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FIRE PROTECTION IN CAVES, CANYONS,
AND HOT CELLS

MASTER

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FIRE PROTECTION IN CAVES, CANYONS AND HOT CELLS

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Abstract

The Atlantic Richfield Hanford Company in Richland, Washington, under contract by the Atomic Energy Commission, is conducting a study on fire characteristics in caves, canyons, and hot cells, and methods of detecting and extinguishing these fires. This paper presents results that have been obtained and outlines the direction the program will take in the future.

Tests have been made of various methods for detecting and extinguishing fires in a full-size simulated process cell. Information is presented on fire development, detection, and extinguishing times for fires in typical hot cells. Data are presented on smoke density and particulate size from fires of typical hot cell combustibles. Attempts were made to cool and remove the particulate matter from the gaseous effluents from these fires. Data were taken on temperature patterns and their effect on the optimum location of fire detectors. Results are presented on the effect of a fire on the ventilation system, such as turbulence within the hot cells, pressure, gas volumes, and mixing of the hot gaseous effluents with effluents from adjacent hot cells.

Future efforts will be directed toward studying problems of detecting and extinguishing fires in heavily shielded cells using a wider variety of combustibles, as well as studying the role radioactivity plays in hot cell fires.

I. Introduction

The problem of fires in caves, canyons, and hot cells has not received a great deal of attention in the past. At first glance, a fire that involves a relatively small amount of combustible and is enclosed almost entirely by heavy concrete walls does not appear to pose much of a threat. But because of the quantities of radioactive contamination usually present and its potential for damage if released to the atmosphere, it is well to know as much about the fire potential as possible.

The Division of Operational Safety of the Atomic Energy Commission requested that the Atlantic Richfield Hanford Company undertake to study the subject of fires in caves, canyons, and hot cells with the intent of learning as much about such fires as possible and how to deal with them.

The first step was to define the problem. A questionnaire was sent to AEC installations that include caves, canyons, and hot cells to determine the characteristics of these existing facilities, including their fire potential and fire protection capabilities. Briefly, we found the size to vary from the Hanford Purex canyon, which is over 1,000 feet long over 50 feet wide and 54 feet high, to some of only a few cubic feet. The combustibles varied from none at all to a large quantity of kerosene-like solvent. The exhaust system may be unfiltered or have as much as twelve high efficiency-particulate air (HEPA) filters in series.

The fire detection and extinguishing provided for those caves and hot cells varied as much as the cells themselves. Detectors, where

provided, were of every type available. Thermocouples were the most prevalent with rate-of-rise detectors second.

Extinguishing methods for the cells were of all types. The three favorites were dry chemicals, water and Halon 1301, in that order.

These facilities do have a few features in common. They are all shielded, although the thickness varies widely, and they all have a form of ventilation planned to contain radioactive contamination. It is obvious that it is at least unwise to seek to prescribe a single fire protection plan for all such enclosures.

A literature search⁽¹⁾ was undertaken to determine the present state-of-the-art of fire protection for caves, canyons and hot cells. It was at once apparent that fire protection is an old and well-developed subject and far from a stagnant one. Veritable libraries of information are available including codes, standards, guides, reports, and other references on all phases of fire protection. In addition, many people in code committees, insurance groups, and investigative bodies are constantly adding to this accumulation. Much of this information can be used in planning the fire protection for caves, canyons, and hot cells.

At the same time, manufacturers are adding new products and improving old ones to add to the tools available to the fire protection engineers.

A test facility was built to test detection and extinguishing materials, equipment, and methods as well as to collect information

on how fire develops in various fuels and under varying conditions in a hot cell. A program of testing is underway and will continue in conjunction with other phases of the program. The facility, which is described in CONF-710401⁽²⁾ and shown on Figure 1, consists of a 12 by 12 cell (inside dimensions) with an adjustable ceiling. It has an exhaust system in which washers, filters, demisters, and instrumentation is installed as needed (see Figure 2).

The fire that can be expected in a hot cell depends, of course, on the fuel type, quantity, and arrangement; on the ventilation of the cell, quantity and distribution of the air; and on the heat absorbing and reflecting surfaces in the cell.

It is understood that these fires can be of an infinite variety, but Figure 3 shows one type fire that may occur. This one was in 1 gpm of 70 percent normal paraffin hydrocarbon 30 (NPH-30) percent tributyl phosphate (TBP) fuel spilled on the floor of the 12 by 12 cell with 2,000 cfm of air drawn from the cell by the exhaust system.

Note that the fire is slow to develop in the high flash point (158° F.) solvent. When the solvent and the cell become sufficiently heated, the fire develops rapidly to a maximum and then begins to recede. This corresponds to a point where the cell pressure approaches zero and the inflow of air is at a minimum. Near this point, the smoke release hits a high point and then reduces.

After the initial surge and reduction, the cell temperature continues to rise slowly and the smoke density decreases. The static pressure at the bottom of the 40 foot deep cell is lower than at the top because of the chimney effect of the hot gases. The oxygen content of the air gradually reduces as the temperature of the cell increases.

The program undertaken to study fires in caves, canyons and hot cells is divided into several categories:

1. Extinguishing.
2. Detection.
3. Protection of filters during fires.
4. Effect of ventilation control on fire suppression.
5. Effect of radiation on combustion.
6. Effect of solvent temperature on the ignition and burning process.
7. Release of airborne contamination from burning radioactive solvents.
8. Protection of miscellaneous cell openings.

II. Extinguishing

It is desirable that the extinguishing media for use in caves, canyons, and hot cells meet several criteria.

1. The supply should be inexhaustible to cope with a fire of any size or duration.
2. It should leave no mess to clean up.
3. It should be simple and reliable to apply.
4. It should not damage equipment or process.
5. It should be completely effective.

It is apparent that no agent meets all of these requirements.

Of the several types of agents available are:

1. Water
2. Inert gases, including CO₂ and Halon
3. Dry chemicals
4. Foams, including high expansion, low expansion, and aqueous film-forming foams
5. Steam

Water meets the first requirements if the plant water system has been designed to withstand the maximum credible accident. However, it does have a clean-up problem, especially now that all contaminated wastes are concentrated and stored. It can damage equipment, especially electrical equipment; and it is not 100 percent

effective, for instance, when dealing with metal fire or with organic solvents.

Extinguishment with water was tested on the organic solvent most frequently used in nuclear separations processes. A variety of nozzles were used including standard sprinklers, three types of fog nozzles, water foam nozzles, and a spray wash-down nozzle. It was found that under certain conditions the water will extinguish fires in the organic solvent. If the fire has been allowed to get very hot, the water will flash to steam on the hot surfaces and extinguish the fire in a few seconds. Continuing the spray will cool the cell and prevent rekindling. Also, if the sprays are arranged so that they cover all of the fire directly, they will extinguish the fire. When the nozzles were located high in the cell and some of the solvent was under the tank, the fire resisted prolonged application of water whether by fog or spray.

The inert gases have the advantage of leaving the least mess but have the serious disadvantage of a limited reserve. We have done no testing of gases in the large cell because of this. Information is available for the design of such systems, and they will extinguish the fire. However, the problem of rekindling, especially in Class A materials, must be dealt with. Small caves or hot cells, where the ventilation is low, present much the same fire protection problems as glove boxes. Halon-1301 is being adapted to many glove boxes as well as small hot cells at the Savannah River Laboratory. These

compact systems should be highly effective when connected to an alarm system and supplemented as necessary with water.

Dry chemicals have the disadvantages of creating a mess in the cell, having a limited capacity, and allowing rekindling of the Class A fires. They also tend to plug the exhaust filters. Their use should be limited to places where their rapid action is needed and can be effective as a supplement to another system.

The foams, as a group, are very effective agents for dealing with most cell fires, especially in Class A and Class B materials.

Many kinds of foams were tested on organic solvent fires and all were effective. They do not meet the criteria of having an inexhaustible supply, but it is easy to provide a supply sufficient to cope with any credible fire. It has the advantage of being backed with water without any addition to the system.

The high-expansion foam was tested on organic solvent fires, and while not as effective as the other foams, it did an adequate job of extinguishing the fire. The main problem is finding a suitable means to apply it. Because it cannot be depended upon to produce a good foam when using air containing smoke from a cell fire, large openings must be provided in the shielding walls for application. Smoke or air must also be exhausted from the cell rapidly enough to prevent pressurization.

Tests of high-expansion foam showed that 2,000 cfm of foam did not extinguish an organic fire nearly as rapidly as 40 gpm of low-expansion foam or aqueous film-forming foam. In addition, the light foam was carried into the exhaust system where it would have plugged the filters. Efforts to stop it with screens, sprays, and air washers were largely ineffective. Figure 4 shows the foam used to extinguish an organic fire in the test cell. Figure 5 is a view looking into the filter housing showing it almost half full of foam in spite of efforts to remove it from the exhaust stream.

The low-expansion foams tested were very effective in extinguishing the fires. The foams were persistent and would resist rekindling and burnback. They also were difficult to clean up requiring direct and forceful water spray. When applied through any other than a water-foam nozzle, the foam was very poor and ineffective. These materials could well be considered for hot cell use if their chemical makeup is compatible with the waste system and means can be provided for cleanup.

Aqueous film-forming foams are relative newcomers to the fire-fighting scene. When mixed in the proper proportions with water, they form a highly mobile foam that floats on organic solvents. They are also strong wetting agents making them effective on both Class A and Class B materials. Several kinds of these foams were tested and found to be especially effective on organic solvent fires. Their main drawback is their chemical stability and adverse effect on the waste concentration process. A method has been developed to cope with

this in the Hanford waste streams. This and the fact that it is very effective when applied through existing sprinkler heads has allowed this material to be included in the fire extinguishing plans of two existing processing plants.

Steam has been used in the past in many fire extinguishing systems such as on naval vessels and factories where large quantities of steam are available. Lately this has fallen into disuse. For application to caves, canyons, and hot cells, it might be considered in special cases where the steam supply is large enough and danger to equipment and exhaust filters is not a problem.

III. Fire Detection

The matter of fire detection in shielded cells is a subject that has been covered by Arthur J. Hill, Jr. of Savannah River Laboratory in his documents DP-1242³(X) and DP-1261⁴(X). The information contained therein was used as a starting point for testing of detectors in the simulated hot cell.

The problems of detecting hot cell fires is unique in several respects:

1. Radioactivity is usually present in sufficient intensity to interfere with the operation of some types of detectors and to limit the life of others.
2. Hot cells are usually arranged so that maintenance of detectors is difficult because of the necessity of penetrating the shielding with electrical or pneumatic leads and the limited access to personnel.
3. The ventilation is controlled to the point that it may restrict detection.

Examples of several types of detectors that may be considered for hot cells are shown on Figure 10. From left to right they are Fenwall ultraviolet light detector, Pyrotronics infrared light detector, Infrared Industries infrared detector, and Fenwal continuous fire detector. Fenwal rate-compensated thermal detector is shown on the right with a stainless steel sheathed heater for remote testing and an insulating coupling. A stainless steel sheathed thermocouple is in the foreground.

Figure 11 shows how the heater can be used with the rate-compensated thermal detector for remote testing and supervision. The sensitivity of this model is not as high as the others, but its simplicity and ruggedness make it a good choice for hot cells.

The stainless steel sheathed thermocouple is a simple rugged device and is in use in many hot cells.

The reliability of the detection system for caves, canyons, and hot cells is of vital importance. It is desirable that it be sensitive and rapid acting; but if necessary, these characteristics can be sacrificed for greater reliability. Above all, the detectors must survive radiation, corrosive fumes, mechanical abuse, and often neglect and still detect a dangerous fire without fail in time to control and contain it. Remember that there really is no typical cave, canyon, or hot cell. Each is unique to some extent. Consider carefully the needs and characteristics of each installation, before selecting a fire detection system. Perhaps in some cells, two types of detectors should be used.

Some of the characteristics of the available detectors of interest to hot cell application are:

1. Heat detectors are generally slower to react if encased so that they are protected from corrosion or meahanical damage. Models available present some problems of supervision and testing. The rate-compensated thermal detector ^{has} for the best reliability because it can be protected and is of simple

sturdy design. Sensitivity is adequate if well located and the ^{activating} activity temperature setting is low. In some hot cells they may be installed in wells from the clean side as has been suggested for glove boxes⁽²⁾.

2. Products of combustion detectors are sensitive and are capable of detecting fires even before they become visible. However, they are not adaptable to the intense radiation or corrosion fumes found in hot cells. In the exhaust ducts, they were found to be less sensitive than other detectors.⁽³⁾ They are sensitive to dust and vapors and require excessive care and maintenance in hot-cell use.
3. Smoke detectors that use a light source and a light detector are subject to false alarm from dust or chemical fumes and are somewhat difficult to incorporate into hot-cell design to allow for maintenance.
4. The surveillance detectors which include ultraviolet, infrared, and other light detectors are fast acting but are subject to false alarm and failure in the hostile environment usually found in hot cells.

The best location for the detector is closely related to the convection currents that will be caused by the fire and the ventilation system. The tests indicated that both temperature and products of combustion can be detected early during the fire at the top of the

cell directly above the fire even for the tallest cell. However, the hottest temperatures were nearly always found at the exhaust port.

IV. Protection of Filter During a Fire

This phase of the program has been curtailed because of the work in progress at Lawrence Livermore Laboratory on the same subject. Smoke data was taken while conducting other experiments and data on cooling exhaust gases while protecting the fan and duct work. Conclusions are that the smoke from the organic solvent fires is hard to remove in a sufficient quantity to add significantly to the life of the exhaust filters. Typical smoke from an organic solvent fire is shown on the electron microphotograph, Figure 12. It is of a size and character that resists removal by simple water washes. The quantity of smoke varies widely with the character of the fire. The average fire in the test cell appeared to produce about one milligram per cubic foot, but some fires contained as much as three milligrams per cubic foot. A single 1,000 cfm-rated HEPA filter was loaded with soot from a solvent fire. Five gallons of solvent burned in a cut-off steel drum increased its pressure drop from one inch to four inches at rated flow.

V. Effect of Ventilation on Fire Suppression

Down-draft ventilation is more common in the large chemical processing cells than up-draft. The superficial down-draft velocity is only a few feet per minute. Thermals from a fire are many times this velocity. Figure 13 shows one gas-flow pattern that was calculated from a computer program prepared by Battelle-Northwest. The streamlines show direction of flow but give no value for their velocity. The highest velocity is where the lines are closest together.

Figure 14 shows the temperature patterns from the same fire. Note that the high temperatures are near the exhaust point of the cell, drawn there no doubt by the high velocity air patterns. Figure 15 is a photograph of a fire in the cell that shows much the same pattern. The program that produced these plots is being improved and included in a computer modeling program for hot cell fires at Battelle-Northwest at this time. It is hoped that it will be possible to predict the action of a fire in a cave, canyon, or hot cell with reasonable accuracy using the program they develop.

From the test data thus far, it appears that restricting the air to a hot cell fire can severely limit the fire and thus expedite its extinguishment and limit the damage. This has not been thoroughly tested in the test facility because of some chance of an explosion. It is hoped the modeling program will show the way to avoid this problem or if it really exists.

VI. The Effect of Radiation on Combustion

It is known that some work has been done that suggests that the presence of radiation may have a significant effect on the burning process.

A literature search revealed studies which showed the effects of nuclear radiation on the combustion of hydrocarbon-air mixtures. The combustion efficiency is increased and flame speed is increased when flames and fuel-air mixtures are irradiated with very intense beta sources. The minimum amount of radiation necessary to show any noticeable effect on combustion is very high (about 2,000 curies of beta per cubic inch). Organic solvents in a radiation field this high would probably not be encountered in caves, canyons, and hot cells.

VII. The Effect of Solvent Temperature on the Ignition and Burning Process

Organic solvents are sometimes used at elevated temperatures in caves, canyons, and hot cells. The additional danger from easier ignition and greater rapidity of fire development is suspected but not quantitatively known.

The ARHCO Separations Chemistry Laboratory is preparing to conduct experiments into the effect of initial temperature of the organic solvent on the ease of ignition, rate of combustion, and the rate of cell pressure increase.

Current efforts are confined to preparing laboratory facilities, gathering information on solvents, and reviewing methods of obtaining the required data.

VIII. The Release of Radioactive Contamination from Burning
Radioactive Solvents

It is known that airborne radioactive contamination is released from a fire in a radioactively contaminated organic solvent. The quantities released and the factors affecting this release are not quantitatively known. This information is needed by the industry to evaluate the hazards of release of radioactive contamination from a fire in a cave, canyon, or hot cell. This will influence the design of safety measures to cope with such fires.

The assistance of Battelle-Northwest has been engaged to carry out this investigation. They will also investigate the possible influence of the presence of water on the release of contaminants. They plan to investigate the release of a variety of radioactive contaminants from fires in five of the organic solvents most commonly used in caves, canyons, and hot cells.

IX. Protection of Miscellaneous Cell Openings

It is recognized that cave, canyon, and hot cell openings such as doors, windows, coverblocks, manipulator sleeves, ventilation inlets and various service ports are the only exit points for radioactive contamination other than the ventilation exhaust system. Existing designs for these openings may not be adequate to cope with a fire. Careful design from existing information on fire hazards may be adequate in many cases. However, improved means of assuring the integrity of some types of openings during a fire are needed. Plans are being made to test some hot cell opening designs for resistance to fire.

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LEGEND

- (T) TEMPERATURE
- (P) PRESSURE
- (ΔP) PRESSURE DIFFERENTIAL
- (F) FLOW
- (M) SMOKE & DUST MEASUREMENT
- (S) SAMPLER (FOR DUST & SMOKE)
- (D) FIRE DETECTORS
- (O) OXYGEN ANALYZER

DIAGRAM OF FIRE TEST FACILITY

FIGURE 2

FIGURE 3

Figure 4. High-expansion foam extinguished the fire when its depth reached eight inches above the tank bottom.

Figure 5. High-expansion foam was carried down the exhaust duct through the washer and half filled the filter housing.

Figure 6. Low-expansion foam at 40 gpm gives an effective extinguishing blanket.

Figure 7. Low-expansion foam resists a 40 gpm wash-down for several minutes. Three days later, it had dried with little volume reduction.

Figure 8. Several types of aqueous film-forming foam concentrates were tested.

Figure 9. One gallon of six percent film-forming foam made an effective blanket over a layer of organic solvent.

Figure 10. Types of Fire Detectors

Figure 11. Diagram for installation of thermal switch in a hot cell.

Figure 12. Smoke particles from 70 percent normal paraffin hydrocarbon, 30 percent tributyl phosphate fire

FIGURE 13 . STREAMLINES FOR HOT CELL FIRE

Figure 15. Fire is drawn to ventilation outlet.

Figure 16. Dry weeds did not burn one side of tank when fire reached 1300°F on the other.

Figure 14. Isotherms for Hot Cell Fire