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Fire Alarm and Communication Systems

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FIRE ALARM AND COMMUNICATION SYSTEMS

R. W. Bukowski, R. L. P. Custer and R. G. Bright

The operation and use of all current types of fire alarm and communication systems are discussed. This includes the differences between and operating features of local, auxiliary, remote station, proprietary, and central station systems, high-rise communication systems and residential fire detection devices. A discussion of commonly used fire detectors is given including operation, installation and application considerations. Indicating devices, sprinkler supervisory devices, maintenance, reliability and code/standard compliance are also covered.

Key words: Control units; fire alarm systems; fire detectors; high-rise communication systems; multiplex systems; NFPA standards; residential fire detector; sprinkler supervisory devices.

1. INTRODUCTION

A good fire alarm and communication system is a key part of the overall fire protection designed into any building. Whether the building is residential, office, manufacturing, or any other type of occupancy, a properly designed and installed fire alarm system can do much to limit both life and property loss in the event of a fire. Since approximately 80% of the life loss from fire is in buildings, the use of early warning fire alarm systems in buildings can have a profound effect on the reduction of life loss.

The systems themselves can take many forms ranging from one single station smoke detector in a small single family detached dwelling, to a complicated computerized high-rise building system inputting data from numerous sources and performing a number of independent actions as a function of the input data. Emergency communication systems in high-rise buildings can be very effective in preventing panic and in allowing orderly evacuation of the endangered portions of the building as well as in directing the fire fighting operation within the building.

In this note we will try to give a general overview of the fire alarm and communication equipment normally used in buildings in order to provide a little better understanding of the function of this equipment by the architect or specifying engineer.

2. CONTROL UNITS

2.1 Common Features

The "brain" of any fire alarm system is referred to as the control unit. This is the central equipment cabinet to which all other subsystems of the fire alarm system are connected The control unit provides power to all active devices and contains all of the switching functions controlled by the initiating devices which perform all of the intended operations of the system. The control unit also contains lights which indicate the status of the system and switches for silencing of audible signals, resetting of alarm conditions and such features as test switches, drill switches, etc.

Control units are classified according to the signaling functions they are expected to perform. Their installation, maintenance and use are covered by the following nationally recognized standards:

NFPA 72A	Local Protective Signaling Systems
NFPA 72B	Auxiliary Protective Signaling Systems
NFPA 72C	Remote Station Protective Signaling Systems
NFPA 72D	Proprietary Protective Signaling Systems
NFPA 71	Central Station Signaling Systems

Before discussing the features which set these systems apart, let us first consider some basic features common to all control units regardless of type. Each has a primary power supply (usually the commercial light and power service) and most have some sort of emergency power supply such as engine driven generators or battery supplies. They have one or more initiating device circuits to which the detectors and manual boxes are connected and have one or more indicating device circuits to which the evacuation signals such as bells, horns, sirens, etc. are connected.

For larger buildings most control units have more than one initiating device circuit so that the fire location can be indicated on an annunciator panel by floor, wing, or subsection. This annunciator panel may be built into the control unit or in a lobby or maintenance area.

Control units have three distinct types of audible signals. These are alarm signals, trouble signals and sprinkler supervisory signals.

An alarm signal is given when a fire is detected either manually or automatically by an initiating device (e.g., manual box or detector). Alarm signals generally involve the ringing of bells or horns throughout the building, but in large buildings alarms may initially be sounded only in the areas in immediate jeopardy. In some newer high-rise building systems the alarm signal may be a taped or live voice message over a special speaker system.

Trouble signals are given when a malfunction occurs in any critical circuit of the control unit. These critical circuits are referred to as being "supervised." Circuits which are normally supervised include main power, initiating (detector) circuits, and indicating (alarm bell) circuits. The trouble signal is usually sounded only in areas where maintenance personnel are normally present.

Sprinkler supervisory signals are given when a critical component in the sprinkler system is in other than its normal position. This would include low water service pressure, loss of power to a fire pump, closing of a water supply valve, or low water level or near freezing temperature in an outdoor water supply tank.

Like trouble signals, sprinkler supervisory signals are usually sounded only in maintenance areas.

2.2 Local Control Units

The local control unit [1][1] is, as the name implies, intended only to sound the local evacuation signal in the protected building (see fig. 1). It generally contains little more than the basic features indicated above and is not required to have emergency stand-by power since a power failure in an occupied building should be known to the occupants. The local control unit is generally of limited value in other than protection of the occupants, since the alarm is not automatically relayed to a fire department and no action by the fire department would be possible unless someone remembers to call them when the alarm occurs. If the building is unoccupied, fire department response would depend on a passerby hearing the alarm and calling the fire department.

2.3 Auxiliary Control Units

An auxiliary control unit [2] is a local control unit which has an additional circuit electrically connecting it to the municipal fire alarm box on the street corner (see fig. 2). Thus the auxiliary control unit not only rings the evacuation signals, but also automatically informs the fire department through the municipal fire alarm circuit that a fire has occurred on that particular city block. The signal received by the fire department is the same as if someone had manually tripped the street corner box so they would have to locate the fire among the buildings on that block when they arrive at the scene. Since trouble signals are not automatically transmitted to the fire department, auxiliary control units are required to have a 60 hour minimum emergency power supply capacity to operate the system in case of a power failure over a weekend.

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[1] Numbers in brackets refer to the list of references at the end of this paper.

2.4 Remote Station Control Unit

A remote station control unit [3] is similar to an auxiliary control unit except that it transmits its signal to a compatible remote station receiving unit at a location which is normally manned 24 hours a day (see fig. 3). This may be a police station, all night garage, restaurant, or even a funeral parlor. The signal is transmitted over a leased telephone line and is announced audibly and visually at the receiving station from which the fire department is notified. Again, since trouble signals are not automatically transmitted to the remote receiving station, remote station control units are required to have a 60 hour emergency power supply capability.

2.5 Proprietary Control Units

The most widely used type of control unit in large commercial occupancies is the proprietary system [4] (see fig. 4).

Proprietary and central station type systems are identical except that the station receiving the fire alarm signal in a proprietary system is operated by someone who has a proprietary interest in the protected buildings. The receiving station is generally a guard office within the building, or group of buildings, protected by the system, whereas a central station receiving station is manned by operators who perform the service for a fee and have no proprietary interest in the protected buildings. This is, in effect, "protection for hire."

In the past, most proprietary systems have had separate initiating device circuits for each zone or subsection within the building, similar to the local, auxiliary, and remote station systems. However, due to the increasing use of electronics, newer proprietary systems for larger buildings are now using signal multiplexing and built-in minicomputer systems which receive all signals from the building over a single pair of wires and determine the exact location of the fire by use of different frequencies or digitally coded information transmitted over the pair. Figure 5 shows the complexity and interrelationships between the many facets of a modern computer controlled proprietary/high-rise communication system. The system illustrated is being used in the new Federal office building in Seattle, Washington. While a proprietary transmitting unit is similar to the other types of control units, the receiving console is quite different. A proprietary receiving console has individual lights or a digital visual display indicating the exact alarm point, an audible alarm to alert the console operator, and some type of visual indication on a permanent printer such as a teletype or line printer and, in some cases, a CRT (television type) display. These large proprietary multiplex and computer control systems do much more than just indicate to the operator and ring evacuation bells. These systems provide for smoke control by automatic closing and opening dampers in the HVAC systems, and turning on exhaust fans. They will also adjust elevator controls so elevators cannot stop on fire floors, automatically route all elevators to the lobby floor for use by the fire department, and do almost any other automatic functions which one would wish.

In addition to the increased flexibility of these proprietary systems, the use of multiplexing signals has greatly reduced the installation cost by minimizing the amount of wire used in the building. A very new concept which is now being explored is the use of multiplexing the fire alarm signals over the existing power wiring within the building by a line carrier technique very similar to the wireless intercom units sold for home use.

Minicomputer based proprietary systems often include energy management capabilities which can pay for the system in energy savings over a period of only a few years. This fact is instrumental in the large increase in use of these systems in large buildings in the last few years.

Proprietary systems are required to transmit trouble and alarm signals to the remote receiving station, so the standby power requirements are only 24 hours for these systems.

2.6 Central Station Control Units

As was stated earlier, the central station system is almost identical to the proprietary system [5] (see fig. 6). While the main difference is in the type of personnel manning the receiving station, there are some additional differences in the means of signal transmission between the protected building and the receiving station.

Since the proprietary receiving station is generally within the protected building or very close to it, proprietary systems transmit signals between the two points by means of single or multiple pairs of wires. This would be impractical, however, in the central station systems since the central station receiving point is generally a long distance from the protected building. Thus, there are two primary means used for transmitting the signals in a central station system.

The oldest transmitting means in central station use is called the "McCulloh" circuit. A McCulloh circuit is one that normally transmits over two wires but can be switched, manually or automatically, to transmit over one wire and ground. With this capability, a break or ground fault of a single wire will not render the system inoperative. In addition, a single McCulloh circuit may have as many as 25 protected buildings on it. Each building transmits a coded signal which generates an audible tone at the receiving station which sounds with the code pattern. In addition, some type of automatic printing means such as a punch or pen register is provided to give a permanent record of the code transmitted.

The second means of signal transmission in central station systems is called the direct wire circuit. This is, as its name implies, a direct dedicated (unswitched) pair of leased telephone lines running between the building and the central station panel. In this case, codes are not necessary since each building is on its own separate circuit.

When a signal is received at a central station, the appropriate authorities are informed and the central station operator dispatches a "runner" (usually an armed guard) to the protected building. This runner acts as an agent of the property owner at the scene and attempts to minimize loss.

As with proprietary systems, central station systems transmit all signals to the central station so the standby power requirements are 24 hours.

3. INITIATING DEVICES

3.1 General

An initiating device is defined as any device which informs the control unit of the presence of a fire. This can be done manually or automatically.

3.2 Manual

A manual initiating device is simply a fire alarm pull station located on an interior wall of a building. Most manual stations are noncoded and provide a simple contact closure to the control unit indicating that the device has operated. In order to get floor or zone discrimination with a noncoded system the control unit must have multiple initiating circuits.

The other type of manual station is a coded station where each individual manual station generates a specific impulse code to the control unit which, in turn, rings the building fire alarm bells in the coded pattern. Anyone in the building can then determine the location of the fire from the code sounded on the fire alarm bells.

Obviously, manual initiating devices are only effective when the protected area is occupied and someone remembers to pull the box. Thus, manual initiating devices are usually only employed in public use buildings in areas which are normally occupied or where the primary fire hazard is only present during the time the area is occupied. Another reason for using a manual system is its very low false alarm rate. Occupancies such as hospitals and schools have historically used manual systems exclusively since false alarms in these areas are highly undesirable.

Frequently, schools which have high false alarm incidence from manual stations will use what is known as a "pre-signal" alarm system. In a pre-signal system, pulling of the manual station does nothing more than ring an alarm bell in the principal's office and/or any other areas where people in authority would normally be present. When this occurs, someone in authority proceeds to the point of alarm and verifies the problem. If they determine a fire is present, they must then operate a key switch on the manual station which then sounds the evacuation signals and automatically notifies the fire department (in other than a local system).

3.3 Automatic

Automatic fire alarm initiating devices are actuated by heat, smoke, flame radiation, or other indicators of a fire. The following sections discuss the operation, installation and selection of each type of detection mode.

4. CLASSIFICATION OF DETECTORS [6]

Fire detectors may be classified in several ways: on the basis of placement, by functional characteristics of detectors, or by operating principle. Classification by placement and functional characteristics are described in this section and classification by operating principle is described in succeeding sections.

4.1 Geometric Classification

Detectors may be classed by the geometry of the area they cover. Spot detectors are devices whose detecting element responds to conditions at a single point. A line detector senses conditions along a continuous linear path. Volume detectors are those which monitor conditions within a specified volume and will respond to signals anywhere within that volume.

4.2 Restoration Classification

Detectors may also be classified by the way in which they are placed in service following operation. Restorable detectors are those which can be restored to operative condition following a fire. Those may be either of the self-restoring or the manually restoring type. Nonrestorable detectors have sensing elements which are destroyed by the fire.

4.3 Alarm Contact Circuit Classification

The type of alarm contact circuit can also be used to classify detectors. An open circuit detector has contacts which are normally open and close on alarm, while a closed circuit type opens the contacts or breaks a circuit on alarm. A transfer circuit type opens one circuit and closes another when the alarm conditions are reached.

5. HEAT DETECTION

Heat detectors are the oldest type of automatic fire detection device. They began with the development of automatic sprinkler heads in the 1860's and have continued to the present with a proliferation of different types of devices. A sprinkler can be considered a combined extinguishing device and heat activated fire detector when the sprinkler system is provided with water flow indicators tied into the fire alarm control unit system. These water flow indicators detect either the flow of water through the pipes or the subsequent pressure drop upon actuation of the system and automatically sound an alarm as the water is being put on the fire.

Electrical heat detectors, which only sound an alarm and have no extinguishing function, are also used. Heat detectors are the least expensive fire detectors, have the lowest false alarm rate of all fire detectors, but are also the slowest in detecting fires. Heat detectors are best suited for fire detection in small confined spaces where rapidly building, high heat output fires are expected and in other areas where ambient conditions would not allow the use of other fire detection devices or where speed of detection or life safety are not the prime consideration. One example of this would be low value protection where fire could cause minimum damage to the structure or contents. Heat detectors may be thought of as detecting fires within minutes of ignition.

Heat detectors respond to the convected thermal energy of a fire and are generally located at or near the ceiling. They may respond either at a predetermined fixed temperature or at a specified rate of temperature change. In general, heat detectors are designed to sense a prescribed change in a physical or electrical property of a material when exposed to heat.

5.1 Fixed-Temperature Detectors

Fixed-temperature detectors are designed to alarm when the temperature of the operating element reaches a specified point. The air temperature at the time of operation is usually higher than the rated temperature due to the thermal inertia of the operating elements. Fixed temperature heat detectors are available to cover a wide range of operating temperatures ranging from 57°C (135°F) and up. Higher temperature detectors are necessary so that detection can be provided in areas which are normally subjected to high ambient (nonfire) temperatures.

5.1.1 Eutectic Metal Type

Eutectic metals, alloys of bismuth, lead, tin and cadmium which melt rapidly at a predetermined temperature, can be used as operating elements for heat detection. The most common such use is the fusible element in an automatic sprinkler head. Fusing of the element allows water to flow in the system which triggers an alarm by various electrical or mechanical means.

A eutectic metal may be used in one of two ways to actuate an electrical alarm circuit. The simplest method is to place the eutectic element in series with a normally closed circuit. Fusing of the metal opens the circuit which triggers an alarm. The second method employs a eutectic metal as a solder to secure a spring under tension. When the element fuses, the spring action is used to close contacts and sound an alarm. Devices using eutectic metals cannot be restored. Either the device or its operating element must be replaced following operation.

5.1.2 Glass Bulb Type

Frangible glass bulbs similar to those used for sprinkler heads have been used to actuate alarm circuits. The bulb, which contains a high vapor pressure liquid and a small air bubble, is used as a strut to maintain a normally open switching circuit. When exposed to heat the liquid expands, compressing the air bubble. When the bubble is completely absorbed, there is a rapid increase in pressure, shattering the bulb and allowing the contacts to close. The desired temperature rating is obtained by controlling the size of the air bubble relative to the amount of liquid in the bulb.

5.1.3 Continuous Line Type

As an alternative to spot-type fixed temperature detection, various methods of continuous line detection have been developed. One type of line detector uses a pair of steel wires in a normally open circuit. The conductors are insulated from each other by a thermoplastic of known fusing temperature. The wires are under tension and held together by a braided sheath to form a single cable assembly (see fig. 7). When the design temperature is reached, the insulation melts, contact is made, and an alarm is generated. Following an alarm, the fused section of the cable must be replaced to restore the system.

A similar alarm device utilizing a semiconductor material and a stainless steel capillary tube has been developed for use where mechanical stability is a factor (see fig. 8). The capillary tube contains a coaxial center conductor separated from the tube wall by a temperature sensitive glass semiconductor material. Under normal conditions, a small current (i.e., below alarm threshold) flows in the circuit.

As the temperature rises the resistance of the semiconductor decreases allowing more current flow and triggering the alarm.

5.1.4 Bimetal Type

When a sandwich of two metals having different coefficients of thermal expansion is heated, differential expansion causes bending or flexing towards the metal having the lower expansion rate. This action closes a normally open circuit. The low expansion metal commonly used is Invar, an alloy of 36 percent nickel and 64 percent iron. Several alloys of manganese-copper-nickel, nickel-chromium-iron or stainless steel may be used for the high expansion component of a bimetal assembly. Bimetals are used for the operating elements of several types of fixed temperature detectors. These detectors are generally of two types, the bimetal strip and the bimetal snap disc.

5.1.4.1 Bimetal Strip. Some devices use bimetal strips placed directly in the alarm circuit. As the strip is heated it deforms in the direction of its contact point. The width of the gap between the contacts determines the operating temperature. The wider the gap, the higher the operating point. Drawbacks to this type of device are its lack of rapid positive action and its susceptibility to false alarms from vibration or jarring, particularly as the rated temperature is approached: for example, during periods of transient high ambient temperatures which are below the alarm point.

5.1.4.2 Snap Disc. The operating element of a snap-disc device is a bimetal disc formed into a concave shape in its unstressed condition (see fig. 9). As the disc is heated the stresses developed cause it to reverse curvature suddenly and become convex. This provides a rapid positive action which allows the alarm contacts to close. The disc itself is not usually part of the electrical circuit. Snap-disc devices are not as sensitive to false or intermittent alarms as the bimetal strips described above.

A different application of the thermal expansion properties of metals is found in the rate compensation detectors which use metals of different thermal expansion rates to compensate for slow changes in temperature while responding with an alarm for rapid rates of temperature rise and at a fixed maximum temperature as well. For a further discussion of this device, see the section on Combination Detectors.

All thermal detectors using bimetal or expanding metal elements have the desirable feature of automatic restoration after operation when the ambient temperature drops below the operating point.

5.2 Rate-of-Rise Detectors

One effect which a fire has on the surrounding environment is to generate a rapid increase in air temperature in the area above the fire. While fixed temperature heat detectors must wait until the gas temperature near the ceiling reaches or exceeds the designated operating point before sounding an alarm, the rate-of-rise detector will function when the rate of temperature change exceeds a predetermined value, typically around 15°F (8.33°C) per minute. Detectors of the rate-of-rise type are designed to compensate either mechanically or electrically for normal changes in ambient temperature which are expected under nonfire conditions. The various types of pneumatic rate-of-rise heat detectors are discussed below.

The increased pressure of gas when heated in a closed system can be used to generate a mechanical force which will operate alarm contacts in a pneumatic fire detection device. In a completely closed system, actuation will occur strictly from a slow change in ambient temperature, regardless of the rate of temperature change. The pneumatic detectors in use today provide a small opening to vent the pressure which builds up during slow changes in temperature. The vents are sized so that when the temperature changes rapidly, such as in a fire situation, the pressure change exceeds the venting rate and the system is pressurized. These systems are generally sensitive to rates of temperature rise exceeding 15°F (8.33°C) per minute. The pressure is converted to mechanical action by a flexible diaphragm. A generalized schematic of a pneumatic heat detection system is shown in figure 10.

Pneumatic heat detectors are available for both line and spot applications. The line systems consist of metal tubing in a loop configuration attached to the ceiling of the area to be protected. Except where specifically approved, Underwriters' Laboratories requires that lines of tubing be spaced not more than 30 feet (9.1 m) apart and that no single circuit exceed 1000 feet (304.8 m) in length. Zoning can be achieved by selected siting of lines or by insulating those portions of a circuit which pass through areas from which a signal is not desired.

For spot applications and in small areas where line systems might not be able to generate sufficient pressures to actuate the alarm contacts, heat collecting air chambers or rosettes are often used. These units act like a spot type detector by providing a large volume of air to be expanded at a single location.

The pneumatic principle is also used to close contacts within spot detectors of the combined rate-of-rise/fixed-temperature type. These devices are discussed below.

5.3 Combination Detectors

Several devices are available which use more than one operating mechanism and will respond to multiple fire signals with a single unit. The combination detectors may be designed to alarm either from any one of several fire signals or only when all the signals are present at predetermined levels.

Several heat detection devices are available which operate on both the rate-of-rise and fixed-temperature principles. The advantage of units such as these is that the rate-of-rise elements will respond quickly to rapidly developing fires, while the fixed temperature elements will respond to slowly developing smoldering fires when the design alarm temperature is reached. The most common type uses a vented hemispherical air chamber and a flexible diaphragm for the rate-of-rise function. The fixed-temperature element may be either a bimetal strip (see fig. 11) or a leaf spring restrained by a eutectic metal (see fig. 12). When the designed operating temperature is reached, either the bimetal strip flexes to the contact point or the eutectic metal fuses, releasing the spring which closes the contacts.

A second device which can be classified as combination rate-of-rise/fixed-temperature is the rate-compensation detector. This detector uses a metal cylinder containing two metal struts. These struts act as the alarm contacts and are under compression in a normally open position (see fig. 13). The outer shell is made of a material with a high coefficient of thermal expansion, usually aluminum, while the struts, usually copper, have a lower expansion coefficient. When exposed to a rapid change in temperature, the shell expands rapidly, relieving the force on the struts allowing them to close. Under slowly increasing temperature conditions both the shell and struts expand. The contacts remain open until the cylinder, which expands at a greater rate, has elongated sufficiently to allow them to close. This closure occurs at the fixed-temperature rating of the device.

5.4 Thermoelectric Detectors

Various thermoelectric properties of metals have been successfully applied in devices for heat detection. Operation is based either on the generation of a voltage between bimetallic junctions (thermocouples) at different temperatures or variations in rates of resistivity change with temperature.

These spot type devices, which operate in the voltage generating mode, use two sets of thermocouples. One set is exposed to changes in the atmospheric temperature and the other is not. During periods of rapid temperature change associated with a fire, the temperature of the exposed set increases faster than the unexposed set and a net potential is generated. The voltage increase associated with this potential is used to operate the alarm circuit.

6. SMOKE DETECTION

Smoke detectors are more costly than heat detectors but provide considerably faster detection times and subsequently higher false alarm rates due to their increased sensitivity. While smoke detectors are very effective for life safety applications, they are also more difficult to locate properly, since air currents, which might affect the direction of smoke flow, must be taken into consideration.

Smoke detectors are classified according to their operating principle, and are of two main types: ionization and photoelectric. Smoke detectors operating on the photoelectric principle give somewhat faster response to the products generated by fires of low energy (smoldering) as these fires generally produce large quantities of visible (larger particle) smoke. Smoke detectors using the ionization principle provide somewhat faster response to fires of high energy (open flaming) as these fires produce the smaller smoke particles which are more easily detected by this type of detector.

Smoke detectors should be used to protect areas of high value and in areas where life safety and fast response times are desired. Smoke detectors can operate within seconds of fire ignition.

Smoke detectors are also installed in return air ducts of HVAC systems in large buildings to prevent recirculation of smoke through the HVAC system from a fire within the building. Upon detection, the associated control system is designed to automatically shut down the circulating blowers or to change them over to a smoke exhaust mode.

Smoke activated devices are also used to automatically close smoke doors in large buildings in order to limit the spread of smoke in case of fire. This may be done with separate corridor ceiling mounted smoke detectors connected to electrically-operated hold-open devices on the doors or smoke detectors that are built into the door closure units themselves.

6.1 Ionization Type

Ionization chambers have been used for many years as laboratory instruments for detecting microscopic particles. In 1939 Dr. Ernst Meili, a Swiss physicist, developed an ionization chamber device for the detection of combustible gases in mines [7]. The major breakthrough in the field resulted from Dr. Meili's invention of a special cold-cathode tube which would amplify the small signal produced by the high impedance detection circuit sufficiently to trigger an alarm circuit. This reduced the electronics required and resulted in a practical detector. In most models today, the cold-cathode tube has been replaced with solid state circuitry which further reduces the size and cost.

The basic detection mechanism of an ionization detector consists of an alpha or beta radiation source in a chamber containing positive and negative electrodes. Alpha radiation sources are commonly Americium 241 or Radium 226 and the strength of the sources generally range from 0.05 to 80 microcuries. The alpha radiation in the chamber ionizes the oxygen and nitrogen molecules in the air between the electrodes causing a small current (of the order of 10^{-11} amps) to flow when voltage is applied (see fig. 14).

When a smoke aerosol enters the chamber, it reduces the mobility of the ions, and therefore the current flow between the electrodes (see fig. 15). The resulting change in the current in the electronic circuit is used to trigger an alarm at a predetermined level of smoke in the chamber. The ionization (or ion) chamber detector reacts both to visible and invisible components of the products of combustion. It responds best to particle sizes between 0.01 and 1.0 micrometers.

Depending on the placement of the alpha source, two types of chambers, unipolar or bipolar, may be produced. A unipolar chamber is created by using a tightly collimated alpha source placed close to the negative electrode thus ionizing only a small part of the chamber space (see fig. 16). With this configuration, most of the positive ions are collected on the cathode leaving a predominance of negative ions flowing through the chamber to the anode. The bipolar chamber has the alpha source centrally located so that the entire chamber space is subject to ionization (see fig. 17). The unipolar chamber is theoretically a unipolar and bipolar chamber in series (see figs. 16 and 18). That is, there is a purely unipolar section and a section which contains ions of both polarities.

A comparison of the relative merits of the two types of chamber design indicate that the unipolar chamber has approximately three times the sensitivity of the bipolar configuration. The reason for the increased sensitivity is believed to be due to the fact that there is less loss of ion carriers by recombination, i.e. neutralization of ions of opposite signs which occurs in the bipolar chamber. This results in a higher signal-to-noise ratio and stronger alarm signal to the amplifier circuit.

The alarm signal in an ion chamber detector is generated by a voltage shift at the junction between a reference circuit and the measuring chamber. The voltage shift results from a current decrease in the measuring chamber when products of combustion are present. The reference circuit may be either electronic or a second ion chamber only partially open to the atmosphere (see fig. 19). These circuits are referred to as single chamber and dual chamber, respectively. The dual chamber has an advantage in the reduction of false alarms due to changes in ambient conditions. The reference chamber will tend to compensate for slow changes in temperature pressure, and humidity.

It should be noted that some ion chamber detector designs are subject to changes in sensitivity with varying velocity of air entering the sampling chamber. Detectors with unipolar chamber designs move slightly away from alarm as velocity increases and are the most stable over wide variations in airflow. Detectors with bipolar chamber designs move toward alarm as velocity increases, and some may shift sufficiently in the more sensitive direction to trigger a false alarm. Care must be taken to choose the appropriate design for the area to be supervised.

Tests have indicated that ion chamber detectors are not suitable for use in applications where high ambient radioactivity levels are to be expected. The effect of radiation is to reduce the sensitivity.

Tests also indicate that false alarms can be triggered by the presence of ozone or ammonia.

Ion chamber detectors are available for both industrial and domestic use. Models are produced for both single station and system applications. Power supply requirements vary from 240 and 120 volt AC or 6 to 24 volt DC for use with fire alarm systems to battery powered units using 9 to 13.5 volts DC for residential use.

6.2 Photoelectric Type

The presence of suspended smoke particles generated during the combustion process affects the propagation of a light beam passing through the air. This effect can be utilized to detect the presence of a fire in two ways: (a) attenuation of the light intensity over the beam path length, and (b) scattering of the light both in the forward direction and at various angles to the beam path.

6.2.1 Light Attenuation Operation

The theory of light attenuation by aerosols dispersed in a medium is described by the Lambert-Beer Law. It states that the attenuation of light is an exponential function of the beam path length (l), the concentration of particles (c) and the extinction coefficient of the particles (k). This relationship is expressed as follows [8]:

$$I = I_o e^{-kcl}$$

where I is the transmitted intensity at length l and I_o is the initial (clear air) intensity of the light source.

Smoke detectors which utilize attenuation consist of a light source, a light beam collimating system, and a photosensitive cell (see fig. 20). In most applications, the light source is an incandescent bulb but lasers and light emitting diodes (LED's) are also used in newer photoelectric aerosol detectors. Light emitting diodes are a reliable long life source of illumination with low current requirements. Pulsed LED's can generate sufficient light intensity for use in detection equipment.

The photosensitive device may be either a photovoltaic or photoresistive cell. The photovoltaic cells are usually selenium or silicon cells which produce a voltage when exposed to light. These have the advantage that no bias voltage is needed but, in most cases, the output signal is low and an amplification circuit is required. These units alarm when the photocell output is reduced by attenuation of the light as it passes through the smoke in the atmosphere between the light source and the photocell. Photoresistive cells change resistance as the intensity of the incident light varies. Cadmium sulfide cells are most commonly employed. These cells are often used as one leg of a Wheatstone bridge and an alarm is triggered when the voltage shift in the bridge circuit reaches a predetermined level related to the light attenuation desired for alarm.

In practice, most light attenuation or projected beam smoke detection systems are used to protect large open areas and are installed with the light source at one end of the area to be protected and the receiver (photocell/relay assembly) at the other end. In some applications, the effective beam path length is increased by the use of mirrors. Projected beam detectors are generally installed close to the ceiling where the earliest detection is possible and false alarms resulting from inadvertent breaking of the beam are minimized.

Although most systems employ a long path length and separation of the light source and the receiver, there are spot type detectors which operate by light attenuation. One such unit uses a 7.8 inch (0.19 m) light path with a sealed reference chamber and an open sampling chamber, each containing a photocell. Presence of smoke in the sampling chamber results in a voltage reduction from its selenium photocell which is measured by a bridge circuit containing the photocell from the reference chamber (see fig. 21).

There are several problems associated with projected beam detection. Since these devices are essentially line detectors, smoke must travel from the point of generation into the path of the light beam. This may take time and allow the fire to develop headway before the alarm is sounded. In addition, for large protected areas where long beam path lengths are necessary, considerable smoke must be generated in any small segment of the beam in order for sufficient attenuation to be achieved. Two common ways of increasing the sensitivity of the system are by the use of multiple beams or reflecting mirrors which would pass the beam through the smoke more than once. Finally, continuous exposure to light can damage or accelerate the aging of photocells, resulting in increased maintenance and possible system failure.

Scattering results when light strikes aerosol particles in suspension. Scattered light reaches its maximum intensity at an angle of about 27° from the path of the beam in both the forward and backward directions and the scattered light intensity is at a minimum in a direction perpendicular to the beam path. The intensity of scattered light is also related to particle size and the wavelength of the incident light. This intensity, as described by Rayleigh's theory for particles with diameters less than 0.1 times the wavelength of the incident light, is directly proportional to the square of the particle volume and inversely proportional to the fourth power of the wavelength. The theory of scattering for larger particles from 0.1 to 4 (times the wavelength of the incident light) has been defined by Mie. These theories of light scattering are valid only for isotropic spherical particles and are very complex. However, smoke particles from a fire consist of a nonhomogeneous mixture of particles which are often neither spherical nor isotropic and scattering intensities must be determined empirically for each aerosol mixture.

Smoke detectors utilizing the scattering principle operate on the forward scattering of light which occurs when smoke particles enter a chamber or labyrinth. The presence of smoke will increase the forward scattering of light from 10 to 12 times, but the intensity of the scattered light will decrease as the angle between the beam path and the photocell increases beyond 27°. The photocells used in these detectors may be either photovoltaic, or photoresistive. Typical component configurations are shown in figure 22. These units are of the spot type and may be used as single station devices with self-contained power supply and alarm or as part of an integrated system with remote power supply, alarm and zone-indicating hardware.

7. FLAME DETECTION

Flame detectors optically sense either the ultraviolet (UV) or infrared (IR) radiation given off by flames or glowing embers. Flame detectors have the highest false alarm rate and the fastest detection times of any type of fire detector. Detection times for flame detectors are generally measured in milliseconds from fire ignition.

Flame detectors are generally only used in high hazard areas such as fuel loading platforms, industrial process areas, hyperbaric chambers, high ceiling areas, and any other areas where hazardous atmospheres in which explosions or very rapid fires may occur. Flame detectors are "line of sight" devices as they must be able to "see" the fire and they are subject to being blocked by objects placed in front of them. However, the infrared type of flame detector has some capability for detecting radiation reflected from walls. In general, the use of flame detectors is restricted to "No Smoking" areas or anywhere where highly flammable materials are stored or used.

7.1 Infrared Type

Infrared detectors basically consist of a filter and lens system to screen out unwanted wavelengths and focus the incoming energy on a photovoltaic or photoresistive cell sensitive to the infrared. Infrared radiation can be detected by any one of several photocells such as silicon, lead sulfide, indium arsenide and lead selenide. The most commonly used are silicon and lead sulfide. These detectors can respond to either the total IR component of the flame alone or in combination with flame flicker in the frequency range of 5 to 30 hertz.

Interference from solar radiation in the infrared region can be a major problem in the use of infrared detectors receiving total IR radiation since the solar background intensity can be considerably larger than that of a flame signal from a small fire. This problem can be partially resolved by choosing filters which exclude all IR except in the 2.5 to 2.8 micrometer and/or 4.2 to 4.5 micrometer ranges. These represent absorption peaks for solar radiation due to the presence of CO_2 and water in the atmosphere. In cases where the detectors are to be used in locations shielded from the sun, such as in vaults, this filtering is not necessary. Another approach to the solar interference problem is to employ two detection circuits. One circuit is sensitive to solar radiation in the 0.6 to 1.0 micrometer range and is used to indicate the presence of sunlight. The second circuit is filtered to respond to wavelengths between 2 and 5 micrometers. A signal from the solar sensor circuit can be used to block the output from the fire sensing cell, giving the detection unit the ability to discriminate against false alarms from solar sources. This is often referred to as a "two color" system. For most applications, flame flicker sensor circuits are preferred since the flicker or modulation characteristic of flaming combustion is not a component of either solar or man-made interference sources. This results in an improved signal-to-noise ratio. These detectors use frequency-sensitive amplifiers whose inputs are tuned to respond to an alternating current signal in the flame flicker range (5 to 30 hz).

Flame detectors are designed for volume supervision and may use either a fixed or scanning mode. The fixed units continuously observe a conical volume limited by the viewing angle of the lens system and the alarm threshold. The viewing angles range from 15° to 170° for typical commercial units. One scanning device has a 400 foot (122 m) range and uses a mirror rotating at 6 revolutions per minute through 360° horizontally with a 100° viewing angle. The mirror stops when a signal is received. To screen out transients, the unit alarms only if the signal persists for 15 seconds.

There are also detectors of this type designed to respond to passing sparks or flame fronts in piping such as in textile mills. The detector looks for glowing lint fibers in air ducting which might cause fires in the downstream filters. The detector turns on a water spray which extinguishes the glowing fiber before it reaches the filter. Of course, these detectors would not contain the flicker circuit.

7.2 Ultraviolet Type

The ultraviolet component of flame radiation is also used for fire detection. The sensing element may be a solid state device such as silicon carbide or aluminum nitride, or a gas-filled tube in which the gas is ionized by UV radiation and becomes conductive, thus sounding the alarm. The operating wavelength range of UV detectors is in the 0.17 to 0.30 micrometer region and in that region they are essentially insensitive to both sunlight and artificial light. The UV detectors are also volume detectors and have viewing angles from 90° or less to 180°.

7.3 Combination Ultraviolet-Infrared Type

The combination of UV-IR sensing has been applied to applications in aircraft and hyperbaric chamber fire protection. These complex devices alarm when there is a predetermined deviation from the prescribed ambient UV-IR discrimination level in conjunction with a signal from a continuous wire overheat detector, the analysis being performed by an on-board minicomputer.

8. SUBMICROMETER PARTICLE COUNTING DETECTORS

During the earliest stages of thermal decomposition, in the pyrolysis or precombustion stage, large numbers of submicrometer size particles are produced. These particles fall largely in the size range between 0.005 and 0.02 micrometers. Although ambient conditions normally find such particles in concentrations from several thousand per cubic centimeter in a rural area to several hundred thousand per cubic centimeter in an industrial area, the presence of an incipient fire can raise the submicrometer particle concentration sufficiently above the background levels to be used as a fire signal.

Condensation nuclei are liquid or solid submicrometer (0.001 to 0.1 micrometers) particles which can act as the nucleus for the formation of a water droplet. By use of an appropriate technique, submicrometer particles can be made to act as condensation nuclei on a one particle-one droplet basis and the concentration of particles is measured by photoelectric methods. A mechanism for performing this function is shown schematically in figure 23. An air sample containing submicrometer particles is drawn through a humidifier where it is brought to 100 percent relative humidity. The sample then passes to an expansion chamber where the pressure is reduced with a vacuum pump. This causes condensation of water on the particles. The droplets quickly reach a size where they can scatter light. The dark field optical system in the chamber will allow light to reach the photomultiplier tube only when the water droplets are present to scatter light. The output voltage from the photomultiplier tube is directly proportional to the number of droplets (i.e., the number of condensation nuclei) present.

The system uses a mechancial valve and switching arrangement to allow sampling from up to 4 detection zones with as many as 10 sampling heads per zone. Each zone is sampled once per second for 15 seconds. All 4 zones are sampled each minute.

The system is nominally set to alarm at concentrations exceeding 8 x 10^{11} particles per cubic meter, although it is possible to select different thresholds for each zone depending on the background noise and the sensitivity required. It is also possible to have the sensitivity vary for conditions differing with time of day. The system design is such that with the maximum sample travel distance from the most remote sampling head, fire will be detected within 2 minutes of the time the products of combustion first reach a sampling head.

9. AMBIENT CONDITIONS AFFECTING DETECTOR RESPONSE

Ambient conditions have a strong influence on the choice, placement and response of detectors. Improper choice of detection mode or improper placement can lead to problems ranging from no alarm or delayed alarm, when a fire occurs, to excessive false alarms.

9.1 Background Levels of Fire Signals

When choosing a detector for a specific location, consideration must be given to the background levels of the signals to which the detector might be exposed under nonfire conditions. For example, the use of a UV or IR detector in a location where gas or arc welding is commonplace can generate false alarms. This is not a failure of the detector but rather it is a response to the presence of the signal for which the unit was designed. However, these responses are considered false alarms since they do not result from a "hostile fire." Detectors responding to invisible aerosols are especially prone to false signals from such sources as cooking fumes, cigarette smoke and automobile exhaust fumes. A survey of false calls from automatic detection systems in Great Britain revealed an overall ratio of 11:1 false calls to real calls for all types of detection including sprinkler alarms. The same survey showed that ambient conditions such as extraneous heat and smoke, extremes in ambient temperature, moisture (snow, rain and steam) and high velocity air movement were responsible for 25.9 percent of the false calls.

It is not likely that false alarms due to localized and transient changes in the ambient levels of fire signals can be completely eliminated. However, with sufficient information about ambient variations in different occupancies, the number could be considerably reduced. A program to establish a data base for variations in ambient conditions is presently underway in Great Britain. This study will include data on aerosol concentration, temperature, humidity, radiation, air velocity, and vibration levels found in industrial and commercial occupancies. It is possible that raising the threshold of alarm for certain fire signals in specific occupancies, could reduce the incidence of false alarms without sacrificing the design goal of the installation. Difficulties arising from transient false signals might also be reduced through the use of multiple signal detectors and integration of the signals such that an alarm will sound either at a high threshold of any one signal or a lower threshold with multiple signals.

9.2 Heating and Air-Conditioning Effects

Heating and air-conditioning systems in buildings can exert several effects on the placement and operation of detection devices. These effects result from forced or convected air movement and the development of thermal inversions. Detectors sensing radiant energy generally are not affected by these factors. Devices responding to convected energy are only slightly affected since the convected energy of a fire which is sufficiently large to actuate these units, easily overpowers ambient circulation patterns. The most important effects of heating and air-conditioning are on the movement of the products of combustion which make up the aerosol and gas signals. Detectors sited without regard to airflow and thermal effects may be slow to respond, or in extreme cases may miss the fire signal completely.

Forced hot air systems are widely used in many occupancies. Airflow patterns must be considered in placing detectors and are related to the overall airflow in the building between supply registers and cold air returns. In a two story dwelling, for example, each room may have its own supply register but the cold air returns may all be on the first floor or in the basement. Under these conditions, cool air descending from above and warm air rising from below creates air currents in the stairwell which may move products of combustion to the upper floors. Detectors placed at the top of a stairwell can sense the aerosols originating in the areas below. Airflow up the stairwell is not always uniform. Changes in direction such as that at the ceiling of the second floor can produce a stagnant area where there is little or no movement. Aerosol or gas detectors placed in this area may be slow to respond due to the lack of sufficient air velocity to carry products through the detector housing to the sensing element.

It is not uncommon to find detectors placed too close to the air stream issuing from a supply register with the result that the units are actually being continuously purged when the system is in operation.

Often detectors are placed in the return air ducts in order to detect aerosol drawn into the system and are used to shut down circulating fans or convert the system to an exhaust mode. In such cases, consideration must be given to the effects of dilution of aerosols by air drawn from areas unaffected by the fire. Often intolerable conditions can exist elsewhere in the building long before a strong signal can reach the detector.

Apartment and office buildings often utilize heating systems which serve a single unit. In apartments, the building corridors may serve as a make-up air supply through undercut or louvered doors with exhaust through kitchen and bathroom ventilators. Noxious products of combustion originating in other areas of the building are often drawn into apartments by this means. Detectors placed appropriately in the corridors can be used to sound a general alarm but will not adequately protect the apartments since the early smoke will be drawn out the exhausts. In these cases, each apartment should have its own detector to warn the occupants of that apartment.

Since the most common cause of false alarms of residential smoke detectors is cooking, detectors in apartments are generally not connected to the building alarm system but sound a local alarm only. The airflow to kitchen and bathroom exhausts should be considered when siting detectors within an apartment. In offices where make-up air is drawn from outside the building, corridors often function as a return air plenum. Airflow within rooms in such cases may tend to be toward the corridor doors.

Gravity hot air systems are often found in older buildings. When in use, they depend largely on vertical supply ducts and natural openings between floors for circulation. Usually the airflow patterns are from supply registers at floor level to the ceiling and down natural openings to the lowest level. Lacking the impetus of fans for diffusion of the supply air, the paths of airflow are often restricted resulting in "dead" spaces. Detailed siting surveys should be conducted prior to installation of detectors where these systems are used. Hot water/steam radiator systems are also common in older buildings. These systems are gravity dependent and have less effect on the transport of aerosols than forced air systems. Movement will be confined to two general regions: the convection cell developed around the radiator itself, and the vertical circulation from floor to floor by natural openings in the structure. As in the case of gravity hot air, care must be taken to seek out eddy areas and dead spots and to avoid them.

The use of radiant heating of the ceiling type can produce a problem. When the system is in operation, a layer of hot gases at the ceiling can prevent the combustion products from reaching ceiling-mounted detectors. In such cases, detectors may have to be wall-mounted perhaps 12 inches below the ceiling.

Complete building air-conditioning systems will generate airflow patterns which are, in general, similar to those of the forced hot air system. An additional problem area can be found with the use of evaporative cooling systems. In the dry areas of the country, air cooling is accomplished using evaporation techniques. Air cooled by this method has a high relative humidity. The effects here are to enhance the agglomeration of smoke particles and trap them in the moist air. The warm dry air rises to the ceiling and a sharp boundary condition is created. Cool moist smoke rising to the ceiling can be trapped at this interface. Unless the air is agitated by a rapidly burning fire, ceiling-mounted detectors, even in the fire area, may not respond to the aerosol signal at all.

Although some specific detector siting information is available in the National Fire Protection Association (NFPA) Standards 72E and 74 and in various manufacturers' application guides, little design data is available to assist in understanding the effects of comfort heating and cooling systems on detector location. Optimization of detector location for heat-on, heat-off and cooling-on, cooling-off conditions should be based on studies of airflow conditions in buildings and existing heating and air conditioning technology.

10. RELIABILITY OF DETECTION DEVICES

Although detailed reliability data are lacking for most detection devices, some general statements can be made regarding certain critical components based on field or laboratory experience and manufacturers' literature.

10.1 Heat Detectors

Heat sensing detectors are generally the most reliable type in terms of component life since these devices respond directly to the presence of heat by a thermal or physical change in the detector operating elements. Heat detection systems may fail due to mechanical damage or abuse to the detectors after installation or by failure of components or circuitry in peripheral equipment such as power supplies or alarm indicating equipment.

Detection devices for fire signals other than heat employ electronic circuitry of varying complexity to sense the presence of a fire signal and to monitor the output of the sensing element. The reliability of such devices is related to the reliability of its components as they are used in each type of circuit and generally decreases with increasing complexity.

10.2 Light Sources and Photocells

The lamps used in photoelectric type smoke detectors are critical to detector operation. The operational lifetime of typical incandescent bulbs used in photoelectric detectors ranges from about one month to about 5 years. Lamp life can be increased by operation at reduced DC voltages. Lowering the operating voltage reduces filament evaporation, one of the primary causes of failure. Vibration and shock, particularly with fragile, aged filaments often lead to premature lamp failure. Power surges and power failures are also significant factors in early lamp failures. It appears that an average life of 3 years in continuous service can be expected with present incandescent bulbs. The problem of bulb life might be solved through the use of light emitting diodes (LED). Manufacturers' data on LED's indicate a possible life span on the order of 5×10^5 hours, approximately 50 years. At that time, barring catastrophic failure, the light intensity would be reduced by one half. These light sources are mechanically stable and should be less prone to damage from vibration.

The sensitivity of photocells used in detectors have a tendency to drift somewhat with aging. The usual method of compensation for such changes is through the use of compensation photocells in various configurations. These cells act as a reference to maintain balance in the circuit.

10.3 Batteries

The use of batteries as the primary power supply for single station smoke detectors introduces several problems which can affect detector reliability. The present requirements for battery-operated devices call for a 1-year lifetime and an audible trouble signal lasting 7 days when some critical lower voltage is reached. The type of battery being used can affect the operation of the detector. Alkaline batteries have a constantly decreasing voltage curve as they wear out. Some detectors using these batteries require periodic sensitivity readjustment to maintain the designed alarm threshold. Failure of a home owner to readjust the detector could result in delayed detection or an inoperative unit. Mercury batteries have a constant voltage throughout most of their life and can be used to control the voltage sensitivity-drift problem. At the end of their life, however, mercury batteries undergo a rapid drop in voltage. This presents two problems. First, the sensitivity will decline rapidly and second, it is possible that the reduced power available may shorten the operating time of the alarm horn or, in some cases, prevent its operation.

11. MAINTENANCE OF DETECTORS

Maintenance problems also affect detector reliability particularly in photoelectric and ionization types. Accumulations of dust and films on the bulbs, lenses and photocells will reduce the intensity of light within the detection element. The effect of this varies with the type of detector. Projected beam type photoelectric detectors will become more sensitive with contamination increasing the possibility of false alarms. Light scattering detectors, on the other hand, may become less sensitive as light intensity is decreased unless some internal compensation is provided. Ionization detectors are also affected by contamination. Deposition of dust and films inside the ion chamber will decrease the current flow across the chamber and raise the sensitivity. This can result in an increase in the false alarm rate. Also, collections of dust, particles of lint and other large airborne contaminants can often be trapped in the protective screens or light shields of smoke detectors. This can block smoke entry and prevent or delay an alarm. Proper cleaning and maintenance including prompt replacement of bulbs and batteries is important to retain the designed operating characteristics of these detectors.

12. SELECTION OF DETECTORS

When laying out a fire detection system the design engineer must keep in mind the operating characteristics of the individual detector type as they relate to the area protected. Such factors as type and quantity of fuel, possible ignition sources, ranges of ambient conditions and value of the protected property are critical in the proper design of the system. Intelligent application of detection devices using such factors will result in the maximization of system performance.

Heat detectors have the lowest cost and false alarm rate but are the slowest in response. Since heat intends to dissipate fairly rapidly (for small fires), heat detectors are best applied to the protection of confined spaces, or directly over hazards where flaming fires could be expected.

Heat detectors are generally installed on a grid pattern at their recommended spacing schedule, or at reduced spacing for faster response or where beams or joists may slow the spread of the hot gas layer.

The operating temperature of a heat detector is usually selected at least 25°F above the maximum expected ambient temperature in the area protected. Pneumatic heat detection systems have a device known as a "blower heater compensator" which is used to prevent false alarms due to the sharp initial heat rise from ceiling mounted unit heaters.

Smoke detectors are higher in cost than heat detectors but are faster responding to fires. Due to their greater sensitivity, false alarms can be more frequent, especially if they are not properly located.

Smoke detectors do not have a specific space rating except for a 30 foot maximum guide derived from the UL full-scale approval tests which they must pass. Grid type installation layouts usually are not used since smoke travel is greatly affected by air currents in the protected area. Thus, smoke detectors are usually placed by engineering judgment based on prevailing conditions.

Since smoke does not dissipate as rapidly as heat, smoke detectors are better suited to the protection of large open spaces than heat detectors. Also, they are less appropriate for small spaces because cost can be prohibitive.

Smoke detectors are more subject to damage by corrosion, dust, and environmental extremes than the simpler heat detectors since smoke detectors contain electronic circuitry. They also consume power, so the number of smoke detectors which can be connected to a control unit is limited by the power supply capability. The number of heat detectors used, however, usually depends only on the limitation of resistance of the detection circuit. Where very long runs are necessary, this can be handled by using heavier gage wire.

Photoelectric smoke detectors are particularly suitable where smoldering fires or fires involving PVC wire insulation may be expected. Ionization smoke detectors are particularly suitable where flaming fires involving any other materials would be the case. The particle counter detector responds to all particle sizes equally, so they may be used without regard to the type of fire expected. These systems, however, are fairly expensive and complex to install and maintain. The design and layout of the sampling tubes is very critical and must be done by someone very familiar with the equipment.

Flame detectors are extremely fast responding but will alarm to any source of radiation in their sensitivity range, so false alarm rates are high if improperly applied. Flame detectors are usually used in hyperbaric chambers and flammable material storage areas where no flames of any sort are allowable.

Flame detectors are "line of sight" devices, so care must be taken to insure that they can "see" the entire protected area and that they will not be accidentally blocked by stacked material or equipment. Their sensitivity is a function of flame size and distance from the detector, and some can be adjusted to ignore a small flame at floor level. Their cost is relatively high but they are well suited for areas where explosive or flammable vapors or dusts are encountered as they are usually available in "explosion proof" housings.

Table 12-1 contains a summary of the information contained in this section. The reader is also referred to NFPA 72E "Automatic Fire Detectors" [9] for more specific information on the installation of the various types of detectors.

Table 12-1. Summary of Detector Application Considerations

Detector Type	Response Speed	False Alarm Rate	Cost	Application
Heat	Slow	Low	Low	Confined Spaces
Smoke	Fast	Medium	Medium	Open or Confined Spaces
Flame	Very Fast	High	High	Flammable Material Storage
Particle Counter	Fast	Medium	High	Open Spaces - High Valve

13. SPRINKLER SUPERVISORY DEVICES

Sprinkler systems are usually electrically connected into the control unit in more ways than just the water flow indications described previously. Since the integrity of the sprinkler system water supply is vital to its operation, the positions of critical water supply valves, electric power to fire pumps, temperature or level of water within a supply tank outside the building are all monitored. Signals from these monitoring devices are called sprinkler supervisory signals and are used to generate separate signals at the control unit distinctive from the fire alarm signals and the trouble signals indicating malfunction of the fire alarm equipment.

14. INDICATING DEVICES

The indicating devices connected to a control unit are those audible devices used to indicate the signals. These can be bells, horns, sirens, etc. and there may be as many as three different audible signals associated with the control unit. These would be a fire alarm (evacuate the building), trouble (indicating a malfunction in one of the control units detection or other critical circuits), or sprinkler supervisory signals (indicating closure or malfunction of a critical feature of the sprinkler system). In general these three audible signals must be different but there are no national standards concerning them. Thus, in one area or building one might find bells for fire alarm, horns for trouble, and electronic tone signals for sprinkler supervisory while another combination might be used in an adjacent area or building. In some of the newer high rise building systems live or taped voice messages are used to give specific instructions on what to do in case of fire. These systems operate from a computer controlled proprietary system and in many cases give different messages depending on location with respect to the fire. There will be one message for the floor on which the fire occurred and the next above it, a different message for people in the elevators, and a third message for the rest of the building. Not only does this eliminate confusion as to what the signal means but hearing a calm voice giving explicit instructions during the crisis situation can have a calming effect.

15. COMMUNICATION SYSTEMS

Voice communication systems were generally introduced above. In addition to their use as indicating devices in the automatic systems they can also be used by the fire department at the scene for overriding the automatic messages and giving live instructions to building occupants as well as for communications to firefighters within the building. Many high rise communication systems have fire warden stations on each floor which contain a telephone directly connected to the fire command center. In case of fire, a designated occupant on each floor goes to the fire warden station and directs the evacuation operations on that floor. He can be questioned by the fire command center and used to quickly evaluate the situation.

Whether one feels the high rise fire problem is large or small there is one thing that all experts agree upon: it is impossible to evacuate a high rise building in a reasonable time. Therefore, occupants must be moved to an area of safety within the building and may have to be moved more than once before the fire is out. This means that an effective and reliable means of communicating with the building occupants is imperative.

The high rise communication system also serves other purposes. Fire department radios may not operate properly in a modern steel structure, so an internal means of directing the fire fighting operations is necessary. The communication system serves this purpose through the two way capabilities of the fire warden stations on each floor. Of course, a third important purpose is the calming effect of a voice message on a person who realizes he must stay in a building on fire.

16. RESIDENTIAL FIRE ALARM SYSTEMS

Automatic fire alarm systems for residential occupancies vary considerably. A high rise residential occupancy might contain a complete sprinkler system as well as a proprietary computerized control unit with elevator capture, smoke control and high rise communication systems. At the other end of the scale a single family detached dwelling may contain only one or more, self-contained fire detectors. All of the national model building codes have adopted the requirement, in their 1975 and 1976 editions, for at least one single station smoke detector to be installed in every living unit. Thus the architect and building designer of residential occupancies will be specifying single station smoke detectors in all such units. By single station smoke detector is meant a self-contained unit containing detection device, power supply, and alarm indicating device.

In residential units requiring more than one detector the building designer may specify a multiple station detector system, which consists simply of single station detectors which are interconnected, such that, when one alarms, all interconnected units alarm. This is highly desirable in larger living units where detectors remote from the sleeping area may not be audible in the sleeping areas.

In general, all living units should have a smoke detector located in the hallway outside of the bedrooms and at least one detector on each level of the home [10]. The location within a given level is not especially critical although it is generally located near the base of the stairway to the next level.

17. CODES AND STANDARDS

Every building must be designed to meet the building and fire codes of the area in which it is built. In many cases these local codes are based wholly or in part on the standards of the National Fire Protection Association (NFPA). Even if they are not, these standards contain a great deal of excellent information with which the architect should be familiar.

NFPA Standards 72A, 72B, 72C, and 72D cover the installation of Local, Auxiliary, Remote Station, and Proprietary alarm systems respectively. NFPA 71 covers Central Station alarm systems and NFPA 74, Household Fire Warning Equipment.

NFPA 72E gives excellent guidance on the proper installation of automatic fire detectors and NFPA 101 specifies the types of alarm systems required for various occupancies.

While the installation standards of the NFPA are probably familiar to most architects, the performance standards of the approval laboratories may not be. Underwriters' Laboratories or Factory Mutual approval of all components of the fire alarm and communication equipment is an important indication that the equipment has been examined for proper design, operation, and reliability.

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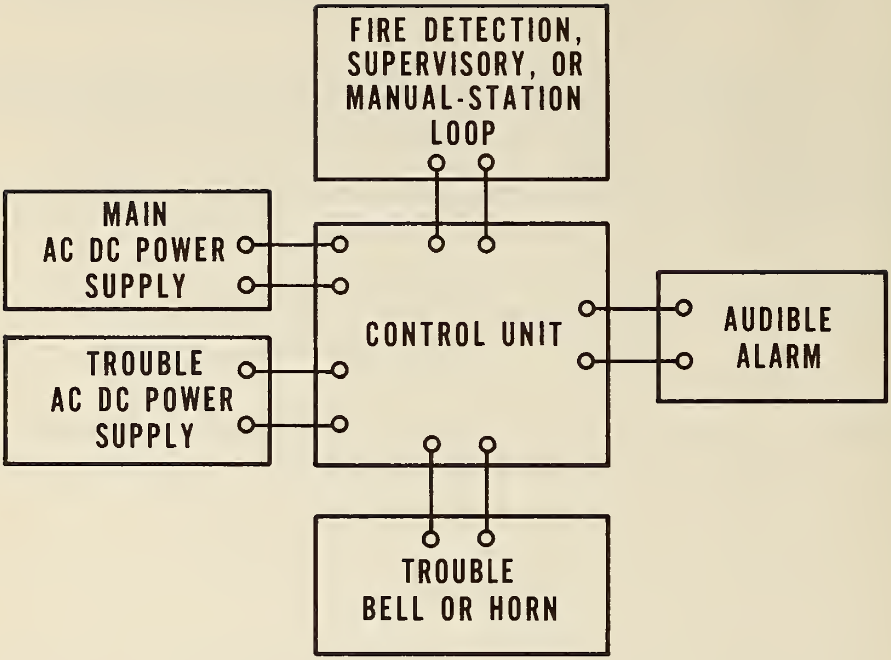
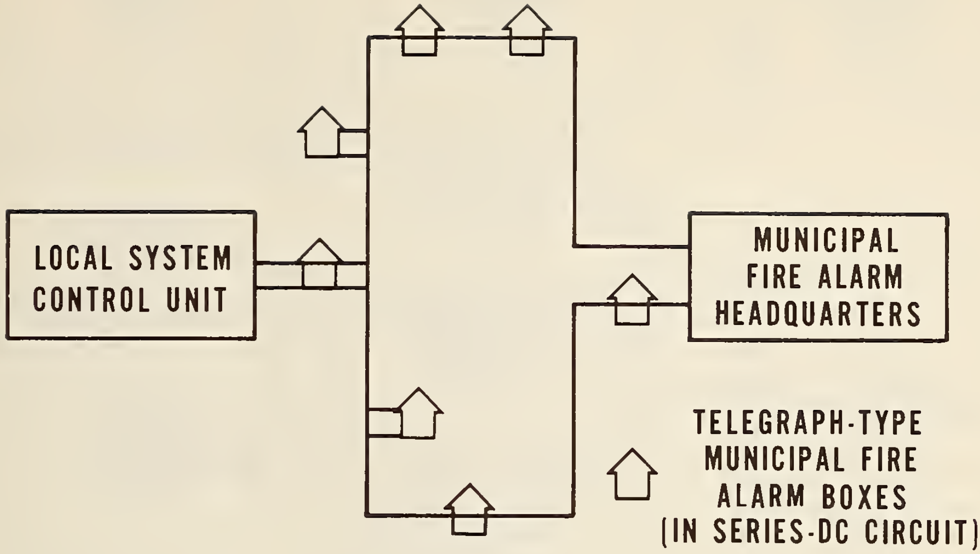


Typical Features:

- No alarm transmission to outside agency.
- Minimum insurance credit.
- Minimum cost.
- All equipment is usually purchased.
- The system is ineffective when the building is vacant or unattended.

(This diagram and accompanying text, of the Local System is reproduced through the courtesy of the NFPA.)

Figure 1. Local Fire Alarm System



Typical Features:

- System alarm transmission is only as good as the city auxiliary loop and receiving equipment.
- Alarm transmission is a coded signal directly to fire department.
- Equipment in the building is usually the property of the building owner, but the coded transmitter, though bought by the building owner, usually becomes the property of the city.
- The city is usually responsible for maintaining the loop up to and including the transmitter. Interior maintenance is the owner's responsibility.
- The interface of these responsibilities is sometimes a problem.
- Auxiliary loop connections may be unavailable or reserved for city property and schools.
- Maintenance is often a problem. To be considered standard, a system should have periodic maintenance, inspection and tests. If the system is installed for insurance credits, most rating bureaus require that this be a contract for monthly maintenance by an authorized installer. Auxiliary loops are usually maintained by city personnel and, as a consequence, may not be acceptable for insurance credits. The arrangement and requirement of the city auxiliary loop are shown in NFPA Standard 73.

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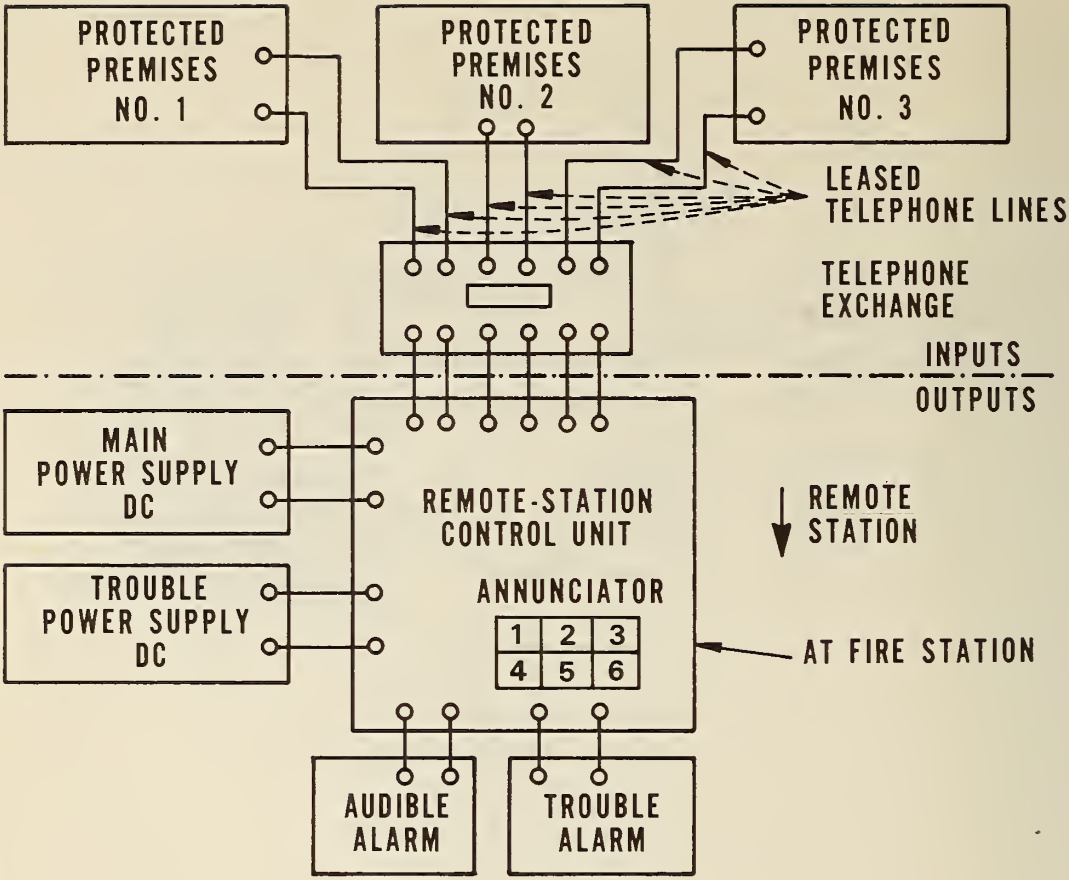
Figure 2. Auxiliary Fire Alarm System



Typical Features:

- Usually a direct connection (noncoded) between the transmitter and the receiver.
- Equipment may be bought or leased. Leased systems usually incorporate design and installation, and testing and maintenance contracts.
- The fire department does not receive trouble or supervisory alarms. This will require a separate transmitter, transmission lines and receiver or trouble signals will be local only. The trouble alarm at the receiving equipment is for that equipment only.
- Multiple-alarm transmissions require separate circuits.
- Number of automatic detection devices in a single circuit should not exceed 100.

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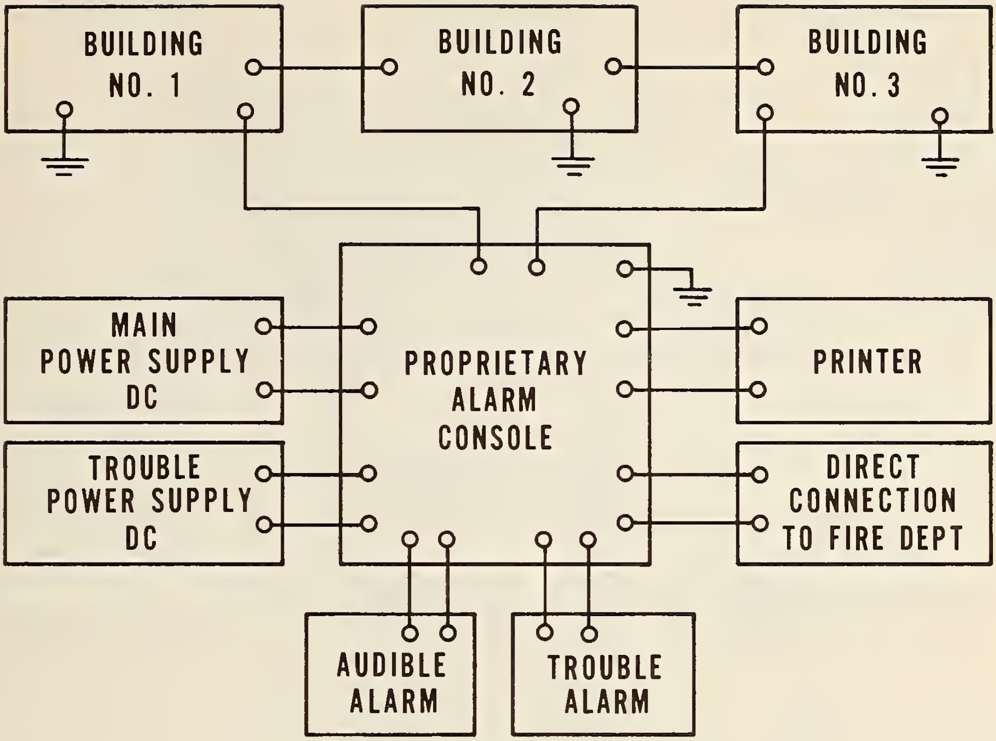
Figure 3. Remote Station Fire Alarm System



Typical Features:

- It is practical only for large facilities because it requires constant attendance by two trained men plus runners. Normally a "Class A" circuit is required.

- All alarm signals are recorded at the alarm office, preferably automatically.

- Alarm office must be in a separate detached fire-resistive building or in a fire-resistive portion of a building with outside access.

- Two means of alarm transmission are usually required (the one being a direct supervised line and the other either a municipal fire alarm box within 50 ft or a telephone that does not go through a switchboard) and can be used for nonfire alarm service such as burglar alarm, access control and building monitoring, and can be combined with energy management systems.

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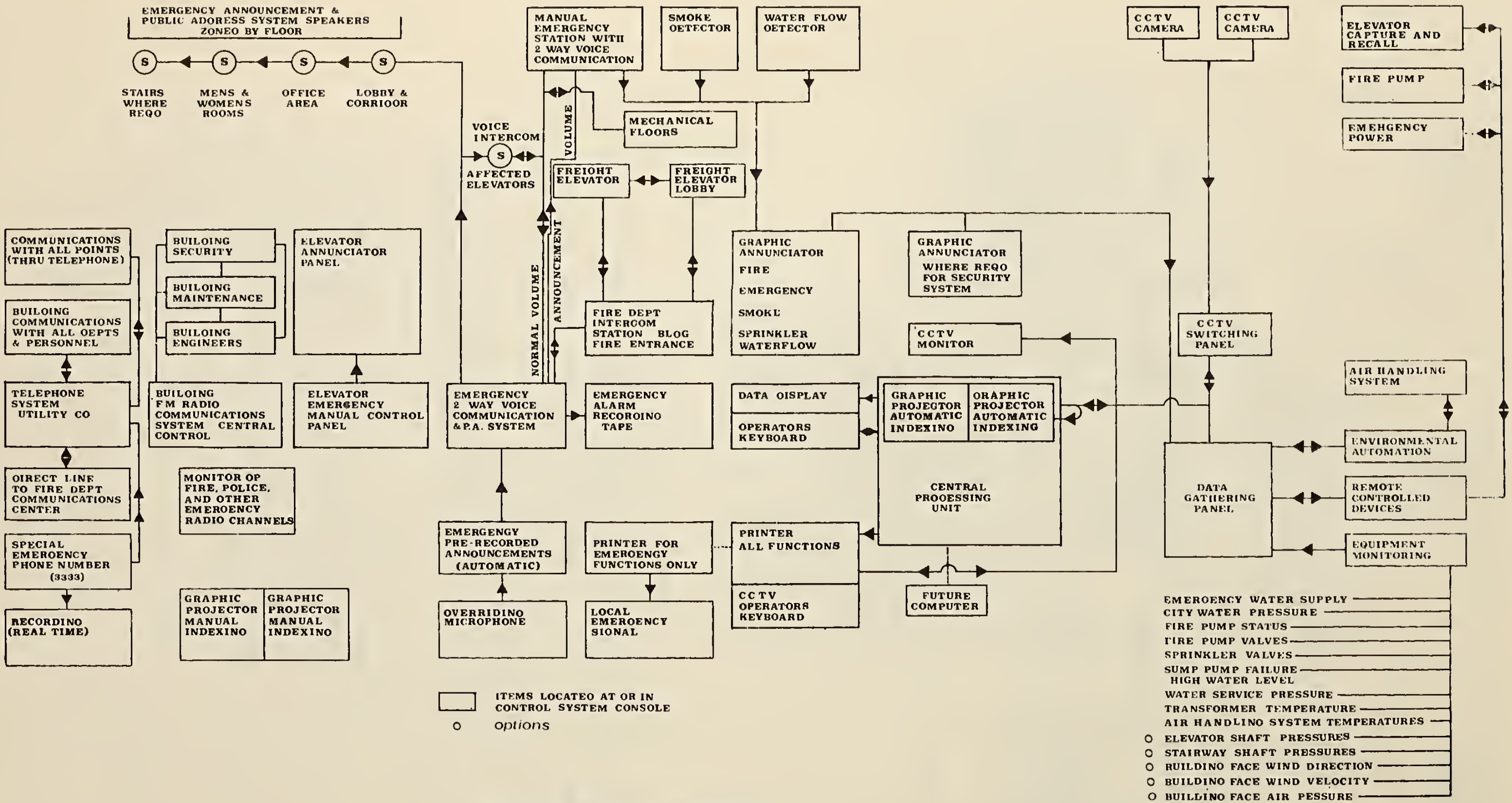
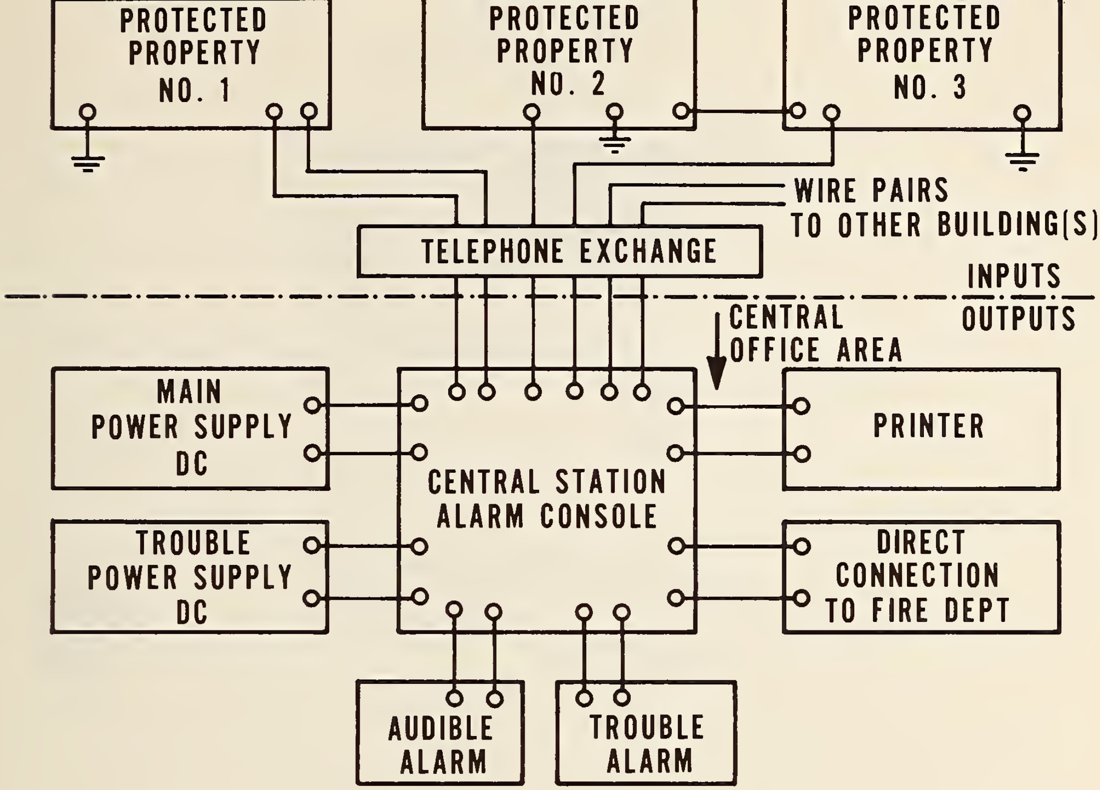
Figure 4. Proprietary Fire Alarm System



BUILDING CONTROL

Figure 5. High-Rise Proprietary Fire Alarm System



Typical Features:

- Leased equipment, no capital investment.
- System design, installation, maintenance and test is provided by the central station operator.
- If an Underwriters' Laboratories listed central station office, maximum insurance credits are possible.
- Automatically recorded coded signals.
- Essential transmission circuits arranged so that a single break or ground fault does not cause a false alarm and will not prevent transmission of a true alarm (McCulloh circuit or other alternate path).
- Runner, usually armed, is sent to take action to protect occupant property.
- It can detect and alarm for other, nonfire conditions, burglar, building temperature, water pressure, loss of electrical power, condition of automatic extinguishing system features.
- Direct-line voice communication with the proper fire department to explain in detail the fire or other emergency. This is usually done by direct-wired telephone, with a requirement for an alternative means of contacting the fire department.

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Figure 6. Central Station Fire Alarm System.

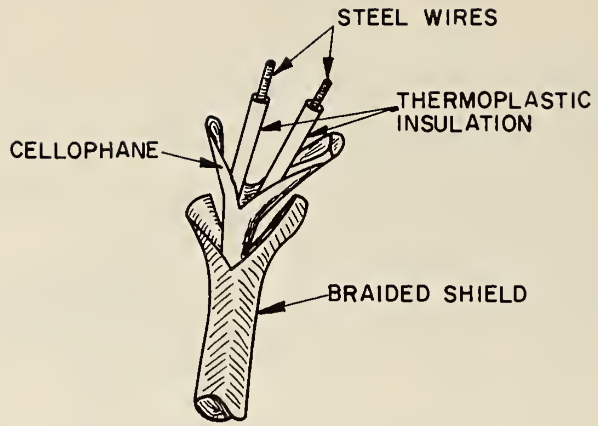

Figure 7. Line Type Fire Detection Cable Using Insulated Parallel Wires.

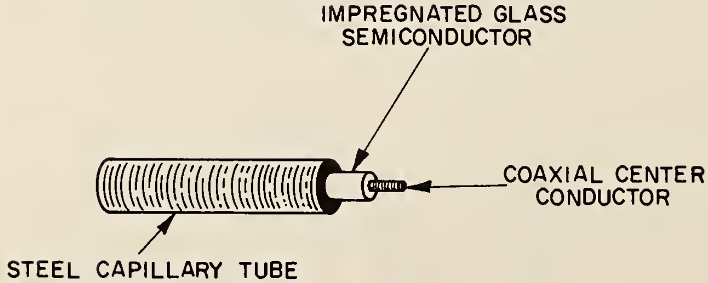

Figure 8. Line Type Fire Detection Cable Using a Glass Semiconductor.

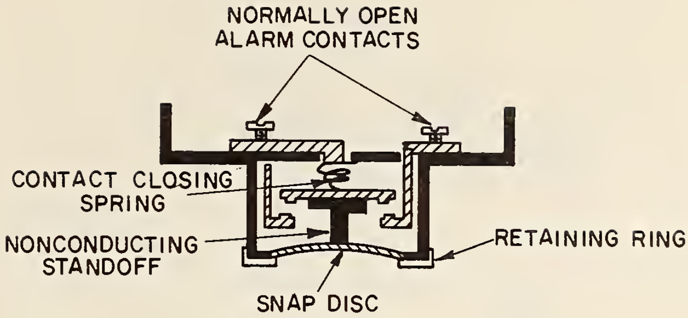

Figure 9. Bimetal Snap Disc Heat Detector.

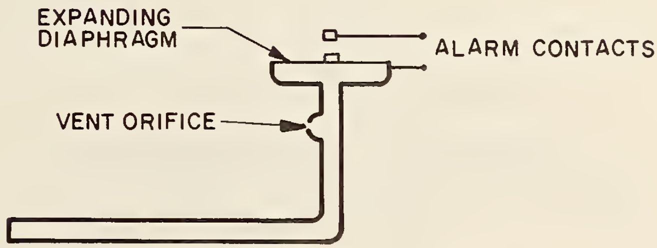

Figure 10. Pneumatic Type Heat Detector.

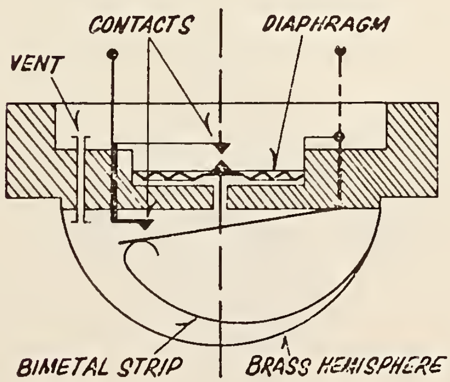

Figure 11. Rate of Rise -- Fixed Temperature Detector Using a Bimetal Element.

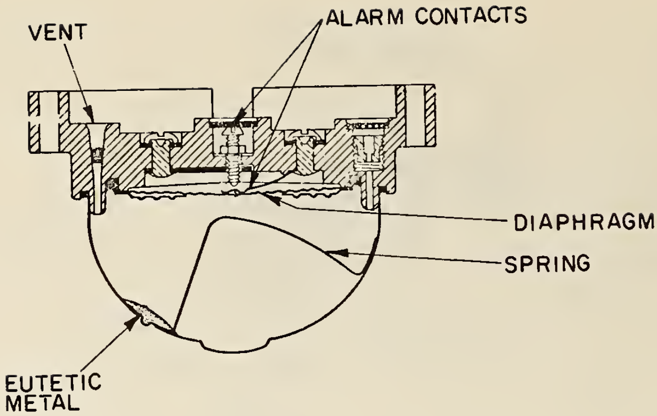

Figure 12. Rate of Rise -- Fixed Temperature Detector Using an Eutectic Metal.

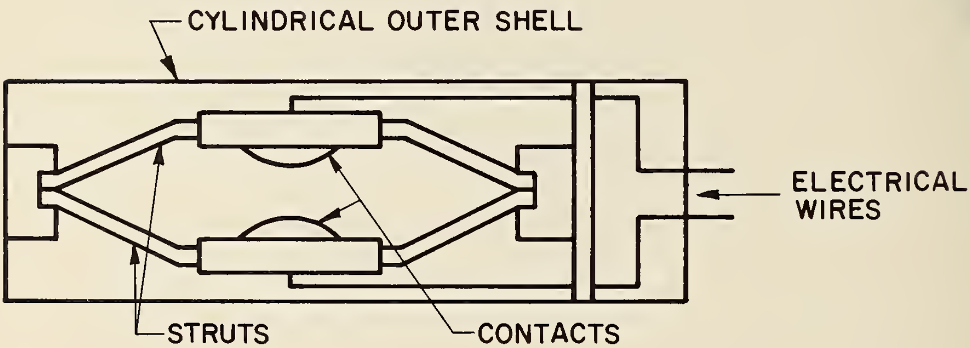

Figure 13. Rate-Compensation Detector.

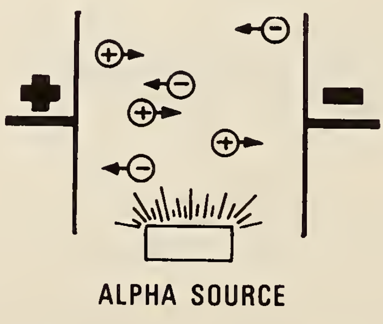

Figure 14. Ionization of Chamber Air Space.

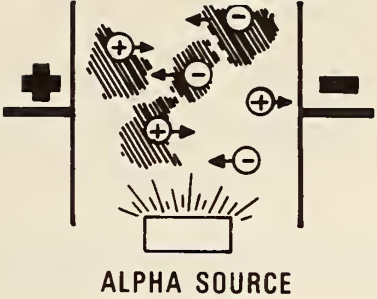

Figure 15. Effect of Aerosol in Ionized Chamber.

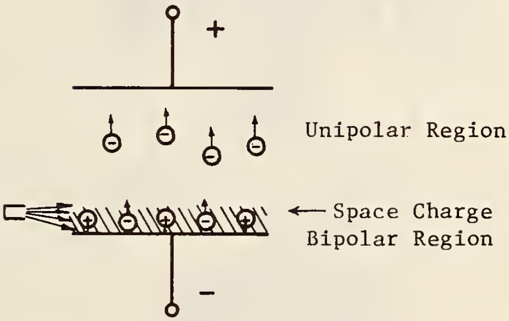

Figure 16. Unipolar Ion Chamber.

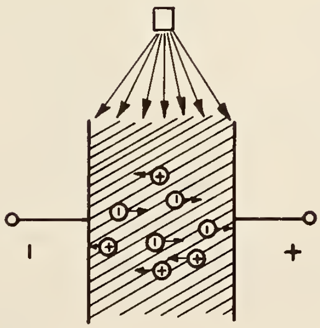

Figure 17. Bipolar Ion Chamber.

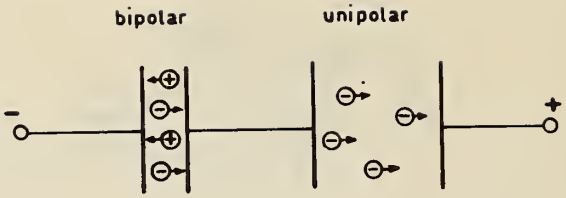

Figure 18. Unipolar Ion Chamber - Consists of Theoretical Unipolar and Bipolar Ion Chamber in Series.

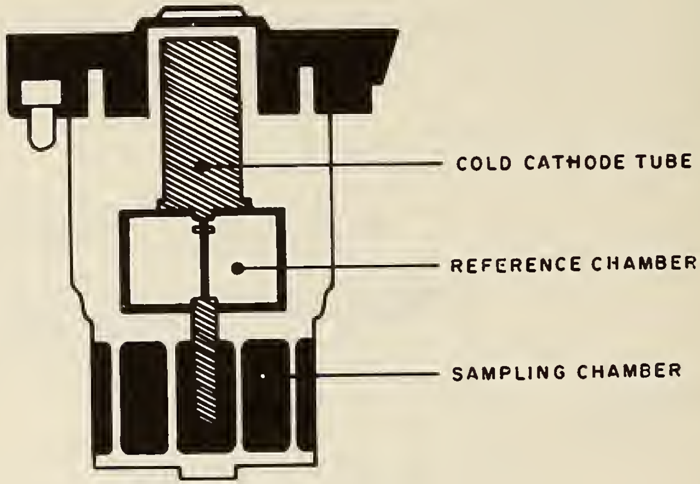

Figure 19. Configuration of a Dual Ion Chamber Detector.

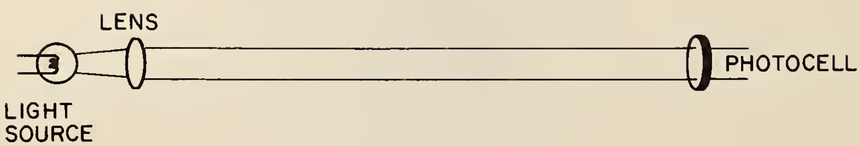

Figure 20. Beam Type Light Attenuation Smoke Detector.

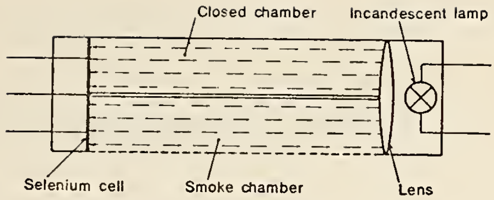

Figure 21. Spot Type Light Attenuation Smoke Detector.

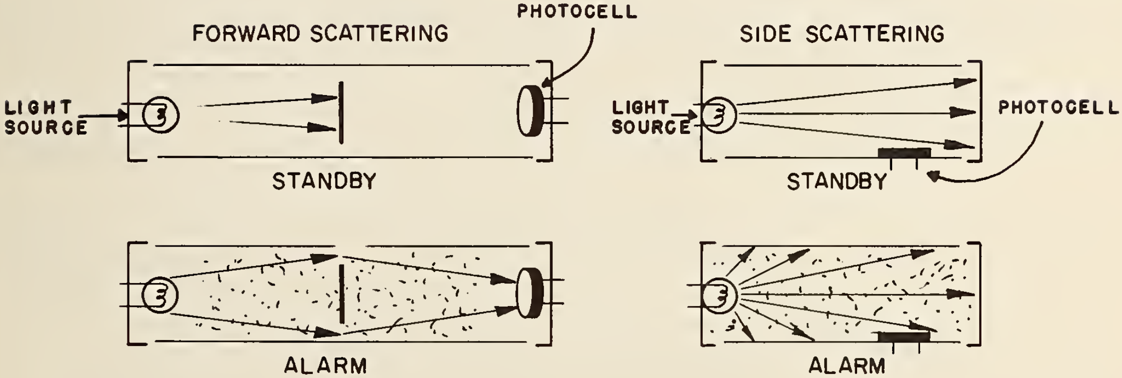

Figure 22. Light Scattering Smoke Detectors.

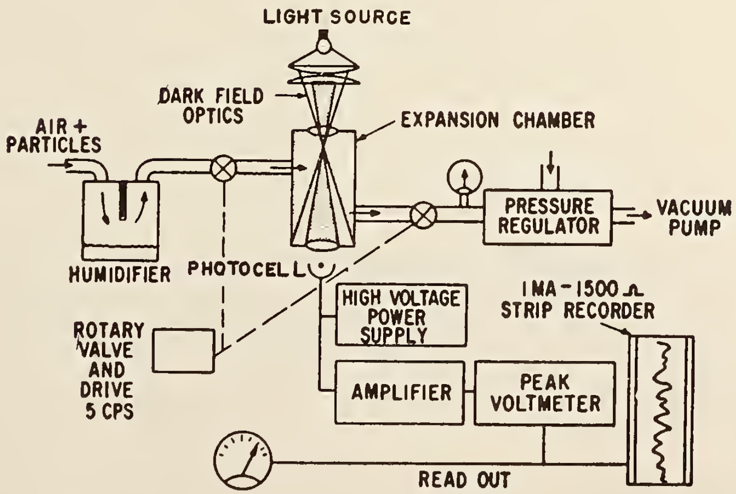

Figure 23. Schematic of Condensation Nuclei Particle Detector.

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16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

The operation and use of all current types of fire alarm and communication systems are discussed. This includes the differences between and operating features of local, auxiliary, remote station, proprietary, and central station systems, high-rise communication systems and residential fire detection devices. A discussion of commonly used fire detectors is given including operation, installation and application considerations. Indicating devices, sprinkler supervisory devices, maintenance, reliability and code/standard compliance are also covered.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*) Control units; fire alarm systems; fire detectors; high-rise communication systems; multiplex systems; NFPA standards; residential fire detector; sprinkler supervisory devices.

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