SMOKE DETECTORS
IONIZATION DETECTORS

INTRODUCTION

The ability to detect a fire in a spacecraft in its earliest stages is difficult to predict. The spacecraft is an extremely complex vehicle in which most of the systems and/or equipment likely to act as initiators or propagators of fire are built into hidden areas or installed in semi-sealed cabinets. It is possible that over-heated, incipient fire conditions could exist for a long time before becoming visible. The purpose of this presentation is to discuss one class of devices capable of sensing these conditions and thus providing an early warning. These are so-called "smoke detectors" which can detect the presence of many of the invisible and visible products of pyrolysis which are given off by most potentially combustible materials when over-heated or in early stages of combustion.

In principle, smoke detection is one of the simplest and least ambiguous of the available techniques which might be used for identifying the presence of an active or incipient fire. Normally, combustible materials such as hydrogen for fuel cells and propellants for altitude stabilization and propulsion, will be stored exterior to the pressurized living area. Many of the materials likely to be brought on board a spacecraft will be relatively fire resistant. Much of the materials, synthetic polymers of many kinds, do not burn easily, and if involved in pyrolysis through overheating or arcing, break down into complex compounds which should be relatively easy to detect. There will undoubtedly be some relatively flammable materials on board, such as ethlyene glycol in heat exchangers or even Kleenex for the crew. Insofar as is known, the products of pyrolysis of all of the materials which are inside the spacecraft can be detected by the smoke detectors. The problem is in space as it is in ground installation, primarily one of proper sampling. This will involve considerable study and research to determine the best location for the sensing units or sampling tubes. Serious consideration should be given to special flight experiments to develop a thorough understanding of the factors involved at both zero "g" and partial "g" conditions.

Most smoke particles range from 0.01 micron to 1.0 micron in size, which are too small to be seen by the human eye. Tobacco smoke for instance, is composed of particles in the 0.01 to 0.1 micron size, and is visible as a haze only when sufficiently concentrated. In the extreme cases, particles of combustion can range up to 10 microns or larger, but these are generally such substances as fly ash or dusts of various kinds and are not considered here.

Several kinds of smoke/ionization detectors are presently commercially available, although none are suitable for application to spaceflight without repackaging or re-engineering. All of the systems may be intentionally deactivated for certain normal spacecraft functions and all systems can be built to automatically reset to the detection mode when the alarm condition is corrected. The success of any of these systems is critically dependent on the careful matching of requirements with the available hardware. They fall into basically three categories:

I. Optical Detection

Smoke can be detected optically by passing a beam of collinated light through the air and detecting the extent to which the beam is obscured or scattered as shown in the first figure. The light source may be a simple incandescent bulb and collinating lens as in a film projector, or it may be more complex for use under special conditions. Figure one schematically illustrates the two basic principles of operation.

A. Obscuration Technique:

In this case, the beam is passed through the sampling area and a detector measures the degree to which the beam is blocked by the smoke. Since the signal is proportional to the difference between the intensity of the emitted light and the transmitted, this technige inherently lacks sensitivity at low smoke levels inasmuch as it requires the accurate measurement of a small difference between two large numbers.

Systems based on this principle have been used commercially for over forty years and have achieved excellent reliability records when installed with proper consideration for their limitations. They are primarily intended for areas where the water vapor, cooking fumes, etc.) Furthermore, the effectiveness of this type system as an early warning alarm is highly dependent on the assumption that all potential combustibles in the area to be protected will generate visible combustion products. The validity of this assumption will require careful analysis and possibly some additional experimental verification. As mentioned earlier, the location of detecting units is extremely critical. These are spot sensors and are dependent on the transport of the combustion products from the source of any incipient fire to the unit. Consequently, considerable study and research will be required to ascertain local airflow patterns, and the effects of partial/zero "g".

II. Ionization Technique:

The principle of the ionization smoke detector is illustrated in Figure Two. The air space between the two electrodes of the detecting unit is ionized by using a radioactive source in preference to employing high voltage which is cumbersome and impractical. The radio-active material is usually an extremely small piece of material about 1/16 inches square containing about 0.1 to 0.2 microcuries of radium 226. This is less than in the average radium dial watch and does not present any hazard in normal use, although the release of radon gas as a by-product of radio-active decay may type of fire anticipated is expected to generate substantial quantities of smoke. Typically, these units are set to signal an alarm when the transmitted light is reduced by approximately 4%. Both spot type and area surveillance systems are employed. The spot type is often installed at a central location and sampling air is brought to it through ducting. It also sees service as a self-contained unit. These units are often employed to monitor areas such as boiler rooms, storage areas, cable-ways and in air circulation systems. The projected beam type is often used to protect large areas by the use of mirrors and is limited only to the practical extent to which the light beam can be reflected around the area to be protected. This type unit is particularly good for after hours protection when human activity is not likely to interrupt the beam such as bank vaults, storage areas, etc. Ultra-violet and infra-red light sources can be used to avoid interference from existing ambient illumination. The use of a laser as a light source may offer special advantages for the projected beam type in that it may permit larger areas to be covered and the sensitivity may be improved.

B. Scattered Light Technique:

A detector mounted off the axis of the beam and looking into a black area would normally receive no signal. The presence of small particles in the beam scatters the light in all directions, thus providing a very sensitive means for smoke detection. It is obvious that other substances than smoke can also cause the light to scatter, and this could be a source for false warning. Small bits of dust, flakes of paint, skin, etc. must be filtered out of the sensing zone to prevent unwanted signals. Electronic means for monitoring the type of signal also will help control the system of sounding an unwanted alarm.

This type of system may offer promise for certain spacecraft applications. Some commerical units are twice as sensitive as the previously discussed obscuration systems (2% smoke density), consume very little power, are small (approximately 3" x 6"), and each detector head weighs approximately a pound. Some repacking and re-engineering would undoubtedly be required for space flight, but the technology is well developed and these tasks should be fairly straight forward. Further improvements in sensitivity can be achieved, but the practical utilization of increased sensitivity depends on the extent to which other non-fire atmospheric obscuration can be controlled (i.e.

present some problems in the closed ecological systems of spacecraft, intended for very long duration missions.

The left side of Figure Two depicts the normal mode of operation in clean air. The oxygen and nitrogen molecules are ionized primarily by the reaction with alpha particles, released from the radioactive material. This produces a large number of electrons and ion pairs which travel to poles of opposite polarity, resulting in a current flow in the system. When products of combustion such as smoke particles and complex hydrocarbons enter the ionization chamber, they attach themselves to the ions, and because of their greater mass, cause a reduction in the speed with which they move towards the plates. This longer transit time increases the chance for them to be neutralized by free electrons, thus decreasing the current in the circuit which provides the signal for alarm. Ionization detectors presently on the market differ mainly in the method whereby the current reduction is converted into an alarm signal. Also some devices employ americum 241 instead of radium. Ionization detectors appear to be most sensitive to particles ranging from 0.1 to 1.0 microns which includes most smoke particles. Smaller particles tend to coagulate and form larger particles. Particles much larger than those included in this range tend to settle out, although in space, this will present a problem which may have to be handled by appropriate filtering around the detector head. Figure three presents the size range of some typical air-borne particles as a matter of interest.

Some consideration must be given to the potential hazards imposed by the use of radioactive materials in these devices. For all practical purposes, the radiation energy is entirely absorbed within the body of the unit. No radiation above normal background levels is detectable along the outer surface of the device.

Typical treatment of the radioactive material involves imbedding and sealing radium 226 as radium sulfate in a bonded silver and gold foil. Approximately 94 percent of the decay product is radon 222 which emits alpha particles and gamma rays of low penetrating power. Further decay produces beta emitting products. The principle hazard, however, is associated with the radium 226 in the possibility that it may gain entrance to the human body. To do so, however, one would have to deliberately disassemble the unit and remove the radioactive material mechanically. Even so, the amount is within the permissible "body burden", recommended by the National Council on Radiation Protection.

Calculations indicate that 1000 detectors will produce approximately 0.034 millicurie of radon gas every 24 hours. This is an exceedingly minute quantity, but will undoubtedly involve careful analysis before an accurate assessment can be made of the hazard from this source for extended space missions.

The first ionization detectors were introduced in Switzerland circa 1945. First commercial marketing of the device in this country occurred about ten years later. At the present time, units of this type are marketed by several manufacturers. All are based on the same principle of detection, but industry experience has been very variable, ranging from excellent to very poor, depending on the manufacturer. Only one manufacturer's system is widely excepted throughout government and industry, but this one is specified, where possible, by the Department of Air Force and Navy, U.S. Coast Guard, private fire protection authorities, and Federal agencies, including NASA. Recently, it was specified in the White House and the Library of Congress. This particular system is very sensitive and could possibly be utilized in almost any area of a spacecraft. Each detector unit weighs about one pound. Construction is rugged and makes use of solid state electronics. Checkout is simple and involves unsophisticated instrumentation. A new model introduced commerically at the first of this year operates on 24 volts D.C. with a power drain of less than 0.01 amp per detection unit. Some repackaging and reengineering will be required to adapt the system for spaceflight usage. This system appears very promising as a way to provide early warning for detection of fires and overheat areas. Although false indications are possible from water vapor and other nonfire atmospheric contamination, proper calibration can minimize these as sources of major concern. According to communications with the manufacturer, the new model is virtually unaffected by pressure changes over a range of several atmospheres and by the N_2/O_2ratio. Engineering studies are underway to evaluate the system's use in deep submergence vehicles at elevated pressures.

The units are spot sensors and are highly dependent on local airflows in the same manner as discussed earlier for the optical systems. Since ionization detectors sense the invisible and visible particles given off by both non-fire and incipient fire sources, some additional research will be required to identify and evaluate the sensitivity of the system for these sources. System calibration should be accomplished utilizing the combustion of identical material to that likely to be involved in any fire or over-heat situation. Another factor of great importance, if the early warning potential of the system is to be achieved, is the implied close spacing of the detector heads in order to minimize the transport time of particles from the source to the detector.

III. <u>Resistance Bridge Technique</u> (Illustrated in Figure 4):

This technique is based upon the fact that some combustion gases and visible smoke affect the conductivity of an exposed resistance element. Each of the detector units contain two sensitive elements. Comb-like electrodes are bonded to a specially-treated substrate. The electrodes are interdigitated to form a grid. One-half of each electrode is the positive element, and the other half forms the negative element. The grid substrate assemblies are of a resistance bridge network. Both of the elements are sensitive to changes in the conductivity of the air and their impedance decreases in the presence of combustion products. The inner element is partially sealed and acts as a compensator to monitor the exposed or outer detecting grid during normal environmental conditions. Slow changes in the normal environment are always occurring. As long as these changes are slow, the impedance of compensator grid will match that of the detector grid and keep the bridge in balance. At the junction of the two grids, a sensitive triggering element is connected which responds to fast changes occuring in the surface impedance of the exposed detector grid in response to the presence of combustion products. This unbalances the bridge and triggers the alarm.

As may be expected, the grid sensors become increasingly conductive with the accumulation of normal air-borne contaminants and eventually normal atmospheric changes will trigger spurious alarms. The manufacturers of these units recommend cleaning the elements at least every six months, or more often as required. Units of this type have performed poorly in various installations. Many business and government organizations will not permit this type of unit to be installed. NASA has had to remove these units from several installations. Needless to say, this type of device is included only for information purposes and is not proposed for active consideration.

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13 January 1970

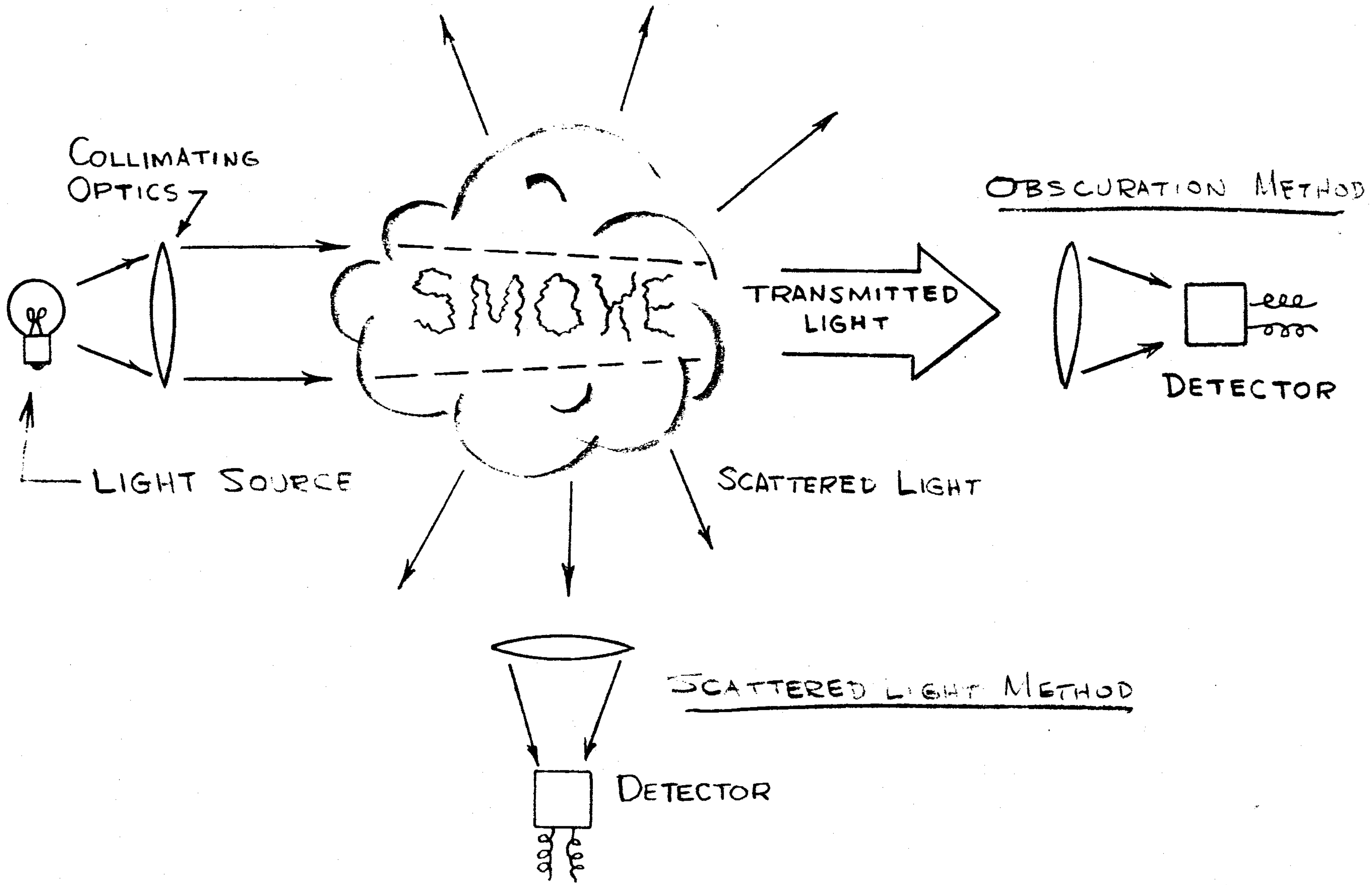

FIGURE 1 - SCHEMATIC ILLUSTRATION, OPTICAL SMOKE DETECTION

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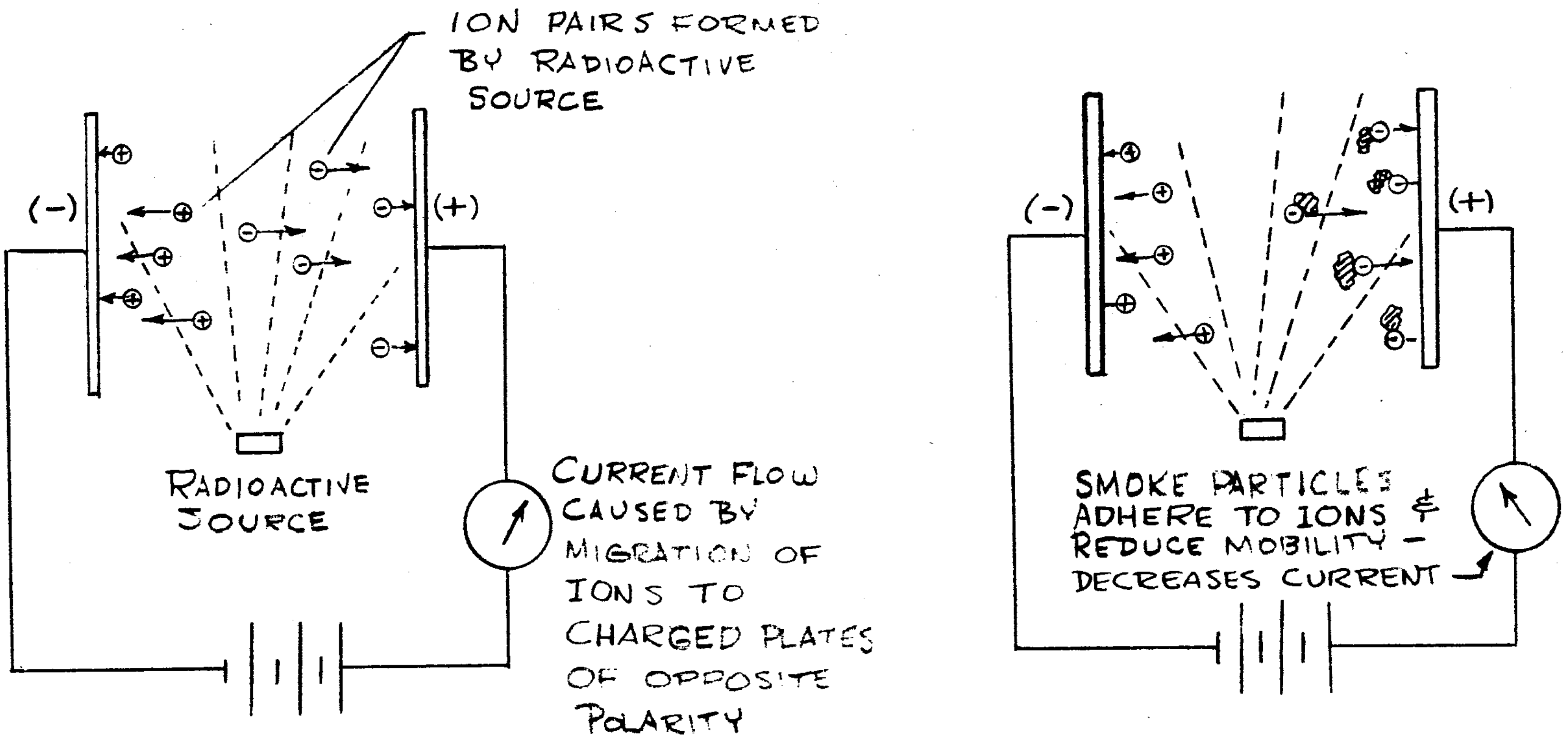

(a) NORMAL MODE - CLEAN AIR

(b) DETECTION MODE

FIGURE 2 - SCHEMATIC ILLUSTRATION, IONIZATION SMOKE DETECTION

IONIZATION DETECTION SYSTEMS

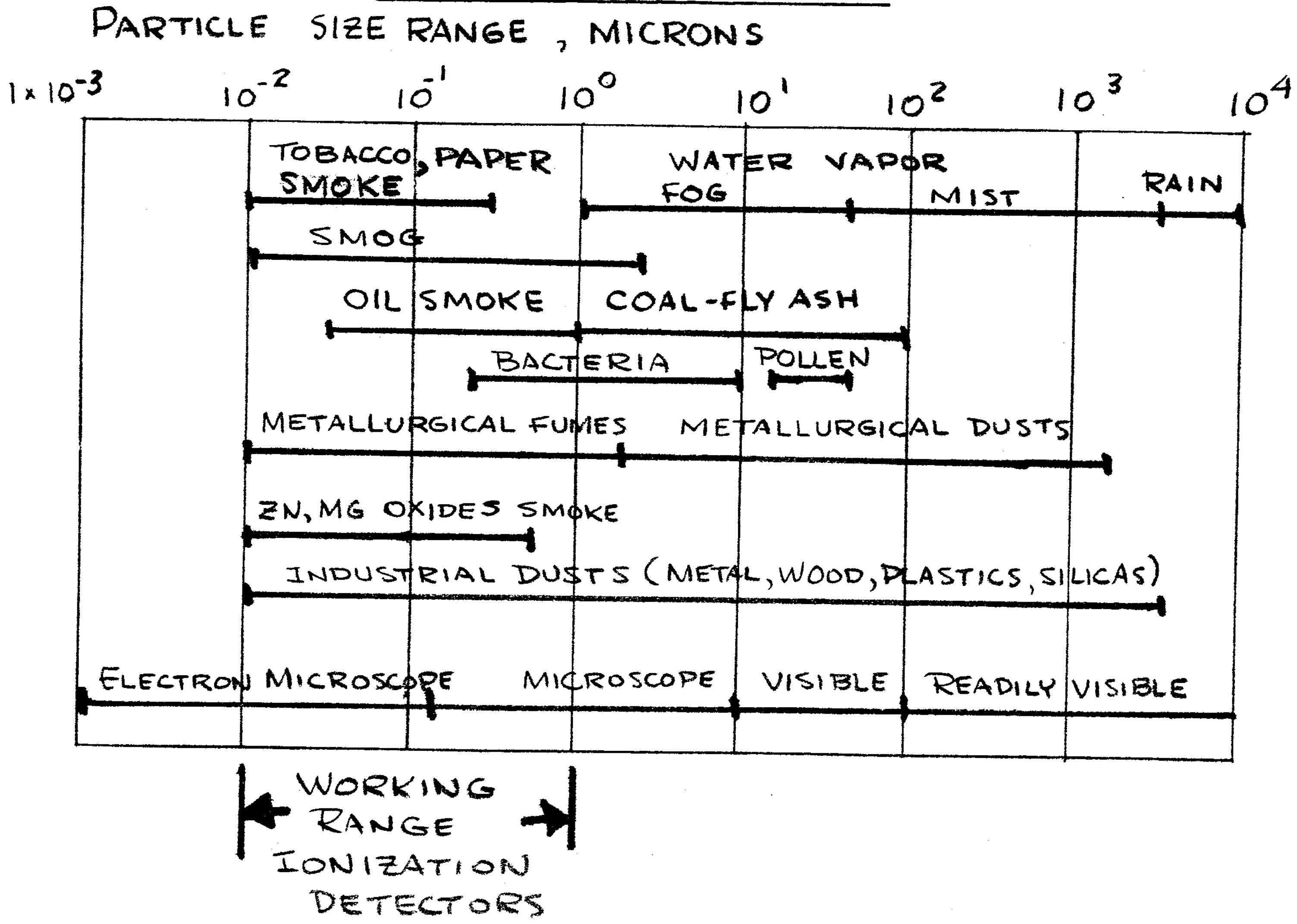

FIGURE 3 SIZE RANGE OF SOME TYPICAL AIR-BORNE PARTICLES

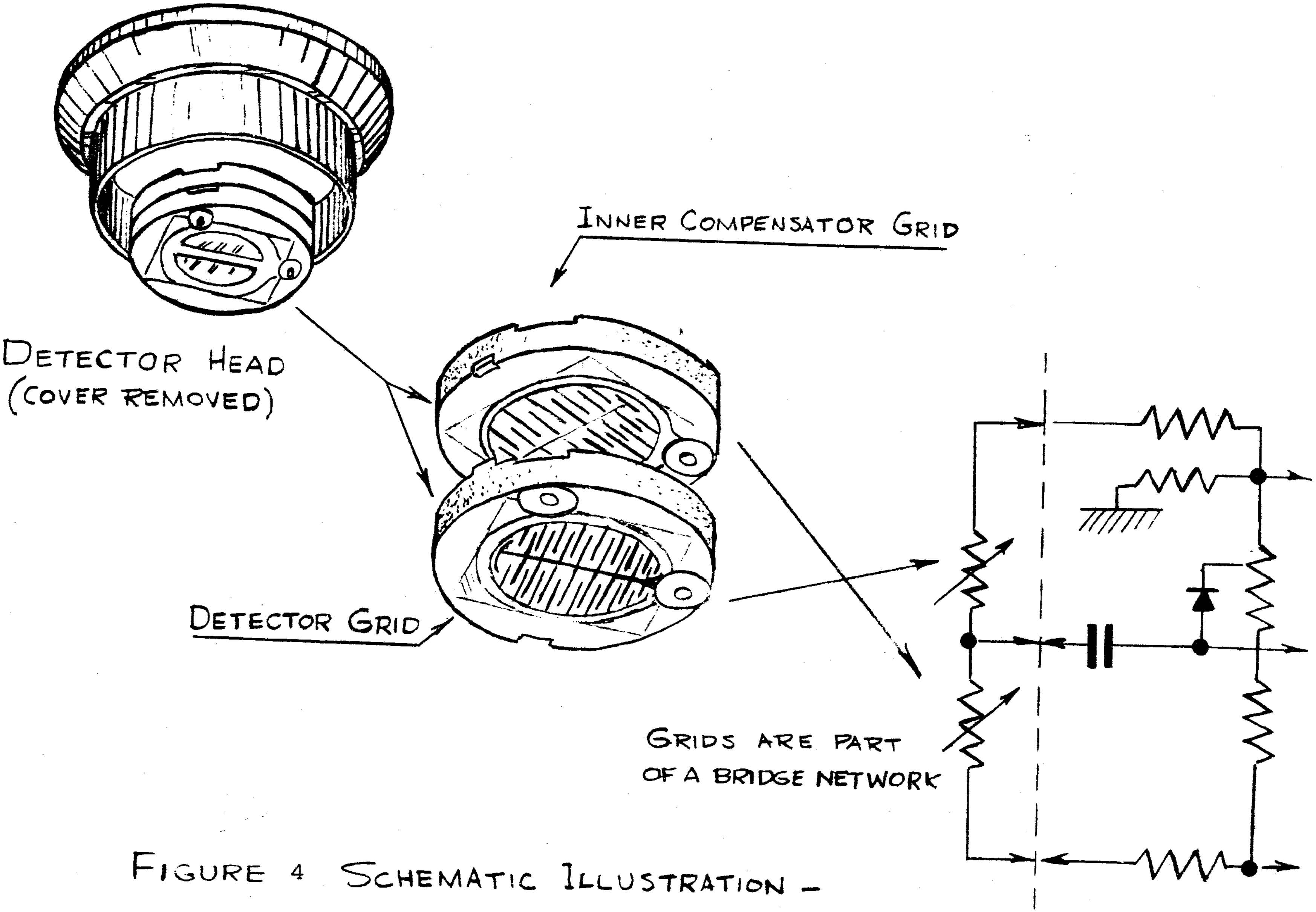

Figure 4 Schematic Illustration –
Resistance Bridge Detection

IONIZATION DETECTION SYSTEMS

- PRIMARILY INTENDED FOR USE AS EARLY WARNING FIRE DETECTOR
- SYSTEMS ARE RELATIVELY COMPLEX, TECHNOLOGY IS WELL DEVELOPED
- TYPICAL INDUSTRIAL USAGE:

  (a) Computer Areas
  (b) Libraries
  (c) Laboratories
  (d) High Value Density Areas

FIGURE I

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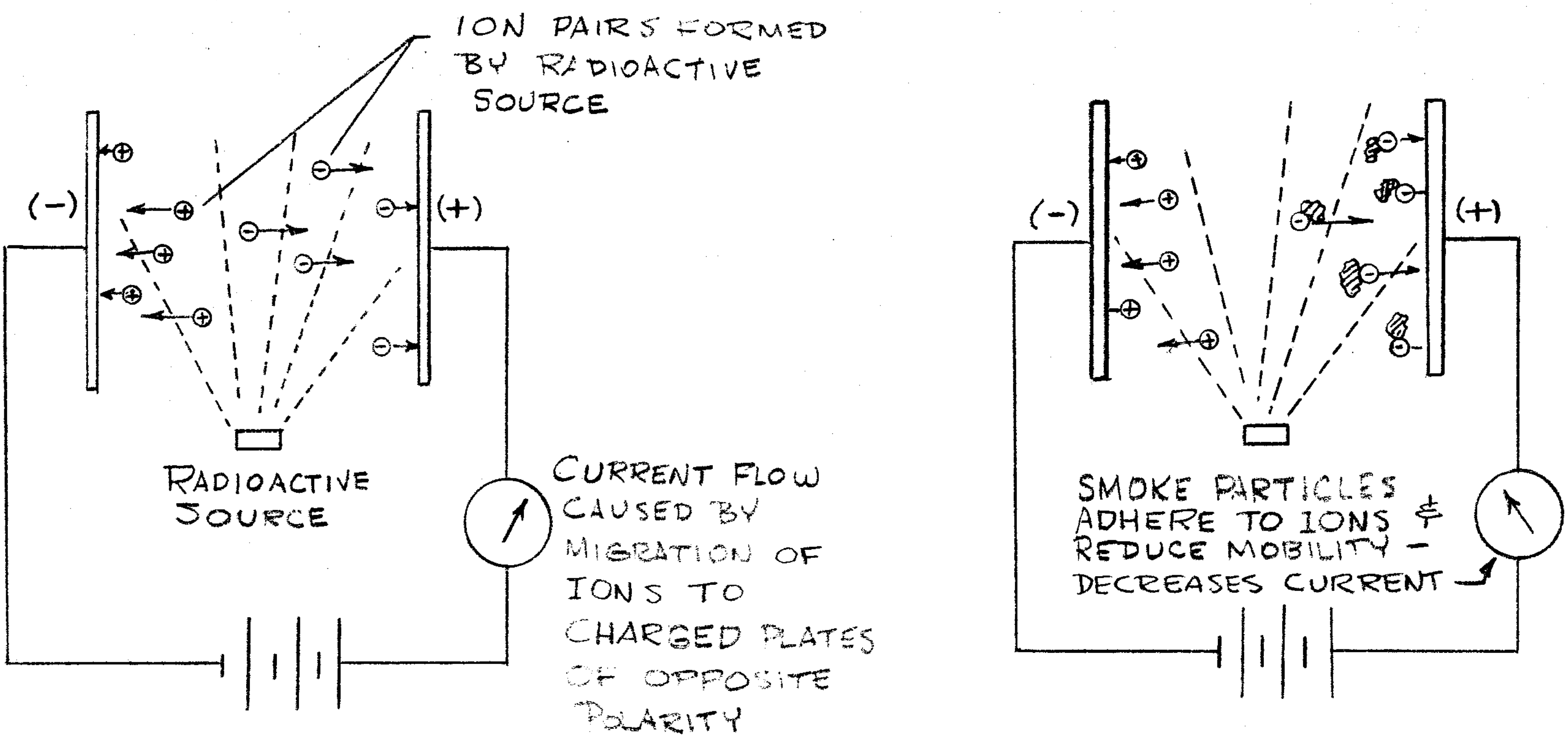
IONIZATION DETEC ON SYSTEMS



(a) NORMAL MODE - CLEAN AIR

(b) DETECTION MODE
(MOST SENSITIVE TO PARTICLES 0.01 → 1.0 MICRONS)

PRINCIPLE OF OPERATION

FIGURE 2

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IONIZATION DETECTION SYSTEMS
POTENTIAL SPACECRAFT APPLICATIONS

- CAN BE INSTALLED IN ANY AREA
- EARLY WARNING FOR DETECTION OF INCIPIENT FIRES AND OVERHEAT AREAS

FIGURE 3

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IONIZATION DETECTION SYSTEMS
RELIABILITY AND ACCURACY

- HIGHLY DEPENDENT ON LOCAL AIRFLOW PATTERNS (Air Vents, Stagnation Zones, Compartment Geometry, Zero/Partial "G" Effects)
- EFFECTIVE EARLY WARNING IMPLIES CLOSE SPACING OF SENSING UNITS TO MINIMIZE TRANSPORT TIME
- REQUIRES KNOWLEDGE OF POTENTIAL NON-FIRE SOURCES OF DETECTABLE SMALL PARTICLES (i.e., Water Vapor, Cooking Fumes, Very Fine Dust)

FIGURE 4

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IONIZATION DETECTION SYSTEMS
ADVANTAGES

- WELL DEVELOPED TECHNOLOGY (Industry Experience Very Good With One Manufacturer's System)
- VERY SENSITIVE
- CAN BE USED IN ALMOST ANY AREA OF SPACECRAFT
- RUGGED CONSTRUCTION, SOLID STATE ELECTRONICS, SIMPLE CHECKOUT
- LOW VOLTAGE (24 Volt D. C.)
- LOW POWER (< 0.2 Watts Per Detector Unit)
- LIGHT WEIGHT (Approximately One Pound Per Detector Unit)
- MODERATE COST

FIGURE 5

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IONIZATION DETECTION SYSTEMS
ADVANTAGES

- SYSTEM MAY BE INTENTIONALLY DEACTIVATED FOR CERTAIN NORMAL SPACECRAFT FUNCTIONS
- SYSTEM AUTOMATICALLY RESETS WHEN ALARM CONDITION CORRECTED
- RELATIVELY UNAFFECTED BY PRESSURE/GAS CONSTITUENT CHANGES, HUMIDITY, DUST AND PARTICLES

FIGURE 5 (continued)

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IONIZATION DETECTION SYSTEMS
DISADVANTAGES

- SPOT SENSOR (Dependent On Transport of Combustion Products From Source to Detector; Sensitivity May Be Affected Changes in Air Flow Patterns From Fans/Blowers Or By Repositioning Of Interior Compartment Panels).

- FALSE INDICATION POSSIBLE FROM WATER VAPOR OR OTHER NON-FIRE ATMOSPHERIC CONTAMINATION

FIGURE 6

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IONIZATION DETECTION SYSTEMS
STATE-OF-THE-ART

- USED COMMERCIALLY FOR APPROXIMATELY 25 YEARS (First Used in Europe ≈ 1945; USA ≈ 1955)
- INDUSTRY EXPERIENCE VARIABLE (Excellent to Very Poor, Depending on Manufacturer)
- ONE MANUFACTURER (PYROTRONICS, INC.) HAS JUST INTRODUCED A SYSTEM WHICH IS CLAIMED TO BE ESSENTIALLY INDEPENDENT OF PRESSURE, O_2/N_2 MIX, TO BE EVALUATED FOR USE IN DEEP SUBMERGENCE APPLICATION AT ELEVATED PRESSURES
- SEVERAL MANUFACTURING SOURCES (ONLY ONE IS GENERALLY ACCEPTED THROUGHOUT GOVERNMENT, INDUSTRY)
- REPACKAGING AND REENGINEERING REQUIRED

FIGURE 7

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