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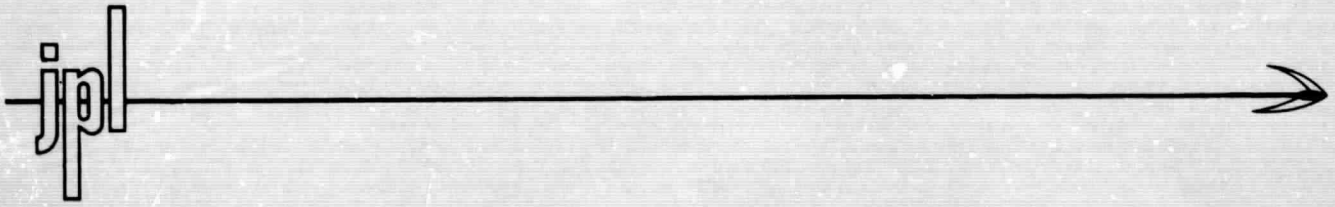
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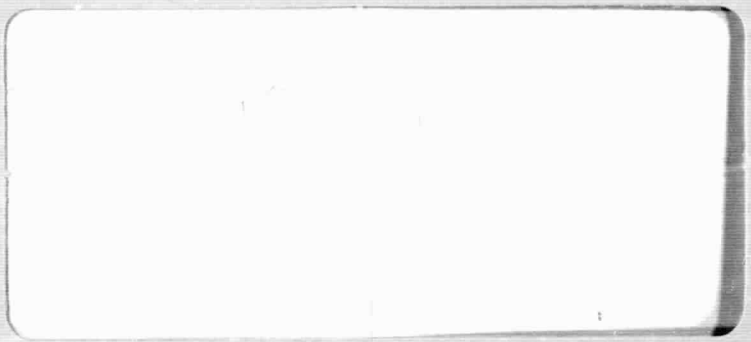
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PASADENA, CALIFORNIA



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DIN 69SD4378
JANUARY 8, 1970

# A SPACECRAFT GAS JET LEAK DETECTION SYSTEM

## FINAL REPORT

COVERING THE PERIOD JUNE 1969 TO OCTOBER 1969

PREPARED UNDER CONTRACT JPL 952578

FOR

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
4800 OAK GROVE DRIVE
PASADENA, CALIFORNIA 91103

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## ABSTRACT

This report describes the feasibility of developing a solenoid valve failure detection system which requires the addition of a radioactive gas to the propellant tank of an attitude control system. The results of measurements of 10% $C^{14}O$ leak rates near 1 $cm^3$/hr with an avalanche detector are presented.

# 1. INTRODUCTION

Historically, solenoid valves have been a source of leaks in gas jet attitude control systems. When the gas leaks out of the nozzle connected to the solenoid at a high enough rate, it imparts a thrust to the spacecraft altering its course. Recently, it has been suggested that if such leaks developed during long-term flights like the proposed Grand Tour it could result in mission failure because of the precise course that must be maintained in order for the spacecraft to fly by each planet. This report deals with the feasibility of developing instrumentation for inflight measurement of solenoid valve leak rates. Such information would provide the mission controller with a means of diagnosing and correcting the condition, thus helping to maintain the course within the accuracy required for a deep space mission. In addition, the same measurement can be performed while the solenoid is actuated, providing mission control with additional data about the attitude control system, including burn time and the quantity of gas expelled. Herein is discussed the feasibility of measurements performed on a prototype system under laboratory conditions along with suggested areas of study believed to be required before this laboratory system can be considered for integration with an operational spacecraft.

## 2. TECHNICAL DISCUSSION

The experimental program began with the assembly of two avalanche detector counting systems: one to evaluate the feasibility of detecting leaks external to a gas jet nozzle and the second was to be used to investigate the feasibility of detecting leaks within the gas system between the source of the leak and the gas jet nozzle.

The avalanche detector counting systems were self-contained, battery-powered counting systems originally designed and developed for the U.S. Atomic Energy Commission's Division of Biology and Medicine. The development of these systems is described in detail in General Electric Report No. NYO 3246TA-3, 4 and 5. The operating instructions are contained in Appendix A.

The sensitive element of the system is the avalanche detector which consists of an avalanche diode and its tunnel diode amplifier. A detailed description of the avalanche detector is contained in Appendix B. Briefly, when radiation is absorbed in a conventional silicon diode it creates hole electron pairs which through their own mobility reach the PN junction and are swept across resulting in a current. The avalanche diode, however, has a high internal field; and each time the radiation produces a hole electron pair, they in turn ionize silicon atoms and if the internal field is high enough there is a cascade of electrons from each absorption.

In order to use this internal gain, a tunnel diode is coupled to the avalanche diode so that it triggers each time this junction current contains 400 electrons. The result is a digital pulse for each radiation absorption, making this couple the solid state analog of the geiger counter.

For this study, shallow junction avalanche diodes were used to maximize the detectors' sensitivity to the low energy beta particles emitted by the radioactive tracer gas which was added to the propellant gas.

The entire test apparatus was designed to simulate a spacecraft gas jet system. The original mechanical drawing of the apparatus is shown in Figure 2-1. The test plan called for the leak rate of the mixture of nitrogen and radioactive tracer gas to be established with a calibrated Vacoa metering valve. The upstream side of the valve was pressurized while the downstream side was evacuated. The gas mixture then leaked through the thruster nozzle past the avalanche detector where it was counted and exhausted into the atmosphere. The acutal test apparatus, including a view of the thruster nozzle-avalanche detector geometry is shown in Figure 2-2.

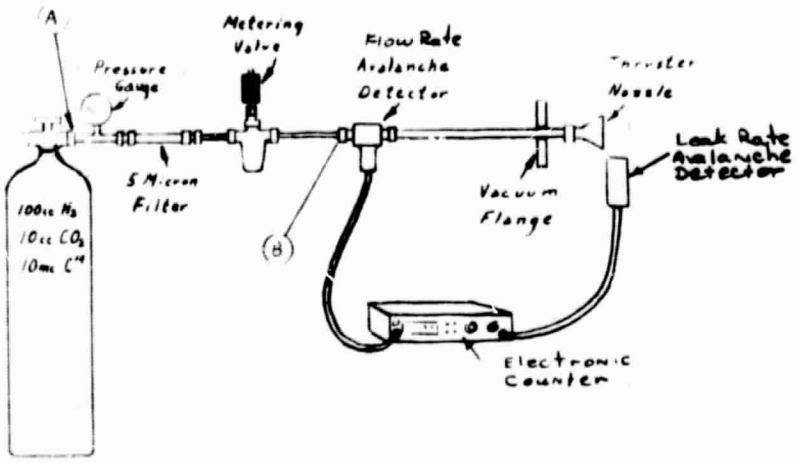
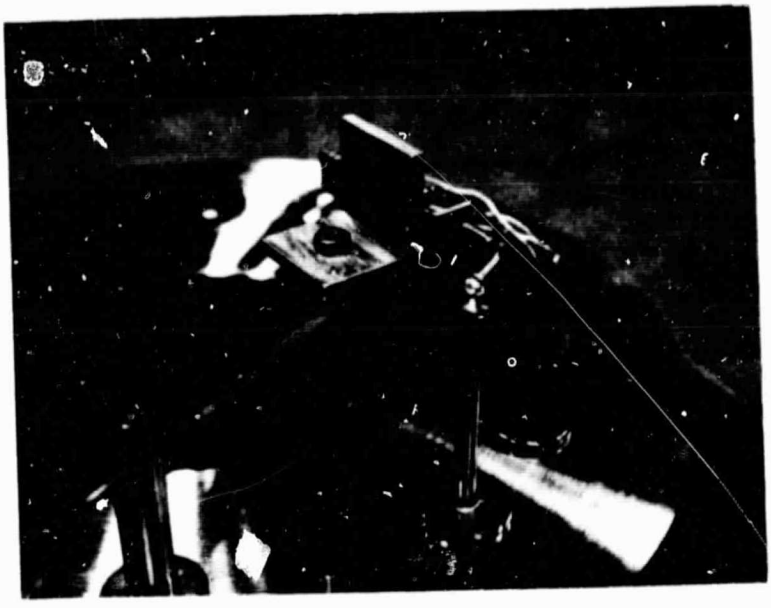


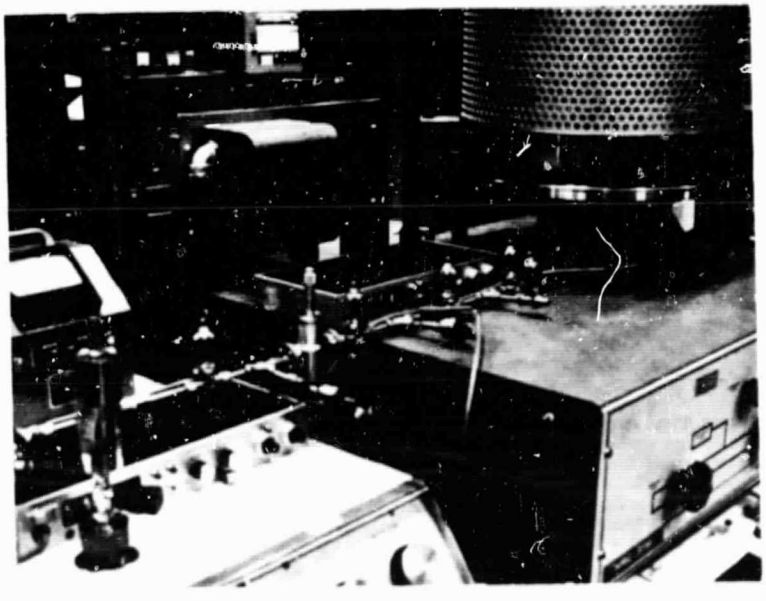

Figure 2-1. Leak Detector System

The radioactive gas used was $C^{14}$ labelled carbon monoxide, purchased from the New England Nuclear Corporation in the proportion of 10% CO + 90% $N_2$. Although the emitted radiation is more difficult to detect than other radioactive gases, $C^{14}$, CO was selected because the molecular weight is the same as nitrogen which allows us to assume, within the accuracy of the empirically derived flow equations, that the $C^{14}$ count rate defined by the CO leak rate would also serve to define the $N_2$ leak rate in these tests.

Initially, the calibration of the metering valve was to be performed with a helium mass spectrometer, leak detector; however, the detector saturated at approximately $3 \times 10^{-6}$ cc/sec and since we knew of no available flow meter for calibrating the metering valves leak rate below $10^{-1}$ cc/sec we attempted a simple calibration technique using a radioactive gas.



a. View of Avalanche Detector and Thruster in Vacuum Chamber



b. View of Leak Test Apparatus

Figure 2-2. Test Apparatus

This required modification of the original test apparatus as shown in Figure 2-3. Briefly, the activity of radioactive $C^{14}$-CO gas calibrated in microamps/microcurie was determined with an ion chamber. The container was then connected at A in Figure 2-3, and allowed to leak through the metering valve at atmospheric pressure. By placing valves No. 1 and 2 above and below the metering valve as well as No. 3 below the in-line detector it was possible to purge the line with nitrogen through Valves 4 and 5 so that all of the gas that had leaked through the metering valve when 7 was closed, could be returned through Valve 6 to the ion chamber at one atmosphere and measured again. When the ion chamber current reading was taken after collection, it provided the number of microcuries which had leaked through the metering valve in time t. Dividing this value by the volumetric activity of the gas (microcuries/$cm^3$) previously calibrated, gave the number of $cm^3$/sec which had been collected. We found this technique to be quite repeatable and sensitive to leak rates in the $10^{-6}$ to $10^{-1}$ $cm^3$/sec range. However, becuase the gas was collected for the calibration the pressure in the collection volume was not a constant; thus, this simple leak calibration technique would not be expected to represent true flow conditions. In order to measure the inlet and outlet pressures of the metering valve to determine if a correction was needed, the test apparatus was again modified by placing thermocouple vacuum gauges just above and below the metering valve. The outlet pressure was observed to increased from 1 micron to 1 millimeter during the collection period. Such an increase would not be too great for accurate flow calibration as long as the inlet pressure was near 1 Torr. This is so because of the strong dependency of flow Q on pressure difference across the leak; i.e., $Q = K (P_2^2 - P_1^2)$ $cm^3$/sec where K = leak geometry

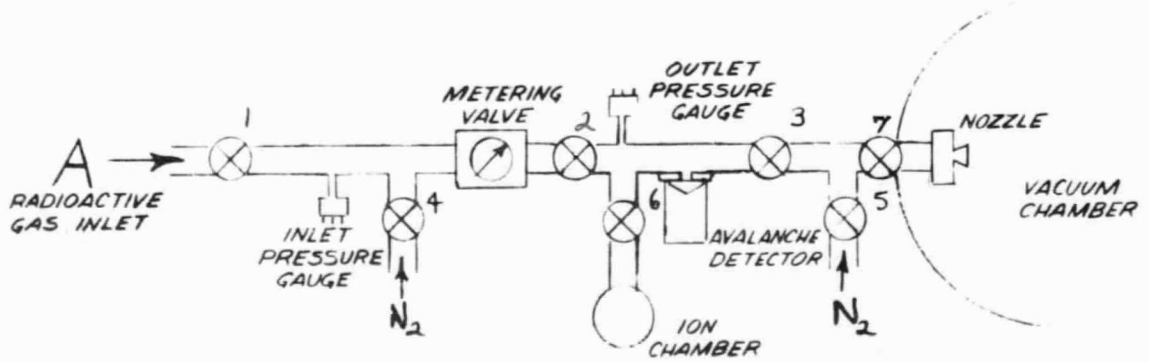



Figure 2-3. Test Apparatus Modification

$P_2$ = outlet pressure

$P_1$ = inlet pressure

Subsequent measurement of the metering valve inlet pressure showed that during these tests the inlet pressure varied little from atmospheric, which means that the calibration of the metering valve using this technique is as good as one's knowledge of the kind of leak involved: i.e., molecular, laminar, etc., for the error introduced by the calibration system is no more than $\pm 5\ \%$.

Having defined the leak rate as shown in Figure 2-4, we then attempted to measure the leak through the thruster with an avalanche detector having an active area of 0.05 $cm^2$. However even at maximum detector sensitivity, where the background was 3 counts/minute, we were only able to obtain 6 to 8 counts/minute. In fact, no counts above background were measured until the detector was placed within the plume of the nozzle. Obviously this was not useful data. In comparison the detector "looking" into the 1/4-inch tubing near the metering

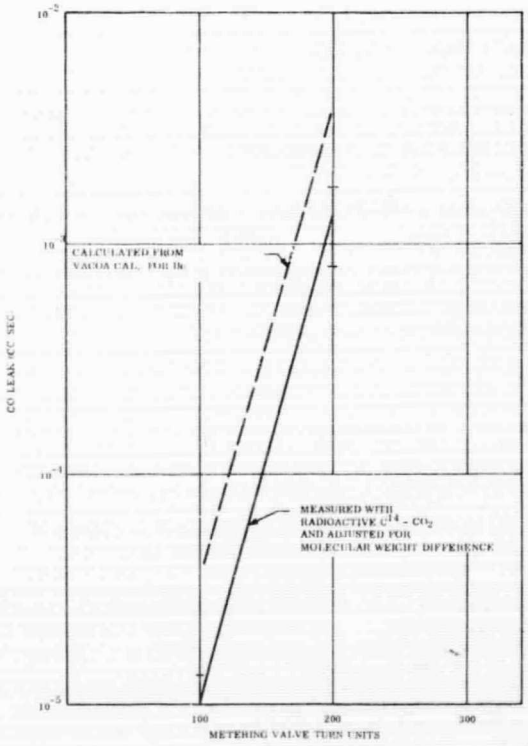
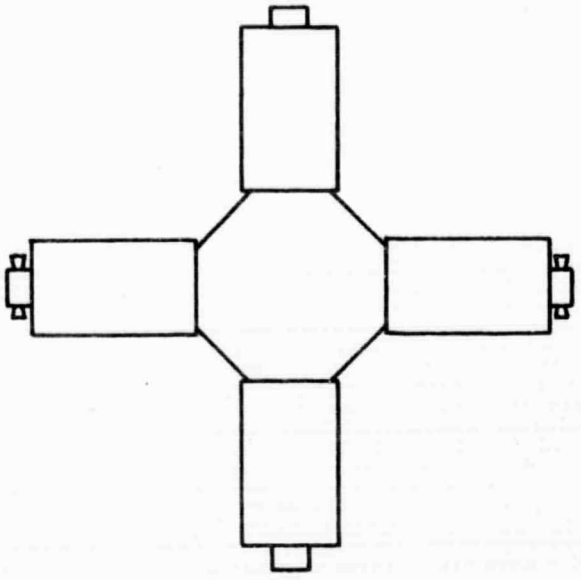



Figure 2-4. Metering Valve Calibration

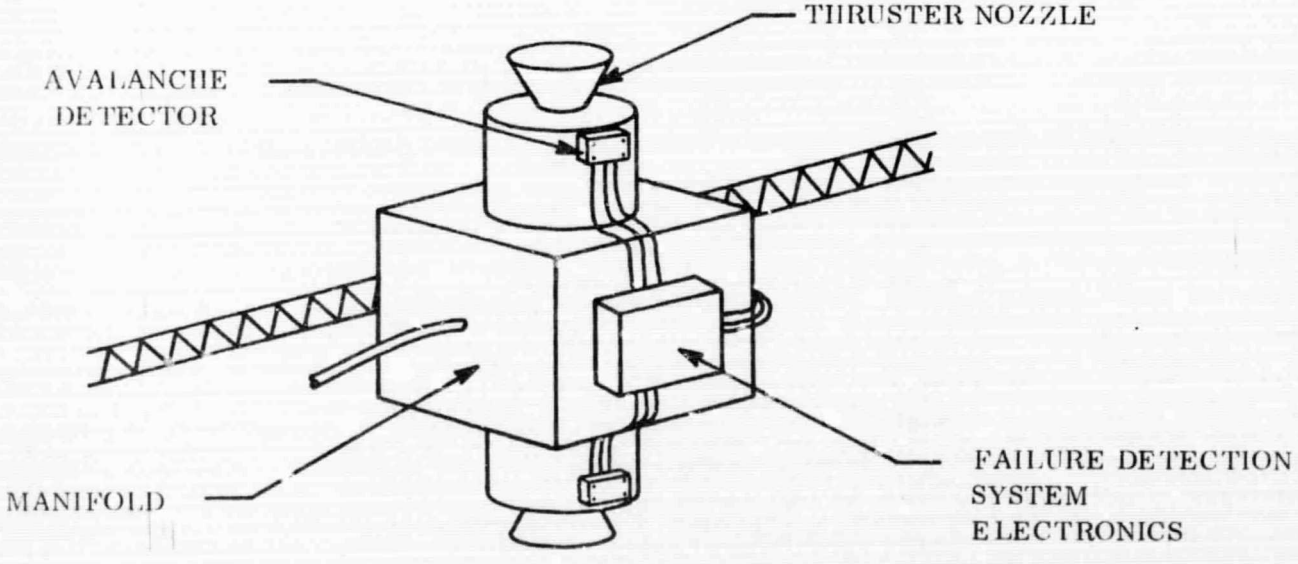
valve outlet had a count rate of 320 counts/minute for the same leak rate ~ 8 $cm^3$/hr. This difference in count rate is the result of the pressure difference inside the 1/4-inch tubing and that in the vacuum chamber; i.e., 1 millimeter and $10^{-4}$ torr, respectively. This is easily understood when considering that the higher pressure allows the radioactive molecules more opportunity to pass in front of the detector than at low pressure.

It seemed likely that with a large area (1 $cm^2$) avalanche detector it would be possible to increase the count rate per leak rate out the nozzle. However, it was not possible to perform this measurement with the existing tunnel diode amplifier mounted inside the vacuum chamber, because the internal capacitance of the large avalanche diode is so great that it reduces the sensitivity of the tunnel diode amplifier to the point where it can no longer detect $C^{14}$ beta particles. In order to perform the thruster leak tests with the large area diode, it would have been necessary to replace the tunnel diode amplifier with a charge sensitive amplifier which would have required considerable time to assemble and check out in the vacuum chamber. Instead, it was decided that it would be better to use the remaining portion of the program to calibrate the avalanche detector which was placed between the metering valve and the thruster nozzle. These data were intended to demonstrate the feasibility of a solenoid failure detection system, assuming that it would be feasible to insert a smaller calibrated detector approximately 0.109-inch diameter between the solenoid valve and the thruster nozzle of a flight system as shown in Figure 2-5. Based on an evaluation of JPL Drawing No. D4201389 Rev. C, it would appear that there is sufficient room between the jet valve seat and the nozzle aperture to insert a detector.

The calibration of the 0.05 $cm^2$ detector was performed by tabulating the number of $C^{14}$ emissions detected in counts/minute as a function of gas flow rate F in $cm^3$/sec. The experimental results are tabulated in Table 2-1 as a function of metering valve turn units. These data are then normalized to the sensitive volume, the activity of the radioactive gas and the pressure in the volume as follows. The sensitive volume $V_s$ is a cylinder defined by the detectors, 0.3 cm diameter which "views" the gas in the tubing, through a 0.11 cm long hole (see Figure 2-6). This volume turns out to be 0.025 $cm^3$. The activity of the $C^{14}$ in the gas bottle is 10 millicuries per 100 $cm^3$ of $CO + N_2$ at 20 psi or 100 microcuries per $cm^3$ at 20 psi.



a. Typical Mariner Attitude Control Gas Jet Configuration




b. Failure Detection

Figure 2-5. Thruster Nozzle of Flight Control

Table 2-1. 0.005 Square Centimeter Detector Calibration

| Valve Turn Units | Upstream Pressure Torr | Downstream Pressure Microns | Avalanche Detector No. 1 Counts/Min | Avalanche Detector No. 2 Counts/Min | Vac. Chamber Pressure Torr |
|---|---|---|---|---|---|
| 0 | 1 | 1 | 0 | 1 | $3 \times 10^{-7}$ |
| | | | 0 | | |
| | | | 1 | | |
| | | | 1 | | |
| | | | 0 | | |
| 100 | 1 | 2 | 0 | 0 | $4 \times 10^{-7}$ |
| | | | 0 | 1 | |
| | | | 1 | 1 | |
| | | | 2 | 1 | |
| | | | 0 | 0 | |
| 160 | 1 | 90 | 7 | 2 | $6 \times 10^{-7}$ |
| | | | 6 | 1 | |
| | | | 8 | 1 | |
| | | | 7 | 2 | |
| | | | 8 | 1 | |
| 175 | 1 | 500 | 21 | 2 | $1 \times 10^{-6}$ |
| | | | 24 | 1 | |
| | | | 20 | 3 | |
| | | | 18 | 2 | |
| | | | 20 | 3 | |
| 200 | 1 | 1000 | 140 | 1 | $5 \times 10^{-6}$ |
| | | | 155 | 2 | |
| | | | 148 | 4 | |
| | | | 160 | 3 | |
| | | | 150 | 1 | |
| 315 | 1 | 2000 | 420 | 2 | $3 \times 10^{-5}$ |
| | | | 380 | 2 | |
| | | | 360 | 2 | |
| | | | 375 | 3 | |
| | | | 400 | 3 | |

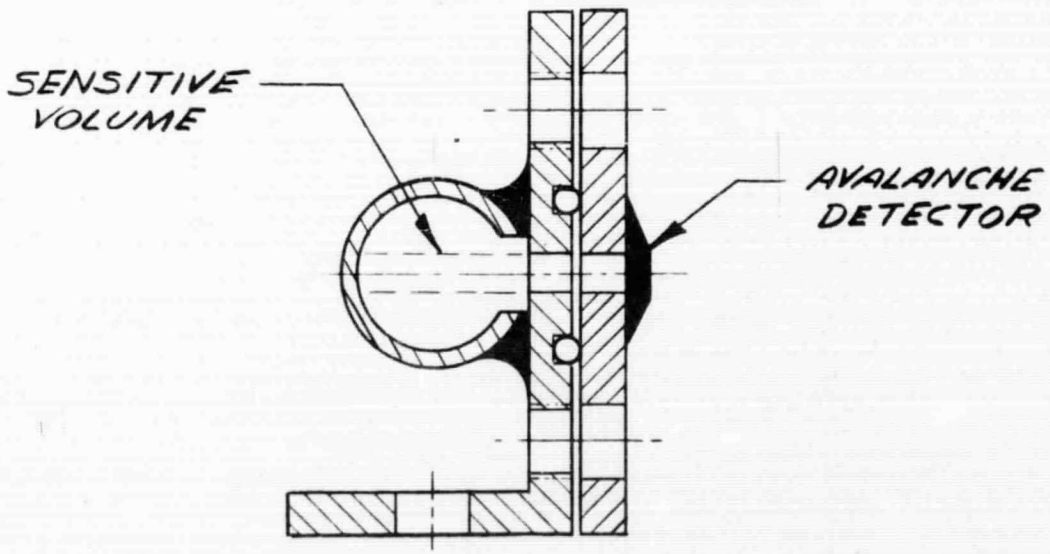



Figure 2-6. Inline Detector

When this gas leaks through the metering valve, it enters the test volume at a lower pressure which essentially lowers the total activity of the radioactive gas. For these tests, it is assumed that the activity $A_t$ of the gas in the test volume is directly proportional to the Activity $A_i$ at 20 psi times the ratio $P_t/P_i$, where $P_t$ = pressure in the test volume and $P_i$ = pressure in the gas reservoir; i.e.,

$$A_t = A_i \, (P_t/P_i)$$

The calibration factor of the detector then takes the following form

$$\frac{C_L/V_s}{\frac{A_t}{F}} = \frac{\frac{\text{counts}}{\text{microcuries}}}{\frac{\text{cm}^3}{\text{hr}}}$$

For example, at 4.32 cc/hr the total number of counts detected in one minute was 150; thus, the calibration factor is

$$\frac{\frac{150 \text{ counts}/0.025 \text{ cm}^3}{100 \, \mu \text{ curie} \cdot 3.86 \times 10^{-2}}}{\frac{\text{cm}^3}{4.32 \text{ cm}^3/\text{hr}} \quad 20 \text{ psi}} = \frac{0.72 \times 10^4 \text{ counts}/\mu \text{ curie}}{\text{cm}^3/\text{hr}}$$

Table 2-2 gives values of the calibration factor obtained at various metering valve settings. These values are in quite good agreement when considering the errors involved. For example, at the higher leak rates the test chamber pressure reading from the thermocouple gauge was probably in error by as much as 20%; whereas, at the lower pressures it is closer to 5%. These differences nearly offset the corresponding differences in error due to counting statistics at the low and high leak rates. The combined error includes the error due to counting statistics, the error in the pressure measurement and the error in the metering valve calibration. Briefly, the error due to counting statistics is $\frac{\sqrt{N}}{N}$ where N = the events counted by the detector.

Table 2-2. Calibration Factor Obtained at Various Metering Valve Settings

| Metering Valve units | Leak Rate $cm^3/hr$ | Detector Calibration Factor $\frac{counts/\mu\ curie}{cm^3/hr}$ | Error Due to Counting Statistics (%) |
|---|---|---|---|
| 160 | 0.72 | $4.87 \times 10^4$ | $\pm$35 |
| 175 | 1.44 | $1.25 \times 10^4$ | $\pm$20 |
| 200 | 4.32 | $0.72 \times 10^4$ | $\pm$8 |

For the thermocouple gauges used, the error was proportional to the pressure range being measured; that is, at 500 microns the gauge accuracy was approximately $\pm$10%, at 1000 microns it was $\pm$20%, and at 5 microns it was approximately $\pm$5%. One error encountered in the calibration of the metering valve was the accuracy of the $C^{14}$ standard, which as specified by the vendor New England Nuclear was $\pm$5%. In the initial calibrations 20 to 30% errors were introduced due to incomplete collection of the gas, but as experience increased, the repeatability improved and the deviation was reduced to 10%.

As a result, the total error in terms of leak rate is approximately 50% at 0.72 $cm^3/hr$, 35% at 1.44 $cm^3/hr$, and 28% at 4.32 $cm^3/hr$.

Obviously, these measurements can be improved by using more accurate pressure gauges and increasing the activity of the gas. In addition, varying the test chamber volume and the sensitive volume of the detector would improve the counting statistics with a corresponding reduction in error. Also, longer counting times can produce the same thing.

Again good agreement was obtained at several leak rates when normalizing the count rate to the sensitive volume, the pressure difference, and the activity of the gas which demonstrates feasibility. However, in order to monitor valve leak rates in space, a detector must be installed between the seat of the solenoid valve and the gas jet nozzle of the

operational attitude control system. After measuring in the lab the counts/min detected at a particular leak rate $\frac{cm^3}{hr}$ out of the nozzle and knowing the amount of radioactive gas added to the propellant tank, one can determine the counts/min for any other nozzle leak rate. For example, if the failure detector in the operational system registered 2000 counts/min at a nozzle leak rate of 1 $cm^3/hr$ when 10 millicuries were added to the propellant tank, then the calibration factor is

$$\frac{2000 \text{ c/min}}{1 \text{ cm}^3/\text{hr}} ;$$

thus, if telemetry data indicated a 1 minute count of 200 the nozzle leak rate at that time in the flight would be 0.1 $cm^3/hr$.

# 3. CONCLUSIONS

In summary, it has been shown that a small area avalanche detector could marginally sense radioactive gas leaking through a gas jet nozzle and by increasing the detector area the count rates should increase proportionally to where quantitative measurements of leak rate out the nozzle could be determined.

More importantly, however, this program demonstrated that a detector placed between the leak source and the nozzle aperture gives useful leak rate data because of the higher detection probability. This means that instead of developing a marginal leak detection system for use external to a spacecraft adjacent to the attitude control thruster, it would be feasible and more practical to develop a sensitive solenoid failure detection system integrated into present attitude control systems by inserting a calibrated avalanche detector between the solenoid valve and the thruster aperture.

# 4. NEW TECHNOLOGY

There is no new technology to report during this period.

# APPENDIX A

## OPERATING INSTRUCTIONS FOR AVALANCHE DETECTOR NUCLEAR COUNTING SYSTEM

### A.1 OPERATING INSTRUCTIONS

#### A.1.1 PRELIMINARY PROCEDURE

The preliminary procedure is:

1. Connect power cord to back of the instrument.
2. Turn POWER switch on front of instrument to OFF.
3. Connect power cord to 115 VAC outlet.

   NOTE: In this state the instrument is in the charging condition for the Ni-Cad batteries which are located within the case. When the instrument is not in use, it should be left connected to a 115 VAC outlet with the POWER switch OFF.

4. Turn the DETECTOR GAIN knob and the DISCRIMINATOR knob to the extreme counter-clockwise position (0.0).

#### A.1.2 OPERATION

To Operate:

1. Turn the POWER ON SWITCH to ON position.
2. Turn SAMPLING RATE switch to HOLD position.
3. Turn GATE TIME switch to INF. (infinity) position.
4. Push the START switch. The gate light will light.
5. Turn the DISCRIMINATOR knob clockwise until counts are observed at a high rate on the display. From this position turn the knob a quarter turn counter-clockwise.

6. Turn the DETECTOR GAIN knob clockwise until counts are again observed at a high rate on the display. From this position turn the knob counter-clockwise a quarter turn.

   NOTE: The sensitivity of the instrument may be increased by adjusting both the DETECTOR GAIN and DISCRIMINATOR knobs closer to the count position (clockwise adjustment) as described previously. The DETECTOR GAIN adjustment has the most effect on sensitivity since it adjusts the multiplication in the silicon detector. The DISCRIMINATOR ADJUSTMENT sets the discriminator level which is a monostable oscillator.

7. Push the STOP switch. The gate light will go off and count accumulation will cease.

8. Push the RESET switch. Display will reset to 0000.

### A.1.3 COUNTER OPERATION

The previous procedure has put the instrument in a count totalizer condition with start, stop, and reset functions performed manually by the user.

### A.1.4 SCALER OPERATION

With the instrument in the counter condition from the previous procedures the counter may be made into a scaler by the following procedure:

1. Turn the GATE TIME switch to the desired counting interval position.

2. Turn the SAMPLING RATE switch clockwise until the desired display time is achieved.

   In this position, the instrument will automatically count for a period of time selected, stop at the end of the period and hold the total count and reset to 0000 and start again.

Parts List

| Item | Quantity | Description |
|---|---|---|
| 1 | 1 | Avalanche Detector Nuclear Counting System<br>Includes (a) Instrument case and power cord<br>(b) Avalanche detector and tunnel diode amplifier<br>(c) Detector and amplifier regulated power supplies<br>(d) Logic circuitry for scaler operation<br>(e) "Nixie" display<br>(f) 5 Ni-Cd rechargeable batteries |
| 2 | 1 | Source Bottle<br>Contains 90% $N_2$<br>10% C14 labeled CO |
| 3 | 1 | In Line Gas Regulator |
| 4 | 1 | Micron Filter |
| 5 | 1 | Vacoa Metering Valve |
| 6 | 1 | Misc. Stainless Steel tubing, connectors and valves |

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# A NEW IONIZING RADIATION DETECTION CONCEPT WHICH EMPLOYS SEMICONDUCTOR AVALANCHE AMPLIFICATION AND THE TUNNEL DIODE ELEMENT

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(Received 22 July 1966; in final form 26 August 1966)

A concept for the detection of ionizing radiation which utilizes the inherent high speed and large amplitude of the induced charge pulse in a semiconductor avalanche detector coupled with the tunnel diode element is described. It has been shown possible to digitally detect extremely low energy events even in high-current-induced noise backgrounds in the avalanche detector. Cryogenic cooling is not required. Detection is accomplished by use of the rate of rise and magnitude of the nuclear pulse (or alternatively a pulse of suitable amplitude and rate of rise generated by optical photons). The high-speed time domain allows discrimination against all noise-generated events because charge is not integrated in this scheme.

With the development of avalanche semiconductor radiation detectors and particularly those of the "contoured surface" type,[1] signals of large amplitude in very fast time have become available from ionizing particle interactions. Using this form of amplification, we have demonstrated that it is thus possible to circumvent, at least for digital or particle detection applications, the more usual external charge-integrating amplification schemes. This Letter will report one scheme which utilizes the tunnel diode as the sensing element in combination with an avalanche detector for nonintegrating charge detection (a system which will respond in the same time period as the movement of the event-induced charges). The result of this combination is (1) high sensitivity as exemplified in the ability to detect a charge of $7 \times 10^{-17}$ C (as generated in silicon by an aluminum fluorescence x ray of 1.49-keV energy), (2) the ability to unambiguously (without background counts) detect such events even in high detector leakage currents (to 100 $\mu$A in one circuit measured) and (3) an extremely wide count-

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ing range—from low level counting to rates in excess of 100 MHz. Such detection is in contrast to the cryogenic cooling required for noise reduction in charge-integrating detection schemes. We believe that it will be found useful in many applications in practical, very high speed or very low energy detection. This concept has been used in our laboratory in an experiment concerned with the detection of low-energy protons (greater than 100 keV) in the inner radiation belt. As mentioned above, the scheme has also been used for soft x-ray detection down to the 1.5 keV (aluminum fluorescence) level—the minimum detectable x-ray energy apparently limited by the entrance dead layer of the avalanche detector and not the tunnel diode circuit. The 5.6-keV x ray from the $^{55}$Fe isotope is particularly easy to detect. The resolving time of this scheme has been demonstrated to be capable of 10-nsec pulse pair resolution of nuclear events.

The basis for the fast signal pulse is an avalanche type of silicon detector as diagrammed in Fig. 1. This is a gallium diffused structure previously

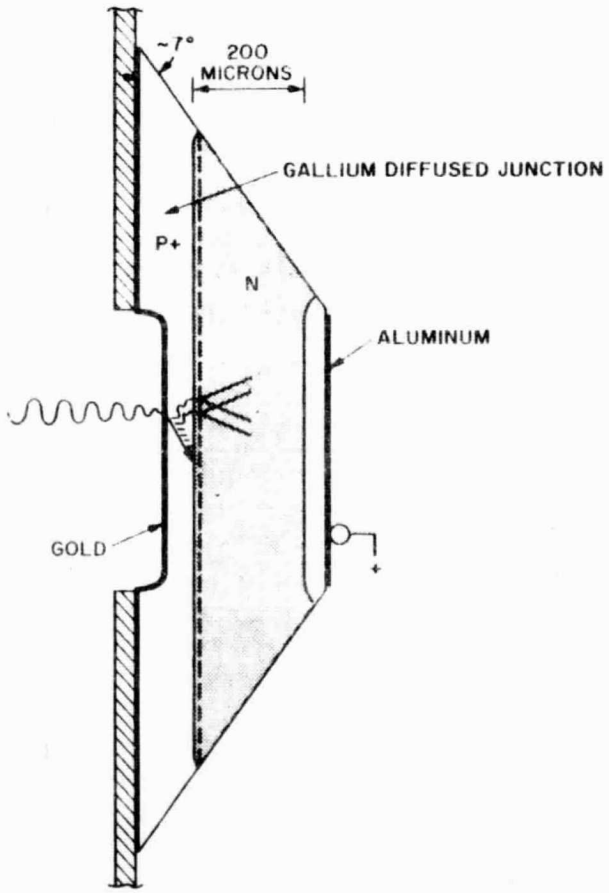



**Fig. 1. Outline of contoured surface, silicon avalanche detector.**

described,[2] which relies on geometrical shaping of the junction surface to achieve stability. Charge multiplication of $10^2$ to $10^3$ is achieved with application of a bias voltage in the 1500–1800 V range. A significant attribute of the simple $p + n$ junction structure is a photomultiplier like signal/noise advantage. If the signal is generated near the front surface, it is multiplied to a greater extent than the average (reverse-bias leakage current generated) noise components. Thus by coupling the detector to an ordinary low noise amplifier, it is possible to detect and view pulses which would, without avalanche amplification, be lost in the noise. The last detector property of note is capacitance which is relatively low per unit area because of the wide (200 $\mu$) depletion width. Detector areas used are approximately 0.1 cm$^2$ corresponding to a capacitance of 1 pF at avalanche bias.

What we have found, however, is that the inherent signal to noise charge enhancement within the avalanche detector can be realized best if it is followed by a noncharge integrating, charge sensing circuit. The noncharge integrating feature of such a circuit implies that the response time of the circuit is at least an order of magnitude faster than the rise time of the induced charge in the semiconductor detector (which is in the nanosecond or even subnanosecond region). This high speed time domain does not allow the noise induced charges to compete with the event-induced charges. For example, the aluminum fluorescence x ray event in the avalanche detector results in an induced charge equal to that of $1.5 \times 10^5$ electrons (after multiplication of $10^3$) at the detector contacts. These electrons collected in nanosecond time can be detected as a charge packet in the presence of an average random charge of $6.3 \times 10^5$ noise electrons/nsec which have been created by a forced leakage current of 100 $\mu$A (dc) in the avalanche detector. Typically such circuits require fast-response active elements having low capacitance. Also the circuit configuration connecting the active device to the semiconductor detector must be optimized for low values of series inductance and resistance and shunt distributed capacitances. The importance of the low capacitance is that the voltage signal available to the sensing active element is directly related to the total capacitance through the charge equation ($V = Q/C$). For a limited charge event the capacitance in the detector, sensing element and circuit must be small to obtain an adequate voltage signal to trigger the sensing device.

A circuit—the subject of this Letter—which has the above characteristics consists of a tunnel diode

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biased in a monostable mode as the active charge-sensing device coupled to an avalanche radiation detector. In this case the avalanche detector is of the "contoured" type. A standardized pulse (in amplitude and width) is then given at the circuit output for the detection in the avalanche device of a nuclear event. The circuit shown in Fig. 2 has the described charge thresholding characteristics by adjusting either the tunnel diode or the avalanche detector bias. Also the tunnel diode is integrally coupled to the avalanche detector to eliminate lead length inductance and is mounted for minimum distributed capacitance as shown in Fig. 3. The pulse width of the standard pulse is primarily controlled by the inductor $L$. The magnitude of the inductor $L$ cannot be reduced below its effectiveness as an rf choke for the rate of rise of the induced charge pulse at the contacts of the avalanche detector.

The fast induced charge pulse at the avalanche detector is translated through the charge equation

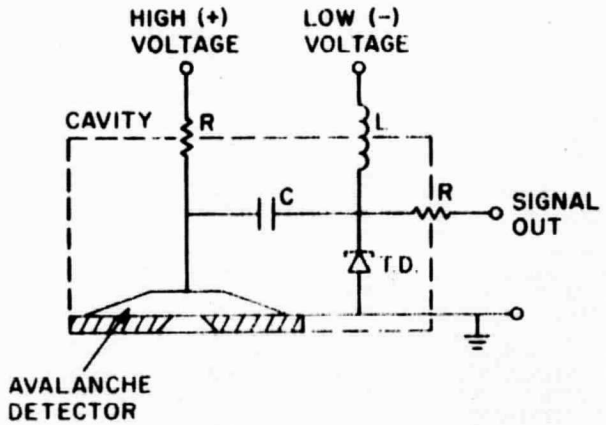



Fig. 2. Schematic diagram.

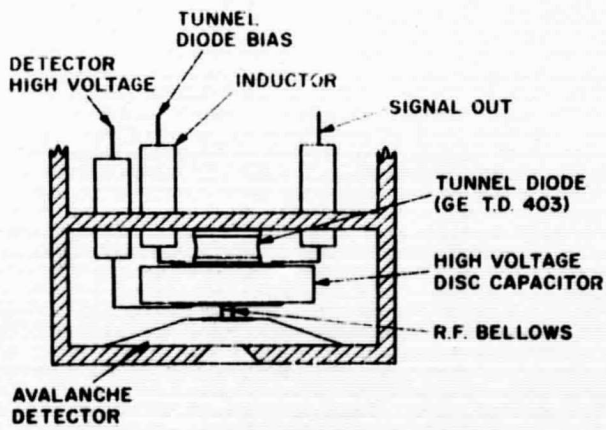



Fig. 3. Detail of avalanche detector tunnel diode cavity.

into a voltage pulse across the junction capacitances of the detector and tunnel diode. The particular tunnel diode used is selected to have a capacitance that is approximately 10% of the capacitance presented by the avalanche detector depletion region in this case, 1 pF. At these conditions the tunnel diode as a sensing element "stores" only 10% of the induced charge collected in the depletion region. The resulting voltage pulse across the tunnel diode junction is sufficient to trigger the circuit. The sensitivity of the circuit is typically (as measured experimentally) 10 $^{-13}$ C.

Prototypes of this circuit (which include a single, rather standard, transistor line-driving stage following the tunnel diode) have demonstrated what we believe to be unique capabilities as follows. The sensitivity is such that even soft x rays (to 1.49 keV or 10 Å wavelength) are detectable. The aluminum fluorescence x ray (1.49 keV corresponding to a pulse of 400 electrons introduced into the avalanche detector) has been detected with an efficiency greater than the 12% value of a gas proportional counter with 2-mm beryllium entrance window. A factor in detection efficiency is the entrance window (or dead layer) of the avalanche device. This value then does not imply a circuitry limitation. This detection is accomplished at laboratory temperature and lighting conditions without background counts. Beyond these conditions, it is possible to raise the detector leakage current to a level of 100 $\mu$A by, for example, directing a visible light source into the avalanche detector face without impairing counting efficiency or introducing background counts. Alternatively, the entire detector circuit can be raised to the vicinity 75°C causing a leakage current in the avalanche device of 0.8 $\mu$A—again without impairing counting efficiency or introducing background counts.

The time of response between the initial formation of free electrons in the avalanche detector by an ionization event and the detection of this event by the active element (the tunnel diode) can be made to be less than the total collection time of the induced charge from the movement of these free electrons. This is accomplished by the adjustable charge threshold capability of the tunnel diode. As the threshold is made to be a smaller percentage of the total collected charge, the response time or delay time is reduced.

In attempting to deduce the waveform of the probable avalanche detector pulse rise (in arguments similar to those presented by Tové and Falk[3]) one can conclude that the waveform is probably logarithmic in shape rather than exponential as in

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the nonavalanche case. This would appear to be a very useful waveform for high speed timing applications in nuclear physics. We propose this as a potentially useful application of this detection concept, but have made no particular measurements in this area.

The small tunnel diode and distributed circuit capacitance has another interesting consequence. For example, the series contact impedance of the avalanche detector is not as critical in this circuit as it is in sensing circuits that have high input capacitance. The series resistance acts as a current limiter in the charge transfer process between the collected charge in the avalanche detector and the required charge integration in the tunnel diode junction to voltage control the switching action of the tunnel diode. Hence, the lower the circuit capacitance, the less effect the avalanche detector series resistance has in limiting the voltage rise in the charge-sensing tunnel diode junction.

[1] Developed under Atomic Energy Commission Contract AT-(30-1)-3246.

[2] G. C. Huth, J. B. Trice and R. A. McKinney, *Rev. Sci. Instr.* **35**, 1220 (1964).

[3] P. A. Tove and K. Falk, *Nucl. Instr. and Meth.* **29**, 66 (1964).