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ARH-3020

Guide to Fire Protection in Caves, Canyons, and Hot Cells

H. A. Lee

July 1974

**Prepared for U. S. Atomic Energy Commission
Under Contract AT (45-1)-2130**

**Atlantic Richfield Hanford Company
Richland, Washington 99352**

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1-50	\$ 4.00
51-150	5.45
151-325	7.60
326-500	10.60
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CANYONS, AND HOT CELLS

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Equipment & Instrument Development
Development Engineering Department
Research and Engineering Division

July 1974

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PREFACE

The advent and growth of the nuclear industry have required the development of unique facilities for handling intensely radioactive materials. These facilities, characterized by exhaust ventilation filtration for containment and massive shielding or other means for prevention of excessive radiation exposure to operating personnel, are referred to as caves, canyons, and hot cells.

The maintenance of total containment while handling radioactive materials in caves, canyons, and hot cells is difficult at best; a fire occurring in these facilities greatly increases the difficulty. This guide presents information intended to aid in preventing such fires or, in the event of their occurrence, assist in minimizing their harmful consequences.

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GUIDE TO FIRE PROTECTION IN CAVES, CANYONS, AND HOT CELLS

I. INTRODUCTION

A. SCOPE

This guide is to be used in conjunction with American Nuclear Society Standard ANS 11.14, "Hot Cell Fire Prevention And Controls;"⁽¹⁾ and National Fire Protection Association (NFPA) 801, "Recommended Fire Protection Practice For Facilities Handling Radioactive Materials,"⁽²⁾ in the design of fire prevention and controls for caves, canyons, and hot cells. Standard ANS 11.14 gives the requirements for fire protection in hot cells. It is the intent of this guide to provide background information to assist the designer in meeting these requirements and in preparing better designs and procedures to protect the public and employees from radioactive and toxic materials, and to protect against loss of property and interruption of operations.

B. DESCRIPTION OF THE PROBLEM

The development of capabilities for the safe handling and processing of highly radioactive materials has resulted in a type of facility characterized by massive shielding for attenuating intensive radiation. These heavily shielded facilities are variously referred to as caves, canyons, and hot cells.

This basic requirement for heavy shielding (such as shown on Figures 1, 2 and 3) that is common to caves, canyons, and hot cells precludes manual handling of the process materials or direct maintenance of equipment within the facility. Even observation of the facility interior must be made through thick windows of leaded glass (as shown on Figure 4) or by indirect viewing methods such as periscopes or closed-circuit television (as shown on Figures 5 and 6). Work may also be performed indirectly with the assistance of remote manipulators or cranes.

FIGURE 1. Thorium Uranium Recycle Facility (TURF)-Oak Ridge TURF Cell Bank

FIGURE 2. High Radiation Level Examination Laboratory (HRLEL) - Oak Ridge. Shielded carrier containing irradiated experiment is shown in the cell access area in position for unloading the equipment into the cell. Carriers of this type, weighing up to 20,000 lb, are used to transfer irradiated materials from reactors and other hot cells to HRLEL.

FIGURE 3. Shielded Door Between Hot Cells -
225-B Canyon Building, Hanford

FIGURE 4. Shielding Windows and Manipulators
of Hot Cells - 225-B Building,
Hanford

FIGURE 5. TV Cameras Mounted on the Canyon Crane of the 225-B Building, Hanford

FIGURE 6. Cover Blocks of Hot Cells in Canyon of 225-B Building, Hanford

Large canyons and hot cells (such as the ones shown on Figures 7 and 8) are also distinguished by the restricted access for repair, maintenance or alteration. Many such cells, which are commonly used in the reprocessing of reactor fuel, have never been entered by personnel after being put in operation. Figure 9 shows one such cell. The function of a cave or hot cell is similar to that of a glovebox in that it provides a barrier between the operators and the radioactive material contained therein and that it also provides an enclosure which prevents the release of radioactive material to the environment.

Fire protection for caves, canyons, and hot cells is a problem that is different in many ways from fire problems in other types of structures:

- The potential for damage from release of airborne contamination generated by the fire is tremendous.
- The heavy wall that surrounds these enclosures is usually a very effective fire wall and almost impervious to any credible fire (however, shielding windows are important weak points and merit special consideration).
- The hot cells are not available for direct application of fire fighting techniques. In fact, it is sometimes not possible to determine whether there is actually a fire or whether fire fighting efforts have been successful.
- Any fire fighting material such as water, dry powder or chemicals that has been applied becomes a part of the radioactive waste and must be cleaned from the cell and added to the inventory of waste that must be concentrated and stored.
- Since these enclosures must be held at a negative pressure to prevent the release of airborne radioactive contamination, the exhaust ventilation must be kept in operation during a fire. The filters and other equipment in the exhaust system must therefore be protected from heat, smoke and burning material regardless of the magnitude or character of the fire involved.

FIGURE 7. 221-B Canyon Building, Hanford

FIGURE 8. 221-B Canyon Building (Showing the Low Combustible Loading Hot Cells Are Under the Cover Blocks) (Hanford)

FIGURE 9. Hot Cell of a Fuel Reprocessing Plant
(Purex Plant at Hanford)

- The environment in many hot cells is corrosive as well as highly radioactive, making equipment short-lived or even inoperative.

In spite of these problems, the fire loss in caves, canyons, or hot cells has been very low (see Appendix A), due in part to the extreme care that has been accorded to operations involving radioactive materials and to the design of facilities and planning of operations.

C. HISTORY

The nuclear industry is scarcely 30-years old at this time. Among the first facilities to be used were hot cells and canyons of the reprocessing facilities at Hanford. These first cells were intended for the first stages in the separation of plutonium from irradiated reactor fuel elements for military purposes. Shielding consisted of approximately 7 ft of concrete between the canyons or hot cells and the operating areas. The removable concrete covers of the hot cells were 6-ft thick. Fire protection was not given much consideration because little in these cells could burn and the risk of airborne contamination was not adequately understood. In fact, the first such processing facilities had no filtration or scrubbing either on the process ventilation or the cell ventilation.

The use of caves, canyons, and hot cells has increased over the years until now, hundreds of such facilities exist throughout the world. The purpose for which the caves and hot cells are built has been changing. Few new large-scale reprocessing facilities have been built, but many smaller hot cell facilities have been built for such purposes as scientific research, medical work, industrial applications of nuclear materials and related activities (such as storage, packaging, etc.).

The fire potential of caves, canyons, or hot cells varies widely. They vary in size from a few cubic feet for certain limited functions such as sampling to a canyon 1,000-ft long, 50-ft wide and 54-ft high above a series of hot cells 40-ft deep and 14-ft wide. The fire hazards in these cells and canyons are often very low and consist of combustibles that could burn completely with no danger to either the

cell or its contents. Others, notably certain reprocessing cells, contain large amounts of combustible materials.

The heavy shielding that characterizes these installations gives a high resistance to fire; but because all have operating openings and ventilation, release of radioactive contamination is likely to accompany a fire.

Although there have been a few serious and many near-serious incidents, very few fires or explosions have occurred in shielded facilities. The consequences of incidents have been reduced by the protective shielding, and serious fires and explosions have been averted by well-trained personnel acting promptly in following established procedures. Operating errors have caused fires and explosions; several incidents have been due, at least in part, to continuing an operation when an important instrument was either inoperable or exhibiting abnormal behavior, and the defective unit was neither replaced nor the reason for the unusual behavior determined. For example, incidents have been caused by overheating of electrical heaters in off-gas systems from controls failing in the closed position.

No fires or explosions have been reported which destroyed the final filters in ventilation exhaust systems of shielded cells. However, because filters have been destroyed in glovebox fires, and because of the potential for similar accidents in shielded cells, means must be provided to protect the filters from all credible fires.

In the large production facilities for processing irradiated fuels, most of the process materials are totally enclosed in steel tanks and piping. Fires, explosions and near-serious incidents have resulted from operating errors, leaks and spills during changes in piping and equipment, abnormal operating conditions (particularly in dissolvers and evaporators), and overheating of gases or reactors in off-gas systems.

In a few fires, costly delays have been attributed to the lack of carefully planned, practical procedures to be followed by personnel. For example, firemen and other specially trained personnel have been delayed because of security regulations and requirements for protective clothing for

contamination control because restrictions had not been evaluated realistically before an emergency arose.

D. DEFINITIONS

1. Hot Cell

A heavily shielded enclosure in which radioactive material can be handled safely by persons working from outside the shield using remote tools and manipulators and viewing the work through special leaded glass or zinc-bromide filled windows or with optical devices.

2. Cave

A small hot cell intended for a specific purpose and limited equipment.

3. Canyon

An enclosure beside or above a series of hot cells for the purpose of servicing the hot cells (see Figure 8).

4. Contact Cell

A hot cell wherein operations are done without entry, but installation and repair of equipment is done by personnel entry.

5. Remote Cell

A hot cell wherein all the mechanical work with equipment including installation, maintenance and operation is done without personnel entry (see Figure 9).

6. Manipulator Cell

A hot cell wherein a major portion of the installation, maintenance and operation is done with manipulators (see Figure 10 and 11).

7. Manipulator

A device for doing work in a hot cell. It consists of an operating station, extension members (electrical or mechanical) that penetrate the shielding wall and a work station within the hot cell.

FIGURE 10. High Radiation Level Examination Laboratory (HRLEL) - Oak Ridge. Multiple Manipulator access and (in-cell machinery) remote control consoles.

NORTH VIEW OF HIGH RADIATION LEVEL EXAMINATION LABORATORY (HRLEL) METALLOGRAPHY CELL

1) Cut-off machine; 2) specimen mounting press; 3) stereomicroscope stage; 4) specimen grinder; 5) specimen lapping machine; 6) vibratory polisher; 7) ultrasonic cleaner; 8) hand manipulator; 9) chemical etching sink and hood; 10) specimen dryer; 11) periscope; 12) air filters; 13) cell lights; 14) 3-ton crane. Services are available from the back (right of photo) of the cell.

FIGURE 11. High Radiation Level Examination Lab. (HRLEL) Inside Cells, HRLEL

8. Remote Crane

A crane within a hot cell, operated entirely by electrical signal from outside the cell, with work observation by periscope, leaded glass windows or closed-circuit television.

9. Containment

As used herein, this refers to keeping all radioactive material within planned boundaries inside a facility.

10. Credible Fire

Any internal or exposure (external) fire which can occur in anticipated operations based on the potential hazards of materials and heat energy sources that will be permitted in or near the cave, canyon or hot cell.

11. Design Basis Fire

The worst credible fire that can occur in the facility in question, used as the basis for the design of the fire protection and containment systems of the cave, canyon or hot cell.

12. Unacceptable Consequences

The release of radioactive or toxic materials to the public environs exceeding the limits of federal, state or local codes, a prolonged shut-down of an essential facility, or death or injury of personnel.

13. Window - Shielding Window - Viewing Window

A direct viewing device in a radiation shield, made from special high-density radiation-resistant glass, or in the form of a tank with glass cover plates, containing a radiation-absorbing liquid such as zinc-bromide solution which provides biological shielding essentially equal to that of the concrete radiation shield.

14. Public Safety

As used herein, public safety means preventing exposure of the public to radiation and/or radioactive contamination above regulatory limits.

15. Rating

The numerical rating or modifying adjective used for indicating the extent to which a material or structure resists the effect of fire.

16. Redundant

Those duplicate facilities which are capable of independently performing an action, actuating a device or accomplishing an intended purpose.

17. Inert Atmosphere

A cell atmosphere in which the concentration of oxygen (and water) has been reduced to a level at which materials in the cell are not considered a fire or explosion hazard.

18. Service Environment, Service Conditions

The conditions of heat, cold, humidity, pressure, corrosion, abrasion, shock, vibration or other environmental factors to which the hot cell will be subjected under normal conditions.

19. Accident

An unexpected or unscheduled event, incident, unfortunate occurrence, mishap, malfunction of equipment or systems, or human error, with consequences which would affect public safety, damage property or interrupt operations.

20. Fail-Safe Features

Devices which assure reliable operation in the event of a single fault, or provide alarms or both, in the event of a failure in the system.

II. FIRE BEHAVIOR IN CAVES, CANYONS, AND HOT CELLS

A. GENERAL

As noted before, the danger of fire in caves, canyons, and hot cells is very difficult to define because of the varied nature of these facilities in both geometry and contents. Before it is possible to design facilities and systems and plan procedures for coping with fire, it is necessary to know the characteristics of hot cell fires and how to anticipate the causes of ignition, the magnitude or intensity of the fire and the effects that a fire will have on the facility and the environment.

B. CAUSES

Causes of past fires in caves, canyons, and hot cells have fallen into five categories:

1. Electrical--by failure of equipment or wiring.
2. Hot Surfaces--including furnaces, heaters, overheated vessels, rotating equipment, welding and open flames.
3. Pyrophoric Metals.
4. Spontaneous Ignition--oil soaked rags, sensitized resins, etc.
5. Improper handling of highly flammable materials such as hydrogen, flammable solvents, sodium, etc.

C. FUELS

1. General

Before a significant fire can be possible in a cave, canyon, or hot cell; sufficient fuel must be present to create a damaging amount of heat or smoke. Because of the nature of the work being done in a given hot cell, sufficient fuel to create a dangerous fire may never be present. In this case, no fire detection or extinguishing capability is necessary. But because the use of a hot cell may change during its lifetime, provisions should be made in the design for addition of this capability.

In the large fuel reprocessing plants, the fuel most likely to contribute to a dangerous fire is the organic solvent used in the solvent

extraction (separation) process. Normally contained in metal tanks or piping, it presents little possibility of fire. However, it is possible for accidental spills or operating errors to create a serious fire hazard. Thus, in spite of the fact that no fires of significance have resulted from this material, a carefully designed automatic system is recommended for these facilities.

Many small hot cells are used for a variety of operations and as a result contain a variety of combustibles. Maintenance of good housekeeping, because of the problems involved in access and removal, is also difficult and time-consuming. Therefore, it is not uncommon to see a hot cell in which there is such an array of combustibles that a fire appears to be inevitable. Any attempt to keep the amount of combustibles low enough to render fire protection unnecessary would be doomed to failure. Fire protection for these cells must be prepared for the variety of fires that are possible, to be capable of detecting and extinguishing each one.

The canyons which are usually located over the remote cells of the fuel reprocessing facilities are normally quite large and in general do not contain sufficient fuel to be of concern. The fuel most frequently present is the plastic sheeting used for contamination control. However, kraft paper is occasionally used for this purpose. Wood is often present in small quantities for blocking, crating, etc. Sometimes solvents and lubricants are present in quantities that would create a substantial fire but seldom is the amount present enough to be any concern to the building structure or containment. Although an automatic extinguishing system is not considered essential in such cases, sufficient emergency equipment including suitable extinguishers or hose lines should be provided so that personnel present can extinguish small fires.

The special situation, which exists when the cover blocks of a hot cell have been removed and the cell contains a large quantity of combustibles, should be taken into account when the detection and extinguishing capability of the hot cell is designed. The danger to the overhead crane and to the exhaust filters should be taken into account.

2. Organic Solvents

Several organic solvents are of particular interest because they are used in large quantities in the separation processes for reactor fuel reprocessing. Studies have been made to determine more accurately the solvent properties that affect fire hazard within a cave, canyon, or hot cell. Appendix B gives information on heat of combustion, burning rate, flash point and other related information on the more important solvents.

D. AIR CURRENTS, TEMPERATURE AND PRESSURES

Fire has a rapid and adverse effect on the atmosphere within a cave, canyon, or hot cell. The first effect is to expand the air within the enclosure and pressurize it. This is caused both by the heat and the increased volume of gas coming from the fire.

The second effect is to start thermal currents that carry the flames upward and sometimes sideward, allowing cooler air which is also richer in oxygen to migrate to the fire. This effect is aggravated by the height of the cell. Tests carried out in a 40-ft deep simulated cell showed air currents of considerable velocity both upward and downward within the cell.⁽³⁾

A third effect of the fire is to create a stack effect. This may not be important in a cell of very low height, but where there is considerable height, it may be possible to have a positive pressure at the top of the cell while there is a negative pressure at the floor. If there are openings at the top of the cell as there often are in the large cells, containing the contaminated smoke during the natural pulsing of the flames may be difficult even with the exhaust system operating.

Heat may be the most dangerous effect of the fire. Damage to the structure, damage to the enclosed equipment and damage to the ventilation system that can allow release of radioactive contamination could be caused by heat (See Section VI).

Smoke is an effect of the fire that is much more important to a cave, canyon, or hot cell than it would be in an ordinary structure. In addition to its reduction of visibility and its danger of smoke explosion and smoke

damage to equipment, it poses a threat to the continued functioning of the exhaust system. Smoke may rapidly increase the pressure drop of the filters until a positive pressure within the cell is unavoidable and radioactive contamination is emitted to the environs.⁽⁴⁾

E. TEMPERATURE PATTERNS

As a result of the thermal currents caused by the flames, temperature patterns emerge that have a definite effect on the fire detection efforts. The immediate effect is for both heat and smoke to rise vertically to the ceiling and spread. Therefore, early fire detection is best accomplished at the ceiling above the fire. Later in the fire, because of the currents within the cell, the highest temperatures are at the exhaust outlet, especially if the outlet is high in the cell.⁽⁵⁻⁹⁾

F. EFFECTS OF RADIATION

Organic compounds are used in many processes involving highly radioactive isotopes. Some are combustible and hence may present a fire hazard for the hot cell, cave, or canyon in which they are contained. Irradiation is known to produce compounds and fragments (radicals) which may speed combustion or cause increased flammability. A literature survey was made to evaluate the possible increased fire hazard of organic compounds due to irradiation. The findings indicating that radiation has only a limited effect on the fire hazard are summarized in Appendix C.

G. RELEASE OF RADIOACTIVITY

The most potentially catastrophic result of a fire in a nuclear facility is the release of radioactive contamination to the environs. The amount of this release has never been accurately predictable. In order to estimate the damage that could result from such a postulated accident, it has been necessary to assume an unreasonably high release.

Experimental work, carried out for the purpose of establishing the radioactive releases from certain more common fires that could occur in caves, canyons, or hot cells; is summarized in Appendix D.

III. FIRE PREVENTION

A. DESIGNING FOR FIRE PREVENTION

A basic part of fire prevention in hot cells is determined by the cell structure--its arrangement, treatment of penetrations, construction features and materials.

The heavy shielding walls of conventional hot cell construction are an advantage in making the cell structure resistant to fire but the resultant inaccessibility makes it difficult to maintain good housekeeping and good repair of operational components within the cell. It is therefore important that the following principles be incorporated in the design of the cell:

1. Noncombustible materials should be used wherever practicable.
2. Each component or item of equipment should be examined first regarding its potential for the ignition of a fire and second for its contribution of fuel on which a fire may feed. If possible, these characteristics in any component (or the component itself), should be eliminated.
3. Materials should be selected that will not be degraded by exposure to high-radiation fields or corrosive atmospheres to the point where they will then present a fire hazard.
4. The arrangement of materials and equipment in the cell should not be such as to contribute to the ignition or the spread of a fire; neither should the arrangement hinder the detection or the extinguishment of a fire.
5. Where practical, visibility should be provided not only for its contribution to maintenance of good housekeeping, but also for its possible contribution to the increased capability for extinguishing fires.
6. The ventilation of the cell should be planned to assist in the prevention and suppression of fires. Downdraft ventilation has been found to be a significant asset to the control and extinguishing of cell fires.⁽⁹⁾
7. Compartmentation of cell areas and enclosure of high-risk combustibles is necessary to limit the possible sources of ignition and to limit the

fuel available to a fire. The materials that should be given special consideration include pyrophoric metals, cutting oils, cleaning solvents and stored Class A or Class B supplies.

8. The floor of the hot cell should be given careful consideration for its ability to contain and assist in the cleanup of spilled liquids (including combustible liquids) and fire extinguishing agents. The performance of this cleanup should be planned to avoid creating a nuclear criticality problem.
9. Careful consideration should be given to each material used in the interior of the cell for its smoke production characteristics. This is important both from a visibility standpoint (where this is pertinent) and for the effect fire smoke will have on the exhaust filtration system.⁽¹⁰⁾
10. The building structure that surrounds the hot cells must be given consideration where it could affect fire prevention or control within the cell. The cell may well be more vulnerable to a fire outside the cell than to a fire inside the cell. Complete coverage by an automatic sprinkler system or equal protection should be provided for these areas outside the cell.
11. All electrical wiring and components should be designed in accordance with the intent of the National Electric Code, making maximum use of UL listed components, and radiation-resistant, noncombustible electrical insulation. Totally enclosed and explosion-proof components should be used both to extend their life and to be prepared for possible explosive gases even if not included in the initial plan.
12. Wherever practical, electrical wiring should be protected from physical damage and fire damage by enclosure in conduit, raceways, or other suitable means.
13. All permanent in-cell electrical installations should be intrinsically safe against fire, arcing, etc. Explosion-proof fixtures [National Electrical Manufacturers Association (NEMA) Class I and II] should be considered for this use. Ground fault protectors should be considered for all circuits.

14. In-cell lighting fixtures should be guarded to prevent accidental breakage and the resultant possibility of short circuiting. Where flammable atmospheres can exist inside a cell, the space lighting should be located external to the cell.
15. In argon atmospheres, electrical installations should be operated at low voltage if all junctions, switches and other sources of arc-over can not be located outside the containment. With careful design, 115 volt equipment can be used safely.
16. Enclose heating elements of furnaces, ovens, hotplates or other heating devices.
17. Equip ovens, furnaces, heaters, reaction vessels and similar equipment with a high-temperature cutoff safety circuit in addition to, and independent of, normal controls.
18. Special care should be exercised in the design, installation and operation of electrical equipment that presents unusual potential for ignition of a fire. Motors, heat producing devices such as ovens, hot plates, soldering irons and direct flame devices should use the minimum of combustible materials and be located away from other combustible materials.
19. Enclosures that are used within a hot cell for the purpose of containing contamination or chemical fumes are especially likely to create a fire hazard. Special care should be taken in the choice and arrangement of materials and in methods of operation to minimize the potential for fire. Provisions should be made for storage of tools and accessories and of process and waste materials to limit the contribution of fuel to a fire or to the hazard of ignition. Separate fire detection and extinguishing capability should be considered for these enclosures.
20. In order to prevent the ignition of a fire because of the misoperation of any of the systems associated with the hot cell, a thorough system of marking should be incorporated in the design. Provisions for posting of instructions and/or diagrams should be a part of the design.

21. Service and utility equipment should be noncombustible and resistant to corrosive conditions both within and outside the hot cell.
22. Routings of services into the hot cell should be planned to free the operating areas and floor area, thus aiding good housekeeping and reducing the potential for fire.
23. Potentially hazardous quantities of flammable liquids and gases should be avoided for hot cell use. When the mission of the hot cell demands the use of such materials, a special hazards evaluation should be conducted and documented.
24. Gases and flammable liquids used in a hot cell must not be connected to an unlimited source. Either the total quantity or flow rate of gases and flammable liquids should be limited to prevent explosion hazards or overpressurization of the hot cell in the event of an accidental release. Gases and flammable liquids shall be stored only in approved containers. When such gases or liquids are not in use, the supply should be shut off outside the cell or disconnected if possible.
25. Pneumatic service to hot cells should be designed so that rupture of a line or other failure in the event of fire will not result in pressurization of the cell.
26. Hydraulic fluids and lubricants used within cells should be fire resistant.
27. When combination of chemicals presents a hazard (such as evolution of hydrogen) and there are no alternatives to their use, special precautions must be made such as special procedures and limitations to quantities and rates of use.
28. Provision should be made for storage of tools, accessories and process and waste materials. Good housekeeping is a vital part of fire prevention and control in cells.
29. Each item of the hot cell system should be examined separately and in combination with other parts of the hot cell system to make certain

that the total system will minimize the potential for fire and will not compromise containment in the event of a credible fire.

30. Special design provisions should be made where resin fires are a possibility, including: equipping facilities in which resin is handled with adequate spray and deluge systems; monitoring the temperature of the columns so that adequate cooling can be applied when required; and providing the resin columns with an appropriate pressure relief system by venting or other means to avoid the possibility of explosion.⁽¹¹⁾
31. Redundant instruments or controls should be provided wherever failure of the primary devices could produce overheating, excessive rates of reaction, or other conditions that could lead to a fire or explosion.

B. FIRE PREVENTION IN OPERATIONS

The overall success of fire prevention in a nuclear facility depends on adequate administration, planning and control. Clear lines of communication and authority should be set up and maintained among the many groups of people concerned: designers, fire protection engineers, safety engineers, health physicists, criticality experts, research scientists, technicians, maintenance workers and fire fighters.

Administration and organization of the fire prevention program will vary with individual conditions. In general, however, the successful program will depend upon:

1. Overall supervision. Defining functions, clarifying responsibilities and making sure that all procedures are properly carried out.
2. Planning. Anticipating hazards, formulating plans and procedures for the prevention of fire and for the overall safety of the facility, pre-planning emergency procedures and reviewing plans and specifications by all concerned with the safety of the facility.
3. Education and Training. Making sure that all operators and other personnel concerned are trained in safe procedures, and that all procedures are properly and safely carried out.

4. Assignment. Delegating specific maintenance and emergency duties to employees (including glovebox operators, maintenance men and guards or watchmen).
5. Coordination. Maintaining liaison with all departments and groups concerned with: (a) new construction and layout, new processes and operational changes; (b) installation and maintenance of fire protection equipment; (c) housekeeping; and (d) safe storage and handling of hazardous materials.
6. Hazard Evaluation and Documentation. Performing a hazard evaluation by competent, specifically designated individuals, knowledgeable of the risks involved and of the measures that need to be taken to assure safety in hot cell operations. This evaluation should assure that no single failure could result in a fire of unacceptable consequences. The evaluation should be documented, periodically reviewed and updated whenever significant changes are made in design or operations. The documentation should include information on the hazards, the probability and consequences of a fire or explosion, the analyses performed and the control or corrective measures to be taken to assure containment in the event of a fire.
7. Operating Procedures. Writing operating procedures designed to promote safe operations, including experimental procedures, all operating limits and measures recommended by the hazard evaluation. These procedures should be originated and kept current by the person responsible for the operation and they should be reviewed by supervisory and appropriate hazard control groups for all phases of safety. Instructions must be thoroughly understood by the operators and provisions made to insure enforcement of approved operating procedures.
8. Emergency Procedures. Preplanning emergency procedures, including evacuation requirements, so that employees can be instructed and trained in their application. The instructions should be coordinated with operating procedures and kept current. Further, emergency procedures for glovebox working areas should be carefully coordinated with similar procedures in effect throughout the rest of the site.

9. Industrial Safety. Maintaining a high standard of safety in day-to-day operations of the nuclear facility in matters other than fire safety will have a favorable effect on the fire prevention activities.
10. Inspections. Inspecting regularly all phases of fire prevention activities including inspection of detection and extinguishing equipment, auditing of adherence to procedures, maintenance of housekeeping and maintenance of equipment. In addition, a continuing updating of all plans and procedures is essential to the effectiveness of fire safety programs.
11. Review. Checking periodically the efficiency of the entire program with appropriate reviewing authorities to insure that the program is kept up-to-date with new developments.

C. FIRE PREVENTION DURING REPAIR OR MAINTENANCE

Because of the varied nature of work that may be performed during repair and maintenance of a cave, canyon, or hot cell; special fire hazards may be introduced without anyone being aware of them. Special materials such as solvents, chemicals or other combustibles may be required. At the same time, it may be necessary to impair the operation of some fire protection systems or to open the containment structure itself.

Careful planning should be done, including a written procedure for each job. Close supervision and safety inspection should be part of the plan.

IV. FIRE EXTINGUISHING

A. GENERAL

Extinguishing a fire in a hot cell is different from extinguishing a fire in other types of installation in several ways:

- Access to the fire by manual fire extinguishing methods is usually not possible.
- Often visibility is very limited and at times nonexistent.
- All extinguishing agents must be collected and stored (except gases which can be filtered and discharged). The design of the extinguishing system for a cave, canyon, or hot cell must include provisions for collection and disposal of the agent and prevention of damage during use. Such problems, which include nuclear criticality, must be addressed in an "expert" manner.
- In some cases, notably large fuel processing cells, it is impossible to ascertain when fire is out.
- The heavy shielding walls give a certain degree of protection from the fire or even a mild explosion.
- Venting of the fire (other than through the filtered exhaust system) is not acceptable. This includes the release of smoke which is probably laden with radioactive contaminants.
- Extinguishing materials must not be capable of traveling through the exhaust ductwork to the exhaust filters and damaging or plugging them. It is generally agreed that the exhaust system must remain in operation during a hot cell fire.⁽¹²⁾

Although the need for automatic extinguishing systems for hot cells has been generally recognized, the factors deterring their installation are:

- Confusion in selecting appropriate extinguishing agents.
- Questionable reliability of detectors in inaccessible and hostile environments.

- High cost.
- Potential for damage from accidental discharge of the system.

B. METHODS

There are three methods of extinguishing a fire in a hot cell as in any other location:

1. Deny fuel.
2. Deny air (oxygen).
3. Cool all combustibles below their ignition point to eliminate the flame.

All of these methods are pertinent and effective for use on hot cell fires. Wherever possible fuel should be denied to such a fire and limited as much as possible in all other cases. In many hot cells, the certainty that fuel will not be present in sufficient amounts to be of concern makes detection and extinguishing systems unnecessary. Before deciding to omit these capabilities from the design, the possible future use of the facility should be considered to prevent costly modification of the facility at a later date.

Because of the fire hazard involved with some operations carried on in hot cells, an inert atmosphere is maintained. Dry gases that are commonly used for this purpose are nitrogen, carbon dioxide, argon and helium. The latter two are generally used where the main purpose is other than fire protection.

Fire protection using inert gases is a complex matter that requires careful design. The combustible present must be taken into account, along with its form, arrangement and temperature (plus other conditions such as moisture content of the air). Some references that assist in the design and operation of such facilities are:

- NFPA 7:69--for organic materials.⁽¹³⁾
- Sodium, NaK Engineering Handbook, Volume III.⁽¹⁴⁾

- ISO-756, R. E. Felt, "Burning and Extinguishing Characteristics of Plutonium Metal Fires."⁽¹⁵⁾

In order to be certain that the required concentration of oxygen is not exceeded, the atmosphere must be monitored constantly. A recorder with an audible alarm should be provided.

Provisions should be made for circulation of the atmosphere if it is possible that stratification of the different density gases will cause the concentration of oxygen to exceed safe levels. Adequate supplies should be provided to assure that the inert atmosphere can be maintained at all times. An automatically activated standby system should be present if failure of either equipment or supply could result in a dangerous condition. A regular monitoring schedule of supply gas should be provided, together with an alarm to indicate inert gas usage from the auxiliary supply.

Two types of atmospheric control systems⁽¹⁾ may be used:

- A recirculating gas system which utilizes an $O_2(H_2O)$ removal system.
- A once-through flow.

Either system may be connected to the $O_2(H_2O)$ Monitor to provide an automatic control of the $O_2(H_2O)$ concentration. An emergency shutdown procedure should be provided which includes removal of combustible materials in case of inert atmosphere loss.

C. AGENTS

1. Water

As in other installations when choosing an extinguishing agent, the first one considered should be water unless the circumstances preclude its use. However, an automatic sprinkler system of a design appropriate to the installation and designed in accordance with established NFPA Standards can be effective in many cases. Several circumstances that may limit its application are:

- a. Water must not be used where there is a danger of criticality.

- b. Water applied to the equipment or material in the hot cell may do excessive damage.
- c. Water may cause a disastrous spread of contamination.
- d. The fire that will be involved may not be extinguishable with water.
- e. A material such as sodium that will react violently with water may be present.
- f. Water may create a waste disposal problem of excessive magnitude.
- g. Water may damage the ventilation exhaust filter system.

It is easy to overemphasize any of these objections to the use of water. Each should be carefully examined before its elimination. An alternative, which limits the water to a fixed quantity which can be accepted by the cell, has been adapted successfully for gloveboxes and for laboratory hoods.⁽¹⁶⁾

Several advantages that should not be overlooked when considering water as an extinguishing agent are:

- No undesirable chemicals will be added to the waste stream.
- Water will usually preclude re-ignition of the fire.
- The cooling provided by the water will prevent the fire from reaching large size.
- It has been shown that in a very hot cell fire, the steam resulting from water sprays will quickly extinguish organic solvent fires.⁽⁶⁾

2. Carbon Dioxide

Carbon dioxide has been used more than any other extinguishing agent to protect hot cells. The installation of carbon dioxide systems has been deterred in some instances by concern over thermal shock to electronic components, plugging of filters by crystals where large amounts of CO₂ are required, and the doubts that it can be effective where a large flow of

cell ventilation air must be maintained. It is much more attractive when the supply air can be reduced or stopped.

Carbon dioxide extinguishing systems designed in accordance with NFPA Standard No. 12 are capable of extinguishing flammable liquid (alcohols, hydrocarbons) and cellulosic fires typical of caves and hot cells. The discharged carbon dioxide reduces available oxygen content until combustion is no longer possible. Because carbon dioxide has no permanent blanketing effect, it is not normally recommended for cellulosic fires where combustion becomes deep seated. For such fires, the agent must be discharged for a prolonged period or the extinguishing concentration maintained to assure extinguishment of subsurface burning. However, typical accumulations in hot cells present more of a surface-burning fire, so carbon dioxide can be successful. Carbon dioxide is not suitable for metal fires.⁽¹⁶⁾

One major advantage of carbon dioxide is that it does not produce any residue although CO₂ "snow" can plug a filter temporarily if discharged directly at it. No corrosive decomposition products are formed during its use.

One disadvantage of carbon dioxide is that its use, at unregulated rates, may increase cell pressure to a degree threatening containment.⁽¹⁷⁾ The fire also has a strong tendency to pressurize the cell and will do so unless the exhaust system is adequate. If the exhaust system is adequate, it is difficult to achieve the residence time necessary to be certain of extinguishment with carbon dioxide. If it is possible for the fire to become deep seated in Class A materials, another extinguishing agent should be considered.

3. Halon

Halon 1301 systems (designed in accordance with NFPA Standard No. 12A) and Halon 1211 systems (designed in accordance with NFPA Standard No. 12B) are very attractive for use in extinguishing hot cell fires. These systems possess several advantages:

- a. A relatively small concentration of about 5 percent is required for most fires.⁽¹⁸⁾
- b. No problem is involved in cleaning up after discharge.
- c. Extinguishing is rapid, especially in Class B materials.
- d. There is no significant adverse effect on the ventilation exhaust filters.
- e. They will not pressurize the cell.⁽¹⁹⁾

However, they have several disadvantages:

- a. With the ventilation flow that may be necessary, maintaining the required concentration for the residence time may be difficult (serious consideration should be given to stopping air supply to a hot cell when Halon is used).
- b. If there is a possibility of the fire becoming deep seated in Class A materials, it may be a marginal application.
- c. The decomposition products of Halon in the presence of a fire are corrosive (with the amount appearing to be in proportion to the size and duration of the fire).⁽²⁰⁾
- d. The recommended downflow ventilation pattern in a hot cell⁽¹²⁾ tends to sweep the Halon from the cell because this heavy gas is cold when introduced and has a tendency to go to the bottom of the cell.
- e. If the Halon does not extinguish the fire, or if the fire is rekindled, there may be no backup. (If a backup is provided, another type such as water sprays should be considered.)
- f. Halon is not suitable for metal fires.

One attractive method of providing backup is used at Savannah River Laboratory: supply cylinders to several hot cells, connected by quick disconnects to the individual automatic systems, can be transferred in a few seconds to any other cell (See Figures 12 and 13).

FIGURE 12. Californium Packaging Facility - Savannah River Laboratory.
Halon 1301 extinguishers with automatic manual actuation.

FIGURE 13. High Level Caves - Savannah River Laboratory.
Halon 1301 extinguishers with manual actuation.

4. Dry Chemicals

Dry chemical extinguishing systems designed in accordance with NFPA Standard No. 17 may be used for hot cell installations. With the principal advantage that of being very rapid acting for extinguishing Class B fires, they have several disadvantages:

- a. The extinguishing of fires in Class A material is uncertain.
- b. The used extinguisher chemical is often difficult and expensive to clean up since it adds to the quantity of radioactive waste that must be collected and stored. Also, the dry powder finds its way into everything: the exhaust filters, the cell equipment, and any exposed materials used or being processed in the cell.⁽¹¹⁾
- c. It increases the potential for spread of contamination because radioactive particles become attached to the powder and become more mobile.
- d. Dry chemicals are sometimes incompatible with the contents of the hot cell.

5. Foams

There are three types of foams that may be considered for use on hot cell fires. Each has characteristics which may make it desirable for a particular hot cell or application therein.

a. High Expansion Foam

High expansion foam systems designed in accordance with the requirements of NFPA Standard No. 11A have only limited application with several objectionable features:

- 1) The application of high expansion foam requires the addition of large quantities of outside air since cell air in the presence of a fire has been found to be unsuitable for forming foam.⁽²¹⁾ This requires large openings in the heavy shielding walls and complicates the design.
- 2) The high expansion foam, moving easily with the cell ventilation air to the exhaust filters, can plug the filters.⁽³⁾

- 3) The high volume addition of foam to the cell requires the exhaust to operate at the same or greater volume or a pressurization of the cell and spread of contamination will result.
- 4) The extinguishing action of the high expansion foam is slower than many other methods.⁽⁷⁾
- 5) There is some problem of cleanup, although most high expansion foam will disappear in a short time.
- 6) The foaming agent, included with radioactive waste when the cell is washed down, may present a problem of compatibility or of foaming if the waste is concentrated by conventional means.
- 7) It is not suitable for metal fires.

If the above objections can be overcome, the agent has some desirable characteristics:

- 1) It can be used to protect against fires within a large space by total flooding without exact knowledge of the location of the fire.
- 2) It will protect uninvolved material from flames until the fire can be extinguished.
- 3) It provides protection from re-ignition.
- 4) It has some ability to retain and fix contaminants.
- 5) It is effective on a wide variety of fires.

b. Low Expansion Foams

Low expansion foam systems designed in accordance with the requirements of NFPA Standard No. 11 may have some limited application to hot cell fires, with the following desirable features:

- 1) The volume required to extinguish most hot cell fires would be relatively low and would create no serious problem with pressurizing the cell.

- 2) Low expansion foam will not readily travel with the ventilation air and cause a plugging problem with exhaust filters not in the direct path of the foam applicator.
- 3) Only small piping is required into the cell (the foam is formed using cell air).

There are several disadvantages that prevent serious consideration of low expansion foams for many hot cell applications:

- 1) They are very persistent and hard to clean up. This cleaning difficulty is accentuated by the methods that must be employed in hot cells.
- 2) A considerable quantity of liquid waste, resulting from cleaning operations, must be stored and probably concentrated. Concentration by conventional methods may be difficult in view of the foaming characteristics.
- 3) Chemical compatibility of the agent with other radioactive wastes must be considered from a corrosion as well as a foaming standpoint during evaporation.
- 4) Low expansion foams, not especially mobile when applied to hot cell equipment, may not penetrate to all places where fire may exist.

c. The Aqueous Film-Forming Foams

Aqueous film-forming foams comprise a relatively new class of fire fighting foams gaining recognition as highly effective fire extinguishing agents for use on many types of fires but especially on liquid fuels. Although no NFPA Standard is directly applicable to the design of systems using these materials, they should be designed carefully using the recommendations of the manufacturer and the limitations imposed in the listing by the Underwriters Laboratories. The use of these agents for hot cell fires has some distinct advantages:

- 1) These agents are fast acting and highly effective on liquid

hydrocarbon fires as well as on fires involving Class A materials where their effectiveness as a wetting agent permits penetration to deep-seated fires.

- 2) The foam produced, which floats on liquid fuels and is quite mobile, reaches places not directly available to the discharge nozzle.
- 3) Not excessively hard to clean up using the limited methods available for hot cell use; a particular advantage is their ability to dissolve readily in water spray.
- 4) The most common products are not corrosive to common materials used in hot cells.
- 5) They require only small pipe penetrations into the hot cells.
- 6) Tests have shown them to be highly effective when used in standard sprinklers, fog nozzles and spray nozzles; thus making it possible to adapt to cells where existing piping and nozzles would be difficult to change.⁽³⁾
- 7) Compatibility of these agents with radioactive waste solutions is not considered to be an insoluble problem although it may require some research to establish compatibility.

There are some disadvantages to the use of the Aqueous Film Forming Foams on hot cell fires, including the following:

- 1) A certain amount of cleanup will be required after use.
- 2) These agents are not applicable to the same hazards as listed for other foams in NFPA Standard 11A, such as chemicals which contain their own oxygen, energized unenclosed electrical equipment, water reactive metal (such as sodium) and water reactive chemicals.
- 3) Compatibility must be established with the waste system.
- 4) Since these agents are in the development stage, they change formulation periodically.
- 5) No standard for the design of systems using these agents is available at this time.

d. Combinations of Agents

It is possible that combinations of extinguishing agents may be much more effective than single agents. Halon 1301 used with water spray appears in some test results to be very effective on hot cell fires involving both Class A and B materials. The water cools the cell and equipment and extinguishes the possible deep-seated Class A fires, thus eliminating the possibility of rekindling. Halon penetrates into hard to reach places and eliminates the remainder of the fire.

The combination of water with CO₂ may also have some application. Since not much is known about the use of such combinations, it may be necessary to design each system to the appropriate NFPA Standards and to perform such testing as may be warranted.

D. COMPATABILITY OF AGENTS

Before selecting an extinguishing agent for use in a cave, canyon, or hot cell, serious consideration must be given to disposal. Agents used in such facilities will become radioactively contaminated and will become part of the inventory of contaminated waste.

If the agent is a gas, it can be discharged through the exhaust ventilation system for radioactive particulate filtration before discharge to the atmosphere.

If the agent is a liquid, it will mix with the other liquids in the cell and will be collected in the waste system. It is possible that the combination of chemicals may have some adverse effects, such as increased corrosion, evolution of an explosive gas, or perhaps foaming when it is processed through the concentrators.

If the agent is a solid, it may have an adverse effect on some of the equipment in the cell. It may be difficult to remove and dispose of, or it may require that it be washed down to clean the cell. In this case, it becomes part of the liquid waste.

E. VENTILATION

Ventilation of a cave, canyon, or hot cell has a marked effect on the fire that occurs therein. The principles that apply to a stove or furnace apply closely to such a fire. Several effects that can be noted are:

1. Air volume into the cell determines the intensity of the fire.
2. Downdraft ventilation reduces the efficiency of the fire and its intensity.
3. It is possible to reduce the fire drastically by denying it air; which cools the fire, makes it inefficient and easier to extinguish.
4. A fire in a cell that is burning with insufficient oxygen creates a lot of smoke, which often will have a very adverse effect on the exhaust filters.

It follows that (for fire considerations) the facility design should utilize downdraft ventilation, provide for means of limiting or stopping the inflow of air to a cell during a fire, and should prepare for containing a considerable quantity of smoke.

F. ORGANIZATION AND PLANNING

A nuclear facility ideally will have a permanent and fully staffed fire-fighting organization that is organized, trained and equipped in accordance with appropriate NFPA fire codes and charged with the responsibility of inspecting and maintaining all fire detection and fighting equipment (as well as training and planning). In practice, the expense of maintaining this organization is so high that alternative methods have been adopted in many cases.

A central station where fire alarms are received and from which personnel and equipment are dispatched is a minimum for a nuclear hot cell facility. The actual fire fighting personnel can be enlisted from the work force normally assigned to a hot cell facility.

The training of plant personnel in the fire fighting techniques applicable to their facility can be the responsibility of the full-time fire

department staff. Equipment involved in the potential fire fighting activities can be maintained by either the fire department staff or by assigned personnel under staff direction.

Prefire plans, prepared for all potential fires of each facility and used in personnel training, should include plans for access to all the areas involved (taking into account security barriers and containment barriers which must be passed).

Coordination of fire fighting activities and plans with neighboring fire departments should be kept current and active for mutual benefit.

V. FIRE DETECTION

A. GENERAL

Fire detection in caves, canyons, and hot cells is as varied a problem as in other types of installations. The installations may be of such different sizes and shapes and contain such a variety and quantity of combustibles that the detectors must be selected to suit the particular application.

Fire detection in a hot cell, cave, or canyon presents two rather unique problems not encountered in most applications: the severe environment associated with nuclear radiation and the relative inaccessibility of all devices and equipment in the cell. Another condition often encountered and not usually recognized is severe corrosive conditions that exist when even small amounts of corrosive fumes are present.

B. SELECTION OF DETECTORS

Before a fire detector is selected for use in a hot cell, several standard references should be consulted:

- NFPA-72E-T - Standard for Automatic Fire Detectors.
- Underwriters Laboratories - Fire Protection Equipment List
- Factory Mutual - Data Sheets and Equipment Lists.
- ANS 11.14 - Hot Cell Fire Prevention and Controls.

In addition, reference should be made to the following report dealing with the specific problem of fire detection in hot cells and canyons:

- DP-1242, April 1971, A. J. Hill, Savannah River Laboratory, "Fire Prevention and Protection in Hot Cells and Canyons."

The detectors must be connected to both a local alarm system and to a central fire department. Design of these systems should follow the recommendations of the following:

- NFPA-71 - Central Station Signaling Systems
- NFPA-72A - Local Protective Signaling Systems

- NFPA-72B - Auxiliary Signaling Systems
- NFPA-72C - Remote Station Signaling Systems

Detectors for use in hot cells should meet several criteria:

1. The detector should be dependable. Dependability is more important than speed of response or sensitivity. This is because the heavy shielding will protect the environs from small fires, but if the fire increases to the point where damage to the facility or release of radioactive contamination is imminent, the detector must work without fail.
2. The detector should be free of false alarms. Where the detector is used for early warning only and not connected to an automatic extinguishing system, this is not as vital. Where a false alarm could cause activation of an automatic extinguishing system, it may be very important because the damage and cost of this action may exceed that of a fire. The expense and damage could result from cleanup and storage of either liquid or dry powder extinguishing agents, and replacement of expended Halon or CO₂ extinguishing agents.
3. The detector should be impervious to the most severe environment in the hot cell. Radioactivity should not degrade the detector or cause false alarms. Neither should corrosive conditions that are easily overlooked in such facilities cause detector degradation or false alarms. (Materials often used in detectors are subject to corrosion in this service.)
4. The detector should be testable without difficulty. Although this may require special design for many installations, remote testing features have been developed and tested for installation at other nuclear installations.⁽⁹⁾
5. The detector should require little if any maintenance within the cell. It is usually very difficult to gain access to detectors that are properly located in a hot cell or cave. Once access is gained, any work must be done under contaminated conditions (which is tedious and expensive).

6. The detector should be automatically self-restoring. In the event of activation it should not require replacement of parts, cleaning or manual restoring. It should require only testing to verify that it is in working condition.
7. The detector should be resistant to mechanical damage. In addition to being located where it is safe from mechanical damage and protected from recognizable mechanical hazards, the detector should be capable of absorbing a reasonable amount of abuse without failure.
8. The detector should be supervised by the associated signaling system to give a trouble signal in case of failure.
9. Only approved detection devices and systems should be installed. Information on suppliers of approved detection and alarm systems is found in the Factory Mutual Approval Guide and Underwriters Laboratories Fire Protection Equipment List.

Several detectors have been found that meet most of the above criteria. One is a rate-compensated thermal device which meets all of the criteria. Its most serious shortcoming is in speed of response, but considering the application, it is entirely adequate in most cases. When properly located, it has very adequate response.

Stainless clad thermocouples with alarm circuitry have been used in some cases and have proven very satisfactory. Because only the couple is required to be inside the cell, repair is usually easy. The most serious shortcoming is the associated circuitry which is likely to be more vulnerable to failure than the simple thermal switch. Because of this and because they are not manufactured and tested as a fire protection device, they are not recommended.

Various smoke (ionization) detectors have been used in hot cells because of their rapidity of response and the general success of tests involving cell fires. It should be remembered that many of these devices need periodic cleaning and adjustment and can be vulnerable to a radioactive or corrosive environment. They are not recommended for activating

a fire extinguishing system. Some smoke detectors are unsuitable for use in high radiation fields.⁽¹¹⁾

Flame detectors, located outside of the cell to receive the light from a fire through leaded glass windows, have been used in some cases. This is a rapid method of fire detection but not reliable enough for activating an automatic extinguishing system. However, it can provide an early warning to allow manual activation of an extinguishing system.

A complete description of the many fire detectors with test results and recommendations as to their use is available in DP-1242 and NFPA-72E.

C. LOCATION OF FIRE DETECTORS

The location of a fire detector in a hot cell is important from three standpoints:

1. It must be located to achieve the most rapid response to a fire.
2. It must be located so that in case of failure it can be replaced or, if possible, repaired.
3. It must be located so that it will not interfere with normal operations in the cell and thus risk damage.

The location generally agreed to be most satisfactory is directly over the fire at/or near the ceiling.^(11,22) It must not be located in the draft of supply air or in blind spaces caused by the geometry of the cell, equipment or the ventilation system.

A second location that has been used in some special situations is the ventilation exhaust duct. However, tests have shown that this is usually not the best location for early detection with either thermal or smoke detectors since the highest temperatures are achieved at this location later in the fire. A location in the exhaust duct with dilution by air from other cells is not a good choice.

Other general considerations in the selection of a location for fire detectors are given in NFPA-72E.

D. MAINTENANCE AND TESTING

Maintenance and testing are necessary to assure that the detector will respond to an actual fire. Although each type of detector has different maintenance requirements, the detector chosen should require little work in the hot cell itself. The amount and type of maintenance required is outlined in NFPA-72E.

The detectors should be tested:

- After installation.
- Periodically after being put in use (the frequency depends upon the type and the installation).
- After any unusual incident involving the detector (such as a fire or mechanical damage).

Reference should be made to NFPA-72E for more detailed requirements of testing.

VI. FIRE CONTAINMENT

A. GENERAL

The most difficult problem in dealing with a fire in a cave, canyon, or hot cell is to assure that the radioactive material in the cell that becomes airborne during the fire is not allowed to escape to the environs. Such airborne material can escape through any openings such as the air inlet, unintentional openings around manipulators, windows, doors, the structure itself or through the ventilation exhaust system. Pressure caused by the fire is of great concern.

B. VENTILATION

Openings other than for ventilation inlet and exhaust should be kept to a minimum; the air inlet wherever practical will be provided with a high-efficiency particulate air (HEPA) filter so that any air reversal will allow the escape of filtered air only. The exhaust system should be designed to maintain a negative pressure in the cell during any credible fire. As a practical matter, this may be quite difficult especially if a rapidly developing fire or explosion can be postulated. If such an event should occur, the enclosure surrounding the hot cell will become contaminated. However, with proper design and thorough training of personnel, contamination will not escape to the environs. The design flow rate can then be kept within reasonable limits as determined by the air flow necessary to remove heat, objectionable gases or fumes.

The ventilation exhaust system must be designed to meet the following demands:

1. An adequate negative pressure must be maintained to assure that contamination will not escape beyond the outer walls of the facility enclosing the hot cell under the maximum credible (design basis) accident conditions specified for the facility.
2. The exhaust system must withstand and continue to act as a containment barrier during and after a maximum credible accident, including

all natural accidents such as earthquake, tornado, fire, and flood; and all eventualities such as power failure, equipment component failure and personnel error.

3. The exhaust stream must be filtered to assure that the amount of radioactive material released to the environment is as low as practical, but in no case will it exceed the levels set in the Atomic Energy Commission Manual Chapter 0511 and 0524 or Title 10, Code of Federal Regulations, Part 20.
4. The exhaust system must be constantly monitored not only to verify that the limits imposed on radioactive releases to the environment are being met, but also to establish numerically the actual performance of the system.
5. The exhaust system must be provided with instruments to log its performance in order to anticipate well in advance action that will be required to assure continuous operation:
 - a. Differential pressure instruments on all filter banks.
 - b. Adequate flow measuring instruments at key points.
 - c. Radioactivity measuring instruments to predict the buildup of prohibitive levels of radioactivity at key points in the system.
 - d. Ports and sampling points for periodic testing of the filter system in accordance with American National Standards Institute (ANSI) Standard N101.1.⁽²³⁾
 - e. Temperature elements, ammeters, etc., as necessary to assure continued operation of the exhaust fans.

C. FILTERS

1. General

Several types of filters have been used to remove radioactive particles in the exhaust air from caves, canyons, and hot cells. The criteria for selecting any given filtration system follow:

- a. Efficiency (the ability of the filter to remove the particles found in the particular air stream).
- b. Capacity for accumulating dirt without increase of pressure drop beyond the capability of the system to maintain air flow.
- c. Resistance to the radioactivity, fumes, aging and other factors of the environment.
- d. Pressure drop (determines the fan size and motor horsepowers).
- e. Cost.
- f. Physical size.
- g. Resistance to accident conditions such as fire, earthquake, tornado, etc.
- h. Confidence factor (based on experience showing the ability to obtain a high integrity filter that will perform in the particular service).

Filtration is a highly complex matter that has been under constant and concentrated study by many people. The proceedings of the 12 United States Atomic Energy Commission Air Cleaning Conferences that have been held to date will serve as a source of information on any particular problem related to exhaust filtration from caves, canyons, or hot cells. A great deal is still not known about the performance of filters for caves, canyons, and hot cells. Therefore, good judgment is required in the design of these facilities.

2. High-Efficiency Particulate Air (HEPA) Filters

This type of filter has evolved from the Chemical Warfare Service filters developed for military use during World War II. Its characteristics have improved steadily since its hurried adoption when the problem of the evolution of radioactive particulates from nuclear facilities was recognized. One of the more significant improvements has been its resistance to fire.

The rather extensive technology that has been developed in the use of this type of filter for nuclear facilities is covered in ORNL-NSIC-65,

"Design, Construction, and Testing of High Efficiency Filtration Systems for Nuclear Application," by Burchsted and Fuller.⁽²³⁾

At this time, this type of filter is the mainstay of filtration systems for caves, canyons, and hot cells because of its high-efficiency (99.97 percent dioctyl phthalate, DOP). One application is shown on Figure 14.

A serious flaw of this type of filter is that the actual filter media (which is only about 0.015-inch thick) and is currently made of a fiberglass that will melt rapidly if subjected to a temperature of 1000°F and will deteriorate at lower temperatures.⁽²⁴⁾ This media, seldom recommended for use at temperatures over 600°F, should be held at much lower temperatures for safety in nuclear service. Hence, a fire within a cave, canyon, or hot cell must be prevented from reaching this type of filter. Although this media is not in itself combustible, some of the material that can be deposited on it may be (such as the smoke from an inefficient fire in the limited environment of a hot cell). Some information on the resistance of HEPA filters to fire and smoke is given in Appendix E.

Other limitations on the integrity of HEPA filters include: vulnerability to water damage,⁽²⁵⁾ mechanical damage,⁽²⁶⁾ aging of components in the cell atmosphere or in a radiation field, and relatively small capacity for dirt before plugging.

3. Fiberglass Filters

One of the earliest types of filters to be applied to exhaust air from caves, canyons, and hot cells was deep-bed fiberglass, as discussed in HW-20847, "Filtration of Radioactive Aerosols by Glass Fibers," by Blasewitz, et al., at Richland, Washington.⁽²⁷⁾ Installations built with this technology have been using Owens Corning 115K fiberglass packed layers (about 7-ft thick) at densities of from 0.75 to 9 lb per cubic foot, as shown in Figures 15 and 16. Since the efficiency of this type of filter is not adequate (about 90+ percent), it must be backed up by additional filters such as HEPA.

291-B EXHAUST FILTER

FIGURE 14. High Efficiency Particulate Air (HEPA) Filters Installed in Two Banks in an Underground Vault.

FIGURE 15. Workers Installing Screens Over One Layer of Owens Corning 115K Fiberglass

Although this type of filter as a barrier to a fire is somewhat better than the HEPA because of its bulk and because of the dispersion of the accumulation of combustibles, its margin of safety over the HEPA filter is unknown. Its temperature limits are similar to the HEPA filter but its capacity for smoke is larger.⁽²⁸⁾ If an accumulation of combustibles should ignite in this type of filter, the filter would be destroyed and a portion of the accumulated radioactive material would be released as with a HEPA filter. Extinguishing this type of fire would not be a practical solution to containment, although a water spray applied to the burning filter might tend to limit the total amount of radioactivity released. Water spray applied to this media for cleaning after it has been in service for a long period would probably damage the filter. One filter of this type was partially regenerated (using steam) when it was found to be plugged with ammonium nitrate.⁽²⁹⁾

D. D.
May '60

FIGURE 16. 291-A Filter No. 1

4. Sand Filters

One type of filter that has been adopted for use with canyons and hot cells of fuels reprocessing plants consist of a deep bed of graded sand and gravel,⁽³¹⁾ placed in an underground concrete enclosure and equipped with air distributors, plenum chambers and ductwork. Since the efficiency of this type of filter is not as good (about 99.5 percent DOP) as currently required, it must be backed up by additional filters such as HEPA.

The resistance to fire is one of the most attractive features of the deep-bed sand filter. Its actual ability to withstand heat and ignition, as well as resist accumulation and release of radioactive material during a fire, has not been completely tested. It is reasonable to assume that all of these characteristics would be excellent. However, the fact that sand filters are large, expensive and require a considerable pressure drop has caused them to be rejected for many nuclear applications.⁽³⁰⁾ Where they have been used, they have performed well.⁽³¹⁾

Figures 17 and 18 show the filter media and physical arrangement of a sand filter. It is sized for about 26,000 cfm at a superficial velocity of 5 ft per minute through the bed.

5. Brink Mist Eliminators

An alternative type of filter for mist and smoke elimination is the Brink Mist Eliminator.⁽³²⁾ Mound Laboratory is pursuing this application.

D. FILTER PROTECTION

1. The Problem

A fire in a cave, canyon, or hot cell presents three threats to the exhaust filters: heat, smoke, and burning material (each of which could cause the destruction of the filter). Therefore, these threats must be prevented from reaching the filter in amounts that could endanger its integrity.

FIGURE 17. Graded Filter Bed

FIGURE 18. Sand Filter Used for 291-B Building at Hanford

Heat must be limited to temperatures that will not damage the filter media by melting or degrading, by ignition of the filter or its contents, or by structural damage to the filter enclosure or components.

Smoke must be prevented from reaching the filter in quantities that will plug the filter beyond the capability of the exhaust fans to maintain an adequate air flow.

Burning material must be stopped until it has burned and cooled to a point where it will not penetrate the filter media or cause the media or contents to ignite.

2. Prefilters

Prefilters have been frequently recommended as a means of protecting filters from fire as well as a means of lengthening the life of filters from dirt accumulation. A prefilter to accomplish these ends should be selected with great care and with the following considerations:

- a. How difficult will the prefilters be to change (it may be an unacceptable personnel hazard because of the radioactivity in the accumulated dirt)?
- b. How rapidly will they plug with particulates of the type present in the cell air?
- c. Can they be washed or otherwise cleaned in place?
- d. Will they withstand the environment?
- e. Will they withstand the heat or burning material to which they may be subjected?

Most prefilters used in caves, canyons, and hot cells are fiberglass, which if changeable, extend the life of the final filters (generally HEPA filters) significantly. Because their ability to withstand heat, smoke, and burning material is limited; use of such filters as a factor in the fire protection of a filter facility must be carefully evaluated.

Where airborne materials that originate in a cave, canyon, or hot cell are known to be flammable (such as metal powders), effective replaceable prefilters should be used as near the source as possible.

3. Air Washers

Fire protection of some filter installations is provided by air washers. One type, a coarse metal prefilter that presents no danger of plugging in normal operation, is covered by a water spray automatically activated by a thermal fire detector in the air stream. It has been found that heat and burning material can be stopped very effectively by this method.⁽³³⁾ If the prefilter is separated from the final filters by as much

as 5 ft there is little danger of carryover of sufficient water to cause damage. The amount of smoke removed by this arrangement has been found to vary.⁽³⁴⁾

The amount of water required to cool the smoke from a cell fire prior to its introduction to a filter can be calculated theoretically and a suitable safety factor applied.⁽³⁵⁾ A series of tests have been run using different types of spray nozzles, quantities of water and temperatures of effluent gases. The results are shown in Appendix E.

Another type of air washer that appears to be equally effective in cooling the smoke and removing the burning material from a fire is an ordinary sprayed-chamber air washer as used in air conditioning.⁽³⁾ Other air washers should be equally effective if designed for the particular service.

4. Duct Cooling

Cooling the fire exhaust gases by routing through the walls of long metal ducts (extending from the hot cell through cool areas prior to reaching the filters) can be used if the flow of gases is low in relation to the length of duct and the duct exterior is adequately cooled. The cooling can be calculated using methods outlined by Lessor⁽³⁶⁾ or by Smith.⁽³⁷⁾ For a particular application, a test may be used to establish the adequacy of the cooling.

5. Firescreens

Burning material must be prevented from reaching the final filters especially if they are HEPA filters. A small ember could penetrate the 0.015-in. thick media and allow the release or passage of radioactive material. For firescreens effective in preventing penetration, selection of the material and mesh is important. In some applications, firescreens of fine mesh (say 40 mesh) will plug with smoke and effectively stop the ventilation. Firescreens of 8 to 16 mesh have been found to be quite effective in removing burning material. Any sparks that pass this mesh

screen are rapidly consumed and present little threat to the integrity of a following filter. Several feet should separate the screen and the following filter for safety.

A firescreen can provide a valuable function immediately following a filter or prefilter where it can prevent the passage of burning material from one bank of filters to another. Firescreens should always be considered for the exits of hot cells or other enclosures where burning material could be released to the filter ductwork.

6. Moisture Separators

It has been found that the filters used in the final filtration of air from caves, canyons, and hot cells are susceptible to water. For HEPA filters in use for a long period, water may cause the filter to disintegrate. Water will also soak the media and increase the pressure drop to the point of plugging.⁽²⁵⁾

A number of moisture separators, usually made of finely woven material such as fiberglass, metal, stainless steel coated with "Teflon," or "Teflon" bats;⁽³⁹⁾ have been proposed for protecting final filters.

Tests have shown that closely woven moisture separators are very susceptible to being plugged by smoke,⁽⁴⁾ especially if the smoke originates in certain plastics or organic solvents. Washing of the smoke to cool and remove particulates seems to aggravate the tendency to accumulate on the moisture separator. If the separator is closely woven, it can plug rapidly with smoke and stop the exhaust air flow unless the unit is breached by the resulting pressure drop.

Before adopting a design that utilizes moisture separators ahead of the exhaust filters, tests should be made to assure they will not plug during a credible fire in the associated facility.

E. CELL OPENINGS

1. General

Any cave, canyon, or hot cell opening (a potential point where radioactive contamination can be emitted when fire occurs within the enclosure and causes the pressure to increase) should be avoided if possible. Where they must exist, as shown on Figure 19, methods of preventing them from becoming contamination release points should be considered.

2. Ventilation Inlets

Where the ventilation inlets could become an exit for radioactively contaminated particles from a hot cell, they should be provided with backflow preventers or HEPA filters. Backflow preventers are seldom completely effective, but for a particular application may be shown to be adequate. Installations which depend only upon the inlet velocity to contain contamination, are satisfactory if it can be shown that this velocity will be maintained under all conditions. Although higher negative pressures are often maintained to provide a safety factor, only about 0.1 in. of water negative pressure is necessary to maintain "capture velocity."⁽⁴⁰⁾

3. Windows

The leaded glass windows often used for viewing the interior of caves and hot cells are particularly vulnerable to fire. If the heat from a fire reaches the window, it may be quickly destroyed. Radiation exposure to personnel and radioactive release could result. If analysis of the fire hazard in a facility shows that the windows can be exposed to significant heat, it is imperative that they be provided with some form of protection. A fireproof curtain could be dropped quickly over the window either manually or automatically, or a metal shield could be moved mechanically between the fire and the window. Either one may be supplemented by a water spray. Since visibility will be precluded after the covers are in place, some other means (such as temperature instrumentation) must be provided to determine whether the fire is out.

FIGURE 19. High-Radiation-Level Analytical Laboratory (HRLAL) - Oak Ridge. Pneumatic operated, cell unloading, air lock door. This is at the rear of the cell bank on view from the cell access area. Note door positions and sample carrier car (on rails).

VII. APPENDICES

APPENDIX A
FIRES IN HOT CELLS AND GLOVEBOXES AT AEC FACILITIES

<u>Date</u>	<u>Loss</u>	<u>Remarks</u>
5-11-69 Bulletin 306	\$45,000,000	A major fire occurred in a plant which produces plutonium parts for nuclear weapons. The origin of the fire, as indicated by available evidence, was a glovebox storage cabinet containing pyrophoric chips and lathe turnings of plutonium pressed into disks 3 in. in diameter and 1-in. thick. The heat from the burning plutonium metal evidently caused the storage cabinet, which was constructed mostly of cellulosic laminate material and plastic, to char and generate flammable gases which could have been ignited by burning plutonium. There were no lost-time injuries from the fire or the firefighting, although one firefighter inhaled 0.021 microcuries of plutonium, which was expected to produce an accumulative annual dose to the lung of 20 rem. His annual lung exposure is 20 rem.
9-11-57 Bulletin 130	\$ 818,600	Fire in plutonium production line. Plutonium ignited spontaneously. Combustible filter at box burned. Fire spread to flammable plastic window and through ventilation system to ignite and destroy main filter bank. Serious spread of contamination.
11-6-63	\$ 397,000	Fire (definite cause undetermined) in plutonium purification facility. Plutonium contamination in immediate area of fire. Firemen received slight skin contamination, readily removed. Costs related directly to fire \$85,400; decontamination costs \$251,300; overhead related to direct losses \$60,300.
6-21-67	\$ 185,000	A fire occurred in the heat exchanger cell of a reactor when primary coolant pump lubricating oil, source of fuel for the fire, ignited after being inadvertently discharged into the cell equipment area when a normally open valve in the return line was not reopened after having been closed the previous day. The exact source of ignition was not determined, although several possibilities

<u>Date</u>	<u>Loss</u>	<u>Remarks</u>
		were considered. Damage was confined to a limited portion of the cell area, with some smoke damage to an adjoining pipe gallery.
11-10-60 Bulletin 175	\$ 101,000	Fire in glovebox in curium processing cave. Oil bath overheated. Combustible glovebox materials ignited. Equipment destroyed. Contamination released to room.
8-23-65 Bulletin 261	\$ 76,800	Explosion in acetone vapors while cleaning wax-like deposits from furnace. Vapors ignited probably by static spark. Three gloves ruptured. Fire controlled by 20 lb dry-chemical extinguisher applied through quick coupling connection. Decontamination costs \$76,200.
6-12-64 Bulletin 246	\$ 56,500	Explosion while degreasing plutonium chips. Chips ignited and accidentally fell into carbon tetrachloride bath, resulting in non-air-dependent chemical reaction type explosion. Window shattered. Employee injured. Decontamination costs \$43,000.
4-3-68	\$ 41,881	<p>A glovebox drying oven explosion blew out plastic shielding (up to 4-1/2-in. thick) on four gloveboxes, ruptured fronts of four others, and broke or displaced ceiling panels. Flying debris inflicted minor lacerations, abrasions and contusions on three employees and knocked their respirators off or out of position. The cause of the explosion was the ignition of the flammable vapors emitted by gloves being dried within the oven, which overheated when the temperature control contacts stuck. The oven did not have a high-temperature safety cutoff.</p> <p>The three injured employees received ^{238}Pu lung and systemic body burdens primarily through inhalation after their respirators had been knocked off or out of position by the explosion. However, only two received lung burdens in excess of 0.016 microcurie (0.295 μc and 0.105 μc which was expected to produce an annual dose to the lung of 110 rem and 39 rem respectively).</p>

<u>Date</u>	<u>Loss</u>	<u>Remarks</u>
10-27-64 Bulletin 242	\$ 34,900	Explosion from undetermined cause in methanol vapors while evaporating plutonium oxide solution. Six gloves torn from their ports. Plutonium oxide discharged through opened ports and spread throughout operating areas.
7-6-60	\$ 31,300	Explosion from undetermined cause in methanol vapors while evaporating plutonium oxide solution. Six gloves torn from their ports. Plutonium oxide discharged through opened ports and spread through operating areas.
7-6-60	\$ 31,300	Explosion (overpressure) of glovebox while purging equipment with argon. Malfunction of solenoid valves caused pressure to build up and blow off gloves. Contamination spread into several areas.
6-14-57	\$ 31,000	Explosion in vessel in glovebox. Gloves and window damaged. Decontamination costs \$11,000.
11-9-65	\$ 23,300	Explosion in acetone vapors ignited by muffle furnace in adjoining box. Paint containing 50 percent acetone being used for stripping and masking. Lack of communication between maintenance and technical groups.
10-1-64	\$ 21,000	Fire (definite cause undetermined) occurred around an ion exchange column in hot canyon. Fire caused airborne contamination to crane used for remote maintenance. Water to quench fire damaged electric motors.
6-14-69	\$ 20,200	An operation involving the burning of enriched fuel elements was shut down and examination revealed that a hole approximately 3 in. in diameter had been melted through the first-stage burner and the first-stage shroud surrounding the burner. This hole permitted escape of the burner contents, including ^{235}U and alumina bed material from the burner interior. Removal of insulation without contamination controls resulted in alpha contamination of the chemical engineering laboratory; costs consisted of \$13,000 for the loss of the ^{235}U and \$7,200 for decontamination. According to uranium inventory studies, 1311 grams of ^{235}U were

<u>Date</u>	<u>Loss</u>	<u>Remarks</u>
		unaccounted for following the incident and the subsequent dismantling and repair activity.
7-30-69	\$ 20,000	Two chemical operators screened plutonium residues from a previous fire, separating the fine material from the larger pieces. The fine material was placed in a can and sealed with plastic tape. The can was then placed inside two plastic bags and transferred to the storage area about 6:00 p.m. Around 11:00 p.m., a fire occurred. Friction during the screening or transfer of the residues probably initiated oxidation resulting in the eventual ignition of unstable plutonium compounds and/or plutonium metal fines within the can. The smoke and flame were produced from ignition of the plastic bag containers, the source for the ignition of the bags being the heat from the can containing the burning plutonium. The two chemical operators were found to have inhaled or ingested plutonium (estimated to be from 0.15 to 0.99 microgram), which was expected to be eliminated by normal body mechanisms.
10-15-65	\$ 17,000	Fire in plutonium chips in plugged drain. Plutonium carbon tetrachloride reaction initiated during forcible attempts to unplug line. Spread of contamination accounted for \$17,000 loss.
Bulletin 262		
10-30-65	\$ 7,200	During an aluminum jacket dissolution in a dissolver, an exothermic reaction involving ammonia and/or hydrogen occurred within an electric heater, through which these gases were accidentally vented. The reaction, which continued for 3 hours, totally destroyed the heater.
6-6-66	\$ 5,500	A fire, of undetermined cause, occurred in a laboratory. It was confined to one hood and a section of ductwork because of the successful operation of a sprinkler head, a fire damper in the exhaust system, and other fire protection controls.
8-27-65	\$ 4,700	Explosion due to decomposition of nitrated resin being dried on hot plate in glovebox. Window blew out. Room required decontamination.

<u>Date</u>	<u>Loss</u>	<u>Remarks</u>
7-19-63	\$ 4,500	Fire caused by resin-nitric acid reaction in plutonium production line. Seven gloves burned through. Carbon dioxide extinguishers used on flames. Magnesium-oxide sand used on glowing embers in box.
9-20-58	\$ 4,500	Steam explosion in water jacket of graphite incinerator within glovebox. Valves to cooling water left closed by mistake. Interlocks to be provided.
3-16-56	\$ 4,400	Fire in vapors given off from ether dissolved in water, ignited by hot plate. Plastic glovebox window burned. Floor, walls, ceiling and ventilating ductwork contaminated.
6-28-65	\$ 4,400	Explosion while machining plutonium. Plutonium chips burned and reacted with trichloroethane. Window cracked, plastic pouch blew out. Area contaminated. Inspection equipment corroded.
2-16-63	\$ 2,700	Overpressure of glovebox used for hydroform press when carbon tetrachloride liquid filled box. Glove burst and contaminated carbon tetrachloride spilled on floor of room.
8-16-57 Bulletin 129	\$ 2,000	Explosion in flammable solvent being used to clean rust from lathe. Sparks from brush ignited vapors. Eighteen gloves blown out, three safety glass windows cracked.
8-6-59 Bulletin 148	\$ 1,900	Explosive chemical reaction of alpha emitting solution involving acetone and nitric acid. Gloves blown off. Safety glass window cracked. Most of loss due to decontamination costs.
3-31-59	\$ 1,700	Explosion from decomposition of trichloroethane inadvertently substituted for trichloroethylene at plutonium machining operation. Glovebox window blown off. Room contaminated.
11-4-63	\$ 1,700	Fire in glovebox caused by rag in contact with hot leach tub. Improper use of dry chemical extinguisher pressurized box and resulted in gross contamination of room.

<u>Date</u>	<u>Loss</u>	<u>Remarks</u>
7-8-66	\$ 23,000 Bulletin 269	Paint was being stripped from a glovebox line, using both a nonflammable and a flammable (50 percent acetone) paint remover called cocoon. While the work permit required an inert atmosphere, and persons involved knew that a muffle furnace was in the same glovebox line, the guillotine door separating the paint stripping and the furnace was left slightly ajar. After removing stripped paint and recocooning the box, the fire started while the airlock door was opened, and contamination spread to the next floor through ductwork being modified.
11-4-66	--	During cleaning of a fission-gas apparatus with butyl alcohol, a small bit of nak dropped out and reacted in air. The spark ignited the alcohol vapor. Manual actuation of a 600 lb total-flooding carbon dioxide system put out the fire, but not before the inner window cracked. The mineral oil was drained, so additional fuel was not available. Cell negative pressure was maintained, and exhaust filters did not clog.
10-64	--	A fire occurred at Savannah River Plant in October 1964 in which spilled resin (in the nitrate form) apparently ignited from a combination of chemical reactions and self-heating from fission products. An accumulated mass of solids of various chemicals, concentrates and resin had been wet with 60 percent nitric acid just before the fire was discovered.
7-14-63	--	Plutonium is recovered from certain waste streams by ion exchange. The column which exploded had been sitting for 4 hours loaded with plutonium solution containing 8N HNO ₃ at ambient. A reaction between nitric acid and resin or hose material pressurized the column and ruptured a gasket blowing out partially oxidized material which started fires and local contamination. Evaluation suggested venting procedures for temporary shutdowns, pressure-relief devices, etc. Magnesium-oxide sand was very effective in extinguishing the fire.

APPENDIX B
PROPERTIES OF SELECTED ORGANIC SOLVENTS

A few organic solvents are used in substantial quantities in the processing of reactor fuel elements and certain other processes within caves, canyons, and hot cells. An attempt has been made to determine accurately the properties of these materials that would have a bearing on a fire involving them.

Information on the heat of combustion of selected solvents has been obtained as a part of the study of fires in caves, canyons, and hot cells by the Atlantic Richfield Hanford Company. Excerpts from this report are given in Table 1. For more detailed information, including the effects of contacting the solvents with water or nitric acid and exposure of the solvents to radiation, see reference 41.

Flash points of the mixtures of solvents used in certain solvent extraction processes were also obtained and are reported in Table 2.

Rates of combustion of the normal paraffin hydrocarbon used in the Purex process were obtained and are reported in Table 3.

Autoignition temperatures of some of the combinations of solvents are given in Table 4.

TABLE 1. Heats of Combustion (Heat of Combustion
calories/gram)

Solvent	Gross (No PV Correction)	Gross	Net (Std. Dev.)	Net (kcal/mole)	Number of Acceptable Runs
NPH (C _{12.23} H _{26.45})	11,340	11,317	10,512 (22)	1820	4
HEXONE	9,050	9,035	8,407 (70)	842.0	2
D2EHPA - Batch 1	7,970	7,955	7,435 (2)	2400	2
H ₂ O Contact	7,780				1
HNO ₃ Contact	7,796				1
D2EHPA - Batch 2	7,921	7,907	7,394	2384	1
Irradiated (1000 W/hr Co-60/liter)	7,442				1
TBP - Distilled	7,365	7,350	6,877 (59)	1832	3
TBP - Batch 1	7,219	7,205	6,732	1793	1
H ₂ O Contact	6,790				1
HNO ₃ Contact	6,320				2
DBBP - Distilled	8,012	7,996	7,513 (96)	1890	3
DBBP - Batch 1	7,920	7,904	7,455	1866	2
H ₂ O Contact	7,042				1
HNO ₃ Contact	6,502				2
TBP/NPH (20/30 vol.)	10,298	10,277	9,554		2
HNO ₃ Contact	10,170				2
0.3 D2EHPA + 0.2M TBP in NPH	10,602	10,582	9,813		1
HNO ₃ Contact	10,556				3

NOTE - To obtain Btu/lb multiply the above values by 1.8.

TABLE 2. Flash Points

<u>Solvent</u>	
NPH	156°F
10% TBP in NPH	158°F
20% TBP in NPH	161°F
30% TBP in NPH	165°F
40% TBP in NPH	167°F
50% TBP in NPH	169°F
TBP	275°F
D2EHPA	385°F
B Plant 1AX Stream (0.3M D2EHPA, 0.2M TBP, NPH)	167°F

TABLE 3. Rate of Combustion

- o The burning rates for NPH in a two-inch diameter quartz burning pool were obtained for a range of temperatures.

<u>Temperature of Solvent</u>	<u>Burning Rate</u>
40°C	Flame not sustained
45	0.8 ml/min
50	0.9
60	1.1
65	1.3
70	1.5
75	1.8
80	1.9
85	1.5
90	1.7

- o The slight decrease in burning rates at elevated temperatures was repeatedly observed.

TABLE 4. Autoignition Temperature

<u>Solvent</u>	<u>Ignition Temperature</u>
NPH	216 $\pm$ 3°C
10% TBP/NPH	222 $\pm$ 5°C
20% TBP/NPH	225 $\pm$ 5°C
30% TBP/NPH	233 $\pm$ 5°C
40% TBP/NPH	240 $\pm$ 5°C
50% TBP/NPH	245 $\pm$ 5°C
TBP	385 $\pm$ 3°C

APPENDIX C
EFFECTS OF IRRADIATION ON COMBUSTION
OF ORGANIC COMPOUNDS - A LITERATURE SURVEY

SUMMARY AND CONCLUSIONS

Several significant references were found concerning effects of irradiation on combustion of organic compounds. Studies show that the combustion efficiency and flame speed are increased when fuel-air mixtures are irradiated with very intense beta sources. Gamma irradiation was found to increase the rate of propane oxidation. Burning rates for solid fuel propellants were also increased by irradiation.

In each of these studies, the minimum amount of radiation necessary to show any noticeable effect was found to be very high. Most operations performed in hot cells or canyons would not involve organic solvents in a beta radiation field intense enough (200 curies per cubic inch) to significantly affect combustion rate.

DISCUSSION

Irradiation of combustible gas mixtures has been found to increase combustion efficiency. Cullen and Gluckstein⁽⁴²⁾ studied the effects of relatively weak beta radiation sources (100 to 2000 curies) on combustion of propane-air mixtures. They found no significant changes in the flame speed at these low source intensities. However, they did observe slightly increased reaction rates in the combustor.

Much more intense beta radiation sources were used by Churchill, et al.,⁽⁴³⁾ to irradiate propane-air Bensen flames. Beta radiation from a 10,000 curie gold source increased the flame speed by almost 50 percent; attributable to the formation of ion pairs by action of beta particles on the gas mixture. These authors also report⁽⁴⁴⁾ an increase in the amount of CH and C₂ radicals in the flames due to irradiation.

Liebenthal, et al.,⁽⁴⁵⁾ irradiated mixtures of propane and oxygen at several temperatures in the range of 95 to 350°C with a ^{60}Co gamma source. The yields of HCHO , AcH , and MeOH increased significantly under gamma irradiation, sometimes as much as 100 to 200 percent. Radiation also increased the overall reaction rate.

Research on the effects of ionizing radiation on combustion engine performance at the University of Michigan⁽⁴⁶⁾ has shown that beta radiation has little effect on combustion. Irradiation of the combustion chamber of a diesel engine with 1200 curies of ^{109}Pd had little influence on the performance of the engine.⁽⁴⁷⁾

Matos and Johnson⁽⁴⁸⁾ have compared the performance of rocket fuel irradiated with gamma radiation to 1500 rads with that of non-irradiated fuel. No significant difference was found when tested under similar conditions with specific impulse as the criterion of comparison.

The effect of irradiation on combustion of solid fuel propellants has been studied by several workers.^(49,50) Radiation was observed to decrease the burning rate of the polystyrene binder while rates increased for the ammonium perchlorate oxidizer and solid mixtures of oxidizer and binder. Only for very large radiation doses in the range of 300 to 400 megarads was any change in the combustion rate observed.

APPENDIX D
RELEASE OF AIRBORNE CONTAMINATION FROM BURNING
RADIOACTIVE SOLVENTS

The combustible organic solvent used in the Purex process, 30 percent n-tributyl phosphate in kerosine, upon burning, can potentially release dissolved radionuclides to the air with products of combustion. The fraction made airborne during a process cell fire was determined in laboratory experiments and engineering scale simulations. Up to 85 percent of the volatile materials (iodine) was made airborne when the solvent was heated to dryness. Less than 1 percent of the semi- and non-volatile components were found airborne under similar conditions.

The burning (oxidation in which heat and light are evolved) of materials is a vapor phase reaction. The combustion of a liquid is a heterogeneous reaction--the generation of a vapor from the liquid and the combustion of the vapor. In air, the vapor mixes with oxygen to produce a flammable mixture at some point above the surface of the liquid. Below auto-ignition temperatures, an ignition source is required.

Once initiated, the reaction provides energy to heat the solids, liquids and gases present as well as continue the reaction. If excess energy is produced, the fire increases and is limited only by fuel, oxygen or energy loss. In flowing airstreams, the combustion may occur at some point downstream from the pool of liquid.

Since most of the fission products present as contaminants of process solvents are heavy metals which do not volatilize appreciably under conditions found at the liquid surface, the airborne release of the contaminants results primarily from the formation of small particles which can be carried upward by the buoyant plume generated by the fire. Two mechanisms are apparent as potential modes of generating fine particles--initially liquid droplets produced by surface turbulence that evaporate in passing through the heated zone of the fire and the charred residue of process solvent deposited on various heated surfaces. Under quiescent conditions, release

via both mechanisms is low--undisturbed liquid surface and moderate charring of the liquid. As the fire grows hotter, the conditions become more rigorous. The rate of vaporization increases and more heat is generated. Air drawn over the surface of the liquid tends to create ripples, enhancing film formation.

Iodine is a volatile element and vaporizes readily even at moderate temperatures. Much greater releases would be anticipated. Compounds containing iodine decompose to liberate iodine.

The fractional airborne release of contaminants during the burning of process solvent was measured in bench- and engineering-scale simulations. The release of uranium and radioactive-isotope traced cesium, cerium, zirconium and iodine were measured in laboratory experiments during the combustion of 30 percent tributyl-phosphate in normal paraffin hydrocarbon solution simulating the organic product from the Purex co-decontamination cycle.⁽⁵¹⁾ Twenty-five milliliters of prepared, heated, organic solvent solution was burned in an upsweep of air. The quantity of uranium and traced isotopes airborne in the combustion products and in the residue deposited on the chimney were measured. The results are tabulated in Table 5.

The validity of the release factors derived from the bench scale for large scale fire was confirmed and engineering scale simulation performed in the 224-T Fire Test Facility.⁽⁵²⁾ Two simulations were conducted, each using 25 grams of strontium (as strontium nitrate) in 150 liters of 30 percent TBP in a kerosine diluent. The solvent was burned in ten stainless steel trays located some 8" above the surface of water upon which additional kerosine diluent had been added to aid ignition. Temperatures exceeded 1000°C in both fires which lasted 70 and 51 minutes. The fractions airborne were 0.22 and 0.19 percent and agree well with release fractions measured for similar materials in bench scale experiments (see Table 5).

TABLE 5. Fractional Airborne Release of Selected Isotopes
in 30 Percent n-Tributyl Phosphate in a Kerosene-
Type Diluent During Combustion

Element	Percent of Source Airborne ¹			
	Self Sustaining Burning Up to the Point of Spon- taneous Extinguishment ²		Self-Sustaining Burning but Heat Added with a Propane Torch in a Later Stage, Taken to Dryness	
	1 cfm	2 cfm	1 cfm	2 cfm
Uranium (270 g/l)	0.027	0.023		0.3
Cesium (0.2 ppm)	0.22	0.25	0.19	1.0*
Cerium (0.2 ppm)	0.74	0.56	0.77	0.71*
Zirconium (0.2 ppm)	0.65*	ND	0.55*	0.24*
Iodine (0.2 ppm)	65.7*	65.3*	81.7*	84.3* 82.8* 83.3*

¹Activity measured in all samples except residue.

²Experiment ended when flame self-extinguished. Usually 5 to 10 milliliters of liquid remained.

*Percent of total activity collected

ND - Not Detectable

APPENDIX E
RESISTANCE OF HIGH-EFFICIENCY (HEPA) FILTERS TO FIRE AND SMOKE

High-efficiency particulate air (HEPA) filters are resistant to a limited amount of fire and smoke. The frames, media and adhesives used in the construction of the filters are required by most user specifications to meet certain requirements:

- Wood Frames - Pressure treated to a flame spread rating of 25 per UL-723.
- Media - Military specification MIL-F-51079, Filter Medium, Fire Resistant, High-Efficiency.
- Adhesive - Will produce a filter that meets the requirements of UL-586 and which after curing, shall not crack, check, or lose more than 5 percent of its weight when heated for 48 hours at 300°F.
- Assembly - UL-586.

The filters produced to these specifications are unexpectedly resistant to fire when new. In tests conducted by Atlantic Richfield Hanford Company at Richland, Washington, they have withstood the heat from a fire in mixed laboratory material including paper products and organic solvents for one hour. During this time, the temperature in the filter varied from 100°F to 400°F and averaged about 225°F with flames intermittently impinging on the filter. After the test, the efficiency of the filter was measured at 99.994 percent DOP at rated flow (see Figure 20).

Another filter was destroyed deliberately by placing it in the same test setup (which simulated placing the filter in the bonnet of a laboratory hood with a fire in the hood) and subjecting it to a large fire. The filter resisted damage for 27 minutes with temperatures within the filter averaging about 400°F and with maximum temperature of 650°F. At this point, a sudden excursion in the temperature ignited the soot that had accumulated on the filter. Within five minutes, the filter was reduced to a mass of molten glass and aluminum. It appeared that the filter, while free of

soot, resisted damage. The binder was evolved as a white smoke for a short period without significant loss of efficiency. Once the fire started in the accumulation of soot, the filter was essentially destroyed in a few seconds. Efforts at fire extinguishing could not have saved the filter but may have cooled the fire enough to protect a downstream filter, and may have helped to fix some of the accumulated radioactive contamination (see Figure 21).

The resistance of high-efficiency filters to plugging by smoke depends to a great extent on the type of smoke, which in turn depends on the material being burned and the conditions under which it is burned.

Although very little is known about the effect of smoke on HEPA filters, some tests have been performed by Ewing⁽⁵³⁾ and by Adley.⁽⁵⁴⁾ The tests by Ewing, which consisted of burning quantities of selected materials and taking the smoke into an 8 x 8 x 5-7/8 in. filter until the pressure drop reached four in. water gauge at rated flow, are summarized in Table 6. With this information, a comparison may be made of the material in a given hot cell and the capacity of the exhaust filters to accept the smoke from cell materials should they burn.

Table 7 shows data taken from selected typical tests on the cooling and cleaning of smoke from a standing-pool solvent fire in a simulated hot cell. The efficiency of water sprays in removing particulates from this type of smoke is quite low. However, cooling of smoke to a temperature that will not harm HEPA filters is certain when using considerable amounts of water in a water spray.

FIGURE 20. This filter was used to filter the smoke from a fire which consumed ten pounds of mixed laboratory material requiring one hour to burn. Conditions of the filter at the beginning and end of the test were as follows:

Efficiency (DOP)	99.996%	99.994%
Weight	18990 grams	19100 grams
Differential Press at 1000 CFM	0.88" wg	2.4" wg

FIGURE 21. This filter was destroyed by a fire in the smoke accumulation. Fire was stopped by shutting off the air flow. Air flow was from top to bottom in this picture. The front (upstream) side of the filter was undamaged.

TABLE 6. Amount of Combustible Material Burned
Which Produces HEPA Filter Plugging

	<u>Amount Causing Plugging</u>		
	<u>g/50 cfm filter</u>	<u>g/ft²</u>	<u>lb/1000 cfm filter*</u>
Sanitary Napkins	650	54.2	23.8
Cellulose Wipes	600	50	22
Polyethylene Bagging	230	19.2	8.4
Polyurethane Gauntlets	110	9.2	4
Polyvinyl Booting	60	5.0	2-1/4
AMSCO	50	4.2	1.8
D2EHPA	50	4.2	1.8

*Calculated on basis of 200 square feet per filter.

Note: Plugging is defined as four inches of water CP at rated flow

From ORNL-TM-845, S. T. Ewing

TABLE 7. Smoke Cooling and Cleaning Tests

Test No.	Equip. Used	cfm Airflow	Water gpm 1000 cfm	ft ³ Air Sample	% Smoke Density	mg/ft ³ Smoke Conc.	% Efficiency	Temperature	
								Hot Gas	Washed Gas
1	A	3850	15	10	18	0.5	8	650-800°	150-170°
2	A	2200	31	10	19	0.7	10	650-800°	150-170°
3	B	2500	27	10	20	0.4	17	800	165
4	B	2000	30	7-1/2	20	1.56	25	400	160
5	A	3800	18	10	35	3.56	4.2	300	160
6	C	4700	14-1/2	10	5	0.3	5	800-950°	150-160°
7	C	2000	30	7-1/2	20	2.1	15	500-1600°	150-190°

Equipment

A - Sprayed Chamber Air Washer

B - A with 2-inch AAF HV-2 Filter Sprayed Both Sides

C - A with 4-inch AAF HV-2 Filter Sprayed Both Sides

Fire was in a standing pool of 158°F flash point normal paraffin hydrocarbon (Purex Process Solvent).

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