MODULE 3.0: FIRE HAZARDS AND FIRE PROTECTION CONCERNS AT FUEL CYCLE FACILITIES

Introduction

Welcome to Module 3.0 of the Fire Protection for Fuel Cycle Facilities Directed Self-Study Course! This is the third of four modules in this self-study course. The purpose of this module is to identify fire hazards and fire protection concerns associated with the processes conducted at fuel cycle facilities. This self-study module is designed to assist you in accomplishing the learning objectives listed at the beginning of the module. There are eight learning objectives in this module. The module has self-check questions and activities to help you assess your understanding of the concepts presented in the module.

Before You Begin

It is recommended that you have access to the following materials:

- Trainee Guide
- NRC Information Notice 99-03, “Exothermic Reactions Involving Dried Uranium Oxide Powder”
- Augumented Inspection Team Report - Portmouth Fire"

Complete the following prerequisites:

- Module 2.0 Fire Protection Features and Systems

How to Complete this Module

1. Review the learning objectives.
2. Read each section within the module in sequential order.
3. Complete the self-check questions and activities within this module.
4. Check off the tracking form as you complete each activity within the module.
5. Contact your administrator as prompted for a progress review meeting.
6. Contact your administrator as prompted for any additional materials and/or specific assignments.
7. Complete all assignments related to this module. If no other materials or assignments are given to you by your administrator, you have completed this module.
8. Ensure that you and your administrator have dated and initialed your progress on your tracking form.
9. Go to the next assigned module.

MODULE 3.0: FIRE HAZARDS AND FIRE PROTECTION CONCERNS AT FUEL CYCLE FACILITIES

TABLE OF CONTENTS

LEARNING OBJECTIVES 3-1
INTRODUCTION 3-3
  Properties of Uranium Metal 3-3
  Pyrophoric Properties of Uranium Metal 3-3
FIRE HAZARDS AT FUEL CYCLE FACILITIES 3-4
  URANIUM MILLS 3-5
  Fire Hazards at Uranium Mills 3-6
  NRC Information Notice 99-03, “Exothermic Reactions Involving Dried Uranium Oxide Powder (Yellowcake)” 3-7
  URANIUM HEXAFLUORIDE (UF_6) CONVERSION FACILITIES 3-9
  Solvent Extraction Process 3-9
  Dry Fluoride Volatility Process 3-11
  Fire Hazards at UF_6 Conversion Facilities 3-11
  GASEOUS DIFFUSION URANIUM ENRICHMENT FACILITIES 3-15
  Fire Hazards at Gaseous Diffusion Facilities 3-17
  Hydrogen Fluoride (HF) and Fluorine System Hazards 3-17
  Lube Oil System 3-17
  Lube Oil System Fire Hazards 3-20
  Examples of Lube Oil Fires 3-20
  1998 Portsmouth Fire 3-21
  Description of Event 3-21
  Cause of Event 3-24
  Corrective Actions 3-26
  Extent of Exposure of Individuals to Radiation or Radioactive Materials 3-27
  Activity 1 – Fire Hazards Associated With Uranium Enrichment Processes and Equipment 3-28
  FUEL FABRICATION FACILITIES 3-31
  Fire Hazards at Fuel Fabrication Facilities 3-32
  Areas of Principal Concern for Fire Hazards 3-32
  Uranium Oxide Fires 3-36
  Examples of Uranium Oxide Fires 3-36
  Preventive Measures and Lessons Learned 3-38
  ZIRCALOY FIRE HAZARDS 3-41
  Glovebox Fire Hazards 3-42
  Nuclear Criticality Safety 3-43
  Example - Rocky Flats Fire, 1969 3-43
  Lessons Learned from the 1969 Rocky Flats Fire 3-44
  Safety Improvements Made as a Result of the 1969 Rocky Flats Fire 3-45

Case Study: Nuclear Fuel Services Erwin, Tennessee 3-45
Activity 2 – Fire Hazards 3-51
COMMON FIRE PROTECTION FEATURES AT FUEL CYCLE FACILITIES 3-55
OTHER FIRE PROTECTION FEATURES 3-55
Fire Hazard Analysis 3-55
Fire-Rated Barriers 3-56
Automatic Fire Detection and Suppression 3-57
Fire Emergency Planning 3-57
SUMMARY 3-58
Self-Check Questions 3-1 3-59

List of Figures

Figure 3-1. Uranium Mill Process Diagram 3-6
Figure 3-2. Solvent Extraction Process 3-10
Figure 3-3. UF_6 Production: Dry Fluoride Volatility Process 3-11
Figure 3-4. Flow Diagram for Gaseous Diffusion 3-16
Figure 3-5. Typical Oak Ridge Gaseous Diffusion Plant (ORGDP) Lube Oil System 3-18
Figure 3-6. Fuel Fabrication Process 3-32
Figure 3-7. ADU Process to Convert UF_6 to UO_2 Powder 3-33
Figure 3-8. Integrated Dry Conversion (Idr) Process Flow 3-34
Figure 3-9. Fuel Fabrication Block Diagram 3-35
Figure 3-10. Erwin Facility 3-47
Figure 3-11. Incinerator Systems 3-48
Figure 3-12. Incinerator Scrubber System 3-49
Figure 3-13. Incinerator Control Panel 3-50

List of Tables

Table 3-1. Chemical Substance Fire Hazards at UF_6 Conversion Facilities 3-12

MODULE 3.0: FIRE HAZARDS AND FIRE PROTECTION CONCERNS AT FUEL CYCLE FACILITIES

LEARNING OBJECTIVES

3.1 Upon completion of this module, you will be able to identify fire hazards and fire protection concerns associated with the processes conducted at fuel cycle facilities. You will be able to:

3.1.1 Identify two sources of fire hazards associated with uranium milling.

3.1.2 Locate the areas of principal concern for fire hazards at a uranium mill.

3.1.3 Identify the fire hazards associated with the acids, organic solvents, and/or gases used during the conversion process.

3.1.4 Locate the areas of principal concern for fire hazards at a uranium conversion facility.

3.1.5 Identify the fire hazards associated with uranium enrichment processes and equipment.

3.1.6 Locate the areas of principal concern for fire hazards at fuel fabrication facilities.

3.1.7 Identify the fire hazards associated with processes that involve zircaloy metal.

3.1.8 Identify common fire protection features found at all fuel cycle facilities.

This page has intentionally been left blank.

MODULE 3.0: FIRE HAZARDS AND FIRE PROTECTION CONCERNS AT FUEL CYCLE FACILITIES

INTRODUCTION

Following an accident (not fire related) in January 1986 in a uranium hexafluoride conversion facility, the NRC instituted the Materials Safety Regulation Review Study Group. This committee identified fire as a notable hazard that could result in the release of radioactive material in the environment. Subsequently, the NRC established fire protection requirements for fuel cycle facilities regulated by the agency. In-depth safety assessments of the major facilities were performed and pertinent issues on fire protection were raised.

This module describes the fire hazards and the fire protection concerns found at fuel cycle facilities. Areas in the processes that present the most likely locations for fires are identified with an oval in the process diagrams. The most common fire protection features are also discussed.

Properties of Uranium Metal

Nonenriched uranium is a radioactive metal that is also combustible. Most metallic uranium is handled in massive forms that do not present a significant fire risk unless exposed to a severe and prolonged external fire. Once ignited, massive metal burns very slowly. In the absence of strong drafts, uranium oxide smoke tends to deposit in the immediate area of the burning metal. Unless covered with oil, massive uranium burns with virtually no visible flame. Burning uranium reacts violently with carbon tetrachloride, 1,1,1-trichloroethane, and the halons. For power reactor purposes, uranium fuel elements are always encased in a metal jacket (usually zirconium or stainless steel).

Pyrophoric Properties of Uranium Metal

The pyrophoric characteristics of uranium are similar to those of plutonium. Both form pyrophoric oxides and hydrides. Both react violently with water and are best stored in their oxide form (UO_2, PuO_2) in dry, inert atmospheres.

Uranium in finely divided form is readily ignitable, and uranium scrap from machining operations is subject to spontaneous ignition. This reaction can usually be avoided by storage under dry (without moisture) oil. Grinding dust has been known to ignite even underwater, and fires have occurred spontaneously in drums of coarser scrap after prolonged exposure to moist air. Because of uranium’s thermal conductivity, larger pieces generally have to be heated entirely to their ignition temperature before igniting.

Depleted uranium (DU) chips and turnings are generated during machining of uranium metal. Because high surface area uranium is pyrophoric, the turnings are subject to spontaneous ignition in air. The oxidation of uranium to UO_2 and U_3O_8 is highly exothermic; therefore, the reaction may be self-sustaining. A uranium fire or even rapid oxidation and thermal convection currents will cause emission of radioactive uranium oxides.

In the presence of water as liquid or vapor, uranium may also oxidize into UO_2 and U_3O_8 with generation of hydrogen, a flammable and explosive gas. The heat generated by the water reaction may ignite the uranium or hydrogen producing a fire, explosion, or convection current resulting in some uranium oxide becoming airborne. Because the high surface area uranium has the hazardous characteristic of reactivity, it is stored immersed in diesel oil preventing contact with water or air. Uranium surfaces treated with concentrated nitric acid are subject to explosion or spontaneous ignition in air.

FIRE HAZARDS AT FUEL CYCLE FACILITIES

The next section of the self-study guide provides a brief description of the processes in each of the fuel cycle facilities of milling, conversion, enrichment, and fuel fabrication. Specific hazards associated with the processes are also identified.

MODULE 3.0: FIRE HAZARDS AND FIRE PROTECTION CONCERNS AT FUEL CYCLE FACILITIES

Learning Objectives

When you finish this section, you will be able to:

3.1.1 Identify two sources of fire hazards associated with uranium milling.

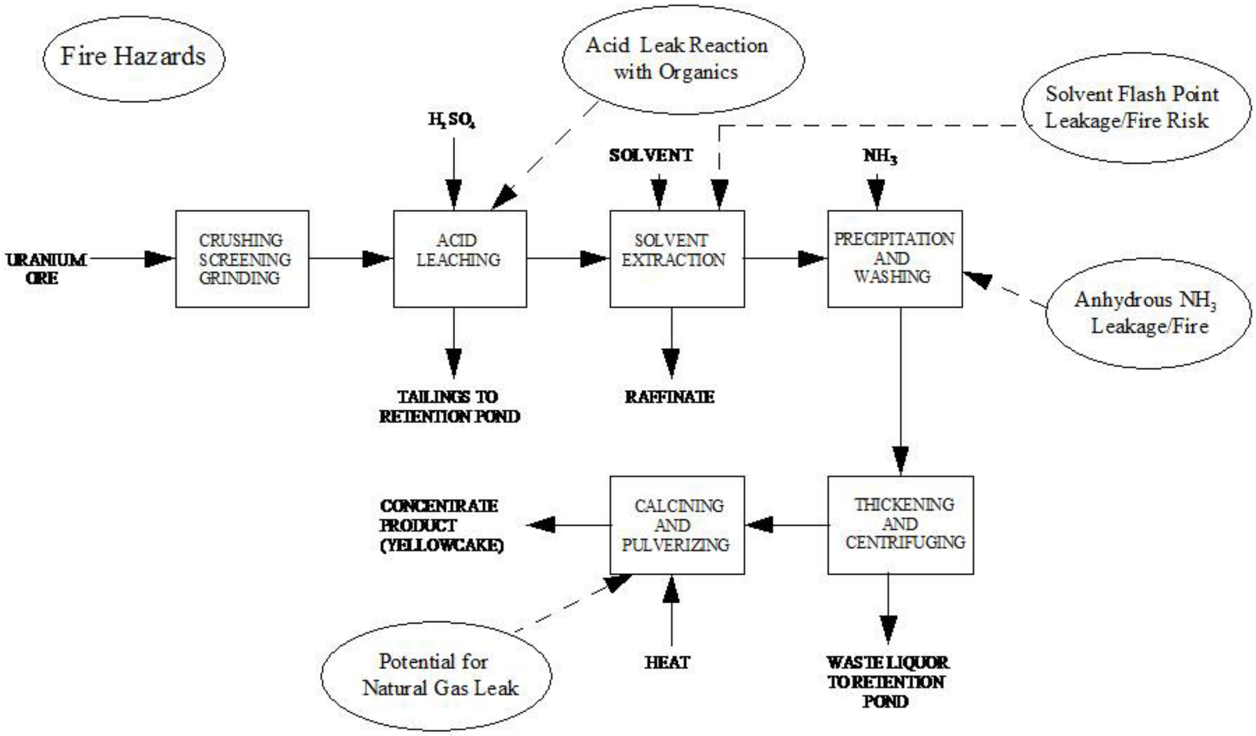
3.1.2 Locate the areas of principal concern for fire hazards at a uranium mill.

URANIUM MILLS

A uranium mill receives uranium ore from the mine and produces semi-refined uranium concentrate of about 85% U_3O_8 called yellowcake.

The ore is crushed and wet-ground in a rod or ball mill. It is then transferred as a slurry to leaching tanks. Most mills use a sulfuric acid leach process. Other mills use a sodium carbonate (alkaline) leach process. The product liquor of the acid leach process is pumped through a solvent extraction circuit, while that of the alkaline process is extracted through a sodium hydroxide solution. The uranium is further concentrated by precipitation with ammonia and centrifuging to separate the concentrate from the residual liquid. The concentrate is then calcined in a rotary furnace at temperatures ranging from 900°F to 1300°F and pulverized to form the end product, yellowcake. See Figure 3-1.

Figure 3-1. Uranium Mill Process Diagram



Fire Hazards at Uranium Mills

The process-related fire hazards at a uranium mill arise from two sources:

- Storage, handling, and process use of a combustible liquid solvent in the acid leach process.

  Tributyl phosphate (TBP) is the commonly used solvent. Other solvents, including hydrocarbon liquids, may also be used. Spills from the extraction vessels and leaks from the solvent storage or the transfer pipelines are not uncommon events.

- High-temperature calcining process.

  Inadvertent carryover of the combustible material into the calciner and a natural gas leak, where heat is provided by natural gas, are possible causes of fire.

NRC Information Notice 99-03, "Exothermic Reactions Involving Dried Uranium Oxide Powder (Yellowcake)"

NRC Information Notice 99-03, "Exothermic Reactions Involving Dried Uranium Oxide Powder," documents incidents that have potential for fire with increased temperatures and oxidation of material.

Fire can also be a concern during the filtration/drying/packaging after dried yellowcake is packaged into drums for shipment to a plant for conversion to UF_6. The potential exists for a fire is caused by peroxide residuals. Incidents have been reported that involved exothermic reactions resulting from the packaging of low-temperature or vacuum-dried U_3O_8 hydrogen peroxide precipitated powder (yellowcake).

In these incidents, dry U_3O_8 hydrogen peroxide precipitated powder, packed in 55 gallon drums, undergoes strong exothermic reactions after the drying and packaging process. The cause of such reaction can be placed into two categories:

1) generation of oxygen as a byproduct of the production process; and

2) hydrocarbon contaminants reacting with U_3O_8 hydrogen peroxide precipitated (yellowcake) product.

Incident of the first category:
A licensee observed expansion of the sealed drums from generation of oxygen resulting from the decay of hydrogen peroxide. In the production process, hydrogen peroxide is used to precipitate uranium in the form of uranium oxide. This precipitate is then pressed through a filter, dried in an oven and packaged in drums for shipment. Even though the dryer temperature reached 537.7 degrees C, converting the precipitate to uranate peroxide (UO_42H_2O), sufficient hydrogen peroxide either remained in the product or was generated to develop oxygen pressure.

The production of gases caused bulging of the lids and sides of the drums, as well as cause a pressure release that, when lid was removed, was sufficient to eject about ¼ of the drummed U_3O_8 or 90.7 kilograms onto workers and through the isolation door.

This can be a problem with the use of newer drums with airtight seals. Older drums had less efficient seals that allowed pressure to escape as it was generated. Corrective action consists mainly of leaving the lids off the drums for a minimum of 3 hours after filling.

Incident of the second category:
An incident occurred when hydrocarbon contaminants were mixed with U_3O_8 hydrogen peroxide precipitated (yellowcake) product. A leaky flange in a bag filter allowed lubricating

oil to leak into the production process, and a deformed tank paddle allowed oil seepage into the mixing tank.

Since uranium is a pyrophoric metal, especially in powder form, any contaminant in contact with yellowcake powder can be hazardous. Hydrocarbons such as lubricating oils and grease are very likely to cause an unstable condition in the packed yellowcake powder. Corrective actions include installation of oil pressure relief valves and a hot oil boiler cutoff with a temperature controller.

MODULE 3.0: FIRE HAZARDS AND FIRE PROTECTION CONCERNS AT FUEL CYCLE FACILITIES

Learning Objectives

When you finish this section, you will be able to:

3.1.3 Identify the fire hazards associated with the acids, organic solvents, and/or gases used during the conversion process.

3.1.4 Locate the areas of principal concern for fire hazards at a uranium conversion facility.

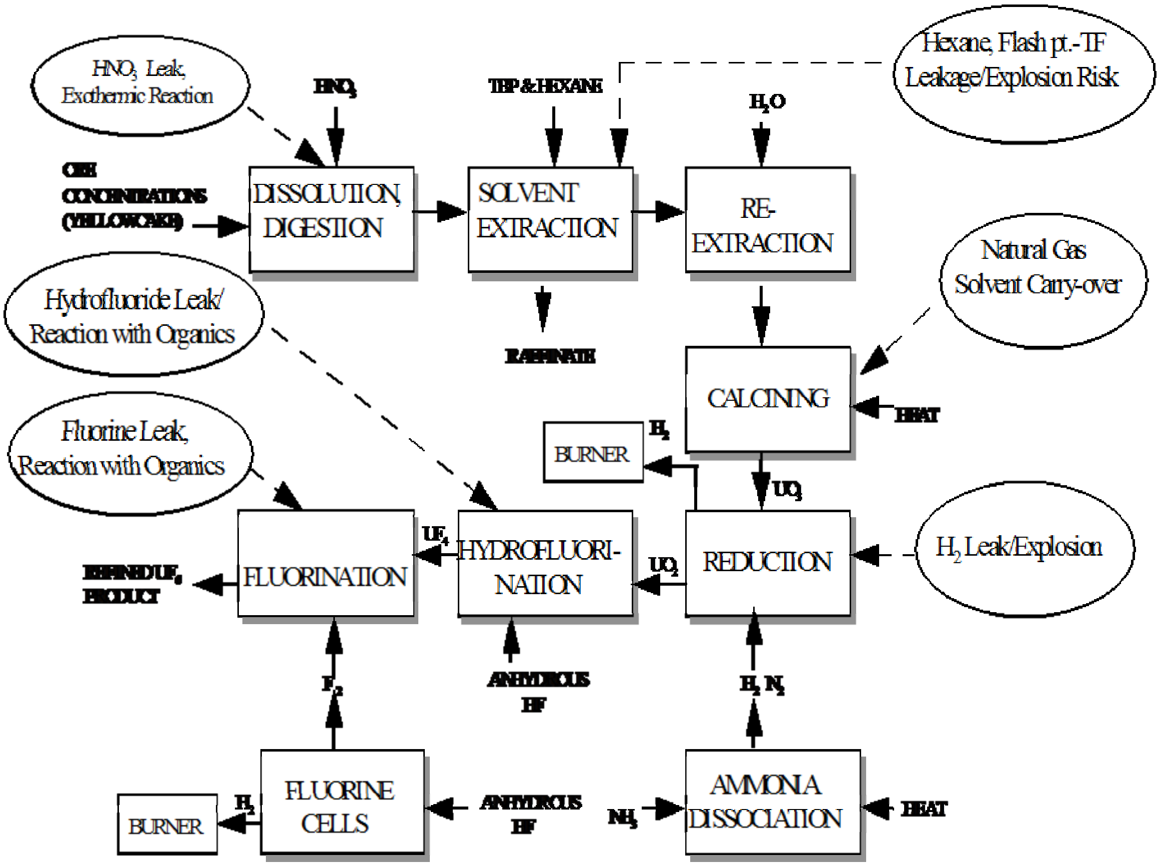
URANIUM HEXAFLUORIDE (UF6) CONVERSION FACILITIES

Yellowcake milled from the ore is the feed material for UF_6 conversion facilities. These facilities remove virtually all of the remaining impurities from the feed and produce UF_6, which will be used in the enrichment facilities. Two different processes are used for UF_6 production.

Solvent Extraction Process

The solvent extraction process consists of digestion of the feed in nitric acid and a wet chemical solvent extraction step at the beginning of the process followed by reduction, hydrofluorination, and fluorination. See Figure 3-2. Solvent extraction processes are dominant overseas, while the dry fluoride process is dominant domestically.

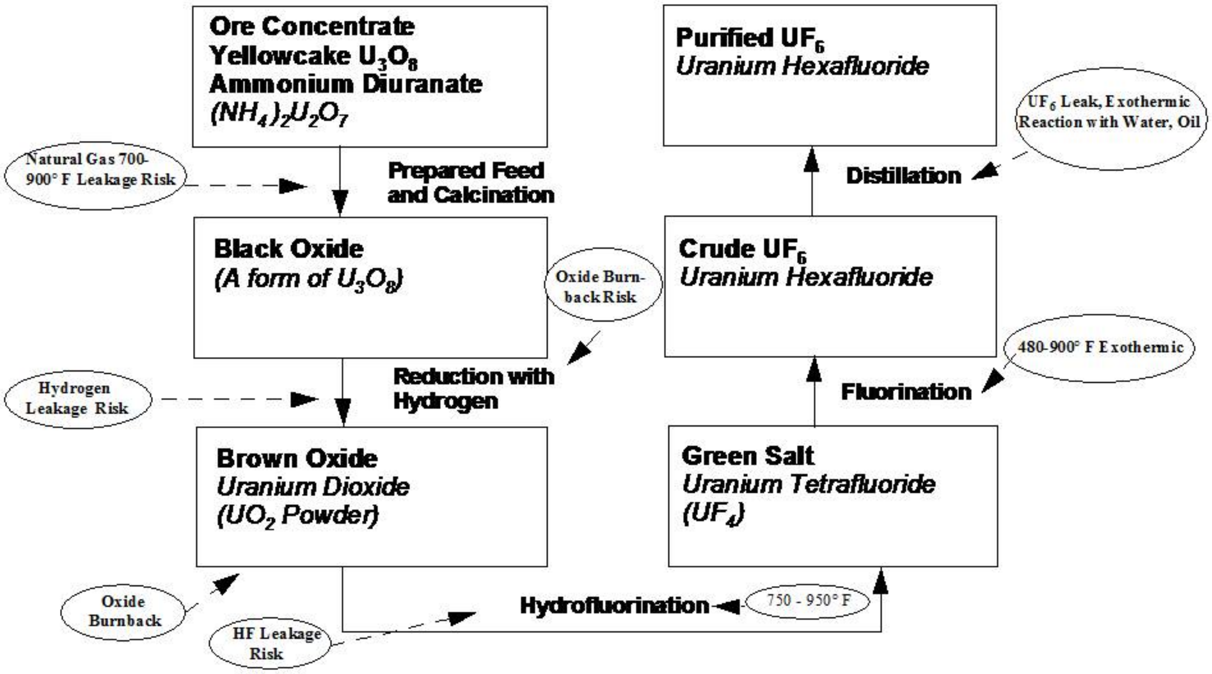
Figure 3-2. Solvent Extraction Process



Dry Fluoride Volatility Process

The dry fluoride volatility process consists of reduction, hydrofluorination, fluorination, and fractional distillation. See Figure 3-3.

Figure 3-3. UF_6 Production: Dry Fluoride Volatility Process



Fire Hazards at UF_6 Conversion Facilities

A number of chemical substances are used as bulk reactants or as source material for production of such reactants in the UF_6 production process. Table 3-1 shows the most prominent fire hazards.

Other process-related hazards are connected with the high-temperature calciners that may be heated electrically or by natural gas flames, and in ammonia dissociators.

Table 3-1. Chemical Substance Fire Hazards at UF_6 Conversion Facilities

Chemical	Process Use	Characteristics
Nitric Acid	In the solvent extraction process, yellowcake is digested with nitric acid in large tanks.	◙ Nonflammable ◙ Nitrates cellulosic and other organic materials under certain conditions making them easily ignitable
Sulfuric Acid	Sulfuric acid is the reagent used for digesting yellowcake with high sodium content before reduction in the hydrofluor process.	◙ Absorbs water from organic materials accompanied by exothermic reaction that may ignite them
Anhydrous Ammonia	This chemical is used as source material for production of hydrogen for use in reduction processes.	◙ Flammable gas ◙ Stored and pumped in the liquefied state ◙ Undergoes dissociation into hydrogen and nitrogen in a high-temperature dissociation at about 1650°F
Hydrogen	Hydrogen is used in the reduction process.	◙ Well-known as having the highest burning velocity of all gases ◙ Has a wide flammable range in mixtures with air The hazards of fire and explosion are present in the event of a leak from any equipment handling or using hydrogen. Additionally, there is a hazard of explosion in vessels, such as reductors, heaters, and filters, where explosive mixtures of hydrogen and an oxidizer may form inadvertently.

Table 3-1. Chemical Substance Fire Hazards at UF_6 Conversion Facilities

Chemical	Process Use	Characteristics
Fluorine	Elemental fluorine gas is used in the final reaction to produce UF_6. Fluorine is produced in a battery of electrolytic cells in which hydrofluoric acid is decomposed into hydrogen and fluorine. Fluorine is compressed by centrifugal compressors and delivered to the fluorination reaction vessels. The hydrogen component is either burned off or released to the atmosphere.	◙ One of the most reactive elements known ◙ Reacts violently with hydrogen and many organic materials causing fires, even though it is itself nonflammable ◙ May also cause explosions in contact with metallic powders and water vapor

This page intentionally left blank.

Learning Objective

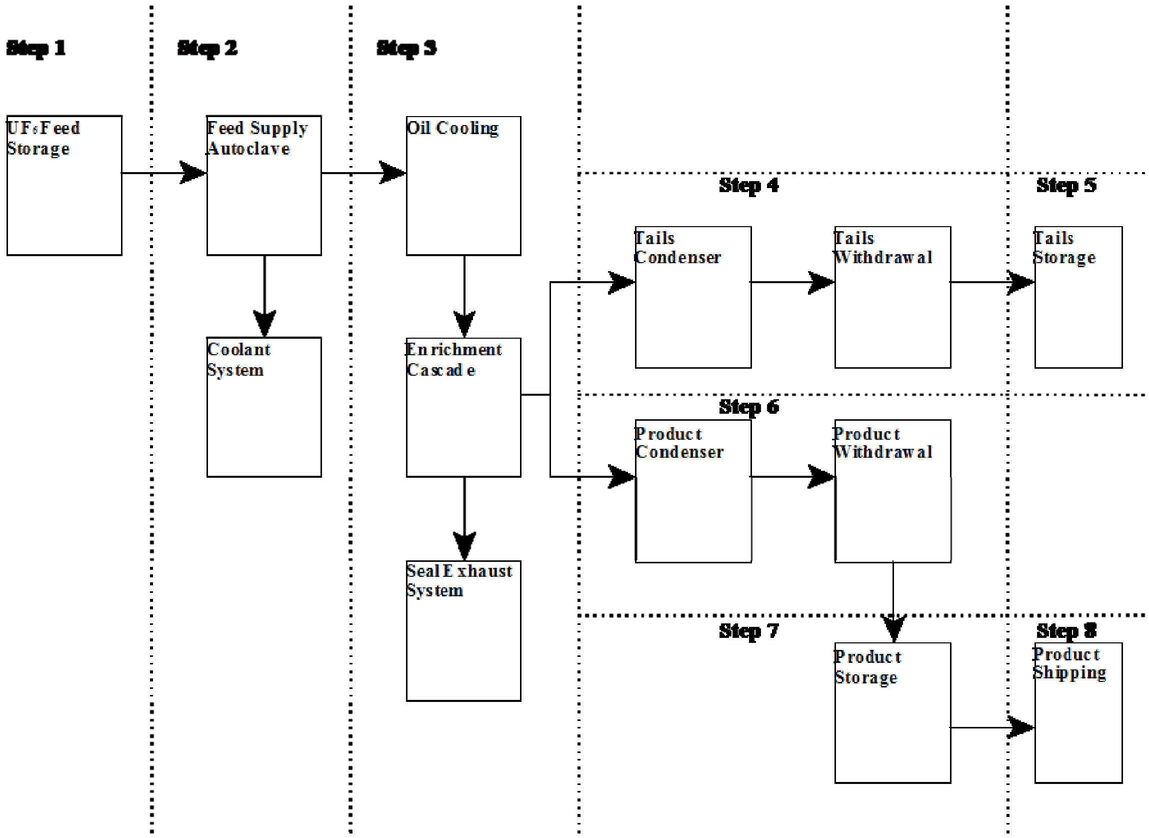
When you finish this section, you will be able to:

3.1.5 Identify the fire hazards associated with uranium enrichment processes and equipment.

GASEOUS DIFFUSION URANIUM ENRICHMENT FACILITIES

Gaseous diffusion uses molecular diffusion to effect separation. The isotopic separation is accomplished by diffusing uranium, which has been combined with fluorine to form UF_6 gas, through a porous membrane (barrier) and utilizing the different molecular velocities of the two isotopes to achieve separation. The U-235 enrichment through each stage is so minute that literally thousands of stages are required to increase the assay from 0.711% to the desired assay. By cascading or connecting the basic separation stages in series, the desired level of enrichment can be achieved. See Figure 3-4.

Figure 3-4. Flow Diagram for Gaseous Diffusion



Fire Hazards at Gaseous Diffusion Facilities

The principal fire hazards in gaseous diffusion facilities are related to storage, transfer, and use of flammable and combustible liquids, such as lube oils and hydrocarbon solvents. Explosive gases, such as fluorine and chlorine trifluoride; and chemicals, such as anhydrous hydrogen fluoride (HF), nitric acid, and fluorine, may combine with organic materials and cause fires. Example: hot metal fire.

Hydrogen Fluoride (HF) and Fluorine System Hazards

Anhydrous HF is used for the production of fluorine (F_2). Fluorine (F_2) is used for cascade equipment maintenance operations. Neither fluorine (F_2) nor HF alone constitutes a fire hazard because both chemicals are nonflammable. However, F_2 and HF, in some cases, will promote ignition (sometimes violent) in contact with wood or other organic materials. There is also a latent fire or explosion hazard due to the possible generation of hydrogen in containers, piping, and equipment used in handling and storage of F_2 or HF. Containers for F_2 or HF should never be heated. They should be protected from direct sunshine and stored in a location where temperatures below 100°F can be maintained.

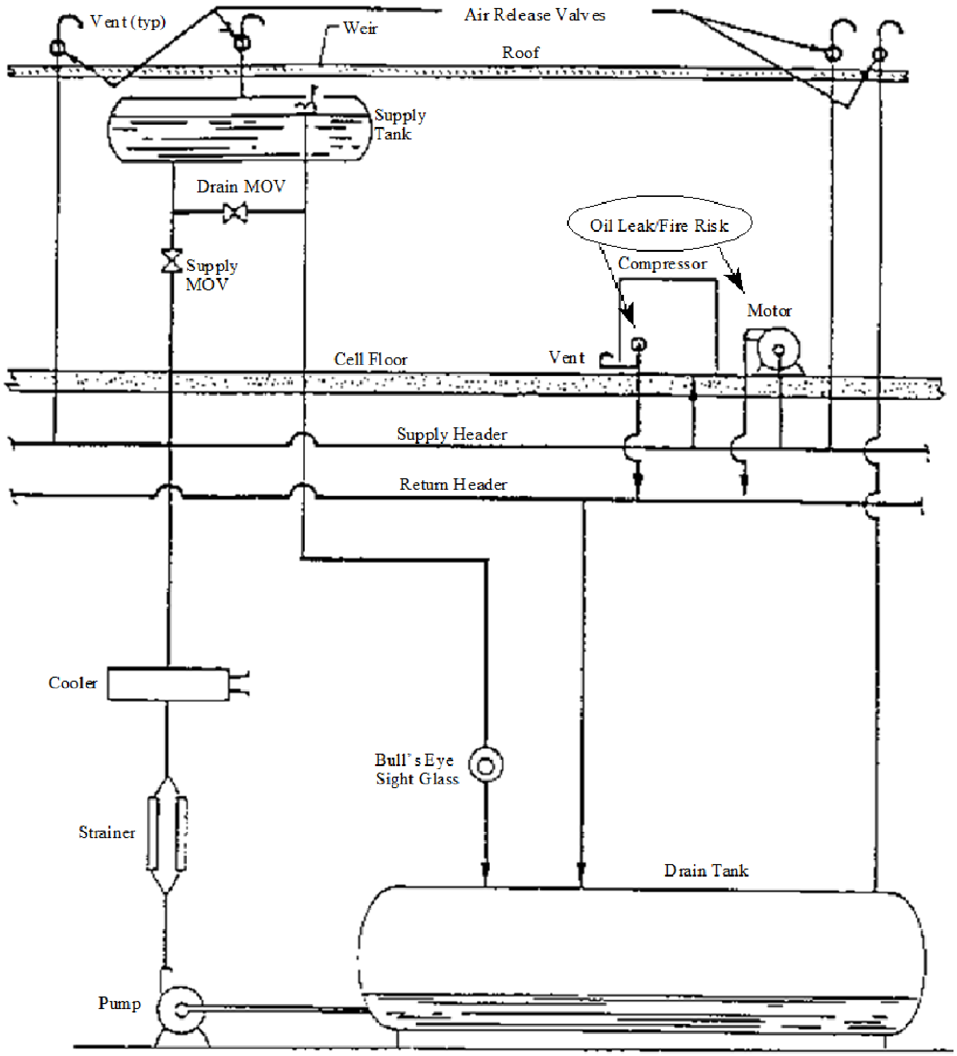
Lube Oil System

The oil in these systems constitutes a serious and unavoidable fire hazard. Fires would most likely be initiated by an oil supply line failure causing reduced oil flow to the bearing resulting in bearing overheating. See Figure 3-5, a typical lube oil system.

Note: The Oak Ridge Gaseous Diffusion Plant is no longer operating.

The process recirculating oil system is provided to maintain a continuous and adequate supply of lubricating oil to the bearings of the major pieces of process equipment. This includes the bearings of all process motors and compressors. Because there are many bearings, it has been found desirable to make this lubrication continuous and automatic, rather than depend on hand filling. Oil is supplied to the bearings at a pressure equal to the gravity force exerted by the oil in the supply tank.

Figure 3-5. Typical Gaseous Diffusion Plant (GDP) Lube Oil System



Dikes

Dikes are provided on the floors around both the gravity supply and storage tanks to hold the inventory of oil in the event of a serious leakage of oil from the tanks.

Pumps

Two motor-driven centrifugal recirculating pumps, which can be automatically or manually controlled, supply oil to the supply tank and header. Only one of these units is generally necessary to supply the required amount of oil for unit operation.

The recirculating system always has one pump in operation. When the liquid level in the gravity tank falls below the level of the weir (a dam in a stream to raise the level or divert the flow), a standby pump is automatically started.

Strainers

The recirculating pumps discharge into a duplex oil strainer or filter to remove any foreign material that may damage lubricated surfaces.

Cooler

A shell and tube-type oil cooler receives oil from the pumps and removes the heat imparted to the oil by the process equipment. Cooling water from the recirculating water system enters the tubes of the cooler. Cooler connections consist of a water supply line, a water return line, an oil inlet line, and an oil outlet line.

Control and Instrumentation

The controls for the system are equipped with audible and visible alarms that will warn the operator when an undesirable or dangerous condition exists in the system.

When there is no flow over the weir in the overhead supply tank, the low-level control actuates the alarm and, at the same time, automatically starts the extra or standby pump.

Oil Feed to Bearings

The oil from the cell header is piped directly to the various compressor and electric motor bearings.

Compressor Load Bearings

Oil is fed to the compressor load bearings through ports in the sides of the bearing lines. The oil is forced between the shaft and bearing lines by the oil pressure in the system.

Used oil drains from the ends of the bearings into the bearing housing cavities and then into oil drain lines. For the oil to flow freely down the drain lines to the storage tank, it is necessary to vent the drain lines to the atmosphere adjacent to the bearing overflow points. This venting is done through flame arrestor vents. Flame arrestors at these points reduce the possibility of the oil igniting in the system in the event of fire.

Compressor Thrust Bearings

Oil supplied to the compressor thrust bearings is restricted in its flow by metering plugs. These allow only the required amount of oil to flow. Oil enters the bottoms of the thrust-bearing cavities and flows out overflow ports at the tops into oil return piping. These cavities are flooded with oil during compressor operation.

Motor Bearings

Oil is metered by small manual control valves into the ring oiler reservoirs of the motor bearings. Overflow ports maintain suitable oil levels in the reservoirs. The excess oil that is supplied to the bearings is allowed to overflow into drain lines that return the oil to the storage tank.

Lube Oil System Fire Hazards

The major fire hazards on the operating floor are associated with the lubricating oil pit areas. The lube oil pits are diked areas containing the lubricating and hydraulic oil pumps, oil drainage tanks, and lube oil coolers.

The most likely points of ignition in the process buildings are the compressor bearing lube oil supply lines.

In the cascade buildings, sparks and slag from welding and burning operations are possible ignition sources for residual oil that may collect around lubricated equipment such as pumps and motors. Failure of motor or transformer windings or cable leads can also provide ignition sources for residual oil deposits.

Examples of Lube Oil Fires

A lube oil fire occurred at the Paducah Gaseous Diffusion Plant in 1956. A major fire was discovered in the C-310 Purge and Product Building. The investigation indicated that the fire originated at a withdrawal compressor position. The compressor was operating at beyond-atmospheric pressure when the shaft seal failed. The seal failure resulted in the escape of process gas and a small quantity of F_2, which reacted vigorously with lube oil on the compressor surface.

The resulting fire burned with an intense heat, which caused the lube oil supply line to the compressor bearing to rupture. The intense heat, together with the additional supply of fuel from the ruptured oil line, caused the fire to grow very rapidly to a size sufficient to ignite the roof. The roof ignited within five minutes of the start of the fire. Extensive structural damage occurred to roof purlins (horizontal members that support the rafters in a roof), trusses, crane girders, beams, and columns. The entire cell floor structural steel required replacement. As a result of this fire, automatic sprinkler systems were installed at the gaseous diffusion plants to protect the process buildings from fires initiated on the cell floor.

A second major fire occurred in the C-337 Process Building in 1962. In this incident, 2,390 sprinkler heads were actuated following a coolant/treatment gas explosion. The reason for the large number of sprinklers operating was assumed to be most likely due to the steam generated from the exothermic reaction that initiated the event. As a result of this incident, sprinkler-head temperature ratings on the cell floors of the process buildings were increased from 212°F to 286°F, and the water supply system was upgraded.

1998 Portsmouth Fire

Description of Event

Note: The following information was excerpted from the "Augumented Inspection Team Report - Portmouth Fire," which occurred at the Portsmouth Gaseous Diffusion Plant on December 9, 1998. The complete report can be found in Appendix D of this Self-Study Guide.

On December 9, 1998, at 0610 hours, Fire Services personnel responded to a fire that occurred in Cell 25-7-2 in the Side Purge Area of the X-326 Process Building. The fire, which breached process equipment in several places, was contained by the building sprinkler system and was extinguished by plant Fire Services personnel. The fire damage was primarily limited to the Cell 25-7-2 equipment, housing, and three stages of the adjacent cell, 25-7-4. Since the fire damaged process equipment and piping that contained radioactive material, this event is reportable in accordance with 10 CFR 76.120 (c) (4). A description of the event is provided below.

Operations were normal on the morning of December 9, 1998. Cell 25-7-2 was the bottom onstream cell of the Side Purge cascade. The purpose of the Side Purge is to vent most of the light gases, such as oxygen and nitrogen, from the cascade. Heavier intermediate weight gases, such as R-114 (coolant), continue up the cascade until they are vented by the Top Purge equipment. Low speed cell 25-7-2 is used to create a stripping section. The B-Stream exiting cell 25-7-2 typically contains less than 10 percent of the low molecular weight "light" gases that enter the Side Purge. The Side Purge configuration was normal with the exception that Cell 25-7-4 was offstream and out of service. A-Stream process gas flow was into Stage 4 A-suction of Cell 25-7-2, from Stage 12 of Cell 27-1-2, through a manual block valve. B-Stream process gas return flow was from Stage 1 of Cell 25-7-2, to the Stage 1 A-Stream of Cell 27-2-1. A coolant (R-114) "bubble" had moved up the cascade at about 0330 hours. The Unit Operator making rounds of the cell floor at about 0600 hours stated that Cell 25-7-2 equipment was running quietly with no unusual indications.

At about 0605 hours, the ACR-6 (Area Control Room 6) operator was taking hourly readings when the operator noticed the cell 25-7-2, Stage 2, Amp meter briefly deflect to about 70 percent full scale and then return to normal position of about 30 percent scale. The operator told the first line manager in training (FLMIT), who was leaving the ACR, that it appeared there was another coolant "bubble" entering the Side Purge cascade. The FLMIT said he would tell the section manager when he reported to ACR-5. Meanwhile, the operator throttled the Side Purge vent remote control valve (CV-1261) to back the suspected coolant bubble out of the Side Purge cells.

At about 0606 hours, the Amp meter in ACR-6 again deflected, which indicated that Cell 25-7-2, Stage 2, compressor surged and then returned to normal load. Cascade Control personnel in X-300 Plant Control Facility (PCF) observed that the Cell 25-7-2 Amp meter, which indicates the total cell Amps from all six motors, was slowly climbing and called ACR-6 to determine the cause. During the phone call, at 0607 hours, Cell 25-7-2 immediately loaded up and tripped on motor overload before the operator could trip the cell motors. Adjacent Side Purge Cells 25-7-6, 25-7-8, and 25-7-10 also loaded, with seal exhaust alarms activating. The operator depressed the cell off full split button to close the three open block valves. The expected response of a green light, indicating the valves had completely closed, did not occur and the panel had a red and a green light indicating one or more of the valves was not fully closed. The cell had not been completely isolated because the internal A-Line, Stage 4, block valve used to create a stripping section remained open.

The X-326 Building CC-Shift FLM was in route to the ACR-6, when the FLM heard the cell compressors and motors wind down. The FLM then proceeded to ACR-6 and found Cell 25-7-2 shut down. Isolation valve ESP-7 had closed automatically, isolating the Side Purge vent stream from atmosphere.

At about 0610 hours, sprinkler system 462, which is located in proximity to Cell 25-7-2, alarmed in the fire station and the PCF. Operators in the nearby X-600 Steam Plant heard the external X-326 Building sprinkler system alarm bell, observed white smoke, smelled an electrical type odor, and heard a muffled pop. A protective force Officer on the cell floor heard a roar followed by two pops.

At 0611 hours, Cascade Control told the ACR-6 FLM that there were reports of smoke and flowing sprinklers in the south end of X-326. The FLM reported a cell coolant alarm, indicating high coolant temperature or low coolant pressure, but did not report smoke. The Fire Services arrived on the scene at 0613 hours.

By 0615 hours, smoke was entering ACR-6. The operator and the FLM did not immediately evacuate because their respirators were stored outside the ACR. Firemen entered X-326, Door 7, and reported heavy, light colored smoke.

At 0617 hours, the section manager and the FLMIT enroute from ACR-5, were attempting to reach ACR-6 with four respirators, but encountered heavy smoke and called the PCF for information. The cscade controller reported the sprinkler 462 alarm, smoke coming out of the building and that the UF_6 front had been pushed down the cascade into the X-330 Building. The section manager and FLMIT continued to attempt to reach ACR-6 while avoiding the heavy smoke.

The unit operator, wearing respiratory protection, entered the cell floor and proceeded toward Cell 25-7-2. The operator saw there was smoke coming from the cell and valved off the lube oil supply located at the top of the exit stairway before he exited the building. Smoke was light but slowly becoming denser above the cell floor.

At 0619 hours, ACR-6 personnel evacuated the control room without respiratory equipment by entering the ACR-6 Basement and going into the tunnel which provided egress from the area.

At 0620 hours, Fire Services personnel checked ACR-6 and determined that it had been evacuated.

At 0621 hours, the section manager and the FLMIT entered ACR-6 by a rear door and began a search of the ACR to be certain the area was empty. The section manager pushed the cell off full split button and received a green light within seconds, indicating the valves were nearly fully closed by the ACR operator on the previous isolation attempt. The section manager closed motor operated valve 7ESP-1, the first isolation valve beyond the Cell 25-7-2, Stage 4, manual valve, which isolated Cell 25-7-2 from the Side Purge supply line and the operating cascade.

At 0622 hours, ACR-4 personnel manually activated the building recall horn.

At 0623 hours, the section manager pushed the automatic recall button located in ACR-6. The recall signal is to alert building personnel to report to designated assembly locations.

At 0625 hours, the section manager and FLMIT exited the building and proceeded to the Command Post.

At 0626 hours, Fire Services personnel entered the cell floor and reported a fire in progress. Flames were reported around the cell housing and from motor openings. Heavy black smoke was filling the area making visibility poor and the oil/water mixture on the cell floor created difficult footing for the firefighters. The Fire Services personnel returned to the Command Post and developed a plan to extinguish the fire.

It was later determined that seven sprinkler heads had activated. Three at the roof level, two under the bypass housing, and one in the aisle way that most likely activated when hot gas jets burned through the cell housing at Stages 1, 3 and 4. One under the coolant platform activated most likely when the cell housing door panel adjacent to Stage 6 became warped and opened. The high pressure fire water sprinkler discharge was successful in containing the fire.

At 0630 hours, Fire Services personnel proceeded to lay hoses on the east side of the building and applied water to the outside of the Cell 25-7-2 housing.

At about 0715, other firefighters gained access to the south door of the building and proceeded to lay hose. Shortly thereafter, the firefighters reported that hydraulic oil to the control valves within the cell may not have been isolated.

At about 0730 hours, the south door of the cell housing was opened and the firefighters proceeded to spray water inside the cell housing. The fire was extinguished and upon examination for hot spots, an open process pipe was observed from the west side of the cell (holes were visible in the process gas cascade piping). Fire fighting activities were curtailed and the firefighters returned to the Command Post. After consultation with the incident commander on nuclear criticality safety (NCS) concerns, the firefighters went back to the cell housing and performed cool down operations while avoiding the open pipe.

At 0749 hours, the sprinkler system was valved off. Total sprinkler discharge was approximately 35,000 gallons.

At 0815 hours, Emergency Squad personnel valved off the Cell 25-7-2 hydraulic oil supply. The fire was declared out by Fire Services at 0817 hours.

Fire damage was limited primarily to Cell 25-7-2 and consisted of severe damage to the components in the compressors, the converters, and the R-114 coolers. A stage control valve disk was melted. Holes were burned in process piping elbows in three stages, several process pipe expansion joints were ruptured, and holes were melted in three stage converters. Minor damage also occurred in three stages of the adjacent cell, 25-7-4.

The material that outgassed was enriched UF_6 at less than 7.0% U-235. The quantity of material released during the event was estimated as approximately 5 kg of uranium.

Cause of Event

On December 9, 1998, immediately following the event, an investigation team was established to determine the root and contributing causes for the event. Outside technical experts were added to the team to assist in the cause determination. The extensive fire damage experienced by Cell 25-7-2 equipment has made it difficult to determine the root cause. Much of the equipment has been damaged to the extent that evidence needed to determine the root cause was destroyed. As a result, investigation activities are continuing and this event report will be revised when the investigation is complete. The investigation team's current understanding of the most likely direct cause for the exothermic chemical reaction is provided below.

The investigation team reviewed plant operating conditions that existed prior to the event to determine if there were any abnormal conditions that could have initiated an exothermic reaction. Cascade operating parameters for the 24 hours prior to the time surging was first detected by the operator, such as purge rates, UF_6 front location, feed and withdrawal rates and surge drum bleed back information were reviewed but did not indicate any activity that could have initiated the event. Cascade monitors such as alarms, line recorders, space recorders, oxidant monitors, and cascade laboratory sample analysis did not reveal any unusual activity. A review of cascade and feed plant valving orders and operational logs also did not reveal any unusual activities that would have initiated the event. Based on these findings, the investigation team concluded that the exothermic reaction was not caused by any abnormal concentration of gases or unusual operating conditions.

The investigation team has determined that the exothermic reaction was most likely caused by rubbing of internal compressor parts. Friction, resulting from rubbing of compressor parts, is believed to have generated enough heat to reach the melting point of aluminum. The molten aluminum then chemically reacted with the UF_6 process gas generating additional heat. As the cell continued to operate onstream, additional UF_6 was available to feed the reaction and spread it to other stages. At least one gas cooler eventually ruptured releasing R-114 coolant into the cell. The release and expansion of the coolant into the cell increased the cell pressure and generated additional heat as aluminum chemically reacted with the coolant. The high temperatures and potentially elevated pressure led to the destruction of the converter tube bundles and breach of the cell boundary.

During the investigation, issues potentially related to the prevention or mitigation of an exothermic reaction were identified by the investigation team. The team identified that the design and operational characteristics of Cell 25-7-2 may have contributed to the severity and extent of the exothermic reaction. These issues are discussed below and immediate actions taken to address these issues are described in the corrective action section.

The Safety Analysis Report (SAR), Section 3.1.2.2.2, Isolation of Failures, states that, "If the Amp loading in a single stage begins increasing, the problem may have been initiated by compressor parts rubbing, deposits in the compressor, bearing failure, or some other failure associated with the motor itself, which requires immediate shutdown." The Side Purge cascade operating procedure did not contain guidance to help the operator differentiate between load changes due to controllable factors such as compressor surging and load changes due to equipment failure, and it did not contain guidance as to the type of Amp increases that would require a cell shutdown.

The investigation team also determined that Cell 25-7-2, Stage 2 and 4 compressors, had been replaced approximately three weeks before this event due to high vibrations. The compressors that were removed from the cell because of the high vibrations were examined. The Stage 4 compressor was found to have extensive first stage impeller damage. Implications of this finding are being further evaluated as it relates to this event.

Corrective Actions

The following actions have been initiated and/or completed to address issues identified during the investigation. A complete list of corrective actions will be provided in a revised event report after the root and contributing causes have been determined.

1. On December 23, 1998, a briefing was initiated from X-236 Facility Operations personnel. The briefings included a description of what happened, how the incident was handled and what to look for as indicators that such an event is happening. The briefing emphasized the steps necessary for tripping and isolating a cell. Actions to be taken if the cell block valves do not fully close were also addressed.

2. On December 15, 1998, the development of a training module was initiated to address recognition of cell surging, cell loading and cell shutdown requirements. This training module is currently being piloted.

3. On January 6, 1999, a lessons learned was developed and issued to Cascade personnel to communicate operating conditions that may increase the possibility of a similar exothermic reaction.

4. On December 9, 1998, administrative controls were established to prevent returning the Side Purge cells to service.

5. On December 10, 1998, a vibration survey was conducted on running motors and compressors in the Top Purge Cascade. Engineering initiated weekly vibration surveys on operating purge cascade equipment.

6. The X-326 Daily Operating Instructions for January 4, 1999, emphasized the procedure administrative controls that state "upon cell startup, any cell indicating abnormal vibration shall be followed up with a full set of vibration readings unless the vibration is excessive upon which the cell shall be shut down."

7. The December 21, 1998, Daily Operating Instructions for cascade process areas contained the administrative control that, "Any centrifugal compressor that is shut down due to high vibration will not be restarted in the presence of UF_6."

8. On December 11, 1998, as a result of the damage observed on Cell 25-7-2, an ultrasonic inspection was performed on B-line elbows in the other Side Purge cells. No evidence of thinning was observed.

Extent of Exposure of Individuals to Radiation or Radioactive Materials

Personnel in the facility at the time of the fire, and all responders to the fire, were monitored for potential intake of radionuclides. Fifty-two personnel involved with the event submitted urine samples. Of these, nineteen personnel working in the building at the onset of the emergency were placed on precautionary restriction until their samples were evaluated. Each sample was analyzed for uranium and technetium and all results were less than 5 g/1 uranium and 6,000 pCi/1 for technetium. Since all samples were less than the SAR Action levels, no further actions were required. All precautionary restrictions were removed for the 19 individuals.

Area radiation readings during and following the event noted no increase over normal background readings for that area. Area posting requirements remained the same (Contamination Area). With the exception of some precautionary expansions of boundaries within already posted "Restricted Areas," only minimal boundary changes were necessary. Personnel access to the area was not restricted for radiological protection reasons nor were radiological dose reduction measures required during or following the emergency response. Air sampling results within the facility indicated slight increases in the airborne radioactivity levels during the fire, while monitors outside of the facility indicated no readings above the minimal detectable activity for the equipment. Prior to the termination of the event, airborne radioactivity levels within the facility had returned to normal.

Although the fire caused several contamination control concerns, worker, environmental, and public exposures were not significantly affected. SAR, Section 5.3 requirements were maintained and normal procedural controls were effective in maintaining contamination control and returning the area back to pre-fire conditions from a radiological control standpoint.

Recovery activities have been successful in removing the oil and water from the affected area. Decontamination efforts have restored the operating floor to pre-fire entry requirements for Personnel Protective Equipment. Approximately 80 percent of area boundaries have been returned to their pre-fire positions and decontamination efforts are continuing to restore the remaining boundaries.

MODULE 3.0: FIRE HAZARDS AND FIRE PROTECTION CONCERNS AT FUEL CYCLE FACILITIES

Activity 1 – Fire Hazards Associated With Uranium Enrichment Processes and Equipment

INSTRUCTIONS: Answer the following questions by referring to the "Augmented Inspection Team Report – Portsmouth Fire" located in Appendix D.

1. In what area of the facility did the fire occur?

2. What type of health problems or injuries were incurred by some of the operational staff and emergency responders?

3. What complicated the firefighters' efforts in the beginning of the fire?

4. What were some of the conclusions determined by inspectors in regards to operational staff's initial response to abnormal conditions involving Cell 25-7-2?

5. What contributed to communication problems between management and the emergency responders?

This page intentionally left blank.

MODULE 3.0: FIRE HAZARDS AND FIRE PROTECTION CONCERNS AT FUEL CYCLE FACILITIES

Learning Objective

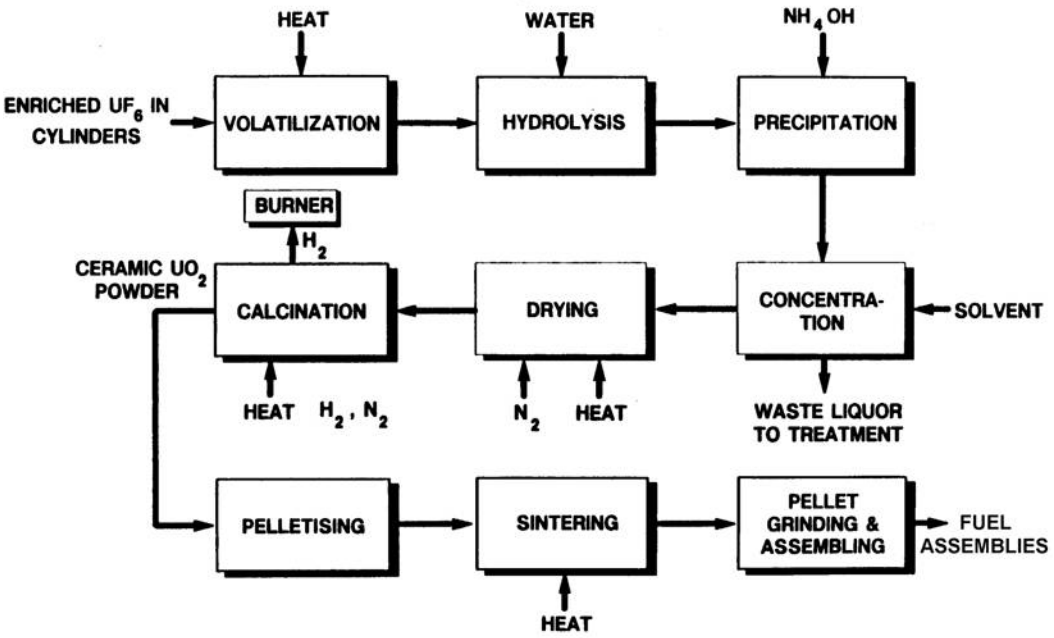
When you finish this section, you will be able to:

3.1.6 Locate the areas of principal concern for fire hazards at fuel fabrication facilities.

FUEL FABRICATION FACILITIES

Enriched uranium hexafluoride is used as feed material for fuel fabrication facilities. The feed is vaporized by application of heat in autoclaves, steam chests or in electrically heated hot air baths at about 220°F and treated successively with water and ammonium hydroxide to produce ammonium diuranate (ADU). In some plants, there is a further step of purification and concentration of the ADU by passing it through columns of a solvent. The ADU is then heated in the hydrogen atmosphere of calciners at approximately 1300°F to produce uranium dioxide powder. The calciner is heated by natural gas or by electricity. The dioxide powder is pressed into pellets that are then sintered at a temperature of approximately 3200°F in a sintering furnace. Grinding of the pellets to precise dimensions, their loading into zircaloy fuel rods, and assembly of the fuel rods into rod bundle assemblies completes the manufacturing process. See Figure 3-6.

Figure 3-6. Fuel Fabrication Process



Fire Hazards at Fuel Fabrication Facilities

The principal process-related fire protection concerns in fuel fabrication facilities arise from storage, handling, and process use of hydrogen and flammable solvents. The high-temperature processes of calcining (1300°F) and sintering (3200°F) also present fire hazards.

The grinding of fuel pellets produces uranium oxide fines, which can ignite spontaneously under certain circumstances. This is normally not a threat since these fines are continuously collected and channeled to the scrap recovery system.

Several facilities use solvent extraction systems for scrap recovery, and these also present fire concerns.

Areas of Principal Concern for Fire Hazards

Figure 3-7 indicates areas of fire concern in the ADU process to convert UF_6 to UO_2 powder.

Figure 3-8 indicates areas of fire concern in the integrated dry conversion (IDR) process.

Figure 3-9 indicates areas of fire concern in a fuel fabrication block diagram.

Figure 3-7. ADU Process to Convert UF_6 to UO_2 Powder

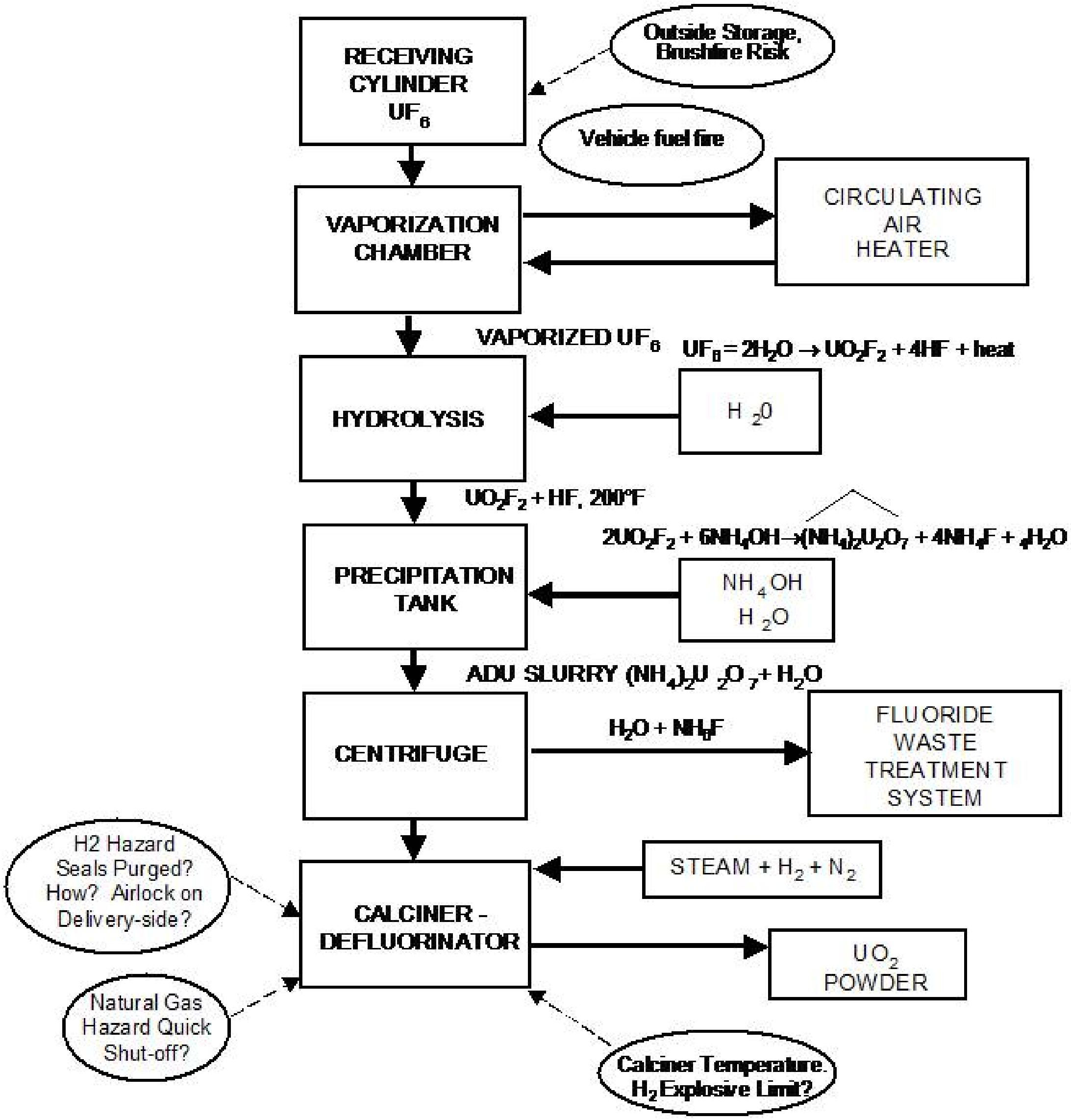


Figure 3-8. Integrated Dry Conversion (Idr) Process Flow

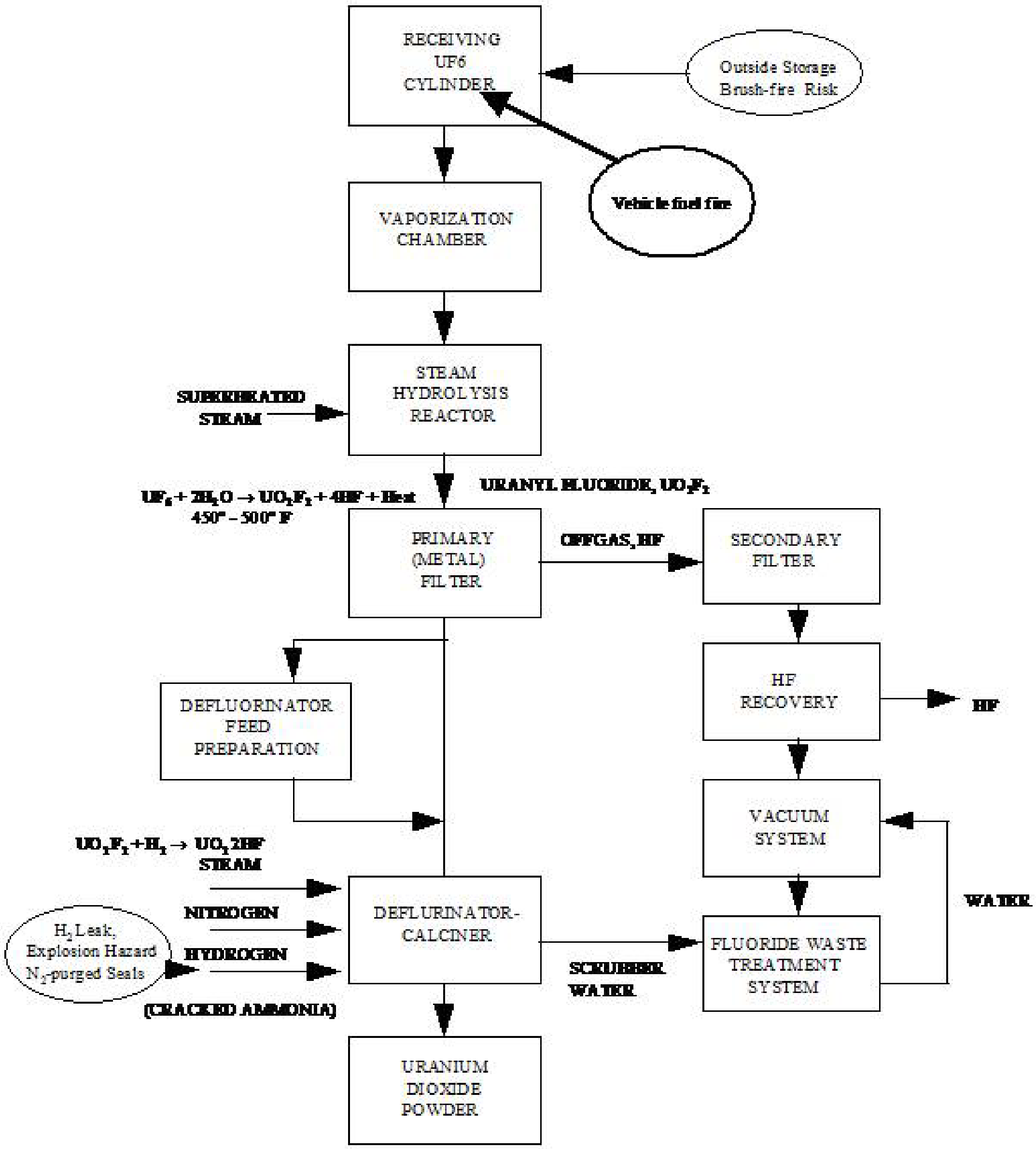
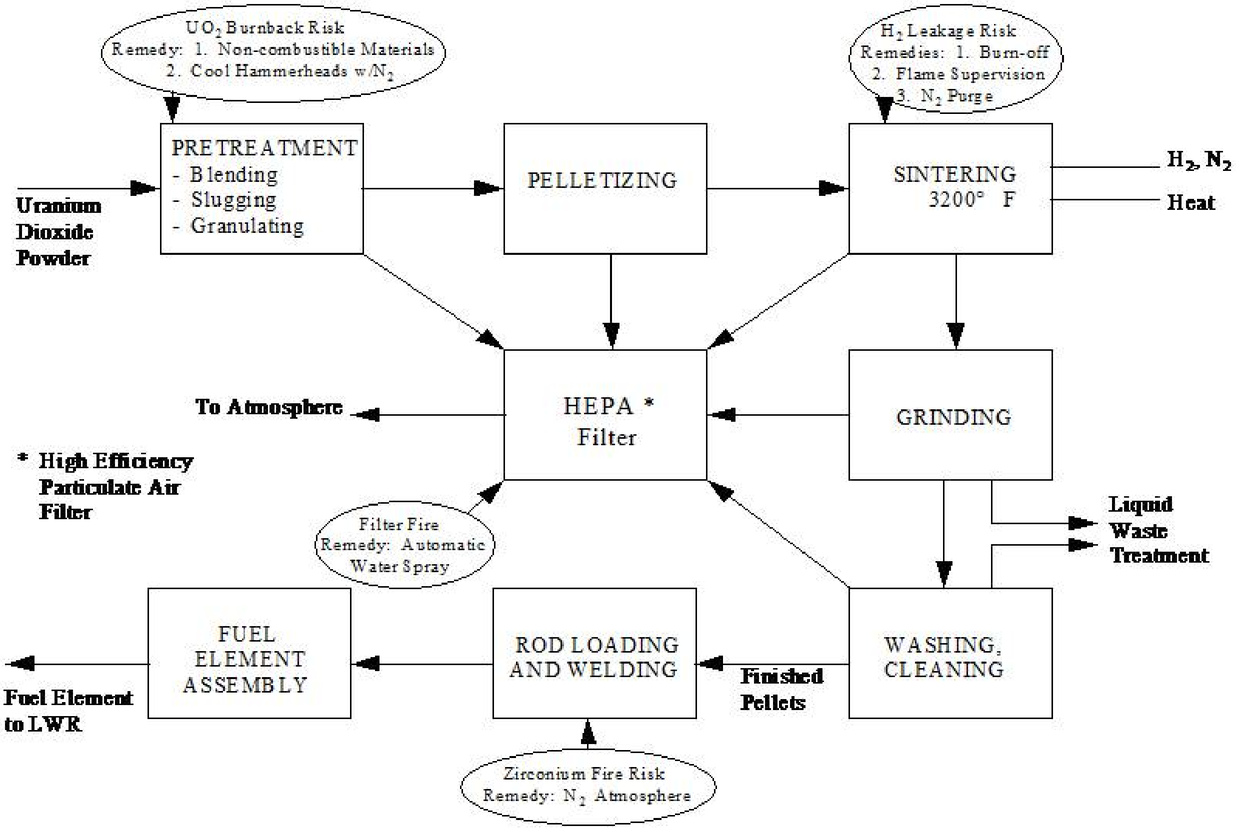


Figure 3-9. Fuel Fabrication Block Diagram



Uranium Oxide Fires

The fuel fabrication process generates several oxides of uranium. The literature on uranium chemistry describes oxidation reactions that are complex, with their rates, heat evolution, and final products depending on several parameters but most importantly on the fineness of the powder and the temperature. UO_2 may be pyrophoric or oxidize rapidly even at room temperatures when in very fine powder form (specific surface area >10sq.m/g). Coarser powders, as is more commonly the case, may require elevated temperatures (>300°C) to oxidize.

Uranium oxide feed material (comprised mostly of UO_2, with a few other oxide forms present) in granulated form and in contact with oxygen undergoes exothermic oxidation reactions. In some cases, the heat generated by the reactions ignites combustible elements of the transfer passages or other powder-handling equipment (e.g., boots, hoses), which then contribute fuel to the fire.

In February 1992, the NRC issued Information Notice 92-14, “Uranium Oxide Fires at Fuel Cycle Facilities,” to provide information on the potential for fires involving uranium dioxide (UO_2) powder at various stages of transfer and conversion.

In licensed fuel fabrication facilities, incidents of fires were reported that involved uranium at various stages of oxidation. Two of the incidents are summarized on pages 3-34 thru 3-37.

Examples of Uranium Oxide Fires

Incident 1

A fire was discovered in a fuel fabrication facility involving a hood, hopper, and feed-screw assembly, which was used to transfer calciner drop powder (uranium oxide) to a nitric acid dissolver tank.

According to the report submitted by the licensee, an operator had started to feed a batch of the powder into the dissolver tank when the feed-screw of the Model 608 Accu-Rate feeder stopped. The operator reversed the screw and tapped on the tube-shaped nylon screw-housing to free the screw. At this time, he observed smoke and sparks coming out of the equipment below the hood. A small crack in the vinyl side of the feeder hopper, apparently the result of contact with the hot powder inside the hopper, was also noticed. The operator and other employees then donned full-face respirators and removed approximately 18 kg of the powder, leaving about 2 kg of powder that could not be removed inside the screw-housing.

Meanwhile, the small crack on the side of the hopper had developed into a baseball-sized hole, spilling some of the powder onto the platform below. The employees cleaned up the spilled powder. Assuming the incipient fire had been extinguished, the employees left the area.

Approximately one hour later, fire alarm bells sounded throughout the plant and the plant emergency team responded. The source of the fire was determined to be the same hood and feeder assembly on which the employees had been working. When plant emergency team members (dressed in protective clothing and using self-contained breathing apparatus) entered the room, they found the visibility reduced to about one or two feet because of the heavy smoke. Using portable dry chemical and carbon dioxide fire extinguishers, they extinguished the fire within 15 minutes of the alarm bells sounding.

All components of the hood and the Accu-Rate feeder that were made of combustible material (e.g., nylon feed tube, vinyl hopper, rubber parts of a valve, and Lexan faces of the hood) were consumed in the fire. The primary stage of the high-efficiency particulate air (HEPA) filter for the room was loaded with soot, and the prefilter was burnt.

The fire alarm bells stopped ringing after about three minutes because the alarm circuitry in the room was damaged by the fire. This confused some of the employees, who could not tell whether the emergency was over. Some employees thought the alarm bells in some areas were not loud enough. Voice communications over the public address system were misunderstood by some employees and not heard by others, especially in the office areas.

The incident exposed a weakness in the emergency communications system between the licensee and the local fire department. Shortly before the incident, the facility had tested a newly installed extension of its fire alarm system in conjunction with the fire department. Even though the facility had notified the fire department that the test was over, the fire department mistook the alarm, which came in about 18 minutes later, to be merely a continuation of the test. A 911 call was needed to alert them of the real emergency. Fortunately, by the time the fire department had arrived, the emergency team had suppressed the fire.

The cause of the fire is believed to be the oxidation of the calciner drop powder consisting principally of uranium dioxide (UO_2), but also including other unstable oxides of uranium, that could further oxidize at elevated temperatures. The friction of the feed-screw sliding on the powder or on the nylon tube could conceivably have contributed to heating the powder.

Incident 2
At another fuel fabrication facility, a fire was reported to have occurred in a slugger press containment housing.

In this configuration, uranium oxide powder, following a blending process, was gravity-fed from a second-floor hammermill baghouse through a 4-inch-diameter by 6-foot-long Viton hose to a first-floor slugger press. The Viton hose was connected to the slugger press shuttle by a Neoprene boot. The slugger press shuttle area, including the Viton hose and the Neoprene boot, was enclosed by the containment housing, which had two Lexan panels for access to the shuttle area. Containment ventilation was provided through the primary and secondary HEPA filters and a water scrubber before exhausting to the environment.

The operator noticed that the granulator downstream of the slugger was not discharging powder. Apparently, this was not an unusual occurrence. The operator started to arrange for replacement of the granulator screen, as was the normal practice. He then noticed a fire in the slugger housing. The ventilation system smoke detector had by this time sensed the fire, and alarm bells were sounding. Employees extinguished the fire within minutes using portable carbon dioxide fire extinguishers.

All of the combustible elements in the containment between the hammermill and the slugger press (i.e., the Viton hose, the Neoprene boot, and the Lexan parts of the containment housing) were consumed by the fire. The primary HEPA filters were extensively damaged. The secondary filters were intact.

In this case, heat generated by oxidation of the powder, which ignited the Neoprene boot, was judged to be the cause of the fire.

Preventive Measures and Lessons Learned

The very nature of the fuel fabrication process involves the handling of unstable uranium powder. Certain preventive measures can be taken to reduce the potential for fires. Many of these have been adopted at licensed facilities. They are:

- Limit the type of feed to stable powder whenever possible.
- Store unstable powder in closed metal containers.
- Replace the combustible components of powder-transfer lines and of equipment with components made of noncombustible materials.
- Require that an operator be present when a process is under way.
- Improve visibility around vulnerable equipment.
- Incorporate fire safety of vulnerable equipment in the operator training program.
- Implement a preventive maintenance program for vulnerable equipment.
- Handle unstable powders in an inert gas atmosphere.
- Partially oxidize the powder to render it stable.

In addition, the following measures for upgrading the fire detection, alarm, and suppression systems should be considered:

- Install fire detectors in hoods and equipment exhaust ducts.
- Check alarm system wiring for vulnerability to fire.

- Implement a manual restart procedure should the alarm circuitry be partially disabled and the alarm stops.
- Upgrade the alarm system and public address system for audibility.
- Add visible alarm signals in noisy areas.

This page intentionally left blank.

MODULE 3.0: FIRE HAZARDS AND FIRE PROTECTION CONCERNS AT FUEL CYCLE FACILITIES

Learning Objective

When you finish this section, you will be able to:

3.1.7 Identify the fire hazards associated with processes that involve zircaloy metal.

ZIRCALOY FIRE HAZARDS

Zircaloy is a combustible metal, especially in thin scrap or powdered form. The electric arc welding of zircaloy tubes loaded with fuel pellets is performed in an inert atmosphere inside the welding machine. The fire potential in the welding process arises from possible malfunction of the machine and impairment of the inert atmosphere. In another operation, defective loaded fuel rods are cut open and the pellets are removed. This operation produces zircaloy scrap, which has the potential for spontaneous ignition.

The zircaloy fuel rod manufacturing system also presents a fire hazard. This process involves machining operations, producing combustible scraps of the zircaloy metal. As a preventive measure, any cutting, grinding, or welding operation with this metal should provide for collection and removal of the scrap. This hazard is of somewhat lesser concern because radioactive materials are not involved.

Appendix B to the NFPA Standard 482 1996 provides the following information on the hazards of zirconium or zircaloy:

- Section B-4.1 states, "Zirconium and its alloys do not present serious risk when handled in most forms in which they are ultimately used, i.e., tubes, bars, and sheets. However, finely divided chips, turnings, or powder may be easily—sometimes spontaneously—ignited and may burn very rapidly. Although other potential hazards exist during melting, those that have resulted in the most serious and lethal accidents have been associated with the handling of zirconium powders, finely divided scrap, and so-called black reaction residues. For this reason, special precautions must be observed during handling or disposal of these materials".

  "Several companies have reported that fires have occurred while zirconium bars, plates, and other shapes were being chopped. A number of fires have occurred when hot or burning chips fell into accumulations of moist fines on or under lathes or milling machines. The most violent reactions have occurred when burning chips fell into drums or deep containers partially filled with moist turnings or scrap."

- Section B-5.2 states, "The burning rate of zirconium chips and turnings increases when water or water-soluble oils are present as a surface coating. The burning rate also increases with increasing pile depth, degree of confinement, and increasing void space in the pile. Chips and turnings less than 0.003 in. (0.8 mm) thick are particularly susceptible to rapid burning. Other factors being equal, partially wet material ignites more easily and burns more rapidly than dry material."
- Section B-5.3 states, "Small amounts of water tend to increase the risk of explosion. Additional heat is liberated on formation of the hydrated oxide, thus increasing the chance of an explosion. Scrap that is fully immersed in water will generally not overheat because the water provides a substantial heat sink. However, with tight-packed, very finely divided zirconium, it would seem that some risk might still be present."

Glovebox Fire Hazards

A glovebox is a sealed enclosure with viewing windows designed to separate the space in the box from its surroundings and in which all items in the box are handled using gloves that are sealed to the enclosure walls. Gloveboxes are used for manual operations with enriched uranium. They are provided with arm-length synthetic gloves attached to flanges around hand holes so that the uranium can be handled without any of the material leaving the system. Manufacturing operations with fire potential are usually performed in an inert atmosphere in a glovebox, but operations are also performed in air with a slightly negative pressure inside. The negative pressure provides assurances that leakage will be into the box.

Process materials such as oxides of uranium are not themselves combustible, but some items of equipment, such as glovebox panels, may be made of combustible materials. Preferably, gloveboxes should be constructed of noncombustible materials such as stainless steel and glass. All shielding should be either noncombustible or encased with noncombustible material. Glovebox windows should be constructed of wire glass, fire-rated glass, or laminated safety glass.

Fires involving gloveboxes give rise to substantial local releases of radioactivity within the plant, and this can lead to occupational hazards. In safety assessments, the fire is assumed to destroy the local filters located on the gloveboxes so that any uranium oxides that become airborne reach the final main plant filters. The main plant's HEPA filters should normally be located some distance from the gloveboxes. This remoteness, along with the provisions of a valve and, in some cases, an extraction duct cooling arrangement located some distance upstream of these filters, are usually sufficient to protect the main filters against the effects of fire. Therefore, these filters, which should include at least two HEPA filters, should be designed to retain these oxides. See underwriters laboratories, Inc. UL 586 Test Performance of High Efficiency, Particulate, Air Filter Units (also identified as ANSI B 132.1).

Nuclear Criticality Safety

NFPA Standard 801, Recommended Fire Protection Practice for Facilities Handling Radioactive Materials, includes the following information concerning nuclear criticality safety issues:

> "...if a criticality incident should occur, the type and quantity of radiation emitted create grave hazards to personnel. Even a small fire within a ‘glove box’ can produce serious consequences if not properly controlled. Fire control systems and procedures for ‘glove boxes’ should be carefully developed and applied before the boxes are used. Generally, such protective systems are custom-designed for each particular application.
>
> "To avoid criticality during fire emergencies, fissile materials that have been arranged to minimize the possibility of a criticality occurring should be moved only if absolutely necessary. ...Since water is a reflector and a moderator of neutrons, concern for a ‘criticality’ hazard sometimes leads to the unjustified and unevaluated exclusion of fire protection water from the area where fissile materials are stored or handled. The possibility of water moderation and reflection bringing about a ‘criticality accident can be calculated in advance. If, in fact, such a hazard exists, combustible material that would require the use of water for fire fighting should be eliminated. If combustible materials are unavoidably present in quantity sufficient to constitute a fire risk, water or other suitable extinguishing agent should be provided for fire fighting purposes. The fissile materials should be so arranged that water moderation and reflection will not present a hazard. In many facilities, fissile materials are stored and handled in sprinklered areas."

Example - Rocky Flats Fire, 1969

Although this fire occurred in a plutonium processing plant, the lessons learned and the subsequent safety improvements have a direct application to uranium fuel cycle facilities.

On May 11, 1969, Rocky Flats experienced the worst accident in plant history, a major fire in the 776-777 building, which was initially caused by pyrophoric plutonium scrap. It was one of the costliest industrial fires of all time—damages were estimated at \$26-\$50 million. This accident was intensified and compounded by a number of operational errors.

The fire occurred at 2:27 p.m. Sunday and was reportedly caused by spontaneous ignition of a 1.5 kg briquette of plutonium alloy scrap contained in a metal can. This scrap was believed to have been oily and coated with residual carbon tetrachloride (CCl_4). Once ignited, the fire spread through several hundred interconnected gloveboxes in the two connected buildings.

The fire started in the west end of the north line, progressed eastward, crossed over to the south line through the interconnecting gloveboxes, and spread through the south line. The fire spread through the machining gloveboxes at the east end of 776 and into the inspection boxes in 777. Damage was extensive. Both Benelex, a combustible neutron shielding material added to the gloveboxes, and the combustible Plexiglas glovebox windows contributed to the rapid spread of the fire. Out of the 6000 lbs of Benelex, 600 lbs burned.

The main fire lasted about four hours, with minor flare-ups occurring through the next night. After futile attempts to control the fire with CO_2, the firemen finally resorted to the applying water to bring the fire under control. This was the first time in history that water had been used to fight a plutonium fire. Despite attendant criticality dangers, the use of water was successful in controlling the fire.

The interiors of the two extremely large, high-bay buildings were grossly contaminated. An extensive, long-term cleanup effort was necessary for decontamination. Limited production was restarted about six months later in a temporary production line constructed in an adjacent building.

As damaging as the fire was, the water use prevented breaching of the outer walls and ceiling of 776 and 777, thus preventing a major release of plutonium to the environment. The small amount of plutonium released—almost entirely contained on the plant site—was about 0.0002 curies. Slightly contaminated external areas were subsequently cleaned up.

Fortunately, the fire created no direct deaths. However, one firefighter received significant plutonium lung burdens, and other firefighter and personnel incurred smaller radiation inhalations and exposures while fighting the fire and later cleaning up heavily contaminated areas.

Immediately prior to the fire, personnel levels were significantly cut with no real decrease in work load or production demands. Strict attention to plutonium chip handling no longer seemed to have been a top priority.

Lessons Learned from the 1969 Rocky Flats Fire

The many lessons learned from this 1969 fire include:

- Plutonium pyrophoricity is unpredictable.
- Combustible materials such as Benelex and Plexiglas must be kept to a minimum in process buildings.
- Uncleaned and uncanned briquettes can not be left unprotected and unattended on off-shifts.
- Buildings 776-777 were essentially one large room with interconnected glovebox trains

with basically no fire breaks or fire walls. This setup allowed for rapid, large-area spread of fire and radioactive contamination.

Safety Improvements Made as a Result of the 1969 Rocky Flats Fire

The lessons learned from the 1969 fire have led to a number of safety improvements including the following equipment modifications and procedural revisions:

- A central, computerized alarm system has been installed.
- A sprinkler/water system has been put in place.
- Gloveboxes with inert atmospheres, heat detectors, and minimal Benelex and Plexiglas shielding are used.
- Water-filled double walls have been constructed for shielding.
- Firewater dams on doors are in place.
- Removal of flammable material from gloveboxes is done regularly.
- Briquettes are stored in metal containers with tight fitting lids.
- Containers are placed on metal racks with heat detectors.
- Canning of briquettes is done in an inert atmosphere or vacuum for unattended (overnight or longer) storage.

Case Study: Nuclear Fuel Services Erwin, Tennessee

Background

Nuclear Fuel Services operates a nuclear fuel fabrication facility at Erwin, Tennessee. Recent activities at the site have involved:

- Decontamination and decommissioning of facilities and plant areas
- Fuel development work

Event Summary

On Tuesday, April 2, 1996, a fire was detected on the roof of Building 302 above the incinerator room. The incinerator exhaust duct was breached by the fire. The incinerator was burning contaminated material at the time so the potential existed for a radioactive release. Figures 3-10 through 3-13 provide schematics of the incinerator system.

Cause of the Fire

An Augmented Inspection Team (AIT) determined that the cause of the fire was less than adequate cooling of the hot exhaust from the incinerator. This resulted in the heating and subsequent ignition of either the resin component of the duct material or the carbon material deposited on the duct wall.

- Less than adequate cooling of the gases occurred from operating the system in an altered condition:
    - Lack of spray fittings on two nozzles
    - One nozzle plugged
    - Nozzles mispositioned
    - Make-up water turned off

- Temperature sensors did not activate additional cooling spray to the system. Duct temperature alarms did not activate. Water supply had been closed to stop water sprays to the incinerator for a period. The audible alarm in the Incinerator Room for high duct temperature had been turned off because of a malfunction. These conditions occurred due to:
    - Lack of preventive maintenance
    - Ineffective surveillance testing
    - Failure to identify safety related equipment
    - Inadequate documentation for the system
    - Inadequate training of the operator
    - "Working around" problems rather than fixing them

- The presence of combustible materials being carried by the exhaust throughout the duct system was not reported to personnel who could have evaluated the consequences. Cooling spray water filters designed to remove some of this material were bypassed due to rapid plugging. These conditions occurred due to:
    - Lack of communication between operations, engineering, and supervision
    - Failure to follow requirements in the procedure

Figure 3-10. Erwin Facility

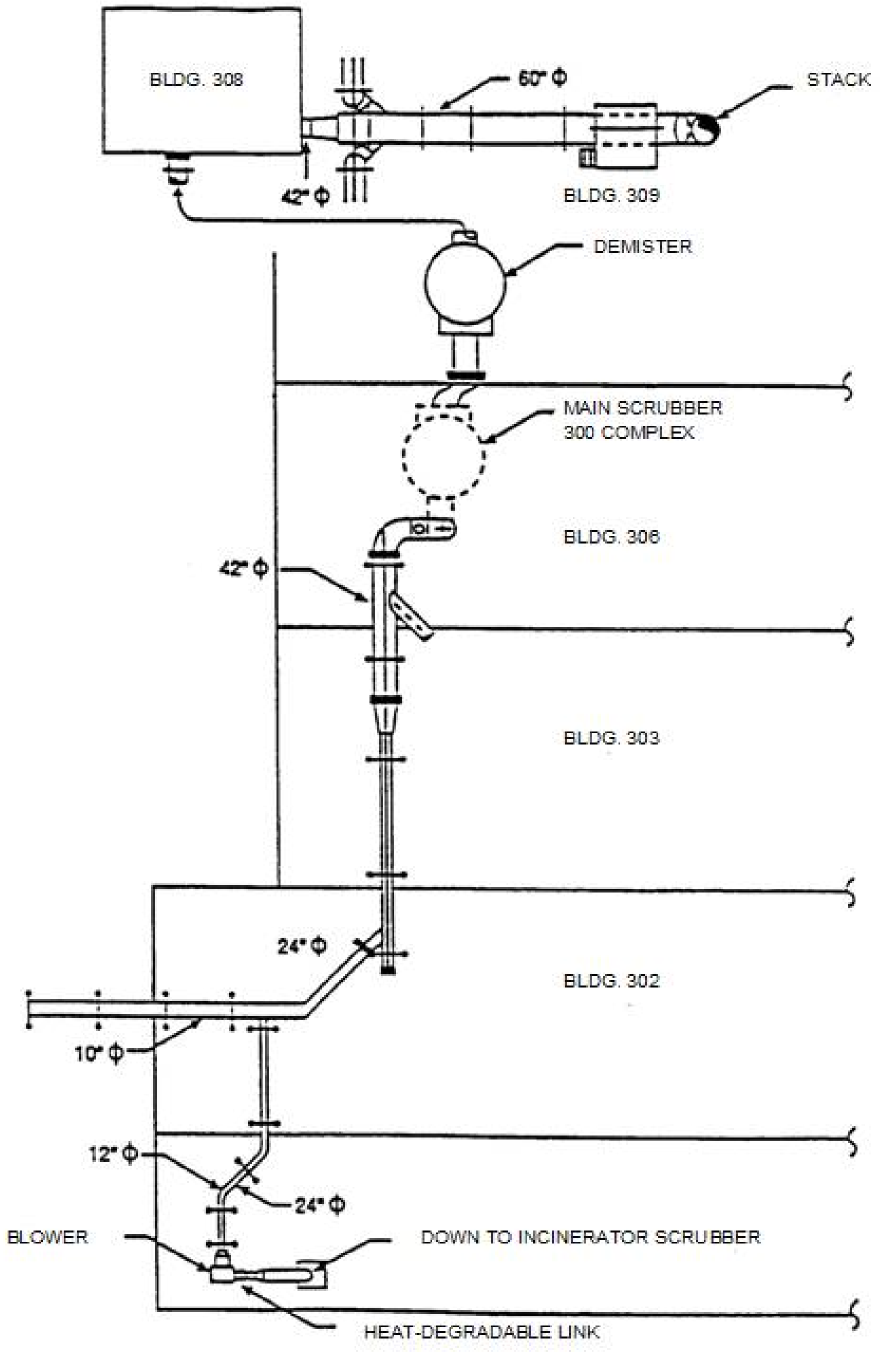


Figure 3-11. Incinerator Systems

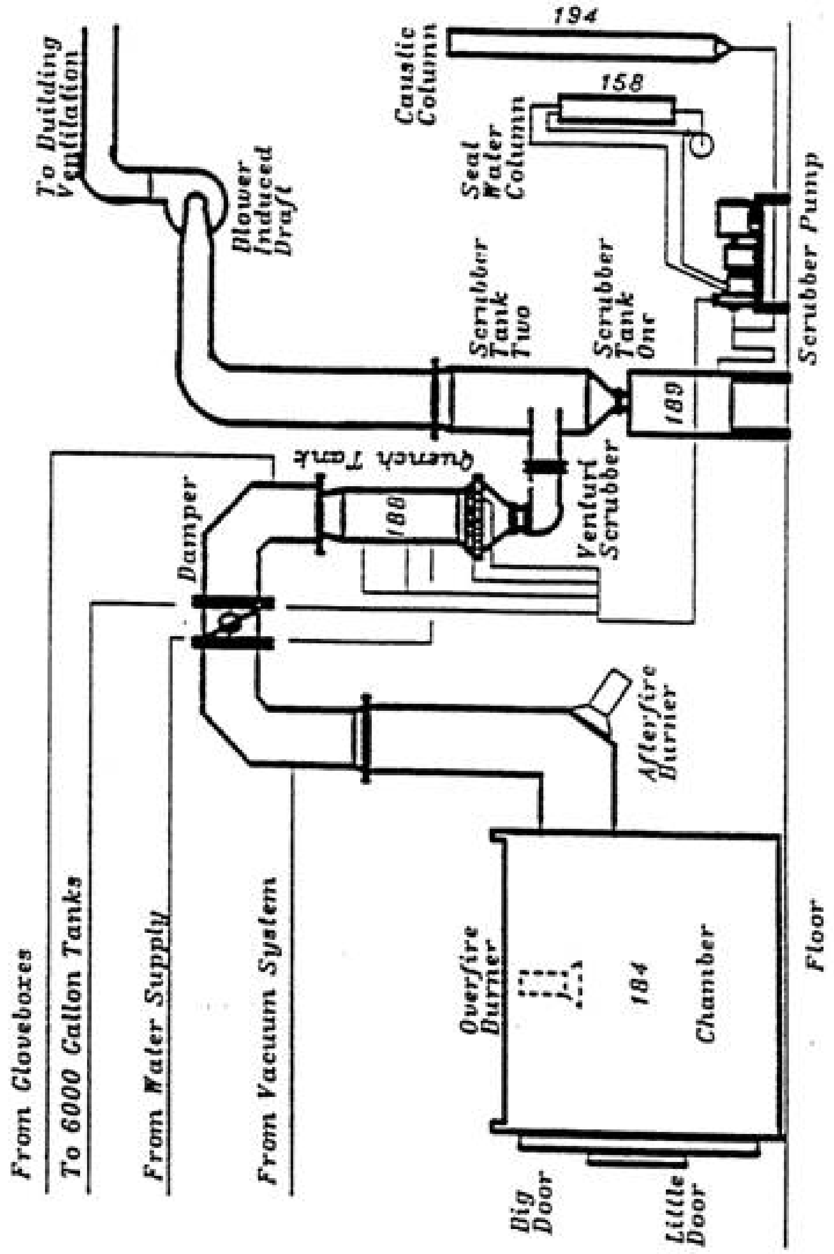


Figure 3-12. Incinerator Scrubber System

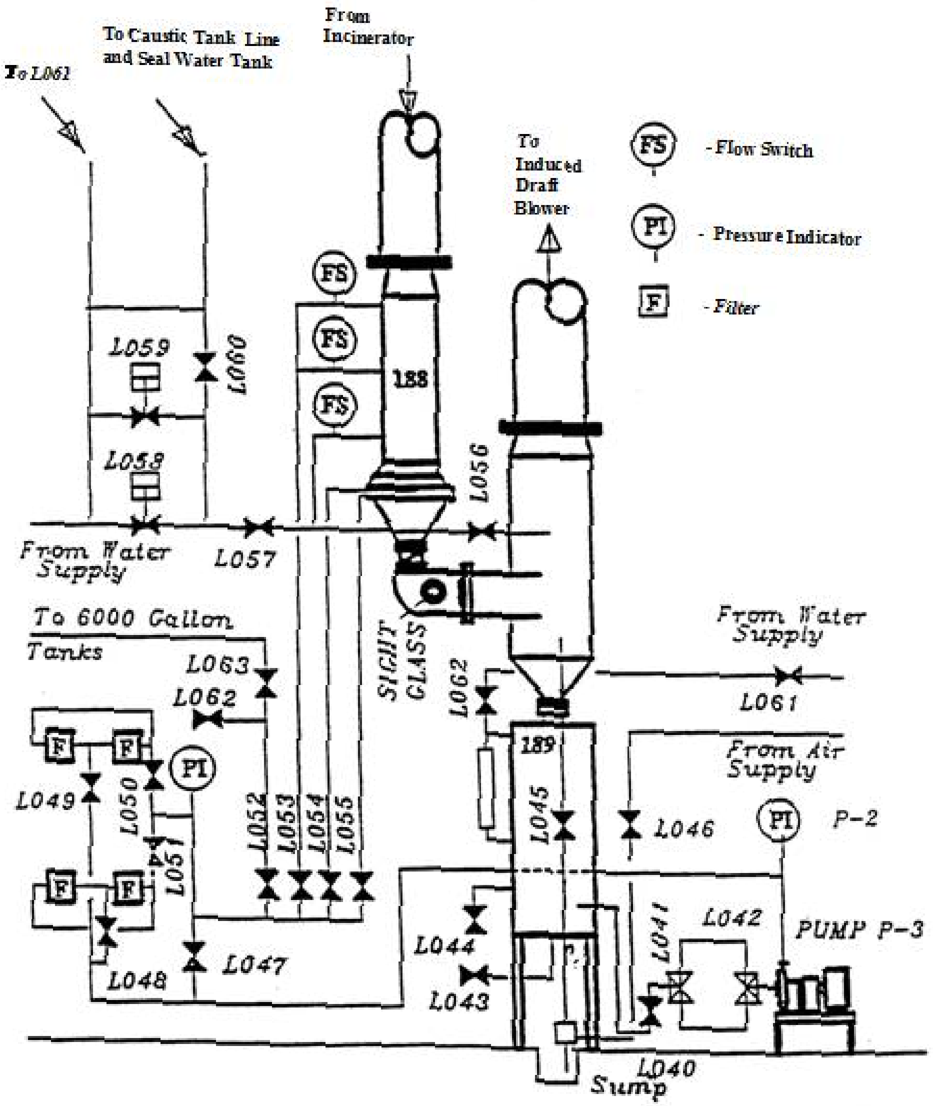
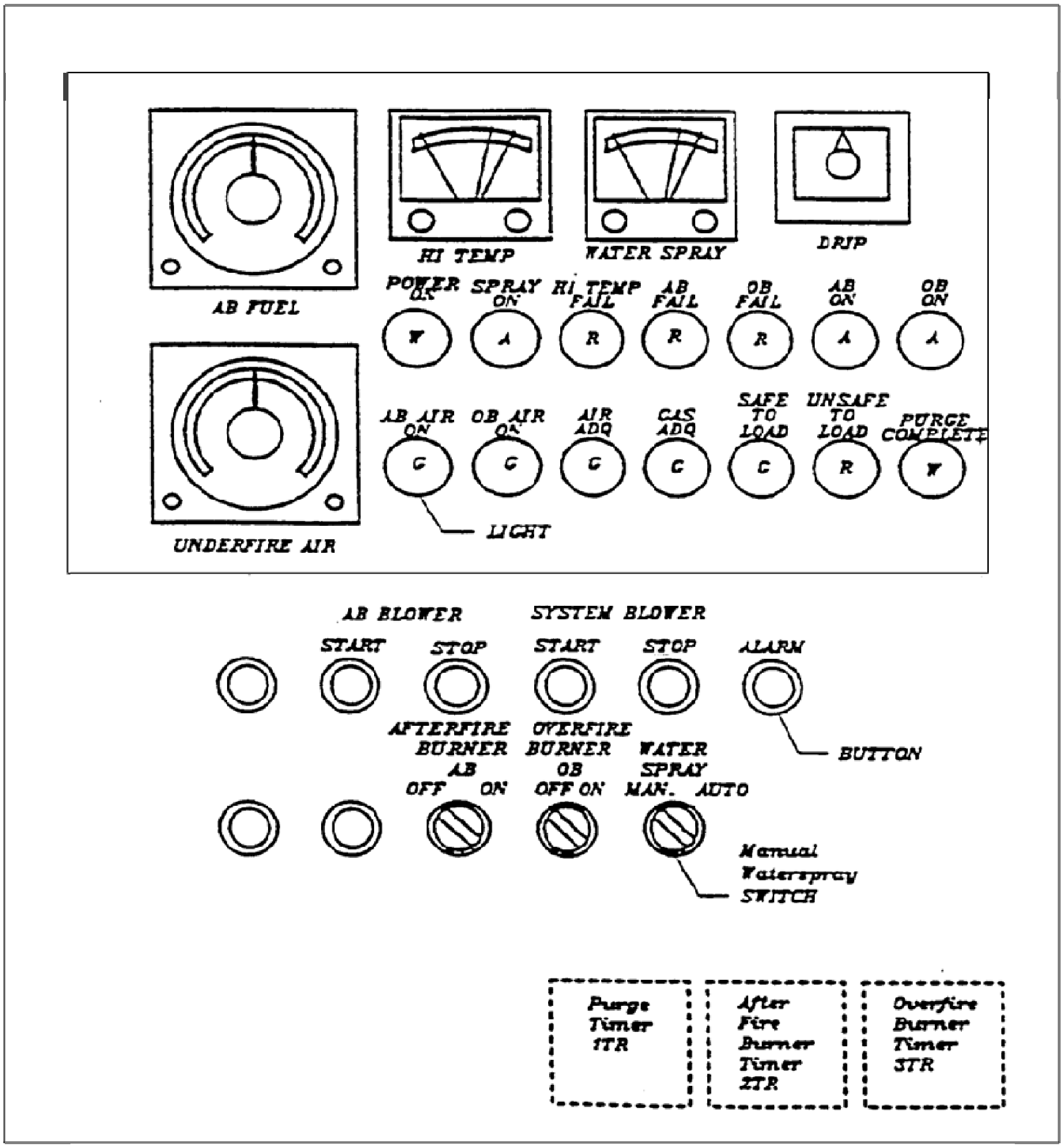


Figure 3-13. Incinerator Control Panel



Activity 2 – Fire Hazards

INSTRUCTIONS: Fill in the blank in each of the following statements. Use the material in the trainee guide to help you. Write the letter on the corresponding line indicated by the number to solve the puzzle. Answers are located in the answer key section of this module.

PART 1

Puzzle:

___ ___ ___ ___ ___ ___ ___ ___ ___
1 2 3 4 5 6 7 5 8

___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___
9 10 11 3 12 10 3 11 9 1 5

___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___
13 14 11 7 15 13 3 1 1 3 16

___ ___ ___ ___ ___ ___ ___ ___ ___ ___.
17 5 14 9 3 1 16 6 18 9

Clues:

1. A material that can ignite spontaneously when exposed to air is called a

___ ___ ___ ___ ___ ___ ___ ___ ___ ___ substance.

18 5 2 16

2. The burning of a gas, liquid, or solid in which the fuel is rapidly oxidized producing heat and often light is called ___ ___ ___ ___ ___ ___ ___ ___ ___ ___.

17 13 1

3. The grinding of fuel pellets during fuel fabrication produces uranium ___ ___ ___ ___ ___ fines, which can ignite spontaneously under certain circumstances.

11

4. ___ ___ ___ ___ ___ ___ ___ ___is well known as having the highest burning

15 4 velocity of all gases.

5. One of the hazards at a uranium mill is the storage, handling, and process use of combustible liquid ___ ___ ___ ___ ___ ___ ___ ___ in the acid leach process.

7 12

6. Uranium in finely divided form is readily ignitable, and uranium scrap from machining operations is subject to ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ignition.

9 3 14

7. During fuel fabrication, the ammonium diuranate (ADU) is heated in the hydrogen atmosphere of the ___ ___ ___ ___ ___ ___ ___ ___ at 1300°F to produce uranium dioxide powder.

6 10

8. ___ ___ ___ ___ ___ ___ ___ ___ acid absorbs water from organic materials

8

accompanied by exothermic reaction that may ignite them.

MODULE 3.0: FIRE HAZARDS AND FIRE PROTECTION CONCERNS AT FUEL CYCLE FACILITIES

PART 2

Puzzle: ___ ___ ___   ___ ___ ___ ___   ___ ___   ___ ___ ___ ___ ___ ___
1 2 3   4 5 6 7   5 8   9 6 1 10 11 3

___ ___   ___ ___   ___ ___ ___ ___ ___   ___ ___ ___ ___ ___ ___
12 13   1 5   14 10 12 7 15   14 3 1 1 3 11

___ ___ ___ ___
16 12 17 3

Clues:

1. One of the principal fire hazards in gaseous diffusion plants is related to the storage, transfer, and use of flammable and combustible liquids such as

___ ___ ___ ___   ___ ___ ___ ___.
3   12

2. ___ ___ ___ ___ ___ ___ ___   ___ ___ ___ ___ ___ feed material in granulated
6 9   16 5   15

form and in contact with oxygen undergoes exothermic oxidation reactions that may ignite combustible materials in the area.

3. At a fuel fabrication plant, defective loaded fuel rods are cut open and the pellets removed. This operation produces ___ ___ ___ ___ ___ ___ ___ ___ scrap, potential for spontaneous ignition.
17 7

4. At Rocky Flats in 1969, a fire spread through several hundred interconnected

___ ___ ___ ___ ___ ___ ___ ___ ___ ___ in the two connected buildings.
4   14   13

5. In the Nuclear Fuel Services fire on April 2, 1996, the Augmented Inspection Team (AIT) determined that the cause of the fire was less than adequate cooling of the

hot ___ ___ ___ ___ ___ ___ ___ from the incinerator.

2 10 1

6. ___ ___ ___ ___ ___ ___ ___ ___ reacts violently with hydrogen and many organic

8 11

materials causing fires even though it is itself nonflammable.

MODULE 3.0: FIRE HAZARDS AND FIRE PROTECTION CONCERNS AT FUEL CYCLE FACILITIES

Learning Objective

When you finish this section, you will be able to:

3.1.8 Identify common fire protection features found at all fuel cycle facilities.

COMMON FIRE PROTECTION FEATURES AT FUEL CYCLE FACILITIES

Common fire protection features used in any industrial plant are found in all of these facilities. These include:

- Protection of flammable and combustible liquid storage and warehouses.
- Provision of fire pumps, water mains, hydrants, hose stations, and portable extinguishers.
- Installation of automatic fire suppression systems.

The adequacy of these features vary from facility to facility.

OTHER FIRE PROTECTION FEATURES

As part of the integrated safety analysis (ISA) required by 10 CFR 70.62(c), new fuel cycle facility and facilities undergoing major renovations must perform systematic fire hazard analyses (see NUREG-1520 for further guidance). In addition, owners and the insurers of these facilities have not performed surveys of fire risk and provide protection features.

Fire Hazard Analysis

A systematic fire hazard analysis (FHA) should divide the facility into "fire areas," evaluate the fire safety of each area, and then evaluate the facility as a whole. For each area, the analysis should:

- Account for all radioactive and combustible materials, including estimates of their heat content.
- Account for processes performed and their potential for fire or explosion.
- Account for sources of ignition such as heat and flame from hot process equipment.
- List all fire detection and suppression equipment.

- Consider credible fire scenarios and evaluate the adequacy of the fire protection measures.

Such an analysis would reveal deficiencies that may have been overlooked or would confirm the adequacy of the fire protection measures. Furthermore, any significant modification of buildings, processes, or inventories should necessitate a review of the fire hazard analysis.

Module 4, Section 1.3, has information about an FHA. In addition, the Standard Review Plans in the Supplemental Reading section at end of Module 1.0 give details and requirements for an FHA. See NUREGs –1718, –1671, and –1702.

Fire-Rated Barriers

Prevention of fire spread through the use of compartments and separation of areas is a basic principle of fire protection. In large fuel cycle facilities, certain processes should be contained in their own fire area. These processes include:

- Solvent extraction/purification
- Calcining
- Ammonia dissociation
- Feed reduction
- Fluorine production
- UF_6 production
- UO_2 blending and sintering
- Pellet machining
- Fuel rod assembly

In addition, boiler rooms, warehouses, maintenance shops, control rooms, and fire pump areas should be separated. Such separation, where it exists, is commonly achieved by 8-inch cement block walls and concrete floors and roofs. This is considered adequate to confine a fire within an area for at least 60 minutes. This is usually the case in fuel fabrication facilities.

Because of the design of the already operating UF_6 enrichment and conversion facilities, hazard separation is not achieved in every case in these plants, thus increasing the risk of fire spread. The relatively open construction of process areas in these plants has the advantage of allowing freer egress of personnel in the event of an accident and easier visual detection of fire. Compensation for lack of confinement by barriers is usually provided by enhanced surveillance of the vulnerable areas by such devices as automatic fire/chemical detectors and television monitors.

Regardless of the lack of uniform standards and although all facilities in the United States comply with local building codes, there are still areas in a facility where a barrier should have existed or where a barrier has an inadequate fire rating. This is a concern that should be resolved in a case-specific way by some combination of facility modification and enhanced fire protection.

Automatic Fire Detection and Suppression

Fuel cycle facility operation is generally not labor-intensive. There are process areas in these facilities that are infrequently visited, and plants do not always operate around the clock. In these cases, surveillance by automatic fire detectors (also chemical and spill detectors) becomes necessary. These detectors should be connected to central annunciator panels that are continuously supervised and indicates the zone of origin of an alarm. In addition, actuation of an automatic fire suppression system, such as a sprinkler system, should also transmit an automatic alarm signal to the central annunciator panel.

Fire Emergency Planning

Fire emergency planning (also termed pre-fire planning) for fuel cycle facilities in the United States is usually encompassed in the general radiological emergency planning required by regulation. Often the same team is trained and responds to both fire and radiological emergencies. The elements of fire and radiological emergencies are similar. A fire emergency plan should assign individual and alternate responsibilities for:

- Suppressing incipient fires
- Calling for the site fire brigade, and, if necessary, the off-site fire department
- Evacuating personnel
- Shutting down processes in an orderly way
- Safeguarding and controlling radioactive materials

The plan should clearly indicate the location of fire fighting equipment, such as portable extinguishers, block valves, and hoses. It should provide precise, written emergency procedures for process shutdown and radioactive material control.

More importantly, fire emergency planning should provide for regular fire drills and a well-organized training program for the fire brigade members. Often a facility is situated in a remote location and the facility fire brigade must be in readiness to handle all fire emergencies on its own. Even when off-site help is available, it is important that the guest firefighters be reasonably familiar with the facility and the specific hazards involved in fighting a fire in it. It is, therefore, strongly recommended that the facility personnel and the offsite fire department personnel train and drill together on-site at reasonable intervals.

MODULE 3.0: FIRE HAZARDS AND FIRE PROTECTION CONCERNS AT FUEL CYCLE FACILITIES

A Memorandum of Understanding (MOU) should be in place between local emergency response personnel and the license. These MOUs should outline the services expected from the local responders.

SUMMARY

The outbreak of fire at fuel cycle facilities can have serious consequences and may result in the spread of radioactive materials into the environment. Fire protection programs can be summarized as follows:

- Prevent the outbreak of fire
- Limit the spread of fire
- Detect fire and provide alarm
- Extinguish the fire

Self-Check Questions 3-1

INSTRUCTIONS: Select the best answer for each of the following questions. Answers are located within the self-check.

1. A common fire protection feature found at most industrial plants and at fuel cycle facilities is:

   a. A detector to determine radioactive releases in smoke; go to 7 to see if your answer is correct
   b. A fire wall able to contain a fire for a minimum of 2 hours; go to 10 to see if your answer is correct
   c. An automatic fire suppression system; go to 5 to see if your answer is correct

2. Sorry. That is not correct. Benelex and Plexiglass are combustible materials. Go to 9 for the correct answer.

3. Good try, but not correct. Go back to 16.

4. Gloveboxes should be constructed of materials such as:

   a. Stainless steel and wire glass; go to 9 to see if your answer is correct
   b. Benelex and Plexiglass; go to 2 to see if your answer is correct

5. Right. You are off to a good start. Go to 4 for the next question.

6. Zircaloy is a combustible metal and is capable of spontaneous combustion especially in:

   a. Long thin sheets; go to 19 to see if your answer is correct
   b. Thin scrap or powdered form; go to 14 to see if your answer is correct

7. Wrong answer. Detectors equipped to determine radioactive releases are not common fire protection features at most industrial plants. Go back to 1.

8. The fuel fabrication process involves the handling of unstable uranium powder. Which of the following would be a preventive measure to reduce the potential for fire?

   a. Require that process equipment contain materials such as neoprene; go to 13 to see if your answer is correct

b. Store unstable powder in closed metal containers; go to 20 to see if your answer is correct
c. Ensure that zircaloy tubes are not present in the process area; go to 27 to see if your answer is correct

9. Correct. Both stainless steel and wire glass are noncombustible. In addition, all shielding should be either noncombustible or encased with noncombustible materials. Go to 16 for the next question.

10. Sorry, this is not the right answer. Go back to 1.

11. Nice try, but incorrect. Go back to 22.

12. Calcining at 1300°F and sintering at 3200°F present fire hazards during the fuel fabrication process. Go to 22 for the next question.

13. Sorry. Neoprene is a combustible material. Combustible materials should be used sparingly in process equipment. Go back to 8.

14. Right! In finely divided chips, turnings, or powder, zircaloy can ignite spontaneously and burn very rapidly. Go to 8 for your next question.

15. Uranium oxide feed material (mostly UO_2) in granulated form and in contact with __________ undergoes exothermic oxidation reactions.

    a. Nitric acid; go to 17 to see if your answer is correct
    b. Oxygen; go to 21 to see if your answer is correct
    c. Water; go to 26 to see if your answer is correct

16. The principal process-related fire protection concerns in fuel fabrication arise from storage, handling, and process use of _____________ and_____________.

    a. Nitrogen; uranium oxides; go to 3 to see if your answer is correct
    b. Hydrogen; combustible solvents; go to 24 to see if your answer is correct

17. Your selection is incorrect. Go back to 15 and try again.

18. Fluorine is used for cascade maintenance during the enrichment process. Neither fluorine nor HF alone constitute a fire hazard. What fire hazard do they promote? Check your answer at number 25.

19. Sorry, that is not correct. Go to 14 for the correct answer.

20. Absolutely right! Go to 15 for the next question.

21. Right on! Proceed to 23 to continue.

22. The major fire hazards on the operating floor at a uranium enrichment plant are associated with the:

    a. Compressors and cooling units; go to 11 to see if your answer is correct
    b. Lubricating oil containment; go to 31 to see if your answer is correct

23. During fuel fabrication, the high temperatures used in _____________ and ______________ present fire hazards. Go to 12 to check your answers.

24. Correct! Your doing great. Go to 6 for your next question.

25. F_2 and HF, in some cases, will promote ignition (sometimes violent) in contact with wood or other organic materials. There is also a latent fire or explosion hazard due to the possible generation of hydrogen in containers, piping, and equipment used in the handling and storage of F_2 or HF. Advance to 30 for your next question.

26. Sorry, water is not the right answer. Go back to 15 and try again.

27. No, zircaloy tubes are not a fire hazard. Go back to 8 and make another selection.

28. Not the correct choice. Go back to 37.

29. You missed this one. Go back to 34 for the correct answer.

30. Hydrogen is used during the uranium conversion process. It is well known as having the highest burning velocity of all gases and has a wide flammable range in mixtures with air.

    a. True; go to 35 to see if your answer is correct
    b. False; go to 32 to see if your answer is correct

31. You got it! The lube oil in these pit areas constitute a serious and unavoidable fire hazard. Go to 18 for the next question.

32. Sorry. Go back to 30 and try again.

33. This is the correct answer. Sulfuric acid is used as a reagent for digesting yellowcake with high sodium content before reduction in the hydrofluor process. The hydrofluor process is no longer used in the U.S., but it is important to understand the basic principles of the process and the fire hazards associated with it. Proceed to 38.

34. Sulfuric acid is used during the uranium conversion process. It is a fire hazard because it:

    a. Reacts violently with metallic powders and water vapor; go to 29 to see if your answer is correct
    b. Absorbs water from organic materials accompanied by exothermic reactions that may ignite them; go to 33 to see if your answer is correct

35. Terrific, you have made the correct selection. Go to 37 and try your hand at the next question.

36. Congratulations, you got it right. Hydrogen is the correct answer. Proceed to 42 and on the way ask yourself: "Which chemical used during the conversion process reacts violently with hydrogen and many organic materials causing fires even though it is itself nonflammable?"

37. Uranium scrap from machining operations is subject to:

    a. Rapid deterioration; go to 39 to see if your answer is correct
    b. Accelerated decay; go to 28 to see if your answer is correct
    c. Spontaneous combustion; go to 40 to see if your answer is correct

38. In the presence of water as liquid or vapor, uranium may also oxidize into UO_2 and U_3O_8 - with generation of ___________________, a flammable and explosive gas.

    a. Hydrogen; go to 36 to see if your answer is correct
    b. Fluorine, go to 41 to see if your answer is correct

39. Sorry, wrong answer. Go back to 37 and try again.

40. Yes! A substance that is capable of spontaneous combustion is also called pyrophoric. Move to 34 for the next question.

41. Incorrect. Go to 36 for the correct answer.

42. The correct answer is fluorine. Congratulations! You have completed the review questions for Module 3.0.

You have completed this module.
Schedule an appointment with your administrator before you go any further.

ANSWER KEY

Activity 1: Fire Hazards Associated with Uranium Enrichment Processes and Equipment

1. Side Purge Cascade.

2. A few operational staff experienced smoke inhalation. Some of the emergency responders incurred some minor injuries due to the result of slipping on spilled lubricating oil.

3. During the response, the firefighting efforts were complicated as a result of:

    - Operations staff's failure to isolate the hydraulic control oil supply to Cell 25-7-2.
    - Low fire water pressure to foam eductors which precluded the use of foam as an extinguishing agent.
    - Weaknesses in the emergency responders' understanding of the proper techniques for fighting a fire concurrent with holes in the process gas equipment.

4. The inspectors determined that the operation staff's initial response to abnormal conditions involving Cell 25-7-2 were not directed by or consistent with some plant procedures and may have allowed the abnormal condition to propagate. Subsequent actions were properly focused on limiting the extent of the fire and ensuring plant staff safety; however, these actions were also not fully consistent with plant procedures and resulted, in part, in a continued supply of hydraulic control oil to the cell throughout the fire.

5. Management's decision not to activate the Emergency Operations Center (EOC) and not to classify the fire as an "alert" increased communication problems observed in the flow of information between the Incident Command (IC) and other management personnel. As a result, safety concerns relative to holes in the cascade piping and the presence of 3,000 gallons of spilled oil were not promptly resolved. Subsequent management oversight of the recovery process was noted to have improved following activation of the EOC and the dedication of a 24-hour, around-the-clock recovery team.

Activity 2: Fire Hazards

PART 1

1. Pyrophoric
2. Combustion
3. Oxide
4. Hydrogen
5. Solvents
6. Spontaneous
7. Calciner
8. Sulfuric

Puzzle: The goal of science is to build better mousetraps.

PART 2

1. Lube oils
2. Uranium oxide
3. Zircaloy
4. Gloveboxes
5. Exhaust
6. Fluorine

Puzzle: The goal of nature is to build better mice.

Self-Check Questions 3-1

Answers already with the questions.

This page has intentionally been left blank.