QA: NA 1-15-08

SAIC-01/2650

An Employee-Owned Company

MOL.20080115.0138

Chemical Agent Disposal Facility Fire Hazard Assessment Methodology

Prepared by:

Science Applications International Corporation
Abingdon, MD 21009
Under Contract DAAM01-96-D-0009

Prepared for:

Program Manager
for Chemical Demilitarization
Aberdeen Proving Ground, MD 21010

March 2002

SAIC-01/2650

An Employee-Owned Company

Chemical Agent Disposal Facility Fire Hazard Assessment Methodology

Prepared by:

Science Applications International Corporation
Abingdon, MD 21009
Under Contract DAAM01-96-D-0009

Prepared for:

Program Manager
for Chemical Demilitarization
Aberdeen Proving Ground, MD 21010

March 2002

EXECUTIVE SUMMARY

Localized or widespread fires occur periodically at chemical plants and manufacturing facilities in the United States and elsewhere. Occurrence of a fire in one of the U.S. Army's Chemical Agent Disposal Facilities (CDFs) could lead to a large release of chemical agent outside the facility if the fire spreads to an area in which a large quantity of chemical agent is stored. This is true for facilities such as the Newport Chemical Agent Disposal Facility (NECDF), which may have a large quantity of nerve agent VX during processing operations. Nerve agent VX is relatively nonvolatile; therefore, a large fire represents the primary means for creating a substantial source of agent vapor that could be transported offsite by winds.

Previous Quantitative Risk Assessments (QRAs) performed for the U.S. Army's CDFs have used methodologies developed for the commercial nuclear industry to estimate the frequency of fires. Recently, questions have been raised regarding the applicability of these methods to the CDFs. This report provides an alternate approach to estimating fire frequencies for the CDFs and for characterizing the spread of a fire within the facility.

The approach outlined in this report uses historical fire data over a 10-year period (1988 to 1997) from databases maintained by the National Fire Protection Association (NFPA) and facility census data maintained by the U.S. Census Bureau (USCB). These databases are used to develop estimates for the total frequency of fires in a CDF, the distribution of fires within the facility, and the probability that a fire in one area will spread to an area with chemical agent. In addition, the analysis has been separately applied to structure fires (fires within the facility) and outside fires (fires in the immediate area around the facility).

Based on the historical data, the total inside fire frequency for the CDF was estimated to be 8×10^{-6} fires per facility per hour. The inside fire frequency then was broken down by the functional area of the facility in which the fire starts. The CDF Fire Hazard Assessment frequency distributions are presented in terms of functional areas. To allow ignition frequency determination, the NFPA areas were grouped into a smaller set of functional areas with similar characteristics: process areas; [service machinery, HVAC (heating, ventilation, and air conditioning), and electrical] (SHE) areas; product storage/receiving/loading/conveyor (SRLC) areas; structural areas; trash/rubbish/incinerator/maintenance/laboratory (TRIM) areas; and other areas.

Based on this evaluation, it was estimated that approximately one-third of the fires in a CDF would start in the process area. Data were also collected to allocate fire frequency within an area of the building to each equipment category resident in the area. Fires in each functional area then were broken down further by the type of equipment involved in the fire.

Given that a fire occurs, it is important to understand how far it spreads in order to assess what quantity of chemical agent could be involved. Based on historical data, probabilities were estimated for fire propagation between rooms or areas of the facility. The propagation probabilities depend on the building construction and layout and on whether or not an automatic fire suppression system is present and functioning. It is believed that the probability of ex-room propagation is related to the function of the room where the fire initiates, since this would affect the types of ignition sources and combustibles that would be resident in the room. Thus, data were collected to portray ex-room propagation probability as a function of building area. It is believed that the probability of in-room propagation is related to the type of equipment involved in ignition, since this would affect the size and duration of the initial fire. Data were collected to portray in-room propagation probability as a function of equipment involved in ignition. From this, an approach was developed for evaluating propagation within a room based on the number and type of ignition sources present in the room and the proximity of these ignition sources to any chemical agent present in the room.

The frequency of outside fires also was estimated from the NFPA and USCB data. Outside fire frequencies were developed for two categories of outside fires: fires that occur following spills or leaks and all other outside fires. The frequency of fires following spills was estimated to be 4×10^{-7} fires per facility per hour, while the frequency of all other outside fires was estimated to be 1×10^{-6} fires per facility per hour. Data were collected in order to allocate the fire frequency for fires outside the CDF buildings to specific functional areas outside the building.

TABLE OF CONTENTS

(This page intentionally left blank.)

LIST OF TABLES

(This page intentionally left blank.)

SECTION 1
INTRODUCTION

Localized or widespread fires occur periodically at chemical plants and manufacturing facilities in the United States and elsewhere. Occurrence of a fire in one of the U.S. Army's Chemical Agent Disposal Facilities (CDFs) could lead to a large release of chemical agent outside the facility if the fire spreads to an area in which a large quantity of chemical agent is stored. This is true for facilities such as the Newport Chemical Agent Disposal Facility (NECDF) where a large quantity of nerve agent VX could be present in the CDF during processing operations. Nerve agent VX is relatively nonvolatile; therefore, a large fire represents the primary means for creating a substantial source of agent vapor that could be transported offsite by winds.

Previous Quantitative Risk Assessments (QRAs) performed for the U.S. Army's CDFs have used methodologies developed for the commercial nuclear industry to estimate the frequency of fires [see, for example, Science Applications International Corporation (SAIC) 1996]. Recently, questions have arisen regarding the applicability of these methods to the CDFs. This report provides a first attempt to develop an alternate approach to estimating fire frequencies for the CDFs and for characterizing the spread of a fire within the facility.

The approach outlined in the remainder of this report uses fire event history information over a 10-year period, 1988 to 1997, from a database maintained by the National Fire Protection Association (NFPA) and facility census data from a database maintained by the U.S. Census Bureau (USCB). These databases are used to generate estimates for the total frequency of fires in facilities similar to a CDF, and the location, cause, and severity of fires within those facilities. In addition, the analysis has been applied separately to structure fires (fires within the facility) and outside fires (fires in the immediate area around the facility).

(This page intentionally left blank.)

SECTION 2
ASSESSMENT OF STRUCTURE FIRES

This section addresses the assessment of the hazards due to structure fires, in facilities conducting operations similar in hazard to CDFs. A structure fire is defined as any fire inside a building or structure whether or not there was structural damage to the building.

2.1 Total Structure Fire Frequency

In order to assess the total fire frequency, two pieces of information are required: the number of facilities and the number of fires in these facilities. The first piece of data is maintained by the U.S. Census Bureau, which conducts an Economic Census (USCB, 1997). The second piece of data is tracked by NFPA. This approach uses historical data over a 10-year period (1988 to 1997) from these databases. Specifically, the fire data used in this report were taken from a report authored by the NFPA – Division of Fire Analysis and Research at the request of SAIC on fires in or at industrial chemical, hazardous chemical, and plastic manufacturing plants (NFPA, 2000b). These data are used to develop estimates for the total frequency of fires in a CDF, the distribution of fires within the facility, and the probability that a fire in one area will spread to an area with chemical agent.

The primary source of data on the number of fires is the National Fire Incident Reporting System (NFIRS), which is jointly administered by the Federal Emergency Management Agency (FEMA) and NFPA (FEMA, undated). The NFIRS is a voluntary program wherein individual fire departments fill out data forms and submit them through their state NFIR coordinator to FEMA/NFPA. Because it is a voluntary program, it is recognized that the NFIRS database does not capture every fire that occurs. NFPA, however, also conducts an annual stratified random-sample survey of fire experience that is used to calibrate the NFIRS data. The combination of these two data sources allows NFPA to perform statistical analyses and develop scaling ratios. These ratios are used to project the NFIRS data into national estimates of numbers of fires.

NFIRS provides annual computerized databases of fire incidents. Data gathered by participating fire departments are submitted to the participating states, which combine them and submit them to FEMA. Because participation is voluntary, NFIRS only captures about one-third to one-half of all U.S. fires each year. The NFIRS data provide the most detailed incident information not limited to large fires and include information on property use, fire cause, the avenues, and extent of flame and smoke spread, as well as the performance of fire detectors and sprinklers.

Projecting the NFIRS results develops NFPA's national fire estimates. To project the NFIRS results, at least an estimate of the NFIRS fires as a fraction of the total is needed. However, the NFIRS data do not provide any information on the total population from which the data are collected, nor do they address the nonuniformity of the data due to the voluntary collection methods used. To address the limitations of the NFIRS data, and to extend the NFIRS data to provide a more complete analysis of the U.S. fire problem, the NFPA conducts an additional annual survey to augment the FEMA NFIRS program.

The NFPA survey is based on a stratified random sample of roughly 3,000 (of 30,000) U.S. fire departments. The survey is stratified by the population size (i.e., the number of people protected by the department) to reduce the uncertainty of the final estimates. Small rural communities protect fewer people and are less likely to respond, so a large number are surveyed to obtain an adequate sample. Large city fire departments are few in number, so all are surveyed and have a high response rate so that an excellent estimate is obtained. A variety of data is collected during the NFPA survey process, which allows the NFIRS data to be projected on a nationwide basis with some accuracy. The NFPA survey also allows individual component parts of the NFIRS data to be projected on a national basis. This multiple-calibration approach makes use of the NFPA survey where its statistics design advantages are the strongest and yields scaling ratios to extend the fractional NFIRS data to a true nationwide estimate of the U.S. fire problem.

For any characteristic of interest in NFIRS, some reported fires list the value as unknown or leave it blank. If these unknowns are not taken into account, the results may be flawed. Therefore, NFPA allocates the unknowns by assuming that the fires with unreported characteristics would show the same proportions as fires with known characteristics. In the study performed for SAIC by NFPA, SAIC requested that unknowns be listed separately so that their extent could be understood. The final results reported here use the same allocation approach as NFPA.

To summarize, the data used for the fire frequency analysis are based on NFIRS data that are calibrated by an additional survey conducted by the NFPA and which allow the limited NFIRS data to be projected to nationwide estimates of the U.S. fire problem.

As noted in discussions with NFPA, some fires might not be reported even in locations where NFIRS is used. This is because both databases depend on data collected by fire departments, and certain fires may not be reported to fire departments. In general, these tend to be small fires that pose little risk of damage to a facility. Based on those discussions, this issue is assessed to be of minimal importance to the current assessment because unreported fires will be the smaller ones, and generally would be so insignificant as not to pose a threat to the facility. However, in recognition of this issue, the fire frequency that is being calculated will be characterized as the frequency of potentially significant fires as opposed to suggesting that it is the total frequency of fires. Further details, on how NFPA calculates national estimates are contained in an NFPA report (NFPA, 2000a).

Data on the number and type of facilities are maintained by the USCB, which conducts an Economic Census (USCB, 1997). It performs a count of all businesses in the United States and categorizes them in accordance with the North American Industry Classification System (NAICS). As this program is not voluntary, these data are believed to be accurate as reported.

The NFPA does not use the NAICS to categorize the type of facility, so there is a need to correlate the two systems in order to ensure that both the number of facilities and the number of fires represent counts from the same population. This is relatively straightforward at the level of the major categories of manufacturing facilities. Table 2-1 gives a cross reference between the two systems at that level. Some of the cross-reference matching of categories shown in the table may not seem obvious from the titles, but a review of the definitions used by NFPA/FEMA (FEMA, undated) and NAICS (USCB, 1997) clearly leads to the classifications shown in the table.

A CDF would be classified by NFPA under Chemical, Plastic, or Petroleum Products. According to the NFPA data, there are approximately 1,300 fires annually in such facilities. According to NAICS, the total number of facilities in the corresponding categories is 29,303. Therefore, the frequency of potentially significant fires in these facilities is:

$$F = \frac{1{,}300 \text{ fires/yr}}{(29{,}303 \text{ facilities} \times 8{,}760 \text{ hrs/yr})} = 5 \times 10^{-6} \text{ fires/facility - hr}$$

While this number can probably be considered reasonably robust given the clear match between the NFPA and NAICS systems, there is some question as to whether a number averaged over all such facilities should be applied to a CDF, given the nature of its operations. Therefore, the analysis was refined further by using subcategories within the classification systems to determine whether a particular subcategory of Chemical, Plastic, or Petroleum Products would be more representative of a CDF. Unfortunately, the correlation between the classification systems at this level is not as clear as at the higher level. In particular, NFPA has the following three subcategories that have some level of similarity to a CDF, but that interrelate to NAICS subcategories in a nonexclusive manner:

- Industrial Chemicals
- Plastics[1]
- Hazardous Chemicals.

---

1 Plastics refers to facilities that deal with raw materials for plastics or synthetic resins, plastics, and elastomers. Facilities that manufacture refined plastic products by molding, extruding, or other methods are addressed in a different category.

Table 2-1. Types of Manufacturing Facilities: Cross Reference Between NFPA and NAICS

NFPA Facility Categories	NAICS Facility Categories
Food Products	Food Products
Beverage, Tobacco, or Related Oil Products	Beverage and Tobacco Products
Textiles	Textile Mills Textile Product Mills
Wearing Apparel, Leather, Rubber Products	Apparel Products Leather and Allied Products Plastics and Rubber (Rubber subgroup)
Wood, Furniture, Paper, or Printing Products	Wood Products Paper Products Printing and Related Support Activities Furniture and Related Products
Chemical, Plastic, or Petroleum Products	Petroleum and Coal Products Chemical Products (except photographic) Plastics and Rubber (Plastics subgroup)
Metal or Metal Products	Primary Metal Products Fabricated Metal Products Machinery Computer and Electronic Products Electrical Equipment, Appliances, and Components
Vehicle Assembly or Manufacturing	Transportation Equipment
Other	Miscellaneous Chemical Products (photographic)
Unclassified or Unknown	Nonmetallic Mineral Products

The Hazardous Chemicals subcategory actually applies to facilities that otherwise would be categorized in the first two subcategories but that deal with materials requiring special handling. With this subcategory, NFPA brings together all the facilities that would functionally belong to the other categories but that deal with materials requiring special care. This categorization is intended to deal with the possibly unique fire hazard posed by processes involving such materials. Unfortunately, NAICS is not interested in this particular distinction, so the facilities are categorized according to their industrial function. For this reason, these three subcategories cannot be separated when trying to determine the fire frequency. The NAICS categories that correspond to the three NFPA subcategories are:

- Industrial Gas
- Dyes and Pigments
- Other Basic Inorganic Chemicals
- Ethyl Alcohol

- All Other Basic Organic Chemicals
- Plastic Material and Resin
- Artificial and Synthetic Fibers and Filaments
- Pesticide, Fertilizer, and Other Agricultural Chemicals
- Explosives
- Custom Compounding of Purchased Resins
- All Other Chemical Products.

According to the NFPA data (NFPA, 2000a), there are approximately 436 fires annually in such facilities. According to NAICS, the total number of facilities in the corresponding subcategories is 5,870. Therefore, the frequency of potentially significant fires in these facilities is:

$$F = \frac{436 \text{ fires/yr}}{(5{,}870 \text{ facilities} \times 8{,}760 \text{ hrs/yr})} = 8 \times 10^{-6} \text{ fires/facility - hr}$$

An attempt also was made to determine the frequency of fires in hazardous chemical facilities only. CDFs that handle munitions containing propellant or bursters would be categorized as hazardous chemical facilities by NFPA. There is, however, substantial difficulty in matching the population of facilities that NFPA would consider hazardous to the NAICS census data since, as previously stated, NAICS categorizes facilities by industrial function rather than hazard. Only one NAICS category, explosives facilities, would come under the NFPA category of hazardous. This would account for 101 facilities. However, there are five other NAICS categories, accounting for another 1,891 facilities, that would contain at least some hazardous facilities. Thus, all that can be stated with regard to the population of hazardous chemical facilities is that it is somewhere between 101 and 1,992 facilities. According to NFPA, these facilities account for 87 fires per year. Using the two extreme values of facility population previously mentioned, the frequency of potentially significant fires in those facilities is:

$$F = 1 \times 10^{-4} \text{ to } 5 \times 10^{-6} \text{ fires/facility - yr}$$

All these values are well within the uncertainty of the calculations, especially given the lower level of confidence that both the numerator and denominator represent the same population in each successive calculation. Overall, the use of a total mean structure fire frequency of 8×10^{-6} fires per facility per hour for a CDF is deemed to be appropriate.

2.2 Distribution of Fires Within the Facility

The next step in the fire assessment is to determine how to distribute the total fire frequency to the various rooms in the facility. The underlying premise of the previous section is that the overall frequency of fires at a CDF is probably not significantly different than for the broad spectrum of process facilities. This, however, is not likely to be true when trying to characterize how fires behave in the facility. In looking at the way the fire data are collected and categorized, it was judged that a key parameter in fire response is the type of construction used for the facility. Overall, the judgment was that the type of process, the equipment involved, and other key aspects of facility operation would drive the decision on the type of construction, and that the subset of facilities most likely to resemble a CDF would be those of similar construction. Therefore, at SAIC's request, NFPA prepared a special evaluation of the fire data for certain types of process facilities of noncombustible construction. This includes three types of non-combustible construction:

- Fire resistive – Structural elements are noncombustible, structural steel is not exposed, and coverings over the steel are very robust (e.g., concrete, concrete block)

- Protected noncombustible – Structural elements are noncombustible, structural steel is not exposed, and coverings over the steel are light (e.g., gypsum board, sprayed fire-resistive coverings)

- Unprotected noncombustible – Structural elements are noncombustible, but structural steel is exposed.

The process of using this data to distribute the total fire frequency within the facility consists of two steps: 1) distributing to the various functional areas of the facility and 2) distributing to the rooms within each functional area.

In performing the assessment, it is necessary to make compromises in the "fineness" that can be achieved. The NFPA uses a large number of parameters to describe fires and several different values for each parameter. Trying to categorize the fires using all of these parameters and values would result in having many categories with no data or very little data, which would invalidate the resulting statistics. As a result, only a limited number of parameters can be used. Because the type of construction is judged to be most significant, this reduced the total number of fires in the 10-year database from over 4,000 to only about 2,500 for the three types of noncombustible construction. It is likely that construction-type differentiation cannot be subdivided any further and still have a sufficient amount of data for analysis. Even so, it was judged that a maximum of two additional parameters could be considered: 1) the functional areas of the facility where the fire originated, and 2) the type of equipment that was involved in the ignition.

2.2.1 Distribution by Functional Area. One analysis performed was in terms of the reported fire distribution in the various functional areas of these types of facilities (section 4 of NFPA, 2000b). With some interpretation, these data can be used to estimate the fraction of the total fire frequency that should be assigned to the various functional areas of a CDF.

NFPA collects data for almost 30 different defined areas of a facility. Using all of these areas would result in dividing up the available data too finely for further analysis based on the ignition source. Therefore, it was decided to group the NFPA areas into a smaller set of functional areas with similar characteristics.

As expected, the majority of fires in such facilities occur in the process area. Fires in this area account for 36 percent of the total fire frequency. Other key areas of the facility include storage areas. The data have been reviewed, and as much as possible, the areas cited have been related to areas of a CDF. Table 2-2 presents the results of this analysis, with the appropriate multiplication factor for each area and the resultant fire frequency (assuming the total fire frequency of 8×10^{-6} facility per hour given in section 2.1). The footnotes to table 2-2 show how the NFPA designation of areas was grouped to establish the six functional areas used in this study.

2.2.2 Distribution to Rooms Within Each Functional Area. It is important to note that the previously listed frequencies represent the sum of fire frequencies for all rooms in each functional area of the facility, not for each room. Thus, the frequency presented must be distributed among all the rooms. Acceptable approaches to distributing the fire frequency would include the following:

a. Distribute the frequency equally to each room.
b. Distribute the frequency based on room floor area.
c. Distribute the frequency based on the specific ignition sources in each room.

In implementing any of these approaches, the category "other areas" should be considered the fire initiation frequency shared across all plant areas not specifically identified in the table. Sensitivity analysis should be performed to assess the significance of the approach based on the results.

To distribute the fire frequency based on the ignition sources present (approach c previously listed), some analysis must be performed to identify how fires in various facility areas are distributed in terms of the equipment involved in ignition. This has been performed for each of the six areas in table 2-2. The data on equipment involved in ignition are provided by the NFPA (section 3 of NFPA, 2000b). Once again, the NFPA collects its data over a large number of equipment-type categories, which in this case is approximately eighty. The number of fires in the database being used in this study is not sufficient to go to this level of detail in each of the six functional areas. Therefore, in performing the analysis, the detailed equipment types used by the

Table 2-2. Multiplication Factor and Fire Frequency for Each Area of a Chemical Agent Disposal Facility

Area	Factor	Fire Frequency
Process area[a] – To include demil machines, drain system, agent lines, furnaces, etc. (e.g., process pumps, valves, pipes)	0.36	2.9×10^{-6}
SHE areas[b] – To include areas primarily containing service machinery, HVAC, and electrical equipment (e.g., elevator machinery rooms, refrigeration rooms, pump rooms, control rooms)	0.20	1.6×10^{-6}
SRLC areas[c] – To include all areas where products are held or moved while awaiting process, shipment, or use (e.g., agent storage, receiving, loading, and conveyor areas)	0.10	0.8×10^{-6}
Structural areas[d] – Areas associated with the structural parts of the facility [e.g., exterior roof or wall surface; ceiling or floor assemblies (or concealed spaces within); utility shafts; and cooling, heating, or exhaust ducts (including filters)]	0.13	1.0×10^{-6}
TRIM areas[e] – To include trash, rubbish, incinerator, maintenance, and laboratory rooms)	0.06	0.5×10^{-6}
Other areas[f] (e.g., offices, admin, and other areas not specified previously)	0.15	1.2×10^{-6}
Totals	1.00	8.0×10^{-6}

Notes:

a This corresponds to the NFPA area designation of process or manufacturing area. This is intended to apply to areas of a facility where actual processing or manufacturing is occurring.

b Sum of the following NFPA areas: 1) machinery room or area, 2) heating equipment area, 3) switchgear area or transformer vault, and 4) electronic equipment room or area. This is intended to apply to areas that contain large amounts of mechanical/electrical equipment, but are not directly used in the processing that occurs in the facility. This would include control rooms and computer rooms.

c The sum of the following NFPA areas are: 1) product storage area, tank, or bin, 2) shipping, receiving, or loading area, and 3) conveyor areas. This is intended to apply to areas where the products, substances, and chemicals involved in the process reside as they progress through the process, but where no actual processing occurs. Therefore, it applies to the areas where such materials enter or leave the facility, where they are transported from process area to process area, or where they stay temporarily awaiting processing. With regard to storage, it applies only to areas where agent or process chemicals are stored.

d The sum of the following NFPA areas are: 1) ceiling/floor assembly or concealed space, 2) attic or ceiling/roof assembly or concealed space, 3) exterior roof surface, 4) exterior wall surface, 5) utility shaft, 6) chimneys, 7) crawl space or substructure space, 8) wall assembly or concealed space, 9) ducts, and 10) unclassified structural area. This is intended to apply generally to areas that are not designated as rooms (i.e., areas within walls, between ceilings and floors, and the like). Such areas could contain equipment, such as electrical lines and HVAC equipment.

e The sum of the following NFPA areas are: 1) trash or rubbish area or container, 2) incinerator room or area, 3) maintenance shop or area, and 4) laboratory. This is intended to apply generally to areas that serve the process or are at the tail end of the process. Generally, these areas are not as "organized" as the previously listed areas of the facility. It could include areas where waste is stored or processed, where small amounts of chemicals reside outside the main process, and where there could be oily rags and similar materials. The areas are characterized by somewhat more "hazardous" fire conditions than other areas because of the potential presence of open containers of chemicals (including drained munitions), waste materials, work benches, and other such items.

f The sum of the following NFPA areas are: 1) unclassified area of origin, 2) unclassified service or equipment area, 3) supply storage room or area, 4) lavatory, locker room, or cloakroom, 5) unclassified function area, 6) office, and 7) all other NFPA areas (most of which do not apply to the facilities considered and contribute very little to the overall frequency).

NFPA were grouped into the 11 broad categories shown in table 2-3, based on the similarity of their fire characteristics.

Table 2-3. NFPA Equipment Categories Included in Broad Equipment (Ignition Source) Categories

Broad Equipment (Ignition Source) Category	NFPA Categories Included
Chemical Process and Recovery (e.g., reactors, distillers, etc.)	Chemical process equipment and waste recovery equipment.
Furnaces	Furnaces
Other Fixed Heat-Generating Process	Casting, molding, or forging equipment; heat treating equipment; dryers; and incinerators.
Other Fixed Non-Heat-Generating	Working, shaping machine; coating machine; painting machine; unclassified process equipment; separate motor or generator; separate pump or compressor; and conveyor
Torches, Welders, and Burners	Torches, welders, and burners
Electrical System	Fixed wiring; transformer, associated over current or disconnect equipment; meter, meter box; power switch gear, over current protection devices; switch, receptacle, outlet; lighting fixture, lamp holder, ballast, sign; cord, plug; lamp, light bulb; unclassified electrical distribution equipment; electronic equipment; and rectifier, charger
Mechanical/Electrical HVAC	Central heating unit; water heater; fixed, stationary local heating unit; central air conditioning, refrigeration equipment; water cooling device, tower; fixed, stationary local refrigeration unit; and fixed, stationary local air conditioning unit
Other HVAC	Chimney, gas vent flue; chimney connector, vent connector; heat transfer system; unclassified heating systems; and unclassified air conditioning, refrigeration systems
Portable Equipment Other than Torches, Welders, and Burners	Portable local heating unit; hand tools; portable appliance designed to produce controlled heat; and portable appliance designed not to produce heat
No Equipment Involved	No equipment
All Other Equipment	All other NFPA equipment categories

Table 2-4 lists the calculated multiplication factors for each ignition source in each area. The first row repeats the functional area multiplication factors from table 2-2. The remaining rows show how these values are distributed across the ignition sources in each functional area. The process areas are used as an example. Of the 36 percent of total building fire frequency that

Table 2-4. Multiplication Factors for Each Ignition Source in Each Functional Area

NFPA Equipment (Ignition Source) Category	Area					
	Process	SRLC	TRIM	SHE	Structural	Other
Fraction of Building Fire Frequency for Functional Area	0.36	0.10	0.06	0.20	0.13	0.15
Chemical Process and Recovery	0.20	0.10	0.11	0.08	0.07	0.14
Furnaces	0.08	0.06	0.14	0.06	0.02	0.03
Other Fixed Heat-Generating Process	0.07	0.01	0.03	0.11	0.02	0.01
Other fixed Non-Heat-Generating Process	0.16	0.10	0.05	0.20	0.11	0.11
Torches, Welders, Burners	0.08	0.05	0.08	0.04	0.15	0.06
Electrical System	0.05	0.03	0.06	0.13	0.07	0.11
Mechanical/Electrical HVAC	0.01	0.02	0.00	0.05	0.04	0.04
Other HVAC	0.03	0.02	0.02	0.04	0.08	0.03
Portable Equipment Other than Torches, Welders, and Burners	0.01	0.03	0.05	0.01	0.01	0.03
All Other Equipment	0.08	0.07	0.17	0.11	0.12	0.14
No Equipment Involved	0.23	0.51	0.29	0.17	0.31	0.30

occurs in these areas, 20 percent of these are caused by chemical process and recovery equipment, 8 percent by furnaces, and so on.

By multiplying the value in the first row by each of the other values in a column, it is possible to determine the multiplication factor on total building fire frequency for each ignition source in each functional area. This is shown on table 2-5. Multiplying the value in each cell by the overall building fire frequency will give the fire frequency for the associated ignition source and functional area. The values in parentheses are the resultant fire frequencies (per hour) using the overall frequency of 8×10^{-6} per hour cited in section 2.1.

The way these values should be used is to perform an inventory of the number of each ignition source type in each functional area of the facility being analyzed. The total frequency of fire for

Table 2-5. Distribution of Building Fire Frequency Among Equipment Types (Ignition Sources) Per Functional Area

	Area					
Ignition Source	Process	SRLC	TRIM	SHE	Structural	Other
Chemical Process and Recovery Equipment	0.073 (5.8×10^{-7})	0.010 (8.0×10^{-8})	0.007 (5.6×10^{-8})	0.015 (1.2×10^{-7})	0.010 (8.0×10^{-8})	0.021 (1.7×10^{-7})
Furnaces	0.028 (2.2×10^{-7})	0.006 (4.8×10^{-8})	0.008 (6.4×10^{-8})	0.013 (1.0×10^{-7})	0.003 (2.4×10^{-8})	0.004 (3.2×10^{-8})
Other Fixed Heat-Generating Process Equipment	0.024 (1.9×10^{-7})	0.001 (8.0×10^{-9})	0.002 (1.6×10^{-8})	0.022 (1.8×10^{-7})	0.002 (1.6×10^{-8})	0.002 (1.6×10^{-8})
Other Fixed Non-Heat-Generating Process Equipment	0.058 (4.6×10^{-7})	0.010 (8.0×10^{-8})	0.003 (2.4×10^{-8})	0.041 (3.3×10^{-7})	0.015 (1.2×10^{-7})	0.016 (1.3×10^{-7})
Torches, Welders, Burners	0.030 (2.4×10^{-7})	0.005 (4.0×10^{-8})	0.005 (4.0×10^{-8})	0.009 (7.2×10^{-8})	0.020 (1.6×10^{-7})	0.009 (7.2×10^{-8})
Electrical System Equipment	0.019 (1.5×10^{-7})	0.003 (2.4×10^{-8})	0.004 (3.2×10^{-8})	0.025 (2.0×10^{-7})	0.008 (6.4×10^{-8})	0.016 (1.3×10^{-7})
Mechanical/Electrical HVAC Equipment	0.002 (1.6×10^{-8})	0.002 (1.6×10^{-8})	0.0 (0)	0.010 (8.0×10^{-8})	0.005 (4.0×10^{-8})	0.006 (4.8×10^{-8})
Other HVAC Equipment	0.010 (8.0×10^{-8})	0.002 (1.6×10^{-8})	0.001 (8.0×10^{-9})	0.009 (7.2×10^{-8})	0.010 (8.0×10^{-8})	0.005 (4.0×10^{-8})
Portable Equipment Other than Torches, Welders, and Burners	0.004 (3.2×10^{-8})	0.003 (2.4×10^{-8})	0.003 (2.4×10^{-8})	0.001 (8.0×10^{-9})	0.001 (8.0×10^{-9})	0.004 (3.2×10^{-8})
All Other Equipment	0.028 (2.2×10^{-7})	0.006 (4.8×10^{-8})	0.010 (8.0×10^{-8})	0.022 (1.8×10^{-7})	0.016 (1.3×10^{-7})	0.022 (1.8×10^{-7})
No Equipment Involved	0.084 (6.7×10^{-7})	0.051 (4.1×10^{-7})	0.017 (1.4×10^{-7})	0.033 (2.6×10^{-7})	0.040 (3.2×10^{-7})	0.045 (3.6×10^{-7})

Note:

The sum of all cells across all rows and columns is 1.0 (values in table are rounded). The sum of all values in parentheses across all rows and columns is the total fire initiation frequency, 8×10^{-6} per hour.

a given type of ignition source in the functional area is then divided by the number of those ignition sources in that functional area to yield a fire frequency per ignition source in the functional area. To determine the fire frequency for a particular room, the number of ignition sources of each type in the room is multiplied by the fire frequency per ignition source and summed across all ignition source types. Note that one of the categories in these tables is "no equipment involved." There are cases where fires start "spontaneously" and are not due to what are commonly thought to be ignition sources. This frequency should be allocated to the various rooms based on floor area.

The ignition source population of each room should be recorded from general arrangement drawings and verified during a site walkdown. In addition, site operators should be consulted to provide insights on maintenance activities that would take place, such as welding, cutting, and grinding, and this information is used to assess the ignition source population for torches and other portable equipment.

The following guidance was provided by the fire methodology used at the Crystal River-3 nuclear power plant (Averett, 1996) as well as the NFPA data in table 2-3, and should be used for determining the ignition source population:

a. Electrical panels were individually counted. Small motors, such as those on conveyors, indexing tables, gates, and charge cars are counted as pumps per guidance by Averett (1996).

b. All transformers were counted, with the exception of control power transformers and other small transformers that are subcomponents in major electrical equipment. Also, yard transformers are not considered.

c. Instrument air dryers are counted as part of the air compressors.

d. Ventilation subsystems include components such as air conditioning units, fan motors, air compressors, etc. A fan motor and compressor housed in the same cabinet are considered one component.

e. Transient and welding sources are considered applicable to all areas unless administrative controls or practices exclude them, or design features essentially eliminate the possibility.

f. Equipment powered by hydraulic motors is not included in the equipment population because the hydraulic fluid used at the CDF is not combustible.

g. Air-operated pumps are not included in the equipment population because they are not ignition sources. Overheating associated with air-operated pumps is negligible.

h. All demilitarization operations are assumed to proceed correctly up to the time of fire initiation. Therefore, the CDF is not in an unexpected state at the time of the fire. As previously stated, fires following other initiating events are treated in the internal event accident progression models.

i. Mine handling system equipment is assumed to be de-energized during non-mine campaigns.

The per-ignition source fire initiator frequency is calculated by dividing the total ignition source fire frequency for a functional area by the total ignition source population in that functional area. The total functional area floor area is used to allocate the frequencies of fire that are a result of "no equipment involved." The fire frequency for a fire-rated zone is determined by first multiplying the number of each type of ignition source in the room by the fire frequency per-ignition source (or per square foot) specific to the functional area, then summing across all equipment types.

Sample calculations:

Imagine a facility (the "XXCDF") where an inventory of ignition sources has been taken. Looking only at the process area (all the process rooms) of the facility, the inventory was determined to be as shown in the fourth column of table 2-6. For each ignition source category, the number of pieces of equipment meeting that definition has been established, except for the case of "no equipment involved." In this case, the population is the total square feet of floor area for the process rooms. The third column shows the previously calculated fire initiation frequency for the different ignition source types for the process area (from table 2-5, column 2). Dividing this frequency by the population yields the fire initiation frequency per ignition source (the last column in table 2-6) for each ignition source type in the process area of this facility.

This can now be used to calculate the fire initiation frequency for each room in the process area. Imagine that the fire initiation frequency needs to be determined in room YYY of the XXCDF. Room YYY is part of the process area of the CDF. Column 2 of table 2-7 shows the ignition source population that exists in this particular room. The third column shows the fire initiation frequency per ignition source (from the last column of table 2-6). By multiplying these two values, the fire initiation frequency contribution from each ignition source type in the room can be obtained. Summing these values yields the total frequency of a fire starting in the room.

2.3 Propagation of Fires Within the Facility

Of key interest for assessing the fire risk, is the extent to which fires that start in a "benign" area can spread to sensitive areas (i.e., areas where chemical agent is present). The likelihood of fire propagation within the building is strongly dependent on the building construction and the presence of automatic fire suppression systems.

Table 2-6. Example Fire Initiator Distribution by Equipment (Ignition Source) for the XXCDF Process Area

Functional Area	Equipment Type (Ignition Source)	Frequency (hr^{-1})	Ignition Source Population	Frequency ($hr\text{-}source^{-1}$)
Process	Chemical Process and Recovery	5.8E-07	25	2.3E-08
	Furnaces	2.2E-07	5	4.5E-08
	Other Fixed Heat-Generating Process	1.9E-07	4	4.8E-08
	Other Fixed Non-Heat-Generating Process	4.6E-07	47	9.9E-09
	Torches, Welders, Burners	2.4E-07	4	6.0E-08
	Electrical System	1.5E-07	98	1.6E-09
	Mechanical/Electrical HVAC	1.6E-08	0	0.0E+00
	Other HVAC	8.0E-08	1	8.0E-08
	Portable Equipment Other than Torches, Welders, and Burners	3.2E-08	0	0.0E+00
	All Other Equipment	2.2E-07	34	6.6E-09
	No Equipment Involved	6.7E-07	12,443	5.4E-11

Table 2-7. Fire Initiation Frequency for a Fire in Process Room YYY

Ignition Source	Ignition Source Population	Ignition Source Fire Frequency ($hr\text{-}source^{-1}$)	Total Fire Frequency
Chemical Process and Recovery Equipment	15	2.3E-08	3.5E-07
Furnaces	0	4.5E-08	0.0E+00
Other Fixed Heat-Generating Process Equipment	0	4.8E-08	0.0E+00
Other Fixed Non-Heat-Generating Process Equipment	22	9.9E-09	2.2E-07
Torches, Welders, Burners	2	6.0E-08	1.2E-07
Electrical System Equipment	19	1.6E-09	2.9E-08
Mechanical/Electrical HVAC	0	0.0E+00	0.0E+00
Other HVAC Equipment	0	8.0E-08	0.0E+00
Portable Equipment Other than Torches, Welders, and Burners	0	0.0E+00	0.0E+00
All Other Equipment	25	6.6E-09	1.6E-07
No Equipment Involved	3,299 (ft^2)	5.4E-11	1.8E-07
Total			1.1E-06

The NFPA evaluation included analysis of the extent of flame damage observed for fires in certain types of noncombustible construction process facilities. The analysis included the distribution of fire damage for all observed events in such facilities as a function of specific construction type and the area of the facility where the fire started (section 2 in NFPA, 2000b). It also considered the extent of fire damage as a function of whether an automatic suppression system was present and functioned properly.

Based on the tabulated results provided by the NFPA, it was concluded that the presence of an automatic suppression system has a significant influence on the extent of fire damage.

Two types of propagation are considered in the fire hazard methodology. The first is propagation from the room where the fire starts to other rooms in the facility. The second is propagation of a fire from the location within the room where it starts to other locations within the room. Because the evaluation of propagation requires consideration of two additional parameters (availability of automatic suppression and extent of fire damage), it was not possible to simultaneously consider both the functional area of the fire and the equipment involved in ignition. At most, only one of these parameters could be considered at a time to ensure that the NFPA fire data are not parsed too finely to support the resulting statistics. In considering this situation, it was judged that the parameter that was most important depended on the extent of propagation being considered. Ultimately, it was decided that the functional area would be retained for propagation beyond a room, and equipment involved in ignition would be retained for propagation within a room. This is discussed further in sections 2.3.1 and 2.3.2, respectively.

The probabilities of various degrees of propagation were determined based on the functional area in which the fire starts and whether or not fire suppression systems are available. Both probabilities of exceedance and conditional probabilities were determined. The probabilities of exceedance are the probabilities that a fire propagates up to a specified limit or beyond. The conditional probabilities are probabilities that a fire spreads to a specified limit.

Probabilities of exceedance are not independent, but rather represent the total probability that a fire spreads up to the specified limit or beyond. These values are provided because, for many fire sequences there will only be one case of interest, i.e., there will be only one target (agent source) of concern, and once the fire reaches that agent source the fact that the fire may propagate even further does not change the outcome of the sequence in terms of agent release. For example, this value could be applied to a case where a fire that spreads throughout a room affects the agent source in that room, and there are no additional agent sources in adjacent rooms or fire zones.

Conditional probabilities are independent, as they represent the probability that a fire spreads to precisely the specified limit. These values are provided to address those cases where the extent of propagation will define the number of agent sources involved in the fire. For example, these values would be applied when a fire that spreads throughout a room affects an agent source in that room; but if it spreads to adjacent rooms, additional sources would be involved; and if it further spreads to an adjacent fire zone, even more agent sources would be involved.

The following sections discuss how the propagation probabilities were determined and how they would be used.

2.3.1 Propagation Beyond Rooms. This section provides propagation probabilities for fires spreading beyond the room in which they start. This type of propagation will be referred to as "ex-room propagation." In considering the data provided by NFPA, it was judged that this type of propagation is dependent on the functional area in which the fire starts. The logic behind this judgment is that the combustible material available to fuel a fire depends on the function of a room. The types of combustibles contained in processing areas of the facility will likely be quite different from shipping and receiving areas, which would both differ from what would be expected in trash and maintenance areas. Therefore, separate values of propagation probabilities are provided for each of the functional areas listed in table 2-2.

As presented in section 2.2, the assignment of fire initiating frequencies to individual rooms requires that each room be assigned to one of these six particular functional areas of the facility. When applying the ex-room propagation model to fires in each room, the associated propagation table should be used. Further, the probability that a fire propagates is significantly affected by the presence of automatic suppression, so separate values are provided for the presence or absence of automatic suppression. Table 2-8 presents all of the ex-room propagation probabilities.

As previously discussed, the probabilities of exceedance shown in these tables are not independent, but rather represent the total probability that a fire spreads beyond the described extent. These values are used when there is only one target room of interest (i.e., where the agent is located). For example, take the case of a fire in the process area where the target room of interest is within the same fire zone as the room where the fire starts, and where an automatic fire protection system is present and functional. Using the third column of table 2-8 for process area, the probability that the fire reaches the target room is 0.08. That is, our interest is whether the fire reaches the target room, regardless of whether it stops at that room or proceeds further. Similarly, if the target room is in an adjacent fire zone, then the probability that a fire propagates to that room is 0.07. If the target room is multiple zones away or on a different floor, then the probability of propagation is 0.05. Although this case represents a fire that spreads extensively within the building, it would be erroneous to assume that all such fires involve the entire facility.

Table 2-8. Probability that a Fire Spreads Beyond a Room by Functional Area

Functional Area[a]	Extent of Propagation	Suppression: Probability of Exceedance[b]	Suppression: Conditional Probability[c]	No Suppression: Probability of Exceedance	No Suppression: Conditional Probability
Process (900)	Fire spreads beyond room of origin	0.08	0.01	0.20	0.01
	Fire spreads beyond fire-rated zone of origin	0.07	0.02	0.19	0.05
	Fire spreads beyond floor of origin (multiple zones)	0.05	0.05	0.14	0.12
	Fire spreads beyond building	0.00	0.00	0.02	0.02
SRLC (250)	Fire spreads beyond room of origin	0.11	0.00	0.41	0.00
	Fire spreads beyond fire-rated zone of origin	0.11	0.02	0.41	0.00
	Fire spreads beyond floor of origin (multiple zones)	0.09	0.09	0.41	0.38
	Fire spreads beyond building	0.00	0.00	0.03	0.03
TRIM (140)	Fire spreads beyond room of origin	0.08	0.03	0.05	0.00
	Fire spreads beyond fire-rated zone of origin	0.05	0.00	0.05	0.00
	Fire spreads beyond floor of origin (multiple zones)	0.05	0.05	0.05	0.05
	Fire spreads beyond building	0.00	0.00	0.00	0.00
SHE (490)	Fire spreads beyond room of origin	0.06	0.00	0.20	0.05
	Fire spreads beyond fire-rated zone of origin	0.06	0.00	0.15	0.04
	Fire spreads beyond floor of origin (multiple zones)	0.06	0.06	0.11	0.07
	Fire spreads beyond building	0.00	0.00	0.04	0.04
Structural (330)	Fire spreads beyond room of origin	0.13	0.00	0.22	0.00
	Fire spreads beyond fire-rated zone of origin	0.13	0.06	0.22	0.04
	Fire spreads beyond floor of origin (multiple zones)	0.07	0.04	0.18	0.16
	Fire spreads beyond building	0.03	0.03	0.02	0.02
All Other Areas (390)	Fire spreads beyond room of origin	0.12	0.00	0.22	0.00
	Fire spreads beyond fire-rated zone of origin	0.12	0.01	0.22	0.02
	Fire spreads beyond floor of origin (multiple zones)	0.11	0.11	0.20	0.17
	Fire spreads beyond building	0.00	0.00	0.03	0.03

Notes:

[a] Number in parentheses is the approximate number of fires in the 10-year NFPA database.

[b] Probability that the extent of propagation of the fire is at least as far as the limit given. Includes the probability that the fire propagates beyond the further limits shown on the table.

[c] Probability that the extent of propagation of the fire is exactly as far as the limit given, and no further.

The probability that the fire spreads beyond the building if the automatic suppression system functions is 0.00. This value is thought to represent the conditional probability of a fire engulfing the entire building and breaching the building boundary for the case of a fire starting in a process area where suppression is present and functioning.

Conversely, the conditional probabilities given on the tables are independent and can be used if there are multiple scenarios of concern that can result from the propagation of a fire. For example, take the case where a fire starts in a particular room and there are multiple nearby target rooms containing agent. One target is an adjacent room in the same zone. On the other side of that room is yet another room containing agent that is in an adjacent fire zone. Finally, a third target is above this room on another floor. In this case, there are three scenarios involving different agent amounts. To consider these three scenarios, it is necessary to use the conditional probabilities where suppression is present (the fourth column) for process area. Scenario one, where the fire spreads to the first target room and no further, would have a probability of 0.01. Scenario two, where the first two target rooms become involved requires the fire to spread beyond the fire-rated zone, and no further, would have a probability of 0.02. Finally, the scenario where all three target rooms are involved requires that the fire spread to the next floor, which would have a probability of 0.05.

2.3.2 Propagation Within Rooms. The preceding section discussed fire propagation from one room in the facility to another. Another important consideration in the fire risk assessment is propagation within a given room. This will be referred to as "in-room propagation." Propagation within the room is important for fires initiated in a room where agent is present. In this case, the question is whether the fire reaches the area within the room in which the agent is located.

The following sections provide a series of tables with the in-room propagation values for the cases with and without automatic fire suppression systems functioning. To use these tables to determine whether the fire spreads sufficiently to threaten agent sources, it is necessary to consider where the fire occurs in the room of interest. To do this, it is necessary to determine the number of ignition sources present and the distribution of these ignition sources within the room. The specific types of ignition sources present in the room also could be considered.

The following two approaches could be used to factor ignition source information into the assessment of the in-room propagation probability:

1. Assume an equal distribution across all ignition sources, and/or equal distribution of ignition sources throughout the room, or

2. Perform a weighted distribution by specific ignition source.

These approaches are presented in the following sections.

2.3.2.1 In-room Propagation Assuming an Equal Distribution of Ignition Sources. To use the first approach, it is only necessary to count the total number of potential ignition sources and determine the fraction of these sources that are "at," "near," or "far from" the target agent source. The fire frequency for the room would be multiplied by these fractions to obtain the frequencies of fires at, near, or far from the agent source.

Categorizing the ignition sources based on their proximity to the agent source would be based on judgment. A good rule of thumb, however, is that an ignition source within a few feet of the agent source would be "at" the source, whereas an ignition source beyond this distance, but within a few yards of the agent source would be "near" the source. The following equation could be used to determine the frequency of a fire potentially affecting the agent source:

$$
\begin{aligned}
\text{F(fires affecting agent)} = \; & \text{F(fire in room)} \times \text{FR(ignition source at agent source)} \\
& + \text{F(fire in room)} \times \text{FR(ignition source near agent source)} \\
& \times \text{P(propagation beyond origin)} \\
& + \text{F(fire in room)} \times \text{FR(ignition source far from agent source)} \\
& \times \text{P(propagation throughout room)}
\end{aligned}
$$

where the F terms are the frequencies for fires, the FR terms are the fraction of ignition sources at, near, or far from the agent source, and the P terms are probabilities of exceedance for propagation beyond the object of origin and throughout the room. If insufficient information is available to estimate the fraction of sources at each location, the values of FR for each location should be set at 0.33.

The values for P in the previous equation were developed from the analysis performed by NFPA (section 1 of NFPA, 2000b). These values depend on whether or not automatic suppression is available and are provided in table 2-9. Because in this approach the propagation probability is equally distributed to all types of ignition sources, a single value can be applied.

Table 2-9. Probability that a Fire Spreads Within a Room

	Suppression		No Suppression	
Extent of Propagation	Probability of Exceedance	Conditional Probability	Probability of Exceedance	Conditional Probability
Fire spreads beyond object of origin to other objects	0.33	0.21	0.46	0.19
Fire spreads throughout room	0.12	0.05	0.27	0.06

2.3.2.2 In-room Propagation Using a Weighted Distribution of Ignition Sources. The second approach to in-room propagation is based on the assumption that the type of equipment involved in the ignition is a significant factor in the extent to which the fire propagates. The logic behind this assumption is that the initial heat rate and the amount of combustibles available to fuel the fire is determined by the point of ignition. It is this initial fire that must further ignite other combustibles in the room that may be available.

To use the second approach, it is necessary to have developed the room fire frequency for each category of equipment (ignition source) in the room (frequency approach "c" from section 2.2.2). That is, in accordance with that approach, the total frequency of fire in the room would be the sum of the frequencies for each equipment category. The following equation would then be used to determine the frequency of fires affecting the agent source:

$$
\begin{aligned}
F(\text{fires affecting agent}) = & \sum F(\text{fire at agent source})_i \\
& + \sum F(\text{fire near source})_i \times P(\text{propagation beyond origin})_i \\
& + \sum F(\text{fire far from source})_i \times P(\text{propagation throughout room})_i
\end{aligned}
$$

where *i* represents the contribution to each fire location from the *i-th* equipment category in the room.

In order to implement this approach, the propagation probabilities, P, must be provided as a function of the 11 equipment categories. This was done based on the analysis performed by the NFPA (section 1 of NFPA, 2000b). Propagation probabilities are provided for cases with and without automatic suppression on table 2-10.

2.3.3 Consideration of "Spontaneous" Fires. When using either of these two approaches, it should be kept in mind that some fires start independent of an ignition source (sometimes referred to as spontaneous fires). In fact, one class of ignition included in the methodology is the category "no equipment involved." Therefore, it is possible that a fire could start near an agent source even if no ignition source is identified. The possibility of spontaneous fires also should be accounted for in the fire assessment.

Section 2.2.2 already addressed how the total frequency of these fires should be allocated to the rooms in a functional area. For the purpose of the in-room propagation evaluation and the application of the three-part formula presented in section 2.3.2.2, the definitions of "at agent source," "near agent source," and "far from agent source" would be applied. The total frequency of "spontaneous" fires should be allocated to each of the three bins based on the fraction of the total floor area that is at an agent source (that is, within a few feet), near an agent source (that is, within a few yards), or far from an agent source (beyond a few yards).

Table 2-10. Probability that a Fire Spreads Within a Room by Ignition Source

		Suppression		No Suppression	
Ignition Source[a]	Extent of Propagation	Probability of Exceedance	Conditional Probability	Probability of Exceedance	Conditional Probability
Chemical Process and Recovery Equipment (340)	Fire spreads beyond object of origin to other objects	0.35	0.09	0.39	0.12
	Fire spreads throughout room	0.26	0.09	0.27	0.07
Furnaces (150)	Fire spreads beyond object of origin to other objects	0.24	0.11	0.22	0.17
	Fire spreads throughout room	0.13	0.05	0.05	0.00
Other Fixed Heat-Generating Process Equipment (130)	Fire spreads beyond object of origin to other objects	0.25	0.16	0.31	0.11
	Fire spreads throughout room	0.09	0.03	0.20	0.05
Other Fixed Non-Heat-Generating Process Equipment (360)	Fire spreads beyond object of origin to other objects	0.25	0.18	0.42	0.11
	Fire spreads throughout room	0.07	0.04	0.31	0.09
Torches, Welders, Burners (200)	Fire spreads beyond object of origin to other objects	0.39	0.30	0.48	0.31
	Fire spreads throughout room	0.09	0.07	0.17	0.06
Electrical Equipment (190)	Fire spreads beyond object of origin to other objects	0.31	0.26	0.45	0.12
	Fire spreads throughout room	0.05	0.02	0.33	0.10
HVAC Mechanical/Electrical (60)	Fire spreads beyond object of origin to other objects	0.13	0.00	0.25	0.00
	Fire spreads throughout room	0.13	0.07	0.25	0.00
Other HVAC Equipment (90)	Fire spreads beyond object of origin to other objects	0.39	0.39	0.74	0.33
	Fire spreads throughout room	0.00	0.00	0.41	0.00
Portable Equipment Other than Torches, Welders, and Burners (40)	Fire spreads beyond object of origin to other objects	0.41	0.27	0.58	0.27
	Fire spreads throughout room	0.14	0.00	0.31	0.00
All Other Equipment (260)	Fire spreads beyond object of origin to other objects	0.33	0.21	0.46	0.19
	Fire spreads throughout room	0.12	0.04	0.27	0.08
No Equipment Involved (680)	Fire spreads beyond object of origin to other objects	0.41	0.28	0.52	0.23
	Fire spreads throughout room	0.13	0.04	0.29	0.05

Note:

[a] Number in parentheses is the approximate number of fires in the 10-year database.

2.3.4 Examples of Modeling Propagation. This section provides examples illustrating the application of the propagation concepts previously discussed. In each example, room YYY, which is part of the process functional area of the facility, is used. The room does not have a suppression system.

In the first example, the design of the facility is such that this room is in a fire-rated zone with another room. The second room is a storage room. Both rooms contain agent, so there are two scenarios of immediate interest: 1) a fire affecting agent only in room YYY, and 2) a fire affecting agent in both rooms. The other rooms/zones on the same floor do not contain agent, but there is agent in rooms on another floor, so a third scenario is: a fire affecting agent on both floors.

The first scenario, a fire affecting agent only in room YYY, is illustrated in table 2-11. The first four columns are identical to table 2-7. The first column shows the 11 types of ignition source used in this methodology. An inventory of these ignition sources was taken during a walkthrough of this room, and it is shown in the second column. Note that this is all in terms of the number of ignition sources (pieces of equipment) except for the use of the room area to treat the case in which no equipment was involved in ignition. The third column shows the fire frequency per unit (per piece of equipment or per square foot) for process areas. The fourth column is the product of the previous two, which yields the total frequency of a fire in the room due to the presence of the ignition sources. Summing across the 11 ignition sources yields the total room fire frequency, about 1.1×10^{-6} per hour.

In order to determine whether the fire reaches the agent source, it is necessary to determine the distribution of the ignition sources in relation to the agent sources. This also would be determined during the walkthrough. For example, of the 15 pieces of process equipment in the room, it was determined that eight were within a few feet of an agent source, five were within a few yards, and two were further away.

If a fire started in any of the first eight ignition sources, it would be assumed close enough to affect the agent source.[2] The frequency contribution of this ignition source to a fire would be the number of units times the fire frequency per unit (third column).

If a fire started in any of the second five ignition sources, it would have to propagate to at least part of the room in order to affect the agent. The frequency contribution of this ignition source to a fire would be the number of units (sixth column) times the fire frequency per unit (third column) times the probability of propagation to at least part of the room (seventh column). This would include fires that propagated throughout the room, but not beyond the room because that

[2] In this context, affect means the fire could cause the agent source to fail, which would result in involvement of the agent in the fire. The probability of that failure would be determined through a fire fragility analysis.

Table 2-11. Example of In-room Propagation Method Application

Ignition Source (Equipment Type)	Number of Units	Fire Frequency Per Unit	Total Fire Frequency	Number of Units at Agent Source	Number of Units Near Agent Source	Propagation to Part of Room (No Suppression)	Number of Units Away from Agent Source	Propagation Throughout Room (No Suppression)	Frequency of Affecting Agent (No Suppression)
Chemical Process	15	2.3E-08[a]	3.5E-07[b]	8[c]	5[d]	0.19	2[e]	0.07	2.5E-07[f]
Furnaces	0	4.5E-08	0.0E+00	0	0	0.17	0	0.00	0.0E+00
Other Heat-Generating	0	4.8E-08	0.0E+00	0	0	0.16	0	0.05	0.0E+00
Other Non-Heat Generating	22	9.9E-09	2.2E-07	10	6	0.20	6	0.09	1.4E-07
Torches, Welders, and Burners	2	6.0E-08	1.2E-07	0	0	0.37	2	0.06	2.0E-08
Electrical System	19	1.6E-09	2.9E-08	4	6	0.22	9	0.10	1.5E-08
Mechanical/ Electrical HVAC	0	0.0E+00	0.0E+00	0	0	0.00	0	0.00	0.0E+00
Other HVAC	0	8.0E-08	0.0E+00	0	0	0.33	0	0.00	0.0E+00
Portable Equipment	0	0.0E+00	0.0E+00	0	0	0.27	0	0.00	0.0E+00
All Other	25	6.6E-09	1.6E-07	6	8	0.27	11	0.08	8.3E-08
Non-Equipment Per Square Foot	3,299	5.4E-11	1.8E-07	330	990	0.28	1,979	0.05	7.7E-08
Total			1.1E-06						3.8E-07[g]

Notes:

[a] The fire frequency per unit (ignition source) for this example was calculated earlier (table 2-6) based on the total fire frequency for the ignition source and the inventory of such ignition sources in the process functional area.

[b] The contributor frequency for room YYY was calculated earlier based on the number of ignition sources in the inventory and the per-piece ignition frequency (table 2-7).

Table 2-11. Example of In-room Propagation Method Application (Continued)

Notes (Continued):

[c] Of the total number of ignition sources in the inventory (15 in the case of process equipment) 8 pieces are located at the target. The contribution of these pieces to the adjusted contributor frequency of process equipment is 8 multiplied by the fire frequency per unit of process equipment.

[d] Of the total number of ignition sources in the inventory (15 in the case of process equipment) 5 pieces are located near the target. The contribution of these pieces to the adjusted contributor frequency of process equipment is 5 multiplied by the conditional probability that the fire will spread to part or all of the room or throughout the room and the fire frequency per unit of process equipment. In the case of process equipment in an area without fire suppression, the conditional probability that the fire will spread to part or all of the room is 0.19 (table 2-10).

[e] Of the total number of ignition sources in the inventory (15 in the case of process equipment) 2 pieces are located far from the target. The contribution of these pieces to the adjusted contributor frequency of process equipment is 2 multiplied by the conditional probability that the fire will spread throughout the room and the fire frequency per unit of equipment. In the case of process equipment in an area without fire suppression, the conditional probability that the fire will spread throughout the room is 0.07 (table 2-10).

[f] The adjusted contributor frequency for process equipment in room YYY is the sum of: 1) the number of ignition sources at the target (8) multiplied by the fire frequency per unit of process equipment (2.3×10^{-8} per hour), 2) the fraction of ignition sources near the target (5) multiplied by the conditional probability that the fire will spread to part or all of the room (0.19) and the fire frequency per unit (2.3×10^{-8} per hour), and 3) the fraction of ignition sources far from the target (2) multiplied by the conditional probability that the fire will spread throughout the room (0.07) and the fire frequency per unit (2.3×10^{-8} per hour). This equals 2.5×10^{-7} per hour.

[g] The adjusted frequency, 3.8×10^{-7} per hour is the sum of adjusted contributor frequencies. This is the frequency with which a munition in the room will be threatened by a fire that does not leave the room.

would involve additional agent and would be treated as a separate scenario. Therefore, the numbers in this column would be the sum of the conditional probability that a fire spreads through part of the room plus the conditional probability that the fire spreads throughout the room for the ignition source and no automatic suppression. For this specific ignition source and room, one would go to table 2-10 and sum the two conditional probabilities, which results in a value of 0.19.

If a fire started due to any of the final two ignition sources, it would have to propagate throughout the room in order to affect the agent. The frequency contribution of this ignition source to a fire would be the number of units (eighth column) times the fire frequency per unit (third column) times the probability of propagation throughout the room (ninth column). This would not include fires that propagated beyond the room because that would include additional agent and would be treated as a separate scenario. Therefore, the numbers in this column would be the conditional probability that the fire spreads throughout the room for the ignition source and no automatic suppression. For this specific ignition source and room, one would go to table 2-10 and find that conditional probability, which results in a value of 0.07.

The last column provides the sum of each of the products previously discussed, and represents the total frequency, which yields the total frequency of a fire in the room affecting an agent source due to the presence of the ignition sources. That is, the frequency that a fire would start in a piece of process equipment and affect an agent source is about 2.5×10^{-7} per hour. Summing across the 11 ignition sources yields the total frequency of a fire in the room affecting an agent source to be approximately 3.8×10^{-7} per hour.

The second scenario, a fire affecting agent in both room YYY and the adjacent room, requires consideration of propagation beyond a room. This is treated using the values in table 2-8. First, given the description of the facility, this outcome can result from any fire that reaches these two rooms, but does not spread beyond the floor. Remember that there is additional agent on another floor, so such a fire would be different in that more agent would be involved. So, the scenario being addressed is a fire that spreads beyond a room, but not beyond the floor. This is addressed through the use of the probability of exceedance.

Table 2-12 shows the calculations for the contributor to this event from fire starting in room YYY. Ex-room propagation is a function of functional area. Column 1 shows that the functional area of the room is "Process." The total fire frequency is as previously calculated for this room (table 2-7). To determine the propagation probability for the specific scenario of interest, the probability of exceedance for a fire spreading beyond the room of origin, process area, no suppression is used (0.20 from table 2-8). However, this value also includes fires that spread beyond the floor. As previously discussed, the design of this example facility is such that if a fire were to spread beyond the floor, it would involve additional agent, which is a different

Table 2-12. Example of Ex-room Propagation Method Application

Functional Area	Total Fire Frequency	Propagation Beyond Room but not Beyond Floor (No Suppression)	Frequency of Affecting Agent
Process	1.1E-06	0.06	6.6E-08

scenario. The probability of exceedance for fire spreading beyond the floor of origin (0.14 from table 2-8) must be subtracted from the probability of exceedance for a fire spreading beyond the room of origin (0.20), which yields the 0.06 shown. Of course, this is only the contribution to this scenario from fires starting in room YYY. Similar calculations must be performed for fires in the adjacent room, and adjacent zones that could also lead to the same agent involvement. These resulting frequencies would all be summed to get the total scenario frequency.

The same approach would be used to assess the frequency of a two-floor fire. The probability of exceedance for a fire spreading beyond the building[3] would be subtracted from the probability of exceedance for a fire spreading beyond a floor. This would be done for each room/zone in the building because any room fire could (in theory) become a multi-floor fire. Whenever such a multi-room analysis is done, the analyst must be careful to apply the correct propagation value for each room — based on the functional area of the room and the status of automatic fire protection in the room.

There are certain cases of fire where the in-room and ex-room propagation models are combined. Take the case where the layout of the building is the same as the one previously discussed, but with the exception that there is no agent in the room next to room YYY. In this case, fires that start in room YYY would have the same affect on agent whether they spread only in the room or they spread further on the same floor.

Table 2-13 illustrates this approach. The table is identical to table 2-11, with the exception of the propagation probability in the seventh and ninth columns and a further adjustment applied to the final column. The values in the seventh column are the probability of exceedance for a fire spreading beyond the point of origin (i.e., the probability the fire spreads at least that far, regardless of how much farther it may spread). The values in the ninth column are the probabilities of exceedance for a fire spreading throughout the room. Both sets of values are taken from table 2-9. The calculation is performed in the same way as table 2-10, but in this case, the resulting frequency (5.8×10^{-7} per hour) includes all fires that start in room YYY and

[3] The scenario of fire spreading beyond the building (a "building-wide fire") must always be analyzed as a separate scenario because it has the unique feature of breaching the building boundary and failing HVAC as a direct result of the fire. This has a significant effect on the source term for the scenario.

Table 2-13. Example of Combined Propagation Method Application

Ignition Source (Equipment Type)	Number of Units	Fire Frequency Per Unit	Total Fire Frequency	Number of Units at Agent Source	Number of Units Near Agent Source	Propagation to Part of Room or Beyond (No Suppression)	Number of Units Away from Agent Source	Propagation Throughout Room or Beyond (No Suppression)	Frequency of Affecting Agent (No Suppression)
Chemical Process	15	2.3E-08[a]	3.5E-07[b]	8[c]	5[d]	0.39	2[e]	0.27	2.5E-07
Furnaces	0	4.5E-08	0.0E+00	0	0	0.22	0	0.05	0.0E+00
Other Heat-Generating	0	4.8E-08	0.0E+00	0	0	0.31	0	0.20	0.0E+00
Other Non-Heat-Generating	22	9.9E-09	2.2E-07	10	6	0.42	6	0.31	1.4E-07
Torches, Welders, and Burners	2	6.0E-08	1.2E-07	0	0	0.48	2	0.17	2.0E-08
Electrical Systems	19	1.6E-09	2.9E-08	4	6	0.45	9	0.33	1.5E-08
Mechanical/ Electrical HVAC	0	0.0E+00	0.0E+00	0	0	0.25	0	0.25	0.0E+00
Other HVAC	0	8.0E-08	0.0E+00	0	0	0.74	0	0.41	0.0E+00
Portable Equipment	0	0.0E+00	0.0E+00	0	0	0.58	0	0.31	0.0E+00
All Other Equipment	25	6.6E-09	1.6E-07	6	8	0.46	11	0.27	8.3E-08
Non-Equipment Per Square Foot	3,299	5.4E-11	1.8E-07	330	990	0.52	1,979	0.29	7.7E-08
Total			1.1E-06						5.8E-07[g]
Propagation Beyond Floor								0.14	-1.5E-07[h]
Final Frequency									3.8E-07

Table 2-13. Example of Combined Propagation Method Application (Continued)

Notes:

[a] The fire frequency per unit (ignition source) for this example was calculated earlier (table 2-6) based on the total fire frequency for the ignition source and the inventory of such ignition sources in the process functional area.

[b] The contributor frequency for room YYY was calculated earlier based on the number of ignition sources in the inventory and the per-piece ignition frequency (table 2-7).

[c] Of the total number of ignition sources in the inventory (15 in the case of process equipment) eight pieces are located at the target. The contribution of these pieces to the adjusted contributor frequency of process equipment is multiplied by the fire frequency per unit of process equipment.

[d] Of the total number of ignition sources in the inventory (15 in the case of process equipment) five pieces are located near the target. The contribution of these pieces to the adjusted contributor frequency of process equipment is five multiplied by the probability of exceedance that the fire will spread at least to part of the room and the fire frequency per unit of process equipment. In the case of process equipment in an area without fire suppression, the probability of exceedance that the fire will spread to part or all of the room is 0.39 (table 2-10).

[e] Of the total number of ignition sources in the inventory (15 in the case of process equipment) two pieces are located far from the target. The contribution of these pieces to the adjusted contributor frequency of process equipment is two multiplied by the probability of exceedance that the fire will spread at least throughout the room and the fire frequency per unit of process equipment. In the case of process equipment in an area without fire suppression, the probability of exceedance that the fire will spread throughout the room is 0.27 (table 2-10).

[f] The adjusted contributor frequency for process equipment in room YYY is the sum of 1) the number of ignition sources at the target (8) multiplied by the fire frequency per unit of process equipment (2.3×10^{-8} per hour), 2) the fraction of ignition sources near the target (5) multiplied by the probability of exceedance that the fire will spread to part of the room (0.39) and the fire frequency per unit (2.3×10^{-8} per hour), and 3) the fraction of ignition sources far from the target (2) multiplied by the probability of exceedance that the fire will spread throughout the room (0.27) and the fire frequency per unit (2.3×10^{-8} per hour). This equals 2.5×10^{-7} per hour.

[g] The frequency with which an agent source in the room will be threatened by a fire that stays in the room, regardless of how far the fire ultimately spreads, is the sum of the adjusted contributor frequencies. This equals 5.8×10^{-7} per hour.

[h] Because a room fire that does not spread outside the floor is the scenario of interest, the probability that the fire will leave the floor must be subtracted from the sum of the adjusted contributor frequencies. The total fire frequency (1.1×10^{-6} per hour) is multiplied by the probability of exceedance that the fire leaves the floor (0.14 for a process room with no suppression, table 2-8) and subtracted from the sum of adjusted contributor frequencies (5.8×10^{-7} per hour). The frequency with which a munition in the room will be threatened by fire that does not leave the floor is 3.8×10^{-7} per hour.

affect the agent in the room, no matter how far they ultimately spread. This is fine up to the point where they only spread on the same floor because there is no additional agent on the floor and so the effect is the same. However, it also includes fires that spread beyond the floor, which is a different scenario. These need to be excluded from this calculation. To do this, the probability of exceedance for a fire in a process area with no suppression spreading beyond the floor (0.14, from table 2-8) needs to be applied to the total fire frequency for the room. It is not necessary to apply this probability to each ignition source calculation, because propagation beyond the room is based only on the functional area of the room. This yields the frequency of fires starting in room YYY that spread beyond the floor.

Subtracting this product from the previous sum yields the frequency of a fire starting in room YYY affecting only the agent in room YYY for the specific design cited. Of course, to determine the total frequency of a fire affecting the agent in room YYY, it is necessary to also consider fires that start in other rooms on the floor and propagate to room YYY.

(This page intentionally left blank.)

SECTION 3
ASSESSMENT OF OUTSIDE FIRES

This section addresses the assessment of the hazards due to outside fires at the CDFs. Outside fires are defined as those fires occurring in the yard area surrounding the facility that are associated with the operation of the facility. They include fires involving burning material that has value, as well as fires involving burning material with no value (i.e., refuse). Currently excluded from consideration are tree, brush, grass, and vehicle fires. Included, but treated separately, are outside spills or leaks that lead to a fire.

3.1 Total Outside Fire Frequency

The total frequency for outside fires is calculated in the same manner as for structure fires. Outside fire frequencies are developed for two basic types of fires: general outside fires and spills or leaks with ensuing fires.

The general outside fires have two subcategories: fires involving property of value and rubbish/trash/waste fires. The definition of these types of fires is such that trash fires only include fires where no property of value was involved, regardless of where the fire started. Thus, fires that started in trash but spread to include property of value were counted in the first subcategory. Given this definition, outside fires at a CDF that involved agent would be considered fires involving property of value. Therefore, in determining the frequency of outside fires at a CDF, only these fires will be considered.

As discussed in section 2.1, a CDF would be classified by NFPA under Chemical, Plastic, or Petroleum Products. According to NFPA data (Ahrens, 2000b), there are approximately 287 outside fires involving property of value annually in such facilities.

According to NAICS, the total number of facilities of this type is 29,303. Therefore, the frequency of potentially significant fires in these facilities is:

$$F = \frac{287 \text{ fires/yr}}{\left(29{,}303 \text{ facilities} \times 8{,}760 \text{ hrs/yr}\right)} = 1 \times 10^{-6} \text{ fires/facility - hr}$$

As with structure fires, the analysis was refined further, using subcategories within the classification systems to determine whether a particular subcategory of Chemical, Plastic, or Petroleum Products would be more representative of a CDF.

According to NFPA data, each year there are approximately 62 outside fires involving property of value in the subcategory Industrial Chemical, Hazardous Chemical, and Plastics facilities. According to NAICS, the total number of facilities in the corresponding subcategories is 5,870. Therefore, the frequency of potentially significant fires in these facilities is:

$$F = \frac{62 \text{ fires/yr}}{(5{,}870 \text{ facilities} \times 8{,}760 \text{ hrs/yr})} = 1 \times 10^{-6} \text{ fires/facility - hr}$$

Thus, the two estimates of the outside fire frequency are virtually the same. Overall, the use of a total mean outside fire frequency of 1×10^{-6} fires per facility per hour for a CDF is deemed to be appropriate.

Similar calculations were performed for the occurrence of an outside spill followed by a fire. Using the full population of Chemical, Plastic, or Petroleum Products, there are approximately 81 fires that follow outside spills in such facilities annually. Therefore, the frequency of such fires in these facilities is:

$$F = \frac{81 \text{ fires/yr}}{(29{,}303 \text{ facilities} \times 8{,}760 \text{ hrs/yr})} = 3 \times 10^{-7} \text{ fires/facility - hr}$$

Refining this estimate further, each year there are approximately 18 fires following outside spills in the subcategory Industrial Chemical, Hazardous Chemical, and Plastics facilities. Therefore, the frequency of such fires in these facilities is:

$$F = \frac{18 \text{ fires/yr}}{(5{,}870 \text{ facilities} \times 8{,}760 \text{ hrs/yr})} = 4 \times 10^{-7} \text{ fires/facility - hr}$$

This value is close to the value calculated in the previous equation based on the broader facility classification, especially given the uncertainty that numerator and denominator represent the same facility population. Overall, the use of a total mean frequency of a fire following an outside spill of 3×10^{-7} fires per facility per hour is deemed to be appropriate for a CDF. This value covers the various ways in which a spill could result in a fire and therefore could be used as a screening value for events of this type.

3.2 Distribution of Fires by Outside Area

Similar to what was discussed in section 2.2 on distribution of fires inside the CDF building, it is useful to look at fires outside the building as a function of where such fires occur. One analysis performed by the NFPA was in terms of this distribution (section 5 of NFPA, 2000b). Because the type of building construction is not relevant to outside fires, this distribution covers all Industrial Chemical, Hazardous Chemical, and Plastics facilities. With some interpretation, these data can be used to estimate the fraction of the total fire frequency that should be assigned to the various onsite areas of a CDF outside the building. The results of this assessment are provided in table 3-1.

Table 3-1. Multiplication Factor and Fire Frequency for Outside Areas of a Chemical Agent Disposal Facility

Area	Factor	Fire Frequency
Storage areas[a] – To include all areas where products are held while awaiting process, shipment, or use	0.20	2.0×10^{-7}
Receiving/loading/conveyor areas[b] – To include all areas where products are moved while onsite but outside the building	0.14	1.4×10^{-7}
Trash/rubbish areas	0.14	1.4×10^{-7}
Areas containing equipment[c] – To include all areas outside the building that contain operating process, HVAC, maintenance, or other machinery and equipment	0.09	9.0×10^{-8}
Open areas[d] – To include fields, roads, and right of ways	0.03	3.0×10^{-8}
Vehicles[e]	0.18	1.8×10^{-7}
Other – Primarily applies to exterior structural areas of buildings	0.22	2.2×10^{-7}

Notes:

[a] The sum of the following NFPA areas are 1) product storage area, tank, or bin, 2) unclassified storage area, and 3) supply storage room or area

[b] The sum of the following NFPA areas are 1) shipping, receiving, or loading area, 2) court, terrace, or patio, and 3) conveyor

[c] The sum of the following NFPA areas are 1) process or manufacturing area, 2) unclassified service or equipment area, 3) heating equipment room or area, 4) incinerator room or area, 5) unclassified service facility, 6) machinery room or area, and 7) maintenance shop or area

[d] The sum of the following NFPA areas are 1) lawn, field, or open areas, 2) railroad right of way or embankment, and 3) highway, public right of way, or street

[e] The sum of the following NFPA areas are 1) engine, wheel, or running area of vehicle, 2) exterior surface of vehicle, 3) truck or load-carrying area of vehicle, and 4) unclassified vehicle area

This distribution applies to the outside fires that involve property of value (i.e., they do not involve just trash or rubbish). This, however, is not to say that all outside fires involve agent. It still is necessary to determine whether agent is involved; for example, consider fires that occur in vehicles. If there are 10 vehicles, each would be allocated part of the vehicle fire total (1.8×10^{-7}). If only one of those vehicles is near an agent source, that is the only one in which agent release would be further considered.

No area distribution is provided for spills followed by fire. By definition, the fire in this case involves the spilled material (NFPA data are based on spills of combustible chemicals). This value can be used in conjunction with a QRA of chemical agent spills outside the facility to approximate a probability that a spill could result in a fire. Should this approach yield a result that such fires are an important risk contribution, a more detailed analysis of ignition mechanisms in the area of the spills should be performed.

SECTION 4
SUMMARY AND CONCLUSIONS

This report has outlined an approach to estimating the fire hazards in the U.S. Army's CDFs using historical fire data from a database maintained by the NFPA and facility census data from a USCB database. These databases are used to develop estimates for the total frequency of fires in a CDF, the distribution of fires within the facility, and the probability that a fire in one area will spread to an area with chemical agent. In addition, the analysis has been separately applied to structure fires (fires within the facility) and outside fires (fires in the immediate area around the facility).

Based on the historical data, the total inside fire frequency for the CDF was estimated to be 8×10^{-6} fires per facility per hour. The inside fire frequency then was broken down by the area of the facility in which the fire starts. Based on this evaluation, it was estimated that approximately one-third of the fires in a CDF would start in the process area. Fires in each area were further broken down by the type of equipment involved in the fire. Tables were developed for allocating the fire frequency to each type of equipment in a facility functional area or, when equipment is not the cause of the fire, by floor area.

Given that a fire occurs, it is important to understand how far it spreads in order to assess what quantity of chemical agent could be involved. Based on historical data, probabilities were estimated for fire propagation between rooms or areas of the facility. The propagation probabilities depend on the building construction and layout and on whether or not an automatic fire suppression system is present and functioning. These probabilities were determined to be related to the function of the facility area where the fire starts. Tables were developed for determining the probability that a fire propagates beyond the room where it starts and how far it ultimately propagates.

An approach also was developed for evaluating propagation within a room based on the number and type of ignition sources present in the room and the proximity of these ignition sources to any chemical agent present in the room. The probability that a fire propagates within a room was determined to be related to the type of equipment involved in the fire. Tables were developed for determining the probability that a fire propagates to varying degrees within a room based on the equipment present in the room. Tables also were developed for estimating the propagation probability following fires initiated by non-equipment sources.

The frequency of outside fires also was estimated from NFPA and USCB data. Outside fires were developed for two categories of outside fires: fires that occur following spills or leaks and all other outside fires. The frequency of fires following spills was estimated to be 4×10^{-7} fires per facility per hour, and the frequency of all other outside fires was estimated to be 1×10^{-6} fires per facility per hour. The total frequency of outside fires was broken down by the type of outside area in which a fire starts. It was not necessary to do this for spills followed by fire, because these events would only apply to areas where agent was present.

APPENDIX A
ACRONYMS/ABBREVIATIONS

APPENDIX A
ACRONYMS/ABBREVIATIONS

CDF	Chemical Agent Disposal Facility
FEMA	Federal Emergency Management Agency
HVAC	heating, ventilation, and air conditioning
NAICS	North American Industry Classification System
NECDF	Newport Chemical Agent Disposal Facility
NFIRS	National Fire Incident Reporting System
NFPA	National Fire Protection Association
QRA	Quantitative Risk Assessment
SAIC	Science Applications International Corporation
SHE	service machinery, HVAC, and electrical
SRLC	storage/receiving/loading/conveyor
TRIM	trash/rubbish/incinerator/maintenance/laboratory
USCB	U.S. Census Bureau

(This page intentionally left blank.)

APPENDIX B
REFERENCES

APPENDIX B
REFERENCES

Ahrens, M., NFPA, *Summary of Structure Fires in Chemical, Plastic, and Petroleum Facilities: 1988-1997*, Fax from M. Ahrens, NFPA, to P. Amico, Science Applications International Corporation (SAIC), 3 August 2000a.

Ahrens, M., NFPA, *Outside and Other Fires in Chemical, Plastic and Petroleum Facilities: 1988-1997*, Electronic mail from M. Ahrens, NFPA, to P. Amico, SAIC, 1 September 2000b.

Averett, M., *Crystal River 3 Individual Plant Examination of External Events*, Florida Power Corporation, June 1996.

Federal Emergency Management Agency (FEMA), NFIRS Incident Form (NFIRS-1), *http://www.usfa.fema.gov/nfdc/codes.htm*.

National Fire Protection Association (NFPA), *The U.S. Fire Problem Overview Report: Leading Causes and Other Patterns and Trends*, NFPA, Quincy, Massachusetts, April 2000a, Appendix A, pages 180 through 183.

NFPA, *Fires in or at Industrial Chemical, Hazardous Chemical, and Plastic Manufacturing Facilities: 1988 - 1997 Unallocated Annual Averages and Narratives*, NFPA, Quincy, Massachusetts, November 2000b.

SAIC, *Tooele Chemical Agent Disposal Facility Quantitative Risk Assessment*, SAIC-96/2600, December 1996.

U.S. Census Bureau, Economic Census, *http://www.census.gov/epcd/ec97/ustotals.htm*, 1997.

(This page intentionally left blank.)