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Minimum Separation Distances for Natural Gas Pipeline and Boilers in the 300 Area, Hanford Site

P. M. Daling
T. M. Graham

August 1997

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EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) is proposing actions to reduce energy expenditures and improve energy system reliability at the 300 Area of the Hanford Site. These actions include replacing the centralized heating system with heating units for individual buildings or groups of buildings, constructing a new natural gas distribution system to provide a fuel source for many of these units, and constructing a central control building to operate and maintain the system. The individual heating units will include steam boilers that are to be housed in individual annex buildings located at some distance away from nearby 300 Area nuclear facilities.

This analysis develops the basis for siting the package boilers and natural gas distribution system to be used to supply steam to 300 Area nuclear facilities. The effects of four potential fire and explosion scenarios involving the boiler and natural gas pipeline were quantified to determine minimum separation distances that would reduce the risks to nearby nuclear facilities. The resulting minimum separation distances are shown in Table ES.1.

TABLE ES.1. Exposed Nuclear Facilities and Minimum Separation Distances

Exposed Nuclear Facility	Minimum Separation Distance, m (ft)					
	Boiler Annex	Boiler Explosion ^(a)	Natural Gas Detonation in Annex ^(a)	Fire Exposure ^(a)	Flame Jet from Pipeline Rupture ^(b)	
					6-in. Pipe	1-in. Pipe
324	324	25 (82)	21 (70)	4.3 (14)	12.5 (41)	7 (21)
325	325	19 (62)	18 (59)	4 (13)	12.5 (41)	7 (21)
	328	18 (59)	12 (40)	3 (10)		
327	327	21 (70)	17 (57)	4 (13)	12.5 (41)	7 (21)
	382B	21 (70)	17 (57)	4 (13)		
308	324	25 (82)	21 (70)	4.3 (14)	12.5 (41)	7 (21)
3712	3720	18 (59)	16 (53)	3.7 (12)	12.5 (41)	7 (21)

- (a) Separation distances were calculated from the boiler (for boiler explosion), mid-point of annex building (for gas detonation), and annex building wall (for annex building fire exposure) to nearest point on nearby nuclear facilities.
- (b) Separation distances were calculated from the natural gas pipeline to the nearest point on nearby nuclear facilities.

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1.0 INTRODUCTION AND BACKGROUND

The U.S. Department of Energy (DOE) is proposing actions to reduce energy expenditures and improve energy system reliability at the 300 Area of the Hanford Site. These actions include replacing the centralized heating system with heating units for individual buildings or groups of buildings, constructing new natural gas pipelines to provide a fuel source for many of these units, and constructing a central control building to operate and maintain the system. The individual heating units will include steam boilers, hot water heaters, and furnaces.

This analysis develops the basis for siting the pipelines and package boilers to be used to supply steam to 300 Area facilities. The analysis focuses on establishing minimum separation distances between boilers and pipelines and the 300 Area nuclear facilities. Natural gas will not be piped directly to nor will package boilers be housed within any of the nuclear facilities in the 300 Area.

This analysis should not be used as the sole basis to authorize activities or justify facility modifications. This document is intended to be used with an Unreviewed Safety Question (USQ) screening analysis.

The balance of this chapter provides information on the proposed replacement project, including the natural gas distribution system and package boilers to be installed in the 300 Area.

1.1 300 AREA NATURAL GAS DISTRIBUTION PIPELINE

The main pipeline will be approximately 11 km (7 mi) long and parallel the existing DOE-owned railroad that serves the Hanford Site along Stevens Drive. It will be tied into the existing Cascade Natural Gas Company pipeline near Thayer Drive and the Bypass Highway. This medium-pressure main will terminate at the south end of the 300 Area near the Cypress Gate. Natural gas will be delivered at the point of entry at a minimum pressure of 30 psig. This main pipeline is located a considerable distance from any of the 300 Area nuclear facilities (that is, greater than approximately 183 m (600 ft) from the 325 Building, which is the closest nuclear facility). Therefore, further evaluation of the main pipeline and potential operational effects on 300 Area nuclear facilities was not performed in this assessment.

Construction of the onsite portion of the pipeline will require excavation to a depth of approximately 0.6 m (2 ft) to 1 m (3.3 ft). It will involve digging through concrete or asphalt paving in roads, walkways, or parking lots as needed; excavating gravel and dirt to create a ditch along a predetermined route; installing the polyethylene distribution pipe and associated instrumentation; and restoring the sites to the preconstruction conditions. As determined in DOE (1997), the construction impacts from the proposed action will be minimal. Construction traffic,

noise, and dust will have no appreciable impact relative to existing activities underway on the site or along the natural gas pipeline route. No radiation exposure is expected; however, there is the potential to encounter radioactive and/or other hazardous materials. Potential accidents during construction include routine industrial events associated with heavy equipment, excavation of pipelines, and other underground utilities (electrical power, water mains, sewer lines, etc.), and building construction. These accidents can result in generally accepted routine risks of accidental death or injury associated with construction work. Pre-job safety briefings and worker training will be in place to minimize anticipated accidents and resultant consequences.

Natural gas distribution onsite will be through a distribution network of 2.5-cm (1-in.) up to 15-cm (6-in.) high-density polyethylene pipes. A regulator at the entry point to the 300 Area will reduce the gas pressure to 15 psig. The gas pressure will be reduced again to 5 psig by regulators at stations outside the individual annex buildings. A manual shutoff valve for the 300 Area natural gas distribution system will also be located at the point of entry to the 300 Area near the Cypress Gate. The 300 Area distribution system will be monitored by METASYS to a central location in the 300 Area (3707D Building), where an operator will be on duty 24 hours per day to monitor and control the flow of natural gas to the boiler/heater units. It is estimated that fuel consumption will be about 180 billion Btu of natural gas in an average year. A diagram of the natural gas distribution network is provided in Figure 1.1.

The piping below grade will be thermoplastic with wall thickness equivalent to or greater than Schedule 40 pipe, specifically marked for gas service in accordance with American Society for Testing of Materials (ASTM) Standard D2513. Piping above grade will be Schedule 40 black steel in accordance with ASTM A53. Piping will be fabricated, installed, and tested in accordance with National Fire Protection Association (NFPA) 54, "National Fuel Gas Code." Electrically-continuous, corrosion-resistant tracer wire or tape will be applied to underground piping. Underground piping will be laid on 10 cm (4 in.) of sand and will have a minimum backfill cover of 46 cm (18 in.). Manual isolation valves are being placed throughout the distribution system to facilitate termination of gas flow upon detection of natural gas leakage from the pipeline or to allow isolation of certain segments of the pipeline for general maintenance and construction purposes.

1.2 STEAM BOILERS AND ANNEX BUILDINGS

1.2.1 Annex and Boiler Design Information

Annex buildings are being constructed to house the steam boilers of interest to this siting analysis. The occupancy class under the Uniform Building Code 1994 Edition, adopted state-wide, is S-2 and the Code construction class is II-N (noncombustible, not fire rated). Vinyl-fiberglass batts, which is UL-listed material with flame spread rating less than 25, will be used

Figure 1.1. 300 Area Natural Gas Distribution System

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to insulate the buildings. The annex buildings are of noncombustible construction and will be constructed on concrete pads. Manually operated fuel shutoff valves for emergency closing in case of fire or other emergency will be located outside of each annex building in an accessible location. Table 1.1 provides approximate dimensions of the annex buildings. The annex buildings and exposed nuclear facilities in the table were selected to bound the impacts of boiler and natural gas pipeline accidents. Other nuclear facilities in the 300 Area (e.g., the 340 Building) were not explicitly evaluated as they are located farther away from the boilers and pipeline than the facilities listed in Table 1.1.

The majority of the steam boilers planned for the 300 Area are small gas-fired boilers (less than 157 hp or 117 kW). Four of the boiler annexes (that is, the annexes for the 324, 327, 382B, and 331 Buildings) will house medium gas-fired boilers (between 157 and 4,900 hp or 117 to 3660 kW). Two 200 hp boilers are planned for the 327 and 382B Buildings and two 300 hp boilers are planned for the 331 and 324 Buildings, all of which are at the low end of the size range for medium boilers. No large boilers (greater than 4,900 hp or 3660 kW) are planned. The basic dimensions and other physical parameters of the boilers are shown in Table 1.2. A schematic of the type of boiler design to be installed in the 300 Area is shown in Figure 1.2.

1.2.2 Fire Protection and Loss Prevention Features Incorporated in 300 Area Natural-Gas-Fired Boilers and Boiler Annexes

The proposed activity involves operation of natural-gas-fired boilers for steam heating and process steam of 300 Area facilities. The design, installation, and operation of the boilers will be covered by applicable codes and standards. Good facility design, selection of reliable equipment, system monitoring, and malfunction alarm instrumentation are key elements in preventing fires and explosions in boiler-furnace systems. Local and central monitoring of boiler fire and function alarms will expedite corrective action and/or suppression efforts and minimize damage to the annex buildings and adjacent facilities. Housekeeping and noncombustible construction minimize the fire exposure. Active fire safety program, fire hydrant availability within 300 feet of the annex buildings, and fire department vehicular access will mitigate the consequences of a fire or explosion (NFPA 1997; Christensen 1997).

The boiler systems (conventional "firetube" configuration) and annex buildings will be equipped with gas meters and separate discharge stacks. The boilers will have full modulating capabilities operating from 1/4 up to full load, will be equipped with a single, low-NO_x burner with induced flue gas recirculation (FRG), will be automated and normally unattended. The boilers will be provided with ASME-rated safety relief valves set at 15 or 150 psig (depending on the boiler). Flame Safeguard with automatic burner sequencing, flame supervision, and system status indication is planned.

Table 1.1. Boiler Annex Dimensions and Relation to 300 Area Nuclear Facilities

Exposed Nuclear Facility	Boiler Annex in vicinity	Boiler Annex Dimensions, ft
324, 308	324	29.5 x 37.5 x 18 H
325	325	23.5 x 31.5 x 16 H
	328	17.5 x 17.5 x 12 H
327	327	23.5 x 25.5 x 18 H
	382B	23.5 x 25.5 x 18 H
3712	3720	23.5 x 23.5 x 16 H

Note: "H" denotes approximate building height.

Table 1.2. Boiler-Specific Size, Dimensions, and Operating and Design Pressures

Building	Boiler Numbers and Sizes, hp	Normal Operating Pressure, psig	Design Pressure, psig	Tested Pressure, psig	Inside Diameter, in.	Boiler Shell Thickness, in.
324	2-300	100	150	300	78	1/2
325	2-125	100	150	300	60	3/8
328	1-30	12	15	100	36	1/4
327	1-200	12	15	100	60	5/16
382B	1-200	12	15	100	60	5/16
3720	1-125	12	15	100	60	5/16

Preventive features that are being included in the design packages for the boilers and annex buildings are described by Christensen (1997).

Figure 1.2. Schematic of a Typical Boiler To Be Installed in the 300 Area

2.0 IDENTIFICATION OF HAZARDS

This chapter identifies the known and postulated hazards of natural gas pipelines and natural-gas-burning boilers. Quantification of these hazards will provide the basis for siting the gas pipelines and boilers in the 300 Area.

2.1 NATURAL GAS PIPELINE

Natural gas pipeline ruptures are due to three main causes: 1) damage from outside forces such as excavation equipment, 2) external corrosion, and 3) construction or material defects. Statistics for transmission and distribution pipeline incidents reported to the Office of Pipeline Safety (OPS) for calendar year 1992 (OPS 1993) show that one pipeline failure occurs per 9,100 miles (14,600 km) of pipeline per year (0.00011 incidents per mile per year). This is based on incidents in which damage exceeded \$50,000 per incident, or hospitalization injury or death occurred. This failure frequency is slightly lower than experienced from 1988 through 1992 (0.00013 per mile per year). In 1992, 48% percent of the incidents were caused by damage from outside forces, 6% from external corrosion, 8% from construction or material defects, and 38% from other causes.

Natural gas leaks pose two separate hazards: asphyxiation of workers exposed in confined spaces to an oxygen-deficient atmosphere and fires/explosions from ignition of a natural gas fuel/air mixture. Asphyxiation hazards are reduced through the addition of an odorant that warns exposed persons of the presence of natural gas. The natural gas cloud would not be an asphyxiation hazard unless it is confined. Confined conditions rarely occur outdoors and would only occur indoors if the natural gas is somehow drawn into the building and not exhausted. Therefore, asphyxiation of workers would be prevented by the odorant providing an early warning that natural gas is present and by the dilution effects that would be provided by building ventilation systems.

The other main hazard of natural gas is related to fires and explosions. Leakage of natural gas could lead to formation of a flammable natural gas/air mixture that, if ignited, could result in a severe fire or explosion. The leaking pipeline could also lead to a high-velocity release of natural gas from the broken pipe that would form a flame jet if ignited. Impingement of the flame on a nearby facility could fail its outer walls. The radiant energy released from the flame jet is a significant hazard, even if direct flame impingement on the exposed building does not occur. Flame jet impingement is minimized through burial of the pipe in an underground trench, which places the trench walls between the pipeline and target building. Other preventive/mitigative measures include monitoring of pipeline pressure to sense the large pressure drop that would occur if a pipeline was to rupture, gas supply shutoff valves, and

requirements to obtain excavation permits that would reduce the likelihood that the pipeline would be damaged by excavation equipment.

Ignition does not occur in all cases where natural gas has been released; however, when it has, the resulting flames varied from 100 ft (30 m) to 1,000 ft (300 m) in height, depending on the size of the break and the pressures at the time of the incident. Pipeline valves are often 10 miles (16 km) or more apart. In the confusion caused by a severe fire, it has taken up to 5 hours to find and close the valves (Factory Mutual 1990). However, this observation is applicable to long stretches of pipe through remote areas and is not generally applicable to a relatively short stretch of pipeline in an industrial area.

The final hazard from natural gas to be addressed here is an explosion. Leakage from the natural gas pipeline could lead to an explosion under certain conditions. However, although natural gas fires have occurred, outdoor vapor cloud explosions have not occurred with natural gas (Factory Mutual 1990). Therefore, they will not be addressed further in this assessment.

Instances of natural gas pipeline explosions and fires scenarios have occurred in which the leaked gas has been directly released to the environment, such as from an excavation incident in which the buried pipeline has been uncovered; directly released into a building, such as from a failed gas line in a building; or indirectly released into a building. The former two cases are addressed in this assessment. The latter case, in which natural gas is indirectly released into a building, occurs when the leaking gas finds other underground utilities or services that connect to a building and the gas follows these and enters the building. Once inside the building, the natural gas concentration could build to its lower flammable limit and ignite if an ignition source is present, resulting in damage to a building located at a distance from the actual leak. Ventilated buildings are not particularly susceptible to such a scenario because the natural gas would be continuously removed from the buildings by the exhaust fans. Special precautions may be needed to mitigate this hazard in non-ventilated nuclear facilities.

2.2 STEAM BOILERS

The hazards of boiler furnaces are documented in several references. Examples of these hazards include:

- Explosion and fire are the most serious hazards in boiler furnaces and their associated pipes, ducts, and fans. One type of explosion may occur when an ignition source contacts a combustible mixture of fuel and air. When a combustible mixture has accumulated in a large, confined space of the equipment, a damaging explosion can occur. Such accumulations may result from an equipment malfunction or an operator error associated with an inadequate or improper purge or incorrect operation of burner

equipment. Because even a minute ignition source may initiate a substantial explosion and ignition sources may abound in a furnace (for example, static electricity, hot surfaces, igniters), safe operation must emphasize avoiding creation of a large combustible mixture (NFPA 1997).

- A second type of explosion is one in which pressure builds within the vessel and eventually causes its failure. The boilers to be installed in the 300 Area are equipped with pressure relief devices that are intended to protect the vessel from overpressurization failures. If these devices fail, catastrophic failure of the vessel could occur and the subsequent vessel explosion could cause severe damage to surrounding equipment and facilities. Damage would be caused by a blast wave or missiles. This type of boiler explosion is addressed in these siting calculations because it would generate significantly larger blast energies than a natural gas explosion in the boiler. In addition, a natural gas explosion in the annex building is also addressed that would involve significantly larger quantities of natural gas and thus significantly larger blast energies than a natural gas explosion in the boiler.
- Hazards in gas-fired systems start with gas leaks and the development of flammable mixtures within the boiler or ductwork. Potentially hazardous accumulation may also develop within other building areas, particularly where gas piping is routed through spaces that are not adequately ventilated. Unlike oil, gas leaks are not visible and plant noise may prevent the leak from being heard. Odorants may or may not be present at sufficient concentration to be detected by the nose (NFPA 1997).
- Resistance heating and arcing in the various electrical components are the primary fire sources in the boiler rooms, followed by burner maladjustment or linkage slipping that does not trip safety controls, and wear or breakage of fuel piping allowing fuel contact with hot surfaces (Christensen 1997).
- Damage from boiler explosions may be caused by the blast wave and by missile fragments and shrapnel ejected from the boiler.
- Boiler-furnace fuel explosions may occur during lighting-off, while firing, or after shutdown, from ignition of dangerous accumulations of unburned fuel or of flammable products of incomplete combustion (Factory Mutual 1992). More explosions occur during lighting-off than during firing. The predominant deficiencies in boiler explosions may be grouped in three broad categories: 1) human element failures, 2) incomplete safety controls or improper equipment arrangement, and 3) malfunction of equipment.

2.3 HAZARD SUMMARY

The predominant hazards associated with boilers and natural gas pipelines were concluded to be explosions (including blast effects and missile damage) and various fires (including a flame jet from a ruptured pipeline and severe fire in the boiler annex building). Explosions may be caused by overpressurization of the boiler or ignition of a confined natural gas fuel/air mixture. Fires are also well-recognized hazards associated with natural gas pipelines and facilities containing natural gas-powered systems. Therefore, the siting analyses for the 300 Area natural gas pipeline distribution system and the associated steam boilers and annex buildings will be based on estimating the minimum separation distances necessary to eliminate or reduce the risks of these potential accidents to negligible levels at nearby nuclear facilities.

3.0 SITING EVALUATION METHODOLOGY

The methodology employed here used standard engineering textbooks and handbooks to supply the equations and data used in the analysis. Four potential accident scenarios were quantitatively evaluated: 1) shock overpressure from a boiler explosion and its effect on the exterior walls of nearby buildings; 2) detonation of a stoichiometric quantity of natural gas that was assumed to leak into and be confined within the boiler annex buildings and its effect on the exterior walls of nearby buildings; 3) exposure of nearby buildings to fires in the boiler annex buildings, and 4) exposure of nearby buildings to a flame jet resulting from a ruptured natural gas pipeline. Minimum separation distances are calculated that would prevent these potential accident scenarios from damaging nearby nuclear facilities or affecting the radiological inventories contained therein. The methodologies used to calculate the separation distances between the nuclear facilities and the boiler annex buildings for these four scenarios are described in Sections 3.1 to 3.4.

A scenario involving missiles and fragments generated by a boiler explosion was considered. It was concluded that it is likely that shrapnel would penetrate the steel wall panels of most 300 Area facilities. Placement of the boilers farther away from the buildings would provide little additional protection, according to the methods used to determine breach thicknesses as a function of initial missile velocity and fragment size. Protection from missiles would be provided by the type, form, quantity, and location of radioactive and hazardous materials in the exposed nuclear facilities. Further information on missile damage potential in the 300 Area nuclear facilities is presented in Chapter 4.

3.1 SHOCK OVERPRESSURE FROM BOILER EXPLOSION

A methodology described by Baker et al. (1983) was used to examine the effects of boiler explosions on nearby buildings in the 300 Area. This methodology was used to determine shock overpressure as a function of distance from an exploding, gas-filled vessel. Key assumptions used in the analysis of shock overpressure are:

- In calculating the shock overpressure on the target buildings, it was assumed that there are no intervening structures between the boiler and the buildings at risk from the explosion. In reality, some of the energy generated by the explosion would be absorbed during destruction of the boiler annex building and a less-energetic shock wave would strike the target building than was calculated. Absorption of shock energy by the boiler annex buildings was accounted for by using the high end of the range of failure pressures for the target buildings.

- Boiler dimensions were taken from vendor literature and the facility design packages (Christensen 1997).
- All safety features of the boiler relative to overpressurization were assumed to fail.
- Boiler failure was assumed to be instantaneous. A more likely failure mode would be a small split or orifice-type opening that reduces pressure gradually.
- The boiler was assumed to burst at a theoretical hoop stress adjusted to account for reductions in strength of steel at high temperatures. For the theoretical peak pressure calculation, the vessel was assumed to be full of water and saturated steam at the start of the overpressurization event. An initial burst pressure was calculated using the room temperature strength of the carbon steel the vessel is fabricated from. Steam tables were then used to determine the temperature of saturated steam at the theoretical failure pressure of the vessel. An adjusted burst pressure was then calculated using the steel strength at the saturated steam temperature determined above. Only one iteration of this calculation cycle was performed because additional cycles would not change the calculated burst pressure significantly. The reductions in saturated steam (and assumed vessel) temperatures from the 1st to 2nd calculation cycles and beyond are small enough that the changes in steel strength are insensitive (or not detectable) to small differences in temperature.
- The mass of the boiler was neglected in the overpressure calculations. All of the blast energy was applied to shock-wave generation. In reality, a substantial fraction of the blast energy would be applied to acceleration of missiles and fragments, thus reducing the energy applied to shock-wave generation and reducing the peak overpressures.
- The entire volume of the water-steam space was assumed to be filled with saturated steam at the time of the explosion. This maximizes the amount of compressed vapor involved and thus the total energy released in the explosion.

The possibility of a Boiling Liquid Expanding Vapor Explosion (BLEVE) was considered and dismissed for the following reasons. In a BLEVE-like incident, the vessel would contain water and steam at well above the normal atmospheric boiling point. If quickly depressurized (such as via catastrophic failure of the vessel), a large fraction of water would flash to steam, forming a large volume of vapor. The change in volume from water to steam could potentially blow the vessel apart. The most spectacular BLEVEs occur when the released vapor is flammable. If ignited, the vapor cloud could form a large rising fireball, vapor cloud explosion, or pool fire involving residual liquid, depending upon the length of time ignition of the vapor is delayed. The boilers to be located in the 300 Area do not contain a pressurized, flammable

liquid so ignition of the vapor generated by flash evaporation would not occur. The blast wave generated by the expanding vapor has been shown to produce lower pressures than the equivalent ideal blast-wave pressures (SFPE/NFPA 1995), calculated by the method discussed above. The physical explanation for this is that either the evaporation/expansion process takes too long to generate a strong blast wave or a large fraction of the expansion energy is applied to ejection of missile fragments from the vessel. In either event, the damage from a BLEVE-like incident without a fireball would be less severe than the damage from an exploding, steam-filled vessel.

The boiler explosion methodology employed here determines peak overpressure as a function of distance from the boiler. These values were then compared to the magnitude of overpressure that the 300 Area nuclear facilities can withstand. Failure thresholds for external overpressure events for the 300 Area facilities are uncertain. Some general rules of thumb, consistently used throughout various handbooks and standard references, were used to determine the effects of overpressure on the walls of nearby buildings (Zabetakis 1965; SFPE/NFPA 1995; FEMA 1989). The failure pressure condition relevant to this analysis is that for steel-framed buildings with steel panel walls. For such construction, overpressurization failures occur in the range from approximately 1 to 2 psig (connection failure followed by buckling). The high end of the range, 2 psig, was used in this assessment because some of the shock energy would be absorbed by the steel-construction boiler annex buildings, thus reducing the peak overpressure on the nuclear facilities. This was not accounted for in the overpressure calculations. Therefore, unless the overpressure is much greater than 2 psig, damage to the building would be limited to skin failure, and the consequences of any radioactive or hazardous chemical release would be negligible.

3.2 NATURAL GAS EXPLOSION

The second scenario evaluated here involves leakage of natural gas into the boiler annex buildings and subsequent ignition of the flammable natural gas/air mixture. Two methodologies were used to calculate the peak overpressure from a natural gas explosion in the annex building. The primary methodology is described in Section 3.2.1, and the alternative methodology, which was employed to check the results of the primary methodology, is described in Section 3.2.2.

3.2.1 Primary Natural Gas Explosion Methodology

The primary methodology for estimating the peak overpressure from an explosion in the boiler annex building was taken from SFPE/NFPA (1995). A leak in the natural gas system in the annex building was assumed to occur, resulting in the annex filling with natural gas to its stoichiometric concentration in air (9.48 vol% for methane/air mixtures; Zabetakis 1965). The blast wave energy, E , was calculated using an equation provided by SFPE/NFPA (1995), shown below:

$$E = \alpha \Delta H_c m_f$$

where: α = Yield (unitless)
 ΔH_c = Theoretical heat of combustion, kJ/kg
 m_f = mass of methane in building, kg

The explosive yield, α , was indicated in SFPE/NFPA (1995) to be in the range from 0.01 to 0.05. However, based on recommendations given in FEMA (1989), the value of α used here will be 0.03. The heat of combustion of methane used in the calculations was 50 kJ/g (SFPE/NFPA 1995). The mass of the flammable vapor was calculated by multiplying the approximate volume of each annex building by the stoichiometric composition for methane/air mixtures (0.0948) and the density of methane at standard temperature and pressure (0.5547 g/L; CRC 1981).

The next step is to calculate the TNT-equivalent weight of the blast energy and then use a standard formula to determine the scaled distance at which the blast energy is equal to the building failure pressure (assumed to be 2 psig; see Section 3.1). The equation for converting the blast energy to TNT-equivalent weight, W_{TNT} , is:

$$W_{TNT} = \frac{E}{4500} \text{ kg}$$

The equation used to calculate the separation distance required to reduce the pressure from the blast wave to less than 2 psig, $D_{\Delta P=2 \text{ psig}}$, is:

$$D_{\Delta P=2 \text{ psig}} = D_{\text{scaled}} W_{TNT}^{1/3}$$

The scaled distance, D_{scaled} , for a peak overpressure of 2 psig is 25 ft/lb^{1/3} (SFPE/NFPA 1995).

The key assumptions related to this methodology are as follows:

- The entire internal volume of the annex building was used to calculate the quantities of natural gas used in the energy calculations. No volume reductions were taken for space occupied by the boiler, control system, or other internal features of the annex building.

- The effects of the methane explosion were assumed to be represented by an ideal (point source) blast wave correlation.
- The energy released was calculated based on the heat of combustion of methane.
- The stoichiometric composition of methane in air was used in the energy release calculations.
- A range of values for the explosive yield was used to bracket the blast-wave energies from the methane explosion. The range of values, from 1 to 5%, represents conservative explosive yields (SFPE/NFPA 1995).

3.2.2 Alternative Natural Gas Explosion Methodology

As was done in Section 3.2.1, natural gas was assumed to accumulate in the boiler annex building until the concentration reaches the stoichiometric composition of methane in air (9.48 vol%; Zabetakis 1965). The volume of methane in the building was calculated assuming the dimensions of the largest annex building (29.5 ft x 37.5 ft x 18 ft for the 324 Building annex). Ignition of the vapor cloud was then assumed to occur. The total energy released was calculated using the volumetric energy density of a methane and oxygen mixture taken from Kogarko et al. (1966). Kogarko provides a formula, shown below, for calculating overpressure as a function of distance (R) from the center of the vapor cloud and the energy released (E).

$$\Delta P = 0.6 \times 10^{-3} \frac{E^{1/3}}{R} + 1.4 \times 10^{-2} \frac{E^{2/3}}{R^2} + 2.5 \times 10^{-3} \frac{E}{R^3}$$

This formula was solved for a range of values for R (10, 30, and 50 m), and a plot of overpressure as a function of distance was developed. The plot was used to determine the separation distance necessary to reduce the shock overpressure to levels that the outer walls of the 300 Area nuclear facilities can withstand (i.e., 2 psig).

The key assumptions used in these methane gas detonation calculations are as follows:

- The methane explosion was assumed to be represented by spherical detonation waves in fuel-air mixtures.
- The stoichiometric composition of methane in air was used in the energy-release calculations.

- The energy released from the explosion was calculated using the volumetric energy density of a fuel-oxygen mixture, which is about a factor of 4 greater than a fuel-air mixture, for conservatism.
- The volume of the largest annex building was used in the energy-release calculation; this yields the largest minimum separation distance and provides conservative results for smaller annex buildings.

3.3 FIRE EXPOSURE

This section describes the methodology used to estimate minimum separation distances from fires that could occur in the boiler annex buildings.

The hazards of exposure to a structure from adjacent exposing fires, as discussed in NFPA 80A (1996), "Recommended Practice for Protection of Buildings from Exterior Fire Exposures," were reviewed and the practices applied to the boiler annex buildings and potential fire exposures to adjacent facilities in the 300 Area. There are basically two types of fire exposure to be considered: exposure to radiation (that is, radiant energy) and exposure to flames. Exposure to radiation can result from: 1) radiant energy passing through windows or other openings in the facade of a burning building; 2) flames issuing from windows of a burning building; or 3) flames issuing from the burning facade of a building. Exposure to flames can result from flames issuing from the roof or top of a burning building in cases where the exposed building is higher than the burning building.

The spread of fire from one building to another across a vacant space may be due to convective or radiative heat transfer or flying brands. The hazard created by large flying brands was not considered in the recommendations of NFPA 80A (Table 2-3). Convective heat transfer is also disregarded where the source of hazard is associated with openings in the facade of the exposing building, because ignition by radiation can occur at distances substantially greater than those at which flame impingement and convective heat transfer will usually constitute a hazard. Ignition as a result of radiative heat transfer is thus the event that the recommendations of NFPA 80A are intended to address.

Where a building is exposed by a building of greater or equal height, only the thermal radiation from walls or wall openings of the exposing building will be considered. Then separation distances must be determined only so that pilot ignition of the exposed building or its contents is unlikely, assuming no means of protection are installed in connection with either building.

The boiler annexes to be built in the 300 Area are of one-story construction (approximately 16 to 18 ft in height) and the exposed facilities (that is, the 300 Area nuclear facilities within the vicinity of a boiler annex) are of one- or two-story construction (Christensen 1997). When a building is exposed by a building of lesser height, the horizontal separation distance indicated in Table 2-4 of NFPA 80A (1996) should also be considered when separation distances derived from the radiant heat basis (Table 2-3 of NFPA 80A) are less than the distances indicated in Table 2-3. In the event of a moderate wind, flames can be expected to extend horizontally for as great a distance as they might otherwise extend upwards. Thus, protection may be called for if the separation between two buildings is no more than the height to which flames might otherwise extend, as noted in Table A-2-4 of NFPA 80A.

To determine the minimum separation distances necessary, the following parameters were considered: width of the exposing fire, height of the exposing fire, percentage of openings in exposing wall area (that is, the percentage of the exposing wall made up of doors, windows, or other openings within the assumed height and width of the exposing fire), and the three levels of exposure severity (that is, light, moderate, or severe, which are influenced by the average combustible load per unit of floor area and the characteristics and average flame spread ratings of the interior wall and ceiling finishes).

Table 2-3 of NFPA 80A (1996) determines the separation distance necessary between two buildings so that pilot ignition of the exposed building or its contents is unlikely, assuming no means of protection are installed in connection with either building. To determine distances, the lesser dimension, width or height, should be multiplied by the guide number and 5 ft added to the result. The additional 5 ft is added to the computed values of separation distance, partly to account for the horizontal projection for flames from windows and partly to guard against the risk of ignition by direct flame impingement where small separations are involved. Table 2-3 is based on a maximum tolerable level of incident radiation at the facade of an unprotected exposed building of 12.5 kW/m^2 or 66 Btu/sq ft/min. This assumes that the facade is constructed of typical cellulosic materials. Where other combustible materials are used and incident radiation is indicated by appropriate tests to be less than 12.5 kW/m^2 or where incident radiation is indicated to be greater than 12.5 kW/m^2 and where there are no openings in the facade of the exposed building, the percentage openings should be adjusted by multiplying by the ratio of 12.5 kW/m^2 /incident radiation. Suggested separation distances contemplate fire department response.

3.4 FLAME JET FROM NATURAL GAS PIPELINE RUPTURE

The following section describes the methodology for establishing minimum separation distances from a natural gas pipeline failure that results in a flame jet. The scenario is initiated by a pipeline rupture from an excavation incident, seismic event, or other scenario that could

lead to a breach of the pressurized natural gas pipeline. For conservatism, the broken pipe was assumed to be 6 in. diameter, the largest pipe size in the 300 Area. The pipe rupture leads to a pressurized release of natural gas, which is assumed to ignite, causing a flame jet to be emitted from the broken pipe. Because the pipeline is buried approximately 2 ft underground and the nearest nuclear facilities are more than 50 ft away from the nearest 6-in. pipeline, the geometry is such that the flame jet would not directly impinge on a nuclear facility. However, the facilities would be exposed to substantial thermal energy radiated from the flame jet. The radiated energy would heat the outer skin of the nuclear facilities.

A second set of calculations was performed to determine the heat flux from a broken 1-in. pipeline, as the 1-in. pipes will be closer to the nuclear facilities than the 6-in. pipes.

The approach to calculating minimum separation distances between the natural gas pipeline and the nuclear facilities is as follows. First, the thermal energy represented by the flame jet was calculated. This was done by first implementing the ARCHIE computer code (FEMA 1989) to calculate the quantity of natural gas released from a broken pipeline (model for discharges from pressurized containers) and the duration of the discharge from the pipe. The pipe rupture was assumed to occur at 50 psig and empty a 5000 ft length of 6-in. pipe before the flow of natural gas is halted. The calculated mass release rate was used to calculate the energy release rate from the jet flame, as follows:

$$Q_{rel} = m_{rel} \Delta H_c$$

where Q_{rel} = Energy release rate, kW
 m_{rel} = Mass release rate, kg/sec
 ΔH_c = Theoretical heat of combustion, kJ/kg

Then, using the following equation taken from SFPE/NFPA (1995), the incident heat flux on a vertical steel panel was calculated as a function of distance from the jet flame.

$$q = F Q_{rel} / 4\pi D^2$$

where q = incident heat flux, kW/m²
 F = Fraction of combustion energy resulting in radiation
 D = Distance from jet flame center, m

A vertical flame jet was assumed to simplify the calculations. The effects of crosswinds on the flame jet were ignored.

4.0 RESULTS

The results of this siting evaluation are presented in this section. Boiler explosions are addressed in Section 4.1, natural gas explosions in the boiler annex buildings are discussed in Section 4.2. Section 4.3 addresses annex building fire exposures, and Section 4.4 addresses flame jets from natural gas pipeline rupture events. Minimum separation distances are quantified for each of these potential accident scenarios. Missile generation is qualitatively examined in Section 4.5.

4.1 BOILER EXPLOSION

The boiler overpressurization calculations are provided in Appendix A. Separate calculations were performed for four boiler sizes to determine minimum separation distances for each 300 Area facility. The pressure vessel parameters, taken from vendor information, that were used in the calculations are summarized in Table 4.1. The results of the boiler explosion calculations, taken from Appendix A, were plotted on a scale of overpressure (psi) as a function of distance from the blast (m). These plots are shown in Figures 4.1 through 4.4 for the different sizes of boilers.

As shown in Figure 4.1, the minimum separation distance from the 125 hp, 150 psi boilers is about 19 m (62 ft). The separation distance would be measured from the boiler to the nearest point of the potentially affected building. This assumes that the target buildings are steel wall panel construction with a failure pressure of about 2 psig.

Minimum separation distances were calculated for three additional boiler sizes. Figure 4.2 shows overpressure as a function of separation distance for a low-pressure (15 psig rated pressure), 125 hp boiler; Figure 4.3 shows the same curve for a 150 psi, 300 hp boiler; and Figure 4.4 is for a 200 hp, 15 psi boiler. The minimum separation distances from these three boiler sizes were determined to be 18 m (59 ft) from the 125 hp, 15 psi boiler; 21 m (70 ft) from the 200 hp, 15 psi boiler; and 25 m (82 ft) from the 300 hp, 150 psi boiler. Much of the difference between separation distances arises from vessel design differences (primarily shell thickness) that lead to differences in the theoretical burst pressures and differences in the volumes of steam and water in the vessels.

Table 4.1. Pressure Vessel Data Used in Boiler Explosion Calculations

Parameter	Value (Taken From Vendor Information)			
Boiler hp	300	125	200	125
Design pressure, psig	150	150	15	15
Test pressure, psig	300	300	100	100
Vessel inside diameter, in.	78	60	60	60
Vessel length, in.	171	125	125	125
Shell thickness, in.	0.5	0.375	0.3125	0.3125

Figure 4.1. Overpressure as a Function of Distance for a Boiler Explosion Involving a 150 psi, 125 hp Boiler

Figure 4.2. Overpressure as a Function of Distance for a Boiler Explosion Involving a 15 psi, 125 hp Boiler

Figure 4.3. Overpressure as a Function of Distance for a Boiler Explosion Involving a 150 psi, 300 hp Boiler

Figure 4.4. Overpressure as a Function of Distance for a Boiler Explosion Involving a 15 psi, 200 hp Boiler

4.2 NATURAL GAS EXPLOSION

Shock overpressure from the postulated natural gas explosion as a function of the separation distance is plotted in Figure 4.5. The calculations that support the values in this figure are shown in Appendix B. Using the same building failure thresholds used for the boiler explosion (2 psig), it can be seen that the minimum separation distance is about 21 m (70 ft) between the 324 Building boiler annex and nearby nuclear facilities. In this scenario, the minimum separation distance is measured from the center of the vapor cloud. This was assumed to be the center of the annex building, so the distance from the center of the boiler annex to the potentially affected building must be greater than 21 m (70 ft). Based on the 3% yield case recommended by FEMA (1989), the minimum separation distances for the other boiler annex buildings are: 18 m (59 ft) from the 325 Building annex, 17 m (57 ft) from the 327 Building annex, 12 m (40 ft) from the 328 Building annex, 17 m (57 ft) from the 382B Building annex, and 16 m (53 ft) from the 3720 Building annex. The 327 and 382B annex buildings are the same size so the minimum separation distances are the same.

Note that the two methodologies used to determine the separation distances are in reasonable agreement with each other. The calculated separation distance from the 324

Figure 4.5. Overpressure as a Function of Separation Distance from Natural Gas Explosions in Boiler Annex Buildings

Building annex was approximately 20 m (66 ft) using the secondary methodology. The primary methodology calculated a separation distance of 21 m (69 ft). The difference between these values is well within the uncertainty in the calculations.

4.3 FIRE EXPOSURE

The minimum separation distances to protect against damaging nearby nuclear facilities by severe fires in the boiler annex buildings are summarized in Table 4.2. The fire exposure calculations are presented in Appendix C. In comparing these results to the minimum separation distances for boiler explosions and natural gas explosions, the separation distances based on fire exposure calculations are less limiting than those for the boiler explosions and natural gas explosions.

4.4 GAS PIPELINE RUPTURE

The natural gas pipeline rupture and jet flame exposure calculations are presented in Appendix D. The incident heat flux on nearby buildings as a function of distance from the pipeline is plotted in Figure 4.6 for 6-in. and 1-in. diameter pipes. The minimum separation

Table 4.2. Minimum Separation Distances Derived from Fire Exposure Calculations

Nuclear Facility	Boiler Annex	Minimum Separation Distance, m (ft)
325	325	10 (32)
325	328	10 (32)
324, 308	324	10 (32)
327	327 and 382B	10 (32)
3712	3720	3.7 (12)
Bounding Assessment ^(a)	Assumes 50% openings, moderate severity class	12.2 (40)

(a) This calculation was performed to illustrate the bounding nature of the boiler and annex building explosion calculations performed previously.

Figure 4.6. Incident Heat Flux as a Function of Separation Distance from a Flame Jet Emitted from Broken 6-in. and 1-in. Natural Gas Pipelines

distances between the nuclear facilities and the natural gas distribution systems are based on maintaining the incident heat flux below 12.5 kW/m^2 , the same heat flux target used by the NFPA (1996) for determining separation distances for exterior fire exposures (see Section 4.3). Therefore, the minimum separation distance would be approximately 12.5 m (41 ft) from the 6-in. diameter pipeline to the nearest point on the exposed nuclear facility. The minimum separation distance is much less for the 1-in. pipe. However, to prevent direct flame impingement, it was determined in Appendix D that the minimum separation distance from the 1-in. pipeline is 7 m (21 ft) from the nearest nuclear facility.

4.5 MISSILE GENERATION

The explosion scenarios will produce missiles and shrapnel as well as the shock overpressure effects evaluated above. A review of the literature on missile generation and subsequent damage concluded that missile damage (i.e., penetration of the outer skin of the building) could not be precluded at distances less than 50 m (160 ft) from the annex building. The methods employed were observed to be relatively insensitive to separation distance between the location of the explosion and the potentially-affected building. Thus, a different approach is taken to demonstrate that the building inventories of radioactive and hazardous materials are adequately protected from the effects of missiles.

The locations of the inventories of radioactive and hazardous chemicals in the potentially-affected buildings were reviewed to determine if they would be in locations that could conceivably be affected by a missile. Any missiles would have to pass through the annex building walls and retain enough energy and velocity to penetrate the steel panel construction of the nuclear facilities and then penetrate interior walls. Therefore, missile damage would likely be limited to creation of holes in the outer skins of the buildings and damage to rooms adjacent to the outer walls. Radioactive and hazardous chemical materials located in rooms adjacent to the outer walls would potentially be affected, but impact on materials located in rooms not adjacent to the outer walls would not be expected. Taking into account the type, form, quantity, and location of radioactive and hazardous materials in the exposed nuclear facilities, highly dispersible forms of these materials would account for the most likely release following a missile strike. Significant quantities of highly dispersible materials would most likely be housed in hot cells, below-grade basins, glove boxes, and dry storage areas. Penetration of the massive concrete, steel, or lead glass components of hot cells by missiles is not considered to be a credible event.

The 324 and 308 Buildings are located approximately 50 m (160 ft) from the 324 boiler annex building and would likely not be affected by missile damage. The 324 Building contains several hot cells and a fissionable material storage vault which provide substantial protection for the radioactive materials stored therein. The 308 Building is a nonoperating facility that is in

the process of being reclassified from a Hazard Category 3 nuclear facility to a radiological facility. The current inventory in the building is protected by reinforced concrete walls (main part of building), concrete block walls with reinforced concrete pillars (first floor section of east and west walls), or reinforced concrete block (308 Annex). Radioactive materials are located in the center of the main building within gloveboxes that have been encased in plastic in preparation for removal from the building. Consequently, these buildings would provide adequate protection of their radioactive material inventories from missile damage.

The 325 Building is located approximately 23 m from the 325 boiler annex building and 26 m from the 328 Building boiler annex building. The 325 Building contains several hot cells, gloveboxes, and storage rooms for radioactive materials. The outer skin of the building is of steel panel construction. Highly-dispersible radioactive materials are located within high-density cast iron, magnetite concrete, and reinforced concrete hot cells enclosed within steel-framed, reinforced concrete structures. A fissionable material storage room is located on the opposite side of the 325 Building from its boiler annex building and is not within the line of sight of the 328 boiler annex building. Consequently, the radioactive materials located in the 325 Building were not considered to be vulnerable to missile damage from the nearby boiler annex buildings.

The nearest location of the 327 Building to the boilers in the 327 and 382B boiler annex buildings is about 22 m. The 327 Building contains fissile materials as well as materials that are highly-radioactive materials as a result of in-reactor irradiation. The building walls are of steel panel construction on welded steel framework. The first floor operating area is of reinforced concrete construction or steel decking with concrete, providing substantial protection from missiles. Radioactive materials are tested within shielded cells constructed of either high-density cast iron or lead-brick. Highly-radioactive materials are stored in below-grade water-filled pools or in a steel-lined, reinforced concrete dry storage facility also located below-grade. Therefore, the radioactive materials in the 327 Building were not considered to be vulnerable to missile damage.

The 303A, 303B, and 340 Buildings are well beyond 50 m from any of the boiler annex buildings. Damage to these buildings and their associated radioactive and hazardous material inventories from missiles ejected from a boiler annex building was not considered to be credible.

The 3712 Building has radioactive material stored adjacent to an outer wall. This facility could potentially be affected by a missile generated in the 3720 Building boiler annex. Safety documentation for the 3712 building (Benecke 1996) was reviewed to determine the type, form, and quantity of material that would be vulnerable to missile damage. The 3712 Building is used for storage of finished uranium fuel (unirradiated), billet, and scrap material. The uranium fuel is stored in wooden boxes, some of which are stacked adjacent to the outer wall that would be exposed to a missile generated by the boiler explosion. The uranium is all in solid form,

enriched to no higher than 1.25 wt% U-235, and the maximum quantity of uranium in the building is 1122 MTU. Thus, the radioactive material is not in a readily dispersible form. In addition, the low radiotoxicity of uranium contributes to the presumption that the material does not represent a high risk.

A severe fire accident at the 3712 Building was examined by Benecke (1996). The fire was conservatively assumed to occur for an 8-hr period with no mitigation (i.e., no fire suppression) and no barriers to the transport of material out of the building (e.g., HEPA filters, material deposition, confinement systems). It was determined that the consequences of such a fire would be within risk evaluation guidelines for radioactive and toxic material releases. This fire would cause significantly more damage to the uranium in the storage building than a missile would, because the effects of the missile would be more localized and would involve a much smaller quantity of uranium than would be affected by a severe fire. The consequence of the fire would then be significantly higher than the consequences of a missile scenario. Missile damage frequencies would not be greater than the frequency of the severe fire.

The 3716 and 303G Buildings are within 50 m (160 ft) of the 3720 boiler annex. The form and content of the radioactive materials within these buildings are similar to the 3712 Building and the consequences of missile damage would be similar.

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5.0 CONCLUSIONS

The minimum separation distances determined from postulated boiler and natural gas explosions and fires in the boiler annex buildings are as follows. Table 5.1 summarizes the following information in addition to identifying the boiler annex buildings and the potentially-exposed nuclear facilities.

- **Boiler explosion:** (1) 19 m (62 ft) from the 125 hp, 150 psi boiler to the nearest point on the potentially affected building; (2) 18 m (59 ft) from the 125 hp, 15 psi boiler; (3) 25 m (82 ft) from the 300 hp, 150 psi boiler; and (4) 21 m (70 ft) from the 200 hp, 15 psi boiler. These distances are measured from the center of the pressure vessel to the nearest point on the potentially-affected nuclear facility.
- **Natural gas explosion in boiler annex building:** Minimum separation distances are functions of the sizes of the annex buildings. They are: 21 m (70 ft) from the 324 Building boiler annex; 18 m (59 ft) from the 325 Building annex; 17 m (57 ft) from the 327 Building annex; 12 m (40 ft) from the 328 Building annex; 17 m (57 ft) from the 382B Building annex; and 16 m (53 ft) from the 3720 Building annex.
- **Boiler annex building fire:** Minimum separation distances were calculated in accordance with NFPA recommendations. Minimum separation distances ranged from 3 m (10 ft) to 4.3 m (14 ft) for radiant energy exposure, depending upon the size of the annex building. However, the minimum separation distance from two-story nuclear facilities was determined to be 10 m (32 ft), which becomes the limiting minimum separation distance for all but the 3720 boiler annex building. The minimum separation distance from the 3720 boiler annex building was determined to be 3.7 m (12 ft) from the 3712 Building.
- **Jet flame from ruptured natural gas pipeline:** A 12.5 m (41 ft) minimum separation distance should be provided between 6-in diameter natural gas pipelines and the nuclear facilities to maintain the incident heat flux below that used in fire exposure calculations (i.e., 12.5 kW/m²). A minimum separation distance of 7 m (21 ft) was calculated for 1-in. diameter pipelines, based on preventing direct flame impingement on the exposed nuclear facilities. For the 1-in. pipe sections, the separation distance required to prevent direct flame impingement was more limiting than the distance required to ensure the incident heat flux is below 12.5 kW/m².

TABLE 5.1. Exposed Nuclear Facilities and Minimum Separation Distances from Boiler Annex Buildings

Exposed Nuclear Facility	Minimum Separation Distance, m (ft)					
	Boiler Annex	Boiler Explosion ^(a)	Natural Gas Detonation in Annex ^(a)	Fire Exposure ^(a)	Flame Jet from Pipeline Rupture ^(b)	
					6-in. Pipe	1-in. Pipe
324	324	25 (82)	21 (70)	10 (32)	12.5 (41)	7 (21)
325	325	19 (62)	18 (59)	10 (32)	12.5 (41)	7 (21)
	328	18 (59)	12 (40)	10 (32)		
327	327	21 (69)	17 (57)	10 (32)	12.5 (41)	7 (21)
	382B	21 (69)	17 (57)	10 (32)		
308	324	25 (82)	21 (70)	10 (32)	12.5 (41)	7 (21)
3712	3720	18 (59)	16 (53)	3.7 (12)	12.5 (41)	7 (21)

- (a) Separation distances were calculated from the boiler (for boiler explosion), mid-point of annex building (for gas detonation), and annex building wall (for annex building fire exposure) to nearest point on nearby nuclear facilities.
- (b) Separation distances were calculated from the natural gas pipeline to the nearest point on nearby nuclear facilities.

Three additional accident scenarios were considered but not used as the basis for calculating minimum separation distances. These scenarios and the rationale for eliminating them from the calculations are as follows:

- Missile generation by the postulated explosions was considered. It was determined that missile penetration and damage is not sensitive to the separation distance between the boiler annex and the affected buildings. An examination was made of the types, forms, quantities, and locations within the nuclear facilities of radioactive and hazardous chemical materials that could be affected by missiles. It was concluded that most of the inventories are not located in rooms adjacent to the external skins of the buildings. For these buildings, which represent all but the 3712 Building, no releases of radioactive or hazardous materials would occur as a result of the postulated missile damage. For the 3712 finished uranium fuel storage building, it was shown that missile damage would be limited because of the nondispersible form, low radiotoxicity, and relatively small inventory of the uranium fuel.

- It was also concluded that minimum separation distances would not be calculated based on the overpressure effects of an outdoor natural gas vapor cloud explosion. This was based on the observation that an unconfined vapor cloud explosion has not occurred in the past, even though there is substantial experience and operating history with natural gas distribution systems.
- The possibility of a boiling liquid expanding vapor explosion (BLEVE) was considered and dismissed because: 1) although rupture of a liquid-filled vessel would involve more energy than a gas-filled vessel, the blast effects and subsequent damage are less severe for liquid-filled than gas-filled vessels; and 2) the 300 Area boilers are not filled with a liquid that would form a flammable vapor cloud so a BLEVE-like incident involving a 300 Area boiler would not generate a fireball; damage from a BLEVE-like incident would include only blast effects

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APPENDIX A

CALCULATION SHEETS FOR
SHOCK OVERPRESSURE FROM BOILER EXPLOSION

CASE 1: 125 hp boiler, 150 psi rating

1. Calculate theoretical burst pressure, assuming vessel filled with saturated steam and water.

Boiler DATA (From cleaver-Brooks pressure vessel DATA sheet)

- INSIDE DIAMETER: 60 IN.
- Length: 125 IN.
- wall thickness: $\frac{3}{8}$ IN.
- MATERIAL ASSUMED to be CARBON STEEL

(A) Halverson (1986) gives following formula for calculating maximum hoop stress

$$\sigma = PD / 2t$$

T = ultimate tensile strength, psi

P = Burst pressure, psi

 t_2 wall thickness, in.

$D =$ vessel diameter, in.

Rearranging and solving for P

$$P = \sigma_2 t / D$$

For $G = 65,000$ psi (Halverson 1986, p. 11)

$$D = 60 \text{ in}$$
$$t = 0.375 \text{ s.}$$

$$P = (45,000 \text{ psi})(2)(0.375)/60$$

= 812 psig (827 psia) (Longitudinal split in a seamless vessel).

(B) Adjust burst pressure to account for reduction in steel strength at high temperature.

Using STEAM TABLES, temperature of saturated steam at 82.7 psia is 522 F. Assuming the vessel reaches this temperature, steel strength is reduced by approx. 26%.

$$\begin{aligned} T_{UTS} (522 F) &\approx 0.74 (T_{UTS} \text{ at } 80 F) \\ &\approx 0.74 (65,000) = 48,000 \text{ psi} \end{aligned}$$

Recalculate max. hoop stress

$$P = (48,000 \text{ psi})(2)(0.375 \text{ in.}) / 60 \text{ in.}$$

$$= 600 \text{ psi} (615 \text{ psia})$$

2. Shock wave calculations

The following equations for a bursting sphere were taken from Baker (1983), pp. 145-153 and 205-206

- (A) Determine specific curve in Figure 2-15 to be used. Curve relates P_s (shock pressure) to $\bar{R}$ (energy-scaled radius of a bursting sphere).

- (1) Solve for $\bar{R}$

$$\bar{R} = r P_0^{1/3} / E^{1/3}$$

where r = distance to point of interest, m
 P_0 = Atmospheric pressure, $1.013 \text{E}+5 \text{ Pa}$
 E = Energy of burst, N-m

Setting r = initial radius of an equivalent bursting sphere of steam/water mixture.

$$\text{Total water + steam volume} = 3.33 \text{ m}^3$$

$$V_{\text{sphere}} = \frac{4}{3} \pi r^3 ; \quad r = \left(\frac{3V}{4\pi} \right)^{1/3}$$

$$= 0.93 \text{ m}$$

$$E = \left(\frac{P_1 - P_0}{\gamma - 1} \right) V$$

P_0 = Atmospheric pressure
 P_1 = Burst pressure
 γ = ratio of specific heats;
 use 1.4

$$P_1 = 615 \text{ psia} = 4.24 \text{E}+6 \text{ Pa}$$

$$E = \left(\frac{4.24 \text{E}+6 - 1.013 \text{E}+5}{1.4 - 1} \right) 3.33 \text{ m}^3$$

$$= 3.45 \text{E}+7 \text{ N-m}$$

* See pages 14 to 17 for calculation of steam, water volumes.

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National® Brand

$$= (0.93 \text{ m})(1.013 \times 10^5 \text{ Pa})^{1/3} / (3.45 \times 10^7 \text{ N}\cdot\text{m})^{1/3}$$

$$= 0.133$$

$$\frac{P_1}{P_0} = \frac{615 \text{ psia}}{14.7 \text{ psia}} = 41.8$$

Kinsler and Frey, p. 117, gives the following equation:

$$a = \sqrt{rT}$$

r = constant, depends on gas involved
 T = temperature

$$-a_0 = (\gamma_{\text{ex}} r_{\text{ex}} T)^{1/2}$$

$$\gamma_{air} = 1.4 \quad c_{air} = 53.34 \frac{\text{ft-lbf}}{\text{lbm R}} \quad (\text{Van Wylen, Table A.8})$$

$$a_0 = \sqrt{(1.4)(1.329)(530 R)}^{1/2}$$

$530^{\circ}\text{R} = \text{Room temp.}$
assumed to be 72°F

$$= 199$$

$$a_1 = (x_{\text{steam}} r_{\text{steam}} T)^{1/2}$$

$$= \sqrt{(1.329)(85.76)(950 R)}^{\frac{1}{2}} \quad \rho_{\text{steam}} = 85.76 \frac{\text{lbm}}{\text{ft}^3}$$

$$= 329$$

$T_2 = 949^\circ\text{R}$ (saturated steam temperature at 615 psi.)

$$-\left(\frac{a_1}{q_0}\right)^2 = \left(\frac{329}{199}\right)^2 = 2.7$$

From Fig 2-15 (Baker), when $\frac{P_1}{P_0} = 4.2$ and $\left(\frac{a_1}{a_0}\right)^2 = 2.7$,

$$\bar{P}_{50} = 6 \text{ psi}$$

(3) Lookup in Fig 2-15 (Baker); when $p = 6$ psi and $R = 0.13$, the point falls on the 6th curve from the top of the page.

(C) Solve for P given values of R

$$\begin{aligned} (1) \bar{R} &= r P_0^{1/3} / E^{1/3} \\ &= r (1.013E+5)^{1/3} / 3.45E+7^{1/3} \\ &= r (0.14) \end{aligned}$$

$$(2) \bar{P}_s = (P_s - P_0) / P_0 = \text{scaled, side-on overpressure}$$

P_s = pressure at distance, r

P_0 = Atmospheric pressure

$$\text{so } \bar{P}_s(P_0) = P_s - P_0 = \text{overpressure (Baker, p.204)}$$

Using Fig 2-15 (BAKER), 6th curve from top.

r, m	$\bar{R} = r(0.14)$	$\bar{P}_s$ (Fig 2-15)	$(\bar{P}_s \cdot P_0)$ overpressure
10	1.4	0.26	3.8 psi
30	4.2	0.078	1.15
50	7.0	0.04	0.59

For $\bar{R} > 3$, use the following formula to calculate $\bar{P}_s$; based on extrapolation of curves in Fig 2-15.

$$\log \bar{P}_s = -1.3 \log \bar{R} - 0.3$$

$$\bar{P}_s = 10^{(-1.3 \log \bar{R} - 0.3)}$$

$$\begin{aligned} \text{For } \bar{R} = 4.2, \bar{P}_s &= 10^{(-1.3 \log 4.2 - 0.3)} \\ &= 10^{(-1.11)} = 0.078 \end{aligned}$$

$$\begin{aligned} \bar{R} = 7.0, \bar{P}_s &= 10^{(-1.3 \log 7 - 0.3)} \\ &= 0.04 \end{aligned}$$

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Approx. overpressure At Failure (connection, buckling) is in the range 1-2 psi (several sources including NFPA/SFPE Fire Protection Engineering handbook on p. 3-327, FEMA/DOT/EPA 1989, p. 5-5).

overpressure vs. distance values (above) plotted to identify distance at which overpressure is below building failure threshold.

High end of range (2 psi) used as building failure threshold. The over-pressure shock wave would be substantially attenuated via energy required to destroy boiler annex building. This would reduce shock on side of nuclear facility. Also would need to fail inner building walls and in some cases hot cell walls before radioactive and hazardous material inventories.

National® Brand

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$$(1) \bar{R} = r p_0^{1/3} / E^{1/3} = r \left(\frac{1.013 \times 10^5}{8.08 \times 10^{17}} \right)^{1/3}$$

$$= r(0.11)$$

(2) $\bar{P}_s(P_0) = \text{over pressure}$

r, m	$\bar{R} = r(0.11)$	$\bar{P}_3 (F_g 2-15)$	$(\bar{P}_3 \cdot P_0)$ over pressure
10	1.1	0.42	6.2 psi
30	3.3	0.11	1.6
50	5.5	0.055	0.81

For $\bar{R} > 3$; $\bar{P}_3 = 10^{(-1.3 \log \bar{R} - 0.3)}$

For $\bar{R} = 3.3$, $\bar{P}_s = 10^{(-1.3 \log 3.3 - 0.3)}$
 $= 0.11$

For $\bar{R} = 5.5$, $\bar{P}_3 = 10^{-1.3 (\log 5.5 - 0.3)}$
 $= 0.055$

CASE 3 125 hp, 15 psi boiler

1. Calculate theoretical burst pressure

Boiler data

- Inside Diameter: 60 in
- Length: 125 in.
- Wall thickness: $5/16$ in = 0.3125 in.

(A) Calculate burst pressure at room temp.

$$P = 0.2t/D$$

$$= \frac{(65,000)(2)(0.3125)}{60 \text{ in}}$$

$$t = 0.3125 \text{ in}$$

$$\sigma = 65,000 \text{ psi}$$

$$= 677 \text{ psig (692 psia)}$$

(B) Adjust for temperature effect on σ_{urs}

AT 692 psia, saturated steam temperature is about 502°F (say 500°F). Therefore, σ_{urs} is about 74% of σ_{urs} at room temp (same as previous).

$$\text{Therefore, } P = (0.74)(65,000 \text{ psi})(2)(0.3125 \text{ in}) / 60 \text{ in.}$$

$$= 501 \text{ psig (515 psia)}$$

2. Shock wave calculations

(A) Determine curve to use in Baker, Fig 2-15.

(1) Solve for $\bar{R}$

13-782 500 SHEETS, FILLER 5 SQUARE
42-381 50 SHEETS EYE EASE 5 SQUARE
42-382 100 SHEETS EYE EASE 5 SQUARE
42-383 100 SHEETS EYE EASE 5 SQUARE
42-384 100 SHEETS EYE EASE 5 SQUARE
42-385 100 RECYCLED WHITE 5 SQUARE
42-386 100 RECYCLED WHITE 5 SQUARE
Made in U.S.A.

where $r = \left(\frac{3V}{4\pi}\right)^{1/3}$ $V =$ Volume of steam plus water
 $= 3.65 \text{ m}^3$ *

$$= 0.96 \text{ m}$$

$$P_1 = 515 \text{ psi} = 3.55 \text{E}+6 \text{ Pa}$$

$$V_0 = 1.013 \text{E}+5 \text{ Pa}$$

$\gamma = 1.4$ (See Page 2)

$$= 3.15 \text{ E}+7 \text{ N-m}$$

$$= (0.96 \text{ m})(1.013 \text{E}+5)^{1/3} / 3.15 \text{E}+7^{1/3}$$

$$= 0.14$$

$$\frac{P_1}{P_0} = \frac{515 \text{ psia}}{14.7 \text{ psia}} = 35$$

515 psia $\approx$ 930 R

$$a_1 = \sqrt{\gamma_{\text{steam}} r_{\text{steam}} T} = [(1.329)(85.76)(930.12)]^{1/2}$$

$$= 324$$

$$\left(\frac{a_1}{a_0}\right)^2 = \left(\frac{326}{199}\right)^2 = 2.7 \quad (\text{No change from page 3})$$

(3) LookUp in Fig. 2-15; when $P_{30} = 6 \text{ psi}$ and

$\bar{R} = 0.14$, the point Falls on the 6th curve from top.

A.10

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(2) $\bar{p}_s(p_0) = \text{overpressure}$

For $\bar{R} = 7.5$, $P_2 = 10^{(-1.3 \log 7.5 - 0.3)}$
 $= 0.037$

Boiler data

- inside diameter: 60 in.
- length: 125 in.
- wall thickness: $\frac{5}{16}$ in (0.3125 in.)

(A) calculate Burst pressure At room temp.

SAME AS calculation on p. 9.

(B) Adjust for temperature

SAME AS CALCULATION ON p-9; $P_{BLIST} = 501 \text{ psig (515 psia)}$

2. SHOCK WAVE CALCULATIONS

(A) Determine curve to use in Baker, Fig 2-15

(1) Solve For $\overline{R}$

$$\bar{R} = r P_0^{1/3} / E^{1/3}$$

$V = \text{Volume of steam plus water} = 5.45 \text{ m}^3$ *

$$r = \left(\frac{3V}{4\pi} \right)^{1/3} = \left(\frac{3(5.45)}{4\pi} \right)^{1/3}$$

$$= 1.09 \text{ m}$$

$$E = \left(\frac{P_1 - P_0}{x - 1} \right) V$$

$$P_1 = 515 \text{ psia} = 3.55 \times 10^6 \text{ Pa}$$

$$P_D = 1.013 \text{ bar} + 5 \text{ Pa}$$

$\delta = 1.4$ (see page 2)

$$= \left(\frac{3.55E+6 - 1.013E+5}{1.4 - 1} \right) 5.45$$

$$= 4.70 \bar{E} + 7 \text{ N-m}$$

★ See pages 14 to 17 for water, steam volumes

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**CALCULATION OF STEAM BOILER PRESSURIZED VOLUMES
FOR 300 AREA GAS-FIRED BOILERS**

V_p = Pressurized volume = Water volume plus steam volume

Water volume = Normal water weight/density of water
= Water weight (lb)/[62.4 lb/ft³ x 35.31 ft³/m³]
= Water weight (lb)/2203 lb/m³

Density of water at room temperature = 62.4 lb/ft³

Boiler	Water weight, lb	Water volume, m ³	Steam volume, m ³ *	Total volume, m ³ **
15 psi, 125 hp	5,750	2.61	1.04	3.65
15 psi, 200 hp	8,625	3.91	1.54	5.45
150 psi, 125 hp	5,750	2.61	0.72	3.33
150 psi, 300 hp	13,000	5.90	1.69	7.59

* Information obtained from Cole Industrial, Inc., for the boilers planned to be installed in the 300 Area, Model CB (LE) boilers. Data sheets are attached.

** Total volume = water volume plus steam volume.

Firetube Boilers

Model CB (LE) Boilers

Table A3-19. Steam Volume and Disengaging Area

BOILER HP	STEAM VOLUME CU-FT		STEAM DISENGAGING AREA SQ-IN	
	HIGH PRESSURE ^A	LOW PRESSURE ^B	HIGH PRESSURE ^A	LOW PRESSURE ^B
125	25.4	36.6	5371	5887
150	30.7	44.3	6511	7138
200	37.7	54.4	7985	8752
250	49.2	70.6	7980	8695
300	59.5	85.3	9651	10516
350	70.9	101.7	11507	12538
400	72.1	97.9	9793	10883
500	83.7	113.7	11376	12303
600	101.5	137.8	13787	14911
700-800	119.8	182.7	16273	17600

NOTE: Based on normal water level.
A. Based on 150 psig design pressure.
B. Based on 15 psig design pressure.

Table A3-20. Recommended Steam Nozzle Size
(To Maintain 4000 to 5000 fpm Nozzle Velocity)

OPERATING PRESSURE PSIG	125	150	200	250	300	350	400	500	600	700	800
15	8	8	10	10	12	12	12	12	12	12	12
30	6	6	8	8	8	10	10	10	12	12	12
40	6	6	6	8	8	8	10	10	10	12	12
50	6	6	8	8	8	8	8	8	10	10	12
75	4	4	6	6	6	8	8	8	8	10	10
100	4	4	6	6	6	6	6	8	8	8	10
125	4	4	4	6	6	6	6	6	8	8	8
150	3	3	4	4	6	6	6	6	6	8	8
200	2.5	3	4	4	4	4	6	6	6	6	6
250	2.5	2.5	3	4	4	4	4	6	6	6	6

NOTES:
1. Steam nozzle sizes given in inches.
2. Recommended steam nozzle sizes based on 4000 to 5000 fpm steam velocity. Spool pieces (300 lb flanges) are available in the following sizes (in inches): 3x2-1/2, 2x30, 4x3x30, 6x4x36, 8x5x48, 10x8x48, and 12x8x48.

Table A3-21. Recommended Non-Return Valve Size

BOILER HP	BOILER CAPACITY (LBS/HR)	OPERATING PRESSURES (PSIG)				
		125	150	175	200	250
125	4313	3	3	2-1/2	2-1/2	2-1/2
150	5175	3	3	3	2-1/2	2-1/2
200	6800	3	3	3	3	3
250	8625	4	3	3	3	3
300	10350	4	4	4	4	3
350	12025	4	4	4	4	3
400	13800	4	4	4	4	4
500	17210	6	4	4	4	4
600	20700	6	6	4	4	4
700	24150	6	6	6	6	6
800	27600	6	6	6	6	6

NOTE: Valve sizes (300 # Flanges) given in inches.

Firetube Boilers

Model CB (LE) Boilers

BOILER HP	DIM	250	300	350
WIDTHS				
Overall	I	103	103	103
I.D. Boiler	J	78	78	78
Center to Water Column	K	54	54	54
Center to Outside Hinge	KK	51	51	51
Center to Lagging	L	42	42	42
Center to Auxiliary LWCO	LL	49	49	49
Base, Outside	M	64	64	64
Base, Inside	N	52	52	52
HEIGHTS				
Base to Steam Outlet	X	96	96	96
Overall	OO	115	115	115
Base to Vent Outlet	O	106	106	106
Height of Base	Q	10	10	10
Base to Bottom of Boiler	R	17	17	17
BOILER CONNECTIONS				
Feedwater, Right and Left	S	2	2	2-1/2
Chemical Feed	Z	1	1	1
Low Pressure (15 lb only) Steam Nozzle Drain, Front and Rear	U W	10 ^A 2	12 ^A 2	12 ^A 2
High Pressure (150 lb only) Surface Blowoff, Top C _L Steam Nozzle Blowdown, Front and Rear	T Y W	1 6 ^B 1-1/2	1 6 ^B 1-1/2	1 6 ^B 1-1/2
VENT STACK				
Diameter (fig'd. connection)	BB	20	20	20
MINIMUM CLEARANCES				
Rear Door Swing	DD	43	43	43
Front Door Swing	EE	89	89	89
Tube Removal, Rear	FF	131	157	187
Tube Removal, Front	GG	118	142	172
MINIMUM BOILER ROOM LENGTH ALLOWING FOR DOOR SWING AND TUBE REMOVAL FROM:				
Rear of Boiler	RR	364	417	477
Front of Boiler	RF	303	356	416
Thru Window or Doorway	RD	275	302	332
WEIGHT IN LBS				
Normal Water Capacity		10670	13000	15465
Approx. Ship Wgt - 15 lb		21500	23600	26800
Approx. Ship Wgt - 150 lb		22800	25200	27800

NOTES: All connections are threaded unless indicated.
A. ANSI 150 lb flange.
B. ANSI 300 lb flange.

Figure A3-2. Model CB (LE) Steam Boiler Dimensions, 78" (15 - 150 psig Design Pressure) - Sheet 2 of 2

Firetube Boilers

Model CB (LE) Boilers

BOILER HP	DIM	125	150	200
WIDTHS				
Overall	I	85	85	85
I.D. Boiler	J	60	60	60
Center to Water Column	K	45	45	45
Center to Outside Hinge	KK	35	35	35
Center to Lagging	L	33	33	33
Center to Auxiliary LWCO	LL	40	40	40
Base, Outside	M	52-1/2	52-1/2	52-1/2
Base, Inside	N	44-1/2	44-1/2	44-1/2
HEIGHTS				
Base to Steam Outlet	X	77	77	77
Overall	OO	86	86	86
Base to Vent Outlet	O	85	85	85
Height of Base	Q	12	12	12
Base to Bottom of Boiler	R	16	16	16
BOILER CONNECTIONS				
Feedwater, Right and Left	S	1-1/2	1-1/2	2
Chemical Feed	Z	1	1	1
Low Pressure (15 lb only) Steam Nozzle Drain, Front and Rear	U W	8 ^A 1-1/2	8 ^A 1-1/2	10 ^A 2
High Pressure (150 lb only) Surface Blowoff, Top C ₁ Steam Nozzle Blowdown, Front and Rear	T Y W	1 4 ^B 1-1/2	1 4 ^B 1-1/2	1 4 ^B 1-1/2
VENT STACK				
Diameter (figd. connection)	BB	16	16	16
MINIMUM CLEARANCES				
Rear Door Swing (Devil Equipped)	DD	32	32	32
Front Door Swing	EE	67	67	67
Tube Removal, Rear	FF	115	139	170
Tube Removal, Front	GG	103	127	158
MINIMUM BOILER ROOM LENGTH ALLOWING FOR DOOR SWING AND TUBE REMOVAL FROM:				
Rear of Boiler	RR	307	355	417
Front of Boiler	RF	260	308	370
Thru Window or Doorway	RD	224	248	279
WEIGHT IN LBS				
Normal Water Capacity		5750	7250	8625
Approx. Ship Wgt - 15 lb		11300	12600	14600
Approx. Ship Wgt - 150 lb		12400	13500	15800

NOTES: All connections are threaded unless indicated.
A. ANSI 150 lb flange.
B. ANSI 300 lb flange.

Figure A3-1. Model CB (LE) Steam Boiler Dimensions, 60" (15 - 150 psig Design Pressure) - Sheet 2 of 2

APPENDIX B

CALCULATION SHEETS FOR SHOCK OVERPRESSURE FROM METHANE EXPLOSION

Le National[®] Brand

SCENARIO: AUNDER BUILDING FILLS WITH METHANE TO STOICHIOMETRIC COMPOSITION, IGNITES (DETONATION ASSUMED TO OCCUR). SOLVE FOR DISTANCE AT WHICH OVERPRESSURE IS LESS THAN 2 PSIG.

$$E = \alpha \Delta H_c M_F$$
$$\alpha = 7.0 \text{ rad}$$
$$\Delta H_c = \text{Heat of combustion}$$
$$m_F = \text{MASS OF FLAMMABLE VAPOR}$$

α : SFPE, p. 3-326 (1 to 5%)

 $\Delta H_c: 50 \text{ KJ/g}$ (SFPE HANDBOOK, p1-83)
$$m_f = \text{mass of methane in building}$$
$$= (\text{Volume of BLDG}) (\text{Fraction CH}_4 \text{ AT stoichiometric composition})$$

Stoichiometric composition of methane/air mixture is 9.48% CH_4 (Zabetakis, p. 21)

$$\therefore m_F = \frac{564 \text{ m}^3}{\times 0.0948} \quad (\text{see p. 1; largest annex Bldg.})$$

$$= 53.5 \text{ m}^3 \text{ methane}$$

CALCULATE E

$$E = \alpha \Delta H_{cmf} \quad \text{Density of methane} = 0.5547 \text{ g/L}$$

$$= (0.05)(50 \text{ kJ/g})(53.5 \text{ m}^3)(0.5547 \text{ g/L})\left(\frac{1000 \text{ L}}{\text{m}^3}\right)$$

$$= 74.19 \text{ MJ}$$

$$W_{TNT} = E / 4500 \text{ kg} \quad (\text{SFPE HANDBOOK, p3-325})$$

$$= \frac{74,190 \text{ KJ}}{4500}$$

$$= 16.5 \text{ kg TNT-equivalent (36.3 lb TNT)}$$

Fig 3-16.14 (p 3-326, SFPE Handbook)

AT 2 psi, scaled distance = 25 FT/16^{1/3}

$$\text{DISTANCE} = 25(36.3)^{1/3}$$

$$= 82.8 \text{ FT } (25.2 \text{ m})$$

(D) Complete calculations for other ANNEX BUILDINGS (INSERT DIMENSIONS OF ANNEX BUILDINGS AND SOLVE FOR DISTANCE). PERFORM CALCULATIONS FOR 1, 3, AND 5% YIELDS. PLOT DISTANCE AS A FUNCTION OF ASSUMED YIELD FOR EACH BOILER.

Spreadsheet (attached) developed to perform calculations. The above-calculated case (324 Annex, 5% yield) was used to validate the spreadsheet calculations.

FEHA (1988) recommends use of 3% (p. B-42)
for explosive yield for Methane

boiler

Alternative Annex Bldg Explosion

CH4 stoichiometric composition	0.0948	(Zabetakis, p. 21)
Density of methane	0.5547 g/L	(CRC Handbook, p. C-371)
Delta H (combustion)	50 kJ/g	(SFPE Handbook, p. 1-83)
Scaled Distance for 2 psi overpressure	25 ft/lb(1/3)	(Lookup in SFPE Handbook, p. 3-326)

Calculations for 5% Yield

Annex	L	W	H	Vol CH4, Mass CH4				Blast				Separation Distance	
				Vol, ft3	Vol, m3	m3	g	Yield	Energy, kJ	kg TNT	lb TNT	ft	m
324	29.5	37.5	18	19912.5	563.922	53.45981	29654.1542	0.05	74135.3854	16.47453	36.24397	83	25
325	23.5	31.5	16	11844	335.4221	31.79801	17638.3579	0.05	44095.8948	9.799088	21.55799	70	21
327	23.5	25.5	18	10786.5	305.4737	28.9589	16063.5045	0.05	40158.7613	8.924169	19.63317	67	20
328	17.5	17.5	12	3675	104.076	9.866405	5472.89474	0.05	13682.2369	3.040497	6.689094	47	14
382B	23.5	25.5	18	10786.5	305.4737	28.9589	16063.5045	0.05	40158.7613	8.924169	19.63317	67	20
3720	23.5	23.5	16	8836	250.2355	23.72233	13158.775	0.05	32896.9374	7.310431	16.08295	63	19

Calculations for 1% Yield

Annex	L	W	H	Vol CH4, Mass CH4				Blast				Separation Distance	
				Vol, ft3	Vol, m3	m3	g	Yield	Energy, kJ	kg TNT	lb TNT	ft	m
324	29.5	37.5	18	19912.5	563.922	53.45981	29654.1542	0.01	14827.0771	3.294906	7.248793	48	15
325	23.5	31.6	16	11881.6	336.4869	31.89896	17694.3527	0.01	8847.17635	1.966039	4.325286	41	12
327	23.5	25.5	18	10786.5	305.4737	28.9589	16063.5045	0.01	8031.75226	1.784834	3.926634	39	12
328	17.5	17.5	12	3675	104.076	9.866405	5472.89474	0.01	2736.44737	0.608099	1.337819	28	9
382B	23.5	25.5	18	10786.5	305.4737	28.9589	16063.5045	0.01	8031.75226	1.784834	3.926634	39	12
3720	23.5	23.5	16	8836	250.2355	23.72233	13158.775	0.01	6579.38748	1.462086	3.216589	37	11

Calculations for 3% Yield

Annex	L	W	H	Vol CH4, Mass CH4				Blast				Separation Distance	
				Vol, ft3	Vol, m3	m3	g	Yield	Energy, kJ	kg TNT	lb TNT	ft	m
324	29.5	37.5	18	19912.5	563.922	53.45981	29654.1542	0.03	44481.2312	9.884718	21.74638	70	21
325	23.5	31.6	16	11881.6	336.4869	31.89896	17694.3527	0.03	26541.5291	5.898118	12.97586	59	18
327	23.5	25.5	18	10786.5	305.4737	28.9589	16063.5045	0.03	24095.2568	5.354502	11.7799	57	17
328	17.5	17.5	12	3675	104.076	9.866405	5472.89474	0.03	8209.34211	1.824298	4.013456	40	12
382B	23.5	25.5	18	10786.5	305.4737	28.9589	16063.5045	0.03	24095.2568	5.354502	11.7799	57	17
3720	23.5	23.5	16	8836	250.2355	23.72233	13158.775	0.03	19738.1624	4.386258	9.649768	53	16

Rev 0

B. CALCULATE METHANE VOLUME AT STOICHIOMETRIC COMPOSITION.

$$\text{Volume} = 9 \times 11.4 \times 5.5 = 564 \text{ m}^3$$

stoichiometric composition = 9.48 Vol% (in air)
(Zabetakis, p. 21)

C. Assume ignition occurs, calculate energy released

D. Calculate Δp at various distances. Use formula taken from Kogarko (1996, p. 397)

- AT $R=10m$, $R/\epsilon' \lambda = 10/52.45 \approx 0.19$

∴ use Equation 8; marginal

- At $R = 20\Omega$, $R/E^{1/3} = 20/52.45 = 0.38$

2. USE Equation 8 ; ALSO FOR LARGER values of R

$$(2) \Delta p = 0.6 \times 10^{-3} \frac{\bar{E}^{1/3}}{R} + 1.4 \times 10^{-2} \frac{\bar{E}^{1/3}}{R^2} + 2.5 \times 10^{-3} \frac{\bar{E}^{1/3}}{R^3}$$

This is for Detonation of Fuel-Air mixtures

- AT 10 M (R=10)

$$\Delta p = 0.6 \times 10^{-3} \frac{(1.45E+5)^{1/3}}{10} + 1.4 \times 10^{-2} \frac{(1.45E+5)^{1/3}}{100} + 2.5 \times 10^{-3} \frac{(1.45E+5)^{1/3}}{1000}$$

$$= 0.0032 + 0.386 + 0.362$$

$$= 0.752 \text{ kg/cm}^2 \text{ (10.7 psi)}$$

- AT 30 M (R=30)

$$\Delta p = 0.6 \times 10^{-3} \left(\frac{1.45E+5^{1/3}}{30} \right) + 1.4E-2 \left(\frac{1.45E+5^{1/3}}{900} \right) + 2.5 \times 10^{-3} \left(\frac{1.45E+5^{1/3}}{27,000} \right)$$

$$= 0.001 + 0.043 + 0.013$$

$$= 0.057 \text{ kg/cm}^2 \text{ (0.82 psi)}$$

- AT 50 M (R=50)

$$\Delta p = 0.6 \times 10^{-3} \left(\frac{1.45E+5^{1/3}}{50} \right) + 1.4 \times 10^{-2} \left(\frac{1.45E+5^{1/3}}{2500} \right) + 2.5 \times 10^{-3} \left(\frac{1.45E+5^{1/3}}{125,000} \right)$$

$$= 6.3E-4 + 0.016 + 0.0029$$

$$= 0.019 \text{ kg/cm}^2 \text{ (0.27 psi)}$$

APPENDIX C

CALCULATIONS FOR FIRE EXPOSURE SCENARIOS

APPENDIX C

CALCULATIONS FOR FIRE EXPOSURE SCENARIOS

Building dimensions for the annex facilities that may affect 300 Area nuclear facilities are as follows:

325	325 Building Annex	31.5 ft x 23.5 ft x 16 ft h
	328 Building Annex	17.5 ft x 17.5 ft x 12 ft h
324	324 Building Annex	37.5 ft x 29.5 ft x 18 ft h
327	327 Building Annex	25.5 ft x 23.5 ft x 18 ft h
	382B Building Annex	25.5 ft x 23.5 ft x 18 ft h
3712	3720 Building Annex	23.5 ft x 23.5 ft x 16 ft h

ANALYSIS OF EXPOSURE OF ONE EXPOSING WALL OF THE ANNEX BUILDING (APPLICATION OF NFPA 80A, TABLE 2-3)

C.1 325 Building from 325 Boiler Annex

Width of exposing fire	-	31 ft
Height of exposing fire	-	16 ft
Severity [from Table 2-2.4(a) and 2-2.4(b)]	-	light

This was based on the designs proposed for the boiler annex buildings, the class of severity is determined to be "light," based on Tables 2-2.4(a) and 2-2.4(b) in NFPA 80A, NFPA 1996).

Width/height or h/w	-	31 ft/ 16 ft	=	1.9
Percent openings	-		=	20 percent
Guide number (from Table 2-3)			=	0.45

$$\text{Separation distance } 0.45 \times 16 + 5 = 7.2 + 5 = 12.2 \text{ ft}$$

Assuming that the Percent Openings in the annex building are 20% and the height of the annex building is 16 ft (the height of 16 feet is the lesser dimension of height versus the width of the annex buildings), the 16 ft is multiplied by the Guide Number of 0.45 (Table 2-3) and 5 ft is added to obtain the building-to-building separation distance or $0.45 \times 16 \text{ ft} + 5 \text{ ft} = 12.2 \text{ ft}$.

C.2 325 Building from 328 Boiler Annex

Width of exposing fire - 17 ft
Height of exposing fire - 12 ft
Severity [from Table 2-2.4(a) and 2-2.4(b)] - light

Based on the designs proposed for the boiler annex buildings, the class of severity is determined to be "light," based on Tables 2-2.4(a) and 2-2.4(b) in NFPA 80A.

Width/height or h/w - 17 ft/ 12 ft = 1.4
Percent openings - = 20 percent
Guide number (from Table 2-3) = 0.42

Separation distance $0.42 \times 12 + 5 = 5.0 + 5 = 10$ ft

C.3 324 Building from 324 Boiler Annex

Width of exposing fire - 37 ft
Height of exposing fire - 18 ft
Severity [from Table 2-2.4(a) and 2-2.4(b)] - light

Based on the designs proposed for the boiler annex buildings, the class of severity is determined to be "light," based on Tables 2-2.4(a) and 2-2.4(b) in NFPA 80A.

Width/height or h/w - 37 ft/ 18 ft = 2
Percent openings - = 20 percent
Guide number (from Table 2-3) = 0.46

Separation distance $0.46 \times 18 + 5 = 8.3 + 5 = 13.3$ ft

C.4 327 Building from 327 Boiler Annex and 382B Boiler Annex

Both have the same dimensions so the following calculation applies to both.

Width of exposing fire - 25 ft
Height of exposing fire - 18 ft
Severity [from Table 2-2.4(a) and 2-2.4(b)] - light

Based on the designs proposed for the boiler annex buildings, the class of severity is determined to be "light," based on Tables 2-2.4(a) and 2-2.4(b) in NFPA 80A.

Width/height or h/w	-	25 ft/ 18 ft	=	1.4
Percent openings	-		=	20 percent
Guide number (from Table 2-3)			=	0.40
Separation distance $0.40 \times 18 + 5$	=	$7.2 + 5$	=	12.2 ft

C.5 3712 Building from 3720 Boiler Annex

Width of exposing fire	-	23 ft
Height of exposing fire	-	16 ft
Severity [from Table 2-2.4(a) and 2-2.4(b)]	-	light

Based on the designs proposed for the boiler annex buildings, the class of severity is determined to be "light," based on Tables 2-2.4(a) and 2-2.4(b) in NFPA 80A.

Width/height or h/w	-	23 ft/ 16 ft	=	1.4
Percent openings	-		=	20 percent
Guide number (from Table 2-3)			=	0.42
Separation distance $0.42 \times 16 + 5$	=	$6.7 + 5$	=	11.7 ft

C.6 Other Analyses

If more conservative assumptions were made, such as, light severity class, percent openings of 100%, and an annex building height of 18 ft, the building-to-building separation distance would be:

$$(18 \text{ ft} \times 1.93) + 5 \text{ ft} = 39.7 \text{ feet}$$

If the annex buildings were assumed to be 18 feet in height, light severity class, and percent openings of 50%, the building-to-building separation would be:

$$(18 \text{ ft} \times 1.22) + 5 \text{ ft} = 27 \text{ feet}$$

Based on the above assumptions and calculations and that the annex buildings in the 300 Area are being constructed at 13-20 ft in height, a building-to-building separation distance of 25 to 30 ft is considered a conservative distance to be required between the annex buildings and adjacent nuclear facilities. Using the more conservative calculations presented above, a building-to-building separation of up to 30 or 40 ft would be considered an

appropriate distance to be required between the annex buildings and adjacent nuclear facilities buildings.

C.7 Fire Exposure from Buildings of Lesser Height

In addition to the above calculations, exposure from buildings of a lesser height needs to be considered because the annex buildings in the 300 Area are of one story construction and the 308, 324, 325, and 327 buildings are of two-story construction (or equivalent). When a building is exposed by a building of lesser height, the horizontal separation distance indicated in Table 2-4 of NFPA 80A should also be considered when separation distances derived from the radiant heat basis (Table 2-3 of NFPA 80A) are less than the distances indicated in Table 2-3. In the event of a moderate wind, flames can be expected to extend horizontally for as great a distance as they might otherwise extend upwards. Thus, protection may be called for if the separation between two buildings is no more than the height to which flames might otherwise extend, as noted in Table A-2-4 of NFPA 80A. Using Table 2-4 (NFPA 80A), a one story exposing building must have a horizontal separation distance or a means of protection applied on the side of the exposed building to a height of 25 ft (or 32 ft for a two-story exposing face) from an exposed adjacent nuclear facility. For conservatism, a minimum horizontal separation distance of 32 ft is established for the 324, 325, 327, 308 Buildings. This is more limiting than the minimum separation distances calculated using the radiant energy method. The minimum separation distance calculated using the radiant energy method is applicable to the 3720 Building boiler annex because the exposed nuclear facility (3712 Building) is of one-story construction.

APPENDIX D

NATURAL GAS PIPELINE RUPTURE AND FLAME JET

Johnson National's Brand

A. Scenario: Backhoe breaks 6-in. natural gas pipeline leading to pressurized natural gas release. Gas assumed to ignite, resulting in flame jet. Because the pipe is buried at least 2 ft., geometry is such that the jet would not directly impinge on a building. However, building would be exposed to radiant energy from flame. Approach taken here is to calculate incident heat flux on building as a function of distance from the flame and compare calculated heat flux to heat flux that could cause building skin (bolted sheet metal) to fail, most likely from thermal expansion.

Source of following equation is Fire Protection Engineering, 2nd Edition (SFPE/NFPA 1995, p. 3-221)

$\dot{q}''$ = incident heat flux, kW/m^2
 $\dot{Q}_{\text{rel}}$ = energy release rate, kW
 F = fraction of combustion energy resulting in radiation
 D = distance from flame to building, m .

D.1

(2) $\dot{Q}_{rel}$: energy release rate

$$\dot{Q}_{rel} = \dot{m} \Delta H_c$$

$\dot{m}$ = mass release rate, kg/sec
 ΔH_c = Theoretical heat of of combustion, kJ/kg

$$\Delta H_c (\text{methane}) = 50 \text{ kJ/g} = 50,000 \text{ kJ/kg}$$

$\dot{m}$: mass release rate.

Calculated using ARCHIE (FEMA 1989) computer code. Implemented model that calculates discharges from pressurized containers.

Input Parameters:

- Methane boiling point: -164°C (-263°F)
(CRC Handbook 1981, p C-371)
- Pipeline pressure: 50 psi
- Specific heat ratio: 1.3 (FEMA 1989, value given within ARCHIE)
- Pipeline diameter: 6 in. (largest line)
- Pipeline length: 5000 FT (Assumption)
- Discharge hole diameter: 4 in. (based on assumed break geometry; only break in top of pipeline would jet upward)
- Discharge coefficient of hole: 0.62 (From FEMA 1989, given within ARCHIE).

RESULTS: See ARCHIE output FILE (Attached)

- Amount released: 172.7 lbs (78.5 Kg)
- Duration of discharge: 0.528 min (32 sec)
- $\dot{m} = 78.5 \text{ Kg} / 32 \text{ sec} = 2.45 \text{ Kg/sec}$

$$Q_{rel} = \dot{m} \Delta H_c = (2.45 \text{ kg/sec})(50,000 \text{ kJ/kg})$$

$$= 1.23E+5 \text{ kW}$$

(3) Calculate $\dot{q}''$ as function of D

• D = 10 m

$$\dot{q}'' = FQ_{rel} / 4\pi D^2 = (0.2)(1.23E+5 \text{ kW}) / 4\pi (10)^2$$

$$= 19.6 \text{ kW/m}^2$$

• D = 30 m

$$\dot{q}'' = (0.2)(1.23E+5) / 4\pi (30)^2$$

$$= 2.18 \text{ kW/m}^2$$

• D = 50 m

$$\dot{q}'' = (0.2)(1.23E+5) / 4\pi (50)^2$$

$$= 0.78 \text{ kW/m}^2$$

(c) Determine failure threshold of steel plate building in terms of incident heat flux.

NFPA 80A uses 12.5 kW/m^2 incident heat flux to estimate building separation distances. 12.5 kW/m^2 is said to be the "maximum tolerable level of incident radiation at the facade of an unprotected exposed building (BOA-5)."

Illustration of conservatism is using this value for a steel panel building. SFPE/NFPA 1995, Table 3-4.2, provides critical heat flux (CHF)

500 SHEETS PER 5 SQUARE
40 SHEETS PER 4 SQUARE
30 SHEETS PER 3 SQUARE
20 SHEETS PER 2 SQUARE
10 SHEETS PER 1 SQUARE
5 SHEETS PER 1/2 SQUARE
2 SHEETS PER 1/4 SQUARE
1 SHEET PER 1/8 SQUARE
1/2 SHEET PER 1/16 SQUARE
1/4 SHEET PER 1/32 SQUARE
1/8 SHEET PER 1/64 SQUARE
1/16 SHEET PER 1/128 SQUARE
1/32 SHEET PER 1/256 SQUARE
1/64 SHEET PER 1/512 SQUARE
1/128 SHEET PER 1/1024 SQUARE
1/256 SHEET PER 1/2048 SQUARE
1/512 SHEET PER 1/4096 SQUARE
1/1024 SHEET PER 1/8192 SQUARE
1/2048 SHEET PER 1/16384 SQUARE
1/4096 SHEET PER 1/32768 SQUARE
1/8192 SHEET PER 1/65536 SQUARE
1/16384 SHEET PER 1/131072 SQUARE
1/32768 SHEET PER 1/262144 SQUARE
1/65536 SHEET PER 1/524288 SQUARE
1/131072 SHEET PER 1/1048576 SQUARE
1/262144 SHEET PER 1/2097152 SQUARE
1/524288 SHEET PER 1/4194304 SQUARE
1/1048576 SHEET PER 1/8388608 SQUARE
1/2097152 SHEET PER 1/16777216 SQUARE
1/4194304 SHEET PER 1/33554432 SQUARE
1/8388608 SHEET PER 1/67108864 SQUARE
1/16777216 SHEET PER 1/134217728 SQUARE
1/33554432 SHEET PER 1/268435456 SQUARE
1/67108864 SHEET PER 1/536870912 SQUARE
1/134217728 SHEET PER 1/1073741824 SQUARE
1/268435456 SHEET PER 1/2147483648 SQUARE
1/536870912 SHEET PER 1/4294967296 SQUARE
1/1073741824 SHEET PER 1/8589934592 SQUARE
1/2147483648 SHEET PER 1/17179869184 SQUARE
1/4294967296 SHEET PER 1/34359738368 SQUARE
1/8589934592 SHEET PER 1/68719476736 SQUARE
1/17179869184 SHEET PER 1/137438953472 SQUARE
1/34359738368 SHEET PER 1/274877906944 SQUARE
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1/137438953472 SHEET PER 1/1099511627776 SQUARE
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1/1099511627776 SHEET PER 1/8796093022208 SQUARE
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1/140737488355328 SHEET PER 1/1125899906842624 SQUARE
1/281474976710656 SHEET PER 1/2251799813685248 SQUARE
1/562949953421312 SHEET PER 1/4503599627370496 SQUARE
1/1125899906842624 SHEET PER 1/9007199254740992 SQUARE
1/2251799813685248 SHEET PER 1/18034398509481984 SQUARE
1/4503599627370496 SHEET PER 1/36070797018963968 SQUARE
1/9007199254740992 SHEET PER 1/72141594037927936 SQUARE
1/18034398509481984 SHEET PER 1/144283188075855872 SQUARE
1/36070797018963968 SHEET PER 1/288566376151711744 SQUARE
1/72141594037927936 SHEET PER 1/577132752303423488 SQUARE
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1/9234124036854775808 SHEET PER 1/73872992294838206464 SQUARE
1/18468248073709551616 SHEET PER 1/147745984589676412928 SQUARE
1/36936496147419103232 SHEET PER 1/295491969179352825856 SQUARE
1/73872992294838206464 SHEET PER 1/590983938358705651712 SQUARE
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1/4727871506869645213696 SHEET PER 1/37822972054957161709568 SQUARE
1/9455743013739290427392 SHEET PER 1/75645944109914323419136 SQUARE
1/18911486027478580854784 SHEET PER 1/151291888219828646838272 SQUARE
1/37822972054957161709568 SHEET PER 1/302583776439657293676544 SQUARE
1/75645944109914323419136 SHEET PER 1/605167552879314587353088 SQUARE
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1/302583776439657293676544 SHEET PER 1/2420670211517258349412352 SQUARE
1/605167552879314587353088 SHEET PER 1/4841340423034516698824704 SQUARE
1/1210335105758629174706176 SHEET PER 1/9682680846069033397649408 SQUARE
1/2420670211517258349412352 SHEET PER 1/19365361692138066795298816 SQUARE
1/4841340423034516698824704 SHEET PER 1/38730723384276133590597632 SQUARE
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1/19365361692138066795298816 SHEET PER 1/154922893537104534362390528 SQUARE
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Values for a number of materials. CHF is the heat flux below which ignition does not occur for about 15 minutes. Materials with CHF about 15 include: high-density polyethylene, nylon, PVC, and more. These materials are obviously less resistant to external heat than would be a steel panel. Consequently, 12.5 kW/m² is considered to be conservative.

Heat Flux plotted as a function of Distance

Also, solve equation for D using $\dot{q}'' = 12.5 \text{ kW/m}^2$

$$\dot{q}'' = F Q_{rel} / 4\pi D^2$$

$$D = \left(\frac{F Q_{rel}}{4\pi \dot{q}''} \right)^{1/2}$$

$F = 0.2$
 $Q_{rel} = 1.23E+5 \text{ kW}$
 $\dot{q}'' = 12.5 \text{ kW/m}^2$

$$= \left[\frac{(0.2)(1.23E+5)}{(4)(\pi)(12.5)} \right]^{1/2}$$

$$= 12.5 \text{ m (41 FT)}$$

As long as D > 12.5 m, heat flux will be below 12.5 kW/m² on External surface of exposed nuclear facility.

Wynn National's Brand

$$\dot{q}'' = F \dot{Q}_{rel} / 4\pi D^2$$

(1) $F = 0.2$ (SFPE/NFPA 1995, p. 3-11.8)

$$\Delta H_c = 50 \text{ KJ/g} = 50,000 \text{ KJ/kg}$$

$$\dot{Q}_{rel} = (0.16 \text{ kg/sec})(50,000 \text{ kJ/kg})$$
$$= 8000 \text{ kW}$$

• $D = 10 \text{ m}$

D.5

NEW National Brand

$$\dot{q}'' = (0.2)(8000) / 4\pi(30)^2$$

$$= 0.14 \text{ Kw/m}^2$$

$$\dot{q}'' = (0.2)(8000) / 4\pi(50)^2$$

$$= 0.051 \text{ kW/m}^2$$

$$\dot{q}'' = (0.2)(8000) / 4\pi(5)^2$$

$$= 5.1 \text{ kW/m}^2$$

Assume pipeline is located X m away from a 30 ft. tall building. Trench is 2 ft deep and excavator is digging a 4 ft wide trench and then ruptures 1 inch pipe. Geometry is illustrated below. In $\triangle ABC$, segments $\overline{AB}$

Since $\triangle ABC \cong \triangle CDE$, $\overline{EC} = \overline{DE}$.

Therefore, to prevent direct flame impingement, pipe should be located at a distance away from the building equal to the building height. However, ARCTIC output indicates flame jet length is 29 FT. Therefore, separation distance could be $29 \text{ FT} \times \cos(45^\circ) = 20.5 \text{ FT}$ from building (assuming flame jet source is at ground level) and the flame jet will not be long enough to directly impinge on building. Therefore, siting criteria is 1 inch. line must be located at least 21 FT from nearest nuclear facility.

D.7

ARCHIE OUTPUT FILE

6-inch Line

HAZARDOUS MATERIAL = Natural Gas
NAME OF DISK FILE = PIPE.ASF

*** SCENARIO DESCRIPTION

Natural Gas pipeline rupture

***** DISCHARGE RATE/DURATION ESTIMATES

Discharge from long distance gas pipeline

Duration of discharge	=	.528	minutes
Amount discharged	=	172.7	lbs
State of material	=	Gas	

***** FLAME JET HAZARD RESULTS

Flame jet length	=	115	feet
Safe separation distance	=	230	feet
Flame jet duration	=	.528	minutes

INPUT PARAMETER SUMMARY

PHYSIOCHEMICAL PROPERTIES OF MATERIAL

NORMAL BOILING POINT	= -263	degrees F
MOLECULAR WEIGHT	= 20	
VAPOR PRES AT CONTAINER TEMP	= 50	psia
	= 2587	mm Hg
VAPOR PRES AT AMBIENT TEMP	= 50.01	psia
	= 2587	mm Hg
SPECIFIC HEAT RATIO FOR GAS	= 1.3	
LOWER FLAMMABLE LIMIT (LFL)	= 5	vol%

CONTAINER CHARACTERISTICS

CONTAINER TYPE	= Pipeline	
PIPELINE DIAMETER	= 6	inches
PIPELINE LENGTH	= 5000	feet
	= .95	miles
INTERNAL PIPELINE PRESSURE	= 50	psia
NO. PIPELINE DISCHARGE POINTS	= 0	
TOTAL WEIGHT OF CONTENTS	= 172.7	lbs
WEIGHT OF LIQUID	= 0	lbs
LIQUID HEIGHT IN CONTAINER	= 0	feet
WEIGHT OF GAS UNDER PRESSURE	= 172.7	lbs
TOTAL CONTAINER VOLUME	= 981.8	ft3
	= 7344	gals
VAPOR/GAS VOLUME IN CONTAINER	= 981.8	ft3
DISCHARGE HOLE DIAMETER	= 4	inch(es)
DISCHARGE COEFFICIENT OF HOLE	= .62	
TEMP OF CONTAINER CONTENTS	= 70	degrees F

ENVIRONMENTAL/LOCATION CHARACTERISTICS

AMBIENT TEMPERATURE	= 70	degrees F
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KEY RESULTS PROVIDED BY USER INSTEAD OF BY EVALUATION METHODS
NONE OBSERVED

KEY RESULTS OVERRIDDEN BY USER AT SOME POINT AFTER COMPUTATION
NONE OBSERVED

ARCHIE OUTPUT FILE

1-inch Line

HAZARDOUS MATERIAL = Natural Gas
NAME OF DISK FILE = PIPE-2.ASF

*** SCENARIO DESCRIPTION

Natural Gas Pipeline Rupture
1 inch Line

***** DISCHARGE RATE/DURATION ESTIMATES

Discharge from long distance gas pipeline

75% Peak discharge rate	=	20.5	lbs/min
Duration of discharge	=	.235	minutes
Amount discharged	=	4.8	lbs
State of material	=	Gas	

***** FLAME JET HAZARD RESULTS

Flame jet length	=	29	feet
Safe separation distance	=	58	feet
Flame jet duration	=	.235	minutes

INPUT PARAMETER SUMMARY

PHYSIOCHEMICAL PROPERTIES OF MATERIAL

NORMAL BOILING POINT	= -263	degrees F
MOLECULAR WEIGHT	= 20	
VAPOR PRES AT CONTAINER TEMP	= 50	psia
	= 2587	mm Hg
VAPOR PRES AT AMBIENT TEMP	= 50.01	psia
	= 2587	mm Hg
SPECIFIC HEAT RATIO FOR GAS	= 1.3	
LOWER FLAMMABLE LIMIT (LFL)	= 5	vol%

CONTAINER CHARACTERISTICS

CONTAINER TYPE	= Pipeline	
PIPELINE DIAMETER	= 1	inches
PIPELINE LENGTH	= 5000	feet
	= .95	miles
INTERNAL PIPELINE PRESSURE	= 50	psia
NO. PIPELINE DISCHARGE POINTS	= 1	
TOTAL WEIGHT OF CONTENTS	= 4.8	lbs
WEIGHT OF LIQUID	= 0	lbs
LIQUID HEIGHT IN CONTAINER	= 0	feet
WEIGHT OF GAS UNDER PRESSURE	= 4.8	lbs
TOTAL CONTAINER VOLUME	= 27.3	ft3
	= 204.3	gals
VAPOR/GAS VOLUME IN CONTAINER	= 27.3	ft3
DISCHARGE HOLE DIAMETER	= 1	inch(es)
DISCHARGE COEFFICIENT OF HOLE	= .62	
TEMP OF CONTAINER CONTENTS	= 70	degrees F

ENVIRONMENTAL/LOCATION CHARACTERISTICS

AMBIENT TEMPERATURE	= 70	degrees F
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