS ANALYSIS
Date & Time Collected 06/05/91 Category

COMPONENT	MOLE%	D. L.	WEIGHT%
Helium	ND		
Hydrogen	0.08	0.01	0.01
Oxygen & Argon	0.10	0.01	0.11
Nitrogen	4.84	0.01	4.82
Carbon Dioxide	40.9	0.01	64.1
Methane	54.0	0.05	30.8
Ethane	BDL	0.01	
Propane	BDL	0.01	
i-Butane	BDL	0.01	
n-Butane	BDL	0.01	
neo-Pentane	BDL	0.01	
i-Pentane	BDL	0.01	
n-Pentane	BDL	0.01	
C-6 & Heavier	0.05	0.01	0.15
Hydrogen sulfide	ND		
Total	100.0		100.0

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

Specific Gravity : 0.972
Compressibility [Z] : 0.9974

Gross Heating Value (BTU/SCF)		Net Heating Value (BTU/SCF)	
-- dry -- :	551	-- dry -- :	496
-- sat.-- :	541	-- sat.-- :	487

Analyst : Jeff Lander

NOTES: BDL = below detection limit (D.L.) 0.01 mole% if not specified
ND = Component not determined by this analysis

***** GAS FUEL ANALYSIS *****
*** WITH ASTM CORRECTIONS ***

"EL COMPOSITION IN MOLE FRACTIONS:

CH4:	0.5520			N2:	0.0329
C2H6:	0.0000	C2H4:	0.0000	O2:	0.0005
C3H8:	0.0000	C3H6:	0.0000	AIR:	0.0000
IC4H10:	0.0000	H2:	0.0013	CO2:	0.4130
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:	0.0002				
C7H16:	0.0000				

THE SUM OF THE FUEL MOLE FRACTIONS IS 0.99990

THE APPARENT FUEL MOLECULAR WEIGHT IS 27.99224

****
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 41.463 %
THE TOTAL FUEL HYDROGEN PERCENTAGE IS 7.971 %
THE FUEL OXYGEN PERCENTAGE IS 47.273 %
THE FUEL NITROGEN PERCENTAGE IS 3.293 %
: FUEL SULFUR PERCENTAGE IS 0.000 %
.E 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 23.740 %
THE BURNABLE HYDROGEN PERCENTAGE IS 7.971 %

THE ATOMIC HYDROGEN/CARBON RATIO OF THE BURNABLE FUEL FRACTION IS 4.001

THE STOICHIOMETRIC SPINDT AFR IS 5.46:1 BY MASS.

THE UNSATURATED HIGH HEATING VALUE IS 560.9 BTU/FT3
THE UNSATURATED LOW HEATING VALUE IS 504.9 BTU/FT3
THE SATURATED LOW HEATING VALUE IS 496.1 BTU/FT3

THE FUEL SPECIFIC GRAVITY IS .9686
THE FUEL DENSITY IS .0741 LB/FT3
THE MOTOR OCTANE NUMBER OF THE FUEL IS 119.7
: IDEAL STOICHIOMETRIC FLAME TEMPERATURE IS 3594 DEG F.

PLE ID Rhode Island Gas sample #1 FRACTION 01A TEST CODE GAS1 NAME GAS ANALYSIS
Date & Time Collected 06/04/91 Category ________

COMPONENT	MOLE%	D. L.	WEIGHT%
Helium	ND		
Hydrogen	0.13	0.01	0.01
Oxygen & Argon	0.05	0.01	0.05
Nitrogen	3.29	0.01	3.29
Carbon Dioxide	41.3	0.01	65.0
Methane	55.2	0.02	31.6
Ethane	BDL	0.01	
Propane	BDL	0.01	
i-Butane	BDL	0.01	
n-Butane	BDL	0.01	
neo-Pentane	BDL	0.01	
i-Pentane	BDL	0.01	
n-Pentane	BDL	0.01	
C-6 & Heavier	0.02	0.01	0.06
Hydrogen sulfide	ND		
Total	100.0		100.0

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

Specific Gravity : 0.989
Compressibility [z] : 0.9974

Gross Heating Value (BTU/SCF)		Net Heating Value (BTU/SCF)	
-- dry -- :	561	-- dry -- :	506
-- sat.-- :	552	-- sat.-- :	497

Analyst : Jeff Lander

NOTES: BDL = below detection limit (D.L.) 0.01 mole% if not specified
ND = Component not determined by this analysis

Received: 06/12/91 06/24/91 08:45:12

REPORT TO: Waukesha Engine Division
Dresser Industries, Inc.
1000 West Saint Paul Avenue
Waukesha, WI, 53188-4999
ATTEN Mr. Bob Alyea

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 3
COMPANY Waukesha Engine Division
FACILITY Dresser Industries, Inc.
Waukesha, WI, 53188-4999

(For additional information, phone the CONTACT above.)
NEITHER IGT NOR ANY PERSON ACTING ON BEHALF OF IGT ASSUMES ANY LIABILITY WITH RESPECT TO THE USE OF, OR FOR DAMAGES RESULTING FROM THE USE OF, ANY INFORMATION PRESENTED IN THIS REPORT.

WORK ID Rhode Island Gas Samples
TAKEN
TRANS
TYPE
P.O. # J251382
INVOICE under separate cover

FAX a copy of the reports to Bob Alyea at 414-549-2590!

SAMPLE IDENTIFICATION
01 Rhode Island Gas sample #1
02 Rhode Island Gas Sample #2
03 Rhode Island Gas Sample #3

TEST CODES and NAMES used on this workorder
GAS1 GAS ANALYSIS

12VAT25GL 17° BTDC WB - 67° DB - 93° HUMIDITY - 58 gr/Lb 25% RH

READING	SPEED - RPM	LOAD - KWe	BHP @ 96%	GAS TEMP. - °F	GAS PRESS PSIG	OBS FT³	OBS TIME MIN	SLHV	BSFC BTU/BHP-HR	CATALYST EXH. TEMP. - °F	FUEL G/A "Hg	INTAKE MANIF PRESS - PSIG	OIL PRESS. PSIG	OIL TEMP °F	WATER TEMP °F	AUX. WATER TEMP. - °F	INTAKE MANIF TEMP °F	[illegible]	[illegible]		
1	901	1700	2375	102°	45½	200	1.267	472	7111	910°	9½	17	47	180°	214°	115°	130°				
2	901	1700	2375	103°	43½	200	1.232	472	7058	920°	9½	16	46½	182°	217°	119°	134°				
3	901	1725	2410	104°	45½	200	1.242	472	7124	925°	9½	17	46½	183°	220°	120°	139°				
4	901	1725	2410	105°	45½	200	1.230	472	7181	920°	9½	16½	46½	183°	214°	115°	138°	46.110		1:55	
5	901	1725	2410	105°	44½	200	1.214	472	7154	920°	9½	16	46½	183°	214°	115°	136°			2:00	OUT
																		46.305		2:10	
							$\bar{\Sigma}=$	7130									$\bar{\Sigma}=$	45.924			

PANEL CLOCK - START 6392.6

PANEL CLOCK - STOP 6393.3

OBSERVERS STACHOWICZ ROOM NO. ____ BAROMETER 29.83 DATE 6-6-91 AM

SUBJECT JOHNSTON LANDFILL CERTIFICATION: UNIT #1

12VAT25GL   17° BTDC   WB - 68°   DB - 97°   HUMIDITY - 57 gr/Lb   22% RH

READING	SPEED - RPM	LOAD - KWe	BHP @ 96%	GAS TEMP - °F	GAS PRESS PSIG	OBS FT³	OBS TIME MIN	SLHV	BSFC BTU/BHP-HR	CATALYST EXH. TEMP - °F	FUEL G/A "Hg	INTAKE MANIF PRESS - PSIG	OIL PRESS PSIG	OIL TEMP °F	WATER TEMP °F	AUX WATER TEMP - °F	INTAKE MANIF TEMP - °F	FUEL RATE Lb/MIN		TIME	
1	903	1725	2410	102°	45	200	1.234	472	7140	850°	9½	17	41	183°	223°	112°	134°	46.214		11:20	
2	903	1725	2410	103°	45	200	1.219	472	7215	855°	9½	17½	41	184°	225°	118°	136°			11:25	out
3	903	1725	2410	103°	45	200	1.222	472	7197	855°	9½	17½	41	185°	227°	120°	137°	46.583		11:35	
4	903	1725	2410	103°	44	200	1.218	472	7100	860°	9½	17½	41	185°	230°	120°	140°			11:45	out
5	903	1725	2410	104°	45½	200	1.242	472	7128	860°	9½	17½	40½	186°	230°	121°	141°	46.136		12:00	
								$\bar{\Sigma}$ =	7155								$\bar{\Sigma}$ =	46.311			

PANEL CLOCK - START 6739.3

PANEL CLOCK - STOP 6740.1

OBSERVERS STACHOWICZ

ROOM NO

12VAT25GL S/N 17° BTDC WB - 71° DB - 96° HUM: 76gr/Lb - 29%

READING	SPEED · RPM	LOAD : KWe	BHP @ 96%	GAS TEMP - °F	GAS PRESS PSIG		OBS FT³	OBS TIME MIN	SLHV	BSFC BTU/BHP-HR	CATALYST EXH. TEMP - °F	FUEL G/A "Hg	INT. MANIF PRESS - PSIG	OIL PRESS PSIG	OIL TEMP °F	WATER TEMP °F	AUX WATER TEMP - °F	INTAKE MANIF TEMP - °F	FUEL RATE LB/MIN		TIME	
1	903	1725	2410	84°	47	200	1.357	472	6913	855°	9½	—	41½	182°	222°	130°	134°			2:12	OUT
2	903	1725	2410	85°	47½	200	1.354	472	6972	855°	9½	—	41½	182°	222°	130°	135°	45.127		2:20	
3	903	1700	2375	87°	47	200	1.315	472	7199	855°	9½	—	41½	183°	222°	130°	138°			2:35	OUT
4	903	1725	2410	87°	46½	200	1.323	472	6994	855°	9½	—	41½	183°	222°	130°	138°	45.269		2:40	
5	903	1700	2375	87°	46½	200	1.333	472	7044	855°	9½	—	41½	183°	221°	130°	138°	44.430		2:47	
								$\bar{\Sigma}$ =	7003								$\bar{\Sigma}$ =	45.109			

PANEL CLOCK - START 5712.5

PANEL CLOCK - STOP 5713.2

OBSERVERS STACHOWICZ

ROOM NO. ______ BAROMETER 29.55 DATE 6-4-91

12VAT25GL S/N 17° BTDC WB-60° DB-69° HUM: 63gr/lb -60%

READING	SPEED-RPM	LOAD: KWe	BHP@96%	GAS TEMP °F	GAS PRESS PSIG	OBS FT³	OBS TIME MIN	SLHV	BSFC BTU/BHP-HR	CATALYST EXH. TEMP °F	FUEL G/A "Hg	INT. MANIF PRESS - PSIG	OIL PRESS PSIG	OIL TEMP °F	WATER TEMP °F	AUX WATER TEMP °F	INTAKE MANIF TEMP °F	FUEL RATE LB/MIN		TIME	
1	900	1750	2445	87°	48	200	1.370	472	6821	850°	9½	18.5	41	192°	260°	125°	126°	44.790		12:02	
2	900	1700	2375	87°	48	200	1.365	472	7047	855°	9½	19	41	192°	265°	125°	127°			12:12	OUT
3	900	1750	2445	87°	48	200	1.373	472	6806	857°	9½	19	41	193°	268°	125°	128°			12:20	OUT
4	900	1725	2410	87°	48	200	1.366	472	6940	859°	9½	19	41	192°	267°	124°	127°	44.919		12:28	
5	900	1725	2410	88°	48	200	1.355	472	6983	859°	9½	18¾	41	192°	268°	125°	127°	45.198		12:37	
								$\bar{\Sigma}$ =	6915								$\bar{\Sigma}$ =	44.969			
	PANEL	CLOCK		START		5575.6															
	PANEL	CLOCK		END		5576.3															

OBSERVERS STACHOWICZ

JOHNSTON LANDELL [illegible]

ROOM NO. ______ BAROMETER 29.53 DATE 6-11-91

12VAT25GL 17° BTDC WB - 58° DB - 73° HUMIDITY 48 gr/Lb 40% RH

READING	SPEED - RPM	LOAD - KWe	BHP @ 96%	GAS TEMP - °F	GAS PRESS PSIG	OBS. FT3	OBS TIME MIN	SLHV	BSFC BTU/BHP-HR	CATALYST EXH. TEMP - °F	FUEL G/A "Hg	INTAKE MANIF PRESS - PSIG	OIL PRESS PSIG	OIL TEMP °F	WATER TEMP °F	AUX. WATER TEMP - °F	INTAKE MANIF TEMP - °F	FUEL RATE Lb/MIN		TIME	
1	903	1700	2375	117°	45½	200	1.185	472	7414	845°	9½	20½	45	185°	217°	124°	140°			9:47	OUT
2	903	1700	2375	116°	44	200	1.162	472	7385	845°	9½	20½	45	185°	217°	124°	140°	47.105		9:55	
3	903	1700	2375	114°	45½	200	1.201	472	7353	845°	9½	20	45	185°	217°	124°	140°			10:05	OUT
4	903	1700	2375	113°	44	200	1.166	472	7398	845°	9½	19½	45	185°	217°	124°	140°	47.188		10:15	
5	903	1700	2375	113°	44½	200	1.182	472	7360	840°	9½	20½	45	185°	217°	124°	140°	46.946		10:25	

$\bar{\Sigma}$ = 7381

$\bar{\Sigma}$ = 47.080

PANEL CLOCK - START 7604.3

PANEL CLOCK - STOP 7605.0

OBSERVERS STACHOWICZ

SUBJECT JOHNSTON LANDFILL CERTIFICATION UNIT #[illegible] ROOM NO. BAROMETER 29.96 DATE 6-7-91 AM

12VAT25GL 17°BTDC WB-53° DB-63° HUMIDITY - 43 gr/Lb 50% RH

READING	SPEED-RPM	LOAD-KWe	BHP @ 96%	GAS TEMP - °F	GAS PRESS PSIG	OBS FT 3	OBS. TIME MIN	SLHV	BSFC BTU/BHP-HR	CATALYST EXH. TEMP - °F	FUEL G/A "Hg	INTAKE MANIF PRESS - PSIG	OIL PRESS PSIG	OIL TEMP -°F-	WATER TEMP °F	AUX WATER TEMP - °F	INTAKE MANIF TEMP -°F	FUEL RATE Lb/MIN		TIME	
1	902	1700	2375	106°	46	200	1.242	472	7273	880°	9 1/2	20	41 1/2	180°	228°	—	138°	46.391		9:00	
2	903	1700	2375	104°	45	200	1.226	472	7272	880°	9 1/2	20	41 1/2	180°	227°	—	138°			9:09	OUT
3	903	1700	2375	103°	45	200	1.223	472	7303	880°	9 1/2	20 1/2	41 1/2	180°	227°	—	138°	46.582		9:20	
4	903	1700	2375	102°	45 1/2	200	1.224	472	7359	880°	9 1/2	20 1/2	41 1/2	180°	228°	—	138°	46.440		9:25	
5	903	1700	2375	100°	45 1/2	200	1.228	472	7374	880°	9 1/2	20 1/2	41 1/2	181°	228°	—	138°			9:35	OUT
								$\bar{\Sigma}$ =	7312								$\bar{\Sigma}$ =	46.638			

PANEL CLOCK - START 6575.3

PANEL CLOCK - STOP 6575.9

OBSERVERS STACHOWICZ

ROOM NO.

12VAT25GL S/N

17° BTDC WB - 60° DB - 75° HUM: 54 gr/lb ; 41%

READING	SPEED-RPM	LOAD-KWe	BHP@96%	GAS TEMP-°F	GAS PRESS PSIG	OBS FT³	OBS. TIME MIN	SLHV	BSFC BTU/BHP-HR	CATALYST EXH. TEMP-°F	FUEL G/A "Hg	INTAKE MANIF PRESS-PSIG	OIL PRESS PSIG	OIL TEMP °F	WATER TEMP °F	AUX WATER TEMP-°F	INTAKE MANIF TEMP-°F	FUEL RATE LB/MIN		TIME	
1	904	1700	2375	91°	44	200	1.224	472	7319	845°	9½	16½	44	—	200°	121°	125°			8:52	OUT
2	904	1700	2375	91°	43	200	1.217	472	7236	850°	9½	16½	44	—	202°	122°	126°	46.155		9:00	
3	904	1700	2375	91°	43	200	1.221	472	7212	855°	9½	16½	44	—	204°	122°	128°			9:10	OUT
4	904	1700	2375	90°	42½	200	1.205	472	7258	850°	9½	17	44	—	204°	122°	130°	46.295		9:20	
5	904	1700	2375	91°	43	200	1.206	472	7302	850°	9½	16½	43½	—	204°	122°	130°	46.576		9:30	
								$\bar{\Sigma}$ = 7265									$\bar{\Sigma}$ = 46.342				

PANEL CLOCK - START 6296.4
PANEL CLOCK - STOP 6297.0

OBSERVERS STACHOWICZ

SUBJECT JOHNSTON LANDFILL CERTIFICATION • UNIT #7 ROOM NO. ______ BAROMETER 29.80 DATE 6-5-91 AM

12VAT25GL S/N 17°BTDC WB - 51° DB - 53° HUM: 52gr/Lb 85% RH

READING	SPEED-RPM	LOAD-KWe	BHP @ 96.7%	GAS TEMP-°F	GAS PRESS PSIG	OBS FT³	OBS TIME MIN	SLHV	BSFC BTU/BHP-HR	CATALYST EXH. TEMP-°F	FUEL G/A	"Hg INTAKE MANIF	PRESS-PSIG OIL PRESS PSIG	OIL TEMP °F	WATER TEMP °F	AUX WATER TEMP-°F	INTAKE MANIF TEMP-°F	FUEL RATE LB/MIN		TIME	
1	903	1700	2375	75°	45	200	1.344	472	6984	835°	9.8	19½	46	195°	214°	116°	120°			11:18	OUT
2	903	1700	2375	79°	45	200	1.333	472	6990	845°	9.8	19½	45½	195°	215°	119°	121°	44.586		11:27	
3	903	1700	2375	79°	45	200	1.334	472	6986	850°	9.8	20	45½	195°	213°	119°	121°	44.560		11:37	
4	903	1700	2375	80°	45	200	1.330	472	6993	850°	9.8	20	45½	195°	213°	119°	121°	44.605		11:45	
5	903	1700	2375	81°	45½	200	1.323	472	7075	850°	9.8	20	45½	195°	213°	119°	121°			11:50	OUT
								$\bar{\Sigma}$ =	6990								$\bar{\Sigma}$ =	44.584			

PANEL CLOCK - START 6014.9

PANEL CLOCK - STOP 6015.6

OBSERVERS STACHOWICZ

DATE [illegible]

UNIT #1 6-6-91 Rhode Island

	A/F SPINDT	CO	CO_2 %	O_2 %	PPM HC	PPM NO	PPM NOX	PPM NMHC
Pre	8.664	466	11.27	8.58	1875	30	86	34
Post	8.628	196	11.36	8.50	1800	65	90	33
STACK	8.881	220	11.00	8.95	2175	63	93	39 PPM NMHC
POST	8.669	192	11.27	8.55	1860	55	80	34
Pre	8.614	460	11.36	8.50	1800	38	98	33

UNIT #2 6-6-91

	A/F SPINDT	CO	CO_2 %	O_2 %	PPM THC	PPM NO	PPM NOX	PPM NMHC
Pre	8.747	442	11.21	8.68	1650	30	85	30
Post	8.765	185	11.21	8.68	1620	50	83	29
STACK	9.006	180	10.87	9.08	1935	54	93	NMHC 35PPM
Post	8.763	187	11.21	8.68	1635	53	88	30
Pre	8.738	442	11.21	8.65	1620	47	83	29

SLOW WANDER

AFR CHANGED

OCCASIONAL MISFIRE

MISFIRE

6-4-91 UNIT# 3 Rhode Island

	A/F SPINDT	CO	CO_2 %	O_2 %	PPM THC	PPM NO	PPM NOX	PPM NMHC
Pre	9.030	442	11.09	8.83	1710	38	93	27
Post	9.044	100	11.12	8.83	1680	75	94	27
STACK	9.223	98	10.85	9.11	1950	69	85	31 PPM NMHC
Post	9.070	98	11.09	8.88	1725	68	82	28
Pre	9,080	440	11.00	8.90	1785	33	84	29
								MISFIRES 1-4 MIN

UNIT #4 , 6-4-91 Rhode Island

	A/F SPINDT	CO	CO_2 %	O_2 %	PPM THC	PPM NO	PPM NOX	PPM NMHC
Pre	8.943	425	11.20	8.68	1620	38	83	22
POST	8.927	69	11.25	8.65	1710	68	85	23
STACK	9.275	68	10.82	9.18	1860	69	83	25 ppm NMHC
post	8.982	62	11.18	8.73	1718	64	83	23
Pre	8.979	419	11.15	8.75	1710	35	93	23

UNIT #5 6-7-91 Rhode Island

	A/F SPINDT	CO	CO_2 %	O_2 %	PPM THC	PPM NO	PPM NOX	PPM NMHC
pre	8.649	501	11.30	8.58	1920	45	96	27
Post	8.734	104	11.21	8.68	1965	71	105	27
STACK	8.758	100	11.18	8.75	2100	100	121	29 PPM NMHC
POST	8.632	110	11.36	8.50	1815	89	105	25
Pre	8.634	500	11.31	8.55	1920	44	101	27

AFTER WASHERS

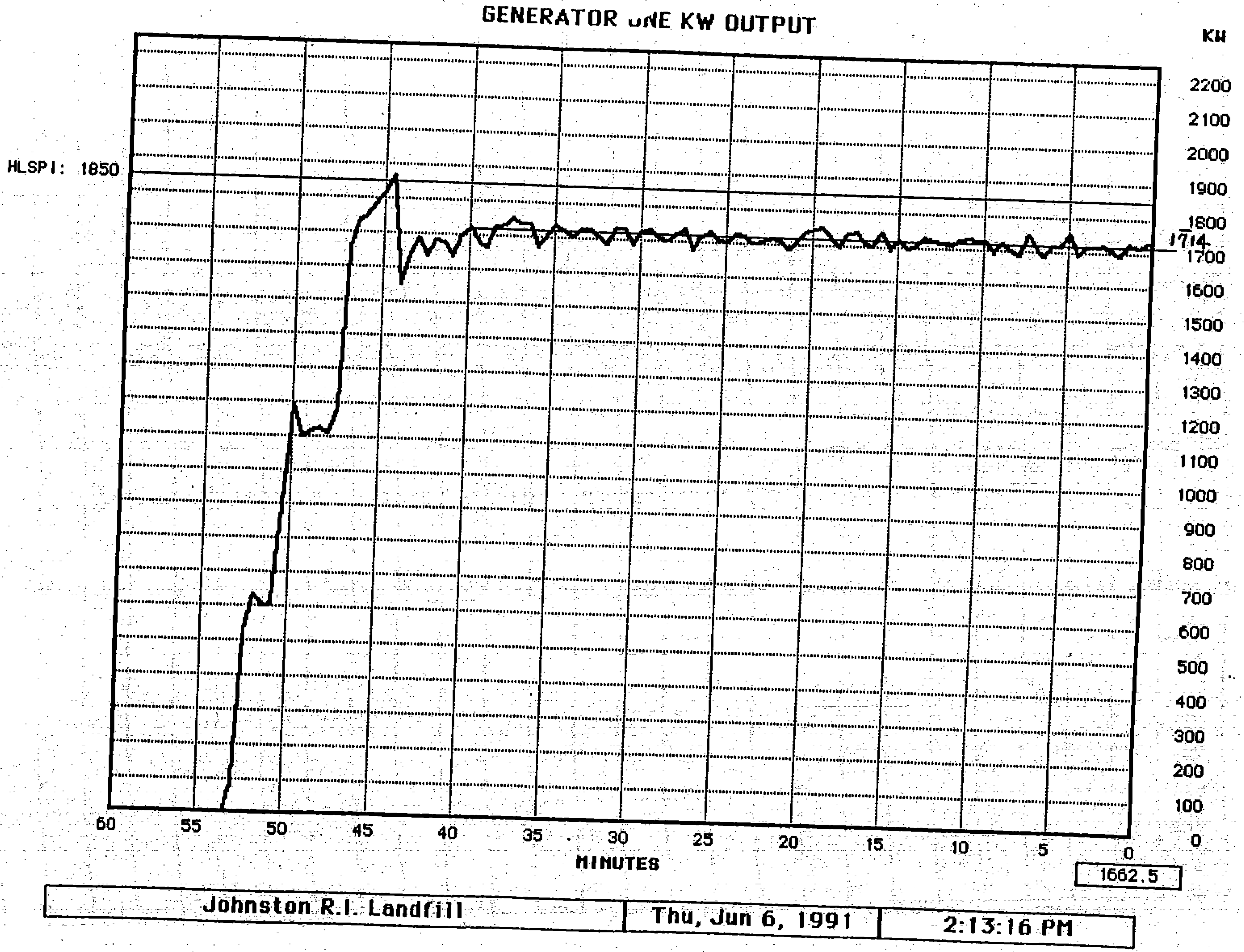
6-6-91 UNIT #6 Rhode Island

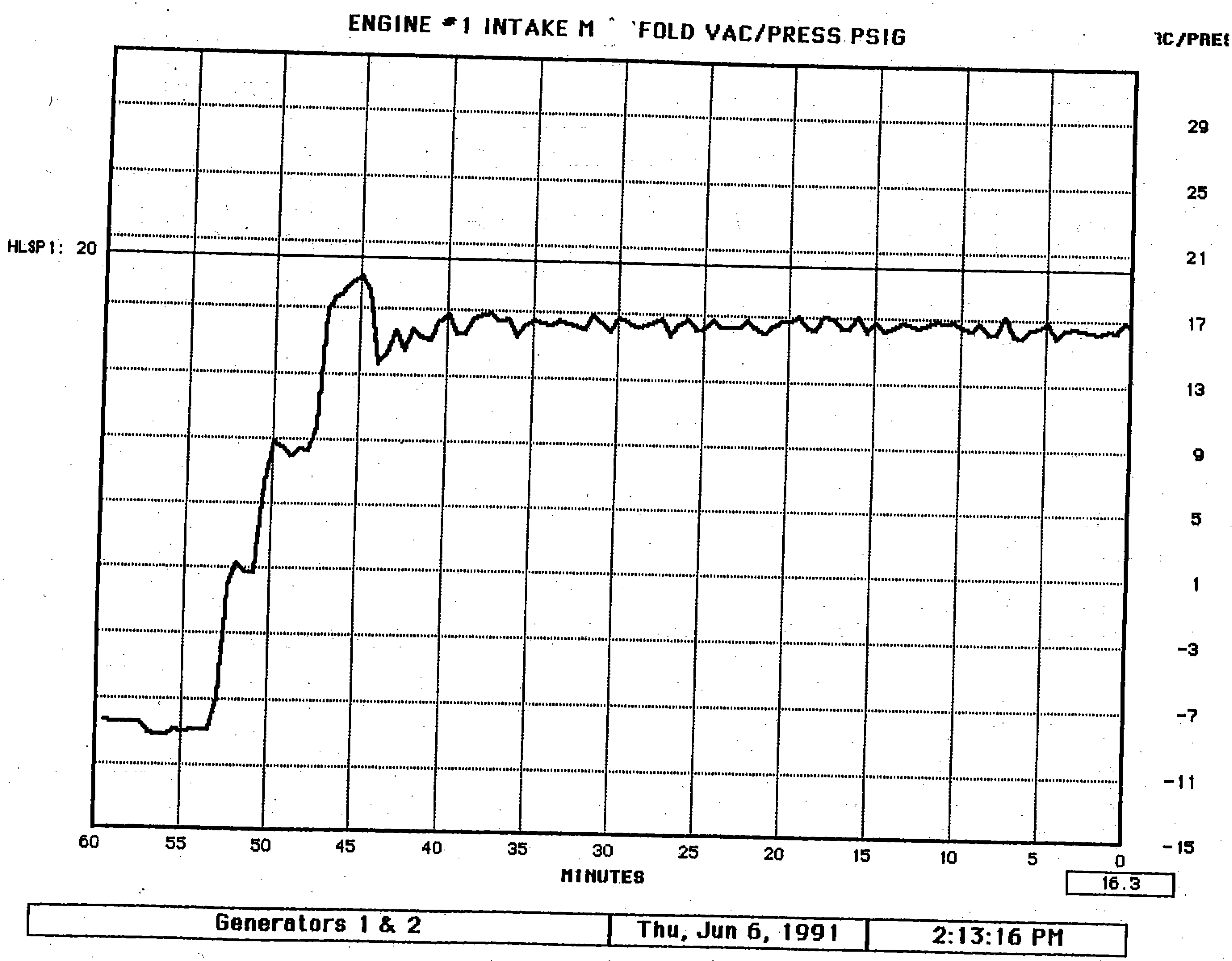
	A/F SPINDT	CO	CO_2 %	O_2 %	PPM THC	PPM NO	PPM NOX	PPM NMHC
Pre	8.681	442	11.27	8.60	1800	24	62	24
Post	8.673	53	11.34	8.50	1500	55	63	20
STACK	8.879	53	11.03	8.85	1800	56	63	24 ppm NMHC
Post	8.640	53	11.36	8.45	1560	57	64	21
Pre	8.649	442	11.29	8.55	1860	26	66	25

TOTAL Hydrocarbons UNSTEADY

Unit # 7 6-5-91 Rhode Is

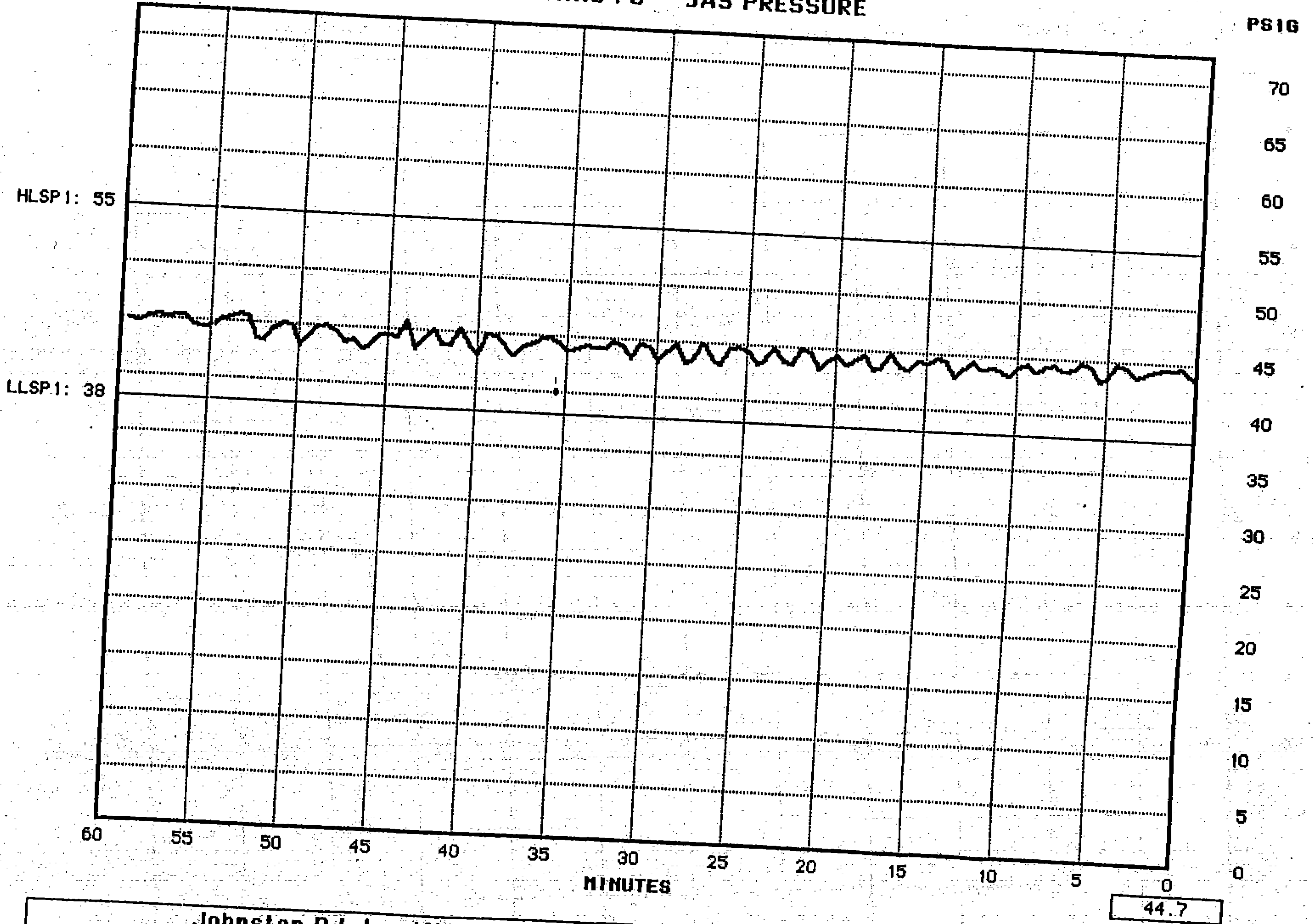
	A/F SPINDT	CO	CO_2 %	O_2 %	PPM THC	PPM NO	PPM NOX	PPM NMHC
Pre	8.687	419	11.22	8.68	2220	18	50	32
Post	8.698	58	11.25	8.68	2220	40	52	32
STACK	9.171	58	10.63	9.40	2490	40	48	36 ppm NMHC
Post	8.706	60	11.21	8.70	2340	43	49	34
Pre	8.710	419	11.18	8.75	2385	18	47	34


GENERATOR ONE KW OUTPUT
KW
2200
2100
2000
1900
1800
1714
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
HLSPI: 1850
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
1662.5
Johnston R.I. Landfill
Thu, Jun 6, 1991
2:13:16 PM

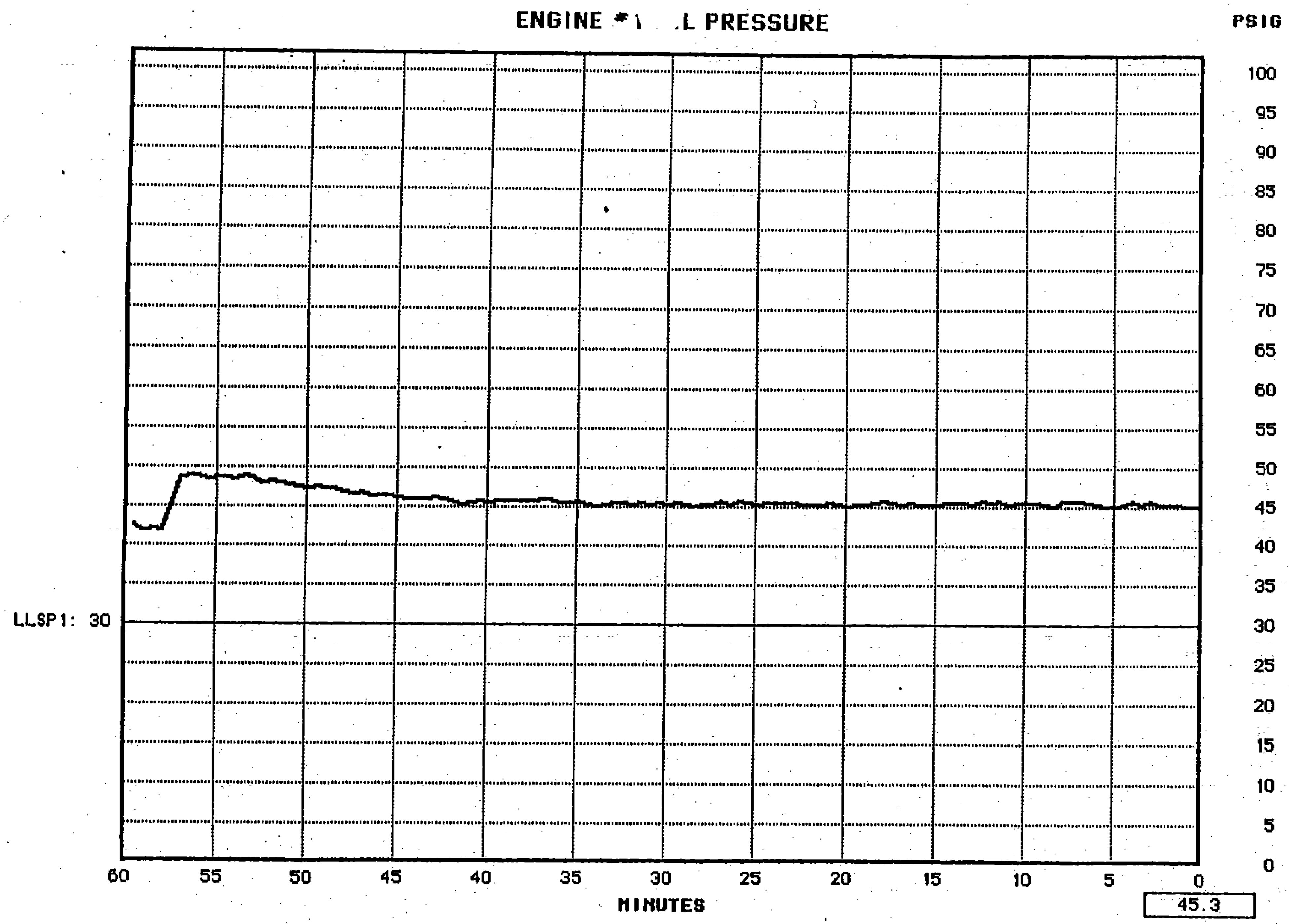


ENGINE #1 INTAKE M 'FOLD VAC/PRESS PSIG
RC/PRES
HLSP1: 20
29
25
21
17
13
9
5
1
-3
-7
-11
-15
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
16.3
Generators 1 & 2
Thu, Jun 6, 1991
2:13:16 PM

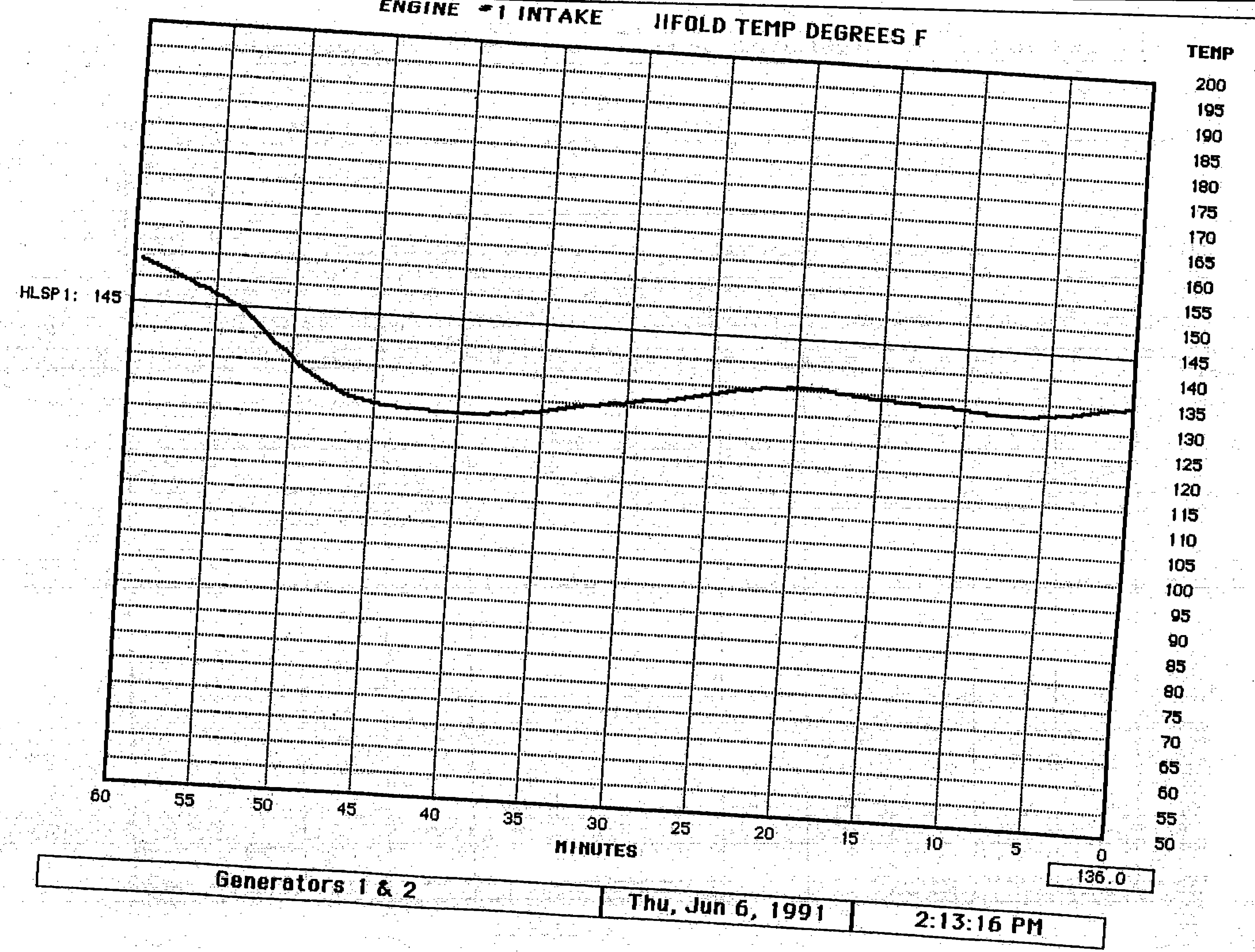
INCOMING FU   3AS PRESSURE



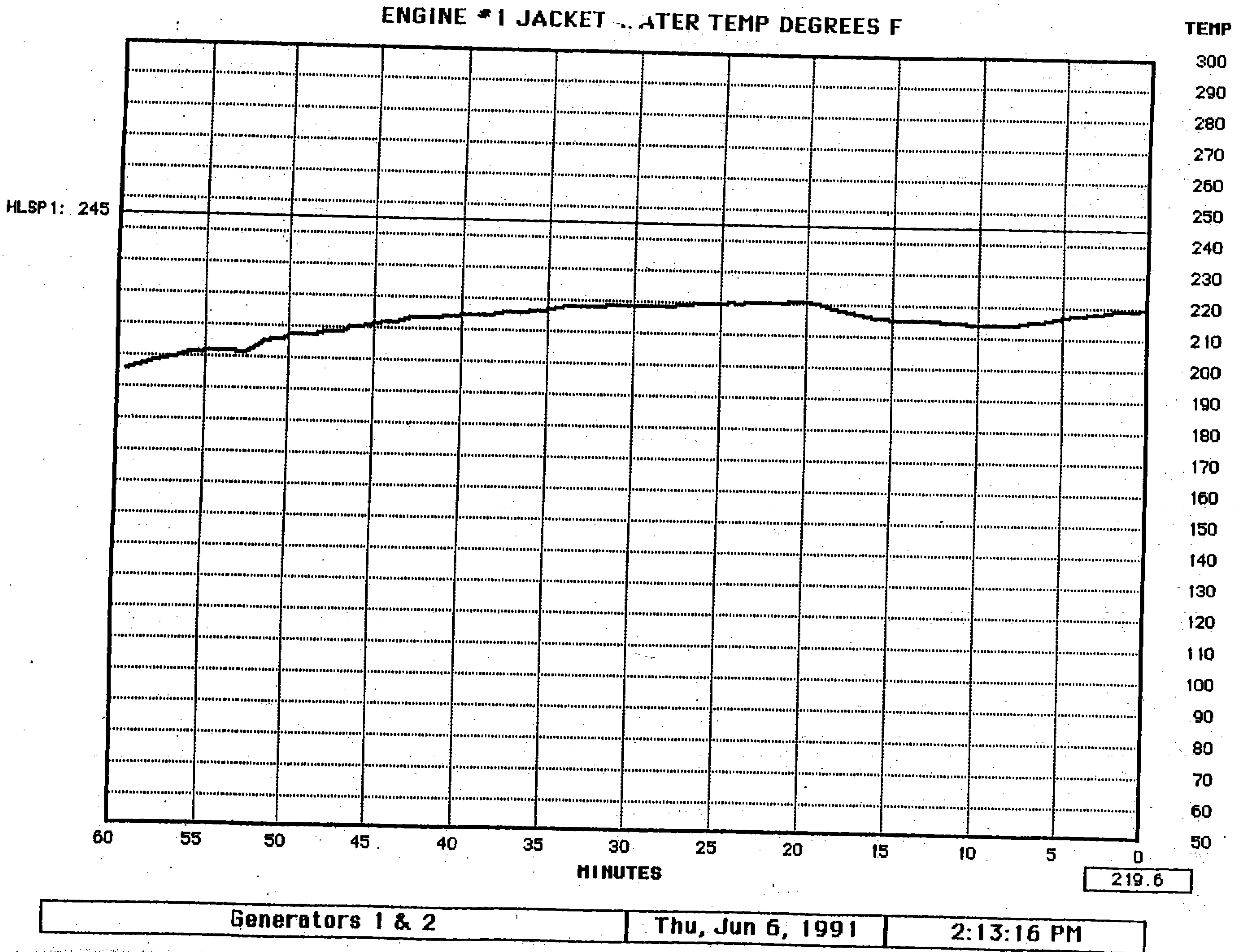
Johnston R.I. Landfill	Thu, Jun 6, 1991	2:13:16 PM



Generators 1 & 2	Thu, Jun 6, 1991	2:13:16 PM

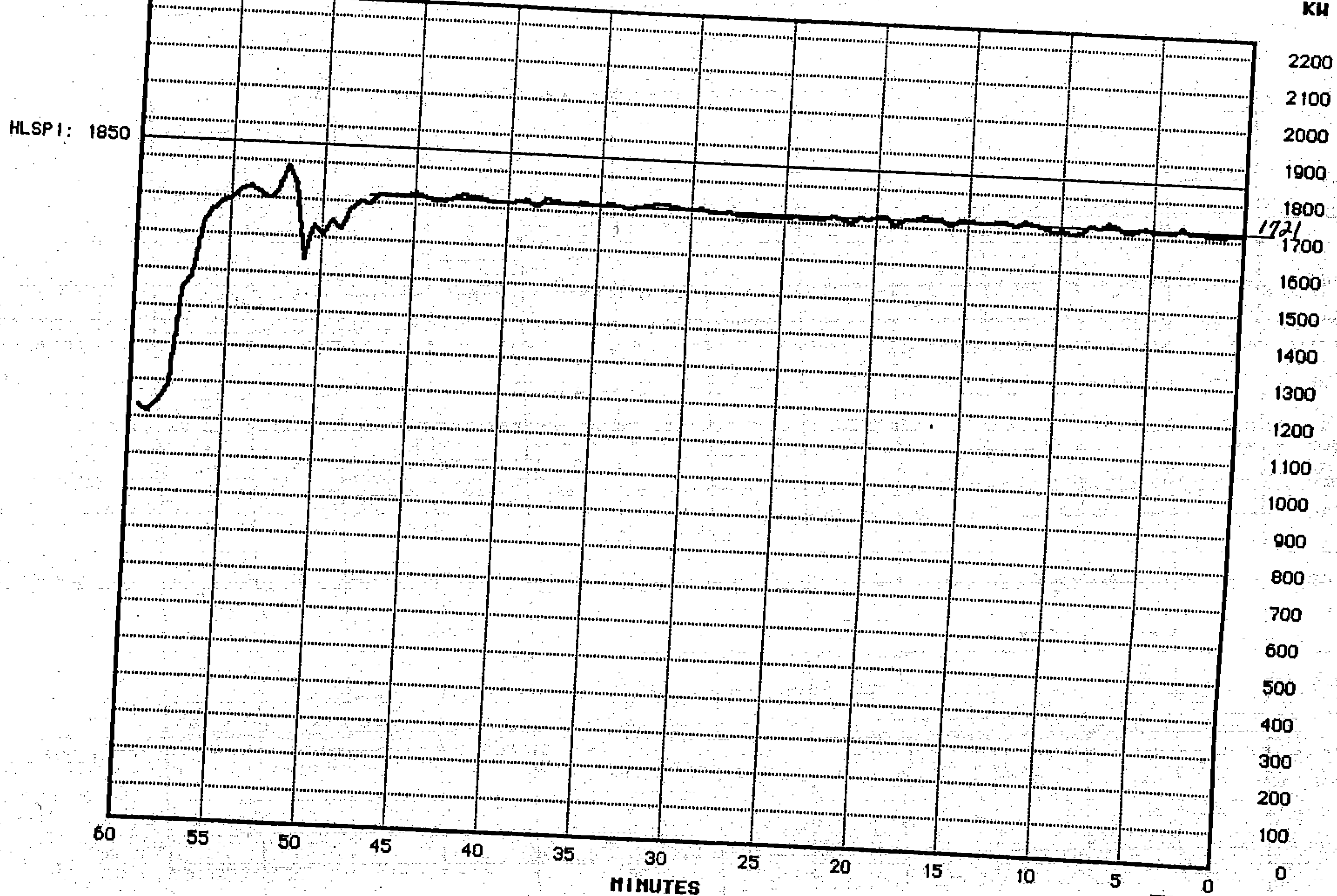


ENGINE #1 INTAKE
IIFOLD TEMP DEGREES F
TEMP
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
HLSP1: 145
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
136.0
Generators 1 & 2
Thu, Jun 6, 1991
2:13:16 PM

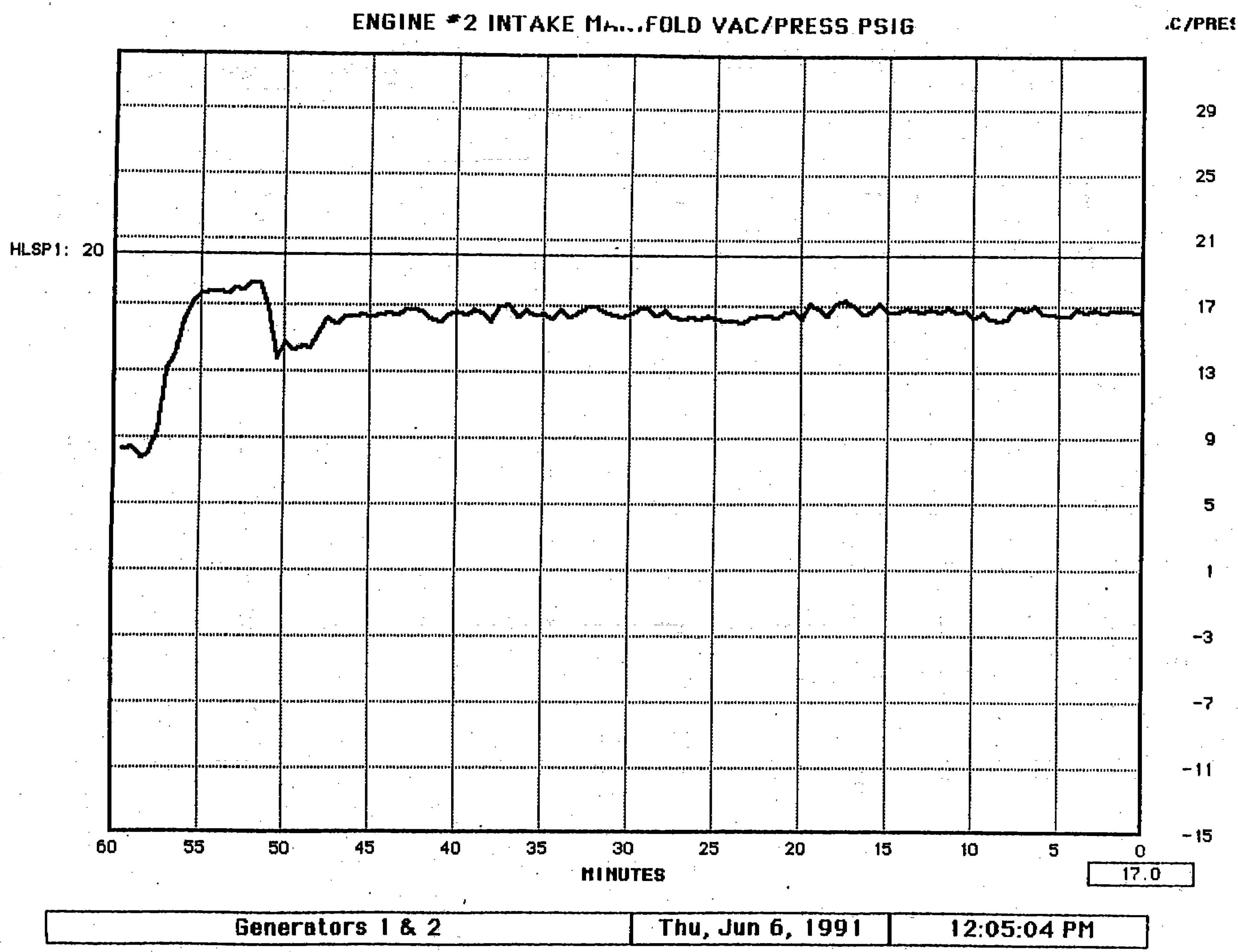


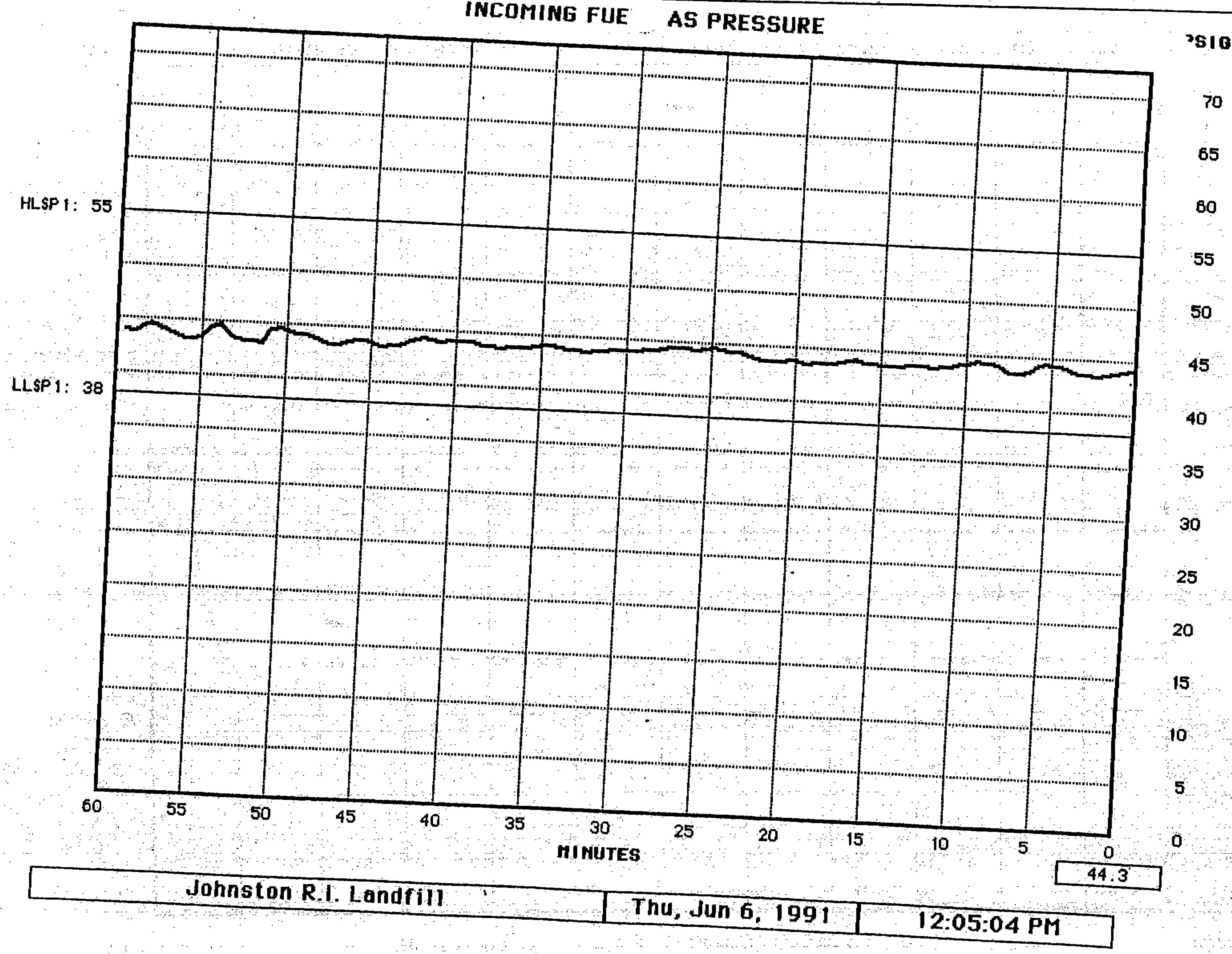
ENGINE #1 JACKET ..ATER TEMP DEGREES F
TEMP
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
HLSP1: 245
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
219.6
Generators 1 & 2
Thu, Jun 6, 1991
2:13:16 PM

GENERATOR TWO KW OUTPUT



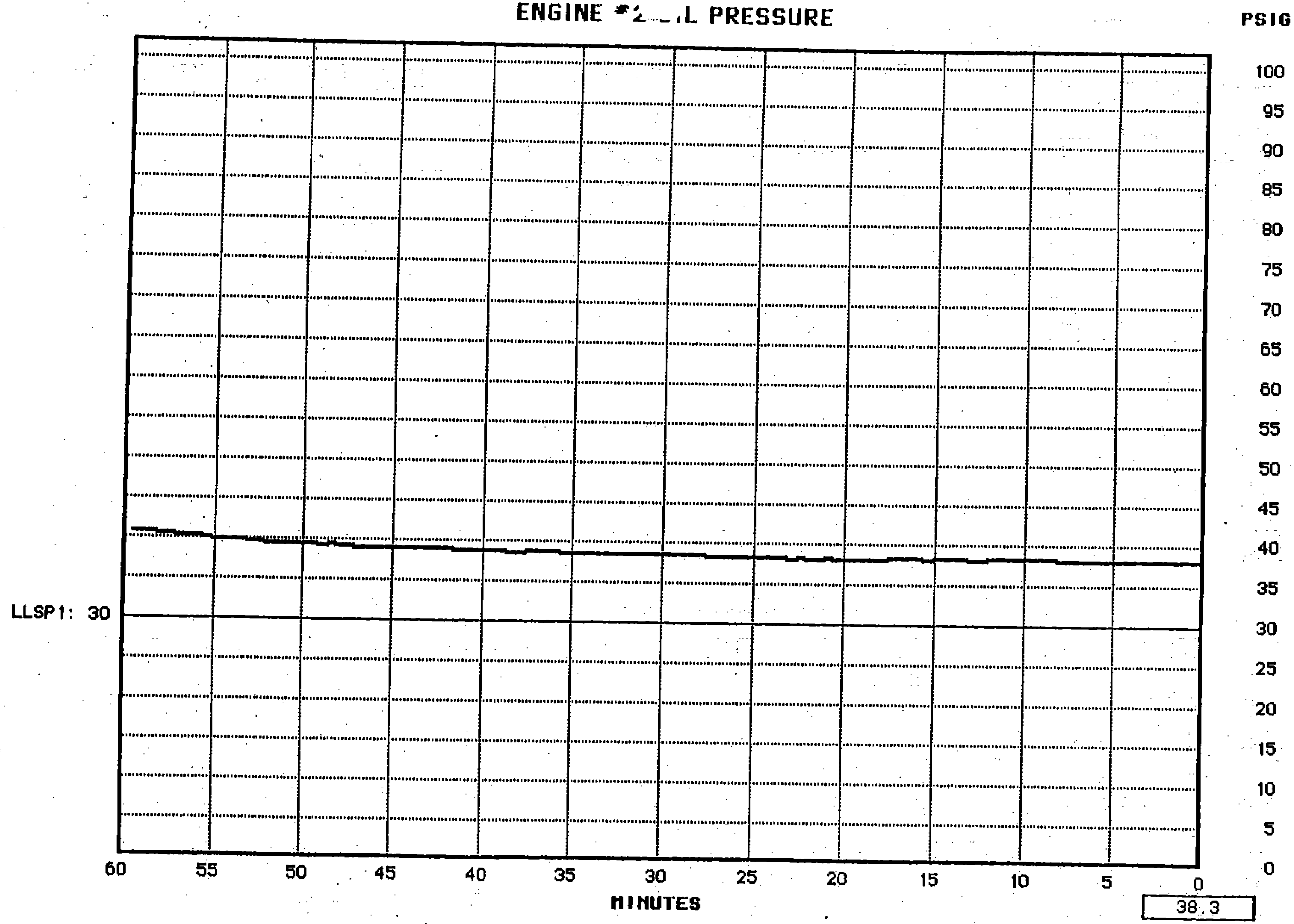
Johnston R.I. Landfill | Thu, Jun 6, 1991 | 12:05:04 PM


ENGINE #2 INTAKE MA...FOLD VAC/PRESS PSIG
.C/PRES
HLSP1: 20
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
17.0
Generators 1 & 2
Thu, Jun 6, 1991
12:05:04 PM

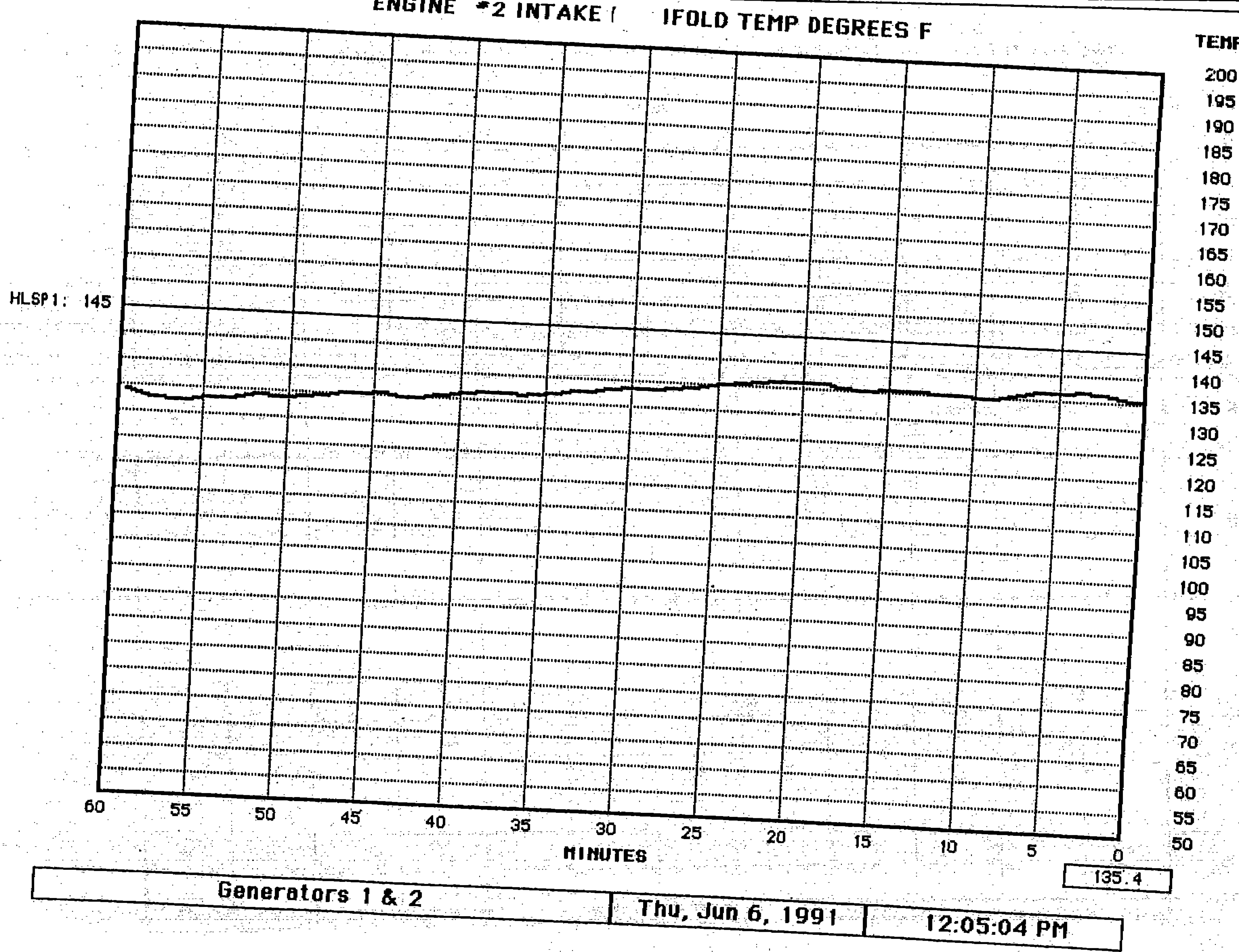


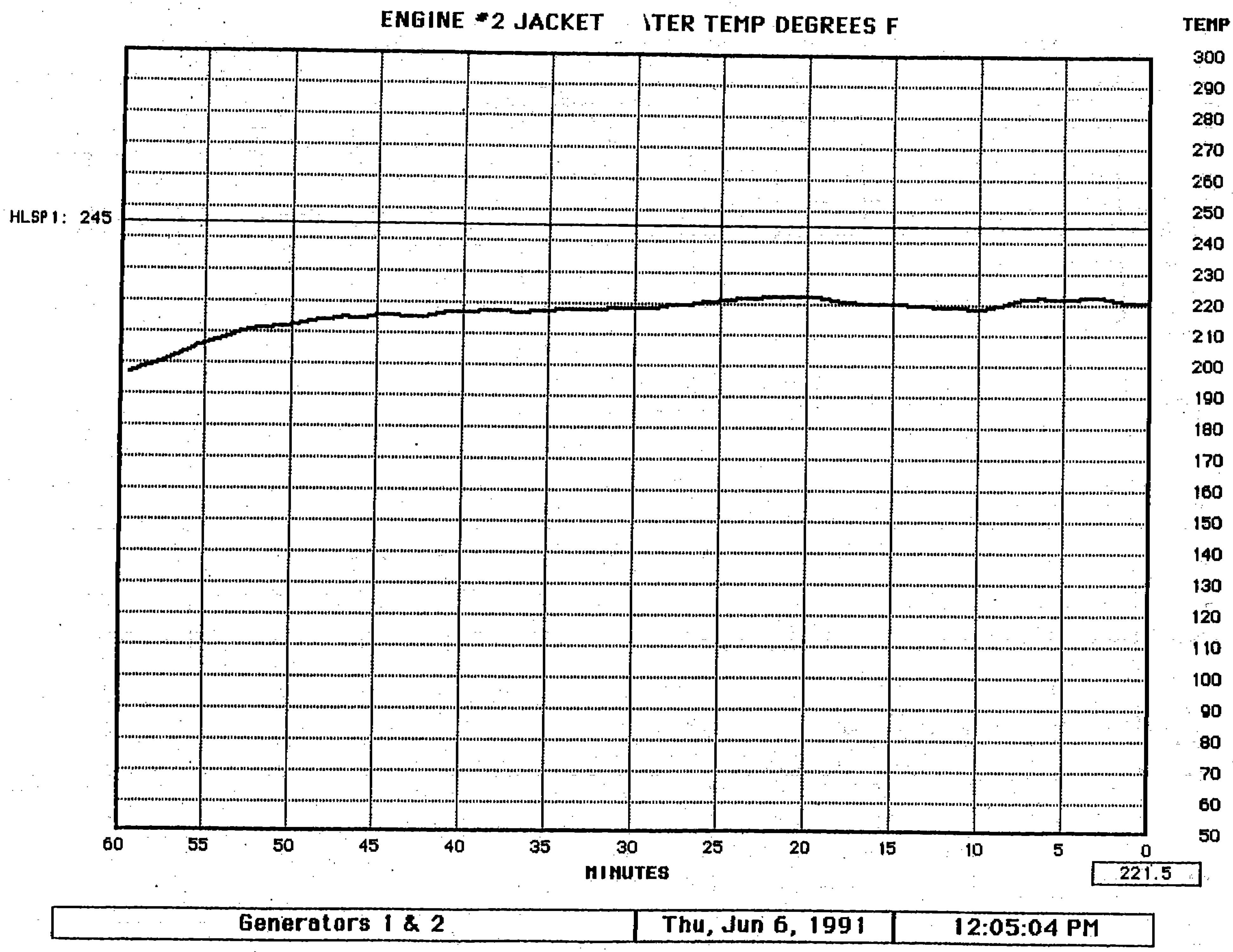
INCOMING FUE AS PRESSURE
PSIG
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
HLSP1: 55
LLSP1: 38
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
44.3
Johnston R.I. Landfill
Thu, Jun 6, 1991
12:05:04 PM

ENGINE #2 OIL PRESSURE



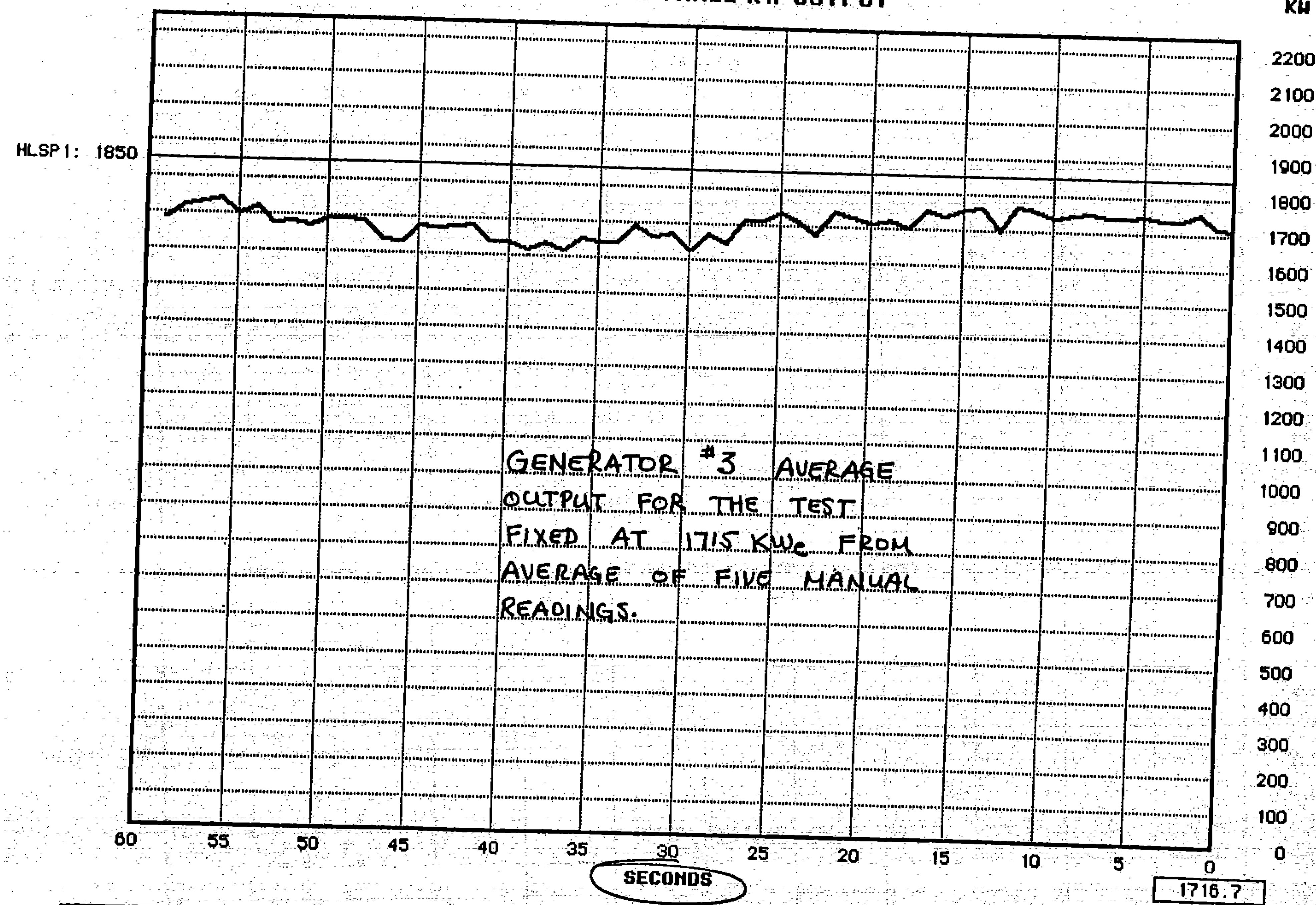
Generators 1 & 2	Thu, Jun 6, 1991	12:05:04 PM


ENGINE #2 INTAKE I IFOLD TEMP DEGREES F
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
HLSP1: 145
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
135.4
Generators 1 & 2
Thu, Jun 6, 1991
12:05:04 PM



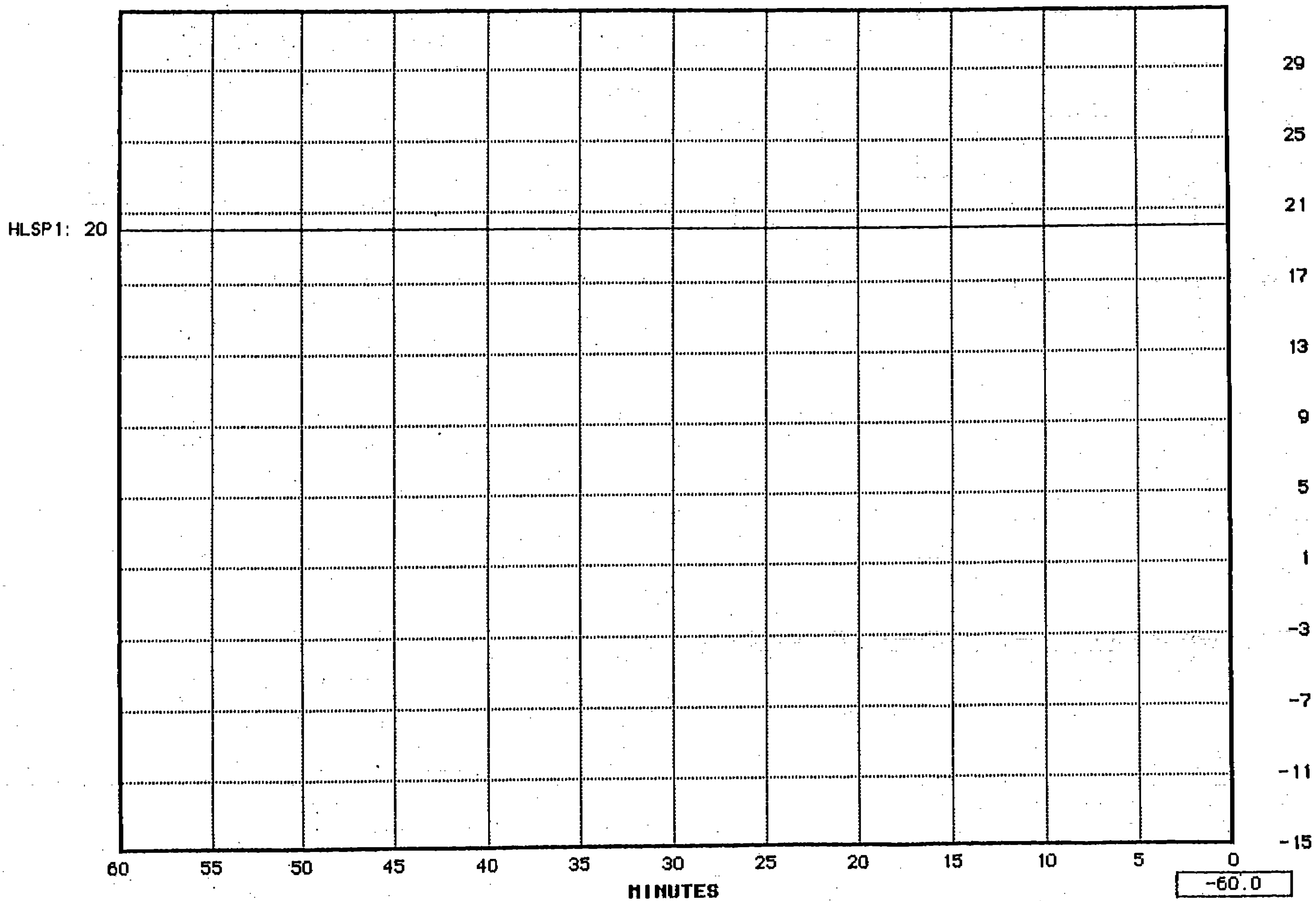
ENGINE *2 JACKET \TER TEMP DEGREES F
TEMP
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
HLSP1: 245
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
221.5
Generators 1 & 2
Thu, Jun 6, 1991
12:05:04 PM

GENERATOR THREE KW OUTPUT

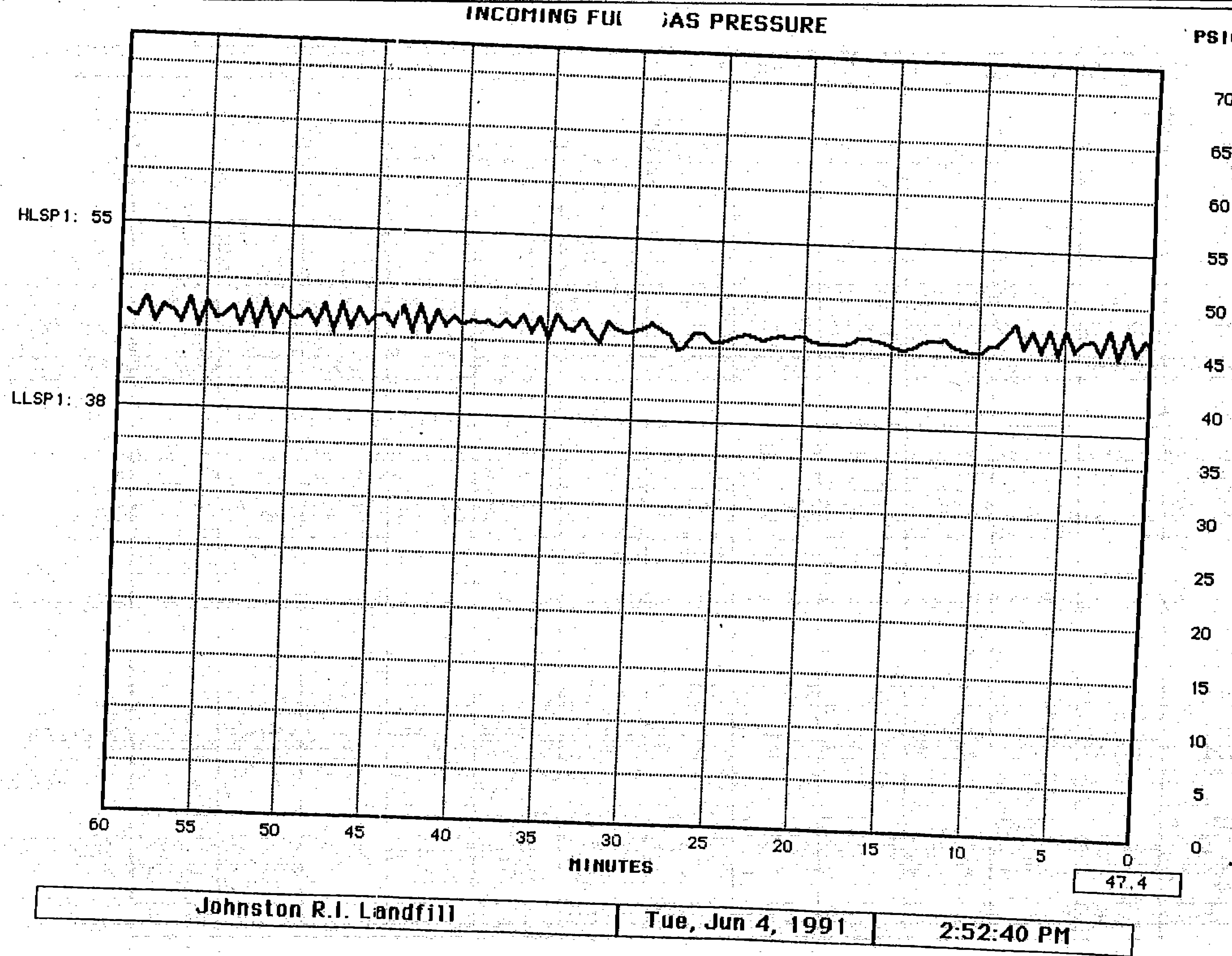


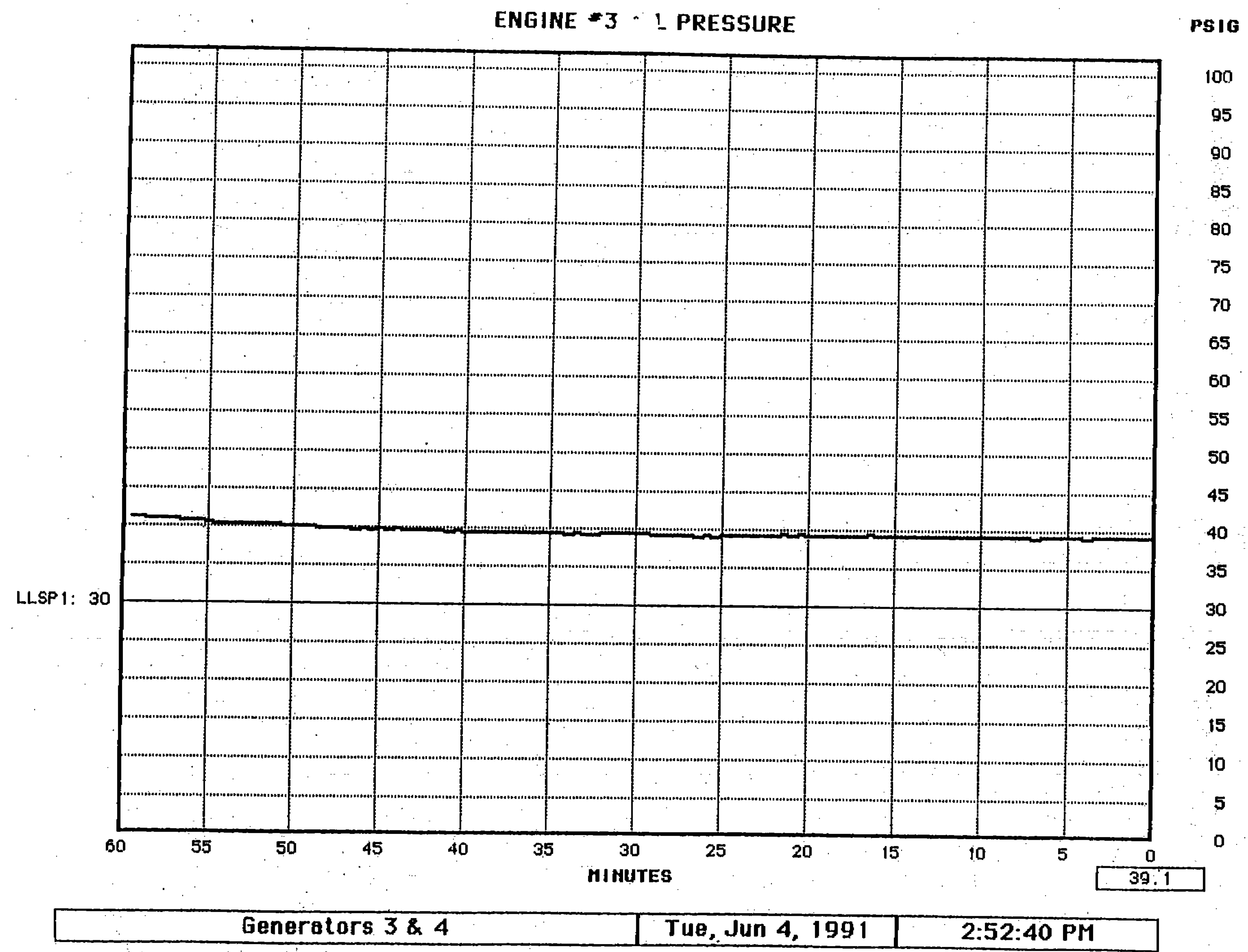
Johnston R.I. Landfill | Tue, Jun 4, 1991 | 2:52:40 PM

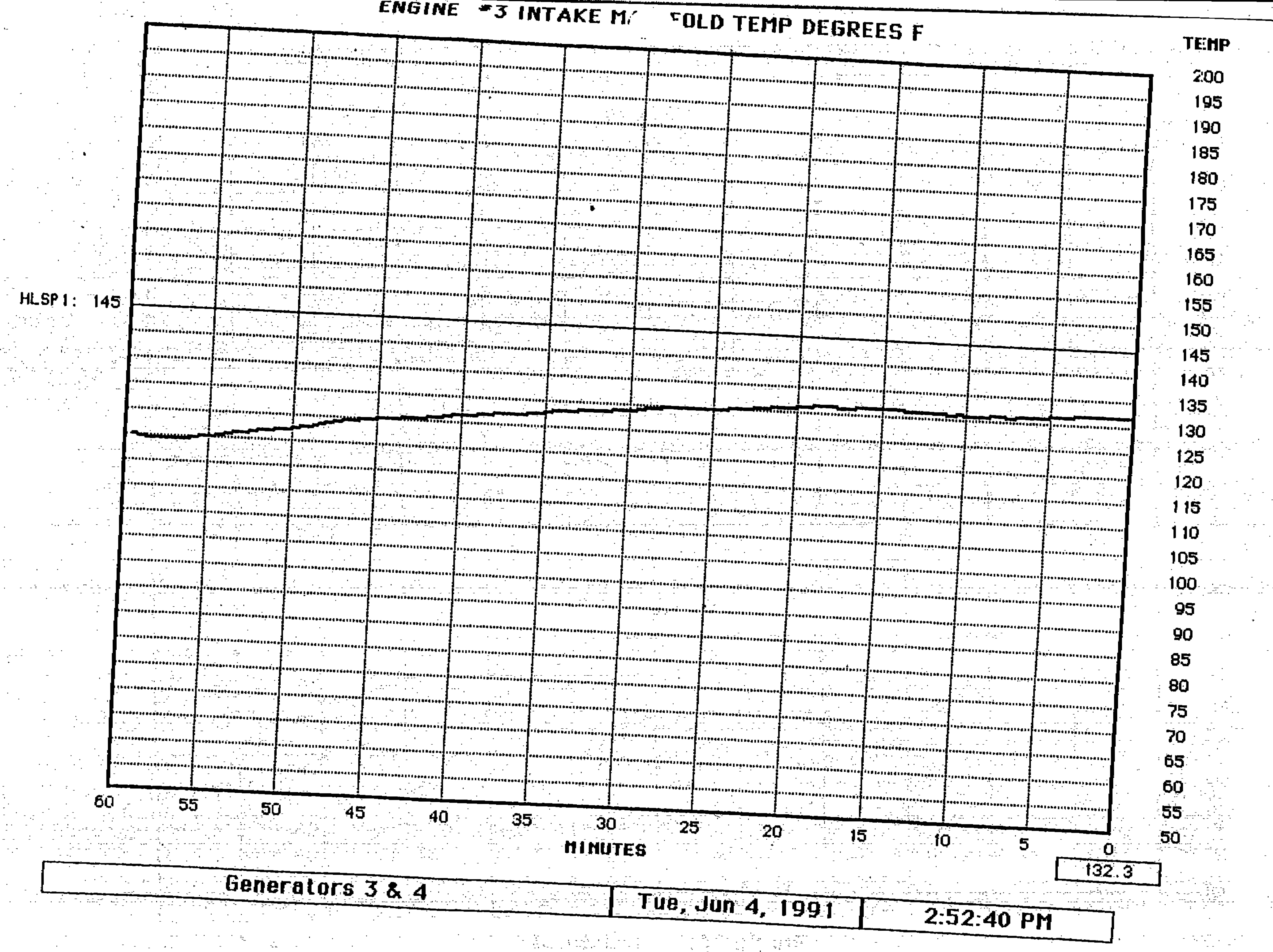
ENGINE #3 INTAKE M   FOLD VAC/PRESS PSIG

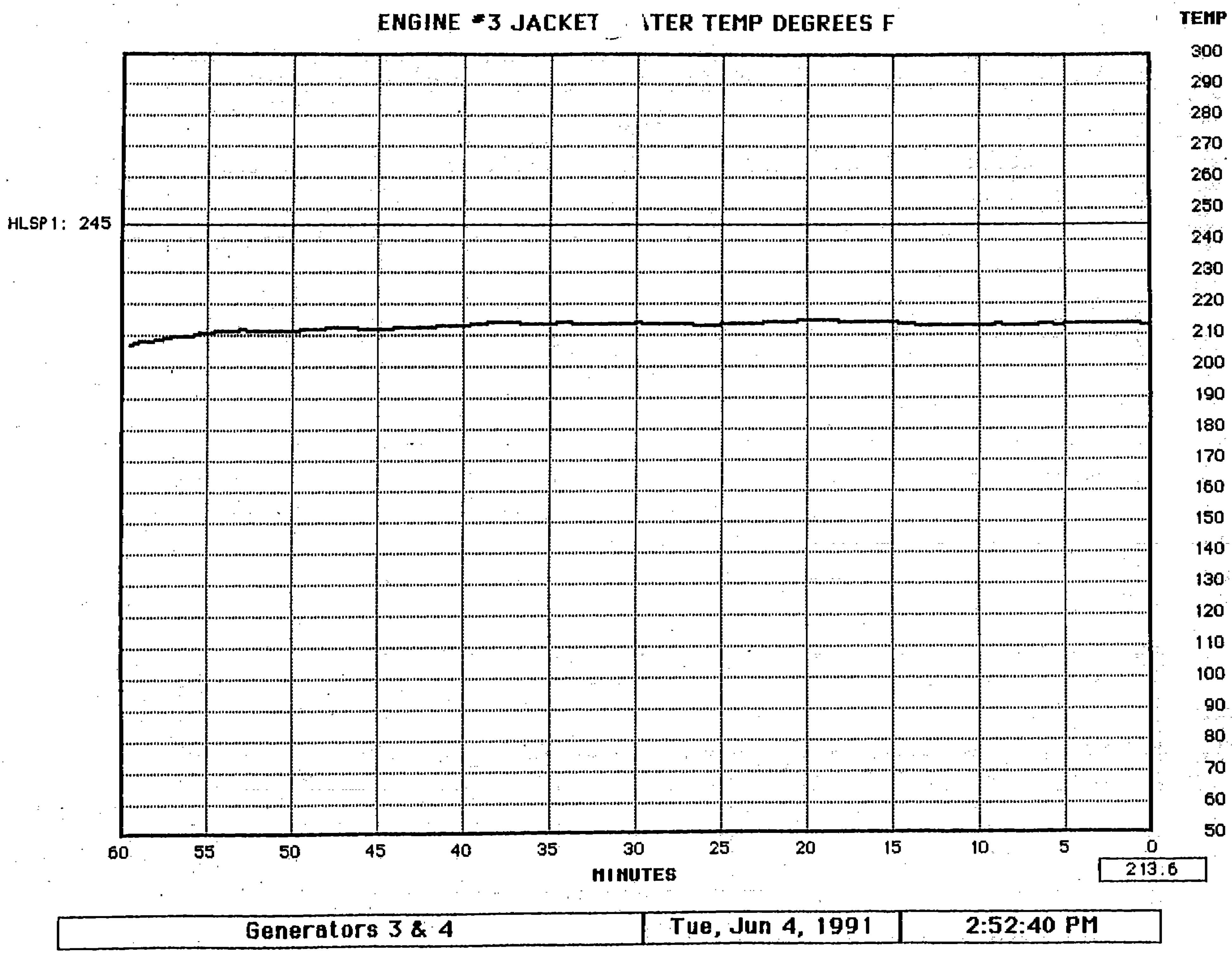


Generators 3 & 4	Tue, Jun 4, 1991	2:52:40 PM

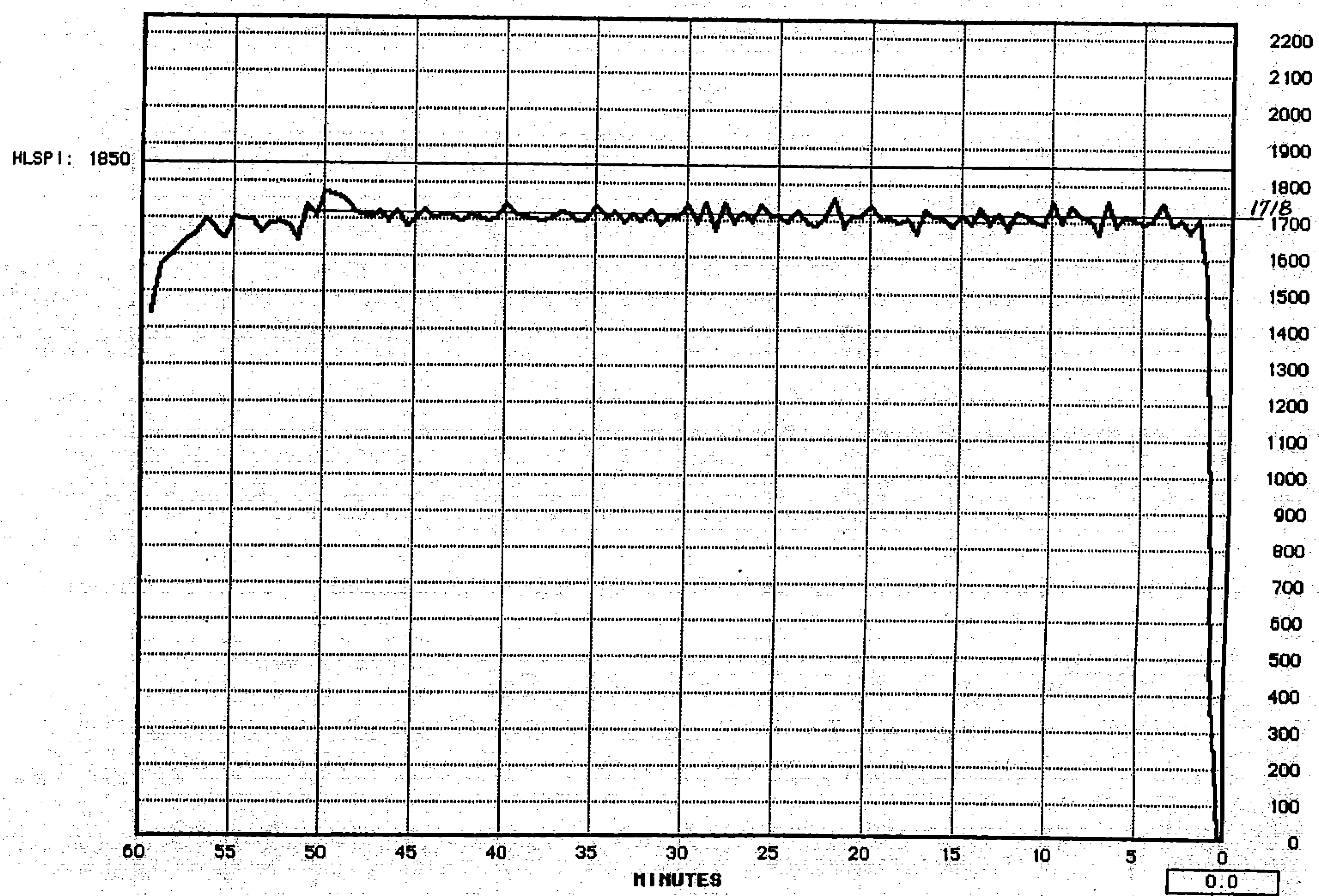

INCOMING FU[;AS PRESSURE
PSIG
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
HLSP1: 55
LLSP1: 38
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
47.4
Johnston R.I. Landfill
Tue, Jun 4, 1991
2:52:40 PM


ENGINE #3 · 1 PRESSURE
PSIG
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
LLSP1: 30
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
39.1
Generators 3 & 4
Tue, Jun 4, 1991
2:52:40 PM


ENGINE #3 INTAKE M/ FOLD TEMP DEGREES F
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
HLSP1: 145
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
132.3
Generators 3 & 4
Tue, Jun 4, 1991
2:52:40 PM

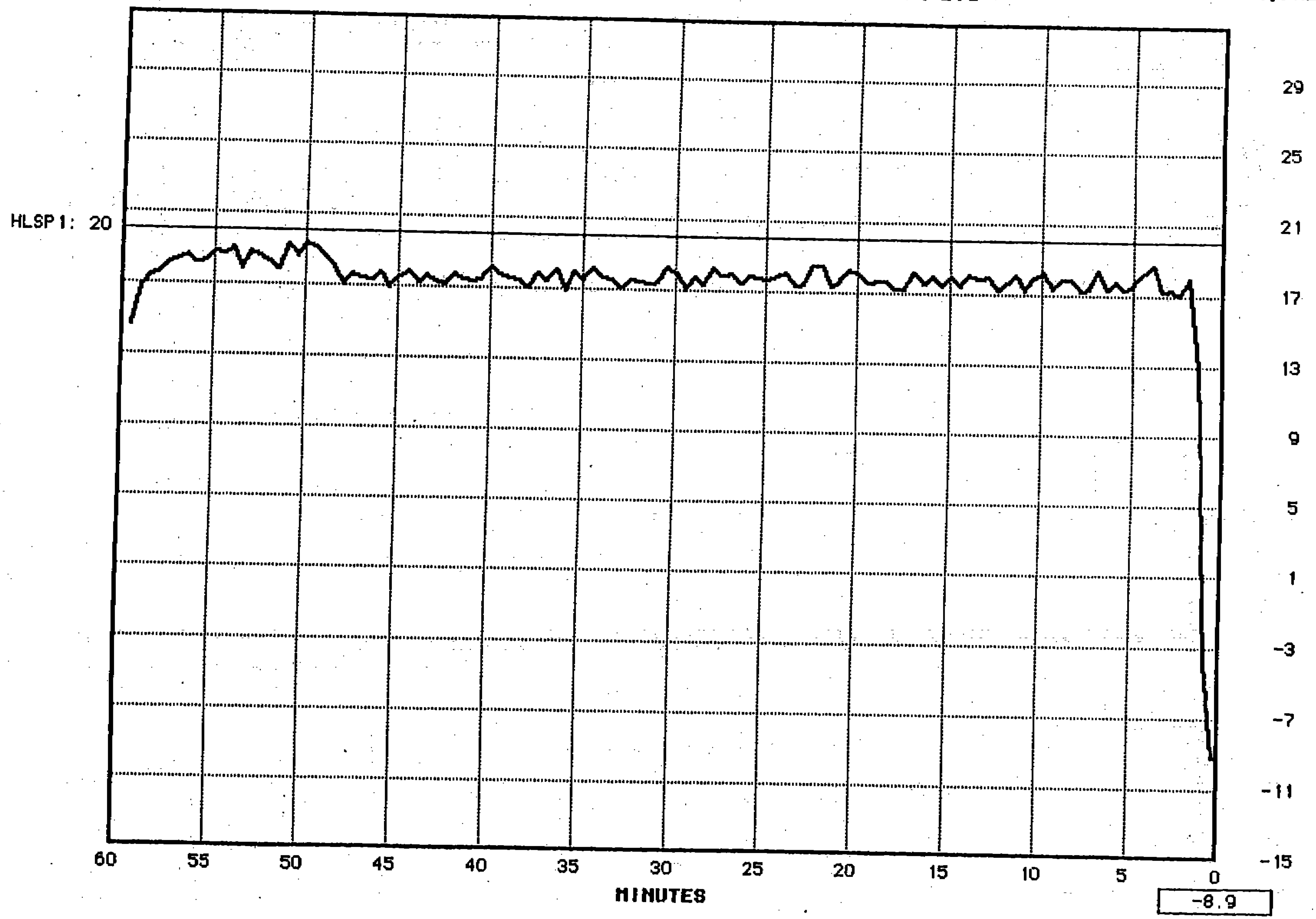

ENGINE #3 JACKET ATER TEMP DEGREES F
TEMP
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
HLSP1: 245
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
213.6
Generators 3 & 4
Tue, Jun 4, 1991
2:52:40 PM

GENERATOR FOUR KW OUTPUT

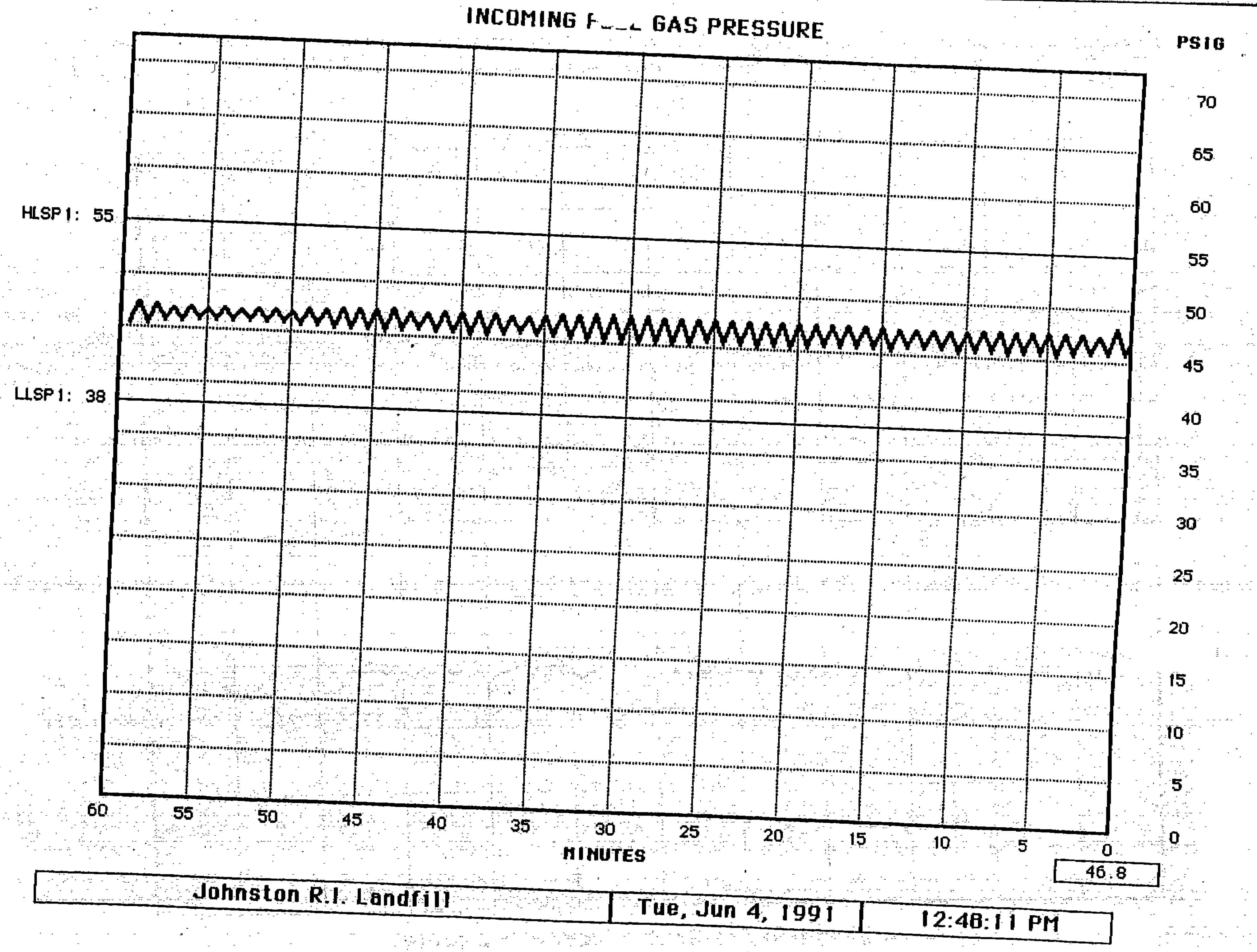


Johnston R.I. Landfill	Tue, Jun 4, 1991	12:48:11 PM

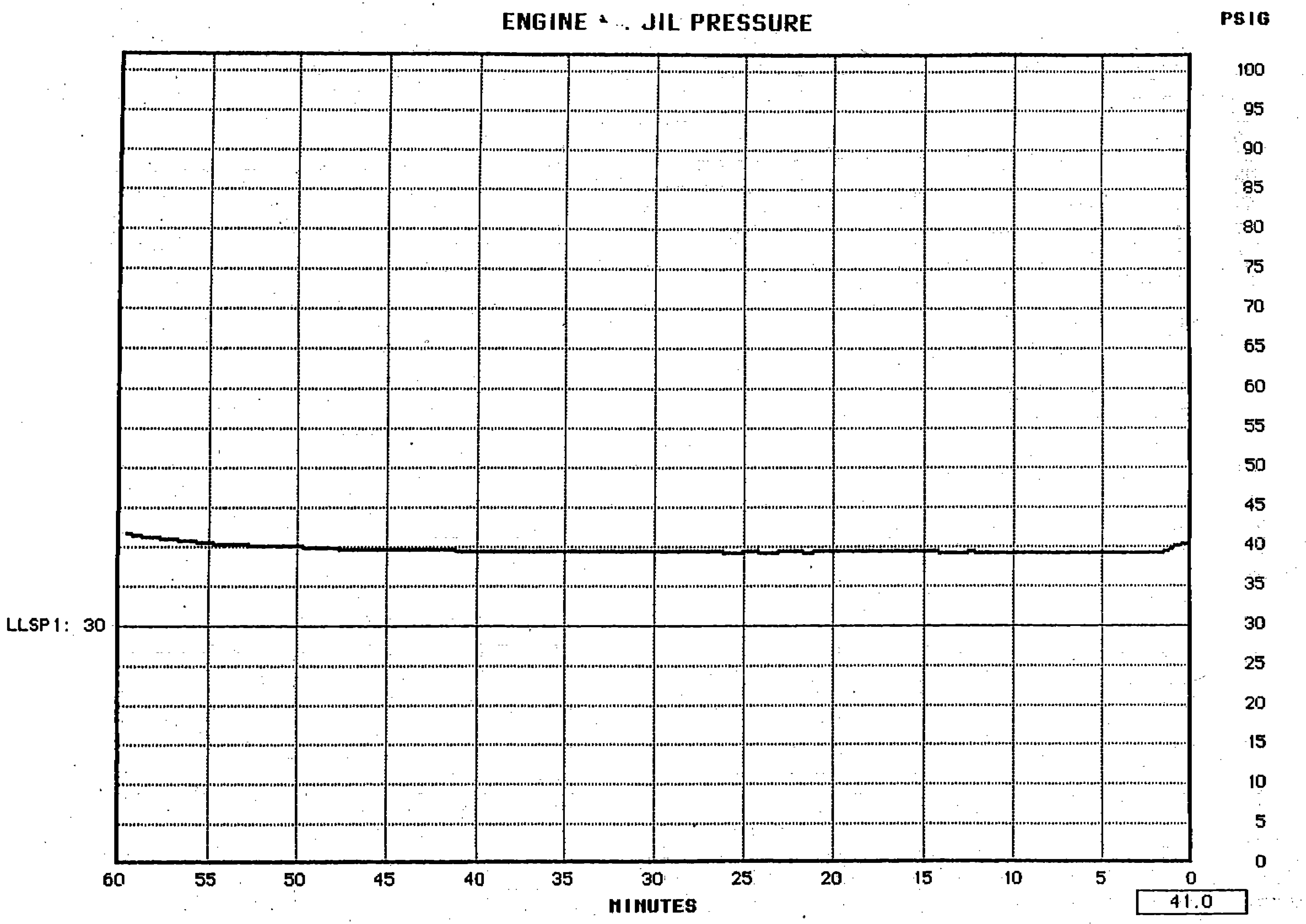
ENGINE #4 INTAKE _ .NIFOLD VAC/PRESS PSIG



Generators 3 & 4	Tue, Jun 4, 1991	12:48:11 PM

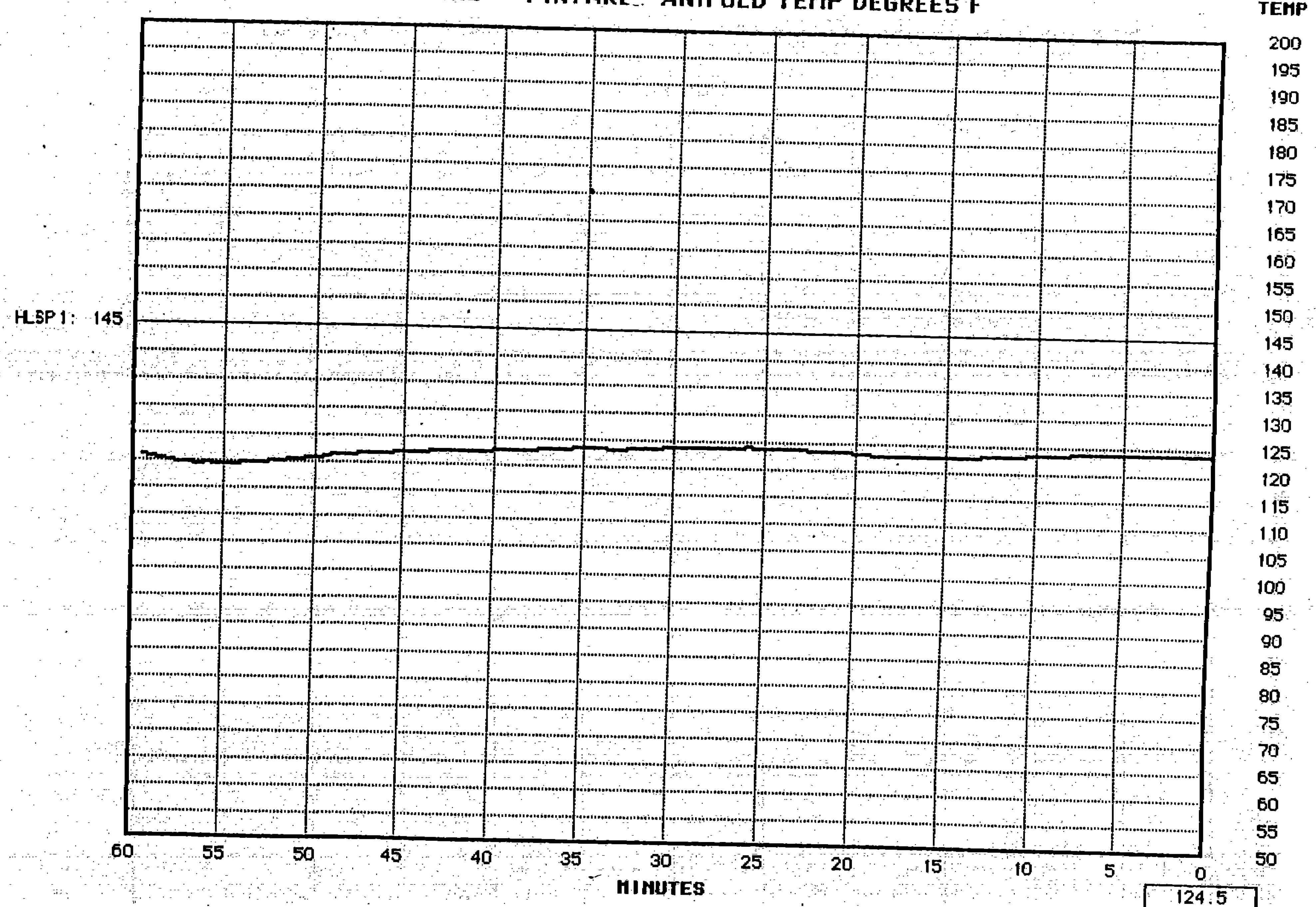


INCOMING F--L GAS PRESSURE
PSIG
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
HLSP1: 55
LLSP1: 38
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
46.8
Johnston R.I. Landfill
Tue, Jun 4, 1991
12:48:11 PM



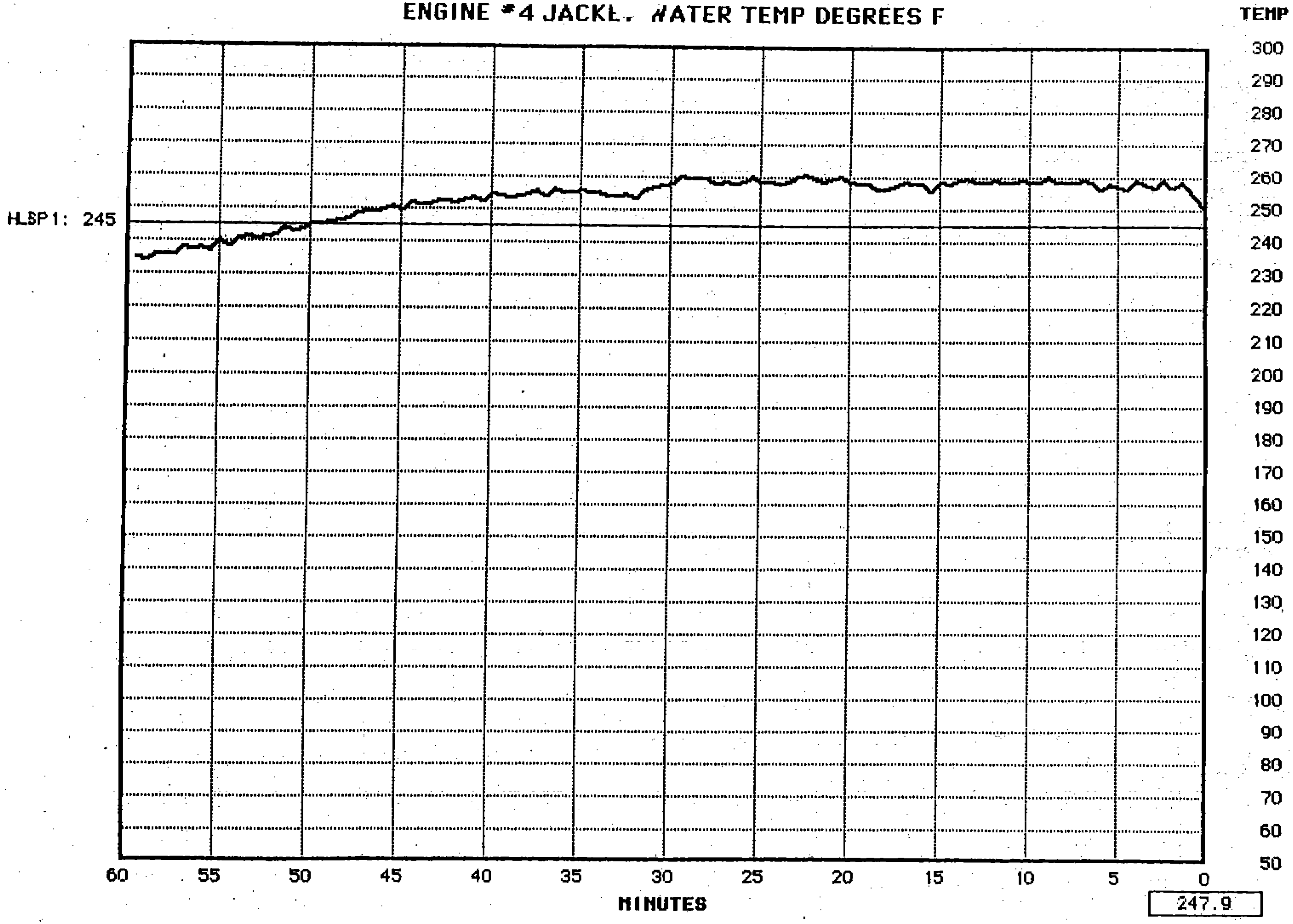
Generators 3 & 4	Tue, Jun 4, 1991	12:48:11 PM

ENGINE *4 INTAKL_ ANIFOLD TEMP DEGREES F

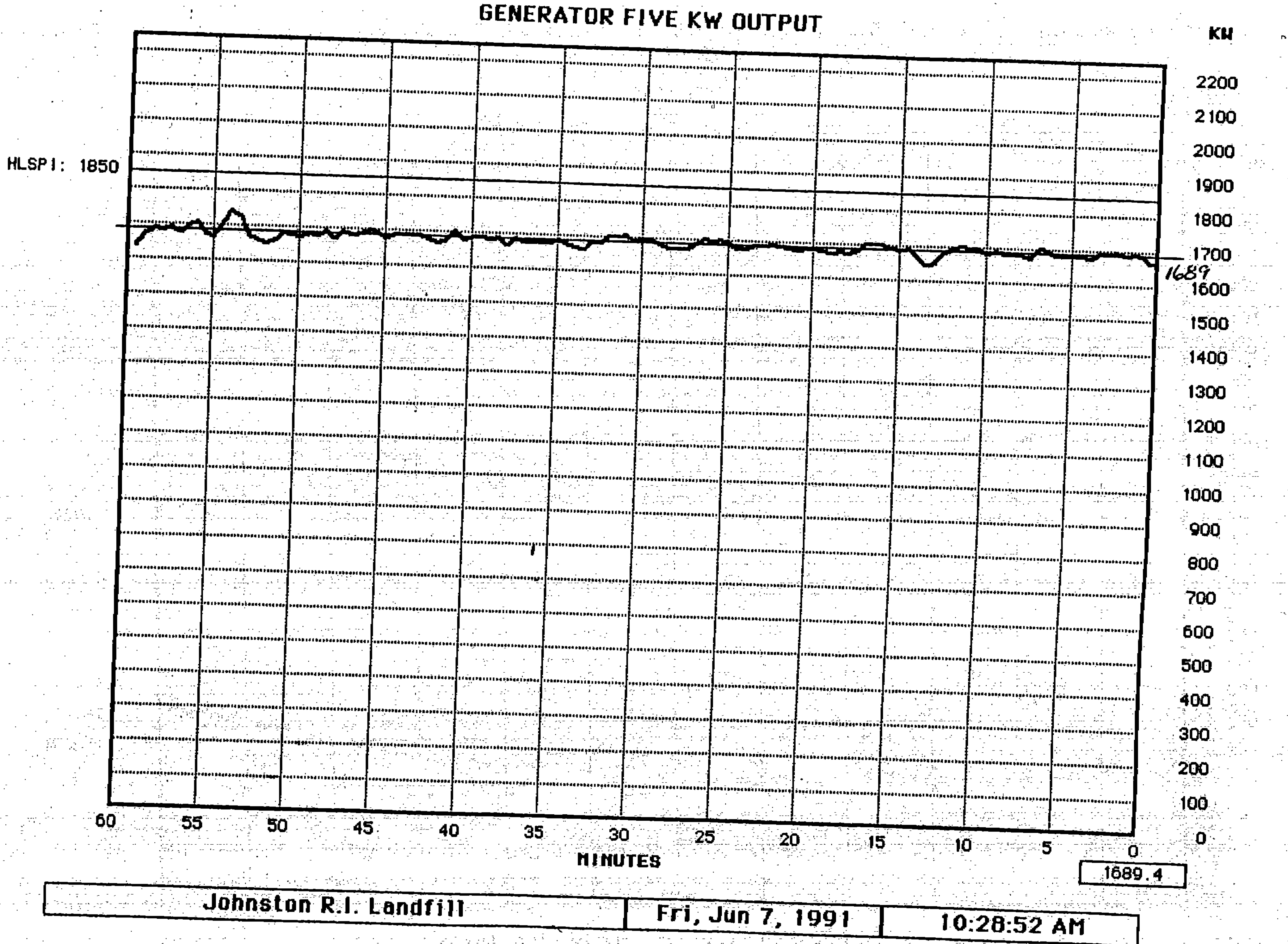


Generators 3 & 4 | Tue, Jun 4, 1991 | 12:48:11 PM

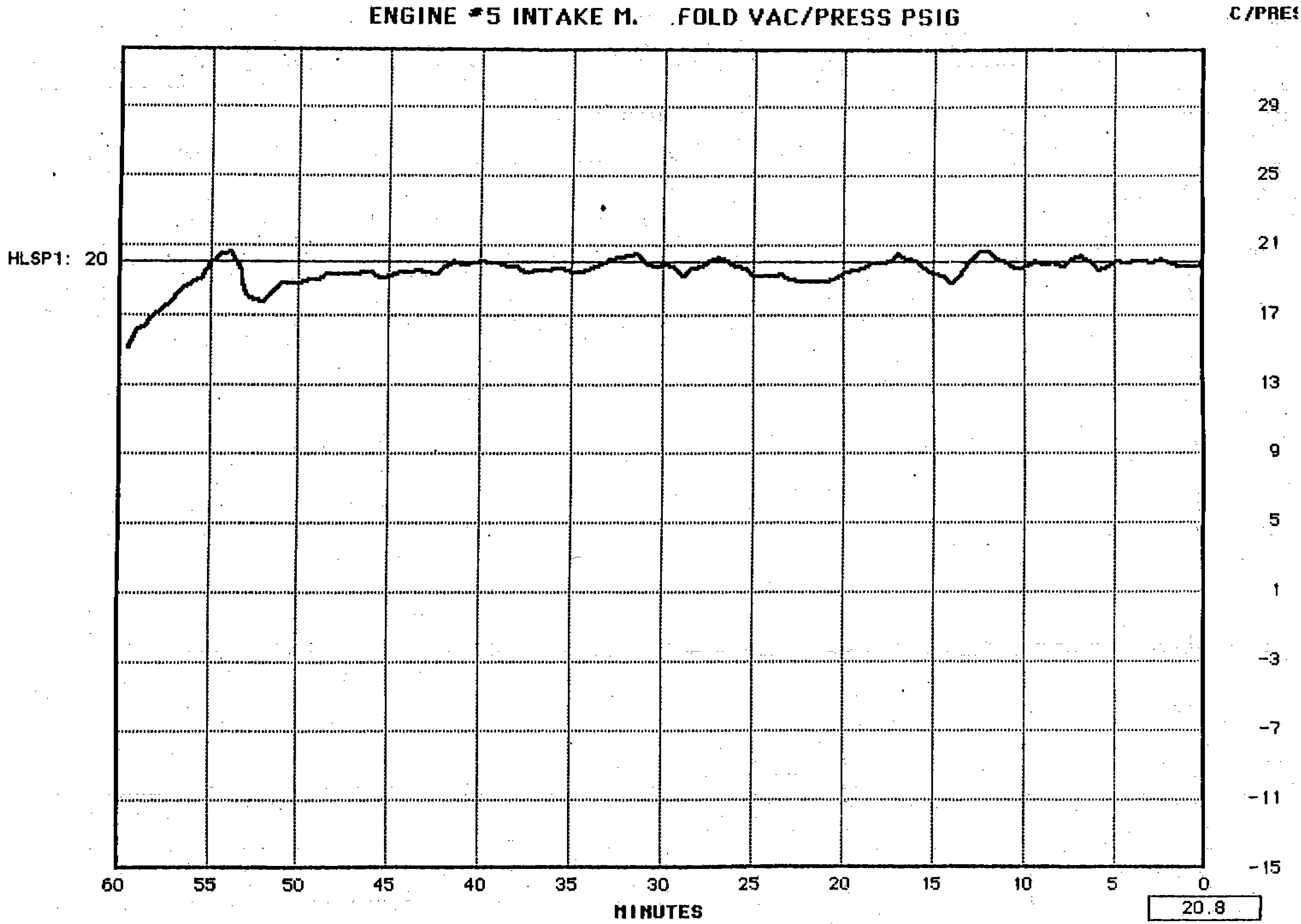
ENGINE #4 JACKE.. WATER TEMP DEGREES F



Generators 3 & 4	Tue, Jun 4, 1991	12:48:11 PM

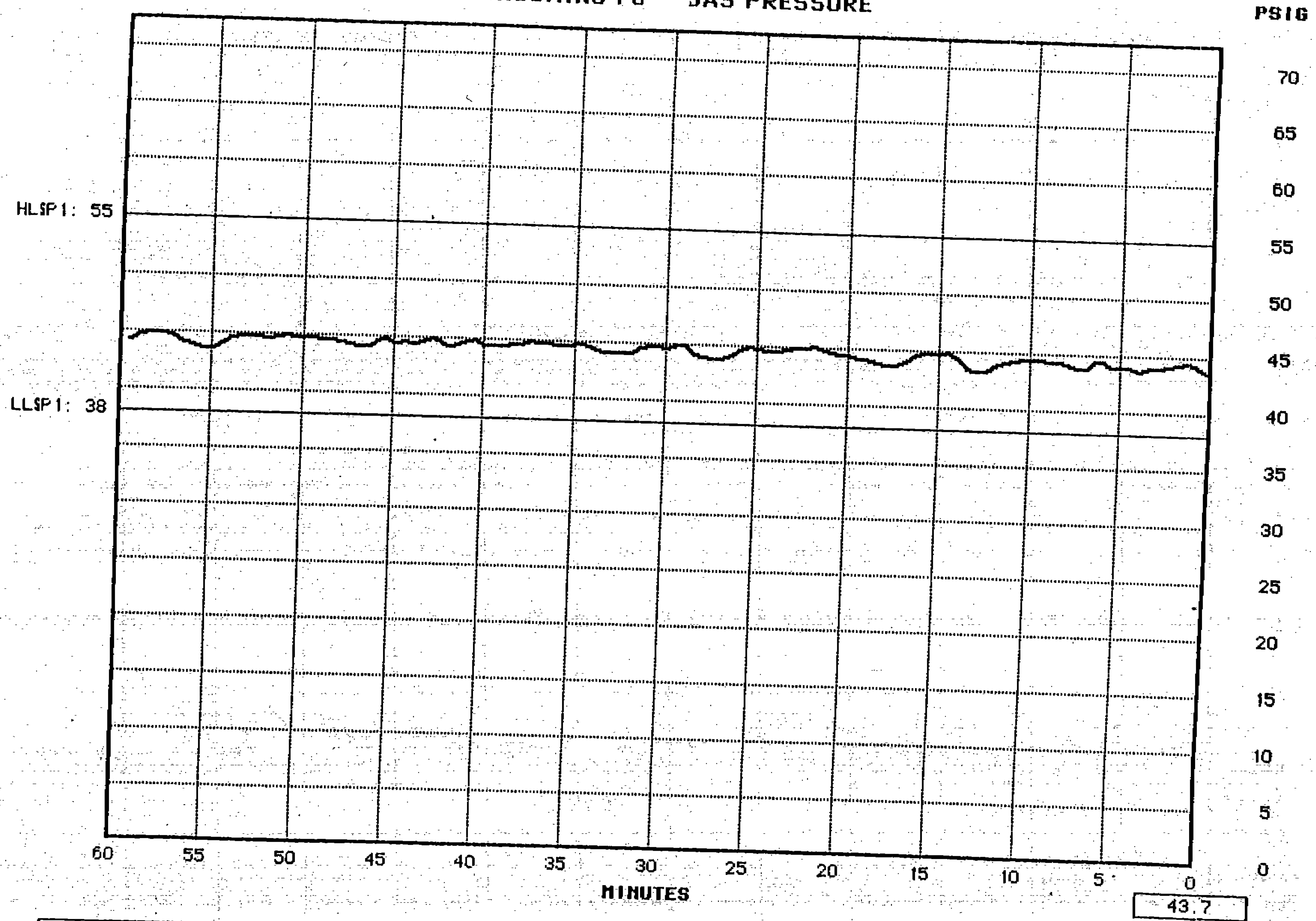

GENERATOR FIVE KW OUTPUT
KW
2200
2100
2000
1900
1800
1700
1689
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
HLSPI: 1850
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
1689.4
Johnston R.I. Landfill
Fri, Jun 7, 1991
10:28:52 AM

ENGINE #5 INTAKE M. .FOLD VAC/PRESS PSIG



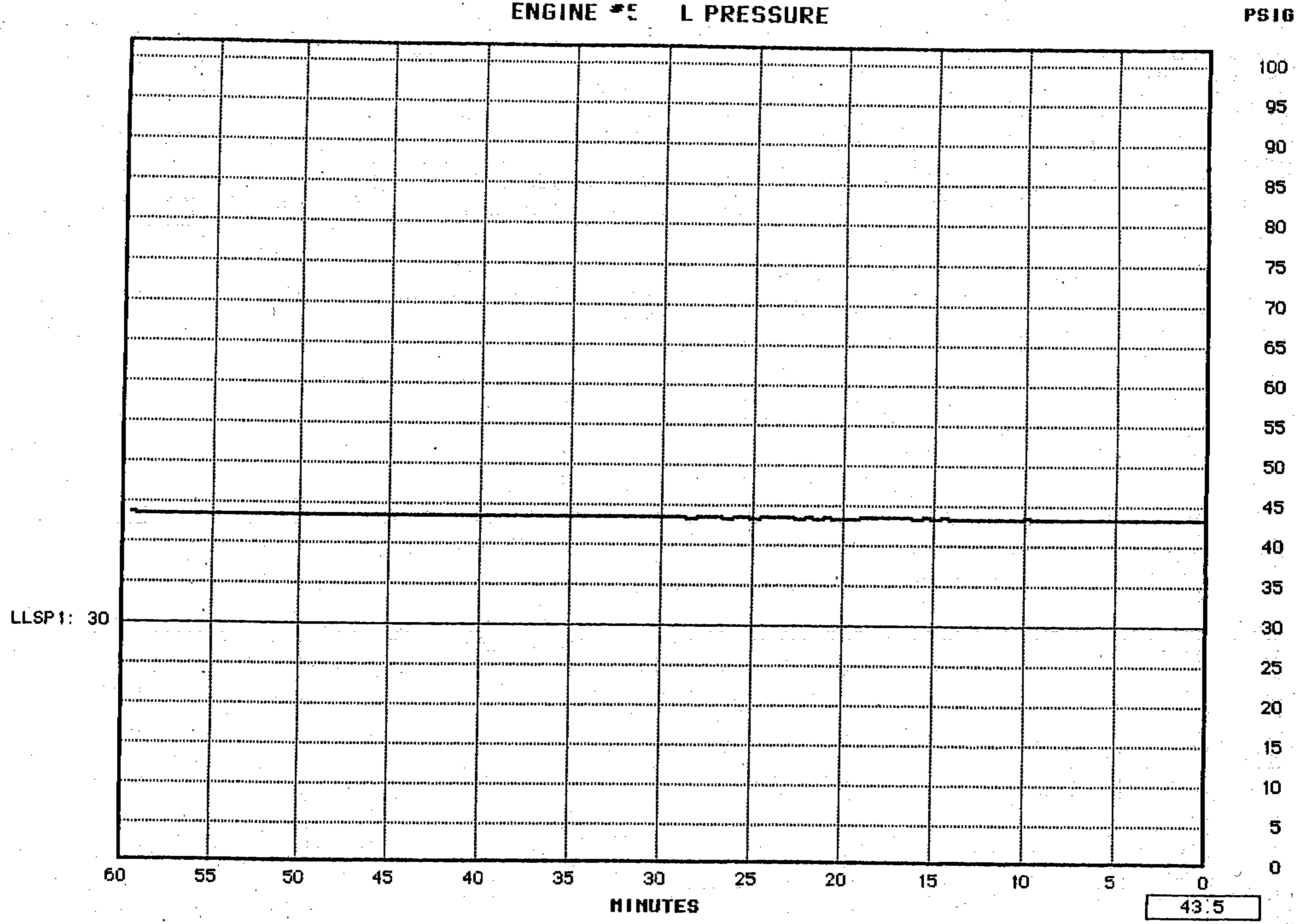
Generators 5 & 6	Fri, Jun 7, 1991	10:28:52 AM

INCOMING FU   GAS PRESSURE



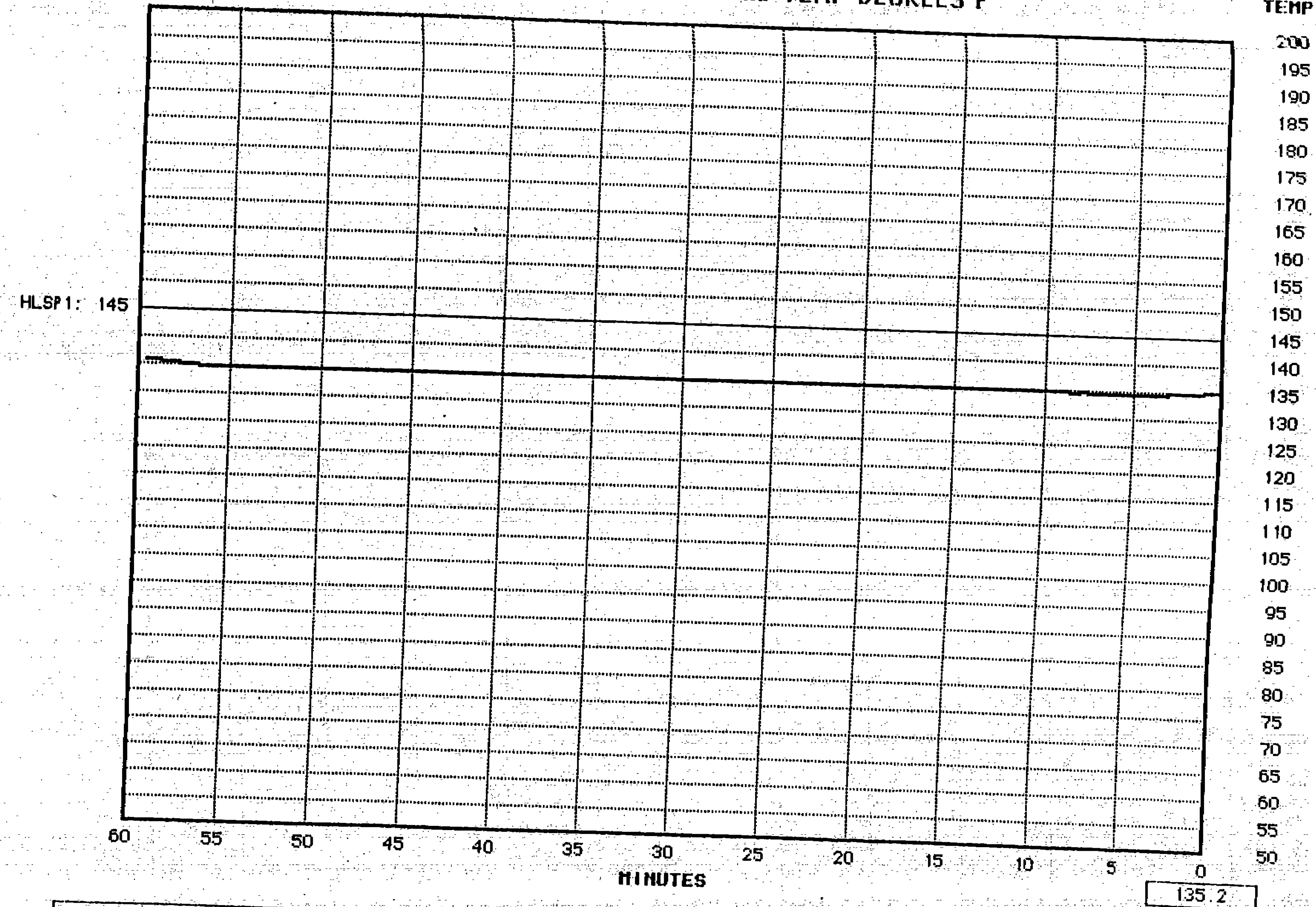
Johnston R.I. Landfill	Fri, Jun 7, 1991	10:28:52 AM

ENGINE #5 L PRESSURE



Generators 5 & 6	Fri, Jun 7, 1991	10:28:52 AM

ENGINE #5 INTAKE ....NIFOLD TEMP DEGREES F

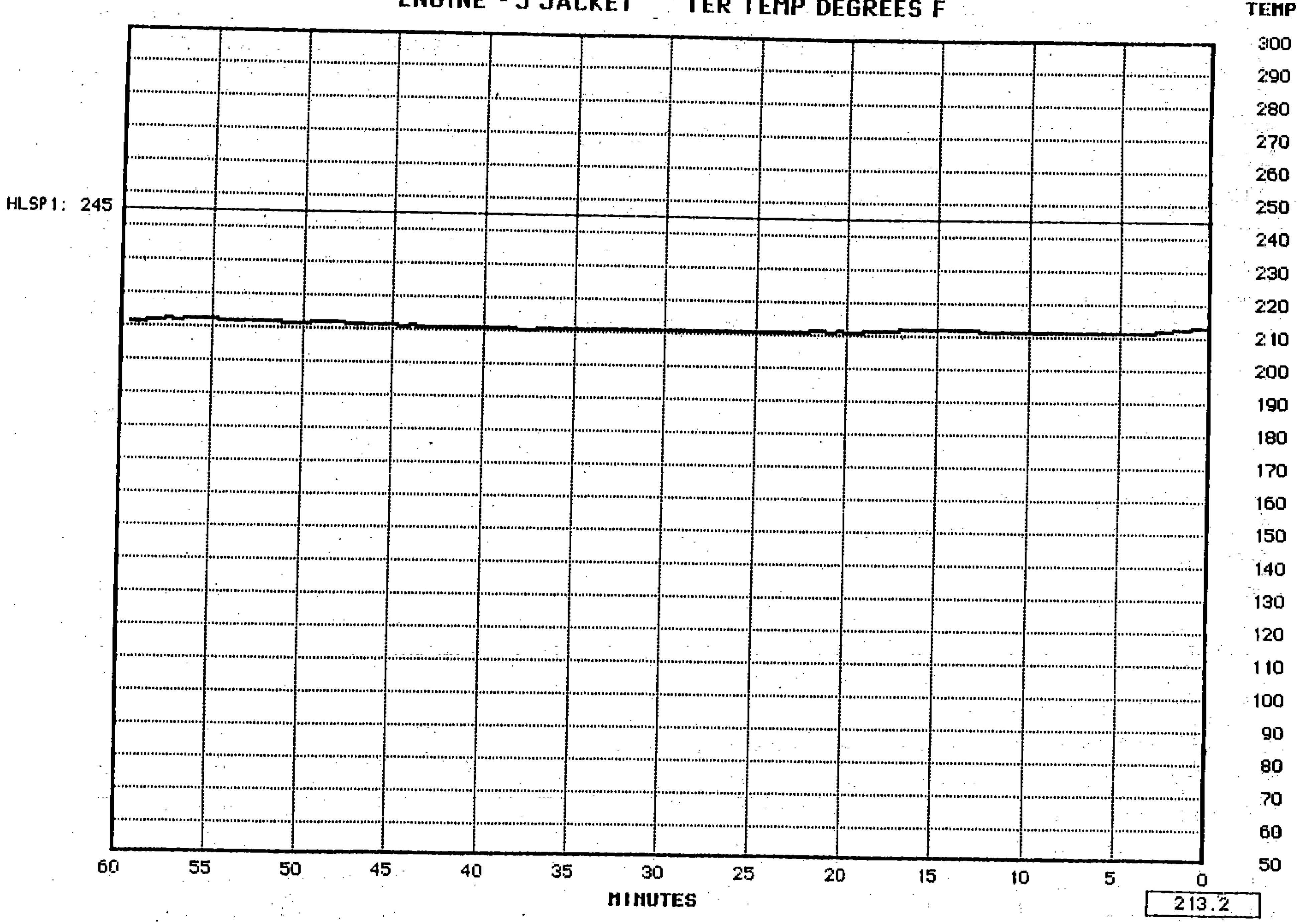


Generators 5 & 6

Fri, Jun 7, 1991

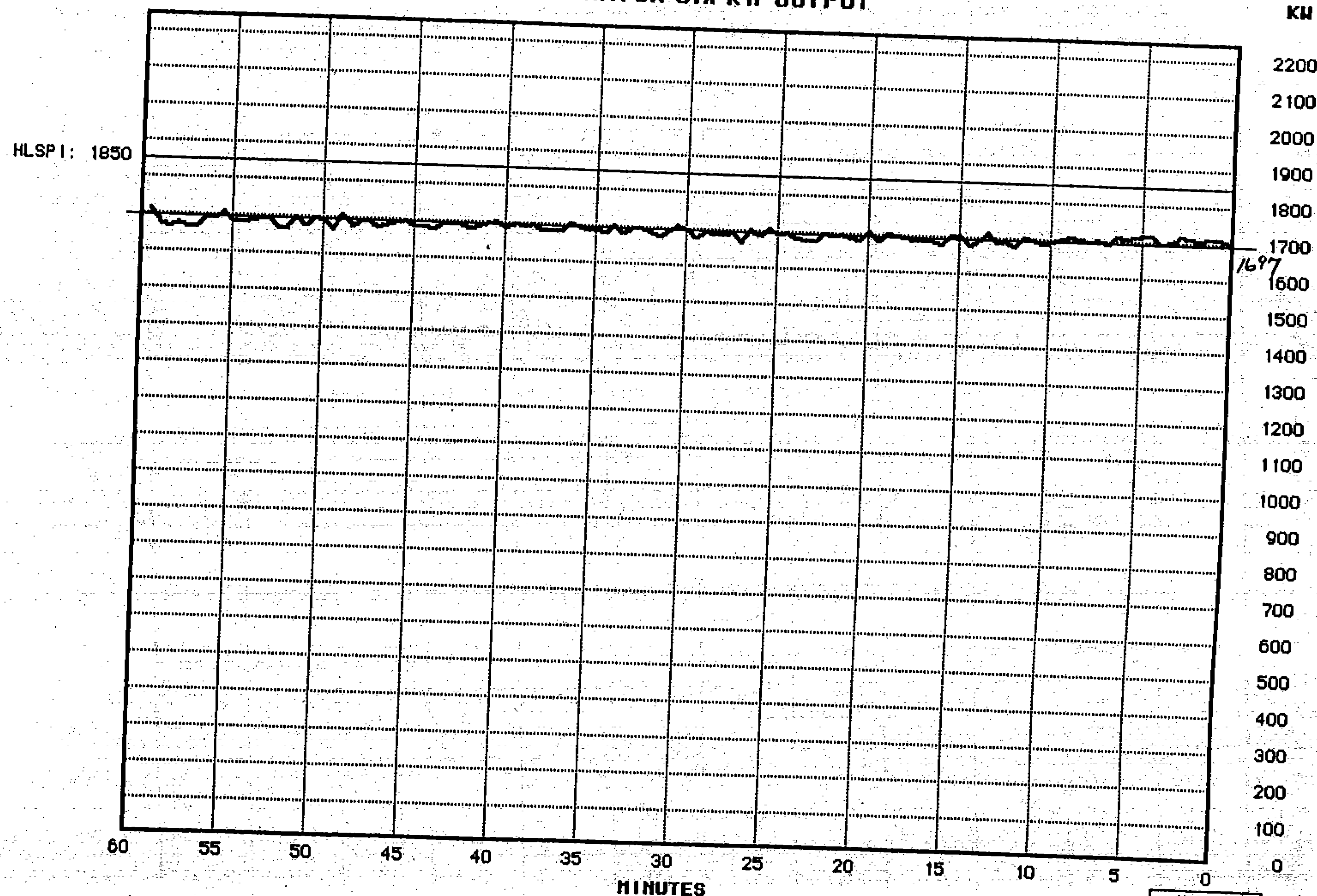
10:28:52 AM

ENGINE #5 JACKET TER TEMP DEGREES F



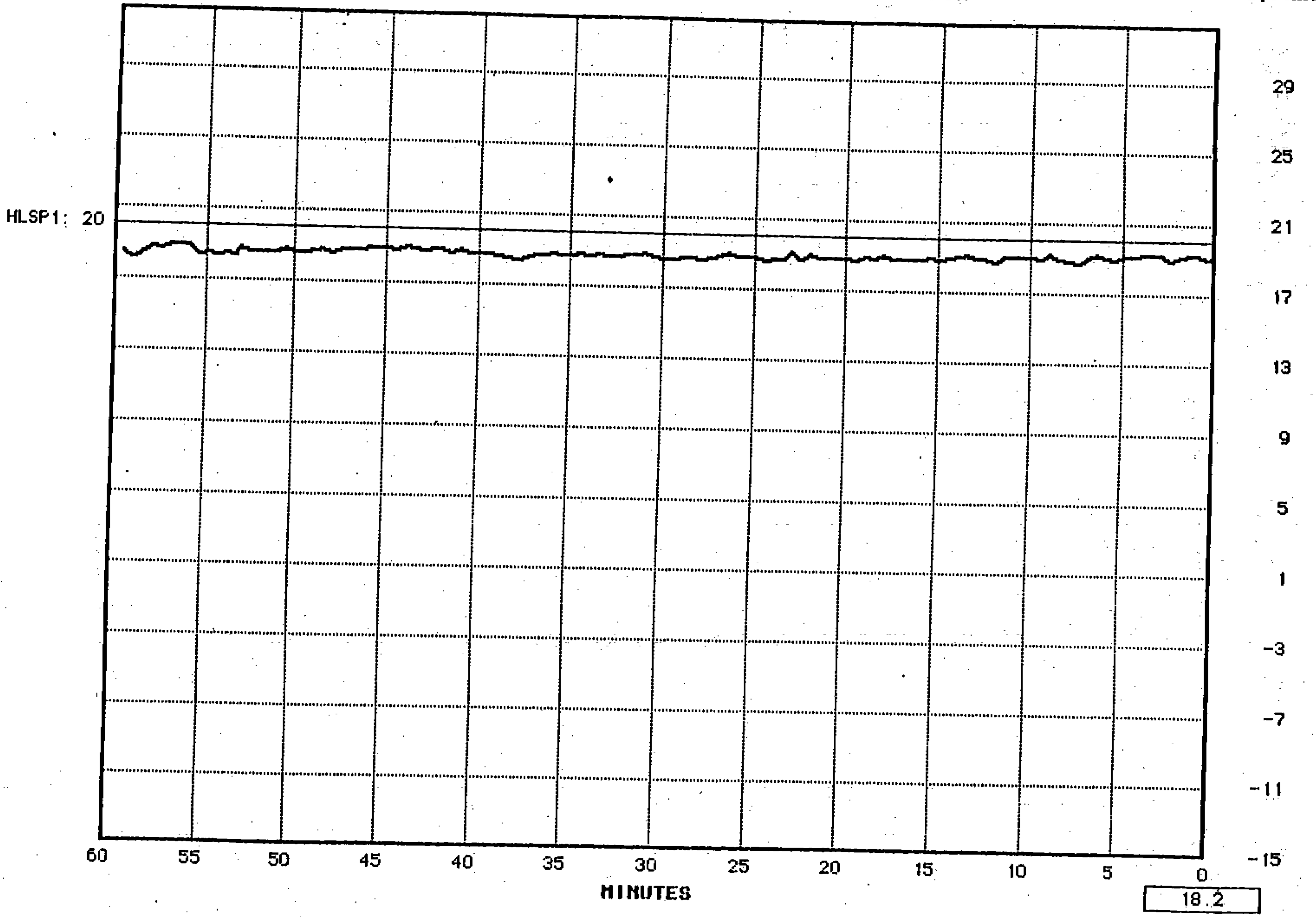
Generators 5 & 6	Fri, Jun 7, 1991	10:28:52 AM

GENERATOR SIX KW OUTPUT

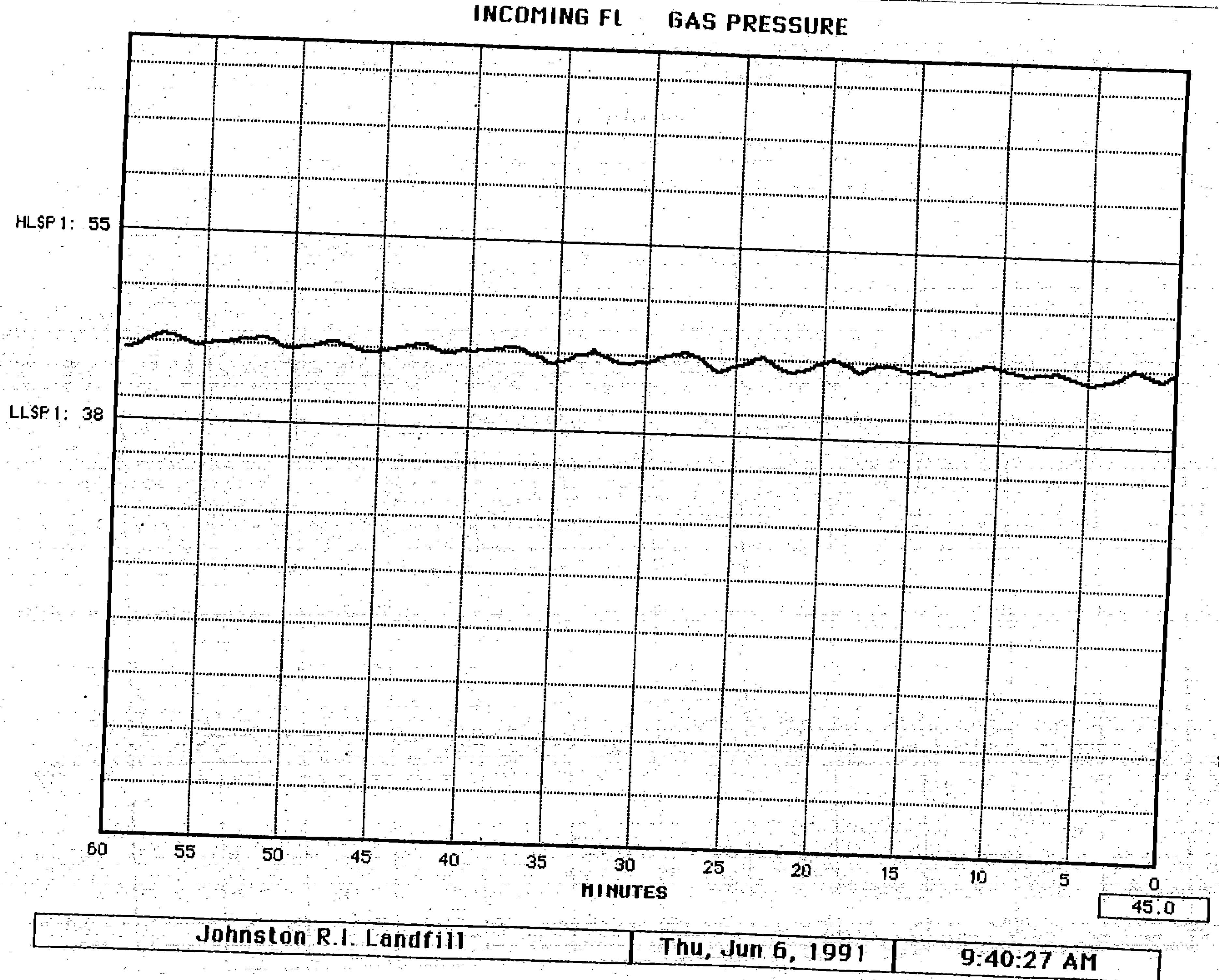


Johnston R.I. Landfill	Thu, Jun 6, 1991	9:40:27 AM

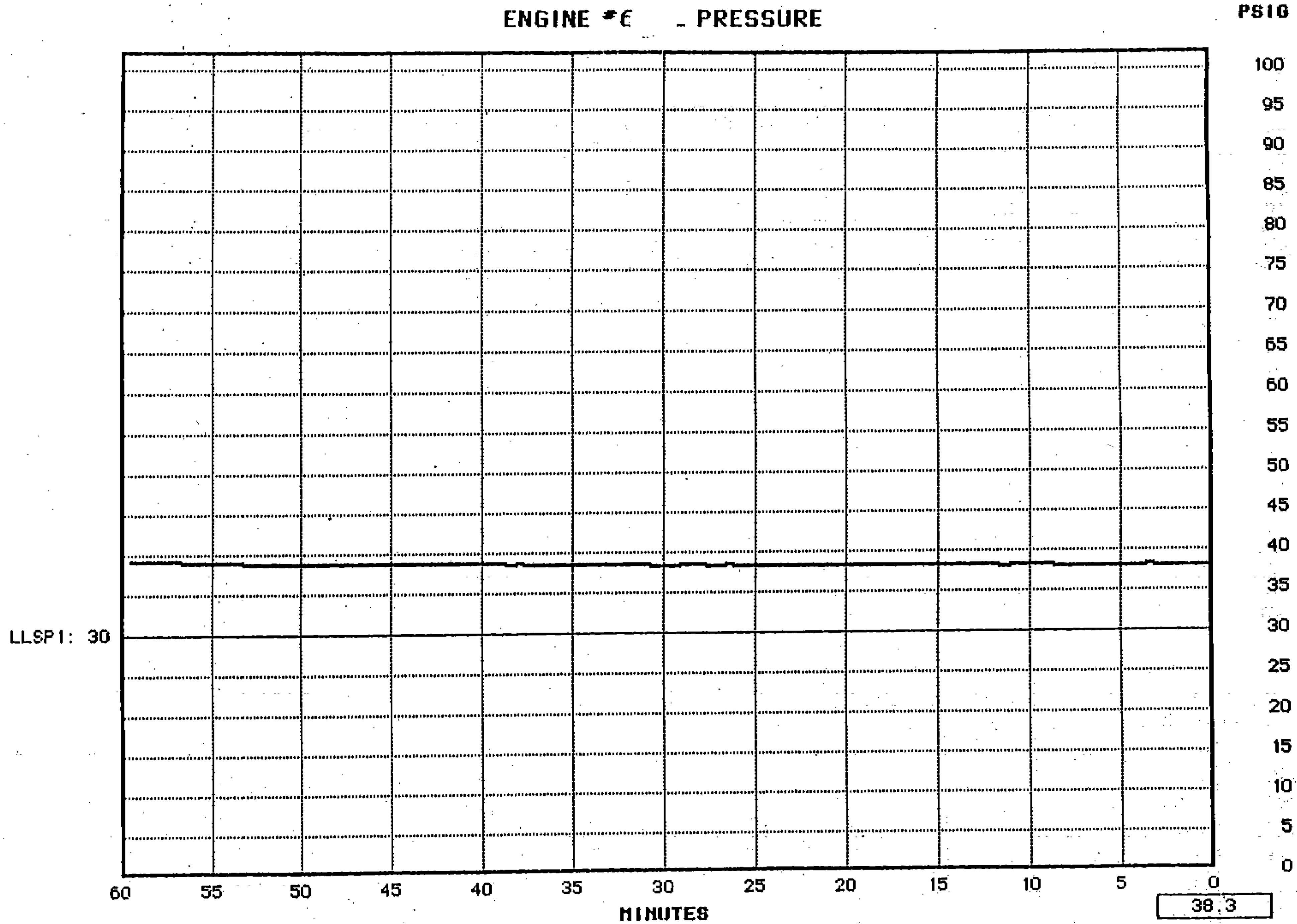
ENGINE #6 INTAKE MA FOLD VAC/PRESS PSIG



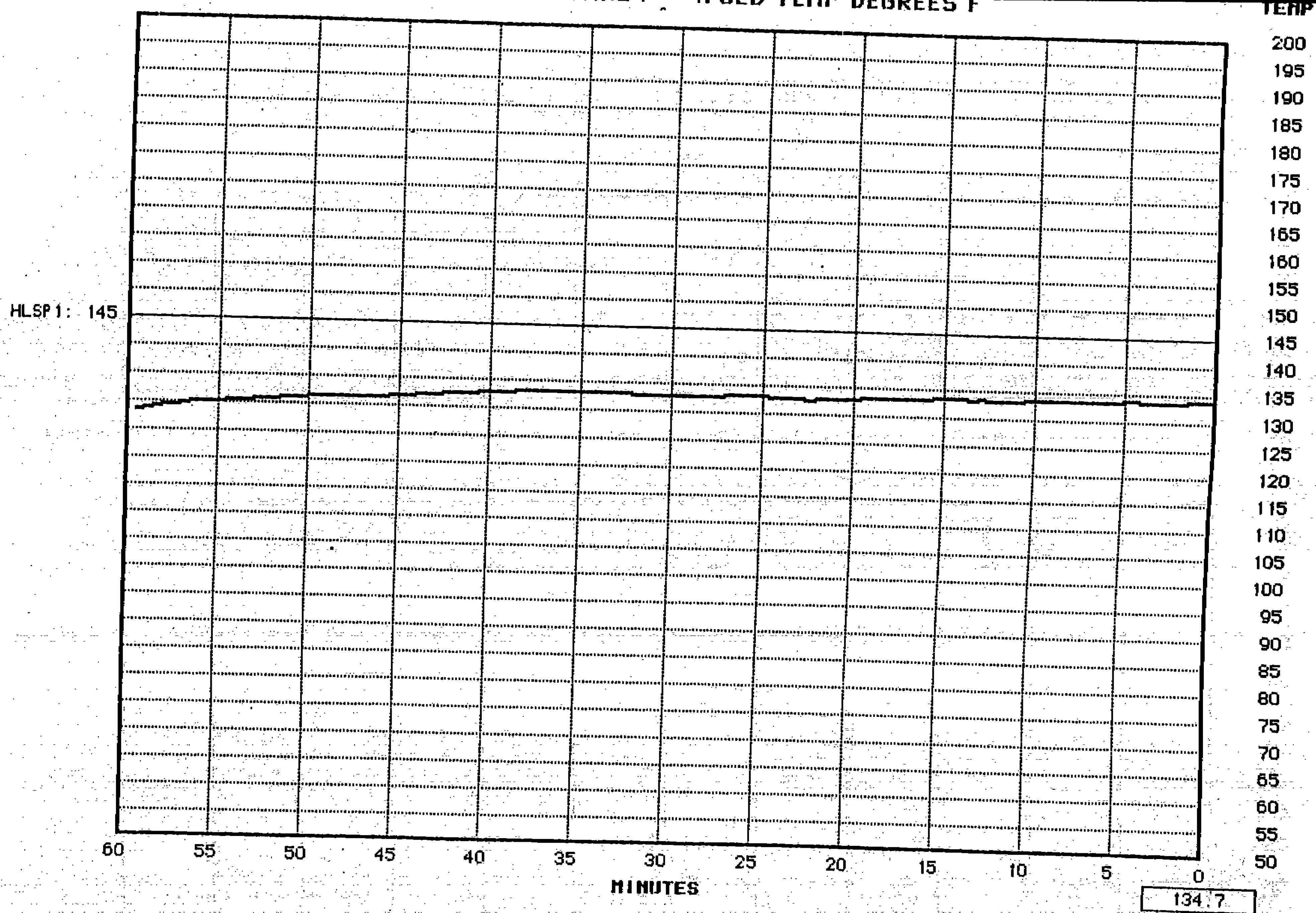
Generators 5 & 6	Thu, Jun 6, 1991	9:40:27 AM


INCOMING FL GAS PRESSURE
PSIG
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
HLSP1: 55
LLSP1: 38
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
45.0
Johnston R.I. Landfill
Thu, Jun 6, 1991
9:40:27 AM

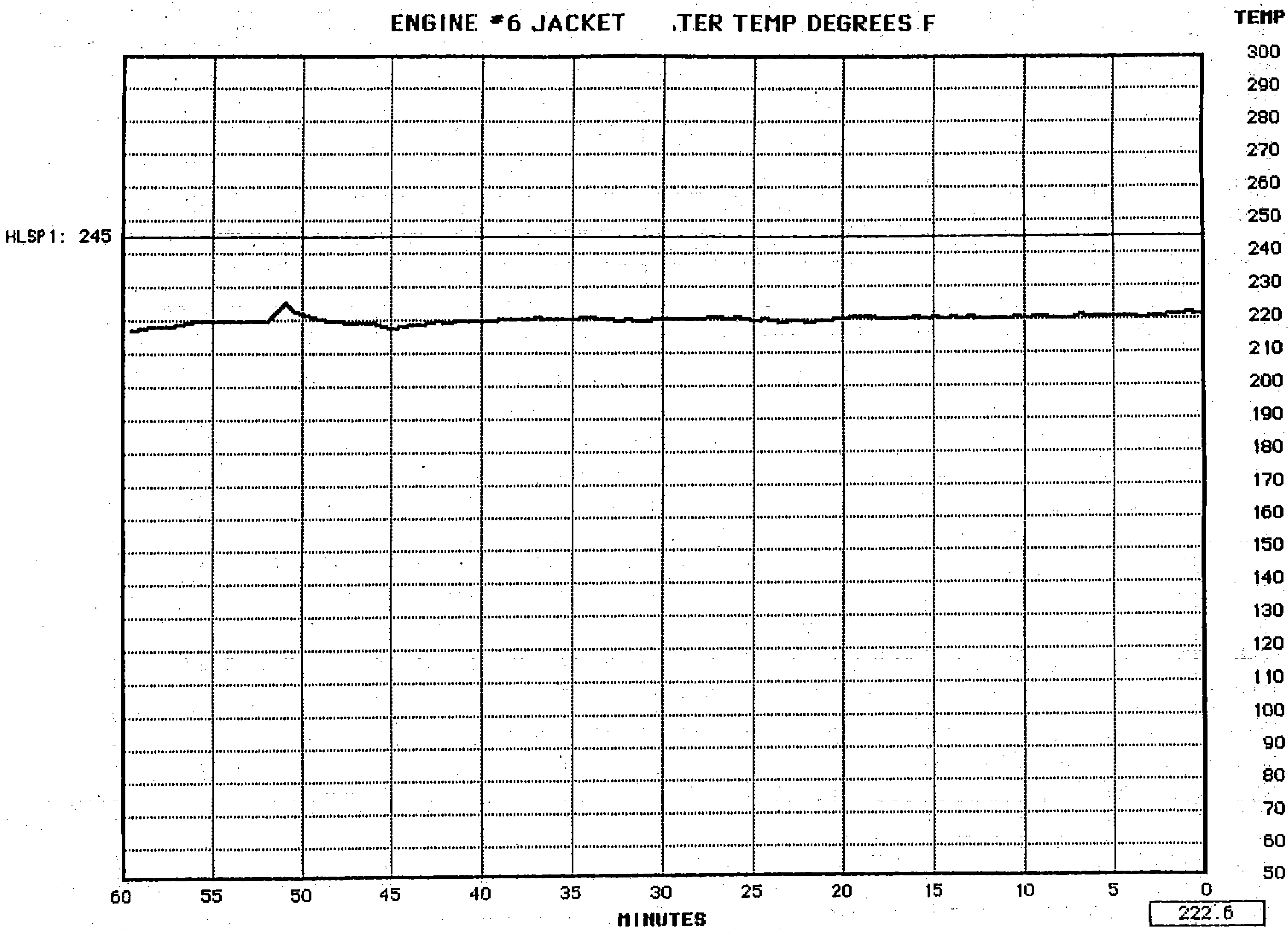
ENGINE #6 _ PRESSURE



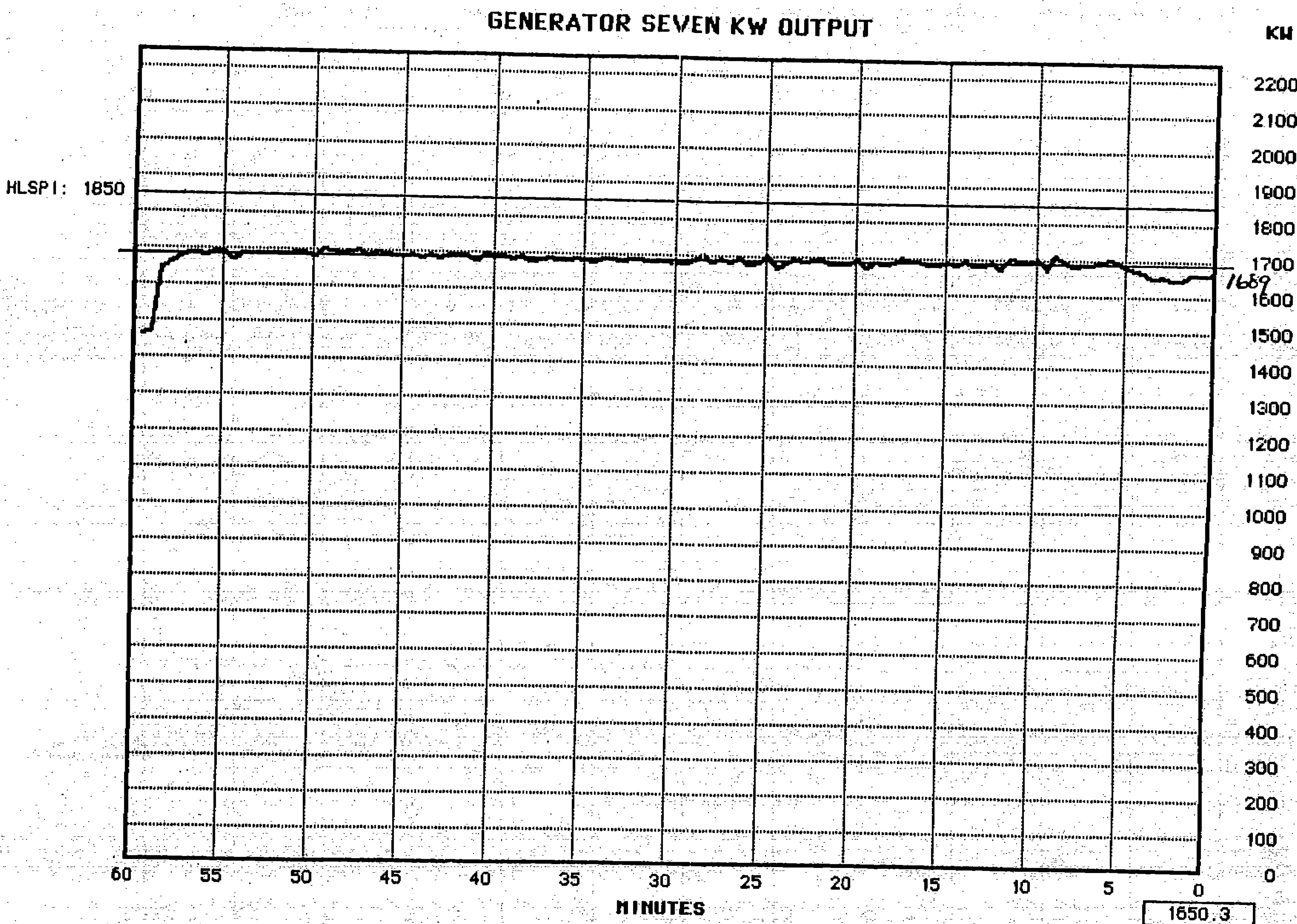
Generators 5 & 6	Thu, Jun 6, 1991	9:40:27 AM



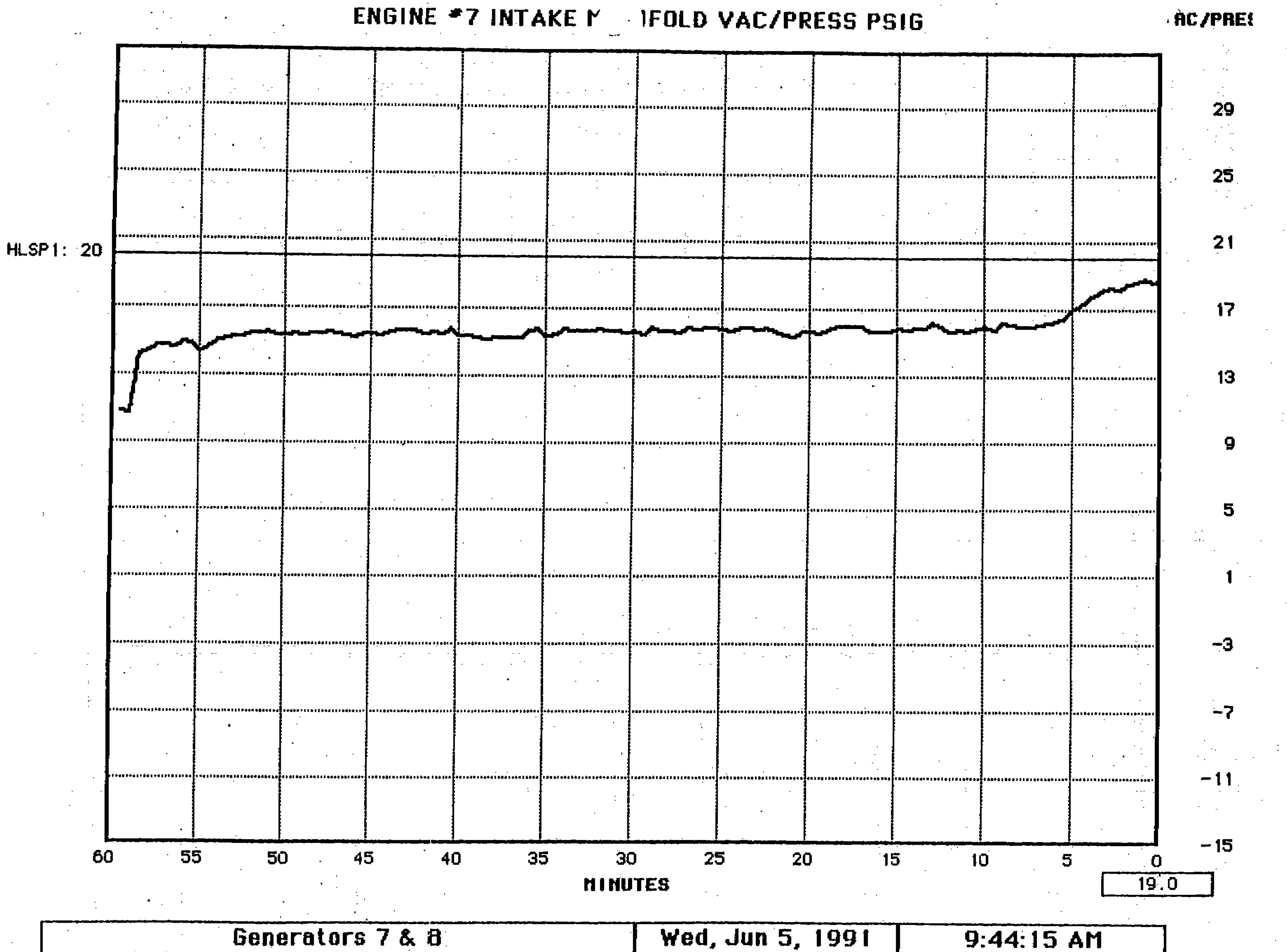
Generators 5 & 6 | Thu, Jun 6, 1991 | 9:40:27 AM



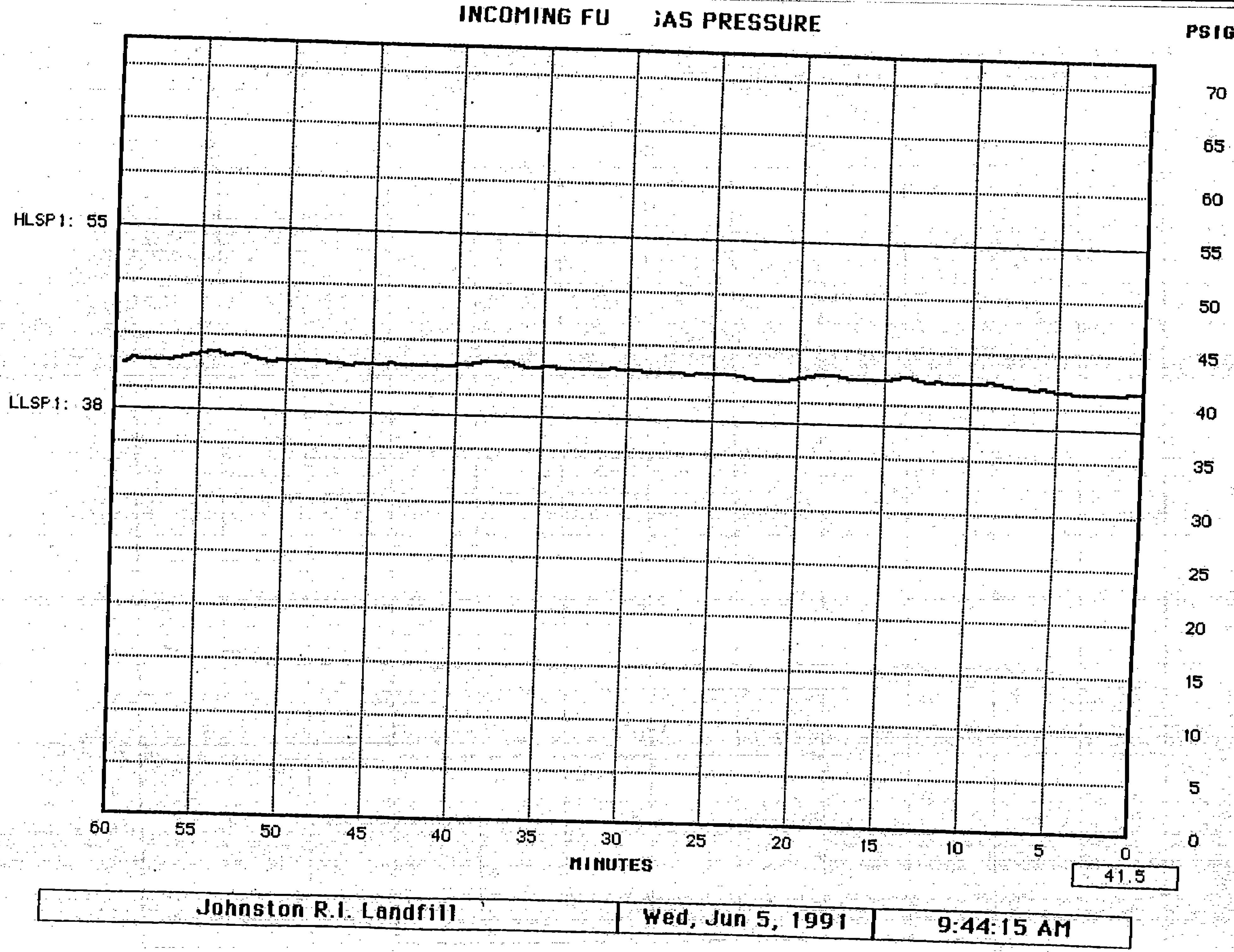
Generators 5 & 6	Thu, Jun 6, 1991	9:40:27 AM



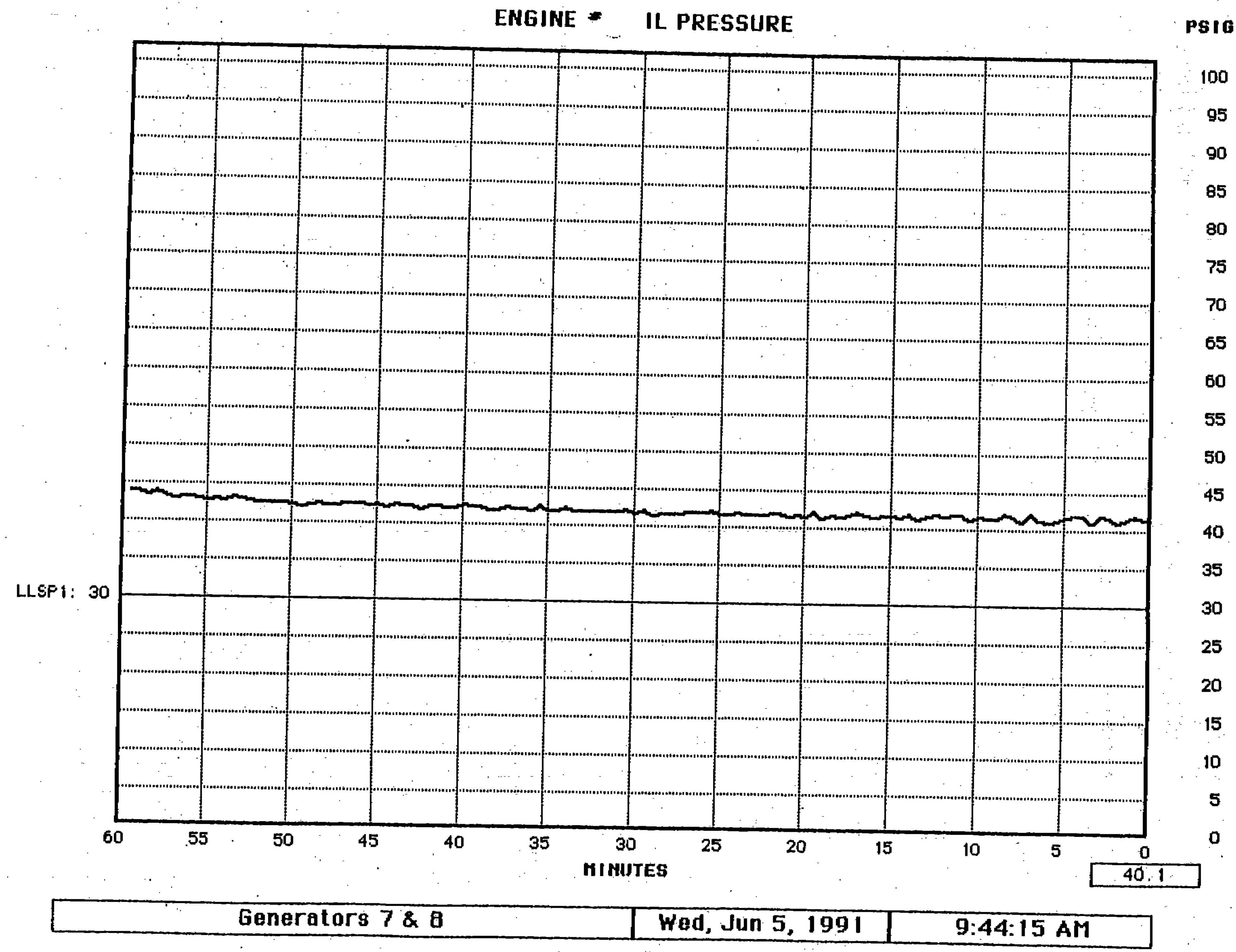
Johnston R.I. Landfill	Wed, Jun 5, 1991	9:44:15 AM



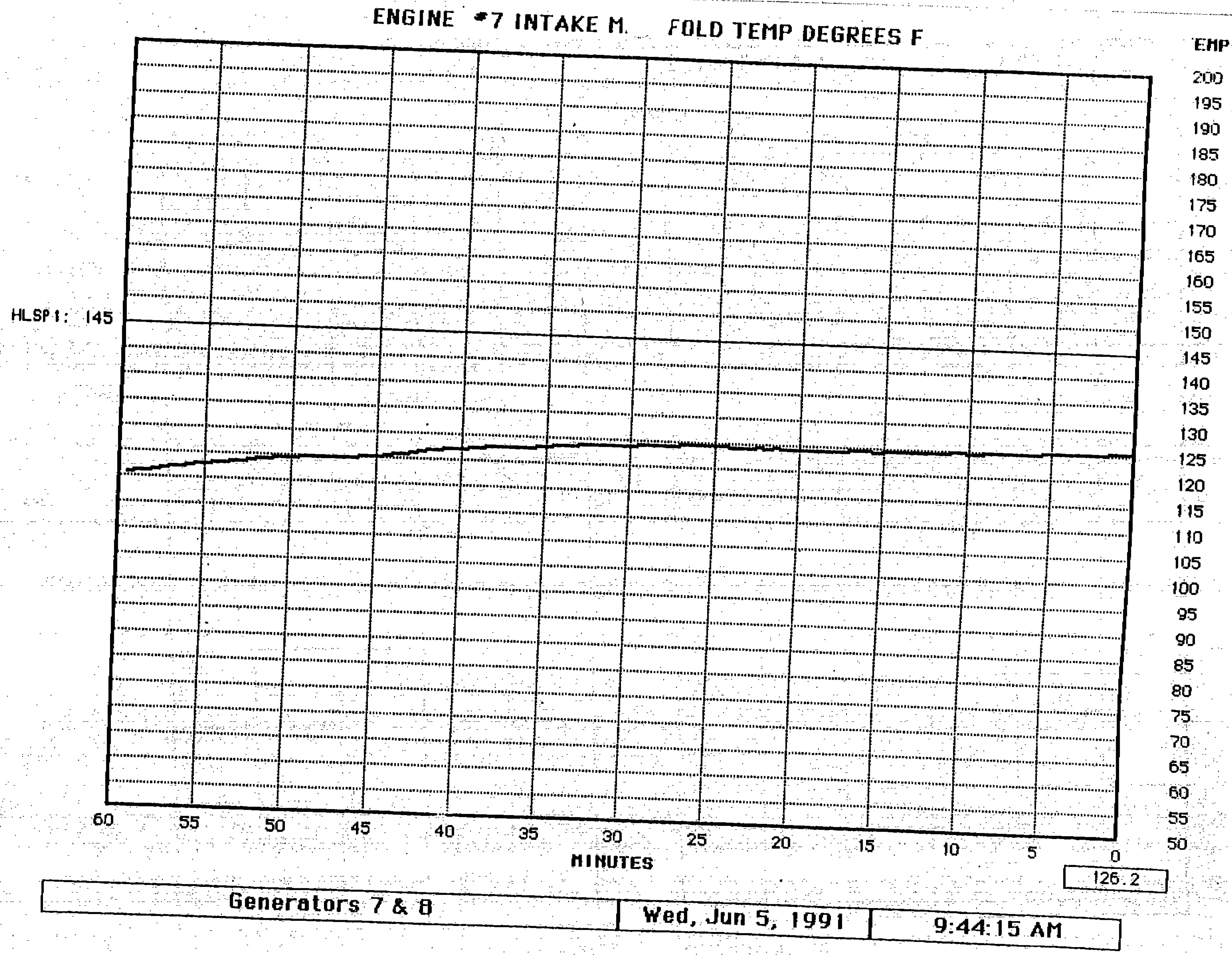
ENGINE #7 INTAKE M IFOLD VAC/PRESS PSIG
AC/PRES
HLSP1: 20
29
25
21
17
13
9
5
1
-3
-7
-11
-15
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
19.0
Generators 7 & 8
Wed, Jun 5, 1991
9:44:15 AM

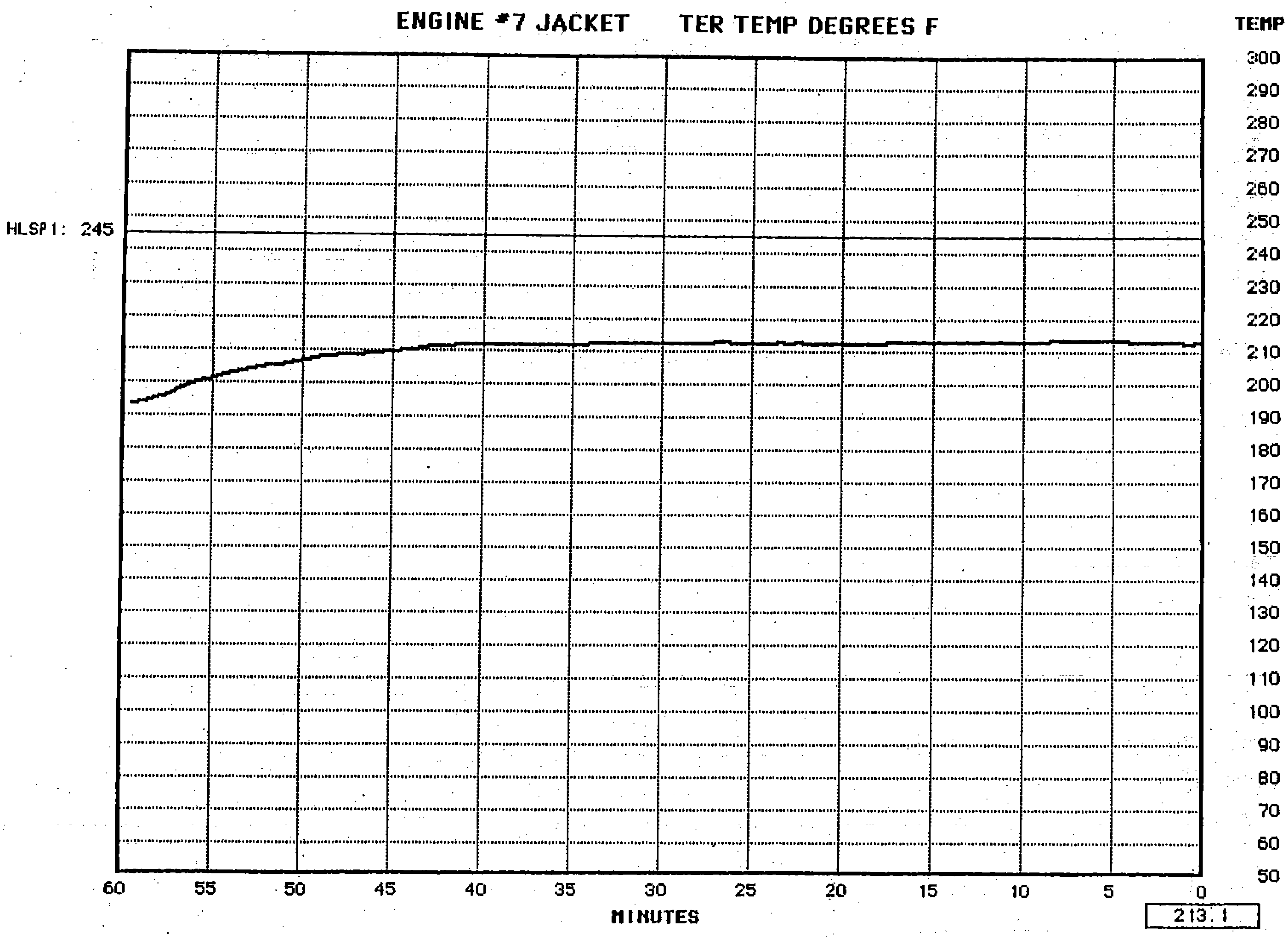


INCOMING FU ;AS PRESSURE
PSIG
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
HLSP1: 55
LLSP1: 38
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
41.5
Johnston R.I. Landfill
Wed, Jun 5, 1991
9:44:15 AM

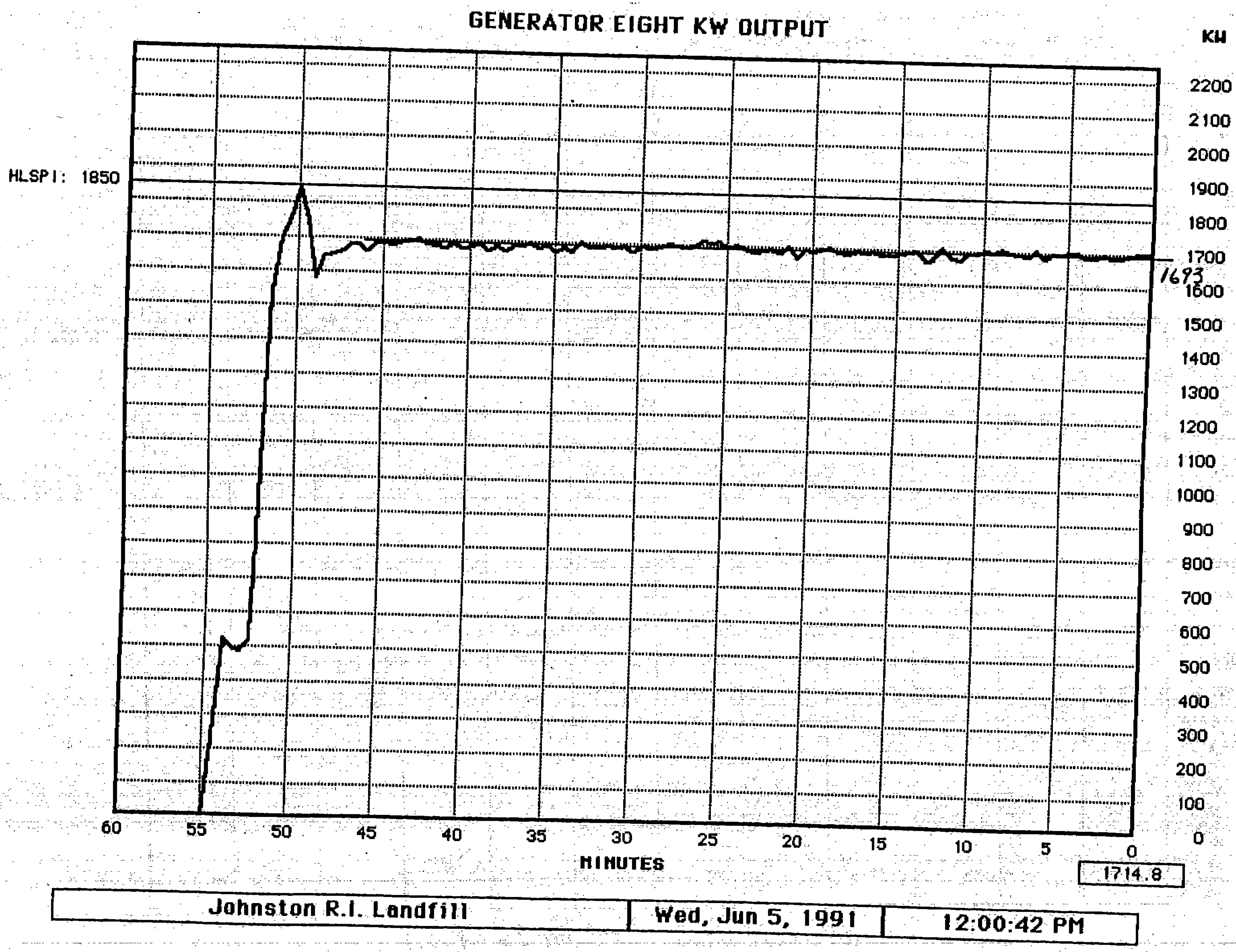


ENGINE * IL PRESSURE
PSIG
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
LLSP1: 30
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
40.1
Generators 7 & 8
Wed, Jun 5, 1991
9:44:15 AM


ENGINE #7 INTAKE M. FOLD TEMP DEGREES F
EMP
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
HLSP1: 145
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
126.2
Generators 7 & 8
Wed, Jun 5, 1991
9:44:15 AM

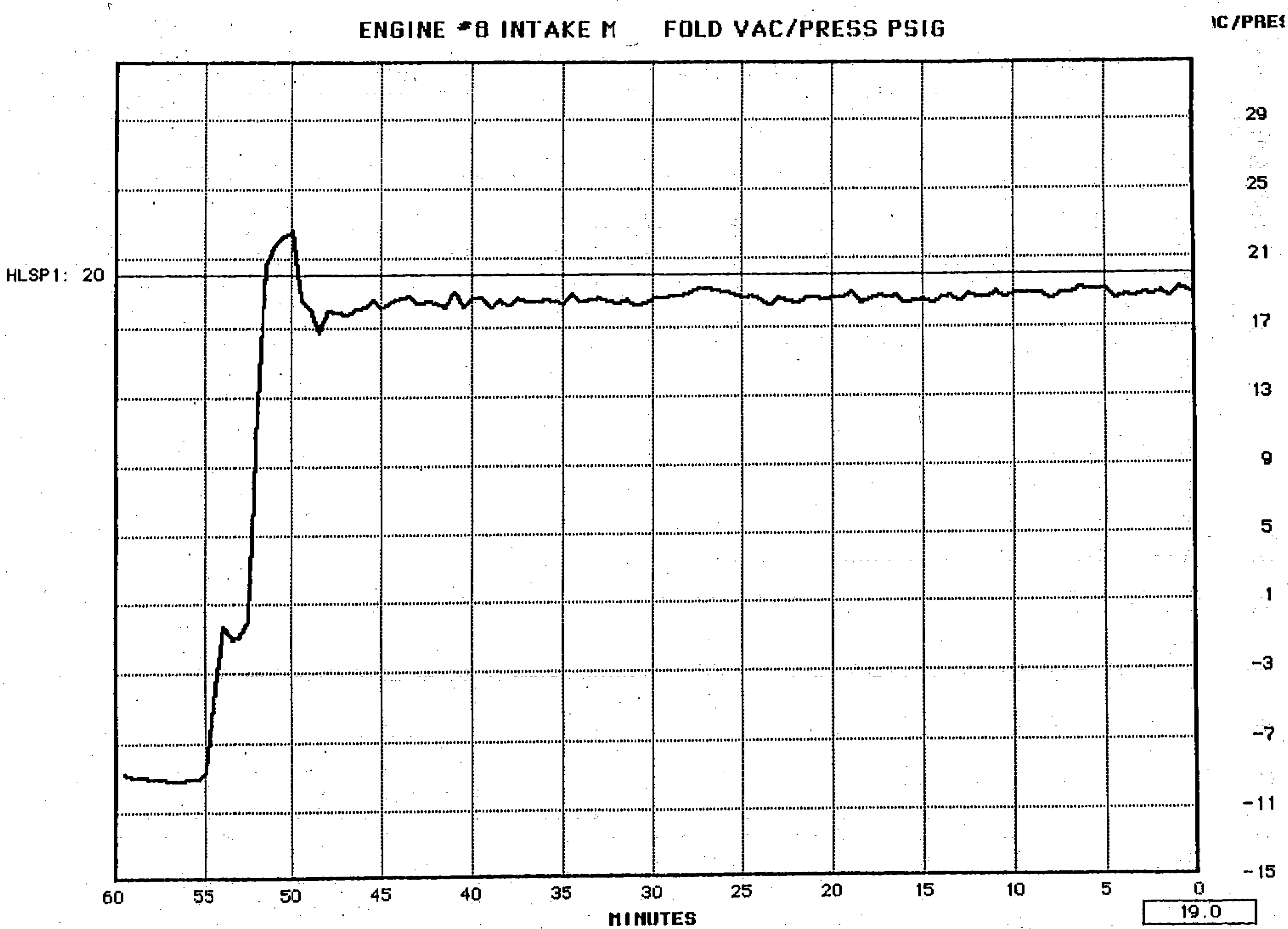


Generators 7 & 8	Wed, Jun 5, 1991	9:44:15 AM



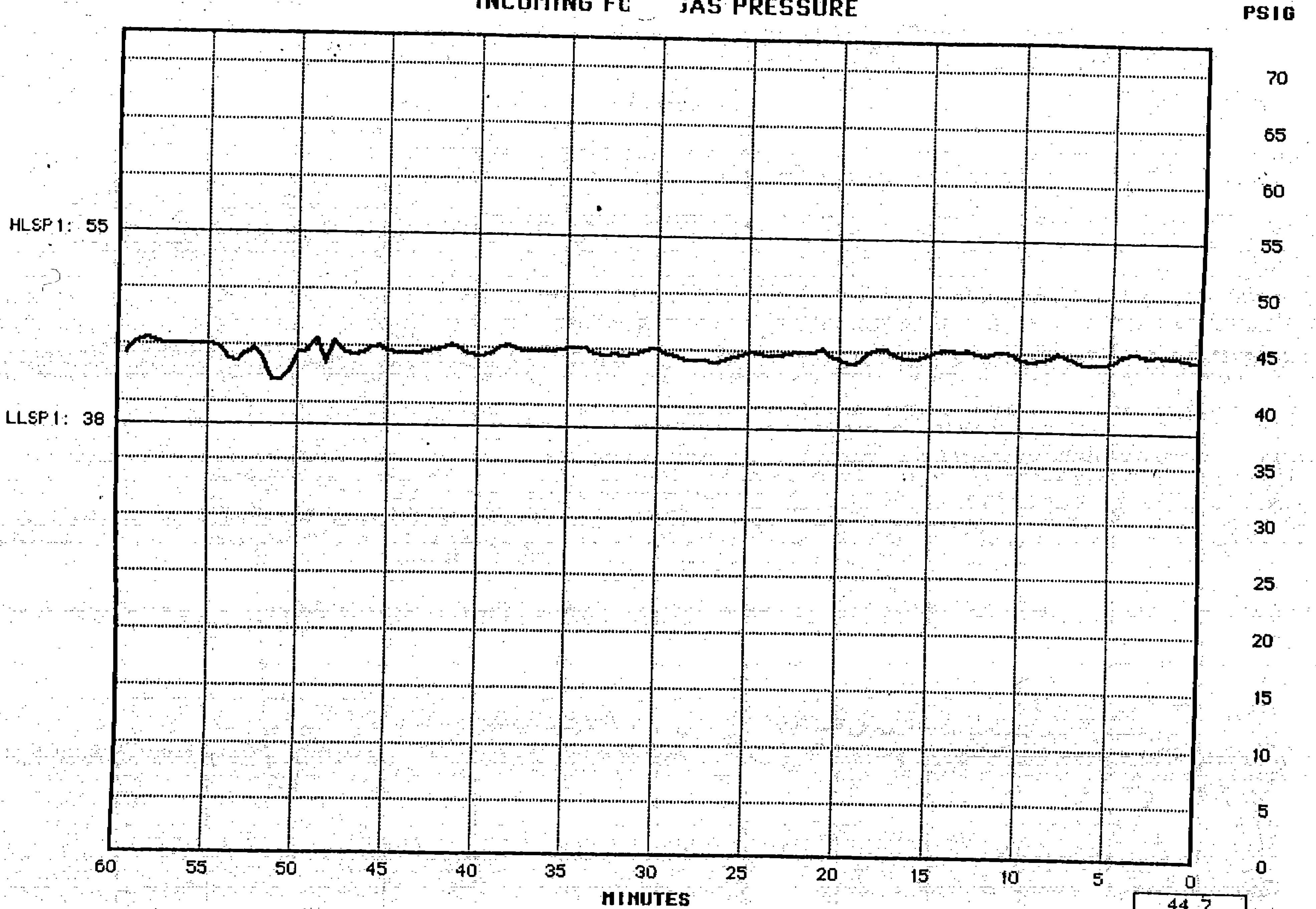
GENERATOR EIGHT KW OUTPUT
KW
HLSPI: 1850
2200
2100
2000
1900
1800
1700
1693
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
1714.8
Johnston R.I. Landfill
Wed, Jun 5, 1991
12:00:42 PM

ENGINE #8 INTAKE M FOLD VAC/PRESS PSIG

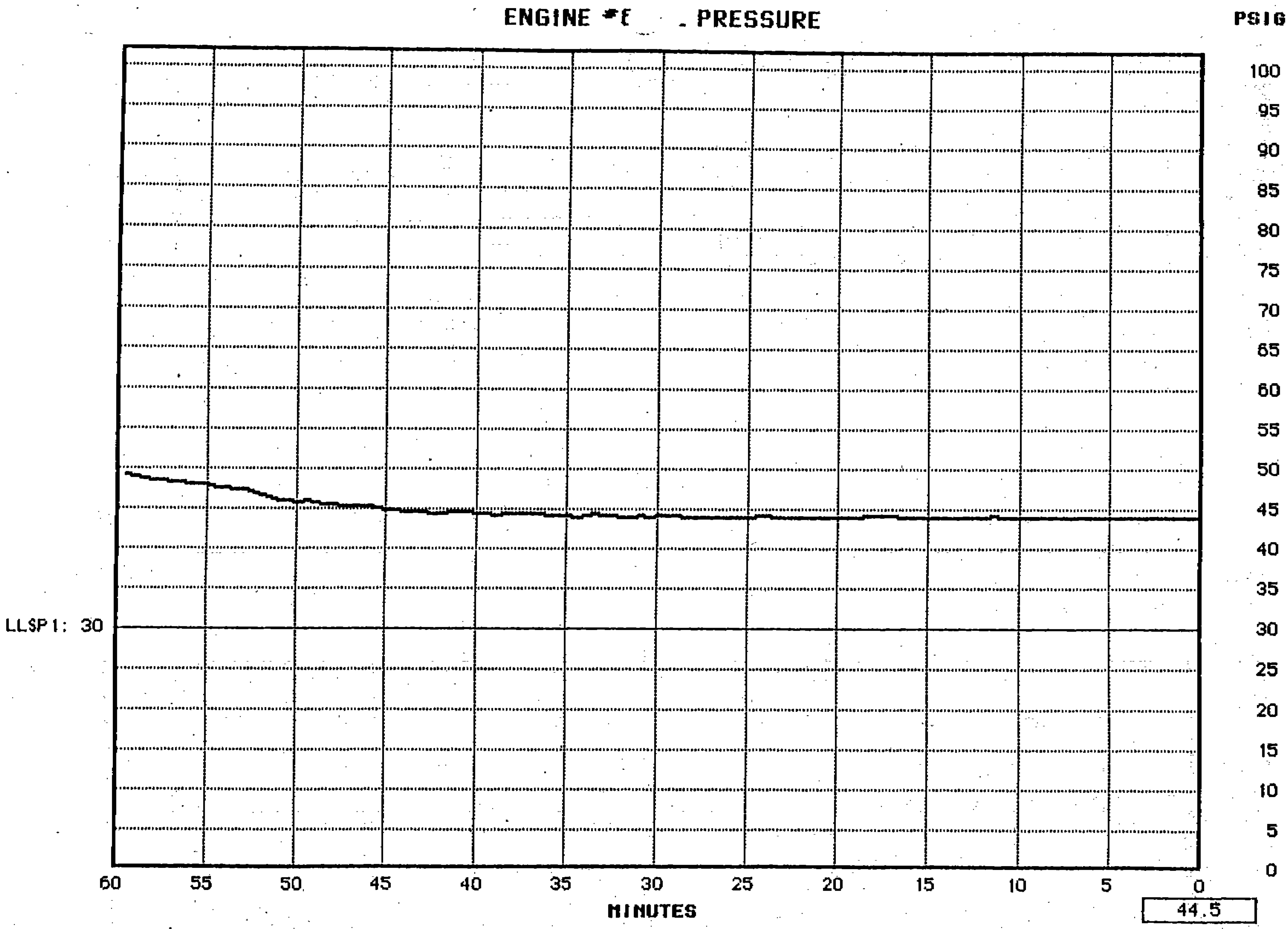


Generators 7 & 8	Wed, Jun 5, 1991	12:00:42 PM

INCOMING FU GAS PRESSURE

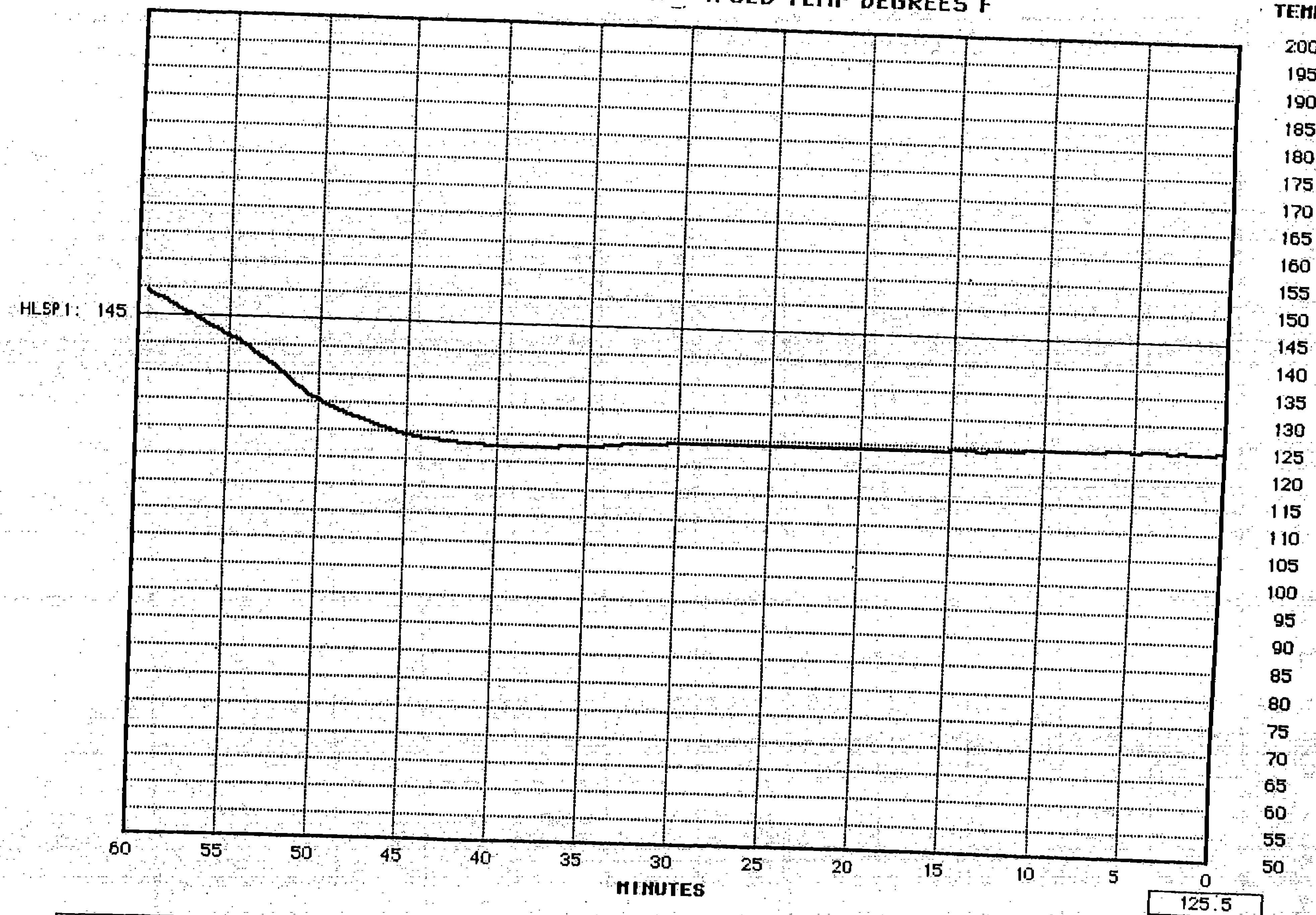


Johnston R.I. Landfill	Wed, Jun 5, 1991	12:00:42 PM

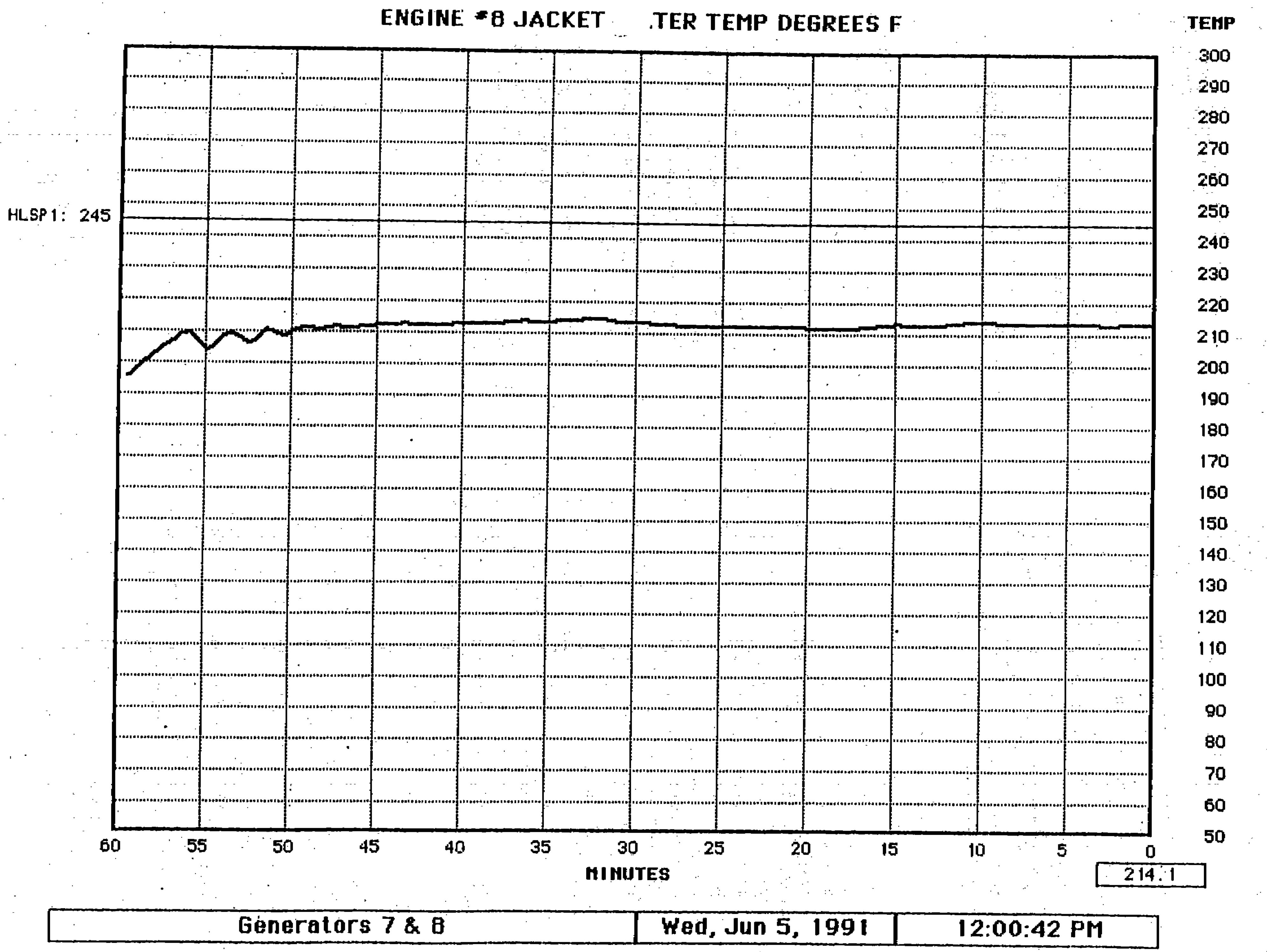


Generators 7 & 8	Wed, Jun 5, 1991	12:00:42 PM

ENGINE #8 INTAKE M_ IFOLD TEMP DEGREES F



Generators 7 & 8	Wed, Jun 5, 1991	12:00:42 PM


ENGINE #8 JACKET .TER TEMP DEGREES F
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
HLSP1: 245
60
55
50
45
40
35
30
25
20
15
10
5
0
MINUTES
214.1
Generators 7 & 8
Wed, Jun 5, 1991
12:00:42 PM

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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

R. S. Spindt
Gulf Research & Development Co.

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.

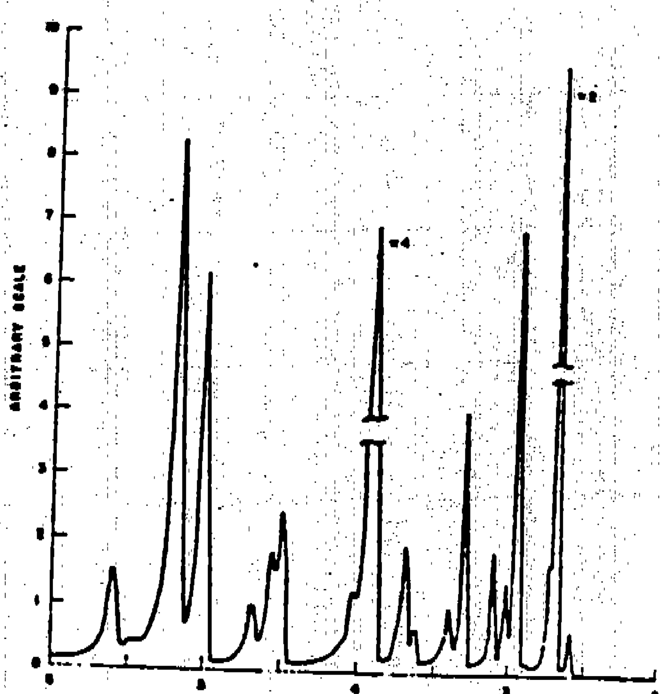
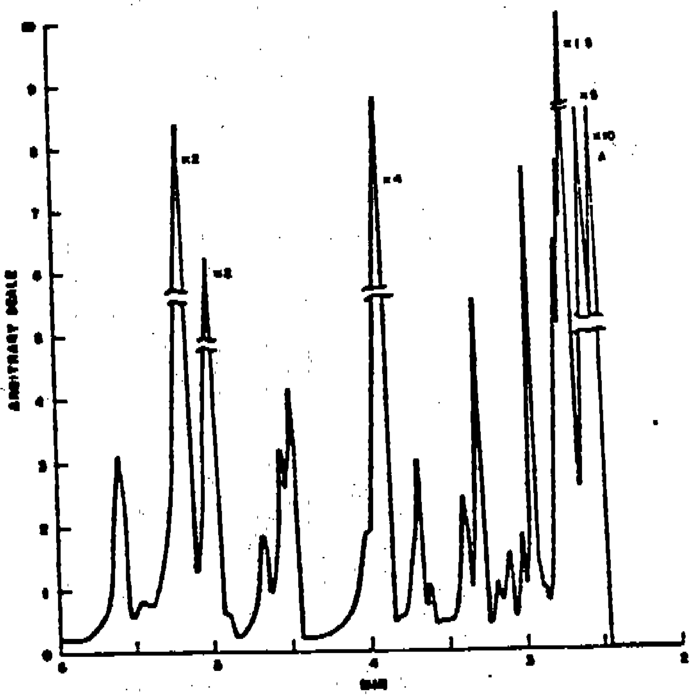


Fig. 1 - Chromatographic record of hydrocarbon components -- original fuel

*Numbers in parentheses designate References at end of paper.



A. METHANE, ETHANE AND ETHYLENE.

Fig. 2 - Exhaust gas cruise conditions

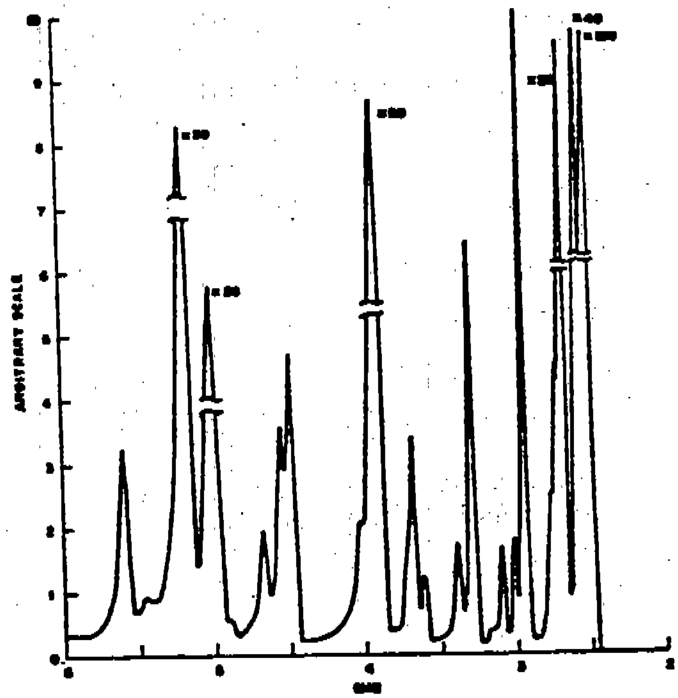


Fig. 3 - Exhaust gas motored conditions (attenuation 10X)

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 with 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 purposes 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 gave 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:

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

(If other elements are present in the fuel, Eqs. 6 and 7 can be readily adjusted without affecting the analysis.) 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:

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

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

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

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

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

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

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

$$= F_b \left[11.492 F_c \left(\frac{1 + R/2 + Q}{1+R} \right) + \left(\frac{120 \times F_h}{3.5+R} \right) \right] \tag{26}$$

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. ? Fb in [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, 12) (25, 20) (35, 28, 30)
MAP, in. Hg Absolute[c]	
Air-fuel ratio	Variable
Total number of A/F ratio observations	243
Fuels	Isooctane
	Diisobutylene
	Tolnene
	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
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	5.80	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 $2 \times 2 \times 2 \times 2$ 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:

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

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WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF NO.1:D700
ENGINE MODEL: V12AT25GL
REF.LOG.NUMBER: -
TEST NUMBER: UNIT 1
LOG SHEET NUMBER: -
OPERATOR: HOLMES
6
DATE: 6/6/91
BENCH NUMBER: TRUCK

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23231 HYDROGEN: .07789
OXYGEN: .00103 CARBON DIOXIDE: .6388

NITROGEN: .04962
HYDROGEN TO CARBON RATIO: 3.995
STOICHIOMETRIC A/F: 5.331

TEST NAME: UNIT NO.1 JOHNSTON LANDFILL RHODE ISLAND

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	195.4	2394	58	44.863	7354	368.69
2	900	195.4	2394	59	44.863	7354	367.02
3	900	195.4	2394	58	44.863	7354	378.47
4	900	195.4	2394	58	44.863	7354	388.93
5	900	195.4	2394	58	44.863	7354	[illegible]

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	THC PPM	NM HC PPM
1	466	30	86	11.27	8.58	1975	34
2	196	65	90	11.36	8.50	1800	33
3	220	67	93	11.00	8.95	2175	79
4	192	55	80	11.27	8.55	1850	34
5	460	38	93	11.76	8.50	1800	33

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH DRY EXH	COMBUSTION EFFICIENCY
1	1.124	8.59	8.66	1.62	1.127	.980
2	1.124	8.56	8.63	1.62	1.130	.982
3	1.124	8.81	8.88	1.67	1.123	.973
4	1.124	8.60	8.67	1.63	1.129	.981
5	1.124	8.54	8.61	1.62	1.130	.921

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

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL HC	METHANE	NON METHANE	NO PPM	NOX PPM
1	2.01	.21	.61	.58	5.20	0.00	0.10	14	41
2	.84	.46	.64	.61	4.97	0.00	0.09	31	43
3	.98	.46	.68	.65	6.16	0.00	0.11	31	46
4	.83	.39	.57	.54	5.16	0.00	0.10	26	38
5	1.98	.27	.69	.66	4.96	0.00	0.09	18	47

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF NO.2:D700
ENGINE MODEL: V12AT25GL
REF.LOG.NUMBER: -
TEST NUMBER: UNIT 2
LOG SHEET NUMBER: -
OPERATOR: HOLMES
6
DATE: 6/6/91
BENCH NUMBER: TRUCK

TEST NAME: UNIT NO.2 JOHNSTON LANDFILL

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23231 HYDROGEN: .07789
OXYGEN: .00103 CARBON DIOXIDE: .6389

NITROGEN: .04962
HYDROGEN TO CARBON RATIO: 3.995
STOICHIOMETRIC A/F: 5.331

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	196.2	2404	57	45.24	7386	395.71
2	900	196.2	2404	57	45.24	7386	396.53
3	900	196.2	2404	57	45.24	7386	396.53
4	900	196.2	2404	57	45.24	7386	407.43
5	900	196.2	2404	57	45.24	7386	395.31

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	THC PPM	NM HC PPM
1	442	30	85	11.21	8.68	1650	30
2	185	50	83	11.21	8.68	1620	29
3	180	54	93	10.87	9.08	1935	35
4	187	53	88	11.21	8.68	1635	30
5	442	47	83	11.21	8.65	1620	29

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.129	8.68	8.75	1.64	1.129	.982
2	1.129	8.69	8.76	1.64	1.129	.983
3	1.129	8.93	9.00	1.69	1.123	.980
4	1.129	8.69	8.76	1.64	1.129	.983
5	1.129	8.67	8.74	1.64	1.129	.983

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

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL HC	METHANE	NON METHANE	NO PPM	NO[illegible] PP[illegible]
1	1.93	.22	.61	.58	4.63	0.00	0.09	14	4[illegible]
2	.81	.36	.60	.57	4.56	0.00	0.08	24	4[illegible]
3	.81	.40	.69	.66	5.57	0.00	0.10	27	46
4	.82	.38	.63	.60	4.60	0.00	0.09	26	4[illegible]
5	1.93	.34	.60	.57	4.54	0.00	0.08	23	40

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF NO.3:D700
ENGINE MODEL: V12AT25GL
REF.LOG.NUMBER: -
TEST NUMBER: UNIT 3
LOG SHEET NUMBER: -
OPERATOR: HOLMES
3
DATE: 6/4/91
BENCH NUMBER: TRUCK

TEST NAME: UNIT NO.3 JOHNSTON LANDFILL

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23740 HYDROGEN: .07971
OXYGEN: .00057 CARBON DIOXIDE: .6493

NITROGEN: .03293
HYDROGEN TO CARBON RATIO: 4.001
STOICHIOMETRIC A/F: 5.454

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	195.5	2396	76	43.932	7367	396.71
2	900	195.5	2396	76	43.932	7367	397.15
3	900	195.5	2396	76	43.932	7367	405.18
4	900	195.5	2396	76	43.932	7367	398.46
5	900	195.5	2396	76	43.932	7367	398.90

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	THC PPM	NMHC PPM
1	442	38	93	11.09	8.83	1710	27
2	100	75	94	11.12	8.83	1680	27
3	98	69	85	10.85	9.11	1950	31
4	98	68	82	11.09	8.88	1725	28
5	440	33	84	11.00	8.90	1785	29

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.100	8.93	9.03	1.66	1.132	.982
2	1.100	8.94	9.04	1.66	1.132	.983
3	1.100	9.12	9.22	1.69	1.127	.980
4	1.100	8.97	9.07	1.66	1.131	.982
5	1.100	8.98	9.08	1.66	1.131	.981

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

EPA HUM.

CORRECTED
TO 15% OXYGEN

POINT	CO	NO	NOX	COR. NOX	TOTAL HC	METHANE	NON METHANE	NO PPM
1	1.94	.27	.67	.67	4.83	0.00	0.08	19
2	.44	.54	.68	.68	4.75	0.00	0.08	37
3	.44	.51	.63	.63	5.62	0.00	0.09	35
4	.43	.49	.59	.60	4.89	0.00	0.08	33
5	1.94	.24	.61	.61	5.07	0.00	0.08	16

NOX
PPM

45
46
43
40
41

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF NO.4:D700
ENGINE MODEL: V12AT25GL
REF.LOG.NUMBER: -
TEST NUMBER: UNIT 4
LOG SHEET NUMBER: -
OPERATOR: HOLMES
3
DATE: 6/4/91
BENCH NUMBER: TRUCK

TEST NAME: UNIT NO.4 JOHNSTON LANDFILL

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23740 HYDROGEN: .07971
OXYGEN: .00057 CARBON DIOXIDE: .649

NITROGEN: .03293
HYDROGEN TO CARBON RATIO: 4.001
STOICHIOMETRIC A/F: 5.454

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	63	43.794	7331	391.65
2	900	195.8	2400	63	43.794	7331	390.95
3	900	195.8	2400	63	43.794	7331	406.19
4	900	195.8	2400	63	43.794	7331	393.36
5	900	195.8	2400	63	43.794	7331	393.23

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	THC PPM	NMHC PPM
1	425	38	83	11.20	8.68	1620	22
2	69	68	85	11.25	8.65	1710	23
3	68	69	83	10.82	9.18	1860	25
4	68	64	83	11.18	8.73	1710	23
5	419	35	93	11.15	8.75	1710	23

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.095	8.86	8.94	1.64	1.131	.983
2	1.095	8.85	8.93	1.64	1.130	.983
3	1.095	9.19	9.27	1.70	1.124	.981
4	1.095	8.90	8.98	1.65	1.130	.983
5	1.095	8.90	8.98	1.65	1.130	.982

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

EPA HUM.

CORRECTED
TO 15% OXYGEN

POINT	CO	NO	NOX	COR. NOX	TOTAL HC	METHANE	NON METHANE	NO PPM	N P
1	1.84	.27	.59	.57	4.51	0.00	0.06	18	
2	.30	.48	.60	.58	4.75	0.00	0.07	33	
3	.31	.51	.61	.59	5.34	0.00	0.07	35	
4	.30	.46	.59	.57	4.77	0.00	0.07	31	
5	1.82	.25	.66	.64	4.77	0.00	0.07	17	

OX
PM

40
41
42
40
45

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF NO.5:D700
ENGINE MODEL: V12AT25GL
REF.LOG.NUMBER: -
TEST NUMBER: UNIT 5
LOG SHEET NUMBER: -
OPERATOR: HOLMES
6
DATE: 6/7/91
BENCH NUMBER: TRUCK

TEST NAME: UNIT NO.5 JOHNSTON LANDFILL

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23231   HYDROGEN: .07789
OXYGEN: .00103   CARBON DIOXIDE: .6388

NITROGEN: .04962
HYDROGEN TO CARBON RATIO: 3.995
STOICHIOMETRIC A/F: 5.331

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	192.5	2359	48	45.991	7651	397.78
2	900	192.5	2359	48	45.991	7651	401.69
3	900	192.5	2359	48	45.991	7651	402.79
4	900	192.5	2359	48	45.991	7651	396.99
5	900	192.5	2359	48	45.991	7651	397.09

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	THC PPM	NMHC PPM
1	501	45	96	11.30	8.58	1920	27
2	104	71	105	11.21	8.68	1965	27
3	100	100	121	11.18	8.75	2100	29
4	110	89	105	11.36	8.50	1815	25
5	500	44	101	11.31	8.55	1920	27

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.170	8.59	8.65	1.62	1.126	.980
2	1.170	8.67	8.73	1.64	1.125	.980
3	1.170	8.70	8.76	1.64	1.123	.979
4	1.170	8.57	8.63	1.62	1.127	.982
5	1.170	8.57	8.63	1.62	1.126	.980

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

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL HC	METHANE	NON METHANE	NO PPM	N(PF
1	2.25	.33	.71	.66	5.52	0.00	0.08	22	[illegible]
2	.47	.53	.78	.73	5.69	0.00	0.08	34	[illegible]
3	.46	.75	.90	.84	6.10	0.00	0.09	49	[illegible]
4	.49	.65	.77	.72	5.21	0.00	0.07	42	[illegible]
5	2.24	.32	.74	.69	5.51	0.00	0.08	21	4

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF NO.6:D700
ENGINE MODEL: V12AT25GL
REF.LOG.NUMBER: -
TEST NUMBER: UNIT 6
LOG SHEET NUMBER: -
OPERATOR: HOLMES
6
DATE: 6/6/91
BENCH NUMBER: TRUCK

TEST NAME: UNIT NO.6 JOHNSTON LANDFILL

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23231   HYDROGEN: .07789
OXYGEN: .00103   CARBON DIOXIDE: .6388

NITROGEN: .04962
HYDROGEN TO CARBON RATIO: 3.995
STOICHIOMETRIC A/F: 5.331

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	193.5	2371	43	45.561	7542	395.52
2	900	193.5	2371	43	45.561	7542	395.15
[illegible]	900	193.5	2371	43	45.561	7542	404.54
[illegible]	900	193.5	2371	43	45.561	7542	393.65
5	900	193.5	2371	43	45.561	7542	394.06

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	THC PPM	NMHC PPM
1	442	24	62	11.27	8.60	1800	24
2	53	55	63	11.34	8.50	1500	20
3	53	56	63	11.03	8.85	1800	24
4	53	57	64	11.36	8.45	1560	21
5	442	26	66	11.29	8.55	1860	25

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.153	8.63	8.68	1.63	1.125	.981
2	1.153	8.62	8.67	1.63	1.128	.985
3	1.153	8.82	8.88	1.67	1.123	.982
4	1.153	8.59	8.64	1.62	1.128	.985
5	1.153	8.60	8.65	1.62	1.125	.981

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

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL HC	METHANE	NON METHANE	NO PPM	N[illegible] P[illegible]
1	1.96	.18	.45	.42	5.11	0.00	0.07	12	[illegible]
[illegible]	.23	.40	.46	.42	4.25	0.00	0.06	26	[illegible]
[illegible]	.24	.42	.47	.43	5.21	0.00	0.07	27	[illegible]
4	.23	.41	.46	.43	4.41	0.00	0.06	27	[illegible]
5	1.96	.19	.48	.44	5.26	0.00	0.07	12	[illegible]

XM00102

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF NO.7:D700
ENGINE MODEL: V12AT25GL
REF.LOG.NUMBER: -
TEST NUMBER: UNIT 7
LOG SHEET NUMBER: -
OPERATOR: HOLMES
6
DATE: 6/5/91
BENCH NUMBER: TRUCK

TEST NAME: UNIT NO.7 JOHNSTON LANDFILL

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23231 HYDROGEN: .07789
OXYGEN: .00103 CARBON DIOXIDE: .638

NITROGEN: .04962
HYDROGEN TO CARBON RATIO: 3.995
STOICHIOMETRIC A/F: 5.331

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	192.5	2359	54	45.268	7531	393.24
2	900	192.5	2359	54	45.268	7531	393.74
3	900	192.5	2359	54	45.268	7531	415.15
4	900	192.5	2359	54	45.268	7531	394.10
5	900	192.5	2359	54	45.268	7531	394.28

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	THC PPM	NM HC PPM
1	419	18	50	11.22	8.68	2220	32
2	58	40	52	11.25	8.68	2220	32
3	58	40	48	10.63	9.40	2490	36
4	60	43	49	11.21	8.70	2340	34
5	419	18	47	11.18	8.75	2385	34

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.151	8.62	8.68	1.63	1.125	.977
2	1.151	8.63	8.70	1.63	1.125	.978
3	1.151	9.10	9.17	1.72	1.116	.974
4	1.151	8.64	8.70	1.63	1.124	.977
5	1.151	8.64	8.71	1.63	1.123	.975

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

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL HC	METHANE	NON METHANE	NO PPM	NC PF
1	1.86	.13	.37	.35	6.31	0.00	0.09	9	2
2	.26	.29	.38	.36	6.32	0.00	0.09	19	2
3	.27	.31	.37	.35	7.43	0.00	0.11	21	2
4	.27	.32	.36	.34	6.66	0.00	0.10	21	2
5	1.87	.13	.34	.33	6.80	0.00	0.10	9	2

X
M
4
5
5
4
3

WAUKESHA ENGINE DIVISION
EMISSIONS ANALYSIS PROGRAM

FILE NAME: JLF NO.8:D700
ENGINE MODEL: V12AT25GL
REF.LOG.NUMBER: -
TEST NUMBER: UNIT 8
LOG SHEET NUMBER: -
OPERATOR: HOLMES
6
DATE: 6/5/91
BENCH NUMBER: TRUCK

TEST NAME: UNIT NO.8 JOHNSTON LANDFILL

FUEL DESCRIPTION: LANDFILL GAS

WEIGHT FRACTIONS
CARBON: .23231 HYDROGEN: .07789
OXYGEN: .00103 CARBON DIOXIDE: .638
NITROGEN: .04962
HYDROGEN TO CARBON RATIO: 3.995
STOICHIOMETRIC A/F: 5.331

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	52	43.548	7227	378.61
2	900	193.0	2365	52	43.548	7227	379.65
3	900	193.0	2365	52	43.548	7227	389.14
4	900	193.0	2365	52	43.548	7227	380.30
5	900	193.0	2365	52	43.548	7227	381.57

DATA POINT	CO PPM	NO PPM	NOX PPM	CO2 %	O2 %	THC PPM	NMHC PPM
1	407	23	63	11.27	8.65	1890	34
2	150	49	65	11.27	8.65	1800	33
3	150	45	63	11.00	9.00	1890	34
4	152	47	63	11.25	8.68	1830	33
5	404	22	61	11.18	8.75	1890	34

EMISSIONS ANALYSIS:

DATA POINT	BSFC LBS/BHP-HR	MEASURED DRY A/F	SPINDT A/F	LAMBDA (SPINDT)	WET EXH/ DRY EXH	COMBUSTION EFFICIENCY
1	1.105	8.63	8.69	1.63	1.127	.980
2	1.105	8.65	8.72	1.63	1.127	.982
3	1.105	8.87	8.93	1.68	1.123	.981
4	1.105	8.67	8.73	1.64	1.127	.982
5	1.105	8.70	8.76	1.64	1.126	.980

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

EPA HUM.

CORRECTED
TO 15% OXYGEN

DATA POINT	CO	NO	NOX	COR. NOX	TOTAL HC	METHANE	NON METHANE	NO PPM	NOX PPM
1	1.73	.16	.44	.42	5.16	0.00	0.09	11	30
2	.64	.34	.46	.43	4.92	0.00	0.09	24	31
3	.66	.32	.45	.43	5.29	0.00	0.10	22	31
4	.65	.33	.44	.42	5.01	0.00	0.09	23	30
5	1.74	.16	.43	.41	5.19	0.00	0.10	11	30

PREPARED BY	Waukesha DRESSER	PAGE 1 OF 9
STACHOWICZ	ENGINEERING CALCULATION FORM	
CHECKED BY	SUBJECT	PROGRAM & PROJECT NO. JOHNSTON
TERMATREX NO.	SAMPLE CALCULATION	DATE 2 JULY 91

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 SHOWN. INSTEAD, FINAL RESULTS FROM THE COMPUTER PRINTOUT WILL BE USED.

A.) <u>BRAKE SPECIFIC FUEL CONSUMPTION (BSFC)</u>

AVERAGE HORSEPOWER 2394 BHP

FUEL PROPERTIES:

SATURATED LOW HEAT VALUE 486 BTU/FT^3

SPECIFIC GRAVITY .9686

FUEL GAS DENSITY $.9686 \times .0765\ LB/FT^3$
$= .0741\ LB/FT^3$

$$BSFC = 1040.0\left(\frac{SLHV}{BHP}\right)\left(\frac{FT^3}{MIN}\right)\left(\frac{BAR.\ P + P_{GAS}}{T_{GAS} + 460^\circ}\right)$$

WHERE:

1040.0	UNIT CONVERSION FACTOR
SLHV	SATURATED LOW HEAT VALUE
BHP	AVERAGE BRAKE HORSEPOWER
FT^3	MEASURED CUBIC FEET OF FUEL GAS

FORM NO. 576-5177

PREPARED BY	Waukesha DRESSER	PAGE 2 OF 9
STACHOWICZ		
CHECKED BY	ENGINEERING CALCULATION FORM	PROGRAM & PROJECT NO. JOHNSTON
TERMATREX NO.	SUBJECT SAMPLE CALCULATION	DATE 2 JULY 91

MIN	MINUTES TO FLOW FT^3
BAR. P.	BAROMETRIC PRESSURE, IN. Hg
P_{GAS}	MEASURED FUEL GAS PRESSURE
T_{GAS}	MEASURED FUEL GAS TEMPERATURE

FOR UNIT #1, READINGS 2 AND 4 ARE DISCARDED PER THE TEST PROTOCOL BASED ON PRELIMINARY CALCULATIONS.

READING #1

$$BSFC = \frac{(1040)(486)}{2394}\left(\frac{200}{1.267}\right)\left(\frac{29.83 + \frac{45.5}{.491}}{102° + 460°}\right)$$

$$= 7264.3 \quad BTU/BHP\text{-}HR$$

READING #3

$$BSFC = \frac{(1040)(486)}{2394}\left(\frac{200}{1.242}\right)\left(\frac{29.83 + \frac{45.5}{.491}}{104° + 460°}\right)$$

$$= 7384.2 \quad BTU/BHP\text{-}HR$$

READING #5

$$BSFC = \frac{(1040)(486)}{2394}\left(\frac{200}{1.214}\right)\left(\frac{29.83 + \frac{44.5}{.491}}{105° + 460°}\right)$$

$$= 7415.8 \quad BTU/BHP\text{-}HR$$

PREPARED BY	Waukesha DRESSER	PAGE 3 OF 9
STACHOWICZ	ENGINEERING CALCULATION FORM	PROGRAM & PROJECT NO. JOHNSTON
CHECKED BY	SUBJECT SAMPLE CALCULATION	DATE 2 JULY 91
TERMATREX NO.		

$$\text{AVERAGE BSFC} = \frac{7264.2 + 7384.2 + 7415.8}{3}$$

$$= 7354.7 \ \text{BTU/BHP-HR}$$

B. FUEL FLOW

$$\text{FUEL FLOW} = \text{BSFC}\ \frac{\text{BTU}}{\text{BHP-HR}} \times \frac{1\ \text{HR}}{60\ \text{MIN}} \times 2394\ \text{BHP} \times \frac{1}{486\ \frac{\text{BTU}}{\text{FT}^3}} \times .0743\ \frac{\text{LB}}{\text{FT}^3}$$

$$\text{FUEL FLOW} = 7354.7 \times \frac{1}{60} \times 2394 \times \frac{1}{486} \times .0743$$

$$= 44.863 = 2691.8\ \text{LB/HR}$$

C. AIR-FUEL RATIO

FROM APPENDIX F, EQUATION (26) THE AIR-FUEL RATIO IS CALCULATED AS:

$$AFR = F_b \left[11.492 \times F_c \left(\frac{1 + R/2 + Q}{1 + R} \right) + \left(\frac{120 \times F_{H2}}{3.5 + R} \right) \right]$$

THIS EQUATION MUST BE MODIFIED FOR FUELS CONTAINING A SIGNIFICANT LEVEL 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 GIVES:

$$AFR = F_b \left[(11.492 F_C + 3.136 FCO_2)\left(\frac{1+\frac{R}{2}+Q}{1+R}\right) + \left(\frac{120 \times FH_2}{3.5+R}\right) - 3.136 FCO_2 \right]$$

THE EQUATION PARAMETERS ARE DEFINED IN APPENDIX F.

TAKING THE APPROPRIATE VALUES FOR FUEL 'B' FROM TABLE I:

CARBON FRACTION $= F_C = .23231$
HYDROGEN FRACTION $= FH_2 = .07789$
CARBON DIOXIDE FRACTION $= FCO_2 = .63886$

FROM APPENDIX E FOR UNIT #1, LINE #1:

CO IN EXHAUST $= P_{CO} = 466$ ppmv $= .0466\%$
CO_2 IN EXHAUST $= P_{CO_2} = 11.27\%$
O_2 IN EXHAUST $= P_{O_2} = 8.58\%$
CH IN EXHAUST $=$ 1875 ppmv $= .1875\%$

THE CH VALUE IS MEASURED "WET" WHILE ALL THE OTHER VALUES ARE MEASURED "DRY". TO CONVERT TO AN EQUIVALENT "DRY" VALUE, IT MUST BE MULTIPLIED BY THE WET/DRY RATIO. THIS IS DETERMINED BY AN ITERATIVE PROCESS. TAKING THE VALUE 1.129 FROM APPENDIX G

$$P_{CH} = .1875\% \times 1.129 = .2117\%$$

PREPARED BY	Waukesha / DRESSER	PAGE 5 OF 9
STACHOWICZ	ENGINEERING CALCULATION FORM	PROGRAM & PROJECT NO. JOHNSTON
CHECKED BY	SUBJECT: SAMPLE CALCULATION	DATE: 2 JULY 91
TERMATREX NO.		

WE CAN NOW CALCULATE:

$$R = P_{CO}/P_{CO_2} = .0466/11.27 = .004135$$

$$Q = P_{O_2}/P_{CO_2} = 8.58/11.27 = .761313$$

$$F_b = \frac{P_{CO} + P_{CO_2}}{P_{CO} + P_{CO_2} + P_{CH}} = \frac{.0466 + 11.27}{.0466 + 11.27 + .2117} = .981636$$

AND

$$AFR = (.981636)\left[\left((11.492 \times .23231) + (3.136)(.63886)\right)\left(\frac{1 + \frac{.004135}{2} + .761313}{1 + .004135}\right) + \left(\frac{120 \times .07789}{3.5 + .004135}\right) - (3.136)(.63886)\right]$$

AFR = 8.707 : 1

D. <u>AIR FLOW</u>

AIR FLOW = FUEL FLOW × AFR
= (2691.8 Lb/HR)(8.707)
= 23437.5 Lb/HR

E. <u>EXHAUST FLOW</u>

THE TOTAL EXHAUST FLOW IS THE SUM OF THE AIR AND FUEL FLOWS.

EXHAUST FLOW = 23437.5 + 2691.8 = 26,129.3 LB/HR

F. BRAKE SPECIFIC EMISSION RATES:

FROM APPENDIX E

NO_x = 86 ppm volume, "DRY" MEASURE
CO = 466 ppm volume, "DRY" MEASURE
THC = 1875 ppm volume, "WET" MEASURE
NMHC = 34 ppm volume, "WET" MEASURE

SINCE WE ARE WORKING ON A TOTAL EXHAUST FLOW BASIS, THE WET/DRY RATIO FROM APPENDIX G MUST BE USED TO CONVERT THE MEASURED NO_x AND CO VALUES TO EQUIVALENT "WET" READINGS:

NO_x = 86 ppm / 1.129 = 76 ppm "WET" volume
CO = 466 ppm / 1.129 = 413 ppm "WET" volume

SINCE WE ARE TRYING TO DETERMINE MASS EMISSION RATES, WE MUST FIRST DETERMINE THE MASS FRACTIONS (PERCENTAGES) EQUIVALENT TO THE MEASURED VOLUME FRACTIONS. TO DO THIS THE APPARENT MOLECULAR WEIGHT OF THE EXHAUST STREAM MUST BE CALCULATED.

FROM APPENDIX E THE MEASURED EXHAUST ANALYSIS IS:

NO_x =	86 ppmv =	.0086 % =	.000086	"DRY"
CO =	466 ppmv =	.0466 % =	.000466	"DRY"
THC =	1875 ppmv =	.1875 % =	.001875	"WET"
CO_2 =		= 11.27 % =	.112700	"DRY"
O_2 =		= 8.58 % =	.085800	"DRY"

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FROM APPENDIX G THE WET/DRY RATIO IS 1.129

$\frac{1}{1.129} = .88574$

THEREFORE, 1 - .88574 = .11426 OR 11.426% OF THE EXHAUST STREAM IS WATER VAPOR.

CONVERTING THE ANALYSIS TO A "WET" BASIS:

NO_x = .0000762
CO = .0004128
THC = .0018750
CO_2 = .0998229
O_2 = .0759965
H_2O = .1142600
BALANCE N_2 = .7075566

THE APPARENT MOLECULAR WEIGHT OF THE EXHAUST STREAM IS CALCULATED AS:

SPECIE	VOLUME FRACTION	x	SPECIE MOL. WT.	=	MOLECULAR WEIGHT FRACTION
NO_x AS NO_2	.0000762		46.01		.004
CO	.0004128		28.01		.012
THC AS CH_4	.0018750		16.04		.030
CO_2	.0998229		44.01		4.393
O_2	.0759965		32.00		2.432
H_2O	.1142600		18.02		2.059
N_2	.7075566		28.02		19.826
SUM	1.0000000				28.756

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TO CONVERT THE MEASURED VOLUME FRACTIONS TO MASS FRACTIONS, MULTIPLY THE VOLUME FRACTION BY THE RATIO OF SPECIE MOLECULAR WEIGHT TO APPARENT EXHAUST STREAM MOLECULAR WEIGHT.

SPECIE	WET VOLUME FRACTION	SPECIE MOLECULAR WEIGHT	SPECIE MOL. WT. / 28.756	WET MASS FRACTION
NO_x AS NO_2	.0000762	46.01	1.6000	.0001219
CO	.0004128	28.01	.9741	.0004021
THC AS CH_4	.0018750	16.04	.5578	.0010459
CO_2	.0998229	44.01	1.5305	.1527753
O_2	.0759965	32.00	1.1128	.0845698
H_2O	.1142600	18.02	.6267	.0716012
N_2	.7075566	28.02	.9744	.6894469
SUM	1.0000000			.9999631

FINALLY, EACH BRAKE SPECIFIC EMISSION RATE IS CALCULATED AS:

$$E_i = \frac{(\text{TOTAL EXHAUST MASS FLOW RATE}) \times (\text{WET MASS FRACTION } i)}{\text{BHP}}$$

$$E_i = 26129.3 \ \frac{\text{LB}}{\text{HR}} \times 453.6 \ \frac{\text{GRAM}}{\text{LB}} \times \frac{1}{2394 \ \text{BHP}} \times MF_i$$

$$E_i = 4950.815 \times MF_i \quad \text{gr/BHP-HR}$$

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NO_X : (4950.815)(.0001219) = .604 gr/BHP-HR

CO : (4950.815)(.0004021) = 1.991 gr/BHP-HR

THC: (4950.815)(.0010459) = 5.178 gr/BHP-HR

FOR NON-METHANE HYDROCARBONS :

1875 ppmv − 34 ppmv = 1841 ppmv METHANE ONLY

.001841 × .5578 = .0010269 MASS FRACTION, METHANE ONLY

THEN :

NMHC = 5.178 − (4950.815)(.0010269) = 5.178 − 5.084
= .094 gr/BHP-HR