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Final Report - Program for Fire Protection, Caves, Canyons, and Hot Cells

August 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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FINAL REPORT
PROGRAM FOR FIRE PROTECTION,
CAVES, CANYONS, AND HOT CELLS

H. A. Lee

Equipment & Instrument Development
Development Engineering Department
Research and Engineering Division

August 1974

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ATLANTIC RICHFIELD HANFORD COMPANY
RICHLAND, WASHINGTON

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FINAL REPORT
PROGRAM FOR FIRE PROTECTION,
CAVES, CANYONS, AND HOT CELLS.

INTRODUCTION

The Atlantic Richfield Hanford Company in Richland, Washington, under contract by the Atomic Energy Commission has conducted a study of fire characteristics in caves, canyons, and hot cells; and of methods of detecting, extinguishing and containing such fires. This document presents a summary of the work done and the results obtained.

During the course of the program several reports have been issued on progress in certain areas. These reports are listed as References 1 through 17. The information that is presented herein repeats information contained in these documents only as necessary to maintain coherence with other data presented.

PROGRAM SCOPE AND OBJECTIVES

The purpose of this program was to establish the theoretical and practical basis for providing suitable fire protection systems for nuclear caves, canyons, and hot cells. Its objective was to develop data and information for the design of fire detection and extinguishing equipment and methods for protection of these critical nuclear facilities from fire or the release of radioactive material as the result of fire. The results were used as the basis for a guide (Reference 1) which was published at the conclusion of the program.

The major areas of investigation were as follows:

Fire Extinguishment

Fire Detection

Protection of Filters During Fires

Effect of Ventilation Control on Fire Suppression

Effect of Radiation on Combustion

Effect of Solvent Temperature on the Ignition and Burning Process

Effect of Airborne Contamination from Burning Radioactive Solvents

STATUS OF EXISTING CAVES, CANYONS, AND HOT CELLS

A questionnaire was sent to AEC installations that include caves, canyons, and hot cells to determine the characteristics of 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 ft long, 50 ft wide and 54 ft 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 systems were unfiltered or had as many as twelve high efficiency particulate air (HEPA) filters in series.

The fire detection and extinguishing capability provided for those caves and hot cells varied as much as the cells themselves. Forty-one percent of the caves and hot cells had no detectors. Fifty percent of the installed detectors were thermocouples. About eighty-eight percent of the caves and hot cells were equipped with an extinguishing system. The three favorites were dry chemical, water and Halon 1301, in that order. Sixty-six percent of the exhaust filter systems were not equipped with fire detectors. Those so equipped depended upon some form of pressure drop instrument or heat detector. Thirty-four percent of the filter systems had fire extinguishing capability. The reported media were CO₂, dry chemicals, nitrogen and water.

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.

In general, there was revealed a divergence of opinion on the need for fire protection as well as on the type and details of application.

LITERATURE SEARCH

A literature search (Reference 2) 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, 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 for fire protection engineers.

TEST FACILITY

A test facility was built to test detection and extinguishing equipment, materials and methods as well as to collect information on how fire develops in various fuels and under varying conditions in a hot cell.

Figure 1 shows a general view of the facility. The simulated hot cell is enclosed within the corrugated shell. It is an insulated box which can be varied in height by lowering the cover. The height was chosen to represent the deepest remote process cell at one of the chemical separations plants operated by ARHCO. The cover can be lowered until it simulates the size of any of the several smaller cells.

The cell contains an old tank and a mass of old used pipes to simulate the vessels and remote jumpers of an active remote process cell.

Fires of various types may be set manually at the base of the cell. There are provisions for adding organic solvent while the fire is in progress to simulate the effect of a broken organic pipe or leaking vessel.

The ventilation duct emerging from the side of the cell is located at about the same height as the exhaust exit of a typical remote process cell. Duct size is chosen to represent the exhaust flow rate and velocity from a cell of this size in its normal operating mode with the cell cover blocks in place.

The exhaust ductwork length was chosen to give some opportunity to study the effect of distance on the smoke, products-of-combustion and other exhaust.

There is an entry point for dilution air into the duct near the exit of the duct from the cell.

At the right end of the picture is the air treatment equipment. It includes a standard sprayed chamber air washer with four banks of sprays, each of which can be operated separately. It has a wave plate moisture separator and space for other types of demisters or prefilters.

The fan is a standard centrifugal model which can be modulated by a variable inlet vane damper to give flow up to 300 percent

FIGURE 1. Fire Test Facility

of that required and negative pressures up to 6 in. of water. Duct sections can be removed or added or their order changed.

Figure 2 shows a diagram of the facility. Instrument types include temperature at nine points, pressure at four points, flows at two points and differential pressures at three points. The fire detectors are located in the cell and in the entrance to the exhaust duct and can be moved as desired. Smoke and dust measurements are shown both upstream and downstream of the air cleaning equipment. The sensing points of any of these instruments may be moved if it proves to be desirable.

The metal building houses the controls, instrument recorders and indicators as well as providing some storage.

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

FIGURE 2. Diagram of Fire Test Facility

FIRE EXTINGUISHMENT

SCOPE AND OBJECTIVES

The work on this program area adds to the information available from the National Fire Protection Association, the Underwriters Laboratories, the Factory Mutual System, the Factory Insurance Association and similar organizations with application to fire protection in caves, canyons, and hot cells. Fires in these facilities differ from ordinary fires primarily in that they must be confined to an enclosed space. This space is often unavailable for direct manual work, whether it be for fire fighting, maintenance or cleanup. This investigation is directed toward finding fire fighting materials and methods that can be automatically and remotely applied, are effective, cause no serious problems of cleanup or process complication and do not damage equipment in the cell.

Several categories of extinguishing agents were considered and some examples of them tested under simulated hot cell conditions. Water was the first and obvious choice. Halon 1301, high expansion foam, low expansion foam, aqueous film forming foams and some similar materials were procured, examined and tested. No tests of carbon dioxide or dry chemicals were made. These materials have been tested by others adequately to establish their limitations under hot cell conditions.

WATER

Water meets most of the requirements of an ideal extinguishing agent. 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 Purex organic solvent 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 water will extinguish fires in the organic solvent. If the fire has been allowed to get very hot, 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. A fire-cycle system was also used. It cycled many times without extinguishing the fire.

Water was used in a variety of nozzles (such as shown in Figure 3) to establish the relative effect on fires in the simulated hot cell. Some of the results are given in Table 1.

Some conclusions that may be drawn from the tests noted here are:

1. Water cannot be depended upon to extinguish a fire in the Purex organic solvent when it is in a cell where the entire surface of the solvent cannot be attacked with the water spray.
2. When the cell is very hot (such as when a hot fire has been burning for at least one min), it is possible for the steam from the water hitting hot surfaces to extinguish the fire.

FIGURE 3. Nozzles Used for Water and Foam Application

TABLE 1. Tests of Extinguishing NPH* Fires with Water

<u>Nozzle</u>	<u>No.</u>	<u>Height, ft</u>	<u>gpm</u>	<u>Time</u>	<u>Fire Temperature, °F</u>	<u>Results</u>
Grinnel Foam Water	2	40	173	3 min	300	Fire con- tinued
Grinnel Foam Water	2	40	173	10 min	500	Fire con- tinued
Bete N4W	2	40	75	30 sec	400	Extinguished
Bete N4W	2	40	75	8 sec	1000	Extinguished
Bete N4W	2	40	75	19 min	700	Fire con- tinued
Bete N4W	2	10	40	≈4 sec	800 Cell hot	Out instantly
Grinnel Sidewall 175° Sprinkler	2	40	47	42 min	300	Fire con- tinued
Grinnel Sidewall 175° Sprinkler on fire cycle	2	40	100	19 min	600	Fire con- tinued
Grinnel Sidewall 175° Sprinkler on fire cycle	2	40	100	30 min	≈175	Fire con- tinued
Spraying System 7N10 Fog Nozzle on fire cycle	2	10	40	19 min	≈600	Fire con- tinued

TABLE 1. (contd)

Nozzle	No.	Height, Ft	gpm	Time	Fire Temperature, °F	Results
Rockwood P-39 water foam	2	20	100	3 min	375	Fire con- tinued
Rockwood P-39 water foam	2	20	40	2 min	850	Time of extinguish- ment estimated
Spraying Systems 1 1/4 H SS-10	2	40	39	2 min	400	Fire con- tinued
Spraying Systems 1 1/4 H SS-10	2	40	39	40 sec	1100 Cell hot	Time of extinguish- ment estimated

* Normal paraffin hydrocarbon--diluent and principle
fire hazard in organic solvents

3. The ability of water to extinguish a fire did not depend on the type of spray or fog or with the type of nozzle. In each case the water had a cooling effect on the fire and reduced its intensity.
4. The cycling (such as with the fire-cycle system) did not aid in extinguishing the fire but, in cases where final extinguishing must be done by other means, it can reduce the quantity of water involved.

Other tests were carried out with the nozzles listed and with other solvents. When lower flash point materials such as hexone were used, the same general pattern was found. The intensity of the fire was reduced and in some cases, when the cell fire was allowed to get very hot, the fire could be extinguished by the action of the generated steam.

AQUEOUS FILM FORMING FOAMS

This is a relatively new category of extinguishing agent that has been developed to deal with organic liquid fires. The primary purpose of the development was for the jet fuels associated with military aircraft and naval aircraft carriers. It will work very well for any type of organic liquid which will not mix readily with water. The tests that were carried out in this series were aimed entirely at the organic solvents expected to be used in caves, canyons, and hot cells. Five foam materials were obtained and tested under similar conditions in the simulated hot cell. They are shown in Figure 4.

First, the foam materials were mixed artificially by shaking them in a gallon container until thoroughly mixed and then pouring them into a large beaker containing a layer of organic solvent floating on a layer of water. The results are shown in Figure 5.

It may be noted that there is some difference in the ability of the foams to remain in place. No direct correlation between foam lasting qualities and extinguishing power can be assumed.

Second, each of the materials was used in a test in the simulated hot cell. A fire was set using 1/2 gallon of the Purex organic solvent and 1 gallon per minute of fuel was added while the fire was in progress. When the exhaust gas temperature reached 300°F, the foam solution was added. Only 1 gallon of the 6 percent concentrates was used because previous tests had shown that no fire could be set in this cell with the solvent in question that could not be extinguished with this amount of solution. The recorded test times are shown in Table 2.

FIGURE 4. Aqueous Film Forming Foam Concentrates

The following conclusions were drawn from these tests:

1. The aqueous film forming foams are extremely effective in extinguishing organic solvent fires in the enclosed space of a hot cell.
2. From the standpoint of extinguishing, several of these materials are about equally effective.
3. The aqueous film forming foams are effective on Class A materials.
4. All aqueous film forming foams are easily rinsed from the cell interior.

Third, each of the aqueous film forming foams were tested for burnback characteristics. The following procedure was followed with each material.

1. Add 90 gallons of water (about 1 in.) on the floor.
2. Add 5 gallons of the organic solvent.

LIGHTWATER
(3M Company)

NO
PHOTO

AEROWATER-3
(National Foam
System, Inc.)

AF⁵
(National Foam
System, Inc.)

NO
PHOTO

EMULSIFLAME
(Elkhart Brass
Co., Inc.)

PROLITE
(Laurentian
Concentrates,
Ltd.)

1 MIN

10 MIN

1 HOUR

18 HOURS

*80 HOURS

FIGURE 5. Lasting Qualities of Aqueous Film
Forming Foams When Applied to
Organic Solvent

TABLE 2. Extinguishing of NPH Fires
with Aqueous Film Forming
Foams

(Fire in 1 gpm of NPH extinguishing at 300°F using
1 gallon of 6 percent concentrate or 1/2 gallon of
Aerowater 3)

<u>Agent</u>	<u>Extinguishing Time</u>
Prolite	1 min, 33 sec
Emulsiflame	35 sec
AF ⁵	35 sec
Aerowater 3	40 sec
Light water	34 sec

* Extinguishing action of the last four materials were essentially the same. When the time of travel from mixing point to the fire is subtracted, the time of extinguishing is about 12 sec.

3. Apply 1 gallon of the 6 percent solution or 1/2 gallon of the 3 percent solution through the mixing proportioner and water foam nozzles; then photograph.
4. Put a 3 in. ball of cotton cloth soaked in kerosene onto the surface and ignite.
5. Observe burnback.
6. When burnback becomes general in the cell, apply water through the water foam nozzles and observe the results.

The results of these tests are recorded in Table 3.

Two typical tests are shown in Figures 6 and 7.

The conclusions that can be drawn from these tests are that some of the aqueous film forming foams are better than others in resisting burnback if a fire should recur after being extinguished with these materials. It also shows that water sprays are very effective in extinguishing fires that rekindle after using some of these materials.

TABLE 3. Burnback Resistance of Aqueous
Film Forming Foam

<u>Agent**</u>	<u>Time of Initial Flame Spread</u>	<u>Time of General Flame Spread</u>	<u>Results of Water Spray</u>
Light water	5 min	6 min	Fire out in 20 sec
Aerowater-3	5 min	14 min*	Fire out in 6 sec
AF ⁵	3 1/2 min	25 min	Fire out in 25 sec
Prolite	10 min	20 min	Fire out in 4 1/2 sec
Emulsiflame	5 sec	10 sec	Fire con- tinued

* Aerowater 3 did not reach a general fire condition. The fire reached maximum size of 10 ft² and receded.

** Manufacturers

HALON*

Halon 1301 was tested on several typical hot cell fires. The intent was to determine the necessary concentrations and their effectiveness on various types of fires. The first tests were with a 2.8 percent concentration maintained for 1 min on a Purex organic solvent cell fire. This was allegedly a system being incorporated in the design of a new hot cell facility.

Additional tests were made using higher and lower concentrations both with and without a soaking period. The results of some of the tests are given in Table 4.

The conclusions that were reached as a result of these tests are:

1. The concentrations given in NFPA 12A for extinguishing may not be adequate under the conditions of a particular hot cell.

* E.I. Du Pont de Nemours, Co.

FIGURE 6. Example of Minor Burnback in an Aqueous Film Forming Foam After 21 min

FIGURE 7. Example of Major Burnback in a Less Effective Aqueous Film Forming Foam After 12 min

TABLE 4. Test of Halon on Hot Cell Fires

Test No.	Halon Conc., %	Time Conc. Held, sec	Fuel, gal	Fire Temp. Ignition, °F	Exting. °C	Remarks
1	2.8	10 sec	10 NPH	67	150	Fire did not develop rapidly and was easily extinguished.
2	1.8	60 sec	15 NPH	180	450	Fire was not extinguished. Water applied 1 min later extinguished the fire easily.
3	2.8	10 sec	15 NPH	150	275	Fire was not extinguished. Water applied 3 min later extinguished the fire after 4 min application.
4	2.8	60 sec	15 NPH	175	250	Fire was not extinguished. Water applied after 4 min delay failed to extinguish the fire.
5	2.8	60 sec	10 NPH	140	220	Fire was not extinguished. Water applied after a 6 min delay did not extinguish.
6	4.5	10 sec	10 NPH	140	200	Fire was extinguished immediately.
7	4	10 sec	10 NPH	140	225	Fire was extinguished immediately.
8	4	10 sec	5 Hexone	70	700	Fire was extinguished.
9	4	10 sec	5 Hexone	70		Fire was not completely extinguished. Water applied after a 30 sec delay extinguished the fire.

2. The concentrations listed for inerting should be used. A 6 percent concentration also is recommended for the Purex solvent. The ventilation that is kept in operation during a hot cell fire will sweep away the Halon and at the same time cause air leaks to become points where the Halon concentration is inadequate to extinguish the fire. (Fires were observed to continue burning at a crack in the wall when all the other fires had been extinguished.)
3. The condition of the simulated hot cell after these tests shows a significant amount of corrosion. It is evident that enough Halon is breaking down during the extinguishing process to have a significant effect on all metal surfaces in the cell including stainless steel. A piece of stainless steel pipe that has been exposed to several tests involving Halon 1301 is shown in Figure 8.
4. When Halon is present in a cell, water will extinguish a cell fire when either agent alone will not. (Water may aggravate the corrosion caused by the Halon breakdown products.)
5. The temperature at which the solvent is being used has a distinct effect on the effectiveness of Halon in extinguishing a fire in the material.
6. The value of the soaking period of 1 min was not detectable.
7. Class A materials that had been soaked with solvent did not appear to present a deep-seated fire at any time.

An attempt was made to determine the concentration of Halon in the simulated hot cell at various points and at different times after discharge. Test apparatus as shown in Figure 9 was set up and the following tests run. Distribution of Halon is given in Table 5.

SAMPLING

1. Freon Grab Samples

250 ml separatory funnels fitted with rubber stoppers, and piece of surgical rubber tubing with a pinch clamp were used to collect grab samples during the test. The separatory funnels were connected to the 5/16 in. I.D. copper sampling line in the vessel through a loose glass wool filter to remove soot. Air-Freon mixtures were drawn through the separatory funnels with a Gast vacuum pump at a rate of 11.4 liters/min. At this rate, there could be

TABLE 4. Test of Halon on Hot Cell Fires

Test No.	Halon Conc., %	Time Conc. Held, sec	Fuel, gal	Fire Temp. Ignition, °F	Exting. °C	Remarks
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2	1.8	60 sec	15 NPH	180	450	Fire was not extinguished. Water applied 1 min later extinguished the fire easily.
3	2.8	10 sec	15 NPH	150	275	Fire was not extinguished. Water applied 3 min later extinguished the fire after 4 min application.
4	2.8	60 sec	15 NPH	175	250	Fire was not extinguished. Water applied after 4 min delay failed to extinguish the fire.
5	2.8	60 sec	10 NPH	140	220	Fire was not extinguished. Water applied after a 6 min delay did not extinguish.
6	4.5	10 sec	10 NPH	140	200	Fire was extinguished immediately.
7	4	10 sec	10 NPH	140	225	Fire was extinguished immediately.
8	4	10 sec	5 Hexone	70	700	Fire was extinguished.
9	4	10 sec	5 Hexone	70		Fire was not completely extinguished. Water applied after a 30 sec delay extinguished the fire.

2. The concentrations listed for inerting should be used. A 6 percent concentration also is recommended for the Purex solvent. The ventilation that is kept in operation during a hot cell fire will sweep away the Halon and at the same time cause air leaks to become points where the Halon concentration is inadequate to extinguish the fire. (Fires were observed to continue burning at a crack in the wall when all the other fires had been extinguished.)
3. The condition of the simulated hot cell after these tests shows a significant amount of corrosion. It is evident that enough Halon is breaking down during the extinguishing process to have a significant effect on all metal surfaces in the cell including stainless steel. A piece of stainless steel pipe that has been exposed to several tests involving Halon 1301 is shown in Figure 8.
4. When Halon is present in a cell, water will extinguish a cell fire when either agent alone will not. (Water may aggravate the corrosion caused by the Halon breakdown products.)
5. The temperature at which the solvent is being used has a distinct effect on the effectiveness of Halon in extinguishing a fire in the material.
6. The value of the soaking period of 1 min was not detectable.
7. Class A materials that had been soaked with solvent did not appear to present a deep-seated fire at any time.

An attempt was made to determine the concentration of Halon in the simulated hot cell at various points and at different times after discharge. Test apparatus as shown in Figure 9 was set up and the following tests run. Distribution of Halon is given in Table 5.

SAMPLING

1. Freon Grab Samples

250 ml separatory funnels fitted with rubber stoppers, and piece of surgical rubber tubing with a pinch clamp were used to collect grab samples during the test. The separatory funnels were connected to the 5/16 in. I.D. copper sampling line in the vessel through a loose glass wool filter to remove soot. Air-Freon mixtures were drawn through the separatory funnels with a Gast vacuum pump at a rate of 11.4 liters/min. At this rate, there could be

FIGURE 8. Pipe Section Showing Corrosion After Several Halon Fire Tests

FIGURE 9. Sampling Equipment for Testing Concentrations of Halon at Several Points in the Cell and H.F. in the Exhaust Gases

TABLE 5. Distribution of Halon 1301 in Hot Cell During Extinguishing Test

Test No. 1

2.8% Halon 1301-Concentration Maintained 1 Min

<u>Sample No.</u>	<u>Location</u>	<u>Conc. Halon (vol%)</u>
1 (10 sec)	S.W. corner 1 ft up	1.0
2 (50 sec)	S.W. corner 1 ft up	1.0
3 (10 sec)	N.W. corner 5 ft up	1.0
4 (50 sec)	N.W. corner 5 ft up	0.85
5 (10 sec)	N.E. corner 1 ft up	1.2
6 (50 sec)	N.E. corner 1 ft up	1.0
7 (10 sec)	S.E. corner 8 ft up	0.70
8 (50 sec)	S.E. corner 8 ft up	1.2

Hydrogen fluoride - exhaust duct 178 ppm (V/V)

Test No. 2

2.8% Freon 12-Concentration Maintained 1 Min

<u>Sample No.</u>	<u>Location</u>	<u>Conc. Freon-12 (vol%)</u>
1 (10 sec)	S.W. corner 1 ft up	3.5
2 (50 sec)	S.W. corner 1 ft up	5.7
3 (10 sec)	N.W. corner 5 ft up	2.4
4 (50 sec)	N.W. corner 5 ft up	5.7
5 (10 sec)	N.E. corner 1 ft up	2.9
6 (50 sec)	N.E. corner 1 ft up	6.2
7 (10 sec)	S.E. corner 8 ft up	4.0
8 (50 sec)	S.E. corner 8 ft up	5.5

Test No. 3

4.5% Halon 1301-Concentration

<u>Sample No.</u>	<u>Location</u>	<u>Conc. Halon 1301 (vol%)</u>
1 (10 sec)	S.W. corner 1 ft up	2.8
2 (50 sec)	S.W. corner 1 ft up	6.4
3 (10 sec)	N.W. corner 5 ft up	2.4
4 (50 sec)	N.W. corner 5 ft up	6.6
5 (10 sec)	N.E. corner 1 ft up	2.3
6 (50 sec)	N.E. corner 1 ft up	5.4
7 (10 sec)	S.E. corner 1 ft up	4.5
8 (50 sec)	S.E. corner 1 ft up	6.5

TABLE 5. (contd)

Test No. 3
Hydrogen Fluoride

<u>Sample Time</u>	<u>Location</u>	<u>Conc. of HF (V/V)</u>	<u>Corrected Conc. HF* (V/V)</u>
0-1 min	S.W. corner 1 ft up	515	1030
0-2 min	Exhaust duct	565	1130
2.5-4.5 min	Exhaust duct	320	640

* This concentration is corrected for an estimated 50% collection efficiency.

expected to be about 0.75 air changes per second in the separatory funnel. Because of mixing and turbulence in the funnels, the funnel concentrations would approach a constant source concentration after 5 sec. This was determined by observing the rate of flushing smoke from a filled separatory funnel at the sampling rate. At selected time intervals after the discharge of Freon the stopcocks and pinch clamps on the separatory funnels were closed, isolating the grab samples.

2. Freon Monitoring (Gas Tech Halide Meter)

The inlet hose of the Halide meter was connected to a 5/16 in. I.D. copper sample line through a glass wool filter. The Halide meter was connected to a recorder to provide a continuous read-out of concentration vs time.

3. Hydrogen Fluoride in Test No. 1

Hydrogen fluoride samples were collected with two 250 ml gas wash bottles equipped with medium porosity glass frits connected in series to a Gast vacuum pump. A glass wool filter was used to remove soot. The collection medium was distilled water. The sample was drawn through the system at a rate of 0.5 ft³/min.

4. Hydrogen Fluoride in Test No. 3

HF samples were collected on 37 mm treated pads at a rate of 2 liters/min. Samples were collected for 1 min, 2 min, and from 2.5 to 4.5 min after the release of Halon.

ANALYSIS

1. In the first test with Halon 1301, analysis of the grab samples was accomplished by directly connecting the separatory funnel to the Halide meter and drawing the contents through the sampling chamber. In the second test with Freon-12 the contents of the separatory funnel were flushed into a plastic saran air sampling bag with a known volume of air for dilution, mixed and then drawn through the Halide meter sampling chamber.

2. Fluoride in Test No. 1

Analysis for hydrogen fluoride was accomplished by making appropriate dilutions and reading directly with an Orion Fluoride specific ion electrode.

3. Fluoride in Test No. 3

Analysis for fluoride was accomplished by soaking the pads in water, making appropriate dilutions and determining fluoride ion concentrations with an Orion specific ion electrode.

The conclusions that were drawn from the Halon distribution tests are:

1. The Halon takes some time after discharge to become distributed to all parts of the hot cell, then it tends to find its way to the lower part of the cell in a disproportionately large concentration.
2. The amount of Halon that is broken down is large enough to create a corrosion problem to some components that will be present in the hot cell.
3. Downflow ventilation, which is an advantage from other standpoints, is a disadvantage when extinguishing with Halon because the Halon will be swept from the cell by the ventilation.

LOW-EXPANSION FOAM

Several brands of low-expansion foams were used in tests on extinguishing fires in the simulated hot cell. In each case the material was mixed in the water stream with a proportioner and was introduced into the cell through water foam nozzles of the type shown on Figure 3. In the close confines of the simulated hot cell, they were all quite effective (see Figure 10). Both Class A and Class B fires were efficiently extinguished by these materials.

After the completion of the extinguishing tests the clean up of the cell was considerably more difficult than with the other types of foam. Also, some of the low expansion foams were of an organic base and had a limited life once the cell had been opened to the air. Some of the concentrates were corrosive and caused damage to the steel equipment and storage containers.

It was concluded that the above materials were not very attractive for use in hot cell extinguishing systems.

HIGH-EXPANSION FOAM

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 11 shows the foam used to extinguish an organic fire in the test cell.

The filters and screens intended to aid in removing the foam from the air stream acted as foam generators and increased rather than decreased the quantity of foam.

FIGURE 10. Low-Expansion Foam Applied to Organic Solvent Fire

FIGURE 11. High-Expansion Foam Applied to Organic Solvent Fire

FIRE DETECTION

SCOPE AND OBJECTIVES

The objective of this program area is to supplement available knowledge of fire detectors and their application to caves, canyons, and hot cells in order to achieve a maximum of reliability and sensitivity in fire detection. The available information on fire detectors and their application to caves, canyons, and hot cells is summarized in Reference 1 and 18.

The problems of detecting hot cell fires are 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. Access to the detector for maintenance, testing, resetting or replacement is usually very difficult dictating a design wherein access is seldom required.
3. Because of the remote operation of the equipment in the cell, the detector may be subject to mechanical damage.
4. Corrosion is usually more severe in the confines of a cave or hot cell.

DESCRIPTION OF THE WORK

The work of this program consisted of selecting fire detectors of each type, choosing models that seemed particularly suited to the task of protecting caves, canyons, and hot cells. Each was subjected to a wide variety of fires in several locations in the cell and ductwork. The times of activation and resistance to the fire conditions in the cell were observed and recorded. A summary and comparison of some of the detectors that were tested is given in Table 6.

Examples of several types of detectors that were tested are shown in Figure 12. From left to right they are Fenwal ultra-violet light detector, Pyrotronics products of combustion detector, Pyrotronics infrared light detector, Infrared Industries infrared detector and Fenwal continuous fire detector. A Fenwal rate-compensated thermal detector is shown on the right with a stainless steel sheathed heater that was evaluated in the search for a means of remotely testing the detector. A stainless steel sheathed thermocouple is in the foreground.

TABLE 6. Summary of Tests of Detectors

<u>Detector</u>	<u>Type</u>	<u>Sensitivity</u>	<u>Chemical Resistance</u>	<u>Radiation Resistance</u>	<u>Need for Maintenance</u>	<u>After a Fire</u>	<u>Resistance to False Alarm</u>	<u>Testable in a Hot cell</u>
Fireye	light	high	mod.	high	low except in outside circuitry	may need cleaning	poor	with diffi- culty
Fenwal Detect-A-Fire								
Mod. 28021-S-140	Rate Comp. thermal	mod.	high	high	none	o.k.	excellent	see Fig- ure 13
Mod. 28021-0-140	Rate Comp. thermal	mod.	mod.	high	none	o.k.	excellent	see Fig- ure 13
Mod. 17021-0	fixed temp.	low	mod.	high	none	o.k.	excellent	see Fig- ure 13
Mod. 90016-2	ultraviolet	high	mod.	mod.	low	may need cleaning	mod.	with diffi- culty
Pyrotronics								
Mod. F3/F5	ionization	high	low	may not work in high radiation	cleaning	needs cleaning	mod.	requires special design
Pyrotronics Pyralarm	photoelectric (visible smoke)	high	low	mod.	cleaning	needs cleaning	mod.	requires special design
Pyrotronics Pyralarm	infrared	high	mod.	mod.	low	probably o.k.	mod.	with diffi- culty
Systron Donner Mod. 804	heat	low	high	?	none	o.k.	high	requires special design or equipment

Left to Right: Fenwal Ultraviolet, Pyrotronics Products of Combustion, Pyrotronics Infrared, Infrared Industries Infrared, Fenwal Continuous Fire, Fenwal Thermal (with Sheathed Test Heater), and a Sheathed Thermocouple

FIGURE 12. Fire Detectors Tested

One of the most difficult aspects of the fire detection problem in hot cells is that of testing the detectors in place. This is because there can be no access to the cell by personnel with hand-held checking equipment. Procedures for checking the fire detectors must be considered when the hot cell is designed. Testing of light detecting instruments will require that light of the particular type produced by a cell fire be simulated; smoke detectors require that smoke of reasonable similarity to the smoke expected from a fire be piped to the detector; and heat detectors require that sufficient heat be applied to the detector to cause it to respond.

One aspect of this program was to develop a means of easily testing a heat detector while in place in a hot cell. The most suitable model is shown in Figure 13. To assure that it will perform adequately it was tested while exposed to a variety of air flows from still air to over 4000 feet a min. The results are shown in Table 7.

The location of the detector in the hot cell has an effect on the response time. This is caused by a variety of factors; several of which depend on the geometry of the cell, the materials involved and the nature of the fire. This was the subject of some testing as part of the program. Considerable

SPECIFICATIONS OF HEATER FOR REMOTELY TESTABLE FIRE DETECTOR

Heater; ARI Industries Part Number BXC-04F-17-16K with the following modifications and as shown on attached sketches 1 and 2:

- A. Cold end to be 2 in. long. If longer cold end is required in fabrication, all in excess of 2 in. shall be coiled same as heated section.
- B. A bulkhead fitting shall be affixed to the cold end as shown on the attached sketch. OD of the threaded portion of the bulkhead fitting shall be no greater than 1/2 in. The threaded portion shall be sufficiently long to handle a 1/4 in. thick bulkhead.
- C. The ID of the coiled portion shall be 0.650 in. minimum, 0.700 in. maximum. The number of turns shall be as needed for 300 W.

FIGURE 13. Heater to Remotely Test a Fire Detector

TABLE 7. Testing of Remotely Testable
Fire Detector (Figure 13)

140°F Fenwal 28021-5 7206
500 W Heater (115 v rating) ARI Tubular (coiled on detector)
60°F Air Temperature at Fan

<u>Air-flow</u>	<u>Loaded Voltage, (W)</u>	<u>Activation Time, sec</u>	<u>Cooling Time</u>
4100 fps	90 V (300)	11	7 sec
4100 fps	115 V (500)	7	7 sec
1800 fps	90 V (300)	9	18 sec
1800 fps	90 V (300)	9	18 sec
1800 fps	115 V (500)	7	21 sec
still air, 72°F	90 V (300)	5	2 min 35 sec
still air, 72°F	115 V (500)	4	2 min 55 sec

225°F Fenwal 28021-0 7207
500 W Heater
60° Air Temperature at Fan

1800 fps	115 V (500)	8	17 sec
1800 fps	90 V (300)	13	12 sec
4300 fps	90 V (300)	25	3 sec
4300 fps	90 V (300)	27	3 sec
4300 fps	115 V (500)	11	7 sec
still air, 72°F	115 V (500)	6	2 min 2 sec
still air, 72°F	90 V (300)	8	1 min 55 sec

testing to determine the optimum location for fire detectors has been done by Hill (Reference 18) and by Alpert (Reference 19). The findings of this program are generally the same with the exception that the long duration fires usually developed higher temperatures at the ventilation outlet than at any other point in the cell. Figure 14 shows a typical cell fire and the fire pattern that produced these high temperatures. The fire is swept more toward the ventilation outlet as the fire progresses.

CONCLUSIONS

Several conclusions were drawn from this work and comparison with similar testing that has been done by others:

1. A suitable detector for use in hot cells must be especially reliable and maintenance free, because access for normal maintenance and repair may be extremely difficult. Even if the detector can be removed from the hot cell for such work it will have been exposed to radioactive contamination and will require clean up before it can be repaired.

FIGURE 14. A General Fire in the Simulated Hot Cell
Showing the Fire Swept Toward the Outlet

2. 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.)
3. 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.
4. A detector to be used in a hot cell should not require resetting, cleaning or adjustment after it has been exposed to a fire.
5. The detector shown in Figure 13 has many of the characteristics desirable in a detector for caves, canyons, and hot cells. It is being adopted in some hot cell installations and is recommended for applications where its speed of response is adequate.
6. The point in the cell where detection is most rapid is directly above the fire where visible light, smoke columns or thermal columns will lead directly from the fire to the detector. The testing showed that earliest detection will be attained near the ceiling of the cell or directly over the fire in nearly every case. Any point near the ceiling (except directly in front of a ventilation inlet) seemed to give adequate response.

FILTER PROTECTION

SCOPE AND OBJECTIVES

Providing caves, canyons, and hot cells with practical ventilation exhaust systems that can remain in service through a maximum credible fire and contain all the radioactive contamination made airborne by the fire has been a goal of the nuclear industry for a long time. In order to realize this goal it is necessary to protect the filter in the exhaust system from heat, smoke and burning material. This program had as one of its early goals the development of systems that would protect exhaust filters from fire. Later, when Lawrence Livermore Laboratory undertook this aspect of the program, the efforts in this direction were confined to collecting pertinent information where it was related to other parts of the program. Nevertheless, exhaust filter protection is recognized as the most serious program area both because of the magnitude of the losses that can be sustained and because it is the area where the least is known.

DESCRIPTION OF THE WORK

The protection of filters was divided into the three logical parts. First the protection of the filters from heat. It is possible to determine the amount of heat that the present filters can withstand by examining available information, especially on HEPA filters. This shows that all of the filters now in use could be easily protected if the temperature of the gas going into the filter is reduced to near the temperature of boiling water. It was suspected that air or gases from a fire can be cooled to near this temperature by a spray system. A computer program was set up with the appropriate variables to determine the theoretical amount of water that must be evaporated into the gas stream to cool it. Then the spray system was set to deliver different multiples of this amount of water as other fire tests were in progress in the simulated hot cell.

The information collected from this activity was given to Wegner (Reference 11) who analyzed it and proposed methods of calculating the water requirement.

A simplification of the conclusions reached may be stated that if sufficient water is sprayed into the gas stream or onto a washed filter pad through which the gas must pass, the gases will be reduced to a temperature at which they can safely pass through any of the currently used filter systems.

Several curves of the amount of water required for cooling were calculated and approximated from the experimental data. These are shown as Figures 15, 16 and 17. The amounts of water required would be different for each type of equipment, each type of fire, temperature, etc. It is evident that it would be wise to provide an excess of water to be certain that the resulting temperatures are below the levels at which the filters will be damaged.

In addition to cooling the gases from a fire using water sprays, it may be convenient in some installations to make use of the cooling effect of long metal ducts exposed to cool air. Experiments were carried out as a part of this program to determine the cooling effect of metal ducts.

An experiment was set up using the equipment shown in Figure 18. An exhaust flow of 50 cfm was set with a manual valve and a fire set in the hood. The temperature in the hood reached 1500°F and was maintained at over 600°F for 40 min. The temperature at the filter 20 ft downstream was never over 185°F. During this time the flow was maintained at about 50 cfm. This leads to the conclusion that the cooling of gases from a fire by metal ducts is possible and practical in some cases. In order to make practical use of this information it should be predictable by calculation.

Lessor (Reference 12) used the experimental information to develop a method of calculating the cooling effect of metal ducts and compared his results with prior work by Smith (Reference 21).

Burning material must be stopped from reaching the exhaust filters where it could ignite an accumulation of combustibles and destroy the filter. At the same time the material cannot be allowed to accumulate so that it will stop the air flow.

Several meshes of screen were selected for testing with the expectation that the fine mesh screens would be the best and would furnish the greatest protection. Some of the screens are shown in Figure 19. A 50 mesh screen plugged with smoke soon after the start of the test fire. The type of smoke given off by each type of combustible was observed to be different and probably would plug different meshes of screen and at differing rates.

The tests that were run with 8 and 16 mesh screens and with fires that involved the usual mix of materials that may be found in caves, canyons, or hot cells were successful. None of the screens plugged with smoke and no significant burning material was observed passing a point just downstream of the

FIGURE 15. Water Cooling of Smoke-1000°F

FIGURE 16. Water Cooling of Smoke-1500°F

FIGURE 17. Water Cooling of Smoke-2000°F

screen. An old-style combustible media filter mounted 20 ft from the screen showed no sign of receiving burning material. The equipment used in this experiment is shown in Figure 18.

It was concluded that screens with meshes from 8 to 16 openings per inch will serve to stop burning particles large enough to damage a filter and are not likely to plug with smoke. It is known, however, that certain materials such as PVC give off such a dense smoke that a screen might be plugged. If such materials are present in large quantities in a hot cell, the fire screen should be of slightly larger mesh.

The protection of filters from plugging by smoke is a very difficult problem, which at this point has no adequate solution. It has been established by consensus and stated in the USAEC Regulatory Guides that: "Ventilation systems shall continue to perform their safety functions effectively under all conditions by confining radioactive or other potentially dangerous materials."

In order to achieve this goal the filter system must either accept all the particulate matter that comes to it during the course of a maximum credible fire and continue to function at some minimum rate, or the particulate material must be removed from the smoke prior to reaching the filter to such an extent that the same end can be realized.

A little work had been done prior to the start of this program on the amount of smoke that can be accepted into HEPA filter and was reported by Ewing (Reference 20). Some work was done in an attempt to verify some of this data under conditions simulating a fire in a large hot cell. Much different results were obtained. Figure 20 shows the results of one such test. It is understandable that different results are obtained in experiments involving such widely varying factors. No accurate prediction of the amount of smoke that will be produced from a fire can be obtained without a careful study of the whole process. Then, to complete the information, the effect on filters must be found.

Previous reports have described the attempts to remove particulates from smoke using air washers. These were generally unsuccessful. Some of the results are shown on Table 8. It is expected that the efficiency of the air washer will depend to a great degree upon the type of smoke, and this in turn will depend upon the material being burned and the conditions under which it is burned.

FIGURE 18. Test Equipment for Fire Screens
Fire Test Facility

FIGURE 19. Screens Tested for Attenuation of
Burning Material Meshes of 100, 50,
16, 8 and 4.

FIGURE 20. This Filter Was Used to Filter the Smoke from a Fire Which Consumed 10 lb of Mixed Laboratory Material Requiring 1 hr 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

TABLE 8. Smoke Cooling and Cleaning Tests

Test No.	Equip. Used	cfm Airflow	Water	ft ³	%	mg/ft ³	% Efficiency	Temperature	
			gpm 1000 cfm	Air Sample	Smoke Density	Smoke Conc.		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).

15,480X
FIGURE 21. Particulates in NPH Solvent Smoke

21,320X
FIGURE 22. Particulates in Hexone Smoke
 Prior to Washing

21,730X

FIGURE 23. Particulates in Hexone Smoke
After Washing

Electron microphotographs were taken of some of the materials contained in smoke. Figure 21 shows the smoke from NPH solvent. The particles which are mostly below the 1μ size appear to be made up of an agglomeration of even smaller particles. Figure 22 shows the smoke from Hexone prior to being passed through an air washer and Figure 23 shows the same smoke after it had passed through the washer. There is a preliminary indication of more agglomeration after the washing. Other tests have indicated that the particulates in the smoke are more likely to be deposited on a prefilter or demister after the washing operation.

The value of proper instrumentation in the evaluation of the smoke problem was recognized and an attempt was made to obtain instruments that will measure the number and size of particulates in the air. The General Electric Condensation Nuclei Counter, the Royco Optical Particle Counter and the Whitby Aerosol Analyzer were tried but were found to be unusable for this application in their normal mode of operation. Adaptations were never completed because of press of other work for Battelle-Northwest who owned the equipment. If this or other equipment could be obtained to do this job, the efficiency of particulate removal devices can be determined for each size

and type of smoke. In addition, the quantity and size distribution of particulates from each type of fire could be determined. This information should be valuable in analyzing the smoke problem.

CONCLUSIONS

It was concluded that of the three elements that threaten exhaust filters (heat, smoke and burning material), that two can be dealt with easily. Heat can be removed by a simple air washer and burning material can be removed effectively by a fire screen.

Smoke remains as a serious threat to the ability of a filter to "continue to perform its safety function." If the combustible cannot be limited either by compartmentation or by administrative control to an amount that will not produce sufficient smoke to plug the exhaust filter, a means must be developed to remove the particulates.

THE EFFECT OF VENTILATION CONTROL ON FIRE SUPPRESSION

SCOPE AND OBJECTIVES

It is known that ventilation has a significant effect on the intensity and efficiency of a fire. Therefore, control of ventilation can be a major factor in the suppression of fires in caves, canyons, and hot cells. Previous testing of fires in glove boxes and hot cells has suggested that there is an advantage to fire control when using downdraft ventilation rather than updraft ventilation. Also, it has been proposed that cutting off the ventilation at the inlet to a hot cell will help to extinguish a fire and thus reduce the load of combustion products on the exhaust filters. This program is intended to confirm or refute these theories and to establish parameters for the design of hot cells and their ventilation accessories.

DESCRIPTION OF THE WORK

The simulated hot cell and test exhaust system was set up with a downdraft pattern similar to those that are used in the majority of large fuel processing plants. Later in the program this arrangement was changed to allow for the introduction of the ventilation air at the bottom of the cell and the removal of the hot air at the top of the cell (updraft ventilation). A series of fires conducted in each operating mode showed a considerable difference in fire effect between downdraft and updraft ventilation. In general the fires with the updraft were hotter, burned steadier, produced less smoke, used a larger percentage of the oxygen in the air, and used more fuel with a given ventilation rate. A typical fire with downdraft ventilation is diagrammed in Figure 24, and a typical fire with updraft ventilation is diagrammed in Figure 25.

A study of the burning process of a hot cell fire was undertaken by Battelle-Northwest as a part of this program. A separate report (Reference 13) describes the work and the computer model developed from it. Using the information presented it is possible to determine the type of convection currents that will be experienced in a hot cell fire and to get some idea of the fire that will result in a given cell with a given air flow and fuel supply.

The effect of reducing the throughput of ventilation air during a fire was observed by adjusting dampers in the exhaust system, and on one occasion the fan was shut off. The fire appeared to be generally in proportion to the amount of air available to it. This reinforces the view that a practical way of aiding fire control in hot cells is to shut off the inlet air and thus

FIGURE 24. Cell Fire with Downdraft Ventilation

FIGURE 25. Cell Fire with Updraft Ventilation

deny oxygen to the fire. When the air flow was completely stopped there was no evidence of a danger of explosion. Rather it appeared that the fire would eventually go completely out with considerable fuel (Purex organic solvent) remaining in the cell.

One test of the effect of ventilation on a cell fire was carried out with 40 gallons of Purex solvent on the floor of the cell and a ventilation rate of 2000 cfm. After the fire had been underway for 4 min the ventilation was stopped. The cell filled with smoke and the fire was no longer visible. The temperatures went down from 325°C to 130°C. When the ventilation was again turned on the temperatures gradually rose to about 250°C. At this point the ventilation rate was increased to about 5000 cfm. The temperature then increased unevenly over a 15 min period until it went off scale at 1000°C.

At other times during the testing program when the ventilation rate was changed the same sort of results were obtained. At no time was there any indication of an imminent explosion.

The effect of ventilation on a filter fire was tested using a HEPA filter with combustible cellulose asbestos media. The filter was placed in the filter holder shown in Figure 18 and ignited by throwing a burning wad of Kleenex onto the front of the filter with an air flow rate of 200 cfm through the filter. When the filter temperature reached 700°F the ventilation was shut off. The flames visible at the back of the filter disappeared immediately and the temperature dropped to approximately the temperature of the air. After a pause of 30 min during which time there was no sign of fire, the ventilation was restarted. The temperature increased more rapidly than before and in 30 sec was at 1100°F at which point the ventilation was stopped. This was repeated 30 min later and 5 gallons of water was sprayed onto the filter. When the ventilation was turned back on, the filter again started to burn. Only when the water was applied and the ventilation completely shut off was the fire successfully extinguished. Figure 26 shows the appearance of the filter after extinguishing.

Figure 27 shows an unusual effect of ventilation on a cell fire. The floor is covered with a layer of organic solvent which is floating on a layer of water. Several pans of simulated contaminated solvent have been scattered about the floor as part of a test for carryover of radioactive material. The picture was taken after several minutes of the fire when the temperature was about 700°C. The oxygen content of the cell had been reduced to the point that nearly all of the burning was taking place at cracks in the cell wall where air was

FIGURE 26. Combustible Filter After Fire Was Extinguished by a Combination of Water and Ventilation Control

entering and combining with the fuel laden gas in the cell. The largest visible opening in the cell wall was near the floor on the far side of the cell. It was not possible to get a picture near the roof where the normal ventilation inlet was located, but at this point the roof temperatures were about 200°C hotter than at any other temperature point.

CONCLUSIONS

It is concluded that control of the ventilation of a cave, canyon, or hot cell can be an important factor in the fire control. Reduction of the ventilation rate can reduce the possible fire in the enclosure.

Because it is known that fire in an enclosed space tends to pressurize the air by heat and volume of combustion products, it is not practical to reduce the ventilation rate by reducing the exhaust rate. Reduction of the ventilation in this case must be done on the inlet side.

The experience of these tests is that downdraft ventilation produces a much less serious fire than updraft.

FIGURE 27. Cell Fire Showing Burning at Ventilation Leaks,
Caused by Low Oxygen Content of Cell Atmosphere

Convection currents caused by a fire within a large hot cell with downdraft ventilation are many times the normal downdraft ventilation rate. The velocity will move organic solvent across the surface of a water layer on the floor and tend to concentrate a fire at one point.

Contaminated smoke will probably escape from a hot cell during a fire. Smoke escaped from the test cell in nearly every case despite a negative pressure that was apparently maintained by the exhaust fan. The negative pressure at the top of a cell is less than at the bottom during a fire by an amount that can be calculated from the temperature of the gases in the cell and cell height.

Surges that are caused by uneven burning of the fire will cause the release of smoke from any openings in the cell.

THE EFFECT OF RADIATION ON COMBUSTION

SCOPE AND OBJECTIVES

It is known that some work has been done that suggests the presence of radiation may have a significant effect on the burning process. This could mean that organic solvents in the presence of intense radiation from reactor fuel in solution could present a serious fire hazard.

As a part of this program, some investigation into this possibility was carried out in order to find whether such a hazard exists and if so what its magnitude is.

PROCEDURE

A literature search was initiated to determine whether experiments had already been carried out to define the hazard of exposure of flammable solvents to intense radiation. The findings are reported in Reference 17.

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 Ci/in.³) to significantly affect combustion rate.

Irradiation of combustible gas mixtures has been found to increase combustion efficiency. Cullen and Gluckstein (Reference 22) studied the effects of relatively weak beta radiation sources (100 to 2000 Ci) 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., (Reference 23), to irradiate propane-air Bensen flames.

Beta radiation from a 10,000 Ci 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 (Reference 24) an increase in the amount of CH and C₂ radicals in the flames due to irradiation.

Liebenthal, et al., (Reference 25), irradiated mixtures of propane and oxygen at several temperatures in the range of 95 to 350°C with a ⁶⁰Co 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 (Reference 26) has shown that beta radiation has little effect on combustion. Irradiation of the combustion chamber of a diesel engine with 1200 Ci of ¹⁰⁹Pd had little influence on the performance of the engine (Reference 27).

Matos and Johnson (Reference 28) have compared the performance of rocket fuel irradiated with gamma radiation to 1500 rads with that of nonirradiated 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 (Reference 29,30). 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 Mrad was any change in the combustion rate observed.

CONCLUSIONS

It was concluded that the risk of increased fire hazard caused by the presence of intense radiation is negligible.

THE EFFECT OF SOLVENT TEMPERATURE ON THE IGNITION AND BURNING PROCESS

SCOPE AND OBJECTIVES

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 an important factor in planning the fire protection for these facilities. In addition, knowledge of the burning rates and heat generation of these solvents is important in estimating the fire that may be generated.

As a part of this program, laboratory work was carried out to establish the heat of combustion, burning rate, flash points, autoignition temperatures and the effect of chemical action on the common solvents used in caves, canyons, and hot cells. The effect of elevated temperatures on the fire development rate in a hot cell was studied, as well.

PROCEDURES AND EQUIPMENT

Laboratory equipment and procedures were used in determining the most useful properties of solvents generally used in caves, canyons, and hot cells; including their heat of combustion, flash points of mixed solvents, rates of combustion, autoignition temperature and burning rate.

Heat of Combustion

The net heats of combustion of the following solvents were measured in an adiabatic bomb calorimeter.

<u>Solvent</u>	<u>ΔH, cal/gram</u>	<u>Std. Dev., cal/gram</u>
Hexone	8,407	70
NPH	10,512	22
TBP	6,877	59
DBBP	7,513	96
D2EHPA	7,435	2

Solvent mixture heats of combustion follow the relationships:

$$\text{TBP in NPH, } \Delta H \text{ (cal/gram)} = \frac{0.9730X + (1-X) (0.745 P)}{0.973X + 0.745(1-X)}$$

TBP, D2EHPA in NPH, ΔH (cal/gram)

$$= \frac{266.3 QY + 322.4 ZT + P(745 - 203.9Y - 244.8Z)}{62.4Y + 77.6Z + 745}$$

where:

X = volume fraction of TBP in NPH
 Y = molar concentration of TBP
 Z = molar concentration of D2EHPA
 P = ΔH gram NPH
 Q = ΔH gram TBP
 T = ΔH gram D2EHPA

The pressure and temperature dependence of the heat of combustion is negligible. Mixtures of the solvents TBP, D2EHPA and NPH have a heat combustion that is an additive function of the individual heats of combustion.

Contacting these solvent mixtures with dilute aqueous HNO_3 has a slight depressing effect on the heat of combustion per gram. In the mixtures TBP/NPH (20/80 vol. ratio) and 0.3M D2EHPA, 0.2M TBP in NPH this depression is less than 2 percent, but would be expected to increase with increasing TBP content.

Contact of unmixed DBBP and TBP with water substantially reduced the heat of combustion per gram. Further reduction occurred after contact with dilute aqueous HNO_3 . This further reduction may be due to an increased water content rather than the HNO_3 itself. The D2EHPA used in this study was affected to a lesser extent by water contact and showed no further depression after HNO_3 contact.

The 6 percent drop in the heat of combustion of D2EHPA after 1000 W-hr/liter of cobalt-60 radiation indicates the need for additional work to characterize the effect of radiation on the heat of combustion.

A more complete discussion of the heats of combustion of nuclear solvents is contained in Reference 14.

Flash Point

Flash points for several process grade solvents were determined using a Pensky-Marten Closed Cup Flash Point Tester. The results are as follows:

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

When 20 percent TBP in NPH was contacted for 2 hr with 2M HNO₃, the flash point of the resulting organic exceeded 230°F. At this point, the organic was smoking and had turned from yellow to bright green. No actual flash point could be determined.

Rate of Combustion

The burning rates for NPH in a 2 in. diameter quartz burning pool at various initial temperatures were determined to be as follows:

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

Autoignition Temperature

The autoignition temperature of some process grade solvents and mixtures were determined to be as follows:

<u>Solvent</u>	<u>Ignition Temperature, °C</u>
NPH	215 ± 3
10% TBP/NPH	222 ± 5
20% TBP/NPH	225 ± 5

<u>Solvent</u>	<u>Ignition Temperature, °C</u>
30% TBP/NPH	233 ± 5
40% TBP/NPH	240 ± 5
50% TBP/NPH	245 ± 5
TBP	385 ± 3

The Effect of Solvent Temperature on Fire Development

The solvent used in the Purex solvent extraction process is sometimes used at elevated temperatures. One plant has a temperature of 140°F in some of its process vessels. It is also possible for the temperature in this plant or others to rise above the planned temperatures because of a malfunction of control systems. Temperatures were selected that covered the range that might be expected and tests run of the fire development characteristics.

A 4 in. layer of water was put on the floor of the 12 ft² simulated cell and the water was heated to the set temperature. Then the 5 gallons of NPH solvent was ignited and the temperatures in the cell recorded. The results are recorded in Figure 28. It may be noted that the temperature varied in the several points in the cell where temperature elements were placed. The temperatures at the 10 ft level on the outlet side of the cell were selected as the most meaningful and were used as a basis for the curves.

The results show that a fire develops significantly faster when the solvent is at a high temperature. No tests were attempted at higher temperatures because of the danger of a flare up or explosion.

CONCLUSIONS

The data developed on heat of combustion, flash points, rates of combustion and autoignition temperatures can be helpful in analyzing the possible fires that can occur in caves, canyons, and hot cells.

The effect of temperature on the fire development rate in the high flash point solvent shows that there is a higher risk involved when the processes are carried out at higher temperatures.

FIGURE 28. Effect of Solvent Temperature on Fire Development

RELEASE OF RADIOACTIVE CONTAMINATION FROM BURNING RADIOACTIVE SOLVENTS

SCOPE AND OBJECTIVES

One of the most important potential causes of damage associated with a fire in a cave, canyon, or hot cell is the spread of radioactive contamination. The organic solvent which has been intimately mixed with dissolved fuel elements appears to pose a threat of considerable magnitude if it should become involved in a fire.

As a part of this program an attempt was made to determine the percentage of various kinds of radioactive contaminants that will become airborne as a result of a fire in contaminated solvent.

PROCEDURES AND EQUIPMENT

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 as reported in Reference 15. 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 was measured. The results are tabulated in Table 9.

The validity of the release factors derived from the bench-scale for large scale fire was confirmed and engineering-scale simulation performed in the Fire Test Facility and as reported in Reference 16. 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 10 stainless steel trays located some 8 in. 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 min. 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 9).

TABLE 9. Fractional Airborne Release of Selected Isotopes
in 30 Percent n-Tributyl Phosphate in a
Kerosine-Type Diluent During Combustion

Element	Percent of Source Airborne*			
	Self-Sustaining Burning up to the Point of Spon- taneous Extinguishment**		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/liter)	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 [†]

* Activity measured in all samples except residue.

** Experiment ended when flame self-extinguished. Usually 5 to 10 ml of liquid remained.

† Percent of initial total radioactive isotope collected.

ND Not Detectable.

CONCLUSIONS

It was shown by the experiments that the amount of radioactive contamination that becomes airborne from burning radioactive solvents is much lower than expected except for certain volatile materials such as iodine. The material quoted here and in the referenced documents will be of considerable help in determining the severity of a contamination spread that could result from a fire in a cave, canyon, or hot cell.

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