Conference Title: SMiRT 10

Date & Place: August 21 - 22, 1989 -- Anaheim, California

A REVIEW OF FIRE HAZARDS AND FIRE PROTECTION CONCERNS OF COMMERCIAL FUEL CYCLE FACILITIES IN THE UNITED STATES

by
A. Datta
U.S. Nuclear Regulatory Commission
Office of Nuclear Materials Safety and Safeguards
Washington, DC 20555, U.S.A.

ABSTRACT

Fuel cycle facilities constitute a basic industry that provides uranium fuel for the generation of electricity in nuclear power plants. Processes carried out in these facilities range from milling and extraction of uranium oxide concentrates from the uranium ore, conversion of the mill concentrates to uranium hexafluoride, enrichment, and fuel fabrication, to spent fuel reprocessing. The hazard of accidental fire and the potential for consequential release of radioactive material, as well as of toxic chemicals, exist at several steps of the manufacturing processes. Conventional fire protection measures, when applied to enriched uranium facilities, must be tempered by the consideration of avoidance of accidental nuclear criticality and by requirements of treatment and filtration of plant effluents, including those generated by fire. This paper examines the facilities and the processes involved in nuclear fuel production, that are currently regulated by the U.S. Nuclear Regulatory Commission (NRC), from the point of view of fire protection. The NRC, at this time, does not regulate fuel enrichment or reprocessing facilities. However, most of the comments contained herein may be generally applicable to all fuel cycle facilities.

DF02
1/1

1 INTRODUCTION

Fuel cycle facilities constitute a basic industry that provides uranium fuel for the generation of electricity in nuclear power plants. The production of nuclear reactor fuel assemblies, from the uranium ore or by recovery of residual fuel from "spent" fuel assemblies from the nuclear power plant, is accomplished in a succession of these facilities, each performing a series of processes, as listed below:

(a) The uranium mill: mills and extracts uranium oxide (U_3O_8), commonly called yellowcake, from the uranium ore;

(b) The uranium hexafluoride conversion facility: purifies and converts yellowcake into uranium hexafluoride (UF_6);

(c) The enrichment facility: enriches UF_6 in its U^{235} isotope content, according to the power plant specification;

(d) The fuel fabrication facility: converts enriched UF_6 to uranium dioxide (UO_2) fuel elements and produces the final product, the fuel assembly; and

(e) The reprocessing facility: recovers residual fissionable material from spent fuel assemblies for reuse as nuclear power plant fuel.

Since the United States Nuclear Regulatory Commission (NRC) presently does not regulate nuclear fuel enrichment or spent fuel reprocessing facilities, this paper draws on the experience of the remaining types of fuel cycle facilities. It is, however, believed that the observations made here would apply equally well to all fuel cycle facilities.

The feed material, the processes and equipment, the chemical reagents employed, and the end product characterize a particular type of facility, as well as the hazards of its operation. The bulk chemicals used as reactants, solvents, or purifying agents include substances such as nitric acid, elemental fluorine, and hydrocarbon liquids, which either are themselves combustible or provide stimulus for ignition when they react with ordinary combustible substances. Some processes are performed in high temperature furnaces and reaction vessels, heated by electricity or by natural gas flames. The potential for fire in the event of a spill or leak is therefore obvious, not to speak of the chemical toxicity hazard. Furthermore, fire protection measures, when applied to fuel cycle facilities, must be tempered by the consideration of avoidance of accidental nuclear criticality and by the requirement of treatment and decontamination of plant effluents, including those generated by fire.

The hazard of accidental fire and the potential for consequential release of radioactive material exist both in nuclear power plants and in fuel cycle facilities. However, while fire protection of nuclear power plants has been studied in considerable detail, comparable studies of fuel cycle facilities are sparse. The reason is that fire in a fuel cycle facility is judged to be of less serious consequence. In the United States, fire protection regulations relating to nuclear power plants have, therefore, been more detailed and precise than those relating to fuel cycle facilities. Following an accident in January 1986 in a uranium hexafluoride conversion facility, which was not fire-related, the NRC instituted the Materials Safety Regulation Review Study Group[1], a "blue ribbon" committee of inquiry into the safety of operation of the major fuel cycle facilities in the country. This committee identified fire, among other events, as a notable hazard that could result in the release of radioactive material in the environment. Thereupon, the Fuel Cycle Safety Branch of the NRC published a "Branch Technical Position"[2], establishing 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. A discussion of fuel cycle facilities and their fire protection concerns follows.

2 FIRE PROTECTION OF FUEL CYCLE FACILITIES AND NUCLEAR POWER PLANTS CONTRASTED

2.1 Fire Protection Objectives

Nuclear power plants are facilities for conversion of nuclear fission energy to electrical energy. Despite there being a few different designs of the nuclear steam supply system, the problems of fire protection relating to them are basically the same. The overriding objective is to protect at all times the ability to shut down the reactor. This is not to suggest that safety of the plant operators and provision of safe egress according to ordinary fire protection design rules are overlooked. Fuel cycle facilities, on the other hand, are a group of plants of different types, which are quite varied as to the feed materials processed, the process methods and equipments, and the end products. The fire protection concerns of uranium mills, UF_6 conversion facilities, and fuel fabrication facilities are, therefore, expectedly varied. The only commonality among them is that the radioactive material undergoing transformation through a succession of process steps is distributed throughout the facility, offering multiple potential sources of its release. Obviously, each such potential source has to be protected.

2.2 Regulatory Requirements

In the United States, the regulatory requirements for fire protection of nuclear power plants are specific. As an example, one can cite the following paragraph from the United States Code of Federal Regulations[3]:

> One train of equipment necessary to achieve hot shutdown from either the control room or emergency control station(s) must be maintained free of fire damage by a single fire, including an exposure fire.... Both trains of equipment necessary to achieve cold shutdown may be damaged by a single fire, including an exposure fire, but damage must be limited so that at least one train can be repaired or made operable within 72 hours using onsite capability.

Following this basic requirement for fire protection, the code goes on to specify detailed regulations concerning the various aspects of plant fire protection ranging from provision of fire water systems, through acceptable methods for separation of redundant trains of reactor shutdown equipment and automatic detection and suppression systems, to organization and training of fire brigades.

The regulatory requirement for fire safety of fuel cycle facilities, on the other hand, is implied in the more general requirement of the United States Code of Federal Regulations[4] that "the applicant's proposed equipment and facilities (be) adequate to protect health and minimize danger to life or property." United States federal regulations apart, the facilities also have to comply with local building codes and with conditions imposed by the fire insurers. In fact, heretofore, the fire insurance and the building code requirements have been the mainstay of fire protection of these facilities.

2.3 Fire Protection Programs

Unlike nuclear power plants, fire protection programs of fuel cycle facilities in the United States have been of varying strength from one facility to another. Many of these facilities are located in relatively remote places, sometimes too far away for timely assistance from well organized city fire departments. Also, fighting fires in manufacturing plants handling radioactive substances, which are chemically hazardous as well, requires special training and knowledge of the operation and layout of the specific facilities. Many fuel cycle facilities, therefore, have to rely principally on their own fire fighting resources. Thus, the training and readiness of the fire brigade members of these facilities become very important. In practice, however, in the absence of detailed regulatory requirements, the fire fighting capabilities of these brigades vary widely.

2.4 Consequences of Fire

The disparity between the regulatory attention paid to the fire protection of nuclear power plants and fuel cycle facilities is of course due to the judgment that fire in the latter is likely to be of less serious consequence. In the case of the power plant, loss of safe shutdown capability may cause reactor core-melt. Then, there would be the potential for intense and widespread release of radioactive material if the reactor containment also were breached. In the case of a fuel cycle facility, too, there is the potential for release of radioactive material, but less intense and widespread than in the case of a reactor core-melt and of shorter duration, even though there is no confining enclosure comparable to the reactor containment building. This may justify the much less stringent regulation. It is generally believed that, notably in the UF_6 conversion facilities, but also in the others, the hazard from the various corrosive and toxic chemicals may be greater than the fire hazard. In fact, the most serious accident in a fuel cycle facility in recent times, the 1986 accident in a UF_6 conversion facility, was not the result of a fire. Yet, there have been serious fires in fuel cycle facilities in the United States, and the committee of inquiry, that the NRC established in the wake of the 1986 accident, recognized fire as an important threat that could lead to radioactive release.

3 FUEL CYCLE FACILITIES, PROCESSES, AND THEIR FIRE HAZARDS

3.1 Uranium Mills

A uranium mill receives uranium ore from the mine and produces a semi-refined uranium concentrate of about 85 percent 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, and the remainder, 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. Figure 1 provides a schematic of the acid leach milling process.

The process-related fire hazards of a uranium mill arise from two sources. One is the storage, handling, and process use of a combustible liquid solvent in the acid leach process. Tributyl phosphate (TBP) is the commonly used solvent, which is not very volatile, but other solvents, including hydrocarbon liquids, may also be used. Spills from the extraction vessels and leaks from the solvent storage or the transfer pipe lines are not uncommon events. The other hazard is from the high temperature calcining process. Inadvertent carryover of the combustible material into the calciner and natural gas leak, where heat is provided by natural gas, are possible causes of fire.

3.2 UF_6 Conversion Facilities

Yellowcake milled from the ore is the feed material for UF_6 conversion facilities, which remove virtually all the remaining impurities from the feed and produce uranium hexafluoride, which is further processed in enrichment facilities. Two different processes are used for UF_6 production. The hydrofluor process consists of reduction, hydrofluorination, and fluorination of the feed to produce still impure UF_6, which then goes through a fractional distillation process to produce the pure product. 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, to prepare a highly pure feed before the reduction, hydrofluorination, and fluorination steps to produce the UF_6 product. A schematic of the solvent extraction process is in Figure 2. 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. The most prominent of them in presenting fire hazard and the nature of the hazard are discussed next.

(a) Nitric acid: In the solvent extraction process, yellowcake is digested with nitric acid in large tanks. Nitric acid itself is nonflammable, but under certain conditions, it nitrates cellulosic and other organic materials, making them easily ignitible. Nitric acid spill thus constitutes a fire hazard, in addition to being a corrosion and toxicity hazard.

(b) Flammable and combustible liquids: The solvent extraction process uses a mixture of organic solvents, some components of which may have flash points (temperatures, determined by standard tests under atmospheric pressure at which vapor issuing from the solvent will ignite upon receiving an ignition stimulus) in the range of 90°F to 165°F. The digested feed, uranyl nitrate, is introduced in the solvent extraction circuit, where the solvent mixture absorbs by stages more and more of the uranium from the nitrate. Spills from the large solvent extraction vessels are fire hazards to be protected against. Typically, there would be a battery of six such vessels of approximately 1000-gallon capacity each.

(c) Sulfuric acid: Sulfuric acid is the reagent used for digesting yellowcake with high sodium content before reduction in the hydrofluor process. In addition to its corrosion and toxicity hazard, this chemical has the property of absorbing water from organic materials accompanied by exothermic reaction, which may ignite them.

(d) Anhydrous ammonia: This chemical is used as source material for production of hydrogen for use in reduction processes, such as in the hydrofluor process of UF_6 production. Anhydrous ammonia is a flammable gas, which is stored and pumped in the liquified state and undergoes dissociation into hydrogen and nitrogen in a high temperature dissociator at about 1650°F. Both gases thereafter flow through heaters and reductors. Anhydrous ammonia presents fire and explosion hazards, the latter if ignited in a confined space. It also presents a toxicity hazard.

(e) Hydrogen: Hydrogen is well known as having the highest burning velocity of all gases and also as having a wide flammable range in mixtures with air. The hazards of fire and explosion in the event of a leak from any equipment handling or using hydrogen are obvious. Additionally, there is the hazard of explosion in vessels, such as reductors, heaters and filters, where explosive mixtures of hydrogen and an oxidizer may form inadvertently.

(f) Fluorine: Elemental gaseous fluorine 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. Fluorine is, of course, one of the most reactive elements known. Apart from its being highly corrosive and toxic, it reacts violently with hydrogen and many organic materials causing fires, even though it is itself nonflammable. Fluorine may also cause explosion in contact with metallic powders and water vapor.

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

3.3 Fuel Fabrication Facilities

Enriched uranium hexafluoride (two to five percent U^{235}), shipped from enrichment facilities in cylinders containing up to 2.5 tons, constitutes the feed material for fuel fabrication facilities. The feed is vaporized by application of heat in 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). There is in some plants 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, which are then sintered at a temperature of approximately 3200°F in a sintering furnace. Grinding of the pellets to precise dimensions, their loading into zircalloy fuel rods, and assembly of fuel rods into rod bundle assemblies completes the manufacturing process. Figure 3 presents a simplified process schematic.

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 and sintering also present fire hazards. The grinding of the fuel pellets produces uranium oxide fines. Hartman et al., [6] have reported that uranium oxide ignites spontaneously under certain circumstances. However, this is normally not a threat, since these fines are confined and channeled to the scrap recovery system.

The electric arc welding of zircalloy tubes loaded with fuel pellets is performed in an inert atmosphere inside the welding machine. Zircalloy is a combustible metal [7], especially in thin scrap or powdered form. 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 unloaded of fuel pellets. The operation produces zircalloy scrap, which is known to have sometimes ignited.

Of somewhat lesser concern, because radioactive material is not involved, is the zircalloy fuel rod manufacturing process, which involves machining operations, producing combustible scraps of the metal. Any cutting, grinding, or welding operation with this metal should have provision for collection and removal of the scrap.

Gloveboxes, in which manual operations with enriched uranium must be performed, also are fire hazards to be protected. These are provided with arm-length synthetic rubber gloves attached to flanges around handholes, so that the uranium can be handled without any of the material leaving the system. Manufacturing operations having 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. A glovebox fire starting in the process material and involving the gloves is a credible threat.

3.4 Other Fire Hazards

Apart from process-related fire hazards, there are others, with which fire protection planners are more familiar and which are common to most large industrial facilities. These involve handling of fuel oils, liquified fuel gases, natural gas, and ordinary combustibles, such as wood and plastics. Also included in this category are large electrical transformers and rectifiers, large storage areas, and boiler plants.

4 FUEL CYCLE FACILITY BUILDINGS

4.1 Building Construction

Buildings housing processes in the major fuel cycle facilities are mostly high-bay enclosures with structural steel frames, sheet metal shells, concrete floors, and sheet metal or concrete-on-metal-deck roofs. Uranium mills and fuel fabrication facilities usually do not have intermediate floors, or if there are intermediate floors, they cover only fractions of the plan area, so that the building areas are essentially open areas of the full height of up to 45 feet. In the case of UF_6 conversion facilities, there are intermediate concrete floors. However, because of the height of the reaction vessels and columns, transfer pipes, and feed elevators, large openings exist in the floors, so that, from the point of view of transmission of smoke from a fire, these too are essentially open to the full roof height. However, from the point of view of sprinkler or standpipe and hose protection, the two types of buildings have to be approached differently. In the case of the high-bay areas, sprinkler heads installed below the roof cover floor areas, unless other equipment, such as pipes and ducts, obstruct. Where obstructions exist, the sprinkler heads have to be placed below such obstructions. In the case of the multi-story buildings, on the other hand, each floor has to be protected.

The buildings are usually compartmented to enclose the more hazardous operations with concrete-block walls, typically 8 inches thick. Solvent extraction, UF_6 cylinder loading and vaporizing, sintering, UO_2 pellet machining and fuel rod loading, and fuel bundle assembly areas in the larger plants are thus separated by barriers. The separation principle is not however universally followed, particularly in plants where the feed throughput volume is relatively small. There are no fire-rating requirements for the barrier walls, and sheet metal walls found in some cases are of little value as fire barriers.

4.2 Ventilation

The heating, ventilation, and air-conditioning (HVAC) systems of the buildings in fuel fabrication facilities, where enriched uranium is handled, are designed to assure air flow from an area of lower to one of higher level of radioactive contamination. This is achieved by controlling the pressures in the respective areas by adjusting air handling rates and dampers in the duct systems. The release to the atmosphere is typically through a scrubber and/or high efficiency particulate air (HEPA) filter. Effluents generated by fire could also be contaminated and would have to be filtered. In the United States, national standards require HEPA filters to be noncombustible.

However, the typical HVAC system in such a facility would also facilitate smoke migration from a room involved in fire to other parts of the building, following the designed air flow paths. If the system is shut down upon receipt of a fire alarm, the fire-driven contaminated air may flow in undesirable directions. Of course, engineered resolution of this problem is possible and has been applied, where it has been recognized as a potential problem. Emergency smoke control measures may include short-circuiting of the air from the fire-involved room directly to a common exhaust stack and filtration system.

5 FIRE DETECTION AND SUPPRESSION SYSTEMS

5.1 Detection

Automatic fire detection in fuel cycle facilities has certain constraints. Most process areas have some amounts of dust or chemical vapors floating in the air because of the nature of the processes, and automatic detectors that rely on detecting small particles of effluents from fire are unsuitable. Heat, rate-of-temperature rise, and infrared types of detectors may be used in such areas. However, in high-bay areas covered by sprinklers, general coverage by heat detectors, placed at the ceiling level, may not provide warnings very much sooner than the sprinklers, whose actuation would provide the obvious detection. There still is justification for detector application in certain areas, such as solvent purification or extraction areas, and wherever flammable liquids are used in the processes. Flammable gas and vapor detectors may be used wherever in confined areas there is potential for such accumulation.

5.2 Suppression

Water is the preferred medium of fire suppression in fuel cycle facilities and is used in most process areas. The exceptions are those areas where enriched uranium fuel is stored or processed in a form or geometrical configuration to preclude water use because of concern for inadvertent nuclear criticality. Such areas are usually protected by portable extinguishers using suppression agents other than water, and the combustible content of these areas is kept at a minimum. Sprinkler protection is especially suitable for the high-bay areas and is commonly used. Foam and carbon dioxide systems, the latter in confined areas, are used for protecting areas using solvents. Standpipe and hose systems are used both as the principal fire suppression system and as a supplement to other systems. The fire water is usually a dedicated storage, supplemented by a year-round source which also supplies process water needs.

6 CONCERNS RELATING TO FIRE PROTECTION OF FUEL CYCLE FACILITIES

6.1 Fire Hazard Analyses

Although there have been relatively few serious fire accidents in fuel cycle facilities in the United States, fairly extensive safety assessments of the major facilities performed by the NRC have identified certain concerns regarding fire protection of these facilities. Unlike nuclear power plants, fuel cycle facilities have not been required to perform systematic fire hazard analyses. This does not mean that the owners and the insurers of these facilities have not performed surveys of fire risk and provided protection features. But the adequacy of these features varies from facility to facility. Common fire protection features used in any industrial plant are found in all of these facilities. These include protection of flammable liquid storages and warehouses; provision of fire pumps, water mains, hydrants, hose stations, and portable extinguishers; and installation of automatic suppression systems. Hazards of fire in the chemical process flow systems are more difficult to estimate and to protect against, and there have been a few serious fires arising from malfunctions in fuel cycle processes. This is an area that should receive the careful attention of both fire protection planners and process designers.

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

(a) account for all the radioactive and combustible materials, including estimates of their heat content;

(b) account for processes performed and their potential for fire or explosion;

(c) account for sources of heat and flame;

(d) list all fire detection and suppression equipment; and

(e) 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, otherwise, would confirm the adequacy of the fire protection measures. Furthermore, any significant modification of buildings, processes, or inventories should necessitate a new fire hazard analysis.

6.2 Fire-Rated Barriers

Compartmentation and separation of areas presenting fire hazards or those that need special protection, is a basic principle of fire protection by prevention of fire spread. In large fuel cycle facilities, one would ideally expect certain processes to be contained in compartments. Such processes include:

solvent extraction/purification, calcining, ammonia dissociation, feed reduction, fluorine production, UF_6 production, UO_2 blending and sintering, pellet machining, and fuel rod assembly. Also, incinerators, boiler rooms, electrical switchgear rooms, control rooms, warehouses, maintenance shops, and fire pump areas should be separated. Such separation, where it exists, is commonly achieved by 8-inch cement block walls and cement 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, although there is no regulatory prescription for it.

In UF_6 conversion facilities, however, because of the design of the already operating plants, hazard separation is not achieved in every case, thus promoting the risk of fire propagation. Nevertheless, the relatively open construction of process areas in these plants has its advantage of allowing freer egress of personnel in the event of an accident, and swift visual detection of fire. Such competing demands on the design process of a plant are of course well known, and balances have to be achieved. 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.

Because of 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 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.

6.3 Automatic Fire Detection and Suppression

Fuel cycle facility operation is generally not manpower intensive. There are process areas in these facilities that are infrequently visited, and plants do not always operate around the clock, so that surveillance by automatic fire detectors (also chemical spill detectors) becomes necessary. Such detectors, where they exist, are usually connected to central annunciator panels, which are continuously supervised. The system also indicates the zone of origin of an alarm. Additionally, actuation of an automatic fire suppression system, such as a sprinkler system, transmits an automatic alarm signal to the central panel.

Although automatic or manual fire suppression systems are generally adequate in fuel cycle facilities, use of automatic fire detection systems to provide early warning of incipient fires is not as common as would be expected.

6.4 Fire Emergency Planning

Fire emergency planning (also termed pre-fire planning) for fuel cycle facilities in the United States usually is encompassed in the general radiological emergency planning required by regulations. Often, the same team of employees is trained to and does respond to both fire and radiological emergencies. This is logical, since a fire emergency may turn out to be a radiological emergency as well. The elements of fire and radiological emergency are similar. For example, a fire emergency plan should, for each fire area, assign individual and alternate responsibilities for: suppressing incipient fires; calling for the site fire brigade and, if necessary, offsite fire department assistance; personnel evacuation; orderly shutdown of processes; and safeguarding and control of radioactive material. 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 materials safeguarding and control. Similar details are typical of radiological emergency planning also.

Most 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 offsite help is available, it is important that the guest fire-fighters 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. In this important area, it is believed, there remains room for improvement.

7 CONCLUSION

In summary, fuel cycle facilities, as well as their fire protection features and concerns, are uniquely different from one another and from nuclear power plants. There is currently in progress a new regulatory appraisal in the United States of fire risk in these facilities. The areas of concern include: fire safety of the chemical processes, systematic fire hazard analyses at each facility, upgrading of fire barriers, automatic fire detection, and fire brigade training.

REFERENCES

[1] C.V. Smith, Jr., et al., Report of the Materials Safety Regulation Review Study Group to the U.S. Nuclear Regulatory Commission (October 1986).

[2] U.S. Nuclear Regulatory Commission, Guidance on Management Controls/ Quality Assurance, Requirements for Operation, Chemical Safety, and Fire Protection for Fuel Cycle Facilities, Federal Register, Vol. 54, No. 53 (March 1989).

[3] U.S. Nuclear Regulatory Commission, Code of Federal Regulations, 10 CFR 50, Appendix R, Fire Protection.

[4] U.S. Nuclear Regulatory Commission, Code of Federal Regulations, 10 CFR 70.23, Requirements for the Approval of Applications.

[5] U.S. Environmental Protection Agency, Environmental Analysis of the Uranium Fuel Cycle, EPA-520/9-73-003 (November 1973).

[6] G. Brauer, Editor, Handbook of Preparative Inorganic Chemistry, Academic Press, New York (1965).

[7] I. Hartman, et al., Explosive Characteristics of Titanium, Zirconium, Thorium, Uranium, and Their Hydrides, U.S. Bureau of Mines Report of Investigations No. 4835 (1951).

List of Figures

Figure 1. Uranium mill process diagram. (Adapted from U.S. Environmental Protection Agency Report [5])

Figure 2. UF_6 production: solvent extraction - fluorination block diagram. (Adapted from U.S. Environmental Protection Agency Report [5])

Figure 3. Fuel fabrication block diagram. (Adapted from U.S. Environmental Protectection Agency Report [5])