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Nuclear Power Plant Fire Protection Fire Detection (Subsystems Study Task 2)

Dennis L. Berry

Manuscript Submitted: December 1977
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Sandia National Laboratories
Albuquerque, NM 87185
Operated by
Sandia Corporation
for the
U. S. Department of Energy

Prepared for
Engineering Methodology Standards Branch
Office of Standards Development
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555
Under Interagency Agreement DOE 40-550-75
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ABSTRACT

This report examines the adequacy of fire detection in the context of nuclear power plant safety. Topics considered are: (1) establishing area detection requirements, (2) selecting specific detector types, (3) locating and spacing detectors, and (4) performing installation tests and maintenance. Based on a thorough review of fire detection codes and standards and fire detection literature, the report concludes that current design and regulatory guidelines alone are insufficient to ensure satisfactory fire detection system performance. To assure adequate fire detection, this report recommends the use of in-place testing of detectors under conditions expected to occur normally in areas being protected.

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I. SUMMARY

An uncontrolled fire in a nuclear power plant can seriously jeopardize overall plant safety. Recognizing this, the Nuclear Regulatory Commission has undertaken a broad program in fire protection research, a portion of which focuses on early fire detection. This report examines the adequacy of fire detection in the context of nuclear power plant safety.

Because of the expanse of a nuclear power plant and the normally limited number of resident operating personnel, remote automatic fire detection represents the only viable method of providing early fire warning for most plant areas. By installing throughout a power plant devices which are sensitive to fire and by electrically connecting these devices to centralized alarm panels, operators can receive fire warnings from anywhere in the plant. The reliability of such a system, however, depends upon correct design and maintenance.

Traditionally, nuclear power plant designers have utilized a combination of fire codes, test standards, fire consultant recommendations, insurance agency requests, and detector vendor suggestions to formulate the design of fire detection systems. Proceeding in this manner, designers often apply detection principles to nuclear power plants which have been proven in residential and commercial installations. However, because the ventilation conditions, ceiling heights, ceiling construction, and types of combustibles existing in nuclear power plants can differ from those used elsewhere, it is difficult to show that traditional detection system design approaches will be adequate for

nuclear power plants. Also, it is doubtful whether any theory can be developed and proven in the near future to describe the effects of different installation conditions on detection system operation.

Therefore, it appears that the best approach to solving the uncertainties of nuclear power plant fire detection is through in-place testing of detectors under environmental conditions anticipated to occur normally in each area being protected. Through in-place testing, during both initial installation and subsequent maintenance intervals, satisfactory detection performance can be assured for the variety of conditions found in nuclear power plants.

II. INTRODUCTION

A. Background

An earlier Sandia Laboratories fire protection system study[1] concluded that much progrers can be made to enhance fire detection effectiveness in nuclear power plants by clarifying fire detection design requirements and by adapting existing detection techniques. This conclusion had been based on both the ready availability of numerous detection devices currently on the market and the lack of adequate design guidance for selecting, locating, testing, and maintaining detection system hardware. Based on these findings, the Nuclear Regulatory Commission decided to undertake a more thorough review of fire detection, as part of a second study addressing several major areas of fire protection. Task 1 of this new study addressed ventilation, while Tasks 3 and 4, to be completed later, will involve fire barriers and fire hazards analysis. Task 2, fire detectors, is the subject of this report.

B. Task 2 Description

The fire detection subsystem review was undertaken to evaluate the following from the standpoint of overall plant safety:

a. the technical bases for detection system <u>design criteria</u>,

b. the adequacy of detailed design guidance currently available, and

c. the effectiveness of qualification testing procedures to simulate actual design applications.

For each of these three evaluation categories, numerous recognized fire protection information sources were chosen for review. The assignment of each information source to an appropriate evaluation category is shown in Table 1 and is based upon the level of detail and scope of information available in each source.

After establishing evaluation categories and information sources, it was decided to focus on the selection and use of detector sensing units, rather than to investigate either the internal design details of the units or the operation of each ancillary detection system component (i.e., transmitters, alarm units, satellite stations, or interconnecting wiring). This decision stemmed from a realization that:

1. Existing detection theory lacks the ability to predict detector performance solely from known internal sensing unit design features.

2. Ancillary detection system components primarily function to transmit electrical signals from detector sensing units to various panels and alarm devices, generally through the use of fundamental electrical design techniques which have been accepted and used extensively throughout other nuclear power plant systems.*

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*One exception to this observation is cited in Appendix A of the report.

TABLE I

Information Sources Reviewed and Corresponding Evaluation Categories

Information Sources Reviewed	Evaluation Categories		
	Design Criteria	Design Details	Qualification Tests
Nuclear Regulatory Commission Documents	x*		
Insurance Agency Documents	x		
National Fire Protection Codes		x	
Underwriters Laboratories Tests			x
Vendor Information and Open Literature (where applicable)	x	x	x

*x refers to the primary charter of the cited information source

Based on these observations, the following design and maintenance activities related to the selecting and use of detector sensing units were chosen for review:

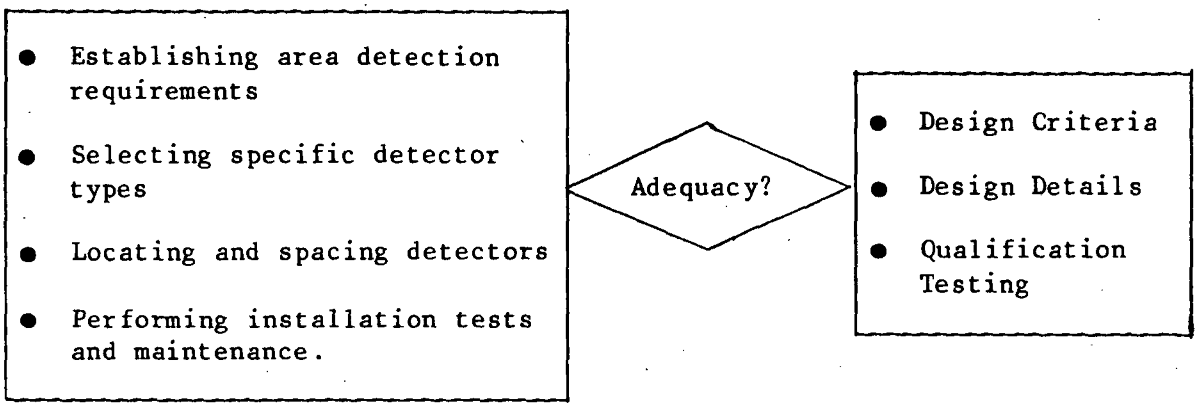
- Establishing area detection requirements
- Selecting specific detector types
- Locating and spacing detectors
- Performing installation tests and maintenance.

As illustrated in Table II, this report separately addresses each of these activities for commercially available detector sensing units and, in so doing, questions the adequacy of applicable design criteria, design details, and qualification testing.

TABLE II

Relationship Between Design and Maintenance Activities
and Evaluation Categories

Design and Maintenance Activities | Task 2 Evaluation Categories



III. DISCUSSION

Before proceeding with the Task 2 evaluation, it was necessary to identify those detectors most suitable for review. For this purpose, it was decided that the following five major types of commercially available detectors should be chosen:

- Area heat detectors
- Continuous line heat detectors
- Ionization type products of combustion detectors
- Photoelectric smoke detectors
- Ultraviolet/infrared flame detectors

Although other types of detectors are being developed, none of the new-concept detectors, as explained in Reference 1, has been proven in situations outside of a laboratory environment. In contrast, each of the commercial detectors listed above has been demonstrated to be effective when installed and maintained in a manner consistent with its governing qualification tests.

A. Establishing Area Detection Requirements

The first decision that must be reached regarding fire detection is whether or not automatic detection is required for a particular power plant area. To make this decision from a plant safety viewpoint, a careful assessment of automatic detection must be made on the basis of many factors, including:

- Importance of the area to overall plant safety
- Susceptibility of the area to surrounding fire hazards
- Degree of fire hazard within the area
- Potential of fire spreading to other areas
- Type of available fire suppression (e.g., manual or automatic; inert gas or water)
- Cost of added detection capability
- Normal occupancy of the area

Unfortunately, it is not always possible to assess all of these factors objectively for each area of a nuclear power plant, and, because of this, detection requirements generally have been designated on the basis of an area's safety importance, regardless of the actual fire risk associated with the area. One possible exception to this practice occurs in those instances where detection requirements are dictated by the operational needs of an associated fire suppression system. This latter detection case is being evaluated separately, in conjunction with another Sandia study addressing suppression system operations.

1. Design Criteria for Establishing Area Detection Requirements

Many factors influence how much added safety automatic detection can provide, including the reliability of the detection system, the method used for fire extinguishment, and the importance of the protected area to overall plant safety. Because of these factors, it is difficult to assess quantitatively what positive benefits are derived from having versus not having automatic fire detection in a particular nuclear power plant area without studying the interrelationships among all affected plant safely systems and their associated fire suppression and fire containment systems. Because such a systems study lies beyond the scope of this report, area fire detection can best be evaluated here on the intuitive basis that the sooner a fire is discovered the better are the chances of limiting the fire damage. On this basis, current nuclear power plant area detection requirements were reviewed.

Table III summarizes the area detection design criteria currently available in nuclear regulatory and insurance agency documents, and although other information sources soon may be available, such as those being developed by the National Fire Protection Association and the American National Standards Institute, drafts of these new documents provide little guidance beyond that shown in Table III. From Table III, it can be seen that each document reviewed provides a unique listing of plant areas requiring automatic fire detection. In some instances, differences between the lists can be explained in terms of each document's charter (i.e., public safety versus property safety), while in other cases the basis for differences is not entirely clear. For example:

(a) The terminology applied to various plant areas is not uniform. For instance, the remote shutdown rooms mentioned in Draft Regulatory Guide 1.120 may be equivalent to the auxiliary panel rooms in the NEL-PIA Guide, or the emergency/standby cooling equipment referred to in the International Guidelines may be comparable to the safety-related pump rooms in Draft Regulatory Guide 1.120. Interpretation of terminology is left to the user of the guides.

(b) There appears to be no consistent use of detectors as a function of potential fire hazard. Some areas, such as the diesel or cable spreading rooms, represent a significant fire potential and should have detectors, while other areas with little or no fire loading, such as many primary containment areas or nuclear fuel storage areas, may need no automatic fire detection.

TABLE III

Area Detection Guidelines

	Draft Regulatory Guide 1.120, Rev. 1, Draft 2, (Ref. 2)	International Guidelines, (Ref. 3)	NEL-PIA Guide, (Ref. 4)
Areas that Contain or Threaten Safety-Related Equipment	x		
Nonsafety-Related Turbine Areas		x	
Control Room	x	x	x
Switchgear Rooms	x	x	x
Decontamination Areas	x	x	x
Emergency Battery/ Diesel Areas	x	x	x
Cable Spreading Room Area	x	x	
Computer Room	x	x	
Remote Shutdown Rooms	x		x
Instrument Rooms		x	x
Relay Rooms		x	x
Primary Containment Area	x		
Hazards Within Primary Containment	x		
Control Room Cabinets/Consoles	x		

TABLE III (cont)

	Draft Regulatory Guide 1.120, Rev. 1, Draft 2, (Ref. 2)	International Guidelines, (Ref. 3)	NEL-PIA Guide, (Ref. 4)
Control Room Inlet Air Ducts	x		
Cable Spreading Room Trays	x		
Safety-Related Pump Rooms	x		
New Fuel Area	x		
Spent Fuel Area	x		
Cable Culverts/ Shafts		x	
Feed Water Pumps		x	
Power & Control for Primary Pumps		x	
Filter Equipment		x	
Emergency/Standby Cooling Equipment		x	
Air Handling System Rooms			x
Motor Control Centers			x
Auxiliary Panel Rooms			x

The seriousness of the above inconsistencies is minimized if it is recognized that detectors are intended to provide improved safety through early fire warning. Accordingly, it is reasonable for automatic detection to serve all plant areas which contain or present potential fire exposure to nuclear safety-related equipment, irrespective of the in situ fire hazard that may exist. This is especially true for those areas which are normally unoccupied. In this regard, Draft Regulatory Guide 1.120 provides the best design criteria currently available for establishing safety area detection requirements, when supplemented by the other two documents for nonsafety plant areas.

2. Design Details and Qualification Tests for Establishing Area Detection Requirements

In the information sources reviewed for this study, there is virtually no guidance addressing either the design details or qualification tests governing area detection requirements. Except in those instances where the use of certain gaseous suppression techniques call for automatic detection, even the National Fire Protection Association (NFPA) codes applying to detectors and nuclear power plant fire protection[5 6] are silent with regard to area detection requirements. Because of this lack of information, several problems arise regarding the design criteria discussed in the previous section. Specifically, the following is noted.

(a) The requirement of Draft Regulatory Guide 1.120 to install detectors in "all areas that present potential fire exposure to safety-related equipment" causes a problem defining which areas actually pose a threat to a given safety area. Areas either immediately adjacent to or separated from a safety area may or may not present a potential fire exposure, depending on the level of fire hazard and the adequacy of existing barriers and suppression systems. An assessment of these factors requires a detailed definition of what constitutes a potential fire exposure. Without such a definition and a design technique for determining potential fire exposure, it is difficult to establish what level of detection coverage actually meets the design criterion in Draft Regulatory Guide 1.120.

(b) The requirement in Draft Regulatory Guide 1.120 to install automatic detection inside control room cabinets and along trays in the cable spreading room lacks confirmatory testing. Because of this, it has not been proven whether any added benefits are derived from these special detection measures, although it can be reasoned that a detector located close to a fire may prove more effective. Without testing to demonstrate the superior effectiveness of cabinet and tray detectors over area detectors, it is difficult to justify, in all cases, the cost and complexity associated with their use. This is especially true when it is recognized that current qualification testing of line detectors uses a ceiling configuration, not a cable tray installation.

B. Selecting Specific Detector Types

Once area detection requirements have been established, it is necessary to determine what type of detector or combination of detectors is most suited to the fire hazards found in each area. As explained earlier, five major types of commercially available detectors have been considered here because of their proven effectiveness when properly installed and maintained. The following sections examine how well existing sources guide in the selection of each detector type and what additional guidance is needed to help designers make an informed detector choice.

1. Design Criteria for Selecting Specific Detector Types

None of the nuclear regulatory or insurance agency documents reviewed for this study[2-4] provides definitive design criteria for the selecting detectors. In Draft Regulatory Guide 1.120 reference is made only to continuous line heat detectors for cable trays, while the International Guidelines state simply that, ". . . detectors should be selected according to the operational and local requirements." Based on this lack of guidance, more specific design criteria need to be defined. At a minimum, detector selection criteria should acknowledge the influence of the following factors on detector choice.

(a) Combustion Products -- Detectors which prove to be sensitive to combustion products from test materials (e.g., cellulosic and liquid flammables) may be insensitive to the combustion products produced by other materials commonly found in power plants (e.g., cable insulation). To illustrate, ionization detectors may not detect large smoke particles, which lack mobility in a static electric field. Similarly, an infrared or ultraviolet detector may not be able to detect flames through heavy smoke or through combustion products that may screen the portion of light spectrum to which the detector is sensitive.

(b) Fire Development -- Because some fires propagate rapidly (e.g., oil fires) while others start more slowly (e.g., cable fires), it would be appropriate to select a detector whose response time is consistent with the speed of anticipated fire development. Also, the size to which a fire may be permitted to grow safely in a particular plant area can influence the appropriateness of a detector choice. A heat detector may be the correct choice for an oil fire but may be too slow to respond to a cable fire.

(c) Ventilation -- In rooms having large ventilation rates, combustion products and heat may be drawn from a room before reaching the point of triggering heat, photoelectric, or ionization detectors. To overcome this, line-of-sight area detectors which do not depend on smoke concentrations for operation or continuous line local heat detectors which may be located closer to the fire source should be considered. However, since ventilation rates are often a function of plant operating conditions, outside temperatures, and ventilation system design, it is difficult to predict how severely ventilation conditions can degrade a particular detector's operation and under what circumstances line-of-sight or continuous line detectors would be superior.

(d) Room Congestion -- In rooms containing large amounts of piping, ductwork, cable trays, and equipment, certain detectors which depend on line-of-sight "viewing" of a fire (e.g., infrared or ultraviolet detectors) may be ineffective because a fire may be blocked from the detector by room congestion.

(e) Room Geometry -- Rooms with high ceilings may render heat, photoelectric, and ionization detectors ineffective because the buoyant effect of the rising combustion gases may be insufficient to overcome the ceiling height and may stratify the gases, especially if ventilation rates are low. In this case, infrared or ultraviolet detectors may be the best choice.

(f) Operational Activities -- If operational activities produce signals to which a given detector is sensitive, false alarms may result. For instance, an infrared or ultraviolet detector may interpret welding activities as a fire or an ionization detector may be unable to distinguish combustion products from an operating diesel from those of a fire.

(g) Maintenance Effect -- The sensitivity of some detectors may degrade more dramatically with age than that of others. As a result, frequent maintenance and testing may be required of certain detectors in order to ensure satisfactory performance.

(h) Cost -- On a relative basis, the costs of detector elements can be expressed approximately as follows:

i) Heat detectors	\$ x
ii) Ionization and photoelectric detectors	\$ 6x
iii) Infrared detectors	\$ 6x
iv) Ultraviolet detectors	\$ 18x

The use of a large number of ultraviolet detectors in areas where heat detectors are sufficient would be prodigal, unless the broader area coverage gained through use of ultraviolet detectors would significantly reduce the total number of detectors required.

The importance of these factors in considering various power plant detector applications is discussed in the next section.

2. Design Details for Selecting Specific Detector Types

Detailed guidance addressing the selection of detectors, based on the criteria listed in the previous section, should be available. However, a review of NFPA codes[5 6] revealed little information useful in determining which detector types should be selected for specific plant locations. Only general guidance describing the operating principles of detectors is presented in the codes. As a result, the selection of a particular detector must be made by a designer on the basis of operating principles, rather than on a rigorous application of the criteria previously listed.

In an effort to define more clearly the types of detectors most suited to different plant areas, a listing was developed of the plant areas outlined in Table III vis a vis the physical characteristics of each area as related to fire detector selection. Table IV shows the result of this effort.

In developing Table IV, a number of judgments were made regarding the relative importance of each area design characteristic and the relative rating of conditions within each plant area. Figure 1 summarizes the logic used in choosing a detector type for each area. From this logic chart and Table IV, a number of observations can be made. First, in those situations where either a fast or slow fire may develop, ionization and photoelectric detectors were chosen over heat detectors because of the delayed response time of heat detectors to slowly developing fires. Only in diesel generator rooms, where diesel combustion products may set off photoelectric or ionization detectors, does the selection of a heat actuated detector appear suitable. Second, it should be recognized that the permissible size of a fire from the standpoint of its effect on plant safety should be considered in the selection of a detection system, in addition to the anticipated speed of fire development. Because of the difficulty in defining what constitutes a maximum acceptable fire size, this factor has been excluded from Figure 1. Third, it may not be possible to quantify what constitutes "significant background radiation," a "corrosive atmosphere," a "cable tray concentration," or a "congested room." Therefore these factors have been only qualitatively considered. Fourth, in those instances where more than one detector choice is given, no effort has been made to define where ionization, photoelectric, or line detectors may be superior. This is because many poorly defined and misunderstood factors can influence the particular choice. For instance, as concluded in an earlier Sandia Laboratories fire protection study,[1] relative detector reliability is understood only in a qualitative manner; none of the additional literature reviewed for this current report has revealed any new data to modify this conclusion. In addition to the reliability factor, other studies[16] have concluded that:

(a) the sensitivity of photocells used in detectors may 'drift' with aging, and

(b) at 'small' distances from a fire, ion chamber detectors are more sensitive than photoelectric devices, while at 'large' distances the situation is reversed.

These examples of subtle differences among detectors demonstrate the difficulty in developing Table IV and Figure 1 much beyond the point shown in this report, and, as will be seen in the next section, detector qualification test procedures fall short of answering many of the more important questions influencing detector selection.

3. <u>Qualification Tests for Selecting Specific Detector Types</u>

The qualification test standards currently being used by Underwriters Laboratories (UL) for nonresidential detector applications are:

UL 167 - 'Smoke Detectors, Combustion Products Type'

UL 168 - 'Smoke Detectors, Photoelectric Type'

UL 521 - 'Fire Detection Thermostats'

TABLE IV

Physical Characteristics of Selected Safety-Related Plant Areas as Related to Detector Selection

Plant Areas	Predominant Combustibles	Anticipated (a) Fire Development	Room Congestion (b) for Detection	Room (d) Ceiling Height	Other Factors	Suitable Detector Choice
Control Room	Cable Insulation	Slow	Low	Low	False Ceilings Continuously Manned	Ionization or Photoelectric
Cable Spreading Room	Cable Insulation	Slow	High	Low	None	Ionization or Photoelectric or Line Type
Switchgear Rooms	Cable Insulation	Initially Fast - High Voltage Short Slow - Propagation	Low	Medium	High Temperature Potential	Ionization or Photoelectric
Decontamination Areas	Plastics, Cloth, Cable Insulation	Fast or Slow	Variable (c)	Variable (c)	Transient Fire Loads, Background Radiation	Photoelectric
Battery Rooms	Hydrogen Gas Cable Insulation	Explosive or Slow	Low	Low	Corrosive Atmosphere	Photoelectric (plus hydrogen sensor or ventilation)
Diesel Rooms	Lube Oil Diesel Fuel Oil Cable Insulation	Fast or Slow	Low	High	Diesel Combustion Products	Heat - Rate of Rise or Ultraviolet or Infrared
Computer Rooms	Plastics, Paper Cable Insulation	Fast or Slow	Low	Low	False Ceilings & False Floors	Ionization or Photoelectric
Safety Pump Rooms	Cable Insulation Lube Oil	Fast or Slow	Low	Variable	None	Ionization or Photoelectric
Nuclear Fuel Areas	Plastics Cable Insulation	Fast or Slow	Variable	High	Transient Fire Loads, Background Radiation	Photoelectric
Primary Containment	Cable Insulation Lube Oil	Fast or Slow	Medium	Variable	Background Radiation	Photoelectric
Relay Rooms	Cable Insulation	Slow	High	Medium	None	Ionization or Photoelectric
Remote Shutdown Rooms	Cable Insulation	Slow	Medium	Variable	None	Ionization or Photoelectric
Instrument Rooms	Cable Insulation	Slow	High	Medium	None	Ionization or Photoelectric
Other Electrical Equipment Areas	Cable Insulation	Slow	Variable	Variable	None	Ionization or Photoelectric

(a) Based on cable burning tests performed at Sandia Laboratories (References 7 and 8) cable fires, involving IEEE - 383 approved cables, develop slowly, in the time span of minutes. In this table, fires, such as oil which can fully develop in time spans of seconds, were rated as "fast".

(b) The influence of room congestion on detector selection is a factor only in those cases where line-of-sight detectors are satisfactory from the standpoint of all other characteristics being considered.

(c) "Variable" refers to those situations in which there are either transient fire conditions within an area or significant variations of physical characteristics between different power plants.

(d) The terms low, medium, and high ceilings were arbitrarily chosen as rooms having real or false ceilings: low, less than 10 feet high; medium, 10 to 30 feet high; high, greater than 30 feet high.

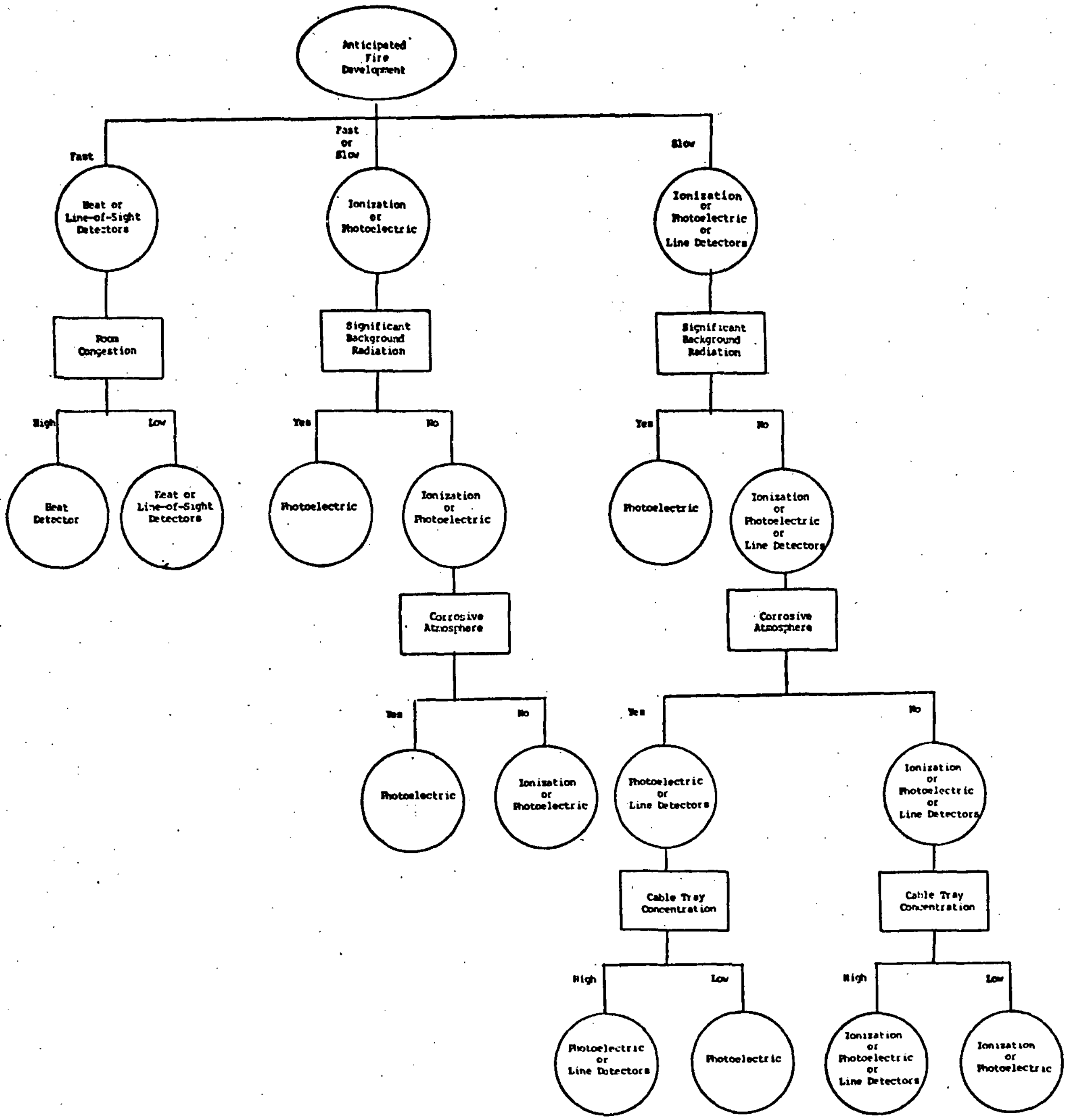


Figure 1. Flow Chart for Detector Selection

In addition to these standards, another standard, UL 268-"Smoke Detectors for Fire Protective Signaling Systems," is being developed to combine UL Standards 167 and 168. A review of a proposed version of UL 268 has revealed, however, that many of the deficiencies to be discussed later, which are inherent in UL 167 and 168 for nuclear power plant fire detection, still exist in the new standard, although some improvements have been attempted by utilizing several air flow rates in one test sequence and by subjecting detectors to a smoldering fire condition in another test. Unfortunately, the varied air flows in UL 268 are used only in a test for checking false alarming and sensitivity to gray smoke produced by a cotton wick, while the smoldering fire test uses smoke from wood heated on a hotplate. Neither of these conditions is typical of nuclear power plant combustibles.

In terms of the detectors considered in this study, no published UL standard covers ultraviolet or infrared detectors, while UL 167, UL 168, and UL 521 address ionization, photoelectric, and area and line heat detectors. Each of these test standards contains a wide range of construction and performance tests to establish detector sensitivity, reliability, safety, and overall quality; once a detector has passed all applicable UL tests, it then may be marketed as a "UL Listed" detector.

Because UL listed detectors are installed in a variety of industrial locations, UL test procedures are generic in nature and may not be applicable to some nuclear power plant situations. Examples of this include the following:

(a) UL Standard 167 for ionization detectors subjects the detectors to combustion products from paper, polystyrene, gasoline, wood, and cotton, while UL 168 for photoelectric detectors uses paper, polystyrene, gasoline, wood, punk, and kerosene. Neither of these standards tests detectors with cable insulations, lube oils, diesel oils, or plastics commonly found in nuclear plants.

(b) None of the UL standards for smoke or heat detectors permits an evaluation of detector response times as a function of smoke and heat release rates. This is because the UL tests subject different detector types to different combustibles. In addition to paper, gasoline, wood, and polystyrene tests, which are common to UL 167 and 168, other tests involving cotton in UL 167, punk and kerosene in UL 168, and alcohol in UL 521 are also performed. No correlation is made among these latter tests and a cable insulation test.

(c) From the standpoint of detector location and spacing, discussed more thoroughly in Section III.C of this report, none of the UL detector tests measures the effect of area ventilation rates on detector performance under fire conditions. Only in the UL 167 cotton test for ionization detectors and the UL 168 punk and kerosene tests for photoelectric detectors has there been an attempt to determine the influence of smoke movement on detector sensitivity. Unfortunately, these tests are conducted in a smoke chamber apparatus, not in a room, and the smoke velocities used in these tests are only 30 to 35 feet per minute (1.6 to 1.9 m/sec)--well below ventilation velocities found in some power plant areas.[13]

(d) For testing detectors in a room environment, all of the UL standards use rooms having a smooth ceiling, with no physical obstructions between the fire source and detectors, and with air movement not exceeding 10 feet per minute (0.5 m/sec). As a result, the influence of room congestion typically found in power plants is not measured.

(e) UL standards 167 and 168 call for test rooms approximately 12 feet (3.65 m) high, while UL 521 specifies a 15-foot (4.57 m) ceiling. Without testing each type of detector at several higher ceiling heights, it is difficult to assess how well a UL listed detector will perform in high bay areas of a power plant.

(f) From the standpoint of operational and maintenance considerations, the UL detector standards are basically complete. Each standard calls for corrosion tests, humidity tests, and vibration tests. In addition, other tests applying only to ionization and photoelectric detectors, include static discharge, paint loading, and dust accumulation tests. For a nuclear plant, only the effects of radiation, diesel combustion products, different corrosive atmospheres, and other interferences are needed to supplement the UL tests.

Based on the above comments, it is apparent that without some additional qualification testing, the indiscriminate installation of UL listed detectors may not, in itself, assure satisfactory detector performance. Because of this uncertainty, at least one other detector study has recommended a new qualification test method.[17] This new procedure calls for all types of detectors to be tested using the same set of conditions. As proposed, the testing would include fifteen different tests made up of three fire sizes for each of five combustibles. To represent a broad spectrum of fire types and detector sensitivities, the fire test combustibles would include a flaming cellulosic, a smoldering cellulosic, a flaming plastic, a smoky oil, and a nonsmoky alcohol, while each of the three fire sizes would be about twice the size of the next smaller fire with the smallest fire for each combustible being selected to assess a detector's maximum sensitivity. Unfortunately, even this new method is susceptible to some of the shortcomings of current procedures, including the use of ceiling heights, ventilation conditions, and some combustibles not common to nuclear power plants.

C. Locating and Spacing Detectors

Once plant areas requiring fire detection have been established, and appropriate detector types chosen, it is necessary to locate and space the detectors in a manner consistent with (1) the environment in which the detector must function and (2) the qualification standard to which the detector was tested. The following sections examine how well existing information sources guide the locating and spacing of detectors and what additional guidance is needed to help designers.

1. Design Criteria for Locating and Spacing Detectors

None of the nuclear regulatory or insurance agency documents reviewed for this study[2-4] provides definitive design criteria for locating and spacing detectors. Only through reference to NFPA 72 E, "Standard for Automatic Fire Detectors"[5] does Draft Regulatory Guide 1.120 acknowledge the influence of location and spacing on detector performance. As a result of this lack of guidance, more specific design criteria need to be defined to take into account the factors listed below, some of which have been assessed in terms of their influence on detector selection (Section III.B).

(a) Ventilation -- Bulk air flow through a room or local air flow in the vicinity of ventilation ductwork can dilute combustion products or prevent the products from reaching a detector. Proper detector positioning must balance the effects of bulk air flow through a room against dilution near return air duct openings.

(b) Ceiling Height -- Stratification of combustion products below the ceiling can delay the response of a heat or smoke detector until a fire has grown to dangerous proportions. Before a detector can be effectively installed, the anticipated stratification in a room must be determined as a function of the floor-to-ceiling combustion product buoyancy gradient under various permissible fire sizes, room ventilation rates, and outside temperature conditions.

(c) Ceiling Construction -- Solid ceiling joists and beams or sloped ceilings can cause stagnant air pockets which prevent combustion products from spreading uniformly. Under these conditions, combustion products may need to spill over from one stagnant zone to another before detection can be accomplished, thereby delaying detector response.

(d) Room Congestion -- Ductwork, piping, and cable trays can deflect combustion products away from a detector, especially if ventilation conditions for detection are already unfavorable. Significant congestion may dictate the installation of detectors away from the ceiling and closer to those fire hazards requiring maximum protection.

(e) Zoning -- To minimize the possibility of unintentionally actuating an automatic suppression system, some form of detection zoning, requiring the operation of more than one detector before automatic suppression starts, may be useful. The type and degree of zoning selected, however, should consider the benefits of reduced false alarms versus the risk of delayed detection system response under actual fire conditions.

The importance each of the above factors plays in power plant applications and the level of design guidance available for each factor are discussed in the next section.

2. Design Details for Locating and Spacing Detectors

A detector can function properly only if the fire properties to which it is sensitive (e.g., heat, smoke, flame, or combustion products) are able to reach the detector. This has been recognized for many years and much of the design guidance developed for detectors in NFPA Standard 72E[5] has addressed location and spacing. Unfortunately, little of the available design guidance goes beyond a qualitative assessment of the criteria listed in Section III.C.1. Even in those instances where quantitative direction is given, there appears to be a lack of supporting experience or test data.

Table V compares the design guidance in NFPA 72E with criteria governing the location and spacing of detectors. A review of Table V shows a number of design uncertainties applying to each locating and spacing design criterion. The significance of these uncertainties is discussed more thoroughly in the following paragraphs.

TABLE V

Comparison of Detector Location and Spacing Criteria with Governing Design Guidance Quoted from NFPA 72E

AREA HEAT DETECTORS

Design Criteria	NFPA 72E Design Guidance	NFPA 72E Paragraph Reference	Comments
(a) Ventilation	None	None	Guidance needed
(b) Ceiling Height	Generally, height is the most important single dimension where ceiling heights exceed 16 feet. As smoke and heat rise from a fire, they tend to spread in the general form of an inverted cone. As the ceiling height increases, a larger size fire is required to actuate the same detector in the same time. In view of this, it is mandatory that the designer of a fire detection system calling for heat detectors consider the size of the fire, and rate of heat release, which may be permitted to develop before detection is ultimately obtained. The most sensitive detectors should be employed which are suitable for the maximum ambient temperature at heights above 30 feet.	B-1.2 thru B-1.5	i. Ventilation interaction ignored ii. Manner of considering fire size and rate of heat release unclear iii. The basis for 16 feet (4.9 m) and 30 feet (9.1 m) is undocumented and apparently unrelated to the UL test heights of 12 feet (3.6 m) for smoke detectors and 15 feet (4.5 m) for heat detectors (See Section III. B. 3)
(c) Ceiling Construction	Spot-type heat detectors shall be located upon the ceiling not less than 6 inches from the side wall, or on the side walls between 6 inches and 12 inches from the ceiling. Spacing Irregular Areas. For irregular shaped areas the spacing between detectors may be greater than the listed spacing, provided the maximum spacing from a detector to the furthest point of a side wall or corner within its zone of protection is not greater than 0.7 times the listed spacing. Open Joist Construction. The spacing of spot-type heat detectors installed on a joisted ceiling shall not exceed 50 percent of their listed spacing when measured at right angles to the solid joists.	3-4.1, 3-5	i. Suitability of 6 and 12 inch (0.15 and 0.3 m) distances not confirmed by UL tests ii. The 50% of listed detector spacing for partitions near smooth ceilings or open joist ceilings is not confirmed by UL detector tests iii. A beam depth of 4 inches (0.1 m) for a "smooth" ceiling may be excessive (Reference 14) iv. The guidance for sloped ceilings is not confirmed by UL detector tests 167, 168, or 521

TABLE V (cont)

Design Criteria	NFPA 72E Design Guidance	NFPA 72E Paragraph Reference	Comments
	Beam Construction. It shall be treated as a smooth ceiling if the beams project no more than 4 inches below the ceiling. If the beams project more than 4 inches below the ceiling, detectors shall be located at no more than two-thirds the spacing schedule in the direction at right angles to the direction of beam travel. If the beams project more than 18 inches below the ceiling, each bay formed by the beams shall be treated as a separate area.		
	Sloped Ceilings. A row of detectors shall first be spaced and located at or within three feet of the peak of the ceiling. The number and spacing of additional detectors, if any, shall be based on the horizontal projection of the ceiling in accordance with the type of ceiling construction.		
(d) Room Congestion	None	None	Guidance needed
(e) Zoning (for minimizing false alarms)	None	None	Guidance needed
CONTINUOUS LINE HEAT DETECTORS			
(a) Ventilation	None	None	Guidance needed; normal ventilation could affect line detectors by interfering with heat buildup along a ceiling
(b) Ceiling Height	Line-type heat detectors shall be located upon the ceiling or on the side walls not more than 20 inches from the ceiling	3-4.2	i. Line detector applications other than on or near a ceiling are ignored (e.g., along cable trays)
	Also, ceiling height design guidance for area heat detectors applies	B-1.2 thru B-1.5	ii. The 20-inch (0.5 m) limit is not confirmed by UL test standard 521
			iii. Other comments for area heat detectors apply
(c) Ceiling Construction	None	None	Guidance unnecessary for line detector applications except on or near ceilings.

TABLE V (cont)

CONTINUOUS LINE HEAT DETECTORS

Design Criteria	NFPA 72E Design Guidance	NFPA 72E Paragraph Reference	Comments
(d) Room Congestion	None	None	Guidance needed; high temperature spots resulting from normal operation of congested equipment could actuate a local line detector
(e) Zoning (for minimizing false alarms)	None	None	Guidance needed

IONIZATION AND PHOTOELECTRIC DETECTORS

Design Criteria	NFPA 72E Design Guidance	NFPA 72E Paragraph Reference	Comments
(a) Ventilation	Spacing of smoke detectors shall result from an evaluation based upon engineering judgment supplemented, if feasible, by field tests. Ceiling shape and surfaces, ceiling height, configuration of contents, burning characteristics of the stored combustibles, and ventilation are some of the parameters that shall be considered.	4-4.1	Guidance inadequate
(b) Ceiling Height	Stratification occurs when the temperature of the smoke particles as generated, usually from a smoldering or small fire, reach the temperature of the surrounding air. Since it has lost the thermal lift, the smoke stops rising and stratifies. For proper protection for buildings with high ceilings, detectors shall be installed alternately at two levels; one half at ceiling level, and the other half at least three feet below the ceiling.	4-4.5.1, 4-4.5.2	i. Stratification from hot air heating systems has been ignored ii. The term "high ceilings" is not defined quantitatively iii. The effectiveness of two level detectors separated by three feet (0.9 m) is questionable for all "high ceilings" found in power plants
(c) Ceiling Construction	Joisted Ceilings. Ceiling obstructions 8 inches or less in depth shall be considered equivalent to a smooth ceiling in view of the "spill over" effect of smoke. Slope Ceilings (Peaked or Shed-Type). A row of detectors shall first be spaced and located within 3 feet of the peak measured horizontally. The number and spacing of additional detectors, if any, shall be based on the horizontal projection of the ceiling.	4-4.3, 4-4.4, 4-4.6	i. None of the distances for ceiling construction or detector location are confirmed suitably by UL tests ii. The recommendations of manufacturers for smooth ceilings are not independently tested for validity by an impartial testing laboratory

TABLE V (cont)

Design Criteria	NFPA 72E Design Guidance	NFPA 72E Paragraph Reference	Comments
	Beam Construction. Beams 8 inches or less in depth can be considered equivalent to a smooth ceiling in view of the "spill over" effect of smoke. In beam construction over 8 inches in depth, movement of heated air and smoke may be slowed by the pocket or bay formed by the beams. In this case, spacing shall be reduced. If the beams exceed 18 inches in depth and are more than 8 feet on centers, each bay shall be treated as a separate area requiring at least one detector.		
(d) Room Congestion	None	None	Guidance needed
(e) Zoning (for minimizing false alarms)	The selection and installation of smoke detectors shall take into consideration both the design characteristics of the detector and the areas into which the detectors will be installed so as to prevent false operation or nonoperation after installation. Some of the considerations are as follows: 1. Smoke detectors having a fixed temperature element as part of the unit shall be selected in accordance with the maximum ceiling temperature that can be expected in service. 2. The installation shall take into consideration the maximum ambient smoke density resulting from manufacturing processes or other sources. 3. Since the projected beam-type unit will operate when the light-path to the receiver is interrupted or obscured, the light-path shall be kept clear of opaque obstacles at all times.	4-5.1	Guidance needed

TABLE V (cont)

Design Criteria	NFPA 72E Design Guidance	NFPA 72E Paragraph Reference	Comments
ULTRAVIOLET/INFRARED DETECTORS			
(a) Ventilation	None	None	Guidance may be needed; normal ventilation rates could affect flame detector operation by allowing a buildup of combustion products which could screen the detector from the fire source
(b) Ceiling Height	Except as otherwise permitted, flame detectors shall not be spaced beyond their listed or approved maximums. Closer spacing shall be utilized where the structural and other characteristics of the protected hazard would otherwise impair the effectiveness of the detection.	5-4.1	There is no standard UL test for flame detectors which establishes listed or approved maximum spacings and installation heights
(c) Ceiling Construction	None	None	Specific guidance unnecessary; guidelines for room congestion should be applicable to ceiling construction considerations
(d) Room Congestion	Flame detectors shall be so designed and installed that their field of vision will be sufficient to assure detection of a specified area of fire. Where conveyance of materials on chutes or belts, or in ducts or tubes, or otherwise, to or past if detector is involved, spacing considerations will not govern, but strategic placement of detectors is required to ensure adequate detection. Since flame detectors are essentially line-of-sight devices, special care shall be taken in applying them to assure that their ability to respond to the required area of fire in the zone which is to be protected will not be unduly compromised by the presence of intervening structural members or other opaque objects or materials. The overall situation shall be reviewed frequently to assure that changes in structural or usage conditions that could interfere with fire detection capabilities are remedied promptly.	5-4.2, 5-4.3, 5-5.1, 5-5.2	Guidance appears adequate if coupled with a standard qualification testing program
(e) Zoning (for minimizing false alarms)	None	None	Guidance needed

Ventilation -- In a power plant, air flow rates through portions of a ventilated room can exceed 100 feet per minute (5.5 m/sec), while rates in the vicinity of supply and return duct openings can reach 1,000 feet per minute (55.0 m/sec).[13] These flow rates are well above both the 30-35 feet per minute (1.6 to 1.9 m/sec) test velocity currently used in detection sensitivity tests and the 10 feet per minute (0.5 m/sec) limiting velocity specified for detector fire tests,[9 10] and a designer has no means of analytically assessing the effects of these higher rates on detector performance. As a further complication, it has been found that some detectors can alarm under high velocity conditions but not under low velocity conditions.[16] The effects of both high and low air flow rates are not completely understood. Since either of these conditions could occur in a particular detctor installation, it is likely that testing under ventilation conditions found outside of a detector's installed environment will be inconclusive.

Ceiling Height and Ceiling Construction -- Ceiling heights in a power plant can vary from 10 feet (3 m) in a pump room to 25 feet (7.6 m) in a diesel generator room, 60 feet (18.2 m) in the turbine building, and 150 feet (45 m) in the reactor containment building; ceiling construction is also variable. Yet, Underwriters Laboratories tests smoke and heat detectors in a smooth-ceiling room at heights of 12 feet (3.6 m) and 15 feet (4.5 m). These disparities between testing conditions and actual application may be significant, as indicated by research performed by R. L. Alpert.[14] Alpert identifies a strong correlation among ceiling height, fire size, and detector sensitivity, as illustrated by the following excerpts:

> . . . the maximum heat or mass transfer rates, and hence minimum response times, will be attained for detectors located a radial distance from the fire axis less than about 18 percent of total ceiling height and a vertical distance below the ceiling of from 1 percent to 3 percent of total ceiling height . . . For optimum response time, fire detectors should be spaced at intervals of 1/4 of the ceiling height. Spacings smaller than this value will yield no significant improvement in detector response time.

Although these conclusions are tempered by a number of restrictions (e.g., ceiling obstructions being less than 2 percent of the ceiling height and the ceiling height being less than 2 to 4 times the room's wall-to-wall horizontal separation), they point out the need to test detectors at ceiling heights more closely approximating actual conditions. According to Alpert, there exists a maximum ceiling height beyond which a fire of given intensity cannot be detected. For example, heat detectors, rated at 135°F(57°C), located on a 20-foot by 20-foot (6 m x 6 m) square spacing and mounted 35 feet (10.6 m) above burning fuel, will respond only to a fire intensity greater than 100,000 BTU/minute (1.76×10^6 J/sec). In a similar manner, Alpert argues that combustion product detectors will sense a fire only if the interrelationship of fire intensity, ceiling height, detector spacing, and detector sensitivity are properly considered. Unfortunately, Alpert provides little quantitative information from which to predict combustion product detector performance, especially in those situations where room ventilation rates and floor-to-ceiling temperature gradients can significantly interfere with the smoke flow patterns induced by a fire.

Other research has demonstrated similar problems resulting from high ceilings, particularly with smoldering fires.[18] The National Bureau of Standards has found that in the early stages of smoldering fires in rooms having ceiling heights greater than 8 feet (2.4 m) (15 feet [4.6 m] and 29 feet [8.8 m] being tested), smoke stopped short of the ceiling and spread horizontally. Such behavior is not conducive to early fire detection.

Room Congestion -- As pointed out in Section III.B.2, it is difficult to determine at what point room congestion constitutes a detection problem. Although in most nuclear power plants auxiliary equipment and cable spreading areas appear more congested than the switchgear or diesel rooms, there exists no proven methodology for assessing what level of congestion actually reduces the effectiveness of a particular detector or what sensitivity and spacing adjustments can be made to overcome congestion detriments. This lack of guidance is not surprising when one considers the variety of room arrangements, ventilation rates, combustible materials, burn rates, and room geometries that would need to be correlated with levels of room congestion.

Zoning -- Current detector zoning techniques for minimizing the incidence of false alarms or false actuation of extinguishing systems typically require two or more adjacent detectors to sense a fire and alarm. Although this approach successfully reduces false alarms, it can also reduce the overall effectiveness of a detection system to below the level at which the individual detectors originally were tested. For two detectors to respond in the same manner as one detector, adjustments must be made in the spacing, sensitivity, and reliability of the two-detector scheme. Designers currently have no guidance for making these adjustments.

3. Qualification Tests for Locating and Spacing Detectors

The following paragraphs, quoted from the Underwriters Laboratories Fire Protection Equipment List,[20] describe the locating and spacing conditions under which detectors are qualified, together with UL recommendations for adapting test results to actual installation conditions.

(a) Area and Continuous Line Heat Detectors

> The spacings specified are for flat, smooth ceiling construction of ordinary height, generally regarded as the most favorable condition for distribution of heated air currents resulting from a fire. Under other forms of ceiling construction reduced spacing of thermostats may be required. The fire tests conducted to determine the suitability of the thermostat spacings are conducted in a 60 by 60 ft room having a 15 ft 9 in.* high smooth ceiling and minimum air movement. The test fire (denatured alcohol) is located approximately 3 ft above the floor and of a magnitude so that sprinkler operation is obtained in approximately two minutes.

. . .

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*It should be noted that a discrepancy exists between the 15 foot-9-inch (4.8 m) test ceiling height quoted for photoelectric and ionization detectors and the 12-foot (3.6 m) height called for in UL Standards 167 and 168.[9,10]

. . . The placement and spacing of thermostatic devices should be based on consideration of the ceiling construction, ceiling height, room or space areas, space subdivisions, the normal room temperature, possible exposure of the devices to abnormal heat such as may be produced by manufacturing processes or equipment, and to draft conditions likely to be encountered at the time of a fire. Authorities having jurisdiction should be consulted in all cases before installation.

(b) Ionization Detectors

Spacings - Although no specific spacings are being allocated to these detectors, the test fire spacings of 30 ft may be used, if practicable, only as a GUIDE or starting point in a detector installation layout. IMPORTANT: THE TEST FIRES CONDUCTED BY THE LABORATORIES ARE BASED ON ONLY ONE SET OF CONDITIONS, NAMELY A 15 FT 9 IN. HIGH SMOOTH CEILING, NO AIR MOVEMENT, AND NO PHYSICAL OBSTRUCTIONS BETWEEN THE FIRE SOURCE AND DETECTOR. It should be realized that these are fairly ideal conditions for a symmetrical detector layout. For conditions other than above it is mandatory that engineering judgment be applied regarding detector location and spacing. In all likelihood closer spacings and irregular distribution would be required for those installations containing high stockpiles, higher than 16 ft high ceilings, small bays and other ceiling obstructions, and particularly in areas where there is rapid air movement from air conditioning and ventilating systems. The air current patterns should be checked by test smoke or light tissue paper to determine proper location of detectors.

(c) Photoelectric Detectors

Guidance similar to that provided for ionization detectors appears to apply to photoelectric detectors, even though the UL listing does not restate the information.

(d) Ultraviolet/Infrared Detectors

The location of flame detectors should be based on an engineering survey of the conditions to be anticipated in service and the principle of operation. Detectors should be installed only after a thorough study has been made of the area or premises to be protected (whether in planning or construction state) and of the life and property values involved. Prior to engineering a layout of an installation, a copy of the manufacturer's technical bulletin should be obtained and reviewed to determine recommended detector locations.

> Consideration should be given to all features which could have a bearing on the location and sensitivity of the detectors, including such pertinent factors as coverage in partitioned sections, ceiling heights, overlapping of areas of cone coverage to provide maximum protection. Test flames should be employed to check proper detector location.

It is apparent from the above statements that the ideal conditions of detector test are recognized, but the guidance provided for adapting qualified detectors to nontest conditions is vague, with considerable reliance placed upon "engineering judgment" and installation testing.

D. Performing Installation Tests and Maintenance

Because detector installations seldom resemble the controlled conditions of a qualification test and because environmental conditions can degrade the original performance of some detectors, in-place testing should be performed following installation and at regular intervals throughout a detector's design life. These activities are of major importance in confirming the adequacy and continued reliability of a detection system, especially in light of the marginal design information and qualification testing alluded to in earlier sections of this report. The following sections examine how well existing information sources guide the installation testing and maintenance of detectors and what additional guidance is needed to help design and operations personnel perform these activities.

1. Design Criteria for Performing Installation Tests and Maintenance

The quality assurance section of Draft Regulatory Guide 1.120 provides the following limited criterion for performing fire protection system testing:

> A test should be established and implemented to ensure that testing is performed and verified by inspection and audit to demonstrate conformance with design and system readiness requirements.

To supplement this criterion, the Standard Technical Specifications, issued by the NRC for nuclear power plant fire protection, states that:

> Each fire detection instrument shall be demonstrated operable by performance of the manufacturer's recommended tests at least once per 6 months.

In addition to these NRC documents, other sources of criteria include the International Guidelines for Fire Protection[3] and a Nuclear Energy Liability-Property Insurance Association bulletin.[15] These sources simply state that:

> The protective measures against the fire hazards should be periodically checked for their efficiency.

and

> Detectors should be properly maintained by qualified persons in accordance with manufacturer's recommendations. As a minimum, annual cleaning, sensitivity adjustment, and operational testing should be performed.

From the above statements, it is clear that the testing and maintenance criteria available in regulatory and insurance documents can easily be expanded into a more definitive list of criteria. Such a list, presented below, was gleaned from a number of sources, including the NFPA Standard on Automatic Fire Detectors[5] and the Underwriters Laboratories Fire Protection Equipment List and associated standards.[9-11 20]

(a) Installation Test Criteria

- A visual inspection of all detectors should be made to ensure that detectors are installed according to design specifications.
- Each detector should be checked to confirm proper wiring and power connections.
- The stability of the detection system should be monitored for several weeks prior to activation of the central fire alarm system to identify potential sources of false alarms, such as background radiation or combustion products.

- The response of the detection systems should be confirmed using a test fire under environmental conditions anticipated to occur normally in the area being protected. The test fire should produce the type and degree of flame, heat, smoke, and combustion products characteristic of combustibles found in the protected area. The environmental test conditions should be representative of the temperatures and ventilation rates expected normally to occur.

(b) Maintenance Criteria

- Detectors should be periodically tested in place to confirm continued satisfactory operation.

- Detectors should be periodically cleaned to remove accumulated dust and dirt. The frequency of cleaning will depend on the type of detector involved and the prevailing environmental conditions.

- Following periodic testing or cleaning, detectors should be restored to service promptly.

It is apparent that a designer needs additional guidance before even these abbreviated testing and maintenance requirements can be implemented. This additional guidance, which is needed to define maintenance intervals, inspection techniques, required training, and calibration standards, traditionally has come from either detector manufacturers or what is termed in fire protection literature as "the authority having jurisdiction." The next section of this report addresses the adequacy of the traditional testing and maintenance design details available with respect to nuclear power plant applications.

2. Design Details for Performing Installation Tests and Maintenance

Performing installation tests and maintenance in accordance with the recommendations of a detector manufacturer has both advantages and disadvantages for a nuclear power plant. Table VI lists some of the more important concerns in this regard.

It can be seen from Table VI that, although detector manufacturers have the potential for providing the most comprehensive guidance for testing and maintaining detector systems, there is little commercial incentive for a manufacturer to research the special problems of nuclear power plant fire detection. Based on this, it is questionable whether the testing and maintenance programs recommended by manufacturers are entirely suitable for power plant applications. Furthermore, since design guidelines such as NFPA Standard 72E,[5] defer much of their authority to "manufacturer's recommendations," there is no standard to which a designer can turn for either absolute or relative evaluation of the performance of an installed detection system. Such a standard appears to be needed for nuclear power plant detection systems.

3. Qualification Tests for Performing Installation Tests and Maintenance

At present, there are no uniformly applied qualification tests for confirming the in-place response characteristics and maintenance requirements of detectors. Although UL standards subject detectors to a variety of corrosion, vibration, humidity, temperature, and dust accumulation conditions, the UL test results are judged as either pass or not pass, with no extension of the qualification tests to developing in-service maintenance procedures or test intervals. In addition, no part of the UL standards identifies what minimum installation tests a UL-listed detector should undergo to confirm performance after installation. Such installation tests should be conducted, although the development and implementation of the tests may be beyond the purview of Underwriters Laboratories and may need to be the subject of a future independent research effort. In the interim, however, it is important to identify what course of action should be followed to assure dependable detector operation in a nuclear power plant. The conclusions and recommendations sections of this report which follow attempt to identify and justify a proper course of action.

TABLE VI

Advantages and Disadvantages of Performing Detector Testing and Maintenance According to Manufacturer's Recommendations

Advantages	Disadvantages
1. Manufacturers are most familiar with the capabilities of their detectors and can best recognize the most stringent conditions under which they should be tested and maintained.	1. Manufacturers have a vested interest in ensuring customer satisfaction by demonstrating that a detector is sensitive enough to detect fire but stable enough to preclude false alarms. This may lead to test and maintenance conditions favoring detector operation but misrepresenting actual fire and environmental conditions.
2. Manufacturers can readily modify their test and maintenance conditions to more appropriately cover the requirements of a particular customer, including changes to reflect room geometry, ventilation conditions, and combustible material present.	2. Testing and maintenance procedures are often proprietary in nature and, as such, vary from one manufacturer to the next. Because of this, there is no uniformity between the procedures used and no independent verification, similar to UL testing, of the validity of each procedure.
3. Manufacturers are willing to assist a customer in testing and correcting a poorly functioning detector system.	3. In the interest of satisfying a customer and "solving" a detector response problem, a manufacturer may find it necessary to reposition and adjust installed detectors, possibly at the expense of overall detection system performance.
4. Manufacturers often have broad experience in the areas of residential and commercial fire detector applications. This experience can benefit a test and maintenance program, especially in solving problems involving ceiling obstructions, fast ventilation rates, and a typical combustion materials.	4. Because of the relatively small nuclear power plant fire detection market, detector manufacturers have concentrated efforts in commerical and residential areas. This means that many available detectors have been designed to perform best under conditions not often found in a power plant (e.g., low ventilation rates, low ceiling heights, smooth ceilings, and cellulosic combustibles).

IV. CONCLUSIONS

This report examined the adequacy of fire detection in the context of nuclear power plant safety. Topics considered were (1) establishing area detection requirements, (2) selecting specific detector types, (3) locating and spacing detectors, and (4) performing installation tests and maintenance. As discussed in Section III of this report, each of these activities lacks the technical bases needed for accomplishing a thorough and quantitative detection system design. The basis for this conclusion is summarized for each activity in the following paragraphs.

Establishment of Area Detection Requirements

- Current insurance and regulatory agency criteria are inconsistent and often conflict by referring to various plant areas by different names and by requiring different levels of detection coverage for the same plant areas.

Selecting Specific Detector Types

- Although it is possible to make gross judgments in choosing a particular detector type, such as an area heat detector in preference to a smoke detector, it is difficult to make more subtle selections among similar detector types, such as ionization versus photoelectric detectors. Furthermore, since different detector types are tested under different conditions, it is doubtful whether any predictable correlation of detector performance can be made for candidate detectors. This is because there are conditions under which detectors now are not fully tested.

Locating and Spacing Detectors

- Locating and spacing cannot be accomplished in an analytical manner based on present testing methods. Instead, engineering judgment and vendor recommendations must bridge the gap between test conditions and installed conditions. Unfortunately, judgment and recommendations can vary widely, depending on the skill of the individual providing the guidance.

Performing Installation Tests and Maintenance

- There is no uniformly applied set of installation tests and maintenance procedures at this time. Only the recommendations of detector manufacturers are available to a designer. Since detector manufacturers often have diversified interests, only a fraction of which may involve nuclear power plant fire protection, there has been little incentive for a manufacturer to develop installation test and maintenance procedures primarily geared to the nuclear power plant market.

From this summary, it is apparent that present fire detection operating principles and qualification tests do not permit the prediction of detector response characteristics. Further, it is doubtful whether any theory can be developed and proven in the near future to describe the complicated interaction of each physical parameter affecting detector operation. Therefore, it appears that the best approach to solving the uncertainties of nuclear power plant fire detection is through in-place testing of detectors under environmental conditions anticipated to occur normally in each area being protected. This conclusion is consistent with: (a) the test results and recommendations of a full-scale test program performed by the Coast Guard in a 100,000 cubic foot ship machinery space[19] and (b) the current approach being followed by the largest detector manufacturer in Europe (Cerberus of Switzerland).

Through in-place testing, during both initial installation and subsequent maintenance intervals, satisfactory detector performance can be assured for the variety of conditions found in power plants. As a further benefit, an in-place testing program can be developed and used in power plants without affecting any of the existing qualification test procedures and installation instructions developed and applied by Underwriters Laboratories and others for primarily commercial and residential applications.

On the basis of these conclusions, the final section of this report recommends a number of steps that may be taken to improve the guidelines now available to designers of nuclear power plant fire detection systems.

V. RECOMMENDATIONS

The recommendations listed here have been developed to address some of the more important detection system design problems identified throughout this report. A few of the recommendations cited involve administrative action, while others require further research and testing. In some instances, the recommendations suggest that no action be taken, because of the limited benefits that could be derived from further work in certain areas. It should be recognized that the objective of each recommendation is to achieve a level of detection system reliability which warrants the added cost and complication associated with detector installation.

A. Establishing Area Detection Requirements

1. The terminology used to describe plant areas requiring detection needs to be made more uniform or at least be descriptive enough to eliminate the need for interpretation on the part of the designer.

2. Plant areas requiring detection need to be determined on the basis of each area's safety importance and the incremental contribution to overall plant safety afforded by a fire detection system. This determination can best be made by comparing the effectiveness of added detection with the safety benefits of other fire protective measures and with the safety importance of the area being protected. Such a comparison should be part of a fire hazards analysis conducted for each area in question.

3. The cost effectiveness of using detectors inside cabinets and along cable trays needs to be confirmed by testing. It may be that such added detection is unjustified.

B. Selecting Specific Detector Types

1. Guidance is needed to make designers aware of the factors influencing detector selection (discussed in Section III.B.1). These factors are combustion products, fire development (both speed and permissible size), ventilation, room congestion, room geometry, operational activities, maintenance effects, and cost.

2. Guidance is needed to identify suitable detector choices and the basis for these choices for those plant areas requiring detection. Information provided in Table IV and Figure 1 of this report can serve as a starting point for this guidance.

3. In those cases where it is difficult to choose among several detector types (e.g., choosing among photoelectric, ionization, and line detectors in Table IV, Section III.B.2), some form of uniform comparative testing needs to be done using combustibles and conditions found in nuclear power plants. As a first step, such testing should focus on determining the performance of various detector types, under some fixed set of environmental conditions, when subjected to combustion products from power plant materials. Subsequent comparative testing should consider as many of the additional factors cited in recommendation B.1 as possible.

4. It appears that no effort needs to be directed toward developing more sophisticated detectors or modifying existing commercially available detectors, because there is a sufficient variety on the market to meet the design requirements of the nuclear industry. Accordingly, the guidance and testing referred to in recommendations B.2 and B.3 may be limited to commonly available detectors.

C. <u>Locating and Spacing Detectors</u>

1. Because of the difficulty in characterizing the numerous room configurations and environmental conditions affecting detector performance, it appears that no effort should be made to develop quantitative detector location and spacing guidelines beyond those already available or being developed by the NFPA and the National Bureau of Standards. Instead, regulatory documents may limit guidance to making designers aware of (a) the qualitative aspects of fire detection, as affected by the factors listed in recommendation B.1, and (b) the importance of in-place testing.

2. It appears that no effort should be directed toward modifying guidance on detector locating and spacing currently provided in the commercial and residential design information developed by independent testing laboratories and fire protection associations. Any major modification of these existing guidelines could only be justified through an extensive detector test program using the range of conditions expected in nuclear power plants. Such an effort would be costly and would not negate the need for the confirmatory in-place testing recommended in C.1 and D.1.

D. <u>Performing Installation Tests and Maintenance</u>

1. A detector installation test procedure needs to be developed which is based on confirmatory research, and is representative of the combustibles, environmental conditions, and detector types (i.e., area, cabinet, and cable tray fire detectors) found in nuclear plants. This test procedure should: (a) address the factors listed in recommendation B.1, (b) provide reproducible test results, and (c) present a minimum disruption to normal plant operations.

2. A detector maintenance procedure needs to be developed. This procedure could identify the maintenance details and maintenance intervals required for each type of detector installed in power plants as a function of enviromental conditions found in various

plant areas. The establishment of maintenance intervals could be accomplished on the basis of analysis or testing which demonstrates a detector's reliability and which corresponds to the minimum acceptable reliability of a detection system.

It is apparent that the greatest benefit to nuclear fire protection can be derived from accomplishing recommendations A.2, B.3, D.1, and D.2. Through the enactment of these and the other recommendations, nuclear power plant detection systems can be selected, installed, tested, and maintained in a manner which assures reliable operation.

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19. Machinery Space Fire Detecting Tests - Phases I and II, United States Coast Guard Office of Research and Development, Shipboard Fire and Safety Testing Facility, Test Advisory Group Report, U. S. Coast Guard Headquarters, Washington, D. C., August 1971.

20. Fire Protection Equipment List, (p. 124), Underwriters Laboratories, January 1976.

APPENDIX A

Confusion Over Class A System Designations

The requirements in Draft Regulatory Guide 1.120[1] for designing detection systems in accordance with the Class A system requirements specified in NFPA 72D "Standard for the Installation, Maintenance and Use of Proprietory Protective Signaling Systems" can be misinterpreted. As explained in Articles 110 and 130 of NFPA 72D, a Class A design provides emergency operation for fire alarms, waterflow alarms, and guard tour signals, in the event of a single break or ground fault of the "signaling line circuit" or of any devices connected to it. NFPA 72D defines a "signaling line circuit" as a circuit connecting transmitters or control units to the central supervising station over which fire alarm, waterflow, guard tour or supervisory signals are transmitted. According to NFPA 72D, circuits of lesser importance connecting individual detectors to control units are not part of the "signaling line circuit," and, therefore, apparently need not meet Class A criteria. Although it is correct to "electrically supervise" individual detector circuits in accordance with Article 240 of NFPA 72D so that the occurrence of a break or ground fault will cause a trouble signal, a requirement that these less important circuits be operable under faulted conditions (Class A) goes beyond the intent of NFPA 72D. Because some licensing confusion regarding this issue has arisen, Regulatory Guide 1.120 should state more clearly the scope of Class A design to be used in nuclear power plants.

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[1]Fire Protection Guidelines for Nuclear Power Plants, Rev. 1, USNRC, November 1977

APPENDIX B

Abbreviated Description of Commercially Available Detectors

a. Heat Detectors (area and line type)

1. Types
    a) Bimetallic strip thermostats (Figure B-1)
    b) Snap-action disc thermostats
    c) Thermostatic cables (Figures B-2 and B-3)
    d) Fusible link and quartzoid bulbs

2. Uses
    a) Area protection
    b) Spot detection
    c) Initiation of extinguishing devices

b. Photoelectric Detectors

1. Types
    a) Beam (Figure B-4)
    b) Spot
        1. Obscuration
        2. Light scattering
    c) Sampling
        1. Obscuration
        2. Light scattering

2. Uses
    a) Air conditioning systems
    b) Vaults
    c) File rooms
    d) Computer centers
    e) Warehouses

c. Ionization Detectors

1. Types
   a) Ionization (Figures B-5 and B-6)
   b) Resistanance grid
   c) Combination ionization/resistance grid

2. Uses-similar to photoelectric detectors

d. Flame Detectors (Figure B-7)

1. Types
   a) Ultraviolet
   b) Infrared

2. Uses
   a) Any industrial or warehousing operations
   b) Spot protection
   c) Control of fixed extinguishing systems
   d) Explosion suppression

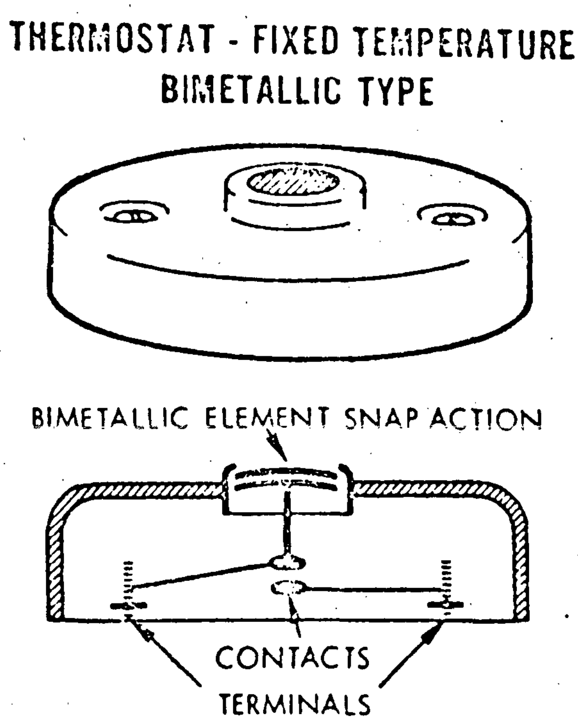


Figure B-1

Thermostatic Cables

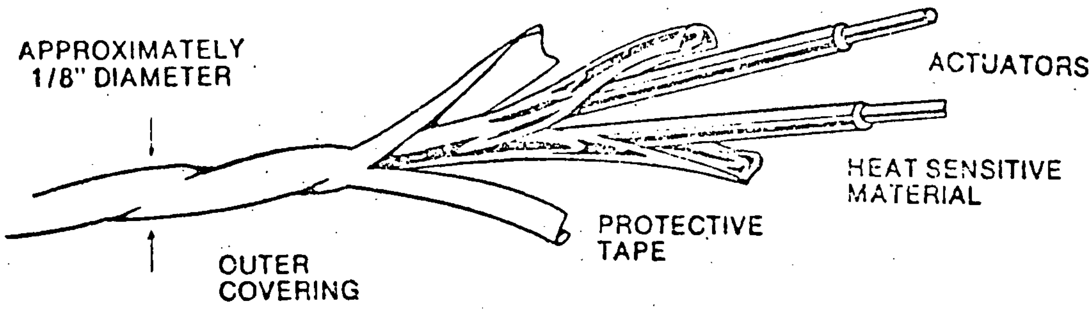


Figure B-2

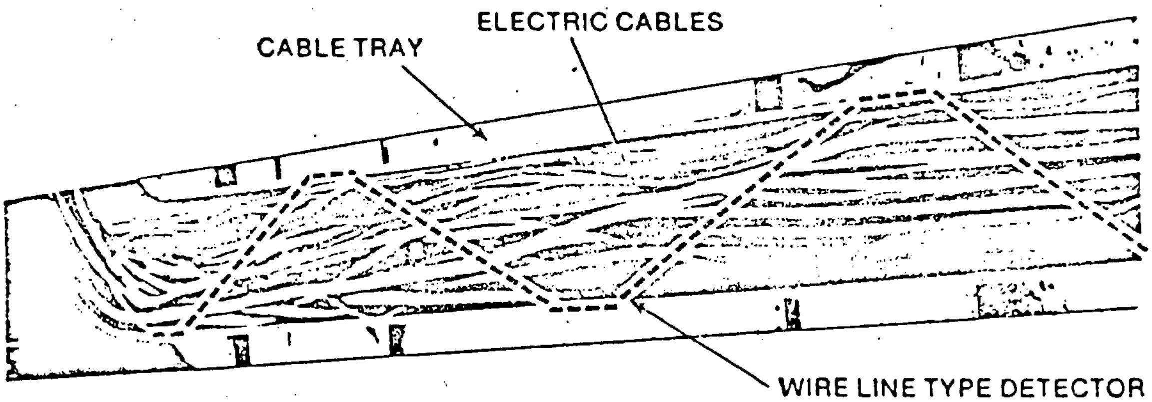


Figure B-3

SMOKE DETECTOR - PROJECTED BEAM TYPE

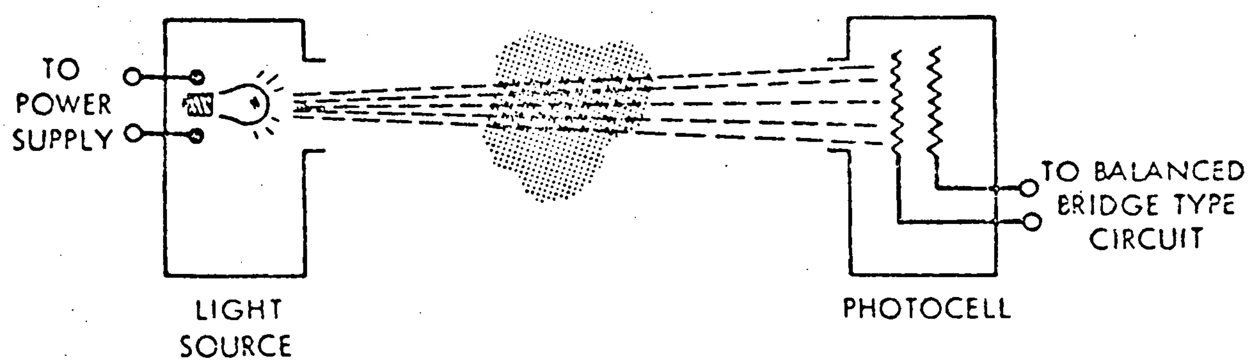
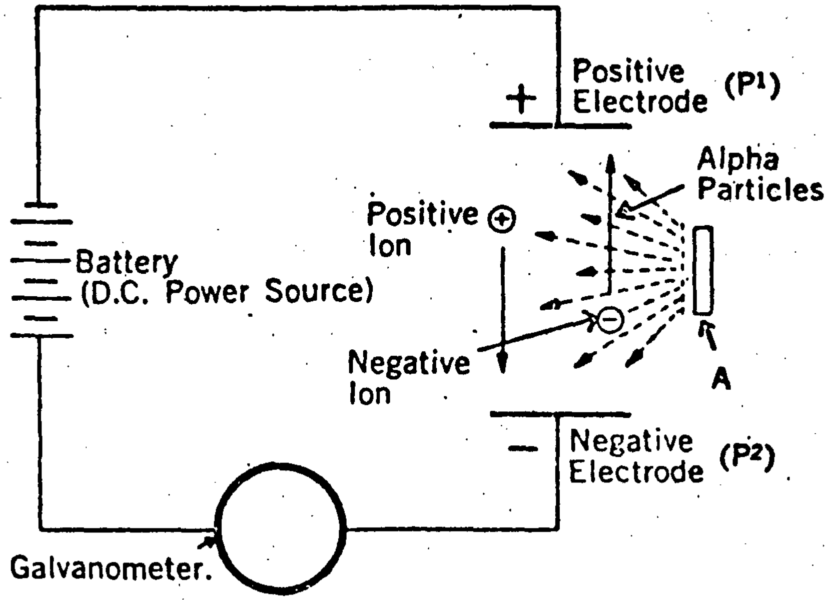
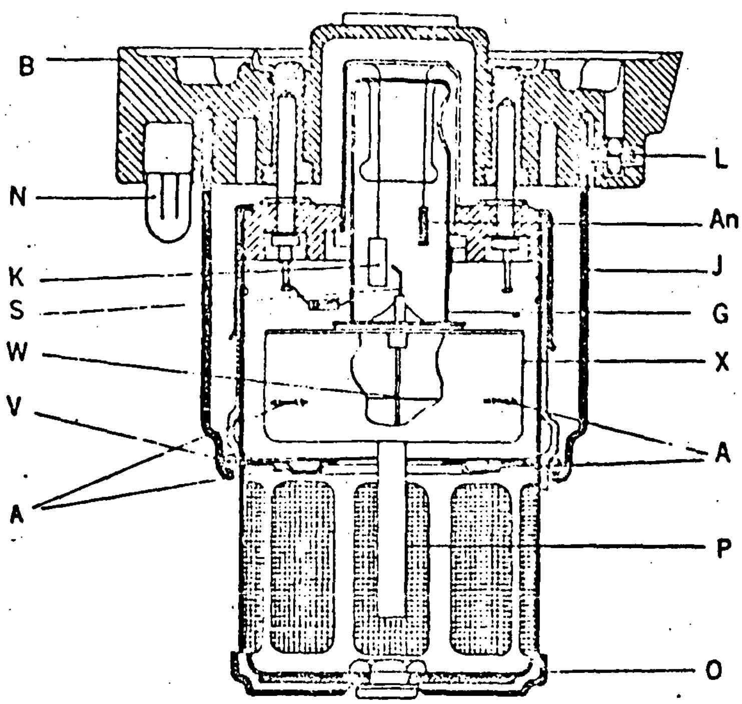


Figure B-4



Ionization Chamber Principle

Figure B-5



DUAL CHAMBER IONIZATION DETECTOR

A–Alpha source; An–anode; B–detector base; G–gas discharge Tube; J–locking shell; K–cathode; L–locking screw; N–neon lamp; O–outer chamber; P–control pin; S–starter electrode; V–O ring; W–inner chamber electrode; X–inner chamber.

Figure B-6

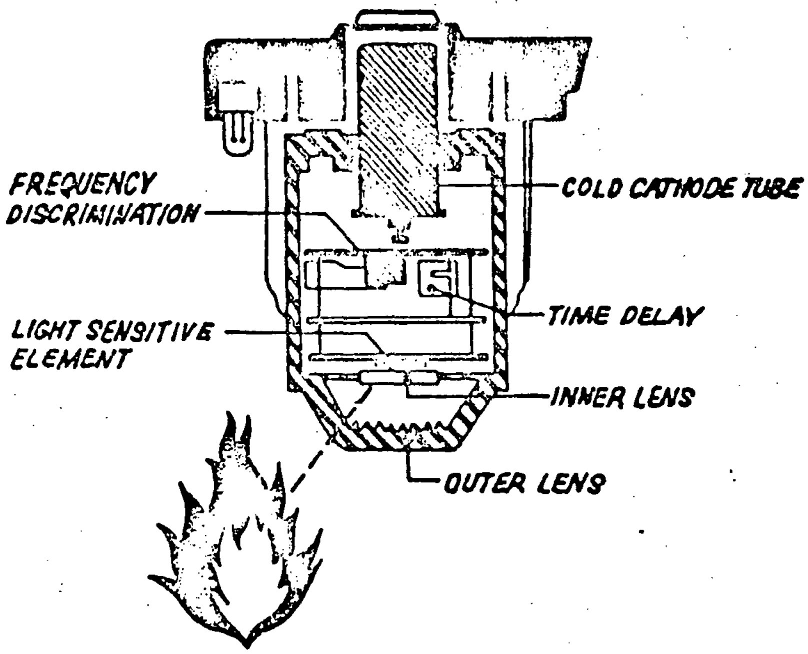

FREQUENCY
DISCRIMINATION
COLD CATHODE TUBE
TIME DELAY
LIGHT SENSITIVE
ELEMENT
INNER LENS
OUTER LENS

Figure B-7

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