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RESPONSE AND PERFORMANCE CHARACTERIZATION OF MSA MODEL 100S PORTABLE COMBUSTIBLE GAS ALARM IN DETECTING MILITARY AVIATION AND MISSILE FUELS

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Response characteristics of MSA Model 100S Portable Combustible Gas Alarm to vapors of JP-4, JP-8, JP-9, and JP-10 were determined. A flame ionization detector served as the reference sensor. Response curves for the alarm to the indicated vapors were established.

Response characteristics of the alarm to mixtures of n-pentane, n-hexane, n-heptane, and n-octane with air were also determined. Hydrocarbon-air mixtures are recommended as calibration substances for specific aircraft or missile fuels.

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FOREWORD

This is a Final Technical Report for the period 1 March 1981 - 31 October 1981, prepared by Monsanto Research Corporation, Dayton Laboratory. The effort was sponsored by the Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio under Contract No. F33615-78-C-2023. The work herein was accomplished under Project 3048, Task 304807, Work Unit No. 30480784, with Messrs. G. Gandee and G. Spencer, AFWAL/POSH, serving as Project Engineers. Dr. Leo Parts of Monsanto Research Corporation was technically responsible for the work. Mr. Thomas J. Bucher from Monsanto Research Corporation participated in this task.

TABLE OF CONTENTS

APPENDICES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

LIST OF TABLES

INTRODUCTION

The MSA Portable Combustible Gas Alarm, Model 100S, is used extensively at Air Force aircraft maintenance facilities to detect combustible vapors at concentrations below the lower explosive limit. The Model 100S Gas Alarm is equipped with a signal generator that provides an audible warning. This generator can be set at selected meter readings. Presently, the Air Force specifies that the signal generator be set to sound the alarm at the meter reading of 20% LEL (lower explosive limit).

In the past, the Air Force has used the gas alarm for the detection of JP-4 and AvGas vapors in air. Aircraft and missile fuels of lower volatility (i.e., JP-8, JP-9, and JP-10) are presently being introduced into service. The chemical compositions, diffusivities, and heat transfer properties of the latter fuel vapors differ from those of JP-4. These properties affect the response of the MSA Model 100S combustible gas alarm. The need to establish the response characteristics of this gas alarm to low volatility fuels was brought to the attention of the Fire Protection Branch, at the Aero Propulsion Laboratory, by the Air Force Logistics Command. The work described in this report was pursued to meet this need. The following objectives were established:

1) Determine the response of MSA Model 100S Combustible Gas Alarm to the vapors of JP-8, JP-9, JP-10 fuels, and Turco 4848-257 solvent. For reference, and for comparison with data presented by the manufacturer in the manual, determine the response characteristics of this instrument to the vapors of JP-4 fuel.

2) Prepare response curves, presenting meter readings vs. percent LEL, for the response of the MSA Model 100S combustible gas alarm to the vapors of JP-4, JP-8, JP-9, JP-10, and Turco 4848-257.

3) Determine the response of MSA Model 100S Combustible Gas Alarm to the vapors of pure hydrocarbons (e.g., n-pentane, n-hexane, n-heptane, and n-octane) in air. Evaluate these substances as alternate calibration materials to the propane-air mixture presently used. It is desirable to use calibration gases such that the alarm meter scale readings would correspond directly to the lower explosive limit percentage values for the fuel vapors being sensed.

4) Note problems that arise during the operation of the fuel vapor monitors.

The above outlined objectives have been attained. The response curves for MSA Model 100S Combustible Gas Alarm to the vapors of JP-4, JP-8, JP-9, JP-10, and Turco 4848-257 are presented as Figure 10 on Page 26.

EXPERIMENTAL

FUELS

The aircraft fuels used in this program were supplied by the Air Force from the storage facility at the AFWAL Fuels Laboratory at Wright-Patterson Air Force Base. The fuel samples that were received carried the following identifying designations:

JP-4

Sample 1; H-Bay, B-10, Reid Vapor Pressure (RVP) 2.4.
Sample 2; No. 673, RVP 2.1.
Sample 3; No. 685, RVP 2.7.

JP-8

Sample 1; from Coker lab. rack, Bldg. 59B (3-16-81).
Sample 2; Tank 167, Bldg. 42D, 8,400 gal. trailer, Compartment 1, flash point ≅98°F, drawn 6 April 1981. (This is a special, high vapor pressure sample.)

JP-9 (methylcyclohexane, 10-12 wt-%; JP-10, 65-70 wt-%, and RJ-5, 20-25 wt-%).

Batch 38, 55 gal. drum, drawn 12 May 1980.

JP-10 (exo-tetrahydrodicyclopentadiene).

Drum No. 31.

PURE HYDROCARBONS

n-Pentane, certified grade, from Fisher Scientific Company, Cat. No. P-400.

Hexane, assay 95.4%, from MCB Manufacturing Chemists, Inc., Cat. No. HX296.

n-Heptane, HPLC grade, from Fisher Scientific Company, Cat. No. H-350.

n-Octane, 99+%, from Aldrich Chemical Company, Cat. No. 0-325-7.

APPARATUS

Total System

Three units of the MSA Model 100S Combustible Gas Alarm were received for this work from the Air Force. These instruments were identified by serial numbers 422, 532, and 575.

The system used in the present work with the combustible gas alarms was developed and built to meet the following requirements:

1) To continuously generate hydrocarbon-air mixtures of desired concentrations from fuels or pure hydrocarbons having different volatilities;

2) To continuously monitor hydrocarbon concentrations with the MSA combustible gas alarms; and

3) To simultaneously determine hydrocarbon concentrations with a reference instrument.

A flame ionization detector was selected as the reference sensor, primarily because its response is nearly linearly related to carbon concentration in gaseous samples composed of paraffinic hydrocarbons [1]. Similar response can be expected with fuel vapors. The lower explosive limits (LEL) of aliphatic hydrocarbon vapors of different compositions can also be expressed as functions of carbon atom (or CH_n) content (∼75,000 ppm). Zabetakis has reported that the vapors of JP-4 and similar fuels contain approximately 48 mg of the fuel per liter of air at the lower flammability limit [2].

The entire system used for performance characterization of combustible gas monitors is shown in Figure 1; it is depicted schematically in Figure 2. The hydrocarbon vapor/air mixtures were generated by bubbling air at a predetermined rate through the liquid fuel or pure hydrocarbon in the sparger (see also Figure 3). To obtain hydrocarbon vapor/air mixtures of lower hydrocarbon concentrations than those formed by this process, the stream exiting from the sparger was mixed in a controlled manner with air. Alternatively, to generate fuel vapor/air mixtures of hydrocarbon concentrations higher than those that can be formed by saturating air at room temperature, this process was conducted at either 30°C (86°F) or 60°C (140°F). Saturation of air with fuel vapors above the ambient temperature was essential with JP-8, to attain combustible vapor concentrations in the 50% LEL range.

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[1] L. S. Ettre, "Relative Molar Response of Hydrocarbons on the Ionization Detectors," in "Gas Chromatography," N. Brenner, J. E. Callen and M. D. Weiss, Editors, Academic Press, New York, New York, 1962, p. 307.

[2] M. G. Zabetakis, "Flammability Characteristics of Combustible Gases and Vapors," Bureau of Mines Bulletin 627, 1965, p. 20.

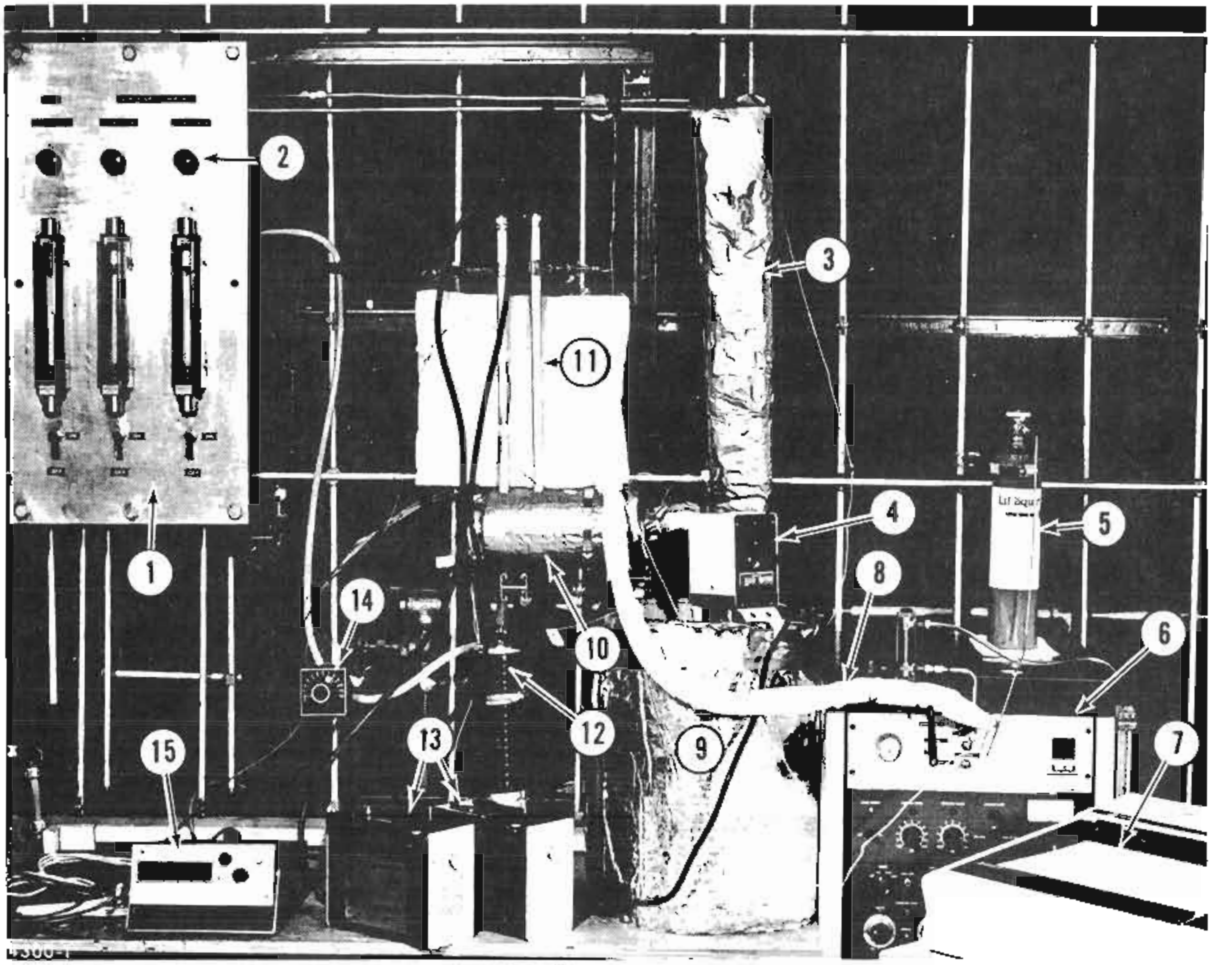

Figure 1. Apparatus for the generation and monitoring of fuel vapor/air mixtures.

1 - Flowmeters
2 - Needle valves
3 - Air supply lines, surrounded by heaters
4 - Temperature-controlling immersion circulator
5 - Calibration gas for the flame ionization detector
6 - Chromatographic analyzer, incorporating the flame ionization detector
7 - Recorder
8 - Heated sample transfer line
9 - Constant temperature bath
10 - Sampling manifold
11 - Combustible gas alarm probes
12 - Vapor trap in the exhaust line
13 - Combustible gas alarms
14 - Rotating switch for the selection of sensing thermocouple
15 - Newport Digital Thermocouple Indicator (Type K)

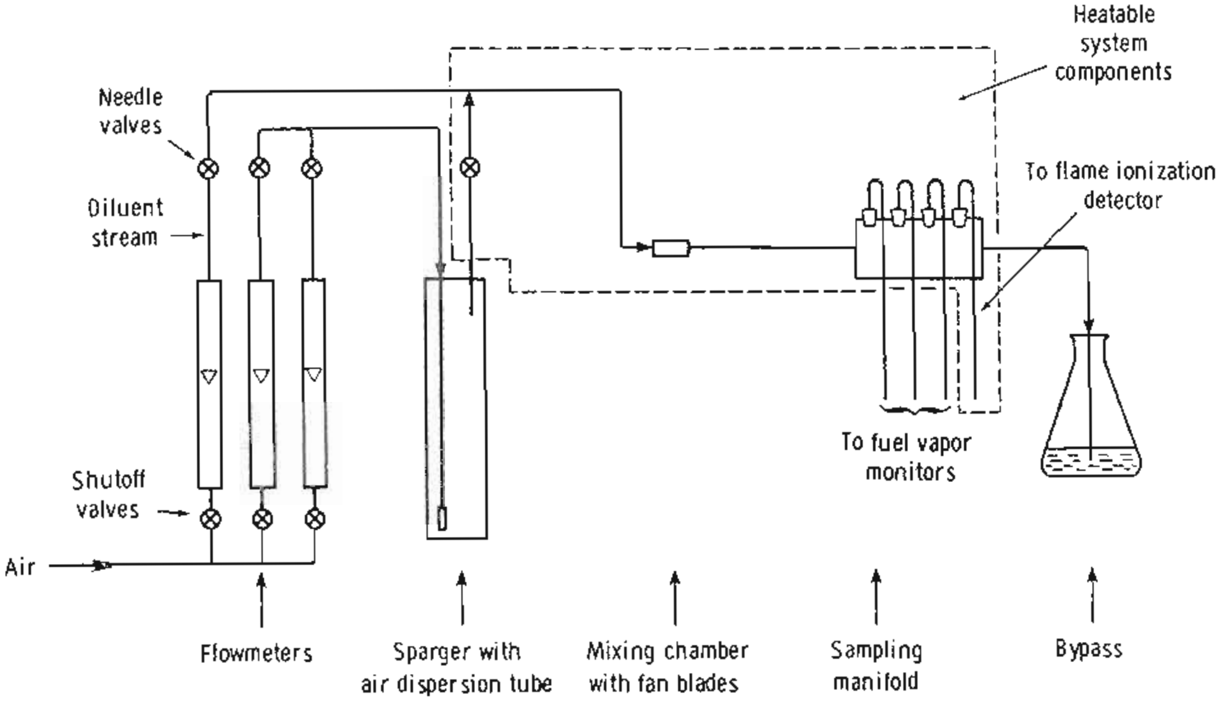

Figure 2. Schematic of the apparatus used for the generation and monitoring of fuel vapors.

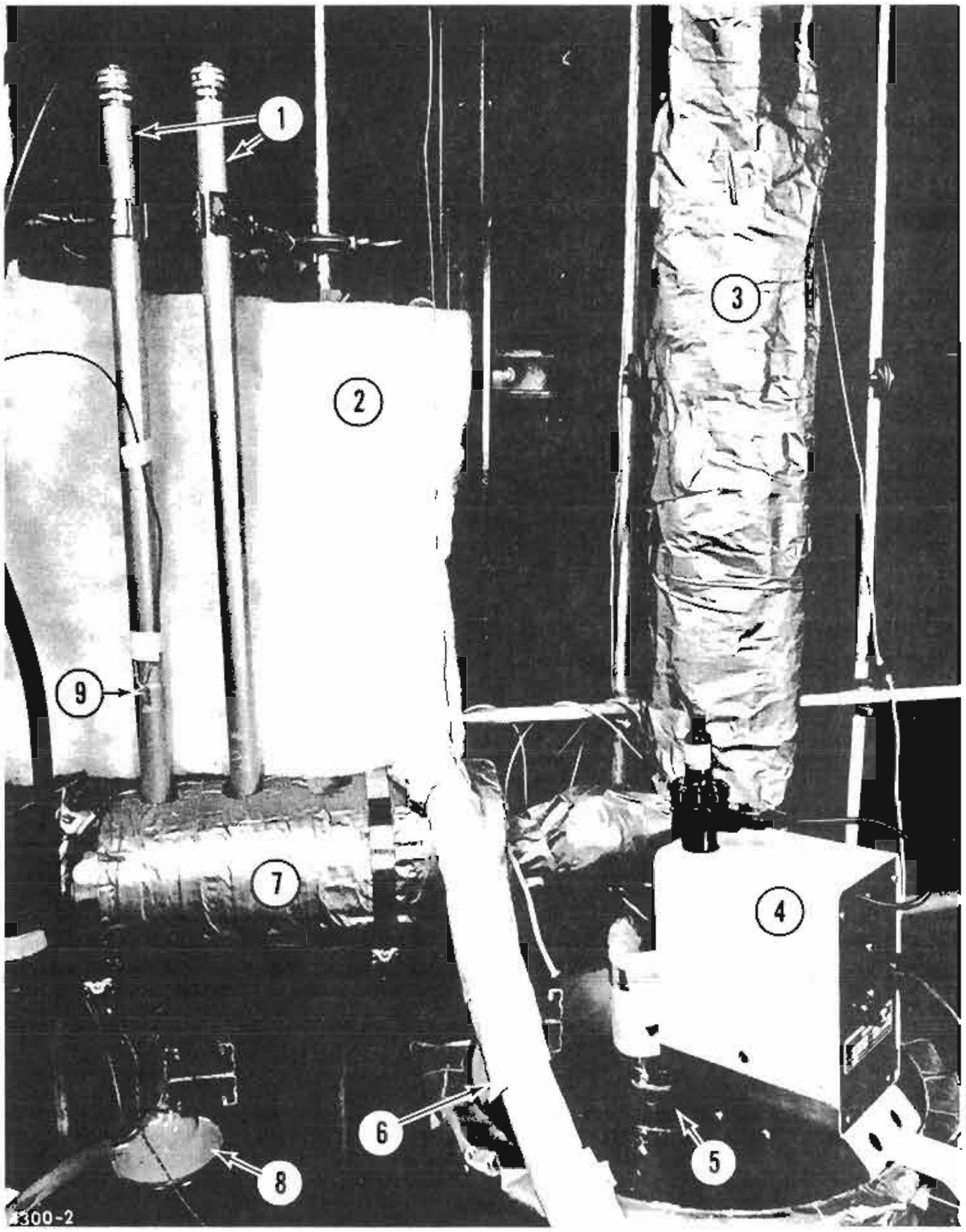

Figure 3. Close-up view of the vapor generation and monitoring subsystems.

1 - Combustible gas alarm probes
2 - Insulation used around the probes. Heating tapes used along 8-in. long sections of the probes are not shown
3 - Air supply lines, surrounded by heaters
4 - Temperature-controlling immersion circulator
5 - Sparger
6 - Sample transfer line to flame ionization detector
7 - Sampling manifold
8 - Vapor trap in the exhaust line
9 - Thermocouple

The sparger (see Figure 3) had an inside diameter of 9.5 cm (3.7 in.) and it was 35 cm (13.8 in.) high. Seven hundred and twelve milliliters of fuel or pure hydrocarbon were introduced for each experiment. Air was bubbled through the liquid by means of a dispersion tube with a sintered glass tip. To produce the needed range of flow rates of hydrocarbon/air mixtures, two flowmeters, having different capacities, were incorporated into the system (see Figures 1-3) for determining the air flow rate through the sparger.

To saturate air with fuel vapor above the ambient temperature, the sparger and its contents were heated in a thermostated water bath. The temperature of the bath and its contents was maintained within ±0.03°C with a Haake Constant Temperature Immersion Circulator, Model E2. The vapor transfer lines and the sampling chamber were maintained at approximately 90°C (194°F) in initial experiments and at 120°C (248°F) in later experiments. Heat was supplied to system components by means of heating tapes. The heated components were wrapped with fiberglass insulation. Their temperatures were monitored with chromel-alumel thermocouples, embedded under the insulation and connected through a rotating switch to a Newport Digital Thermocouple Indicator, Type K.

The hydrocarbon/air mixture entered the sampling manifold through a small mixing chamber equipped with fan blades to enhance mixing.

The combustible gas alarm probes entered into the sampling manifold through rubber stoppers that also formed seals to exclude air. The 1/8 in. OD sample line leading to the flame ionization detector was also sealed into the manifold by means of a rubber stopper. For most experiments, a stainless steel transfer line was used to supply sample continuously to the flame ionization detector. In Experiments 151-154 performed with JP-8, a Teflon sample transfer line was used to minimize adsorption of low-volatility hydrocarbons.

Flame Ionization Detector as Reference Sensor

A Varian Model 1440 chromatographic analyzer, incorporating a flame ionization detector, was used as the reference instrument. The chromatographic column was replaced by an unpacked sample loop. The sample compartment of the reference analyzer was maintained at 160°C (320°F).

The reference instrument was calibrated with n-heptane/air mixtures at concentrations ranging from 90 parts per million volume (ppmv) to 1,050 ppmv. The recorded peak height was found to be a linear function of heptane concentration at constant detector output attenuation. Peak height per 1 ppmv carbon (or CH_n), calculated for attenuation 1, was found to be unaffected by the attenuation used in the measurements.

Calibration of Combustible Gas Monitors

To ascertain electronically stable performance, all monitors (see Figure 4) were turned on at least a half an hour before any calibration adjustments were made. Subsequently, the procedure specified by the manufacturer in the instruction manual [3] was followed. A mixture of propane (0.6 vol-%) in air, supplied by MSA (Part No. 455129) was used as the calibrating gas. Air Force guidelines specify that the calibration of the MSA Combustible Gas Monitors be based on the lower explosive limit of propane-air mixture [4].

For 0.6 vol-% propane in air, the meter response was set on 28.5% LEL, the actual value for this composition, during calibration.

It is desirable to clarify here calibration instructions supplied by the instrument manufacturer. The calibration kit (MSA Part No. 458300) supplied by MSA to the Air Force contains a propane-air mixture whose concentration (0.6 vol-%) corresponds to 28.5% of the LEL. It is stated in the instruction manual for the MSA Portable Combustible Gas Alarm, Model 100S, that this instrument is factory calibrated on propane in air. The response curves included as Foldouts E through G in the instruction manual for Model 100S are based on the meter response setting of 28.5, when the instrument is calibrated with the propane-air mixture supplied by its manufacturer (MSA Part No. 455129).

The calibration kit provided by MSA to the Air Force also contains calibration instructions, and response curves for propane-air and pentane-air mixtures on the inside of its cover. These instructions and calibration curves apply to the industrial instrument, Model 100. They should not be applied by the Air Force for Model 100S instruments. The calibration curves in the instrument manual used by the Air Force do not apply to gas alarms that have been calibrated by the procedure supplied with the calibration kit.

With the exception of two experiments, the combustible gas monitors were calibrated before each experiment. When calibrations before experiments were omitted, it was observed that the differences in instrument readings, made with the different units, increased progressively.

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[3] Instruction Manual for MSA Portable Combustible Gas Alarm, Model 100S; MSA Part No. 465702.

[4] G. Gandee, memorandum to L. Parts, 16 March 1981.

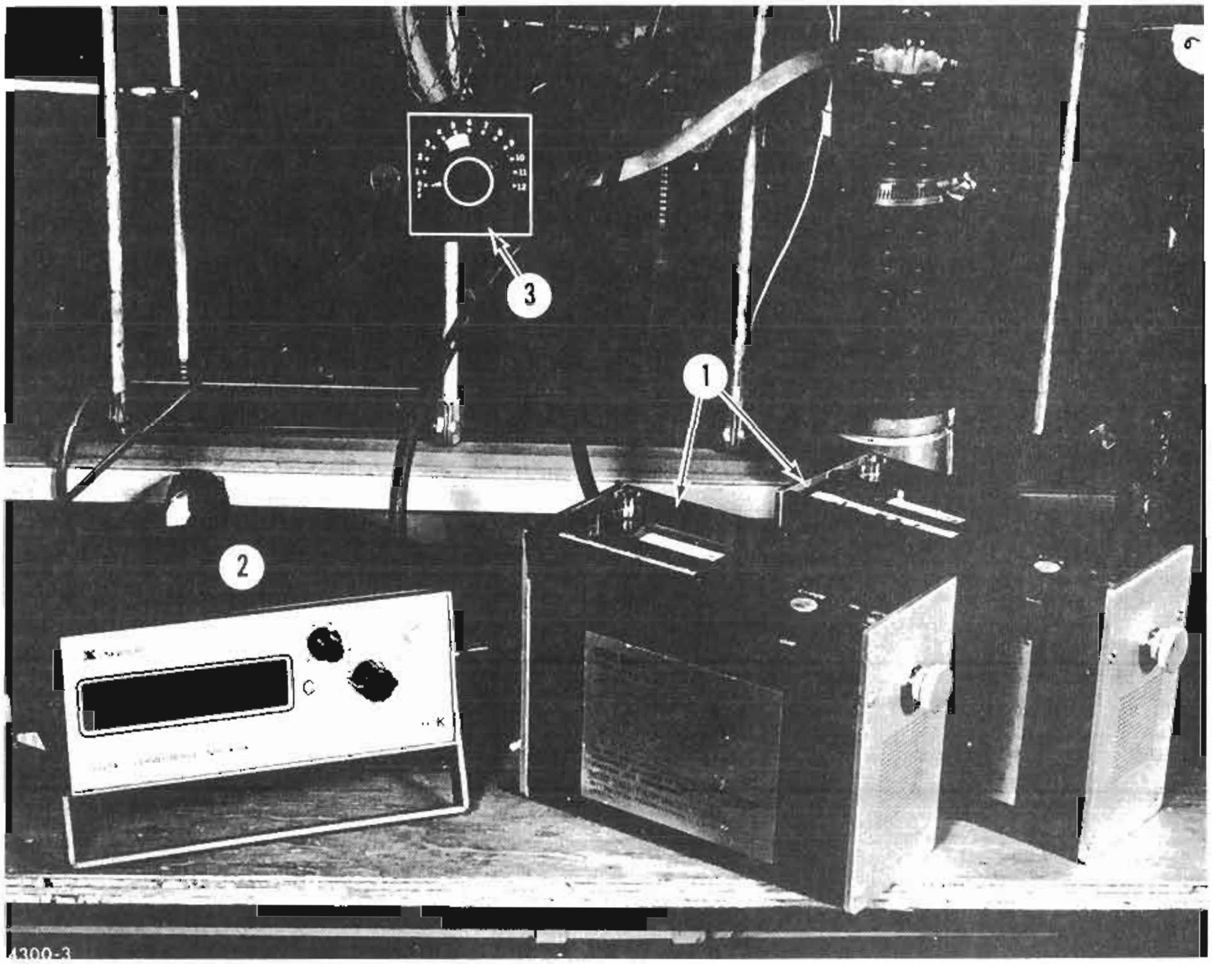

Figure 4. Combustible gas alarms and temperature monitoring devices.

1 - MSA Combustible Gas Alarms, Model 100S
2 - Newport Digital Thermocouple Indicator, Type K
3 - Rotating switch for the selection of sensing thermocouple

All combustible gas alarms used in an experiment were calibrated simultaneously, while their sensors were connected to a common flexible manifold containing calibration gas at the pressure specified by the manufactuer. To maintain the desired pressure, the inflatable rubber balloon and the calibration gas container were also connected to the rubber manifold. A 6 in. diameter wire ring was held around the balloon when the manifold was pressurized with the calibration gas. Sufficient gas pressure was established in the manifold to expand the balloon to a 6 in. diameter. Calibration gas was subsequently introduced in small quantities at frequent intervals, to maintain the balloon inflated to a 6 in. diameter while the range calibrations were made on all instruments connected to the calibration gas manifold. Instrument range values were recorded, with the sensor exposed to the calibration gas, before span adjustments were made during the calibration. These values provide a quantified measure of instrumental response drift between successive experiments.

RESULTS AND DISCUSSION

EXPERIMENTAL DATA

A listing of experiments performed to establish the response curves for the combustible gas alarm, with pure hydrocarbons and jet fuels, is presented in Table 1. The concentration ranges of combustible fuels, in terms of the percentage of lower explosive limit, and instruments used in each experiment are shown in this table.

Three instruments were supplied for this work by the Air Force. The use of fewer than three instruments in an experiment is an indication that the non-checked instrument was either malfunctioning, or had been sent to the manufacturer for repair.

The concentrations of hydrocarbons or fuels determined with the flame ionization detector, and the respective combustible gas alarm meter readings are listed in Table 2.

DETERMINATION OF DETECTOR RESPONSE CURVES BY COMPUTERIZED DATA FITTING

The data from Table 2 were subjected to computerized regression analysis. Data from each experiment were fitted to the quadratic equation of the form:

$$y = a + bx + cx^2 \qquad (1)$$

and to a linear equation:

$$y = a' + b'x \qquad (2)$$

In these equations, y represents the gas alarm meter reading, x is the % LEL value determined with the flame ionization detector, and a, a', b, b', and c are constants. The value of x was calculated on the basis that 75,000 ppm CH_n in air represents the lower explosive limit for hydrocarbon vapors in air [2]. Table 3 contains the numerical values of the constants a, b, and c, determined by regression analysis.

Using the equations obtained by regression analysis, meter readings corresponding to 3, 6, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60% LEL, as determined with the flame ionization detector, were calculated. Those values were subsequently averaged for all tests performed with any hydrocarbon or fuel. The results of these calculations are summarized in Table 4 and presented graphically in Figures 5, 6, 7, and 10.

TABLE 1. SUMMARY OF EXPERIMENTS TO DETERMINE RESPONSE CURVES FOR THE MSA MODEL 100S PORTABLE COMBUSTIBLE GAS ALARM[a]

Experiment number	Hydrocarbon or fuel	Concentration range covered, % LEL[b]	Instruments used No. 422	 No. 532	 No. 575
125	n-Pentane	0 - 58.9	√	√	√
126	n-Pentane	0 - 62.2	√	√	√
127	n-Hexane	0 - 59.2	√	√	
128	n-Hexane	0 - 57.6	√	√	
116	n-Heptane	0 - 59.9	√		√
117	n-Heptane	0 - 54.6	√		√
118	n-Octane	0 - 44.2	√		√
119	n-Octane	0 - 45.3	√	√	√
120	JP-4 (H-Bay, B-10)	0 - 49.5	√	√	√
121	JP-4 (H-Bay, B-10)	0 - 61.3	√	√	√
122	JP-4 (No. 673, RVP 2.1)	0 - 50.5	√	√	√
123	JP-4 (No. 673, RVP 2.1)	0 - 55.2	√	√	√
124	JP-4 (No. 685, RVP 2.7)	0 - 56.5	√	√	√
129	JP-8 (Tank 167, Bldg. 42D)	0 - 37.3	√	√	
130	JP-8 (Tank 167, Bldg. 42D)	0 - 38.6	√	√	
145	JP-8 (Coker lab. rack, Bldg. 59B)	0 - 40.5	√	√	√
148	JP-8 (Coker lab. rack, Bldg. 59B)	0 - 46.0	√		√
154	JP-8 (Coker lab. rack, Bldg. 59B)[c]	4.8 - 16.6	√	√	
155	JP-8 (Coker lab. rack, Bldg. 59B)[c]	4.6 - 15.3	√	√	
152	JP-8 (Coker lab. rack, Bldg. 59B)[d]	13.0 - 52.8	√	√	
153	JP-8 (Coker lab. rack, Bldg. 59B)[d]	10.2 - 56.1	√	√	
131	JP-9 (Batch 38)	0 - 51.7	√	√	
132	JP-9 (Batch 38)	0 - 52.3	√	√	
133	JP-9 (Batch 38)	0 - 46.0	√		
146	JP-10 (Drum 31)[d]	0 - 56.9	√	√	√
147	JP-10 (Drum 31)[d]	0 - 56.9	√	√	√

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[a] Unless indicated differently by footnotes b and c, the liquid hydrocarbon or fuel was maintained at approximately 22°C (72°F), with the sparger being immersed in a water bath.

[b] Concentrations determined with the flame ionization detector in Varian Model 1440 Gas Chromatograph.

[c] Liquid fuel was maintained at 30°C (86°F) during these experiments.

[d] Liquid fuel was maintained at 60°C (140°F) during these experiments.

TABLE 2. CONCENTRATIONS OF HYDROCARBONS OR FUELS AND THE CORRESPONDING MSA MODEL 100S PORTABLE COMBUSTIBLE GAS ALARM METER READINGS

Experiment number	Hydrocarbon or fuel	Instrument[a]	Concentration (% LEL for FID, underlined), or meter reading (for the MSA gas alarms)								
125	n-Pentane	FID	4.9	8.3	12.5	19.4	27.5	36.0	43.5	51.5	58.9
	n-Pentane	422	4.1	6.8	10.0	15.0	20.0	25.0	30.0	35.1	40.0
	n-Pentane	532	4.1	6.8	10.2	15.5	21.5	27.0	33.0	38.2	43.5
	n-Pentane	575	4.5	7.0	11.0	15.5	20.5	25.0	30.0	35.1	39.8
126	n-Pentane	FID	4.9	8.9	13.0	20.8	27.8	37.4	46.1	52.4	62.6
	n-Pentane	422	3.9	7.0	10.0	15.0	19.6	25.0	30.0	35.0	40.0
	n-Pentane	532	4.2	7.7	11.0	16.5	21.5	28.0	33.5	38.2	44.5
	n-Pentane	575	3.5	6.5	9.3	14.0	18.1	23.6	26.5	31.0	36.5
127	n-Hexane	FID	5.2	9.1	14.2	22.6	30.8	41.3	49.3	59.2	
	n-Hexane	422	4.0	7.0	10.0	15.0	20.0	25.0	30.0	35.0	
	n-Hexane	532	3.5	7.0	10.2	16.0	21.1	27.0	32.1	38.2	
128	n-Hexane	FID	5.5	9.6	14.5	21.3	30.5	39.6	48.5	57.6	
	n-Hexane	422	4.1	7.0	10.1	15.0	20.0	25.0	30.0	35.0	
	n-Hexane	532	4.1	7.1	11.0	15.6	21.1	27.0	32.0	38.0	
116	n-Heptane	FID	5.3	9.8	14.3	22.6	31.8	41.5	50.5	59.9	
	n-Heptane	422	4.0	7.0	10.0	15.0	20.0	25.0	30.0	35.0	
	n-Heptane	575	3.2	6.0	8.5	14.2	18.5	22.9	27.1	32.1	
117	n-Heptane	FID	5.6	10.1	15.2	24.4	33.9	44.9	54.6	58.7	
	n-Heptane	422	4.0	7.0	10.0	15.0	20.0	25.0	30.0	35.0	
	n-Heptane	575	4.1	7.0	9.5	15.5	20.6	26.5	31.5	36.9	
118	n-Octane	FID	5.8	10.4	15.3	24.5	35.6	44.2			
	n-Octane	422	4.0	7.0	10.2	15.0	20.1	24.0			
	n-Octane	575	4.0	7.0	11.2	15.6	20.2	24.0			
119	n-Octane	FID	5.8	10.8	15.6	23.8	35.3	45.3			
	n-Octane	422	4.0	7.0	10.1	15.0	20.0	25.0			
	n-Octane	532	3.2	6.3	9.9	14.2	19.5	24.5			
	n-Octane	575	3.6	6.2	10.2	14.7	19.6	24.5			
120	JP-4 (H-Bay, B-10)	FID	3.5	7.1	9.8	16.8	24.5	31.7	40.2	49.5	
	JP-4 (H-Bay, B-10)	422	4.0	7.0	10.0	15.0	19.6	24.8	30.0	34.0	
	JP-4 (H-Bay, B-10)	532	3.2	6.5	9.9	15.0	20.0	25.1	31.0	35.0	
	JP-4 (H-Bay, B-10)	575	4.0	7.0	10.2	14.4	17.5	23.4	28.0	31.5	

(continued)

TABLE 2 (continued)

Experiment number	Hydrocarbon or fuel	Instrument[a]	Concentration (% LEL for FID, underlined), or meter reading (for the MSA gas alarms)								
121	JP-4 (H-Bay, B-10)	FID	3.9	8.0	11.0	18.4	27.1	35.6	44.5	55.0	61.3
	JP-4 (H-Bay, B-10)	422	4.0	7.0	10.0	15.0	19.9	24.2	29.7	34.1	38.5
	JP-4 (H-Bay, B-10)	532	3.8	7.0	9.5	15.0	20.2	25.1	30.9	35.6	40.5
	JP-4 (H-Bay, B-10)	575	4.2	7.5	11.0	16.0	21.0	25.2	31.2	36.0	40.8
122	JP-4 (No. 673, RVP[b] 2.1)	FID	5.0	9.4	14.4	22.5	31.2	40.7	50.5		
	JP-4 (No. 673, RVP[b] 2.1)	422	4.0	7.0	10.1	15.0	19.8	24.2	29.2		
	JP-4 (No. 673, RVP[b] 2.1)	532	4.1	6.9	10.0	15.0	19.8	24.2	30.1		
	JP-4 (No. 673, RVP[b] 2.1)	575	4.0	6.9	10.0	15.2	19.9	24.7	30.2		
123	JP-4 (No. 673, RVP[b] 2.1)	FID	5.0	10.7	14.7	24.6	33.8	44.7	55.2		
	JP-4 (No. 673, RVP[b] 2.1)	422	4.0	7.0	10.0	15.0	19.9	25.0	30.0		
	JP-4 (No. 673, RVP[b] 2.1)	532	4.0	7.1	10.1	15.5	20.2	26.0	31.5		
	JP-4 (No. 673, RVP[b] 2.1)	575	4.1	7.0	10.1	15.5	20.1	26.0	32.0		
124	JP-4 (No. 685, RVP[b] 2.7)	FID	4.5	9.1	13.3	21.5	31.2	40.5	48.1	56.5	
	JP-4 (No. 685, RVP[b] 2.7)	422	4.0	7.0	10.0	15.0	20.0	25.0	29.5	34.3	
	JP-4 (No. 685, RVP[b] 2.7)	532	3.5	6.5	9.2	15.0	20.5	26.0	30.5	36.0	
	JP-4 (No. 685, RVP[b] 2.7)	575	3.5	6.5	9.1	14.0	18.5	23.5	28.0	33.0	
129	JP-8 (Tank 167, Bldg. 42D)	FID	6.3	13.1	19.2	31.7	37.3				
	JP-8 (Tank 167, Bldg. 42D)	422	4.0	7.0	10.0	15.0	17.6				
	JP-8 (Tank 167, Bldg. 42D)	532	4.0	6.6	9.1	14.0	16.1				
130	JP-8 (Tank 167, Bldg. 42D)	FID	6.7	13.5	19.0	33.2	38.6				
	JP-8 (Tank 167, Bldg. 42D)	422	4.0	7.0	10.0	15.0	17.1				
	JP-8 (Tank 167, Bldg. 42D)	532	3.5	6.6	9.1	15.0	17.0				
145	JP-8 (Coker lab. rack, Bldg. 59B)	FID	4.8	10.2	16.1	25.1	31.1	36.4	40.5		
	JP-8 (Coker lab. rack, Bldg. 59B)	422	3.8	6.8	9.9	14.5	19.0	25.0	31.2		
	JP-8 (Coker lab. rack, Bldg. 59B)	532	3.9	6.8	9.1	13.9	17.9	23.9	31.0		
	JP-8 (Coker lab. rack, Bldg. 59B)	575	3.4	6.0	8.0	13.1	16.7	22.0	28.2		
148	JP-8 (Coker lab. rack, Bldg. 59B)	FID	4.8	9.5	14.5	24.9	33.1	38.9	43.4	46.0	
	JP-8 (Coker lab. rack, Bldg. 59B)	422	4.0	6.9	9.7	14.5	19.2	24.5	29.8	33.0	
	JP-8 (Coker lab. rack, Bldg. 59B)	575	4.0	6.4	8.4	13.4	16.9	21.5	26.8	30.1	
154	JP-8 (Coker lab. rack, Bldg. 59B)	FID	4.8	8.8	13.2	16.6					
	JP-8 (Coker lab. rack, Bldg. 59B)	422	3.1	5.4	6.8	7.7					
	JP-8 (Coker lab. rack, Bldg. 59B)	532	3.6	6.7	9.6	12.2					

(continued)

TABLE 2 (continued)

Experiment number	Hydrocarbon or fuel	Instrument[a]	Concentration (% LEL for FID, underlined), or meter reading (for the MSA gas alarms)						
155	JP-8 (Coker lab. rack, Bldg. 59B)	FID	4.6	8.7	12.5	15.3			
	JP-8 (Coker lab. rack, Bldg. 59B)	422	2.9	5.0	6.6	7.7			
	JP-8 (Coker lab. rack, Bldg. 59B)	532	3.5	6.5	9.4	11.1			
152	JP-8 (Coker lab. rack, Bldg. 59B)	FID	13.0	25.2	32.3	37.4	52.8		
	JP-8 (Coker lab. rack, Bldg. 59B)	422	4.7	10.0	15.0	18.0	29.4		
	JP-8 (Coker lab. rack, Bldg. 59B)	532	4.8	10.0	14.8	16.4	25.3		
153	JP-8 (Coker lab. rack, Bldg. 59B)	FID	10.2	21.3	31.5	39.8	56.1		
	JP-8 (Coker lab. rack, Bldg. 59B)	422	5.0	10.0	14.7	19.0	31.2		
	JP-8 (Coker lab. rack, Bldg. 59B)	532	5.0	10.6	15.8	20.2	32.9		
131	JP-9 (Batch 38)	FID	4.5	9.1	13.6	21.4	30.8	41.6	51.7
	JP-9 (Batch 38)	422	4.0	7.0	10.0	15.0	20.0	25.0	30.0
	JP-9 (Batch 38)	532	3.0	6.0	8.2	13.0	17.0	21.5	26.2
132	JP-9 (Batch 38)	FID	5.2	10.7	15.5	24.9	36.0	47.7	52.3
	JP-9 (Batch 38)	422	4.0	7.0	10.0	15.0	20.0	25.0	27.1
	JP-9 (Batch 38)	532	4.0	7.1	10.2	15.1	20.5	26.0	28.0
133	JP-9 (Batch 38)	FID	4.3	8.7	12.8	21.3	30.8	40.4	46.0
	JP-9 (Batch 38)	422	4.0	7.0	10.0	15.0	20.0	25.0	28.5
146	JP-10 (Drum 31)	FID	6.3	12.6	18.5	30.8	41.4	56.9	
	JP-10 (Drum 31)	422	4.0	7.0	10.0	15.0	20.0	25.0	
	JP-10 (Drum 31)	532	4.2	7.2	10.5	15.5	20.0	25.0	
	JP-10 (Drum 31)	575	4.0	6.8	8.9	14.2	18.1	22.0	
147	JP-10 (Drum 31)	FID	7.2	13.6	19.1	30.4	44.0	53.7	
	JP-10 (Drum 31)	422	4.0	7.0	10.0	15.0	20.0	25.0	
	JP-10 (Drum 31)	532	3.8	6.5	8.6	13.5	18.5	23.0	
	JP-10 (Drum 31)	575	4.1	6.9	8.9	14.1	18.8	22.5	

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[a] The notations in this column refer to Varian Model 1440 Gas Chromatograph, equipped with a flame ionization detector (FID), and to three MSA gas alarms, identified by their serial numbers.

[b] Reid Vapor Pressure.

TABLE 3. RESULTS OF COMPUTERIZED DATA ANALYSIS

Experiment number	Hydrocarbon or fuel	First order equation: Concentration range	a'	b'	C.V.[a]	R-square[b]	Second order equation: Concentration range	a	b	c	C.V.[a]	R-square[b]
125	n-Pentane	27.5 - 58.9	2.39	0.6561	0.8119	0.999285	0.0 - 58.9	0.48	0.7716	-0.001492	2.2914	0.999247
126	n-Pentane	20.8 - 62.2	2.54	0.6412	1.1146	0.999160	0.0 - 62.2	0.42	0.7610	-0.001467	2.0525	0.999399
127	n-Hexane	22.6 - 59.2	2.61	0.5741	0.9827	0.999298	0.0 - 59.2	0.30	0.7023	-0.001577	2.1878	0.999377
128	n-Hexane	21.3 - 57.6	2.83	0.5833	0.3977	0.999886	0.0 - 57.6	0.19	0.7279	-0.001783	1.7254	0.999603
116	n-Heptane	22.6 - 59.9	3.11	0.5059	0.5906	0.999730	0.0 - 59.9	0.20	0.6540	-0.001719	2.1799	0.999371
117	n-Heptane	24.4 - 54.6	2.85	0.5111	0.4629	0.999832	0.0 - 54.6	0.27	0.6567	-0.001867	1.7167	0.999643
118	n-Octane	24.5 - 44.2	4.47	0.4414	0.2138	0.999953	0.0 - 44.2	0.00	0.7350	-0.004452	2.9602	0.998964
119	n-Octane	23.8 - 45.3	3.45	0.4660	1.2445	0.998810	0.0 - 45.3	-0.11	0.6768	-0.002941	3.2845	0.998830
120	JP-4 (H-Bay, B-10)	24.5 - 49.5	5.56	0.5783	3.7363	0.983319	0.0 - 49.5	0.53	0.9212	-0.005138	4.0343	0.997790
121	JP-4 (H-Bay, B-10)	27.1 - 61.3	5.07	0.5621	1.9716	0.995673	0.0 - 61.3	0.89	0.7963	-0.002844	4.1900	0.997439
122	JP-4 (No. 673, RVP 2.1)	22.5 - 50.5	3.36	0.5223	1.0329	0.999114	0.0 - 50.5	0.35	0.7051	-0.002520	2.4615	0.999239
123	JP-4 (No. 673, RVP 2.1)	24.6 - 55.2	2.60	0.5171	0.1663	0.999979	0.0 - 55.2	0.45	0.6469	-0.001718	2.8524	0.999014
124	JP-4 (No. 685, RVP 2.7)	21.5 - 56.5	2.22	0.5653	1.2473	0.998835	0.0 - 56.5	0.54	0.6613	-0.001216	2.8727	0.998917
129	JP-8 (Tank 167, Bldg. 42D)	19.2 - 37.3	1.81	0.4021	0.5348	0.999809	0.0 - 37.3	0.26	0.5398	-0.002659	3.9277	0.998300
130	JP-8 (Tank 167, Bldg. 42D)	19.0 - 38.6	2.28	0.3829	0.0931	0.999994	0.0 - 38.6	0.06	0.5480	-0.002845	1.8201	0.999649
145	JP-8 (Coker lab. rack, Bldg. 59B)	10.2 - 31.1	0.64	0.5416	4.5323	0.992513	0.0 - 40.5	1.40	0.2734	1.395558	11.0165	0.986035
148	JP-8 (Coker lab. rack, Bldg. 59B)	9.5 - 33.1	2.05	0.4815	0.6707	0.999835	0.0 - 46.0	1.58	0.3531	0.005880	9.2502	0.988247
131	JP-9 (Batch 38)	21.4 - 51.7	4.14	0.4625	0.6211	0.999694	0.0 - 51.7	0.30	0.6905	-0.003067	2.6548	0.999143
132	JP-9 (Batch 38)	24.9 - 52.3	3.76	0.4557	0.3545	0.999870	0.0 - 52.3	0.32	0.6595	-0.002724	1.9988	0.999476
133	JP-9 (Batch 38)	21.3 - 46.0	3.38	0.5415	1.1121	0.998838	0.0 - 46.0	0.55	0.7467	-0.003249	3.6212	0.998314
146	JP-10 (Drum 31)	18.5 - 56.9	3.26	0.3661	1.8423	0.998227	0.0 - 56.9	0.38	0.5451	-0.002364	3.3544	0.998693
147	JP-10 (Drum 31)	19.1 - 53.7	1.51	0.4070	2.0712	0.997968	0.0 - 53.7	0.24	0.4912	-0.001176	3.0441	0.998948

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[a] Coefficient of variation, in percent.

[b] Multiple-correlation constants from regression analysis.

TABLE 4. COMPUTED METER READINGS AT SELECTED FUEL AND HYDROCARBON VAPOR CONCENTRATIONS[a]

Experiment number	Hydrocarbon or fuel	Meter readings at indicated % LEL values												
		3	6	10	15	20	25	30	35	40	45	50	55	60
125, 126	n-Pentane	2.7	5.0	8.0	11.6	15.2	18.7	22.1	25.5	28.7	31.9	35.1	38.1	41.1
127, 128	n-Hexane	2.4	4.5	7.2	10.6	13.9	17.1	20.2	23.2	26.2	29.0	31.8	34.5	37.1
116, 117	n-Heptane	2.2	4.1	6.6	9.7	12.6	15.5	18.3	21.0	23.6	26.1	28.5	30.9	33.1
118, 119	n-Octane	2.0	4.1	6.6	9.7	12.6	15.3	17.8	20.1	22.3	24.2	26.0	27.6	29.0
120, 121	JP-4 (H-Bay, B-10)	3.3	5.7	8.9	12.7	16.3	19.7	22.9	25.9	28.7	31.3	33.7	35.9	37.9
124	JP-4 (No. 685; HVP)	2.5	4.5	7.0	10.2	13.3	16.3	19.3	22.2	25.0	27.8	30.6	33.2	35.8
122, 123	JP-4 (No. 673; LVP)	2.4	4.4	6.9	10.1	13.1	16.0	18.8	21.5	24.0	26.5	28.9	31.2	33.3
129, 130	JP-8 (Tank 167, Bldg. 42D)	1.8	3.3	5.3	7.7	9.9	12.0	14.0	15.8	17.5	19.1	20.5	21.7	22.9
145, 148	JP-8 (Coker lab. rack, Bldg. 59B)	2.9	4.4	6.4	9.0	11.5	14.1	16.7	19.2	21.8	24.3	26.9	29.5	32.0
131 - 133	JP-9 (Batch 38)	2.5	4.5	7.1	10.2	13.2	16.0	18.6	21.2	23.5	25.7	27.8	29.7	31.5
146, 147	JP-10 (Drum 31)	1.8	3.4	5.3	7.7	10.0	12.2	14.3	16.3	18.2	20.0	21.8	23.5	25.5

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[a] Concentrations are based on measurements with a flame ionization detector. Data for all experiments, with the exception of Experiments 145 and 148, were calculated to fit the curve for the second order equation. The computed meter readings for Experiments 145 and 148 fit the first order equation.

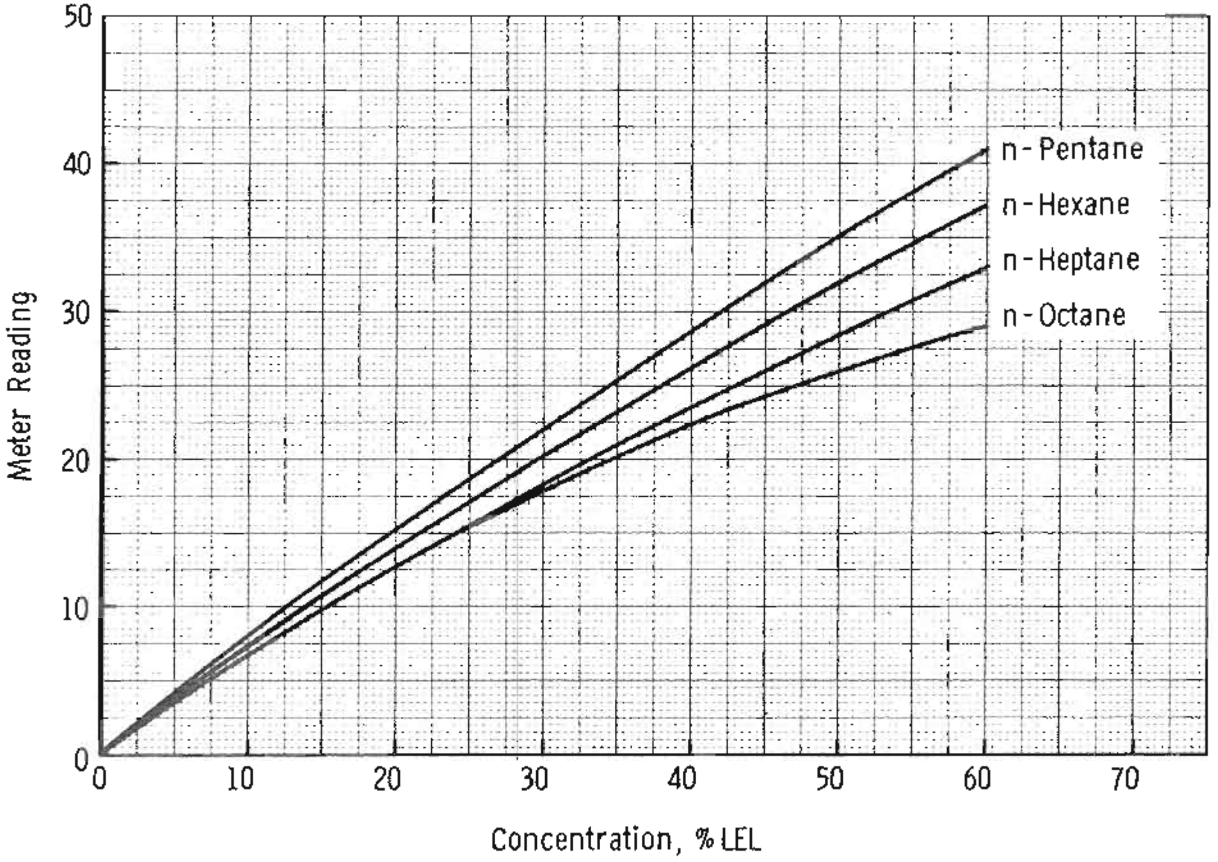

Figure 5. Hydrocarbon vapor response curves for MSA Portable Combustible Gas Alarm, Model 100S, from present work.

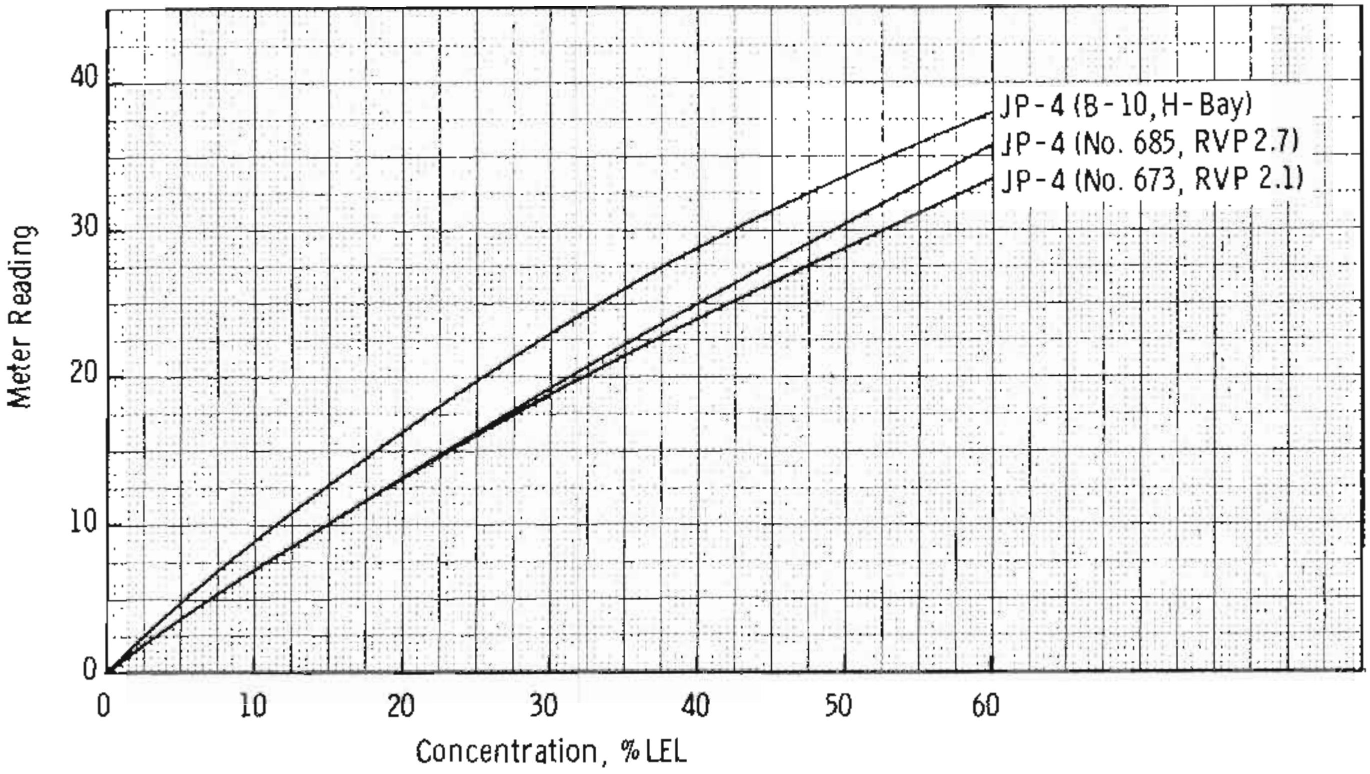

Figure 6. JP-4 vapor response curves for MSA Portable Combustible Gas Alarm, Model 100S, from present work.

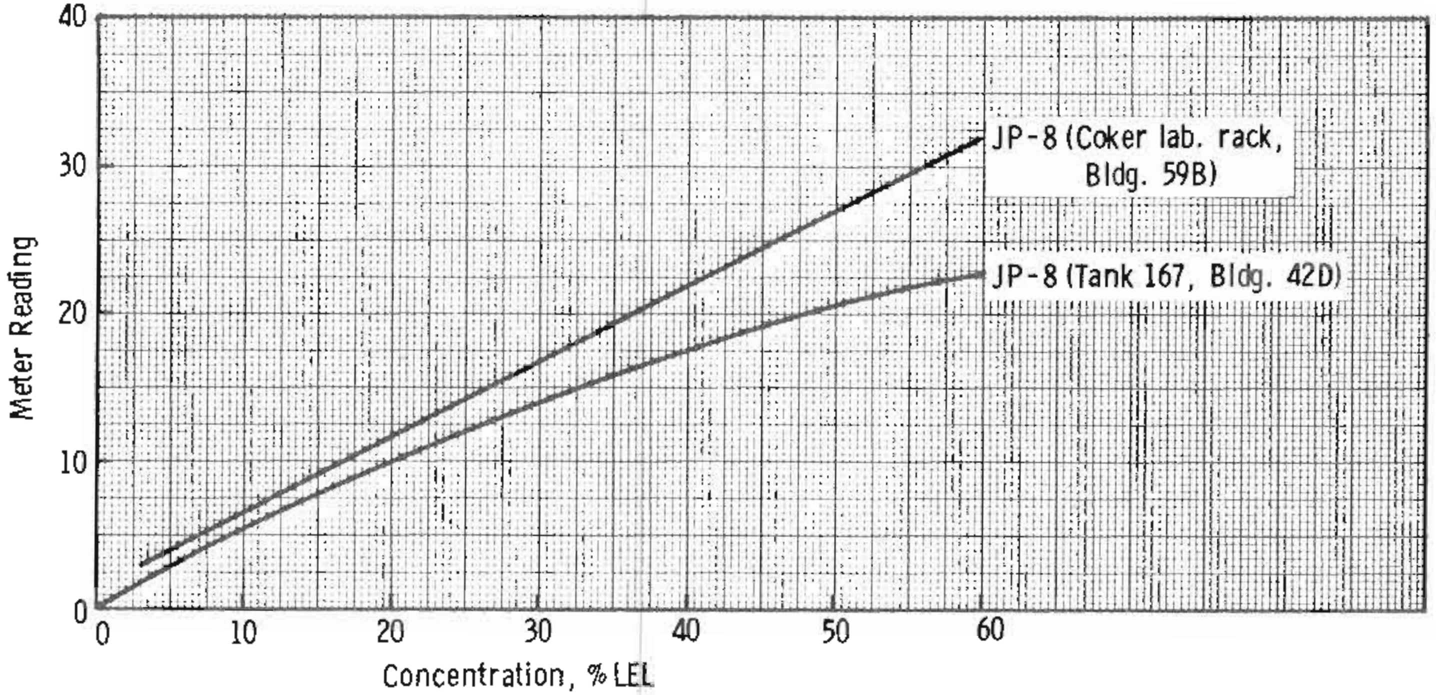

Figure 7. JP-8 vapor response curves for MSA Portable Combustible Gas Alarm, Model 100S, from present work.

An examination of Figures 5 to 7 reveals that the meter reading vs. concentration slope changes at a slower rate at concentrations above 20% LEL than at lower values. To quantify the response of the combustible gas alarm to each of the vapors used in this work, the experimental data at concentrations above 20% LEL were also fitted to the linear equation:

$$y = a' + b'x \qquad (2)$$

The symbols have meanings identical with those in the quadratic equation. The term b' in Equation 2 represents a quantified measure of the response of gas detector, with reference to that of the flame ionization detector, to the specific combustible vapor. We refer to this quantity as the response ratio. The computed values of the constants a' and b' for the vapors used are listed in Table 5. These values represent the averages for all experiments with any vapor.

TABLE 5. AVERAGE COMPUTED RESPONSE RATIO AND INTERCEPT VALUES[a]

Experiment number	Hydrocarbon or fuel	Intercept (a')	Response ratio (b')
125, 126	n-Pentane	2.5	0.65
127, 128	n-Hexane	2.7	0.58
116, 117	n-Heptane	3.0	0.51
118, 119	n-Octane	4.0	0.45
120, 121	JP-4 (H-Bay, B-10)	5.3	0.57
122, 123	JP-4 (No. 673; LVP)	3.0	0.52
124	JP-4 (No. 685; HVP)	2.2	0.57
129, 130	JP-8 (Tank 167, Bldg. 42D)	2.0	0.39
145, 148	JP-8 (Coker lab. rack, Bldg. 59B)	1.3	0.51
131 - 133	JP-9 (Batch 38)	3.8	0.49
146, 147	JP-10 (Drum 31)	2.4	0.39

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[a] The intercept and the response ratio are defined by Equation 2.

The response curve for normal vapor pressure JP-8 sample in Experiments 145 and 148 did not follow the pattern observed with other fuels. It exhibited a pronounced positive change of slope, that was unexpected on the basis of the data obtained with pure hydrocarbons, other fuels, and the reported response characteristics of the sensor used [3]. The unexpected response is attributed to the adsorption of high molecular weight hydrocarbons on the walls of the stainless steel capillary tubing leading from the sampling chamber to the flame ionization detector. The positive slope of the meter reading vs. concentration curve was found to increase significantly at concentrations above 35% LEL, suggesting that more extensive adsorption occurred at higher vapor concentrations, as the experiments progressed.

Subsequent to the experiments with JP-8, the air stream leading through the sparger containing the fuel was turned off. Purge air stream was allowed to flow through the sampling chamber. The output of the detectors was monitored during the purging operation. Gas samples were also fed into the flame ionization detector. The concentration of hydrocarbons in the latter measurements diminished much slower than the concentration in the sampling chamber, indicated by the combustible gas alarms. Consequently, the hydrocarbons sensed by the flame ionization detector emanated mainly from the walls of the capillary transfer tubing.

It should be noted that adsorption occurred on transfer tubing walls despite the fact that they were maintained at 30°C higher temperature (90°C) than the sparger and the sampling chamber (60°C).

The linear correlation of meter reading vs. fuel vapor concentration data, based on the low concentration range (9.5% to 33.1% LEL), minimizes the effect of adsorption of JP-8 vapors in the transfer tube (see Figure 8). Therefore, the data for normal vapor pressure JP-8 in Table 4 and the response curve in Figure 7 were based on the first order correlation (Equation 2).

Additional, confirmatory experiments were conducted with normal vapor pressure JP-8, in which the effect of adsorption was minimized. A limited number of experimental points were determined, in separate experiments (Experiments 152 to 154), at both low and high vapor concentrations. In these experiments, the stainless steel sample transfer tube was replaced with a Teflon tube (3/32 in. ID). This tube was maintained at 120°C (248°F) instead of 90°C (194°F). The results of these experiments are shown in Figure 9.

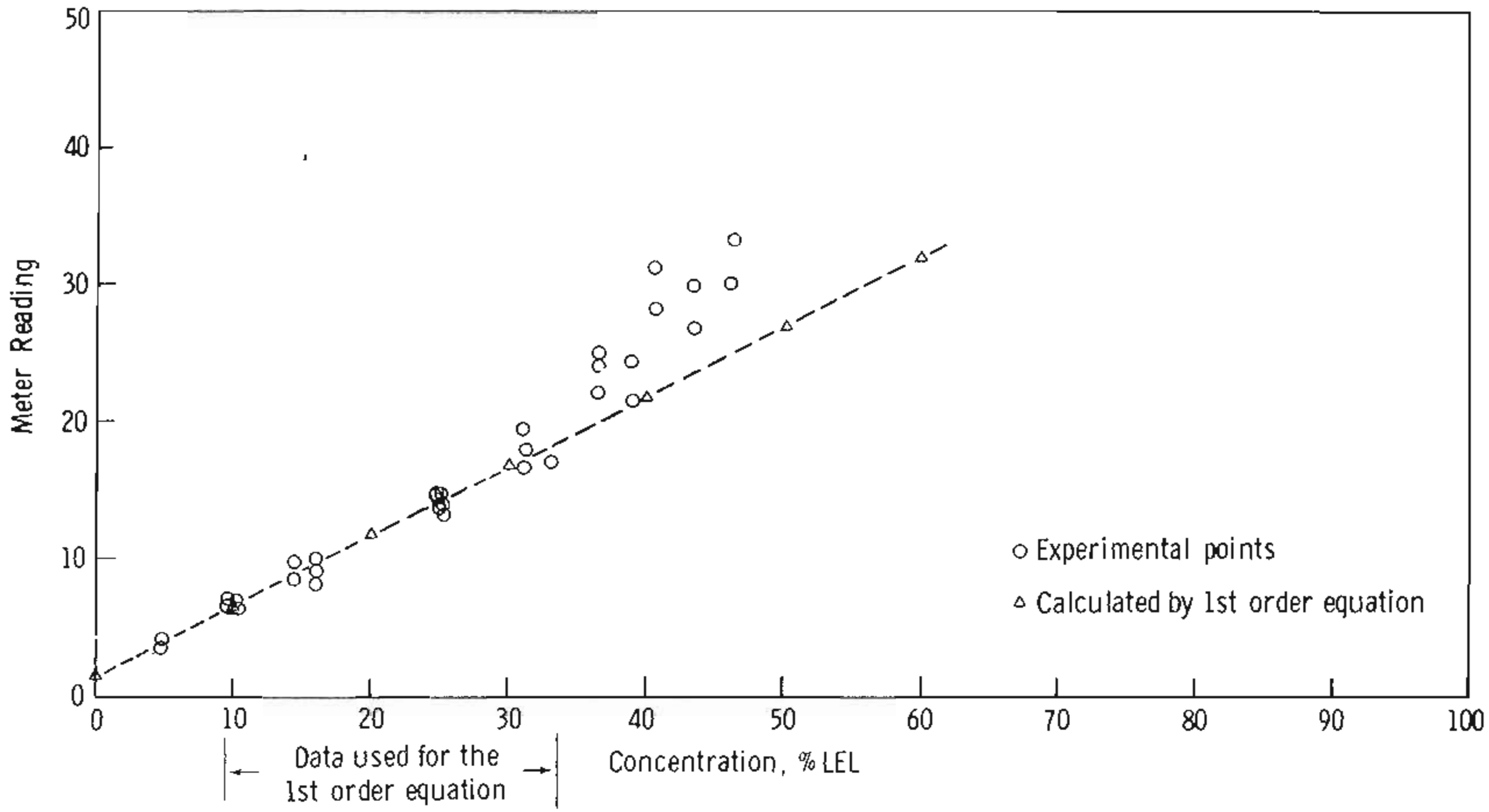

Figure 8. Experimental data points and computed response curves for MSA Portable Combustible Gas Alarm, Model 100S, in monitoring vapors of JP-8 (from Coker lab. rack, Bldg. 59B).

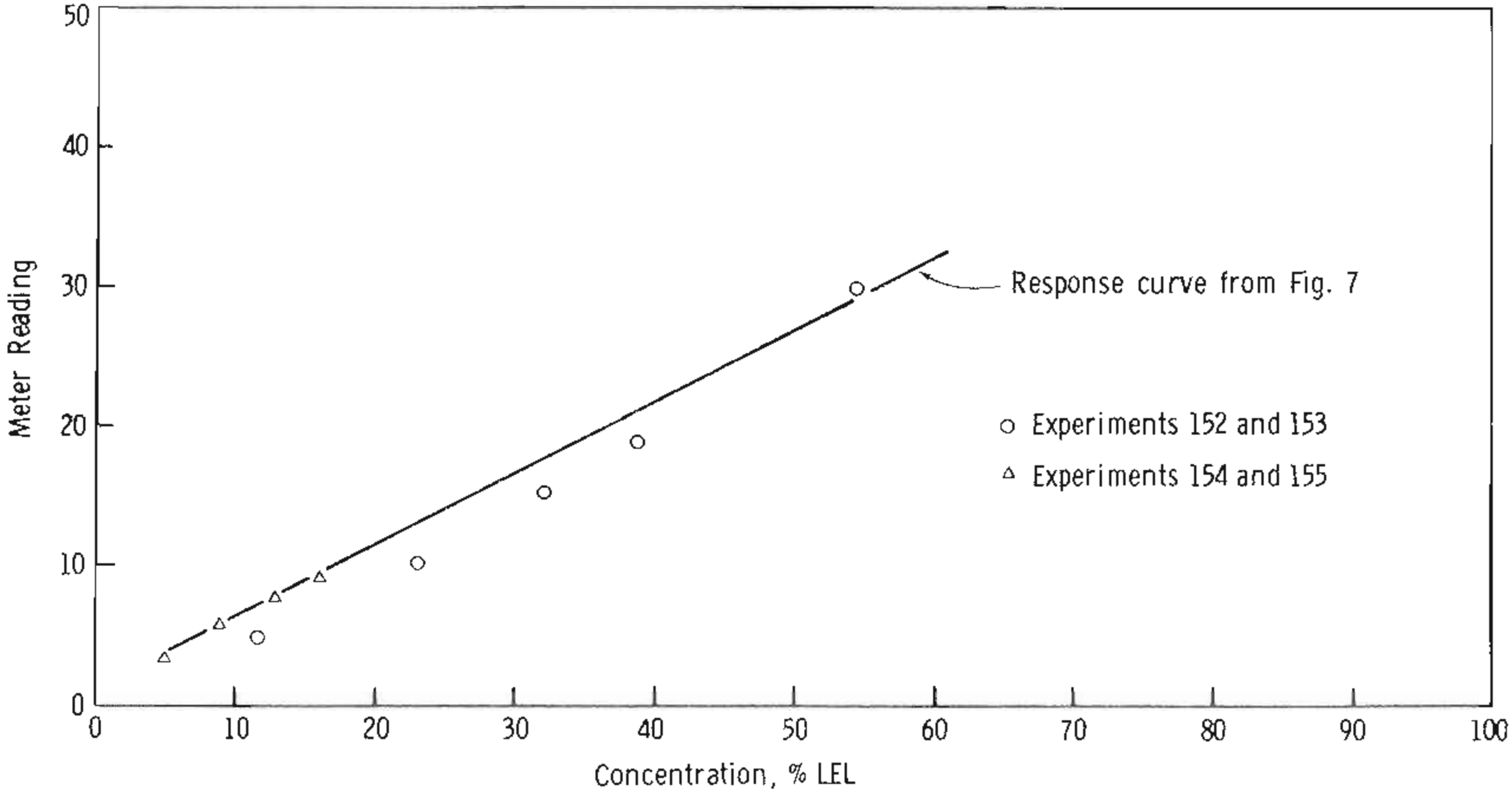

Figure 9. Response curve and confirmatory experimental data points for monitoring JP-8 vapors with MSA Model 100S Portable Combustible Gas Alarm.

The point in Figure 9 that represents the average response at the highest fuel vapor concentration, for the two instruments used in the present experiments, coincides closely with the expected value based on the response curve. Other points from Experiments 152 and 153 fall below the response curve, presumably because of the instrumental drift that we have experienced with these instruments.

Measurements were conducted in the 4.6% to 16.6% LEL range in Experiments 154 and 155. In these experiments, the fuel was maintained at 30°C (86°F) and the sample transfer lines were maintained at 120°C (248°F). The experimentally determined points from these measurements coincide essentially with the response curve.

Based on the described measurements, the linear relationship for normal vapor pressure JP-8 in Figures 7 and 8 represents the response of MSA 100S gas alarms to vapors emanating from a fresh sample of fuel well.

The gas alarm response curves for sensing vapors of JP-4, JP-8, JP-9, and JP-10 were combined into Figure 10. The data for the low vapor pressure JP-4 were incorporated into that figure, to ensure maximum safety for the users of the information on that fuel.

COMPUTED RESPONSE RATIO VALUES AND SELECTION OF CALIBRATION GASES

The response ratio was defined earlier as the slope of the line that expresses the meter reading of the combustible gas detector as a function of the flame ionization detector response. It is a numerically presentable measure of the response of the gas detector to the specific combustible vapor in air.

The Air Force is presently using propane-air mixture for the calibration of the combustible gas alarms.

Since aviation and missile fuels do not contain any, or significant concentrations of propane, it is not desirable to use a mixture of that hydrocarbon with air as the primary calibration gas. The application of such a low molecular weight hydrocarbon for this purpose, without adjustment for response differences, would cause erroneously low meter readings with all fuels whose concentrations need to be monitored.

It is desirable to select and use a hydrocarbon-air mixture for calibration of the combustible gas alarm, such that the response of the instrument to the calibration gas closely approximates its response to the fuel vapor that is to be monitored, at different % LEL values. Two approaches are available for selecting such a calibration gas:

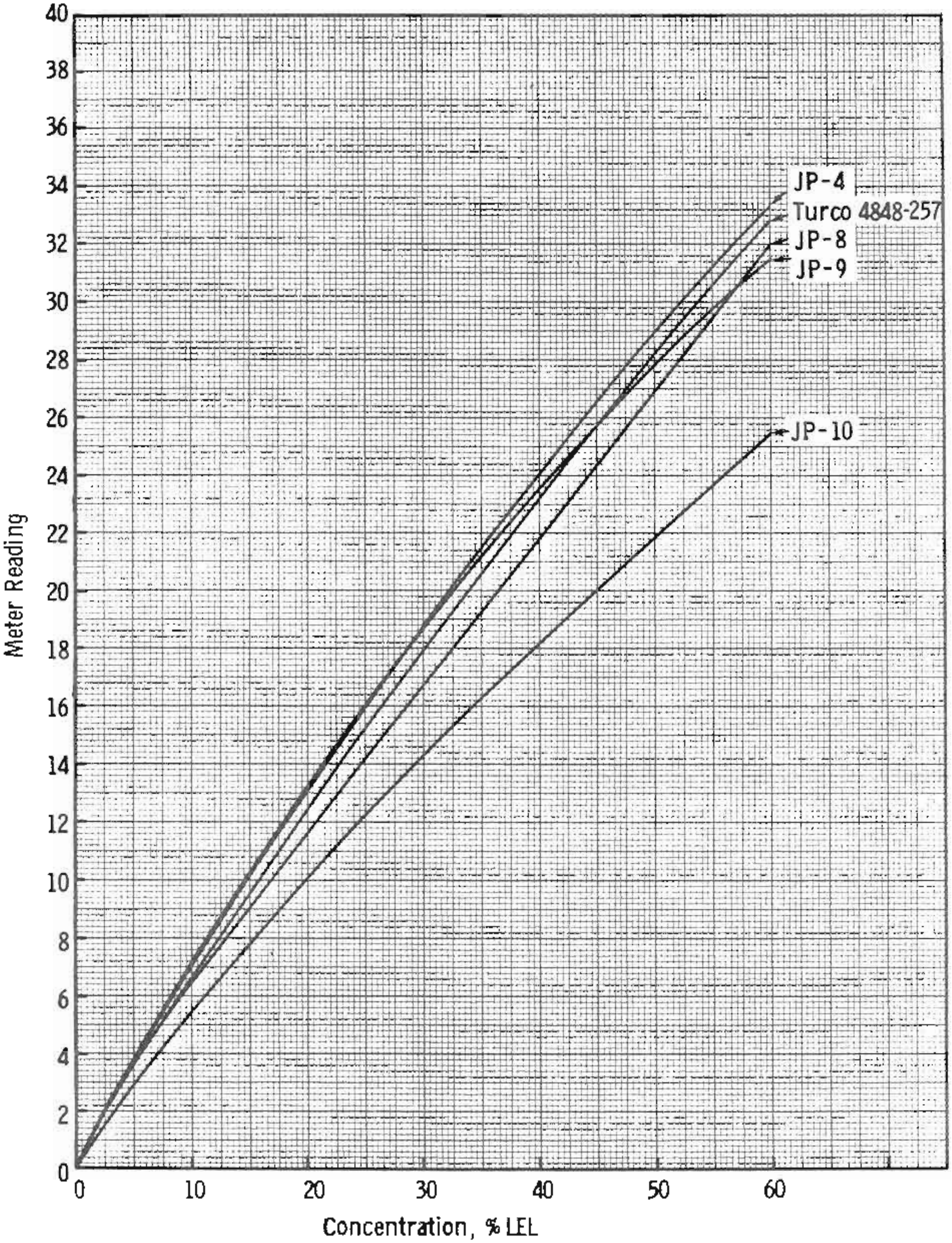

Figure 10. Fuel and solvent vapor (JP-4, JP-8, JP-9, JP-10, and Turco 4848-257) response curves for MSA Portable Combustible Gas Alarm, Model 100S, from present work.

1) Comparison of response ratio values and selection of the one that most closely approaches the value for the fuel vapor, and

2) Comparison of response curves for hydrocarbon-air mixtures with those for fuel-air mixtures.

The response ratios for pure hydrocarbons were plotted as a function of the number of carbon atoms per molecule in Figure 11. A curve was drawn through these points. The response ratios for fuels (represented by triangles) were entered onto this curve. The abscissa readings, nearest to those for the fuels, indicate hydrocarbons that would be the preferred substances, in mixtures with air, for the calibration of the alarms in monitoring the respective fuels. For example, n-hexane/air mixture would be the preferred composition for the calibration of the combustible gas alarm when monitoring JP-4 vapors in air. n-Heptane/air mixture would be the preferred calibration gas mixture when monitoring JP-8 vapors.

Both of the above-described methods of selecting a calibration substance for the monitoring of specific fuel vapors lead essentially to the same result with materials included in the present work. The response ratio graph provides an overview of the response characteristics of the detector to different fuel and pure hydrocarbon vapors. Comparison of response curves of the fuel and pure hydrocarbon vapors indicates the extent of agreement of the responses over the entire concentration range.

STATISTICAL EVALUATION OF DATA

Figure 12 depicts MSA 100S meter readings as a function of hydrocarbon concentration in JP-10 vapor. In a graphical, qualitative manner, it also indicates the repeatability and reproducibility of data obtained in the present work.

The experimental data for all experiments were fitted by regression analysis to first and second order equations. The coefficients of variation and multiple-correlation coefficients [see Ref. 5 for a discussion of the statistical significance of these quantities] from computerized calculations were established for each experiment. These are listed in Table 6.

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[5] N. R. Draper and H. Smith, "Applied Regression Analysis," John Wiley and Sons, Inc., New York, New York, 1967.

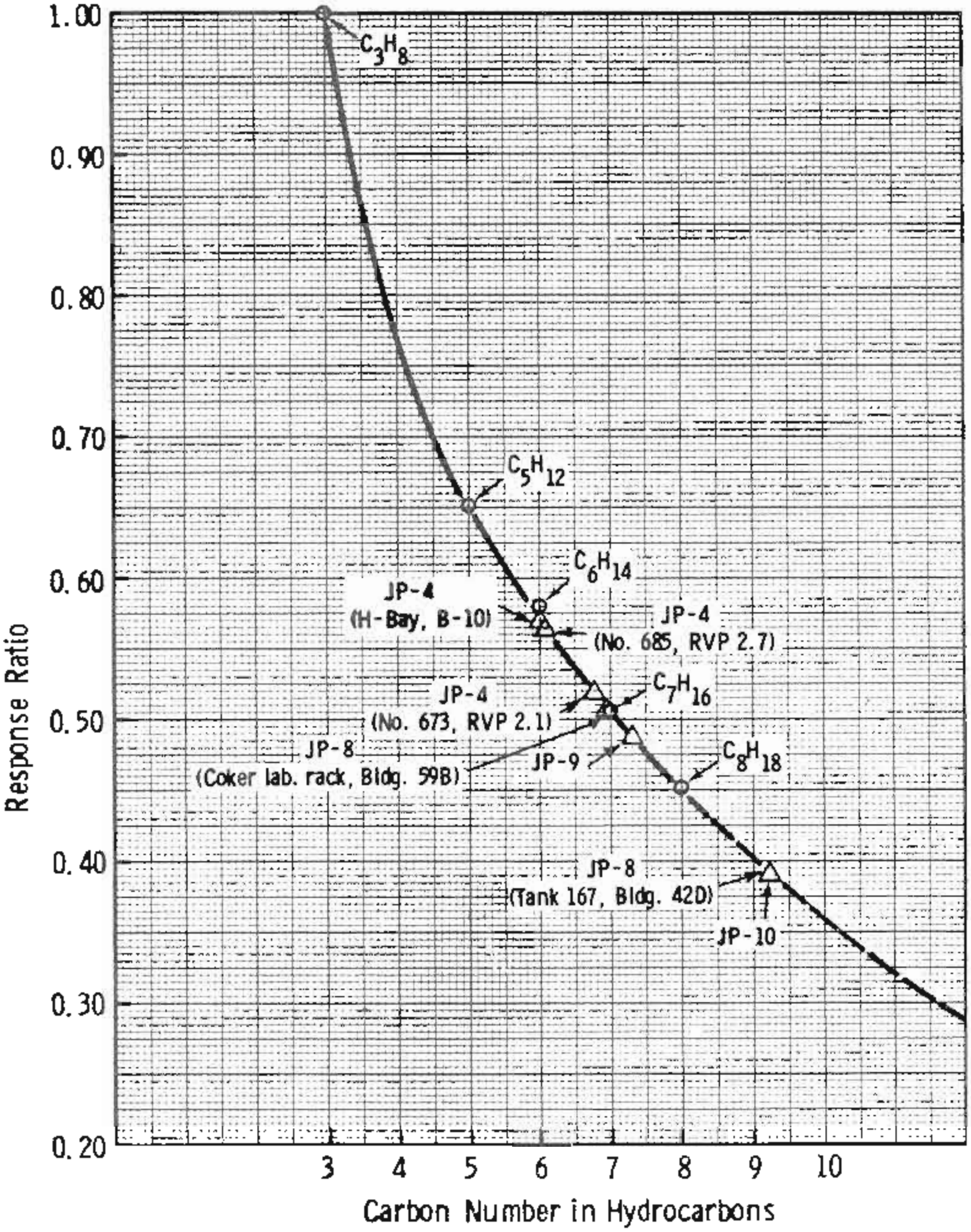

Figure 11. Response ratios for pure hydrocarbons and fuels.

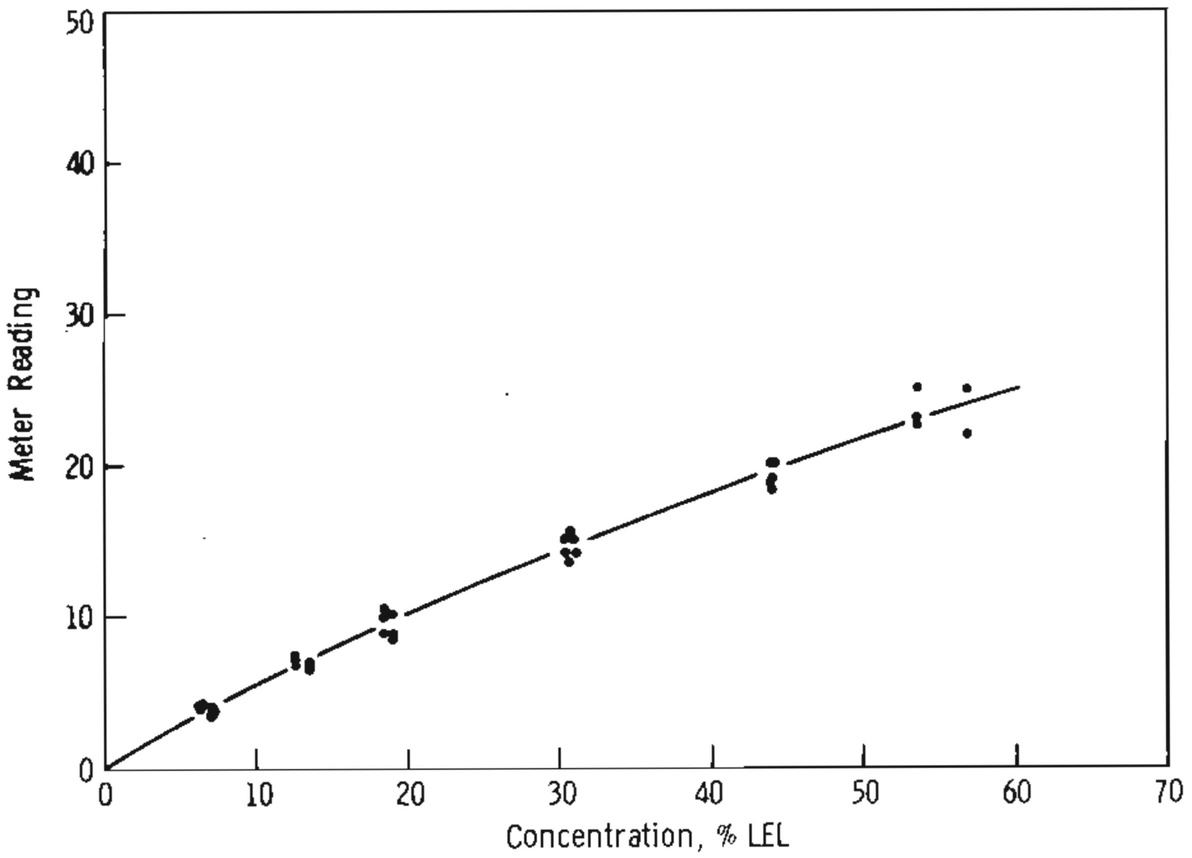

Figure 12. Experimental data points and computed response curve for monitoring vapors of JP-10 (Drum 31).

The following table provides a quantified overview of the quality of fit attained. Average values for the coefficients of variation and multiple-correlation constants were calculated. These averages were calculated for the pure hydrocarbons and the fuels separately; also, overall averages, including all substances used, were determined. These calculations were performed separately for first and second order regression analyses.

The fit of data to both the first and the second order equations is very good, as the coefficients of variation and the multiple-correlation coefficients indicate. The fit to first order equation is better than to the second order equation, partly because the former equation was applied to data covering narrower concentration ranges.

A better fit of data was attained with pure hydrocarbons than with fuels. That difference is attributed to variations of vapor compositions with time for the fuels (with the exception of JP-10) during the experiments, combined with varying experiment durations.

TABLE 6. MEAN VALUES OF COEFFICIENTS OF VARIATION AND MULTIPLE-CORRELATION COEFFICIENTS

	Mean coefficient of variation, %		Mean R-square	
Combustible substances	First order equation	Second order equation	First order equation	Second order equation
Pure hydrocarbons	0.73	2.30	0.9995	0.9993
Fuels	1.30	4.08	0.9974	0.9971
All substances	1.09	3.43	0.9982	0.9979

COMPARISON OF PRESENT RESULTS WITH MSA RESPONSE CURVES

The present data are presented together with the respective MSA response curves in Figures 13-16. With all vapor compositions, except for hexane, the concentrations corresponding to meter readings are lower in present work than the values indicated by the MSA response curves.

To determine the reason for the differences between MSA's and our response data, Mr. C. H. Etheridge of Mine Safety Appliances Company reviewed our interim reports and MSA's records pertaining to the calibration of the Model 100S Combustible Gas Alarm. He concluded that the systematic differences between MSA's and the present response curves arose from two sources [6]:

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[6] C. H. Etheridge, memorandum to G. A. Spencer, 6 November 1981.

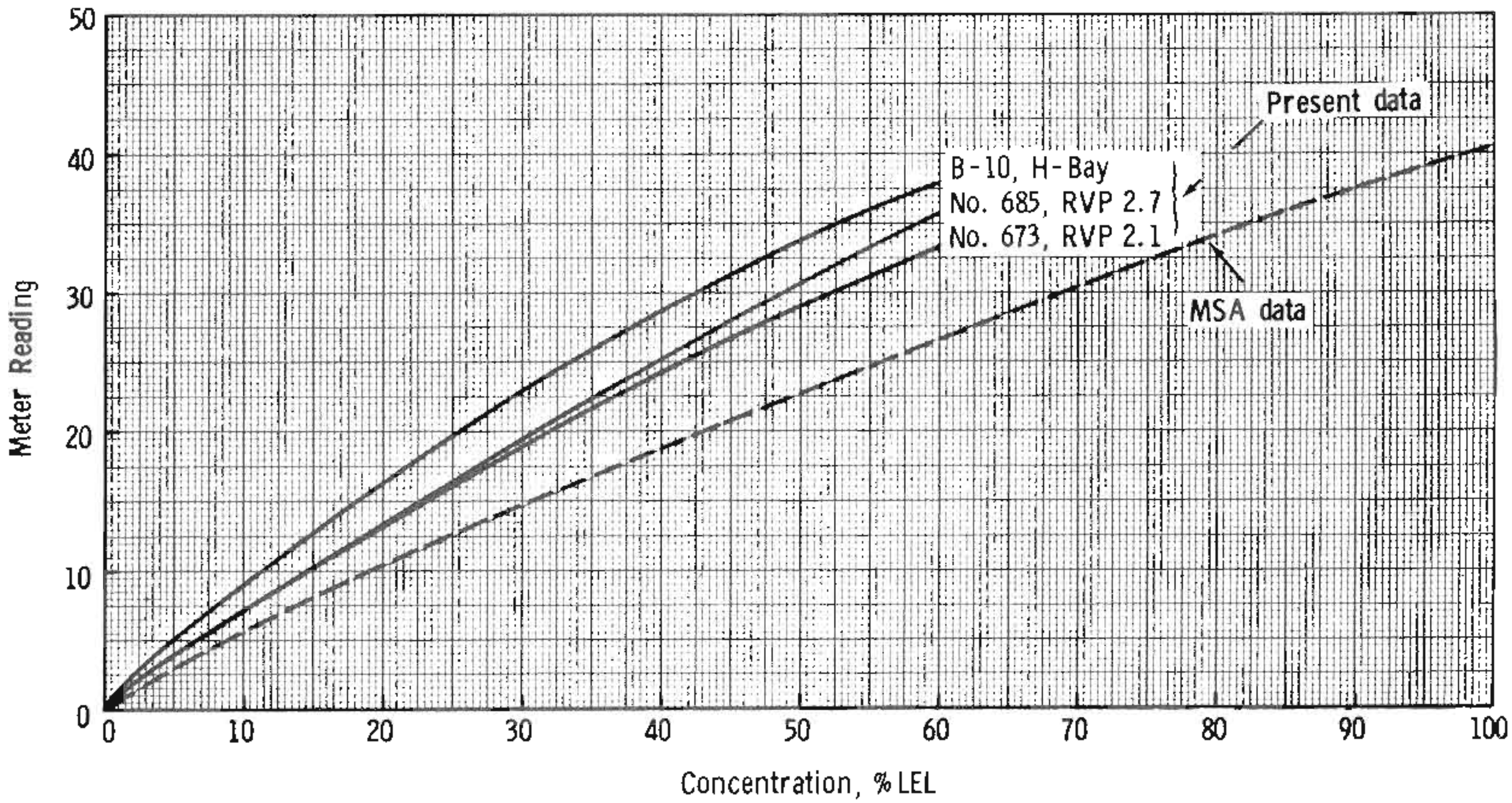

Figure 13. Comparison of JP-4 vapor response curves based on MSA and the present data.

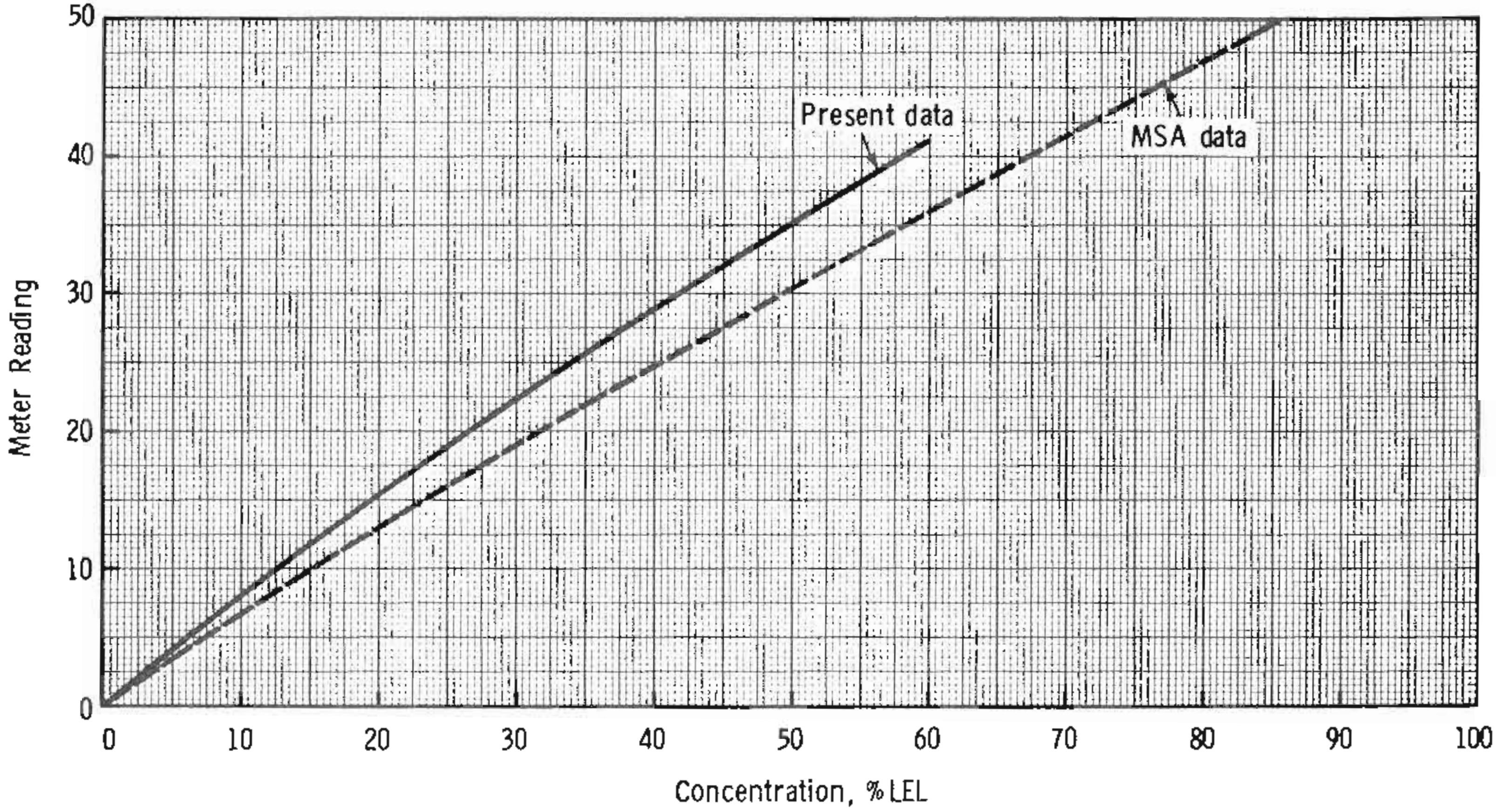

Figure 14. Comparison of pentane vapor response curves based on MSA and the present data.

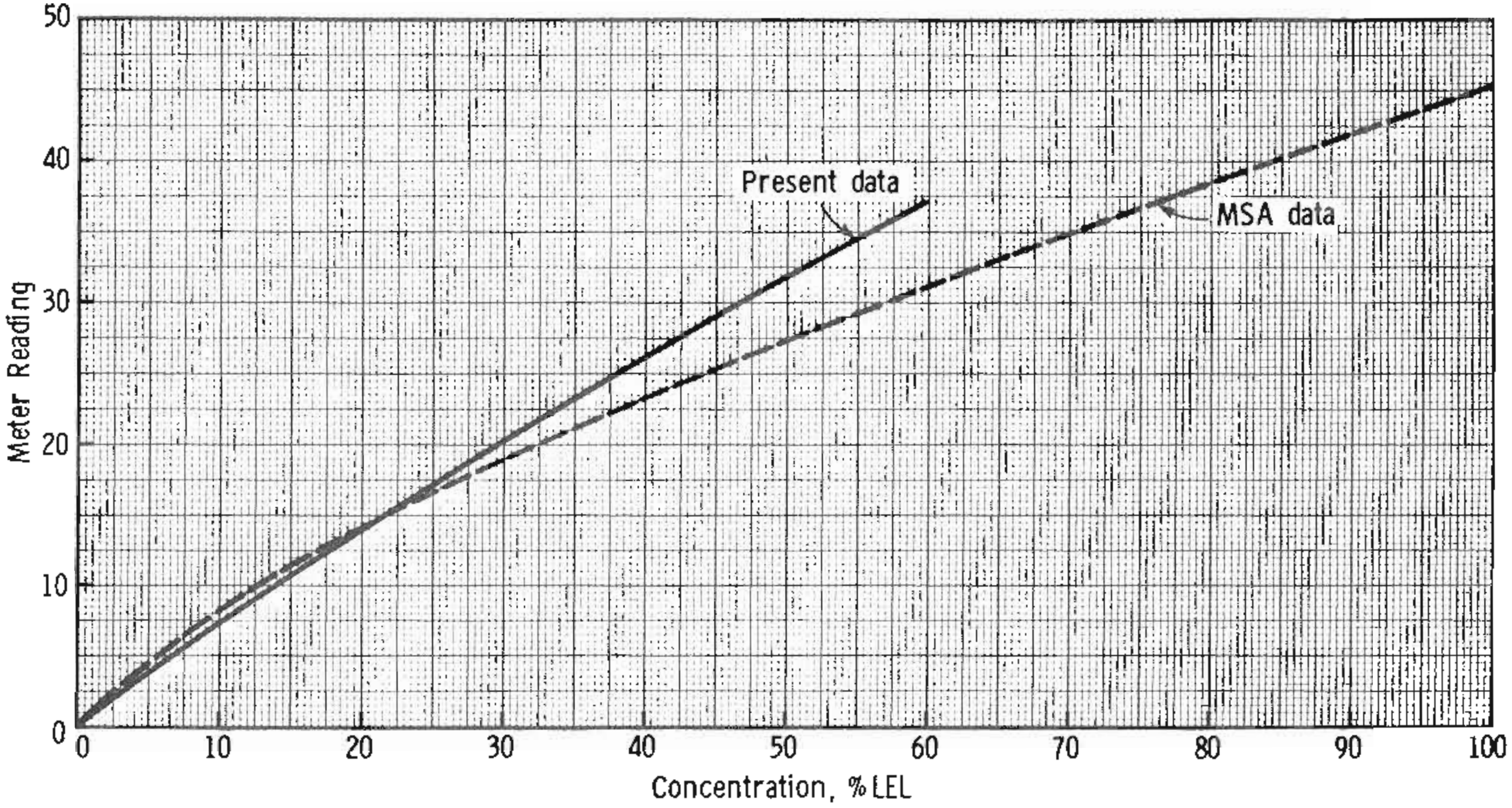

Figure 15. Comparison of hexane vapor response curves based on MSA and the present data.

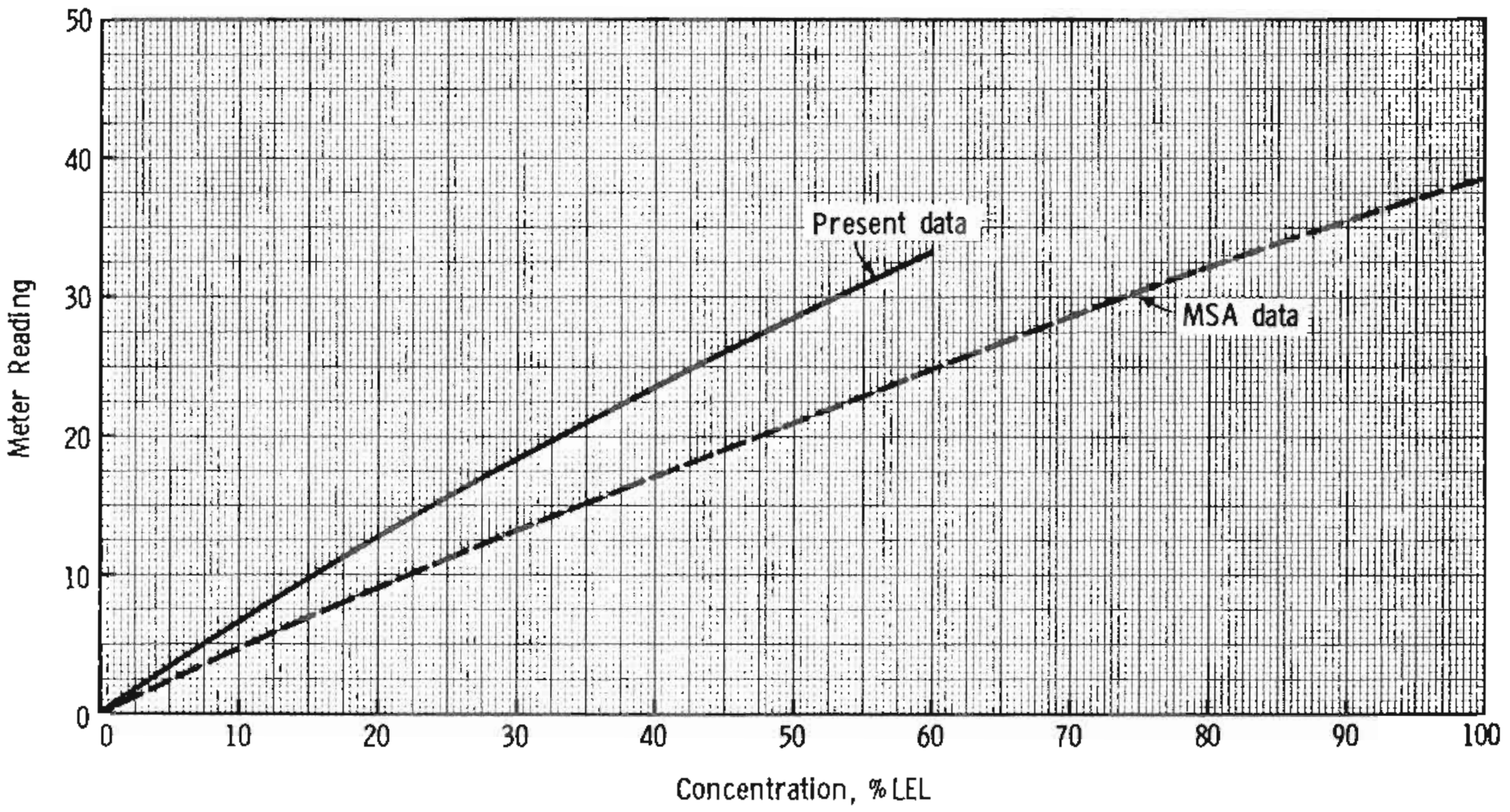

Figure 16. Comparison of heptane vapor response curves based on MSA and the present data.

1) An approximately 15% positive offset of the response curves as they appear in the instrument manual, from actual values.

2) Change in LEL value used for the calibration gas (propane) between 1977 and 1981.

The first of the above two is the major source of differences. By terms of the contract under which the instrument was designed by MSA, it was required to perform with a scale error limit of 0% to +30%. The positive scale error, specified by the Air Force, assured additional protection of personnel and property, beyond that dictated by the actual hazard levels. Consequently, the response curves incorporated into the manual were transposed to indicate concentrations 15% higher than the actual values. Thus the meter indications in testing, used in conjunction with response curves supplied with the instrument, will lead to an over-estimate of the combustible gas concentration by approximately 15%. This is the approximate magnitude of differences between response curves in the manual and the presently determined curves (see Figures 13-16), for substances for which both are available.

CONCLUSIONS

1. The MSA Model 100S Portable Combustible Gas Alarm provides warning when the atmosphere contains fuel vapors.

2. Propane/air mixture, presently used for the calibration of the Combustible Gas Alarm, is not the most appropriate mixture for that purpose, when the instrument is used for the monitoring of aviation and missile fuel vapors.

3. Mixtures of appropriate pure hydrocarbons with air can be used for the calibration of the Combustible Gas Alarm, to obtain meter readings that do not deviate greatly from the actual % LEL values.

4. Very good fit of experimental data to response curves was attained by computerized regression analysis. The MSA response curves in the instrument manual are purposely offset ~15% toward high % LEL values, to provide added safety for personnel and property.

5. Instrument down-time, because of malfunctioning and required repairs, was found to be high.

RECOMMENDATIONS

1. For the monitoring of military aviation and missile fuels, the use of propane-air mixture as a calibration gas should be discontinued.

2. n-Hexane- and n-heptane-air mixtures are recommended as calibration gases for the monitoring of JP-4 and JP-8 vapors, respectively, to obtain meter readings that will not deviate greatly from actual % LEL values for the atmosphere being monitored.

3. The manufacturer should review the repair records of Model 100S Combustible Gas Alarm. Components whose failure frequency has been high should be replaced by higher quality components in instruments to be repaired or manufactured.

4. It would be desirable to have the instrument modified in such a manner that calibration could be performed without disassembling.

5. The potentiometer used for setting the zero response on the meter should be replaced by one not as sensitive to adjustment.

6. The manufacturer should institute quality control on instruments being returned from repair. Repeatedly, we received instruments from repair for which the battery check and meter span readings differed greatly from values specified in the instrument manual.

REFERENCES

1. L. S. Ettre, "Relative Molar Response of Hydrocarbons on the Ionization Detectors," in "Gas Chromatography," N. Brenner, J. E. Callen and M. D. Weiss, Editors, Academic Press, New York, New York, 1962, p. 307.

2. M. G. Zabetakis, "Flammability Characteristics of Combustible Gases and Vapors," Bureau of Mines Bulletin 627, 1965, p. 20.

3. Instruction Manual for MSA Portable Combustible Gas Alarm, Model 100S; MSA Part No. 465702.

4. G. Gandee, memorandum to L. Parts, 16 March 1981.

5. N. R. Draper and H. Smith, "Applied Regression Analysis," John Wiley and Sons, Inc., New York, New York, 1967.

6. C. H. Etheridge, memorandum to G. A. Spencer, 6 November 1981.

A-1. R. C. Cavalari memo to G. A. Spencer, 24 November 1981.

A-2. Military Specification MIL-C-38736A, "Compound, Solvent, For Use In Integral Fuel Tanks," 1 April 1977.

A-3. L. Parts and T. J. Bucher, "Investigation of the Flammability of Aircraft Fuels and Related Materials," R&D Status Report No. 39 under Contract F33615-78-C-2023, 7 January 1982.

APPENDIX I

SUPPLEMENTAL RECOMMENDATIONS FOR CALIBRATION AND OPERATION OF THE MODEL 100S COMBUSTIBLE GAS ALARM

1. Instrument calibrations should be performed at least once a week when the instrument is in frequent use.

2. During calibrations, the instrument should be allowed to warm up for thirty minutes after it has been turned on and before any adjustments are made. (We have observed significant drifting of meter readings during the initial warm-up).

3. During monitoring, the instrument should be allowed to warm up for fifteen minutes after it has been turned on and before it is used.

4. A log should be maintained of instrument calibration. The information recorded should include the meter reading observed with the calibration gas, after the instrument has been zeroed and before the span control is adjusted. Significant drift of the meter reading from previously set value will indicate problems with the functioning of the instrument.

APPENDIX II

PROBLEMS EXPERIENCED DURING THE USE OF MSA MODEL 100S COMBUSTIBLE GAS ALARM

Two problems were experienced during the use of the combustible gas alarm:

1) Instrument downtime, because of malfunctions and needed repairs, was high.

2) Calibration of the instrument is cumbersome.

Three instruments were used in the present program. The average downtime for the instruments, at the times when experiments were conducted, was approximately 20%. The extent of downtime was unexpectedly high for an instrument designed and used for the monitoring of workplace safety.

The following were some symptoms of malfunctioning that we observed:

- Unstable (fluctuating) meter readings.
- Incorrect, very weak response to calibration and test gases.
- Progressive meter drift to lower values.
- Failure of the alarm to produce a warning sound.
- Failure of dial and signal lamps to go on.

No formal reports were received from MSA when the instruments were repaired. In telephone contacts with persons performing the repairs, the following problems were indicated with the combustible gas alarms.

A recurring problem was found to be the failure of rechargeable nickel-cadmium battery packs. On one occasion, a transistor in the battery charging circuit failed. A defective panel meter had to be replaced on one instrument.

We found the calibration of the instruments to be a somewhat cumbersome procedure. The procedure could have been simplified by following these steps:

- Placing the controls for calibration adjustments in a location such that they are accessible without dismantling the instrument.
- Making the zero control on the printed circuit board less sensitive to adjustment.

APPENDIX III

RESPONSE OF MSA PORTABLE COMBUSTIBLE GAS ALARM, MODEL 100S, TO TURCO 4848-257 SOLVENT VAPORS

After the bulk of this report had been completed, measurements were conducted to determine the response of the combustible gas alarm to the vapors of Turco 4848-257 solvent. The results of these measurements are reported in this appendix. The response curve was incorporated into Figure 10 in the main body of this report.

The sample of Turco 4848-257 solvent (MIL-C-38736A) was received from the Project Engineer; it had been supplied to him by R. C. Cavalari, Chief, Engineering/Planning Branch, Directorate of Maintenance, Headquarters Sacramento Air Logistics Center, McClellan AFB, CA 95652 [A-1].

Turco 4848-257 solvent is composed of a mixture of compounds (50 ± 2.5 vol-% Grade B aromatic naphtha, 20 ± 1.0 vol-% ethyl acetate, 20 ± 1.0 vol-% methyl ethyl ketone, and 10 ± 0.5 vol-% isopropyl alcohol) [A-2].

During the experiments described in this appendix, the liquid solvent was maintained at 22°C (72°F). Fuel vapor transfer lines were not heated. Because of the high volatility of solvent components that were vaporized, adsorption of vapors did not pose a problem.

The procedure for experimental measurements was identical with that used in response determinations with the fuels, described on pp. 2-10. The estimations and assumptions used in calculations were outlined in a report [A-3].

The results of experimental measurements are summarized in Table A-1. These data were subjected to computerized regression analysis. The results of this analysis are presented in Table A-2.

[A-1] R. C. Cavalari memo to G. A. Spencer, 24 November 1981.

[A-2] Military Specification MIL-C-38736A, "Compound, Solvent, For Use In Integral Fuel Tanks," 1 April 1977.

[A-3] L. Parts and T. J. Bucher, "Investigation of the Flammability of Aircraft Fuels and Related Materials," R&D Status Report No. 39 under Contract F33615-78-C-2023, 7 January 1982.

TABLE A-1. CONCENTRATIONS OF TURCO 4848-257 VAPORS AND THE CORRESPONDING MSA MODEL 100S PORTABLE COMBUSTIBLE GAS ALARM METER READINGS[a]

Experiment number	Instrument[b]	Concentration (% LEL by FID, underlined) or meter reading (for MSA Model 100S Portable Combustible Gas Alarm)				
177	FID	7.0	15.5	35.0	55.5	75.3
	532	5.0	10.0	20.0	30.0	40.0
178	FID	7.7	16.9	36.6	58.5	83.7
	422	5.0	10.0	20.0	30.2	40.0
	532	5.4	10.3	21.2	33.3	46.0
	575	5.2	11.1	20.5	31.4	41.5
179	FID	6.5	15.2	35.8	56.2	83.1
	422	5.1	10.1	20.3	30.0	40.0
	532	5.1	10.2	21.5	33.0	46.3
	575	5.0	9.9	20.5	30.2	41.7
180	FID	6.5	12.4	30.7	50.9	71.9
	422	5.2	10.0	20.0	30.1	40.1
	532	5.0	8.5	18.1	28.5	39.0
	575	4.9	8.0	17.5	27.0	36.2
181	FID	6.4	12.6	31.3	50.8	72.8
	422	5.1	10.1	20.0	30.1	40.2
	532	5.0	9.0	18.5	28.8	39.8
	575	4.9	8.1	18.0	27.1	37.0

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[a] The MSA Model 100S Portable Combustible Alarm was calibrated with 0.6 vol-% mixture of propane in air (28.5% LEL).

[b] The notations in this column refer to Varian Model 1440 Gas Chromatograph, equipped with a flame ionization detector, and to three MSA gas alarms, identified by their serial numbers.

MSA Model 100S Portable Combustible Gas Alarm meter readings, calculated by using constants for the quadratic equation (from Table A-2), are presented in Table A-3. The curve in Figure A-1 represents computed meter readings as a function of the solvent vapor concentration (in % LEL).

It is estimated that the uncertainty of data, upon which the response curve was based, is ±20%.

TABLE A-2. RESPONSE OF MSA MODEL 100S PORTABLE COMBUSTIBLE GAS ALARM TO TURCO 4848-257 SOLVENT VAPORS. RESULTS OF REGRESSION ANALYSIS

Computed quantity	Experiment No.					
	177	178	179	180	181	Average[a]
a[b]	0.56	0.32	0.55	0.63	0.64	0.54
b[b]	0.5908	0.6062	0.6243	0.6364	0.6347	0.6185
c[b]	-0.000936	-0.001224	-0.001424	-0.001582	-0.001512	-0.001336
C.V.[c]	3.2504	1.8905	2.7622	3.6025	3.6768	3.0365
R-square[d]	0.999183	0.999729	0.999430	0.999021	0.998984	0.999269

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[a] Average value for Experiments 177-181.

[b] The constants of the second order equation.

[c] Coefficient of variation, in percent.

[d] Multiple-correlation coefficient.

TABLE A-3. RESPONSE OF MSA MODEL 100S PORTABLE COMBUSTIBLE GAS ALARM TO TURCO 4848-257 SOLVENT VAPORS. COMPUTED METER READINGS AT SELECTED % LEL VAPOR CONCENTRATIONS

Vapor conc., % LEL	0	3	6	10	15	20	25
Meter reading	0.5	2.4	4.2	6.6	9.5	12.4	15.2
Vapor conc., % LEL	30	35	40	45	50	55	60
Meter reading	17.9	20.6	23.1	25.7	28.1	30.5	32.8
Vapor conc., % LEL	65	70	75	80	85	90	
Meter reading	35.1	37.3	39.4	41.5	43.5	45.4	

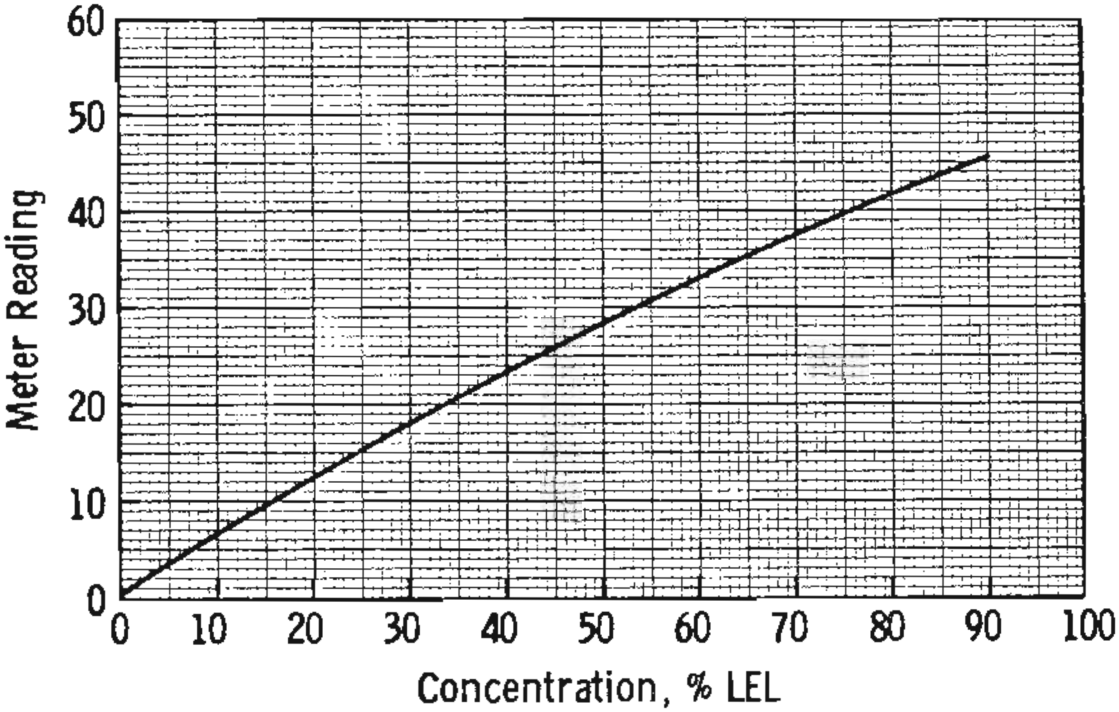

Figure A-1. Turco 4848-257 solvent vapor response curve, for use with MSA Portable Combustible Gas Alarm, Model 100S.