KRYPTONATE-BASED INSTRUMENTATION
DEVELOPMENT FOR AUTOMOBILE
EXHAUST POLLUTANTS

PHASE III Report: Design and Construction of Four (4)
Experimental Models

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for
Division of Isotopes Development
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ABSTRACT

This phase of the program encompassed the design, construction and evaluation of four (4) prototype instruments for the detection of automobile exhaust pollutant detection. These instruments employed the radio release mechanism utilized by Panametrics in detection of various trace gases.

The prototype instruments were of two (2) designs. One design was operable from a power source supplied by an automobile battery. The second design was operable from 110 volts AC power.

Successful evaluation in the laboratory as well as with various automobiles were performed with both type instruments. Scale-up of the quantity of sensor material prepared introduced unexpected problems with respect to detection lifetime which were not satisfactorily resolved within the time and funds available to the program. Nevertheless, a Kryptonate-based instrument using a single detection method for the measurement of hydrocarbons, CO and NO_x as pollutants by automobile exhausts was shown to be operable with actual automobile exhausts, to provide more than adequate sensitivity for inspection purposes, and to provide response and recovery times for full scale reading in the range 10-15 secs.

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1. Introduction

The continuing pollution of the atmosphere by automobile exhaust gases and actual, as well as proposed, pollution control devices installed on automobiles necessitates the development of instrumentation to monitor the effectiveness of the control devices. This program was initiated to develop a portable, inexpensive automobile exhaust monitor capable of measuring exhaust concentrations of the three principal pollutant gases.

The initial phase of the overall program was concerned with developing and characterizing detection methods for the three main pollution constituents of vehicle exhaust. These three pollutants, namely hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x), were readily detected in trace quantities by means of Kryptonates[®] prepared by Panametrics. Such materials are solids into the surface layers of which the radio isotope, Kr-85, has been stably incorporated. During a gas-solid reaction, the entrapped Kr-85 is released at a rate dependent upon the rate of reaction and, hence, upon the gas concentration.

Results of studies¹ conducted during this initial phase of the program were encouraging. Detection sensitivities at levels lower than required were demonstrated. Adverse technical features of the detection method were investigated and found to be either absent or within acceptable limits.

Accordingly, a breadboard instrument was constructed during the second phase of the program. This instrument was evaluated² under normal operating conditions i. e. using a vehicle exhaust. This instrument was operated at the New Jersey Vehicle Emission Laboratory. The instrument was also shown at an ERA laboratory located at Ypsilanti, Michigan.

Based on the results of the first two phases discussed above, a concluding phase was undertaken which is discussed herein. This continuation of the program to date has produced four (4) breadboard instruments.

II. Principal of Operation

Only a brief description of the principle of operation is outlined here. A detailed description has been incorporated in the previous Phase I and II reports of the program (Kryptonate - Based Instrumentation Development for Automobile Exhaust Pollutants I. Feasibility - II. Breadboard Instrument Development).

The technique utilized by Panametrics is based on the radio release of a krypton-85 homolog. The release rate of the krypton gas is linearly dependent upon the reacting gas concentration, thereby providing a calibratable measure of the reacting gas concentration. Only a very simple flow system is required consisting of a sensor containing the radio homolog, a Geiger Muller tube incorporated into a counting chamber to measure the radioactive Kr-85 release rate and a pump to move the gas.

A specific substrate, impregnated with 5% krypton-85 gas is utilized as the sensor. A platinum oxide powder radio homolog is used as the hydrocarbon sensor; an iodine pentoxide homolog is used as the carbon monoxide sensor and a hydroquinone clathrate is used for the detection of nitrogen dioxide. The hydrocarbon and carbon monoxide sensors are operated at elevated temperatures. The hydroquinone radio homolog, operated at ambient temperature, is utilized in conjunction with a catalyst for the conversion of NO to NO₂.

The instrument is designed so that a single channel may be monitored individually or all three channels may be monitored simultaneously. The instrument may be converted to DC operation, i. e., operated by an automobile battery by making a few minor changes.

III. Design and Construction of Prototype Instruments

The basic prototype instrument is the same for both AC as well as DC operation. The electronic portion of the instrument has been so designed that it may be operated from either mode.

The front panel of the prototype instrument contains all function switches and readout. To operate the instrument the "power-on" switch is activated. This initiates warm-up of the heated sensors as well as activating all the electronics and starting the pump.

Two red indicator lamps signify that the heaters for the CO and hydrocarbon sensors are activated. When the operating temperature of the sensor is attained, an ON-OFF controlling mode is displayed by the indicator lamps.

The pump during warm-up, can pull ambient air through the sensors as well as through the counting chambers of the instrument in order to clear the system of any residual pollutant or Kr-85 gases. This inlet is located on the side of the instrument. A filter is located immediately following the inlet to the instrument to eliminate particulate matter from the exhaust as well as to remove water droplets from the stream.

The basic flow system designed for both type instruments is depicted in Fig. 1. The exhaust gas is pumped into the instrument from the exhaust pipe of the vehicle, through a manifold located in the instrument and vented through the pump. The sensors and GM tube-counting chamber assembly are protected from the exhaust gas by means of three way electrically operated solenoid valves. These valves are normally closed in the deactivated mode. Individual front panel switches activate the solenoids and direct the exhaust gas through the sensors. The trace gas constituent reacts with the host material, releases Kr-85 and passes through the counting chamber. The GM 2" pancake tube (TGM No. 273) along with its associated rate-meter measures the Kr-85 concentration passing through the counting chamber. The resulting signal is displayed on the front panel indicators.

A. Direct Current Prototype Instrument

The first of the four instruments was designed as a portable, battery operated instrument. It weighed approximately twenty-five (25) pounds and had a volume of approximately one and one-half (1.5) cubic feet.

Fig. 1. Schematic Drawing of Instrumental Gas Flow System.

The design and construction of an automobile battery operated instrument was initiated for the first prototype instrument as it could readily be utilized as a field instrument as well as be adapted to a fixed installation instrument. Battery operation permitted this instrument to be used insitu for the collection of information from a moving test vehicle by continuously monitoring the exhaust of this test vehicle. Another possible application for a battery operated instrument was for spot checking of apparent pollution offenders on the roadway from a vehicle parked in a rest area near the highway. Because of the quick response of the instrument an immediate measure of the emission characteristics of transient vehicles exhaust could be determined. A further potential application for such an instrument with higher sensitivity levels would be ambient air monitoring of major intersections or arteries of a city during egress time of vehicular commuters.

The battery-operated prototype front panel pollution indicators consisted of three color coded meters. Each meter face was sectioned into thirds, each section being color-coded as green, yellow and red, to indicate a degree of pollution, respectively, low, medium, and high.

A marriage between Kryptonate material and concentration of pollutant gas to be detected allowed the full scale setting of the meters to be varied. The settings for the laboratory evaluation were set as indicated in Table I.

Table I. Meter Reading vs. Pollutant Concentration

Meter Indication	Hydrocarbon Channel	Carbon Monoxide Channel	Nitrogen Oxide Channel
Green	0-65ppm	0-16000ppm	0-330ppm
Yellow	65-135ppm	16000-33000ppm	330-660ppm
Red	135- > 200ppm	33000- > 50000ppm	660-> 1000ppm

B. AC-Operated Prototype Instrument

This second design of the prototype instrument was initiated for fixed installation inspection such as might exist for annual vehicle inspection purposes in garages or other inspection facilities. This instrument could be "rack mounted" if necessary and operated from "house" current.

The front panel design of this second instrument was vastly different than the battery-operated prototype. It is pictured in Fig. 2.

Instead of a front panel consisting of meters, this instrument incorporated a green-yellow-red light "readout". The color coding was the same. An overlap of indicator voltages enabled the observer to determine which end of a given range was being indicated because two adjacent lights could be activated simultaneously. The ranges covered by various light combinations are given in Table II.

Table II. Light Indicators of AC Operated Prototype

Light Indication	Hydrocarbon Channel	Carbon Monoxide Channel	Nitrogen Oxide Channel
Green	0-25ppm	0-2500ppm	0-150ppm
Green-Yellow	25-40ppm	2500-4000ppm	150-250ppm
Yellow	40-50ppm	4000-5500ppm	250-350ppm
Yellow-Red	70-100ppm	5500-7000ppm	350-450ppm
Red	70->100ppm	7000->10000ppm	450->600ppm

The front panel of this instrument also contained an indicating "power-on" push button, as well as indicating sensor temperature control lamps. While operational indicating lamps were also contained on the front panel. Upon activation, these caused solenoids to open, thus switching the internal flow of pollutant to the appropriate sensor.

Fig. 2. AC Operated Exhaust Analyzer.

An optional meter readout could also be incorporated by utilizing the recorder jack outputs located on the rear chassis of the instrument.

The prototype instrument was laboratory tested using the settings recorded in Table II.

IV. Evaluation of Prototype Instruments

A. Laboratory Evaluation

Both prototype instruments were first evaluated in the laboratory with fixed concentrations of pollutant gases from supplies diluted to low concentrations by Matheson Gas Products, Rutherford, New Jersey.

These supply cylinders were nominally 400 ppm hexane balance nitrogen; 10,000 ppm carbon monoxide, balance nitrogen; 1000 ppm NO₂, balance nitrogen; and 1000 ppm NO, balance nitrogen.

A dilution test system, substantially identical to that described in Ref. 1, was constructed for the laboratory evaluation of the instruments. The actual concentration of the test gas at the entrance to the prototype instruments could be both reduced and varied by means of this system.

1. Laboratory Evaluation of Prototype I

Time to reach operating temperature of the sensors in the battery-operated instrument was determined as approximately 35 minutes.

Inherent response time of the system was determined by introducing a trace amount of 5 percent Kr-85 gas from a supply cylinder containing N₂. This gas stream was pulled through the instrument, bypassing the sensor and count chamber. Activation of individual solenoids which divert the stream through both the sensor and the counting chambers permitted the response and recovery of the system to be recorded. The overall response and recovery of each channel to > 95% of final signal was 12-15 seconds. A portion of this response time must be attributed to gas flow transit time but another portion is attributable to ratemeter circuitry response time, the latter constituting an inherent minimum response time for this type of instrument.

The power consumption of the battery-operated instrument, about 450 watts during warm-up but less than 300 watts during operation, was such as to permit usage with a standard, fully charged, 12 volt automobile storage battery for a period of about 3 hours. For times in excess of this, continuous charging of the battery was required.

The trace gas pollutants were individually introduced through the dilution system thru a dilution system similar to that discussed in Ref. 1. The dilutant gas used for this test was ambient air. The results shown in Table III are visual observations of meter deflection, rounded and smoothed by the observer to eliminate statistical fluctuations.

Table III. Meter Reading, % of Full Scale

Test Gas (diluted with ambient air)	HC Channel	CO Channel	NO _x Channel
125 ppm C ₆ H ₁₄	50	0	0
200 ppm C ₆ H ₁₄	80	0	0
500 ppm NO ₂	0	0	50
1000 ppm NO ₂	0	0	100
400 ppm NO	0	0	45
800 ppm NO	0	0	85
2000 ppm CO	0	5	0
4000 ppm CO	0	10	0
10,000 ppm CO	0	20	0
20,000 ppm CO	0	40	0

The DC operated prototype instrument performed well with laboratory test gases. The overall response and recovery of the system to test gases was about 15 seconds for achievement of 100% of the final signal within expected statistical deviation therefrom.

It was found necessary to operate from a battery charger through the battery to insure sufficient power for testing during an eight hour day.

2. Laboratory Evaluation of Prototype II

This prototype instrument was evaluated in the laboratory utilizing the dilution system (see Ref. 1). This instrument, with basically the same internal flow system performed in the same manner as prototype No. I. The response and recovery of the system to the 5% Kr-85 gas stream was also about 10-15 seconds.

This instrument also showed approximately the same performance to pollutant gases as was observed in prototype I. (Because pollutant concentrations were indicated only within a range described above, it was not convenient to accurately measure final readings.) No apparent defects or problems appeared in the laboratory tests for this instrument.

B. Field Evaluation of Prototype Instruments

The two prototype instruments were evaluated with exhausts from automobiles of several different ages and manufacturers. A system was designed utilizing the two prototype instruments as well as a Beckman 400 Hydrocarbon Analyzer and an Intertech CO Detector. No off-the-shelf type instrument was available for the detection of nitrogen oxides at this time.

The Beckman 400 Hydrocarbon Analyzer is a flame ionization type of instrument. A current, resulting from ionization of hydrocarbons introduced into a hydrogen flame, is directly related to the total number of carbon atoms present in the sample. The Intertech CO Detector is based on the nondispersive infrared technique. This instrument utilizes a dual channel arrangement with the sample gas passing through one channel while the reference channel (second channel) monitors a nitrogen atmosphere. This instrument is of a dual range type (ranges 0-5% and 0-10% CO concentration).

Prior to installing the instruments (both prototype as well as Intertech and Beckman) "on stream", they were calibrated with the supply cylinder

gases. All the instruments were then periodically recalibrated with the supply cylinders during the duration of the vehicular testing. A six channel Brush recorder was used in conjunction with the prototype instruments to record the resulting data. No recorder outputs were available from the Beckman or the Intertech instruments, so that observer-recorded data only was obtained.

These instruments were placed "on stream" with the two prototype instruments. (See Fig. 3.) The exhaust of a car passed through a 3" tube and was vented to the outside air. Each instrument utilizing its own pump, sampled a quantity of the exhaust gases flowing through the tube and analyzed the exhaust for pollutants. Table IV shows the reduced data of the pollution measurements from the various vehicles utilized in this study. The periodic introduction of calibration gases is also included in the data. It is to be noted that instrument sensitivities were as shown in the initial lines of Table IV. They were not adjusted for these tests to the nominal ranges given in Tables I and II.

Because of the high sensitivity of the prototype instruments and the high pollution concentration in the exhaust gases of the vehicles available, an immediate problem of incompatibility was encountered. Although the Intertech CO tester on its 0-10% range, was compatible with exhaust concentrations observed, many of the signals on the prototype instruments as well as on the Beckman were greater than full scale and therefore not readable. A dilution system was constructed and placed just prior to the sampling ports for the individual instruments. Because this dilution technique decreased the overall accuracy of the data it was necessary to recalibrate the instruments with test gases to ascertain the calibration with dilution as well as with no dilution. Still as can be seen from the data in Table IV, good agreement was obtained between the results observed on the Beckman Hydrocarbon Analyzer and the Intertech CO Tester and with the Panametrics Prototypes I and II.

No observed signal was obtained from the NO_x channel during the course of the test runs. A signal was obtained, however, from the test gas.

Fig. 3. Schematic Drawing of Instrument Comparison System for use with Vehicular Exhaust Gases.

Table IV. Field Evaluation Data (Percent of Full Scale Readings).

Pollutant	Beckman (HC)		Intertech (CO)		Panametrics Prototype Instruments					
	Range	Reading	Range	Reading	I			II		
					HC	CO	NO _x	HC	CO	NO _x
100 ppm C ₆ H ₁₄ Bal. N ₂	1000	30	-	-	>100	-	-	-	-	-
2% CO Bal. N ₂	-	-	0-5	2-1	-	15	-	-	8	-
100 ppm C ₆ H ₁₄ Bal. N ₂	-	-	-	-	40	-	-	95	-	-
500 ppm NO ₂	-	-	-	-	-	-	95	-	-	<100
330 ppm NO ₂ Bal. N ₂	-	-	-	-	-	-	80	-	-	90
1969 Dodge	1000	>100	0-10	9	>100	68	-	>100	85	6
1973 Pontiac	1000	9.5	-	No signal	-	1.6	No signal	12	10	2
1969 Dodge	1000	65	0-5	3.2	70*	30	No signal	90*	36	No signal
400 ppm C ₆ H ₁₄ Bal. N ₂	1000	30	-	-	15*	-	-	45*	-	-

* Diluted Flows

Table IV. (Continued)

Pollutant	Beckman (HC)		Intertech (CO)		Panametrics Prototype Instruments					
	Range	Reading	Range	Reading	I			II		
2% CO Bal. N ₂	-	-	0-5	2.1	-	5	-	-	8	-
330 ppm NO ₂ Bal. N ₂	-	-	-	-	-	-	75	-	-	90
1969 Dodge	1000	80	0-10	6	70*	15	-	90*	24	-
1973 Pontiac	100	85	1-5	No signal	40	No signal	No signal	32	No signal	No signal
1964 Chevrolet	1000	> 100	0-10	> 10	> 100	25	No signal	-	-	-
1969 Chrysler	1000	> 100	0-5	40	5*	15	No signal	15*	16	-
1964 Buick	1000	> 100	0-5	4	5*	30	No signal	> 100	-	-
400 ppm C ₆ H ₁₄ Bal. N ₂	100	60*	-	-	40*	-	-	45*	-	-
	1000	30	-	-	> 100	-	-	> 100	-	-
100 ppm C ₆ H ₁₄ Bal. N ₂	100	75	-	-	40	-	-	45	-	-

* Diluted Flow

Table IV. (Continued)

Pollutant	Beckman (HC)		Intertech (CO)		Panametrics Prototype Instruments					
	Range	Reading	Range	Reading	I			II		
					HC	CO	NO _x	HC	CO	NO _x
2% CO Bal. N ₂	-	-	0-5	1 [*] 2	-	15	-	20	10	-
1000 ppm NO ₂	-	-	-	-	-	-	>100 [*] 30	-	-	100
1969 Dodge	1000 1000	80 10 [*]	0-5	2 4.5	80 [*]	50	-	95 [*]	30	5
1973 Pontiac	100	40-60	0-5	No signal	20	No signal	No signal	15	No signal	No signal
1964 Chevrolet	1000 1000	>100 [*]	0-10	10	>100	80	No signal	40 [*]	-	5
1964 Buick	1000 1000	>100 [*] 20	0-5	4.8	>100 [*] 100	35	No signal	>100 100	38	No signal
1969 Crysler	1000 1000	>100 [*] 15	0-5	2.8	20 [*]	15	No signal	>100	18	No signal
400 ppm C ₆ H ₁₄ Bal. N ₂	1000 100	35 30 [*]	-	-	40 [*]	-	-	>100 [*] 45	-	-
2% CO Bal. N ₂	-	-	0-5	2.1	-	18	-	-	10	-
1000 ppm NO ₂ Bal. N ₂	-	-	-	-	-	-	>100 [*] 35	-	-	>100 [*] 35

* Diluted Flow

During one of the test runs, 1000 ppm NO_2 was introduced into the exhaust gas stream at the exit from the test vehicle. A signal of a 40% of scale was obtained on the NO_x channel of Prototype I and II. This signal was obtained with no external dilution of the gas stream at the prototype instrument. The magnitude of the signal was approximately correct for the ratio of exhaust gas to test gas flow rates existing at the time.

C. Preparation for User Testing

Following the successful testing with actual automobile exhausts as described in the preceding section, Kryptonates were prepared from additional quantities of substrates in order that a sufficient number of sensing cells could be provided to a potential user so that extensive testing could be performed. Such cells were tested in the laboratory test system described in Section III-A with extremely disappointing results. Although previous testing had indicated constant sensitivity over the expected lifetime of a cell, such constant sensitivity was not observed at this stage of the program. The expected lifetime of an individual cell was also degraded. Perhaps the most severe degradation of performance was encountered with the HC sensor, a Kryptonate prepared from PtO_2 with which Panametrics had had highly successful previous experience not only for HC detection but also for H_2 detection. On the other hand, very little deterioration, if any, in properties was observed for the hydroquinone clathrate used to test NO_2 .

Several possible sources for the failure of sensing cells to perform as expected were considered and explored. The possibility that channelling of gases through the sensing powder was investigated, without success, by introducing separators to reduce channelling and by diluting the sensing substrate. The possibility that the initial Kryptonate preparations were, somehow, faulty was investigated by repeating such preparations with as much care as was feasible. A final possibility studied was that substrates, prior to preparation, had properties different from those of previous supplies. Accordingly, new supplies of substrates were obtained but, again, without success.

Additional causes for these problems were considered but neither time nor funds were available to pursue them. It was observed that the PtO_2 used for these preparations appeared to have a larger grain size than similar supplies used earlier. Since the preparation of a homogeneous PtO_2 Kryptonate is dependent upon saturation of the PtO_2 particles with Kr-85 which can only be achieved with small particle sizes, sieving of the supply as received might improve performance. Still another possibility not investigated was that the Kr-85 supply used to prepare Kryptonates had become contaminated as a result of continuous usage.

The most likely cause of the problems encountered, however, is considered to be the multitude of problems normally encountered in the scaling up of any chemical process. Hence, pilot plants are constructed before full scale plants are designed. Even though the magnitude of the scale-up in quantity of substrates prepared in this program was not large, the fact that properties of the prepared substrates are dependent upon the condition of the substrate particle surface, not its bulk properties, may make any scale-up particularly sensitive to lack of uniformity in preparative parameters. Scale-up problems are normally soluble by careful control of critical parameters, once the appropriate parameters are determined. It is expected that, given sufficient effort, the problems encountered here could be solved. However, neither time nor funds were budgeted for this effort because its necessity was not anticipated.

V. Conclusion

The Panametrics instruments based on the radiochemical exchange technique performed as well during field testing, as the off-the-shelf type purchased for this program. The prototype instruments as designed did not have sufficient latitude for detecting high pollution levels as well as the low pollution levels for which it was designed. Hence, dilution with ambient air is required for higher pollutant concentrations.

Problems were encountered in the preparation of sensing substrates which would provide expected response behaviours when larger quantity preparations were attempted. These problems are considered to be principally associated with normally encountered problems associated with scale-up of chemical processes and, hence, soluble given sufficient effort. Neither time nor funds were available under this program to solve the problems.

Further, at the inception of this project there were no instruments available that were portable, could detect all three pollutants of interest with the same technique and could be operated by unskilled type personnel. At the present time this has changed. There are still no other instruments, except for the Panametrics Auto Analyzer, that are able to detect all three pollutants by the same technique. However, many instruments are now available that will detect each, and even two, of these pollutants without discharging radioactivity, however small, into the atmosphere. This attribute of the Panametrics Auto Analyzer, inherent in its mode of operation, has always been considered its greatest deficiency, since the release of gaseous radioisotopes to the atmosphere is an anathema, whether for general health and welfare or for psychological reasons. The existence of alternate instruments, coupled with the scale-up problems encountered in this program, do not appear to warrant further development at this time.

APPENDIX

Sulfur Hexafluoride Encapsulation

A brief experimental investigation was conducted, in conjunction with the program discussed in this report, to explore whether sulfur hexafluoride (SF_6) can be incorporated into various substrates in the same manner as Kr-85. If successful, encapsulation would provide an alternate to the Kryptonate technique which would not require utilization or release of radioactivity.

SF_6 is a relatively inert gas with approximately the same molecular diameter as the Kr atom. Hence, properties are similar and retention by solids was postulated as being feasible. Further, SF_6 is an electron capturing gas which can be detected with high sensitivity by conventional electron capture (EC) detectors.

Initially PtO_2 was utilized as the host material. A series of runs was made, utilizing on the same temperature and pressure as employed for the preparation of Kryptonates.

Upon completion of the preparation a hydrocarbon, hexane, was passed over the host material and the resulting gas release monitored by an EC detector. No increase in signal was observed. Nitrogen was then passed over the host material and the material was heated. If behavior analogous to that of Kryptonates was followed, and if the host material contained SF_6 , temperatures in excess of about 400°C would release SF_6 from the solid to be detected by the EC detector. No signal was detected. Apparently SF_6 was not encapsulated by PtO_2 in the same manner as is Kr.

The hydroquinone clathrate was also used as the host material. Several preparations were conducted using the parameters successful in producing clathrate-encapsulating krypton. NO_2 was passed through the clathrate after preparation and the resulting effluent monitored for sulfur hexafluoride. In this case a significant but small signal was observed which

was approximately twice background for an input of ~ 500 ppm NO_2 . The combination of SF_6 release rate coupled with the EC detection capability for SF_6 was much inferior to that achieved with Kr-85.

Additional preparations of SF_6 clathrate encapsulation were not in all cases successful. Preparation parameters were varied to increase the retention of SF_6 by the clathrate but none proved to be significantly fruitful.

An alternate approach was briefly explored which involved direct monitoring of the pollutant gases by the EC detector. NO_2 is itself electron capturing and can be observed directly by the EC detector instrument. A signal three times background was obtained for about 10 ppm NO_2 . This signal was linear up to a concentration of about 100 ppm NO_2 . By inserting a catalyst to convert $\text{NO} \longrightarrow \text{NO}_2$, a second linear curve with approximately the same sensitivity was obtained.

Carbon monoxide was not sufficiently electron capturing to be detected by the EC detector. However, reaction with iodine pentoxide, and release of iodine did provide detection capability. Iodine, being a halogen, is itself an electron capturing molecule. Thus, it was possible by means of a gas-solid release mechanism to detect less than 100 ppm carbon monoxide. Because I_2 was observed to deposit on the glass tubing leading to the EC detector, the achievable sensitivity may be much higher if the gas transport system and the EC detector were to be heated to prevent I_2 condensation and removed from the stream.

In the short time allocated to this portion of the total program, no method was found by which the hydrocarbons could be detected utilizing the electron capture principle.

Thus, although this phase of the program was unsuccessful in utilizing SF_6 for pollutant detection, it was possible to show that at least two of the three pollutants of interest could be detected with comparatively high

sensitivity by means of an EC detector and further efforts could result in detection capability for hydrocarbons as well. Despite the success achieved with NO₂ and CO detection, further development was outside the scope of the program.