Atlantic Richfield Hanford Company
Richland, Washington 99352

A LITERATURE SEARCH AND ANALYSIS
OF FIRE PROTECTION IN
NUCLEAR HOT CELLS AND FILTERED EXHAUST SYSTEMS

H. A. Lee

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I. INTRODUCTION

Provision of means for protection of personnel, the environs and the facilities themselves in the event of a fire is fundamental in the design of nuclear facilities. The rapid growth of the nuclear business is creating a concurrent increase in exposure risk. This increase in exposure risk is widely recognized and many Commission sites are actively engaged in various programs to achieve a higher degree of fire safety in their facilities. Existing fire protection codes are basically sound, and are being used to the extent practical; however, with the additional exposure risks it is necessary that the intent of these codes be effectively extended further into many of the areas of greatest concern in the nuclear field such as prevention and detection in high radiation zones and protection of containment systems. Atlantic Richfield Hanford Company is vitally interested in achieving a maximum degree of safety in facilities under its contract responsibility.

To accomplish this end, a program has been undertaken to study the equipment and practices in use at other nuclear sites and to examine development efforts in progress that could contribute to our improved fire safety. This will be supplemented by specific test and development work where necessary to produce equipment and practices that will assure the required fire safety in facilities operated by ARHCO.

The first step has been to conduct a literature search and to talk with those responsible for operation of nuclear facilities. Contact was sought with those engaged in research and development and at improving the fire safety of facilities similar to those operated by ARHCO.

To extend the information acquired through literature and contacts with operating personnel of nuclear plants, a questionnaire has been sent to nuclear plants that include process process cells, caves or hot cells. The answers to the questions will reveal the status of fire protection at each plant and their plans for improvement. It is planned to summarize this information in a separate report.

A market survey was initiated to find fire detection equipment capable of meeting the requirements of fire detection in exhaust filter banks and in large remotely operated chemical process cells.

A test program is proposed to provide additional information on hot cell fires and methods of coping with them.

II. SUMMARY AND CONCLUSIONS

The attached bibliography represents a selection of available literature containing information useful to the design and development of fire protection for nuclear facilities similar to those at Hanford. Most references listed contain additional references not included herein.

A great deal of information is available from codes and standards and other publishings of National Fire Protection agencies. These are rapidly changing to recognize the problems of the nuclear industry.

The information assembled revealed a considerable variation in the equipment and practices in use in the existing nuclear facilities. In some areas, such as the resistance of High Efficiency Particulate Air (HEPA) filters to moisture, a difference of opinion exists even after extensive test and development work. In some areas such as fire detection in remote chemical process cells or detection of filter fires, no satisfactory solution has been produced.

Several areas remain where development test and analysis work would be valuable in improving the fire protection of nuclear facilities. Among these are:

- A. Fire detection in cells where the climate is highly radioactive, corrosive, humid, etc. where maintenance is difficult.
- B. Extinguishing fires under the special conditions existing in hot cells.
- C. Protection of filtered exhaust systems from fire and smoke.

III. RECOMMENDATIONS

The literature search and contacts with those knowledgeable in the field of fire protection in nuclear facilities have

revealed several areas in which additional efforts could productively be made to improve fire protection in ARHCO nuclear processing facilities. It is recommended that a program of research, development, and testing be initiated toward the following areas of specific attention:

- A. Develop a fire detector system capable of high reliability, adequate sensitivity and rapid response with self checking capability and capable of withstanding the corrosive, intensely radioactive atmosphere of the remotely operated and maintained chemical processing cells.
- B. Determine the effect of detector location, air currents, cell geometry, equipment location, and fire patterns and types on the detection of fires.
- C. Study various extinguishing media for effectiveness on the various types of fires expected in cells. Determine response time, extinguishing times, tendency for fire recurrence and ability to cope with adverse air currents and equipment location.
- D. Determine the compatibility of extinguishing media with the chemical process, process equipment and exhaust filter system.
- E. Evaluate the vulnerability of ventilation exhaust filters to fires in process cells both from burnout from excess heat and from plugging by soot and smoke. Consider the effect of variables such as fire size and type, distance from the fire to the filter, filter type, prefilters, moisture separators, and dilution air.
- F. Develop and test methods of protecting the exhaust filters from damage by fire while maintaining sufficient air flow to prevent an air reversal from the fire.
- G. Develop a method of detecting a fire in a large operating exhaust filter with sufficient accuracy to permit application of extinguishant without damage to adjacent filters and with sufficient reliability to protect downstream filter banks.
- H. Test various media for ability to extinguish filter fires both when in operation and out of operation.

- I. Develop criteria for a complete fire protection system for remote process cells which can also be applied to caves and hot cells. The system shall include detector, alarm, extinguishing, filter protection and filter fire detection and extinguishment.

IV. FIRE DETECTION AND SUPPRESSION IN REMOTE PROCESS CELLS, CAVES AND HOT CELLS

A. Description

Nuclear remote process cells, caves and hot cells vary so widely in geometry and function that a single description covering them is difficult. In size they vary from a few cubic feet to over 100 feet long by 40 feet deep and 14 feet wide. Shielding varies from a few inches to ten feet of concrete. Materials also vary.

The remote process cells are generally not under visual surveillance as are the smaller manipulator hot cells and caves.

In all cases, the atmosphere within the enclosure is maintained below atmospheric pressure to contain the radioactive particles and gases generated therein. Ventilation air flow rates vary widely to meet the requirements of the activities in the cell.

The exhaust air from the operating cells is filtered or otherwise cleaned of radioactive aerosols to within limits set by the Code of Federal Regulations before discharge. The most common treatment is filtration using one or more banks of HEPA filters. Details of these systems vary widely.

Conditions within process cells, caves and hot cells vary with the activities within the cell. All operators claim to make an effort toward good housekeeping thus limiting the fire hazard. However, these efforts are not always successful.

Fire protection in remote process cells, caves and hot cells appears to vary widely. For the larger remote process cells, thermal or flame detectors are used with an alarm system. Extinguishing is done by manually actuated water sprays. The smaller caves and hot cells use water, Halon, CO₂, or dry chemical, both in fixed and portable systems. Some have no provisions for fire extinguishing at all, but depend on prevention or lack of sufficient combustible material to create a serious fire.

B. The Hazards and Consequences

The caves and hot cells in use throughout the industry have a wide variety of fire hazards. This makes it very difficult to anticipate all the combinations of events that could lead to fire. It is noteworthy that few fires have occurred in hot cells or remote process cells (reference 68, 149-162), and these were a limited threat to containment of radioactive material. The heavy shielding walls are usually adequate for any conceivable fire.

The problem area of containment is the ventilation systems. It is conceivable that a fire could burn through the filter system and thus allow release of contaminated products-of-combustion, or soot could accumulate on the filters until they are plugged. Pressure from the fire could then cause contaminated air to be discharged via the supply system.

Most of the incidents can be attributed to one or more of the following: electrical failures, hot surfaces or overheated equipment, improper handling of flammable solvents including some procedure violations, exothermic reactions of metals, compounds and alloys with air, water, water or organic materials, and exposure of irradiated ion exchange resins to air (reference 68, 160).

The conditions within the enclosures often complicate the efforts at providing adequate fire protection. For instance, the atmosphere in remote process cells often contains fumes from the acid solvent (principally nitric acid) and on some occasions it has a high humidity. Coupled with the intense radiation from the process solutions, this presents a severe climate to fire detection and extinguishing equipment. The principal fire hazard within these cells is an organic solvent having properties similar to kerosene. Some miscellaneous cellulosic material resulting from maintenance or operations could contribute to the ignition or magnitude of a fire. It can be expected that a fire of this material taking place in such an environment would be very inefficient, and would thus produce an unusual amount of smoke which would tend to plug an exhaust filter.

C. Detection

The early detection of a fire is of great importance. The reduced time to extinguish the fire would limit the damage and would also limit the amount of extinguishing media required. This is important because this material cannot be discarded, but must become a part of the process waste. Indeed, if the fire involves a ruptured line or vessel it may be necessary to reprocess the material to recover valuable isotopes. Some recognition of this fact must be given during selection of the extinguishing media.

Experience with fire detection equipment currently available from manufacturers indicates that there is a lack of reliable equipment that will withstand the ambient conditions in radioactive process cell environments such as encountered in chemical processing plants at ARHCO. It is of utmost importance that a fire detection system for a plant of this type, because of its remoteness, provide long-life with a high degree of reliable performance.

Several criteria for a fire detector for hot cells have been proposed (reference 17, 32, 81).

1. The detection device should be self resetting or capable of being remotely reset after actuation.
2. Provision for routine testing the device should be included.
3. Device should be unaffected by the high radiation and the otherwise severe environment to which it will be subjected.
4. The detection device should be suited to the specific application. This includes cell size, type of combustible, air flow, obstructions and the temperature and content of the cell atmosphere.

Detection of fire in the remote process cell could be accomplished by several methods, but each method has serious disadvantages for use in this location. The analysis of commercial fire detectors and their application to hot cells done by Fenwal Incorporated in collaboration with E.I. du Pont de Nemours and Company at Savannah River Laboratory (reference 32) is very

comprehensive. They found that thermal detectors are the most reliable and maintenance free, but have limitations in sensitivity. Smoke detectors respond similarly to thermal detectors, but are slower with solvent fires and require excessive attention. Surveillance detectors respond faster, but require maintenance and are most prone to false alarms. Ionization-type product-of-combustion detectors are unsuitable for high radiation zones (reference 68). Product-of-combustion detectors may be sensitive to products normally present in the cell air.

One interesting approach that has been proposed is detection employing lasers (reference 60). This system is limited by the geometry of the hot cell system.

Of the nuclear installations that have remote chemical processing cells, Savannah River Laboratory has probably engaged in the most intensive research and development campaign to improve their fire detection (reference 32, 33, 69, 95). Their solution was to install thermocouples at strategic locations connected to an alarm system. Activation of the extinguishing system is manual under administrative control. There are two supplementary alarm systems, one using flame detection in the canyon roof (this was to be used when cover blocks are removed), and one using air analyzers in the exhaust ducts. Latest word is that only the thermocouples are in service and the supplementary systems are delayed pending reevaluation.

Other remote process cell installations include the Idaho Chemical Processing Plant which uses a self-actuated CO₂ system, and the several separations plants at Hanford which use manually activated water sprays and an alarm system using either temperature or flame detectors.

D. Extinguishing Systems

The extinguishment of fires in hot cells includes all the problems of fires in other places plus several that are peculiar to hot cells. First, there is the problem of access for personnel, for observation or for the extinguishing agent. Second, the rate of application of the agent is dictated by the ventilation exhaust rate, to avoid pressurization of the radioactively contaminated enclosure. Third, the compatibility of the extinguishing media with the process must be considered because it will be included in the process waste or may severely complicate cleanup.

Extinguishing systems using water, carbon dioxide, dry chemical or Halon 1301 are used for hot cells. In general, the problems are similar to those encountered in glove box systems which have been summarized by Factory Mutual and others (reference 45, 54, 71, 74, 83, 96).

Water Systems

Water appears to be favored as the extinguishing agent for large remotely operated cells where no danger of criticality or spread of contamination exists. Manual operation is provided where personnel are constantly present. Water can be mixed with a wetting agent for deep seated cellulose fires if so desired.

It has been recommended that a "Firecycle" extinguishing system using water spray be installed in the remote process cells (reference 38, 42). This is dependent upon highly reliable fire detection equipment to avoid damage or disruption of operation by false alarms. This system has the advantage of using the minimum of water where water damage is a serious consideration or simply to reduce the amount of contaminated water that must be collected.

It is possible to use water where there is some possibility of criticality by using a quantity limiting system such as is done in some glove box systems (reference 42). Where there is no danger of criticality, the advantage of having a continuous supply is an important consideration.

Carbon Dioxide System

Carbon dioxide as applied from a fixed system is capable of extinguishing fires in flammable liquids or cellulosic fires by reducing the oxygen content to below the combustible level. It is not effective on metal fires. The main disadvantages are: (1) it has a finite capacity and needs a backup in case of reignition of the fire; (2) the application rate must be geared to the ventilation rate to avoid pressurizing the cell (reference 45, 72); (3) a high ventilation rate reduces the time the concentration is at a safe level; (4) snow from a CO₂ discharge has been known to plug exhaust filters (reference 17,45); and (5) an effective concentration is above 35 percent CO₂ in air.

Dry Chemical Systems

The dry chemical, whether from fixed or portable systems, has been shown to be very effective on all types of fires (reference 45, 119, 120). It extinguishes by interruption of the combustion chain reaction (reference 45). The main disadvantages are: (1) special efforts are required to be certain the chemical is directed on the fire; (2) cleanup and disposal is potentially a problem. In some cases, this is an overriding consideration; (3) filter clogging is a special consideration, but can be overcome by planning (reference 45); (4) compatibility of the agent to the process or equipment is an important consideration.

Halon 1301 Systems

Halon 1301 (bromo trifluoromethane) has been shown to be a very effective extinguishing agent on all but metal fires (reference 31, 40, 41, 51, 56).

The extinguishing action is believed to be by chemical inhibition or chain breaking. The concentrators needed for extinguishing a fire is much lower than for CO₂ (reference 51, 56); therefore, the rate of application is less likely to pressurize the hot cell. The system is being applied to both glove boxes and hot cells with a great deal of confidence (reference 52, 68).

The only disadvantages of the system are: (1) high cost of the agent. This is partially off-set by the reduced quantity required; (2) is not well adapted to high ventilation rates as used in some hot cells; (3) time the concentration is above the combustion level is finite so there is some danger of rekindling. (This is much less serious than for CO₂.); (4) in some cases the Halon breaks down in the fire to form corrosive products (reference 51); and (5) acceptance by insurance underwriter's is incomplete.

High Expansion Foam System

High expansion foam is a fluid aggregate of small gas or air filled bubbles in which the ratio of gas to water may approach 1,000 to 1. It is generated by either fixed or portable units which force air or other gas through a screen that is saturated with water containing a foaming agent.

Extinguishing action is by reducing oxygen supply, cooling with water, preventing air circulation and steam blanketing.

Foam is becoming a more and more favored method of fighting fires in inaccessible places. It is very effective on cellulose, flammable liquid or plastic fires and has great merit for consideration for hot cells. It is relatively easy to clean up. A major advantage of high expansion foam is its ability to protect against fires within a large space by total flooding of the volume, without the exact knowledge of the location of the fire and the need for directional discharge of the agent. In large individual hot cells, fires, aided by ventilation, may travel the entire length of the containment system. High expansion foam can be introduced at any point in the system, reaching a fire at any other location and stopping the spread of fire to other portions of the containment system.

Several special designs have been developed for fighting glove box fires (reference 45) that may well be used in certain hot cells. One uses argon as the aspirating gas and is sized so as not to overfill the space and thus plug the filters (reference 92, 93).

The main disadvantages of high expansion foam are: (1) the rate of application must be geared to the ventilation rate to prevent pressurization; (2) foam will plug the exhaust filters if they are situated in such a way as to be flooded (reference 91); (3) foam will break down if the aspirating air is taken from the cell and includes products-of-combustion (reference 90); and (4) the entry of high expansion foam into a hot cell requires a relatively large opening which will give shielding and contamination problems. In existing hot cells with heavy shielding, the addition of such openings may be impractical.

Low Expansion Foam

Low expansion foam is a foam in which the foam to water volume ratio is in the order of 10 or 20 to 1. It is formed by mixing a foam concentrate with water and discharging it through a special aspirating nozzle. There are a good many types of foam, each formulated for a particular purpose. It is denser and longer lasting and less subject to air currents than high expansion foam. The main

advantage of low expansion foam is its effectiveness on specific types of fires such as alcohols and other flammable hydrocarbons when formulated and applied properly. It is tenacious and nearly precludes reignition of a fire.

The main disadvantages are: (1) by hot cell standards, cleanup is difficult; (2) the residue is more likely to be incompatible with the chemical processes or to give problems when combined with radioactive waste; and (3) for large remote process cells, it is relatively expensive.

Special Extinguishing Systems

For fires in pyrophoric metals materials such as magnesium oxide (reference 83), copper powder, sand and low melting eutectic salts can be applied manually. Plutonium fires are not considered serious if kept from igniting other fires and dealt with promptly (reference 46).

Where a specific fire hazard exists, extinguishing agents in containers in the hot cell may be applied by manipulator or piped directly to the fire from pressurized containers outside the cell.

Studies are being conducted on gelled water which may, if successful, allow incorporation of water when there might otherwise be a danger of criticality (reference 182).

V. FIRE CONTAINMENT, DETECTION AND SUPPRESSION IN FILTERED EXHAUST SYSTEMS

A. Description

The filtered exhaust system serving a remote process cell, cave or hot cell is the most vulnerable part of the containment system. The fibers of HEPA and fiberglass filters are very fine and almost instantly responsive to air temperature. The most practical fire resistant HEPA filter is damaged by temperatures above 700° F (reference 17, 101, 145). The filter media of the latest type of HEPA filter is only about 0.015 inch thick and very susceptible to mechanical damage including direct impingement of water droplets (reference 102, 106, 115). As a filter it removes

essentially all particulate matter from the air stream and in the process becomes more resistant to the passage of air until it becomes a barrier to air movement. Its capacity for dust and dirt is relatively low and is especially low for certain products-of-combustion (reference 35). Among the materials producing a soot capable of early blockage of the filters are the organic solvents in use in many remote process cells and certain caves and hot cells.

It is evident that destruction of the filters by fire and the release of accumulated radioactive material as well as fire generated material is to be prevented. At the same time, the quantity of smoke that is carried to the filter must be reduced to the point that the exhaust system can continue to function for the duration of a fire.

The lack of depth or mass of the HEPA filter and its low capacity for dust have been two factors in the selection of deep bed fiberglass filters for some remote process cell installations and sand filters for others (Hanford, Savannah River and GE Midwest Fuel Reprocessing Plant) (reference 185). These filters may in their lifetime develop high radiation levels where removal or repair is impractical. In these cases, the filters are often abandoned in place when they have served their purpose. The air flow is then diverted to a new filter which is constructed when the failure of the operating filter is anticipated. The life of such filters is quite long. Four sand filters at Hanford are still operable after many years even though the plants they serve may have been shut down for other reasons. The fiberglass filters have been about as successful except for the Hanford Purex filter which succumbed to large but unknown quantities of ammonium nitrate formed in the exhaust stream by an aberration of the chemical process (reference 22).

B. Containment

The prevention of release of significant quantities of airborne radioactivity during a fire in a hot cell depends upon maintaining the integrity of the filter system.

Several methods of protecting the filter system have been proposed. Distance from fire to filter and between filters is considered desirable (reference 15, 58, 132). Screens or baffles to stop burning material are proposed with the additional property of providing a heat sink (reference 17, 30).

Fire resistant prefilters using metallic mesh are considered valuable by some (reference 17, 58, 100). Reduction of ventilation flow and even complete stoppage are considered desirable by some (reference 132).

A water curtain in conjunction with a massive baffling system has been found by Domning to be effective in reducing the heat of the air stream. It serves first as a heat sink and then cools by evaporation. It also removes a major part of the solids (reference 30).

The resistance of HEPA filters to moisture and to sprays is not entirely clear in spite of much testing (reference 17, 20, 102, 106, 115, 122).

All agree that moisture in the filter is to be avoided, especially any direct impingement of spray onto the filter media. At some point, damage to the filter and reduction of efficiency can be expected. Even when the filter is undamaged, radioactive material has been found to be carried through the media by moisture.

Murrow found that very low flows of fine water droplets have only a small plugging effect on new clean filters. Rapid plugging of filters and damage to the media occurs with direct impingement of larger droplets (reference 102).

Nitteberg (reference 106) found that super saturated air at 200° F. did not damage the filter. The pressure differential increased while wet, but the efficiency was unimpaired.

Peters, et al (reference 115), found that filters with moisture separators were undamaged after exposure to wet steam and fog mixture for ten days. Without separators, the results were erratic, but showed that filters without moisture separators were frequently damaged by a severe steam-air-fog mixture applied for periods up to 30 days. Moisture increased the filter pressure drop more with dirty filters than with clean.

Rivers and Trinkle verified that HEPA filters can be protected from plugging during simulated reactor loss of coolant accident conditions by use of moisture separators.

C. Detection of Filter Fires

Since the adoption of the fire resistant HEPA filter, there have been few filter fires and these were of limited damage. However, the possibility of fire still remains where the accumulation of dirt on the filter is combustible. In such a fire, a portion of the accumulated contamination may be released along with that which escapes through the breach. Although it would be very difficult to quantify such an accident, it is regarded as serious enough to merit considerable effort and expense (reference 121, 162, 165).

There is need to improve methods of detection and location of filter fires. Also, a method is needed for extinguishing filter fires without plugging or breaching the filter bank.

The need for immediate action in the event of a fire in an operating filter is evident. First the resulting breach in the filter will pass a disproportionate amount of the radioactively contaminated air. Secondly the fire may spread to adjacent filters or to back-up filters.

The most reasonable method of detection appears to be one installed at Rocky Flats as reported by Walker (reference 178, 179) which consists of a grid of eutectic tubing on the downstream side of the filter banks.

This system has limitations in that the filter may well be breached before detection occurs; the tubing is susceptible to corrosion; the network does not pinpoint the fire location. However, this system is the best available at this time and is being recommended for installation (reference 15, 17).

A method of accurately locating a filter fire thus enabling the extinguishing media to be accurately applied is the subject of a market survey and development program undertaken by Oliver (reference 107). No probable solution has been proposed to date.

Erickson, Geer, and Linch made large scale tests of fires in filter banks (reference 34), and came to the conclusion that a smoke detector performed the best.

D. Suppression of Filter Fires

The best method of dealing with fires in exhaust filters is by prevention. Once a fire has started in a HEPA filter, it will almost surely breach the filter before it is extinguished. When detected, the least serious situation is a small local fire that involves a single filter. The capability of extinguishing such a fire without spraying and thus plugging an entire filter bank seems desirable.

Several methods have been considered for extinguishing fires in filters. Water, preferably with a wetting agent, either in a sprinkler system or in a recycling fog system, Halon 1301, and CO₂ are the methods suggested for operating filters. They all have serious faults.

The water systems have been noted as tending to plug the filter and carrying contamination through. If the filter can be isolated and abandoned, this may be of little concern because the water will tend to capture the contamination until it can be otherwise contained.

Erickson, et al, favor water fog for its reduced tendency to plug the filter and its greater tendency to penetrate the filter and to eliminate explosions.

An automatic, CFD-controlled, electrically operated, recycling deluge system employing water fog nozzles with system designed to prevent direct impinging on the filters has been proposed (reference 15, 34).

The desirability of this is somewhat doubtful. The quantities of water required and the limitations as to size of fire are yet to be determined. A single spot fire in a large filter bank should not require the entire filter bank to be sprayed.

Halon 1301 and CO₂ are suggested means of suppressing filter fires. The Halon has the advantage of requiring a much lower concentration (reference 31, 40, 41, 52), and as a result requires less extinguishant

inventory and less equipment. Carbon Dioxide has the additional disadvantage of at least temporarily loading the filter with snow (reference 17). Neither has been demonstrated to be effective on fires in operating filters. There is little doubt that either would be effective if the filter is isolated so the concentration can be maintained.

It is evident that a valuable feature of any filter fire protection system is the capability of isolating a filter bank while maintaining a minimum flow through a parallel bank. Care must be taken, however, to prevent pressurization from fire or a smoke explosion.

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