Barrier Design Guidance

For

HUD Assisted Projects Near Hazardous Facilities

Guidebook 6600.G

Environmental Planning Division
Office of Environment and Energy

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I – Introduction

A. Purpose

This guidance is intended to provide U.S. Department of Housing and Urban Development (HUD) grantees with information regarding barrier design that will protect HUD-assisted projects from facilities that may pose an explosive or flammable hazard. It provides an analytical foundation and structure towards the understanding of the basic requirements behind the design of a barrier for mitigation. It identifies the information required and analytical guidelines for designing the required protection against blast overpressure and thermal heat flux produced by stationary hazards covered under 24 CFR Part 51 Subpart C.

Only a licensed professional engineer (civil or structural) should design and oversee the construction of mitigation barriers.

This guidance was prepared primarily for civil or structural engineers. For people of other professional backgrounds, this guidance provides procedures for calculating the **required information** the licensed professional will need for designing the required barrier for mitigation.

The "required information" this guidance refers to for the design of barriers for mitigation includes the theoretical and mathematical procedures for the determination of barrier design criteria based on the standards of blast overpressure and thermal radiation within the regulation 24 CFR Part 51 Subpart C. This guidance makes reference to the following barrier design criteria:

- **Peak Positive Incident Pressure, and**
- **Thermal Heat Flux**

This guidance is not intended to provide information in reference to barrier dimensions, materials for construction, or how to construct a barrier for mitigation.

B. Background

The regulation 24 CFR Part 51 Subpart C covers technical requirements for determining Acceptable Separation Distances (ASD's) from HUD-assisted projects in close proximity to hazardous operations. These hazardous operations include the storage, handling or processing of substances of hazardous nature that have the potential to cause an explosion or fire.

Once the Acceptable Separation Distance (ASD) has been calculated, the next common question from HUD grantees is whether the project site provides the ASD required by the regulation. If the ASD is not available, consideration of possible mitigation is the next step in the process towards site compliance within HUD standards.

A detailed site mitigation analysis is recommended for proposed HUD-assisted project sites in proximity to facilities that store, process or handle materials of fire or explosive nature. If the site mitigation analysis reveals that there is no mitigation option other than the design and implementation of a barrier, this guidance provides the required technical information to help HUD grantees and licensed professionals to design the barrier for the HUD-assisted project.

HUD standards are set for thermal radiation and blast overpressure (24 CFR Part 51.203). These standards are applicable to the following:

- Thermal Radiation
  - Structures - 10,000 BTU/ft^2 -hr
  - People – 450 BTU/ft^2 -hr

- Blast Overpressure–
  - Structures - 0.5 psi

To protect buildings and housing units from thermal radiation, HUD established the thermal radiation standard of 10,000 BTU/ft^2-hr.

To protect people in outside areas, such as patios or common areas, or in places where communities congregate, like parks or recreation areas, HUD established the thermal radiation standard of 450 BTU/ft^2-hr. If no mitigation exists or is implemented, it is required to build HUD-assisted projects to the ASD at which the thermal radiation flux will not exceed 450 BTU/ft^2-hr.

Blast overpressure can harm people or destroy buildings if this pressure is higher than 0.5 psi. For proposed HUD-assisted project sites where there are stored hazards that can cause blast overpressures and no mitigation, it is required to build to the ASD at which this pressure is no higher than 0.5 psi.

Barriers as a mitigation measure are expensive and have other drawbacks. If the ASD is achievable, or better mitigation can be used, HUD advises that construction of a barrier be avoided.

II – Basic Guidance requirement

A. This guidance can be applied to the following activities:

- HUD-assisted projects as defined at 24 CFR 51.201.
  - These are projects for residential, institutional, recreational, commercial or industrial use that conduct development, construction, rehabilitation, modernization or conversion with HUD subsidy, grant assistance, loan, loan guarantee, or mortgage insurance.
  - For purposes of Subpart C, the terms “rehabilitation” and modernization” refer only to such repairs and renovation of a building or buildings as will result in an increased number of people being exposed to hazardous operations by increasing residential densities, converting the type of use of a building to habitation, or making a vacant building habitable. In regards to building or buildings, for purposes of this Subpart, the repairs and renovation also applies to other projects for HUD-funding assistance.

B. Entities and personnel who will benefit from this guidance are:

- Planners
- Developers
- Engineers
- HUD field and headquarters staff
- HUD grantees

III – Exclusions and Limitations of this Guidance

1. This guidance does not apply in the following situations, which are excluded from Part 51 Subpart C:

a. Underground Storage Containers – If the hazard is entirely buried, there is no need for an ASD.

b. Stationary containers of 100 gallons or less capacity containing common liquid industrial fuels - Results from the December 19, 1981 study[1] from Rolf Jensen and Associates (RJ&A), Deerfield, Illinois demonstrated that stationary containers of 100 gallons or less capacity containing common liquid industrial fuels (such as gasoline, fuel oil, kerosene and crude oil) do not emit thermal radiation heat flux effects at levels that would pose a danger to HUD-assisted projects. The regulation 24 CFR 51.201, under the "hazard" definition, lists various exceptions to Subpart C of 24 CFR Part 51.
However, the exception of stationary aboveground containers of 100 gallons or less capacity containing common liquid industrial fuels, ***applies only*** to containers of 100 gallons or less capacity, that are aboveground and stationary, containing common liquid industrial fuels **only**, such as gasoline, fuel oil, kerosene and crude oil. This exception ***does not apply*** to aboveground stationary containers containing hazardous gases, as listed in Appendix I of the Regulation or in this guidance.

c. Natural gas holders with floating tops – These are stationary aboveground storage containers used to store natural gas. These containers are less susceptible to corrosion and tank perforations that can cause Bleves (rupture explosions).

d. Mobile conveyances (tank trucks, barges, railroad tank cars) – Containers that are mobile, with capacity of storing common liquid industrial fuels or hazardous gases as listed in Appendix I of the regulation 24 CFR Part 51 Subpart C.

e. Pipelines, such as high pressure natural gas transmission pipelines **or** liquid petroleum pipelines – Pipelines that transmit hazardous substances are not considered a hazard under 24 CFR Part 51 Subpart C if they are located underground or if they comply with applicable Federal, State or local safety standards.

2. This guidance applies subject to the following limitation:

Self-Contained Above Ground Containers (SCACs) for calculation of the ASD

SCACs have two external walls, the first wall has the purpose of containing the product, the second serves as spill prevention to the outside of the container if the first wall ruptures. The interstitial space (space between the first and the second wall) serves as containment of the container's product if there is a rupture in the container's internal wall.

SCACs are considered containers without a dike, **and calculations must be done as for containers without a dike area.**

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[1] Urban Development Siting with Respect to Hazardous Commercial/Industrial Facilities

IV – Applications of this Guidance

The regulation 24 CFR Part 51, Subpart C and this guidance apply only to aboveground stationary containers

1) of more than 100 gallon capacity, containing common liquid industrial fuels listed along with other hazardous substances, in Appendix I of the Regulation and the HUD hazards guidebook "Siting of HUD-Assisted Projects Near Hazardous Facilities"; and
2) of any capacity, containing hazardous liquids or gases that are not common liquid industrial fuels. (See also the list of hazardous substances located in Appendix I of the Regulation and the HUD hazards Guidebook). Keep in mind that you may be required to comply with Part 51 for hazardous substances that are not listed.

The formula provided to calculate the thermal heat flux (Q), can be applied only to stationary aboveground storage containers under pressure, with or without a dike. The dike area does not have any effect on the Acceptable Separation Distance (ASD) calculations when the container being analyzed is under pressure.

To calculate the thermal heat flux (Q) from stationary aboveground containers not under pressure, please contact Headquarters (Office of Environment and Energy, Nelson A. Rivera – 202-402-4455). The variables impacting such a type of fire's behavior are:

1) Changes in chemical properties of stored substances not under pressure; and
2) Outside ambient conditions (wind direction and speed).

A mathematical procedure pertaining to these variables would be extremely complex and unreliable.

V- Definitions

Acceptable Separation Distance (ASD) – Under 24 CFR Part 51 Subpart C, the minimum distance from a hazardous operation to where a HUD-assisted project (including open spaces related to the HUD-assisted project, where people congregate) can be located in accordance with HUD's standards of blast overpressure (0.5 psi-buildings) and thermal radiation (450BTU/ft^2 – hr – people and 10,000 BTU/ft^2 – hr – buildings). In addition, it is the minimum distance that HUD-assisted projects involving the installation of hazardous facilities can be located from existing or planned residences or from any other facility or area where people may congregate or be present.

Barrier – A barrier designed to sustain blast overpressure (generated pressure from an explosion of a substance contained under pressure) from a substance stored under pressure undergoing a liquid-gas unbalanced reaction or thermal radiation (generated heat from the effects of combustion from a flammable substance) or both (blast overpressure and thermal radiation). The design, location and implementation of the barrier it is not the same for all cases; the nature of the barrier varies depending on the results of the analysis of the location of the proposed HUD-assisted project site.

Blast Overpressure (also known as Peak Positive Incident Pressure (Ps)) – Exerted pressure from a compressed liquid (or liquid-gas mixture) inside a container after an incident occurs (usually tank perforation due to corrosion or impact) that prompts a liquid-gas unbalanced reaction and the container to explode with high energy.

Bleve – The type of explosion that occurs when a vessel containing a pressurized liquid is ruptured. A bleve can occur in a vessel that stores a substance that is usually a gas at atmospheric pressure but is a liquid when pressurized (for example, liquefied petroleum gas). The substance will be stored partly in liquid form, with a gaseous vapor above the liquid filling the remainder of the container. If the vessel is ruptured (for example, due to corrosion or failure under pressure) the vapor portion may rapidly leak, dropping the pressure inside the container and releasing a wave of overpressure from the point of rupture. The sudden drop in pressure inside the container causes a liquid-gas unbalanced reaction which produces large amounts of vapor combined with large pressures in the process.

Buried Container (or underground storage container) - Any one or combination of containers (including underground pipes connected thereto) that is used to contain a regulated substance or an accumulation of regulated substances, and is located beneath the surface of the ground. Underground storage containers are not considered to be a hazard under 24 CFR Part 51 Subpart C, this guidance or the ASD assessment tool for the calculation of the ASD from a hazard for a HUD-assisted project.

Combustion – A complex sequence of chemical reactions among oxygen, a fuel source and an ignition source resulting in the production of heat and light in the form of glow or flames.

Container – A structure (also known as a vessel, tank or enclosure) built to contain material in liquid, gas or solid state, that can be designed for stationary or for transport purposes. If this structure contains a product under pressure (this includes gases and liquefied gases that are kept in their liquid state maintained at very low temperatures) it is called a vessel; for liquid or solid products, it is called a tank or an enclosure.

- **Note**: Commercially, containers used to hold liquids, solids or gases, are all referred to as tanks. Technically speaking, however, containers that hold solids or liquids are properly referred to as tanks or enclosures, and those for gases, as vessels.

Cryogenics - The branches of physics and engineering that involve the study of very low temperatures, how to produce them, and how materials behave at those temperatures.

Dike – A continuous wall (built out of soil, asphalt, steel or concrete), surrounding a container, constructed as a defense or as a boundary to provide containment or impoundment during a spill. The dike completes the containment within the diked area and serves as the diked area perimeter. The combination of the diked area and the dike provide spill protection.

Diked area - The area between the container's outside wall and the dike. The dike area provides containment if there is container rupture, causing a spill.

Hazard – Is a stationary operation or facility within a 1-mile surrounding distance from a HUD-assisted project site where chemicals of flammable or explosive nature are handled, stored or manufactured in aboveground containers.

Hazardous Gas – The state of matter distinguished from the solid and the liquid states by relatively low density and viscosity, relatively great expansion and contraction with changes in pressure and temperature, the ability to diffuse readily, and the spontaneous tendency to become distributed uniformly throughout any container. This state of matter as being hazardous means that its properties defines this gas to impact the human health or the environment because it is flammable, toxic or of radioactive nature.

Hazardous Liquid - The state of matter in which a substance exhibits a characteristic readiness to flow, little or no tendency to disperse, and relatively high incompressibility.

Hazardous Products (or substances) **–** Are those flammable and combustible gases or liquids which upon accidental release and ignition or explosion pose a threat to public safety or damage to property.

Liquefied Natural Gas (LNG) – A natural gas that has been processed to remove either valuable components, e.g., helium, or those impurities that could cause difficulty downstream, e.g., water, and heavy hydrocarbons and then condensed into a liquid at almost atmospheric pressure (transport pressure around 25 kPa) by cooling it to approximately -163 degrees Celsius. LNG is transported by specially designed cryogenic sea vessels and cryogenic road tankers; and stored in specially designed tanks.

Liquefied Petroleum Gas (LPG) – A mixture of hydrocarbon gases (also called liquefied petroleum gas, liquid petroleum gas, LPG, LP Gas, or autogas) used as a fuel in heating appliances and vehicles, and increasingly replacing chlorofluorocarbons as an aerosol propellant and a refrigerant to reduce damage to the ozone layer. Varieties of

LPG bought and sold include mixes that are primarily propane, mixes that are primarily butane, and mixes including both propane and butane, depending on the season. In the winter a mix contains more propane and in the summer a mix contains more butane.

Heat of Combustion – The energy released as heat when a compound undergoes complete combustion with oxygen. The chemical reaction is typically a hydrocarbon reacting with oxygen to form carbon dioxide, water and heat.

Mitigation – The process for implementing the required level of protection to a HUD-assisted project site from stationary hazardous operations which store, handle or process materials of explosive or flammable nature. This level of protection can be either designed and implemented (as a designed barrier) or it can be a preexisting barrier, either natural (mountains, hills) or man-made (elevated buildings or housing developments).

Peak Positive Incident Pressure (Ps) – Blast overpressure

Scaled Distance – A calculated distance, requiring the input parameters of the standoff distance and the hazard's equivalent weight of TNT (Trinitrotoluene-useful explosive material with convenient handling properties). This distance is plotted in a special graph for the determination of the peak positive incident pressure.

Self-Contained Above Ground Containers (SCACs) – Containers with interstitial spill countermeasure systems for spill prevention control. SCACs have two external walls, the first wall has the purpose of containing the product of the container, the second serves for spill prevention to the outside of the container if the first wall ruptures. The interstitial space (space between the first and the second wall) serves as containment of the container's product if there is a rupture in the container's internal wall.

Standoff Distance – For the calculation of the thermal heat flux and the peak positive incident pressure, the standoff distance means:

- For the thermal heat flux calculation – Standoff distance is the calculated distance from the center of the fireball to the target. The target can be the perimeter of the proposed HUD-assisted project site or where the fire barrier can be implemented.
- For the peak positive incident pressure calculation – Standfoff distance is the measured distance from the center of the container (hazard) being assessed to the target. The target can be the perimeter of the proposed HUD-assisted project site or where the blast barrier can be implemented.

Thermal Heat Flux (Q) – Amount of heat being radiated from a source. In other words, the heat wave generated from combustion.

Thermal Radiation – Process by which energy is emitted by a warm or hot surface. The energy is electromagnetic radiation and travels at the speed of light and does not require a medium to carry it. Thermal radiation ranges in frequency from infrared rays through visible light to ultraviolet rays. The intensity and frequency distribution of the emitted rays are determined by the nature and temperature of the emitting surface; in general, the hotter the object, the shorter the wavelength.

TNT (Trinitrotoluene) – Useful explosive material with convenient handling properties.

TNT Equivalent Weight – The weight of TNT which would produce an explosion of equal magnitude as a unit mass of the hazardous substance under pressure.

VI - Units of Measure

The following are the units of measure used throughout this guidance:

Area

Unit of measure	Abbreviation
Square foot	ft^2

Density

Unit of measure	Abbreviation
Kilogram per cubic meter	kg/m^3

Heat of Combustion

Unit of measure	Abbreviation
Kilocalories/Kilogram	kcal/kg
MegaJoules/Kilogram	MJ/kg

Heat Emissivity

Unit of measure	Abbreviation
British Thermal Unit per square foot per hour	BTU/ft^2-hr
Kilowatt per square meter	kw/m^2

Length

Unit of measure	Abbreviation
Meter	m
Centimeter	cm
Kilometer	km
Inch	in
Foot	ft
Mile	mi

Mass

Unit of measure	Abbreviation
Kilogram	kg

Pressure

Unit of measure	Abbreviation
Pounds per square inch	psi

Volume

Unit of measure	**Abbreviation**
Cubic Meter	m^3
Cubic Centimeter	cm^3
Cubic Inch	in^3
Cubic Foot	ft^3
Ounce	oz
Pint	pt
Quart	qt
Liter	li
U.S Gallon	gal
British Imperial Gallon	Imp gal

Weight

Unit of measure	**Abbreviation**
Pounds	lbs

VII – Basic Mitigation Principles

Why is mitigation required? - Mitigation is required to protect the buildings and the people that will perform activities related to the proposed HUD-assisted project site locations. This applies whether the HUD-assisted project is intended for residential, recreational, institutional or commercial use.

When is mitigation required? - When the ASD is not achievable between the hazard and the proposed site for development, and no suitable site is available.

If the ASD is achievable, mitigation is not required.

(The requirement for achieving the ASD or using mitigation applies only to HUD-assisted projects close to specific stationary, hazardous operations which store, manage, or process materials of an explosive or flammable nature.)

VIII – Basic Barrier Principles

When is a barrier required? – If the ASD from a facility that processes, stores or manufactures substances of explosive or fire prone nature (hazardous facility) cannot be achieved for a proposed HUD-assisted project based on the following departmental standards:

- Thermal Radiation
  - Structures - 10,000 BTU/ft^2-hr;
  - People – 450 BTU/ft^2-hr

- Blast Overpressure
  - Structures - 0.5 psi

And there are no *natural or man-made barriers* in between the proposed HUD-assisted project and the hazardous facility of adequate size and strength that can shield the proposed HUD-assisted project from the hazardous facility,

The following mitigation options are suggested:

- Bury the hazard – Often a less expensive alternative to building a mitigation barrier.
- Modify the building design to compensate for the ASD - The building design can be modified by using heat retardant and high tensile strength materials in the direction where the hazardous facility is located, to compensate for the ASD. Buildings can also be re-arranged and their exteriors shapes modified. A combination of these approaches may be used to provide an acceptable level of protection, e.g., a horseshoe-shaped building oriented with the convex curve facing the hazard and the structure augmented with heat retardant and tensile strength materials.
- Choose another site
- Lastly, you can resort to a barrier.

How does a barrier work/what does it do? - A barrier works as abatement for thermal heat flux and blast overpressure and provides protection to HUD-assisted projects when the ASD is not achievable.

Depending on the hazard being studied, the barrier can be designed to withstand the following:

- Blast Overpressure
- Thermal Heat Flux
- Or both

Based on the thermal heat flux emitted from combustion of a flammable product or the peak positive incident pressure (blast overpressure) from a containerized product under pressure (if the product is chemically unbalanced and explodes with high energy), a barrier can be designed and implemented to protect the HUD-assisted project.

Who should design a barrier? - Only a licensed professional (e.g., civil or structural engineer) should design and oversee the construction of mitigation barriers.

What information is needed for the design of barriers for mitigation? -

For sites involving projects with blast overpressure conditions – Peak positive incident pressure
For sites involving projects with thermal heat flux conditions – Thermal heat flux value

IX – Guidelines for the Users of this Document

This section is based on a site mitigation analysis, to provide users with a basic guideline using questions (a-e), related to the HUD-assisted project site. Based on the results of the site mitigation analysis, the required information can be provided to the licensed professional engineers (civil or structural) for a barrier to be designed and implemented to provide the required level of protection for the proposed HUD-assisted project site.

Mitigation analysis questions for the proposed site:

a) Has the Acceptable Separation Distance (ASD) been calculated?

If the ASD has not been calculated, then

- Calculate the ASD – The ASD is the first step towards mitigation analysis for HUD-assisted projects near hazardous operations that store, handle or process fire-prone or explosive materials.

If the ASD has been calculated, two results are possible:

- The ASD is achievable using the proposed site - No further action required
- The ASD is not achievable using the proposed site – Mitigation may be required

b) The ASD has been calculated for the proposed HUD-assisted project site and it is not achievable. Do <u>natural or man-made barriers</u> exist between the proposed HUD-assisted project and the hazard?

- <u>Natural barriers</u> are hills, mountains, earthen elevations, etc.
- <u>Man made barriers</u> are buildings, housing developments and other structures.
- <u>Natural or man-made barriers</u> may serve as abatement from thermal heat flux or blast overpressure effects that can impact HUD-assisted projects and the people who will perform activities associated with the respective projects.

If there are natural or man-made barriers between the proposed HUD-assisted project site and the hazard, will the available barrier serve as abatement from the potential effects (thermal heat flux, blast overpressure or both) of the hazard?
The following points provide valuable information to evaluate the available barrier between the proposed HUD-assisted project and the hazard:

- Man-made or natural barriers may serve as abatement from thermal heat flux or blast overpressure effects that can impact HUD-assisted projects and the people that will perform activities associated with the respective projects.
  - If the ASD is not achievable between the proposed HUD-assisted project site and the hazardous operation/facility, but **<u>there is not a clear line of sight</u>** between the proposed HUD-assisted project site and the hazard,

mitigation may not be required. Under the regulation 24 CFR Part 51 Subpart C, if there is natural or man made abatement in between the proposed HUD-assisted project site and the studied hazard site, impeding a clear view from the proposed HUD-assisted project site to the hazard site, the abatement ***might serve*** as mitigation for the proposed HUD-assisted project.

  - If it has been determined that mitigation may not be required using the above mentioned analysis, the natural or man made abatement must be further analyzed to ensure it will provide an acceptable level of protection for the proposed HUD-assisted project site. Only a licensed professional engineer (civil or structural) should analyze and confirm the acceptability of preexisting barriers, based on the hazard being analyzed.

- If the ASD is not achievable between the site to be developed and the hazard operation/facility **and there is a clear line of sight** between the proposed HUD-assisted project site and the hazard operation, **mitigation *is* required**.

c) There are natural or man-made barriers between the HUD-assisted project site and the hazard. How can it be determined if the natural or man-made barriers in between the proposed HUD-assisted project site and the hazard are of adequate size and strength that can shield the proposed HUD-assisted project from the hazard?

Determining if the natural or man-made barriers are of adequate strength and size is done by calculating the peak positive incident pressure (blast overpressure) for a containerized product under pressure (if the product is chemically unbalanced and explodes with high energy) or the thermal heat flux (heat emissivity) from combustion of a flammable product.

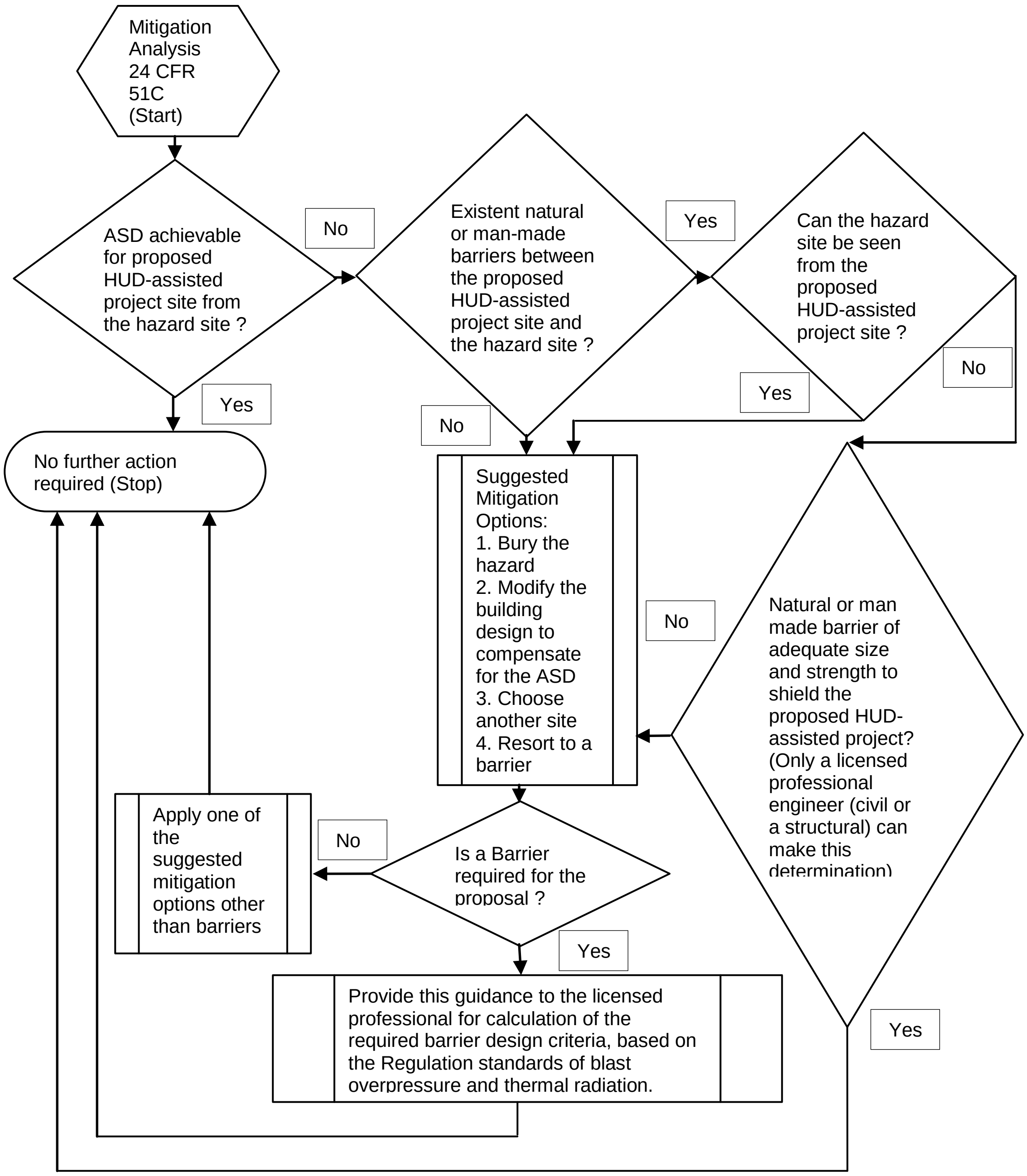
Natural and man-made barriers are analyzd for structural strength, based on the thermal heat flux, peak positive incident pressure or both, emitted from the hazard.

Only a licensed professional engineer (civil or structural) is qualified to analyze a natural or a man-made barrier for structural strength under the following scenarios:

- An existent natural or man-made barrier is located between a hazard and a HUD-assisted project site, or
- A barrier must be designed, constructed and implemented between a hazard and a HUD-assisted project site

The **thermal heat flux and/or the peak positive incident pressure** values must be calculated for a complete analysis or design of mitigation barriers. Only a licensed professional engineer (civil or structural) should design and oversee the construction of mitigation barriers. **For questions or concerns calculating the thermal heat flux or the peak positive incident values on the analysis or design of mitigation barriers, please contact Headquarters** (Office of Environment and Energy, Nelson A. Rivera – 202-402-4455).

Flowchart illustrating a mitigation analysis for a proposed HUD-assisted project site



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- **Calculation of the Thermal Heat Flux (Q)**

For inquiries involving thermal radiation emitted from a hazard, the natural or man-made barrier must be analyzed or designed for the amount of heat the barrier can withstand from the hazard. This heat is known as the thermal heat flux. The thermal heat flux is the heat from combustion emitted from the hazard.

A mathematical formula for the determination of the thermal heat flux emitted from a hazard is as follows:

Formula #1: Q = [828x(Mass of Vapor of Substance being Assessed (kg))$^{0.771}$]/[Standoff Distance(meter)]^2

Note: "x" means multiply; "/" means divide

The following formula is used to determine the mass of vapor of the substance being assessed, emitted from the hazard's container:

Formula #1.1: Mass of Vapor of the Substance being Assessed = Volume of Vapor of the Substance being Assessed (m^3) x Substance Vapor Density (kg/m^3)

Where,

Volume of Vapor of the Substance being assessed = [Volume of Container being Assessed x 0.15] (m^3)

Note: the ratio of 0.15 means the percentage of vapor content in a container with a liquid–gas (vapor) mixture contained under pressure.

Section XIII of this guidance includes a table with fuel vapor density values for most common hydrocarbon fuels used in industry.

Formula #1.2: Standoff Distance = [(Fire ball flame height (m))^2 + (Distance at ground level from the origin (m))^2]$^{0.5}$

Distance at ground level from the origin (m) = distance from the closest point on the perimeter of the container being assessed to either of the following:

- the closest point on the perimeter of the proposed HUD-assisted project site or
- the area where a fire barrier can be implemented.

Formula #1.2a: Fire ball flame height = 12.73 x (Volume of Vapor of the substance being assessed (m^3))$^{1/3}$.

Table I: Volume conversion

The following table provides unit conversion factors for volume calculation

The actual number of a type of unit in the first column should be multiplied by the appropriate factor to convert to the indicated type of unit in the succeeding columns

	meter^3	**centimeter^3**	**liter**	**foot^3**	**inch^3**
cubic meters	1	10^6	1000	35.31	$6.102\text{x}10^4$
cubic centimeters	10^{-6}	1	10^{-3}	$3.531\text{x}10^{-5}$	$6.102\text{x}10^{-2}$
liters	10^{-3}	1000	1	$3.531\text{x}10^{-2}$	61.02
cubic feet	$2.832\text{x}10^{-2}$	$2.832\text{x}10^4$	28.32	1	1728
cubic inches	$1.639\text{x}10^{-5}$	16.39	$1.639\text{x}10^{-2}$	$5.787\text{x}10^{-4}$	1

1 U.S. fluid gallon = 4 U.S. fluid quarts = 8 U.S. fluid pints = 128 U.S. fluid ounces = 231 in^3
1 British imperial gallon = 277.4 in^3
1 liter = 10^{-3} m^3

HINT: To change from gallons to m^3 (cubic meters), multiply the amount of gallons (volume) by the quantity $1.6387\text{x}10^{-5}$ times 231.
This is: Given [volume in gallons] x ($1.6387\text{x}10^{-5}$) x 231

Steps providing clarification for the determination of the following properties from a substance being assessed (hazard):

- Mass of vapor
- Volume of vapor
- Vapor density
- Thermal heat flux

Step 1:

- The mass of vapor of the substance being assessed can be calculated by using **Formula # 1.1**.
- The volume of vapor of the substance being assessed can be calculated by multiplying the volume of the container being assessed by 0.15.
- **Formula # 1.1** requires the volume of vapor of the substance being assessed to be expressed in units of cubic meters.
- Table I and the information following it provide unit conversion factors for container volume calculation.
- **Section XIII** of this guidance includes a table with fuel vapor density values for most common hydrocarbon fuels used in industry.

Step 2:

- Calculate the standoff distance. The standoff distance is calculated by using **Formula #1.2** and **Formula #1.2a**.

The following notes are for standoff distance determination:

Notes:

- When there are two or more containers of the same size, the thermal heat flux needs to be evaluated for the container with the closest standoff distance to the site.
- When two containers of different sizes expose a site and the larger container is closer to the site, the thermal heat flux is evaluated only for the larger container.
- When two of the same kind of containers of different size are exposed to a site and the smaller container is closer to the site, the thermal heat flux needs to be evaluated for both containers.

Formula #1 requires the standoff distance to be expressed in units of meters (m).

Table II: Length conversion

The following table provides unit conversion factors for length calculation

The actual number of a type of unit in the first column should be multiplied by the appropriate factor to convert to the indicated type of unit in the succeeding columns.

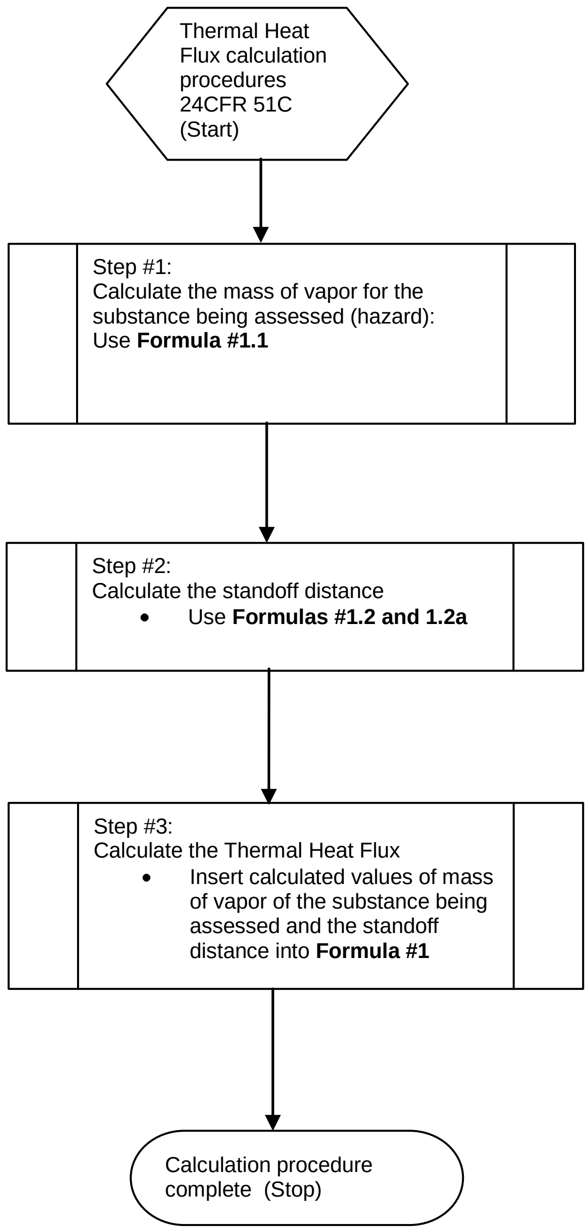
	centimeters	**meters**	**kilometers**	**inches**	**feet**	**miles**
centimeters	1	10^{-2}	10^{-5}	0.3937	3.281×10^{-2}	6.214×10^{-6}
meters	100	1	10^{-3}	39.37	3.281	6.214×10^{-4}
kilometers	10^{5}	1000	1	3.937×10^{4}	3281	0.6214
inches	2.540	2.54×10^{-2}	2.54×10^{-5}	1	8.33×10^{-2}	1.57×10^{-5}
feet	30.48	0.3048	3.04×10^{-4}	12	1	1.89×10^{-4}
miles	1.60×10^{5}	1609	1.609	6.33×10^{4}	5280	1

Step 3:

- Calculate the thermal heat flux by inserting the values previously determined for the mass of vapor of the substance being assessed and the standoff distance into **Formula #1.**

HINT: The thermal heat flux value provided by **Formula #1** is expressed in kw/m^2 (Kilowatt/square meter) units. To convert this value into BTU/ft^2-hr (British Thermal Unit/square foot-hr) units, multiply the kw/m^2 result by 317.0781.

Flowchart illustrating Thermal Heat Flux calculation procedures for a hazard



- **Calculation of the peak positive incident pressure (Ps)**

For inquiries involving blast overpressures emitted from a hazard, the natural or man made barrier must be analyzed or designed for structural strength sufficient for the pressure the barrier may experience from the hazard. This pressure is known as the peak positive incident pressure. The peak positive incident pressure is the pressure emitted from a hazard's pressure wave after an explosion has occurred.

A mathematical formula for the determination of this pressure is as follows:

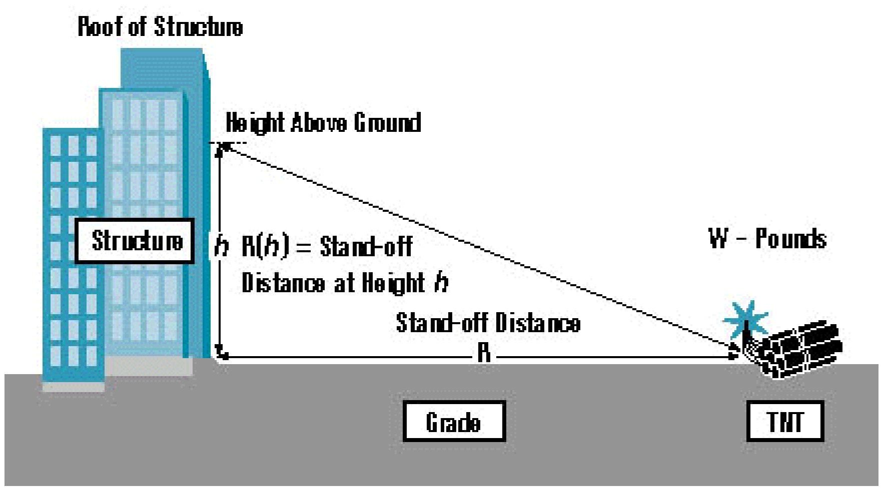
Formula #2: Z = Scaled Distance = $R/(W)^{1/3}$

Where,

R= Standoff distance (ft) between the explosive hazard and the proposed HUD-assisted project site. The distance is measured from the center of the largest capacity container to the proposed HUD-assisted project site or the area where a blast barrier can be implemented.

W= TNT equivalent weight of the hazard being analyzed/studied

Below is a visual representation of a hazard (TNT equivalent weight – W) and the standoff distance (R) between the hazard and a structure



Formula #3: TNT equivalent weight = W = Mc x (Hc/1155) x Y

Where,

Mc = mass of the substance (hazard) being assessed (kg)

Hc = heat of combustion of the substance (hazard) being assessed (kcal/kg),

Y = yield factor (the fraction of the mass of the substance (hazard) that contributes to the explosion).

Steps providing clarification for the determination of the following properties from a substance being assessed (hazard):

- TNT equivalent weight
- Scaled distance
- Peak positive incident pressure

Step 1:

- The TNT equivalent weight for the substance being assessed (hazard) can be calculated by using **Formula #3.**

Where,

Mc = mass of the chemical (hazard) being analyzed, in kilograms

- Density = Mass/Volume, expressed in kilograms per cubic meter (kg/m^3)
  - Mass = Density x Volume, expressed in kilograms

Mc = Density of the chemical (hazard being analyzed) multiplied by the Volume of the container.

Section XI of this guidance includes a table with density values for the most common hazardous and non-hazardous (for reference) substances used in industry.

Formula #3 requires container volume to be expressed in units of cubic meters (m^3).

Table I provides unit conversion factors for container volume calculation.

If the container volume is provided in gallons, multiply the amount of gallons by 1.6387×10^{-5} times 231 to convert gallons to cubic meters.

This is: Given [volume in gallons] x (1.6387×10^{-5}) x 231

Step 1a – The heat of combustion (Hc) for most common fuels and organic compounds can be obtained from **Section XII** of this guidance in unit values of Mega Joules per kilogram (MJ/kg).

- **Formula #3** requires the heat of combustion to be expressed in units of kilocalories per kilogram (kcal/kg).

- To perform this unit change, multiply the Mega Joules per kilogram value by 238.8 to obtain a value in units of kilocalories per kilogram (kcal/kg).

Step 1b – Assign a value of 0.02 to the yield factor (Y). The yield factor is the fraction of the mass of a substance being assessed (hazard) that contributes to the explosion.

Step 1c - The values of Mc (mass of a substance being assessed (hazard)), Hc (heat of combustion of a substance being assessed), and Y (yield factor) are used in **Formula #3** to calculate the equivalent weight of TNT (W).

Step 2 – Calculate the standoff distance (R). The standoff distance is measured from the center of the container (hazard) being assessed to the closest point of the perimeter of the proposed HUD-assisted project site or the area where a blast barrier can be implemented.

HINT: Always measure from the closest point of the perimeter.

<u>The following notes are for standoff distance determination</u>:

Notes:

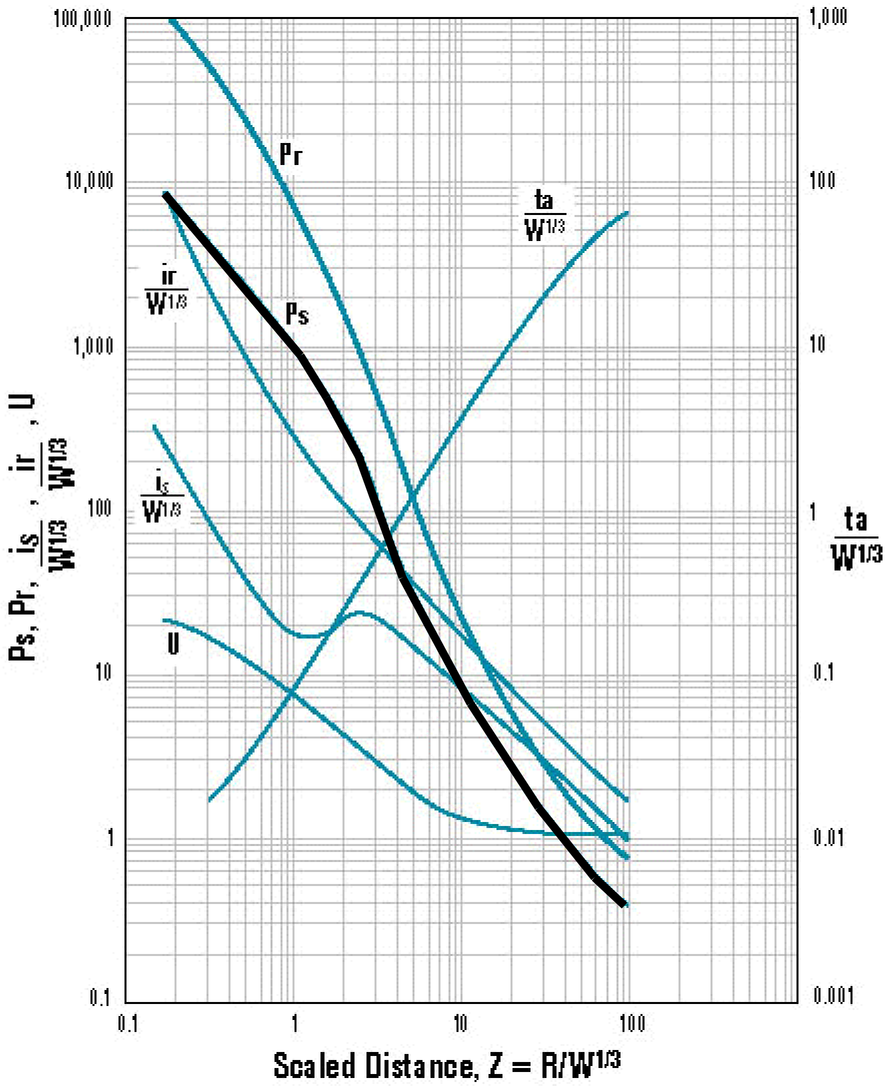
- When there are two or more containers of the same size, the peak positive incident pressure needs to be evaluated for the container with the closest standoff distance to the site.
- When two containers of different sizes expose a site and the larger container is closer to the site, the peak positive incident pressure needs to be evaluated only for the larger container.
- When two of the same kind of containers of different size are exposed to a site and a smaller container is closer to the site, the peak positive incident pressure needs to be evaluated for both containers.

Formula #2 requires the standoff distance to be expressed in units of feet (ft).

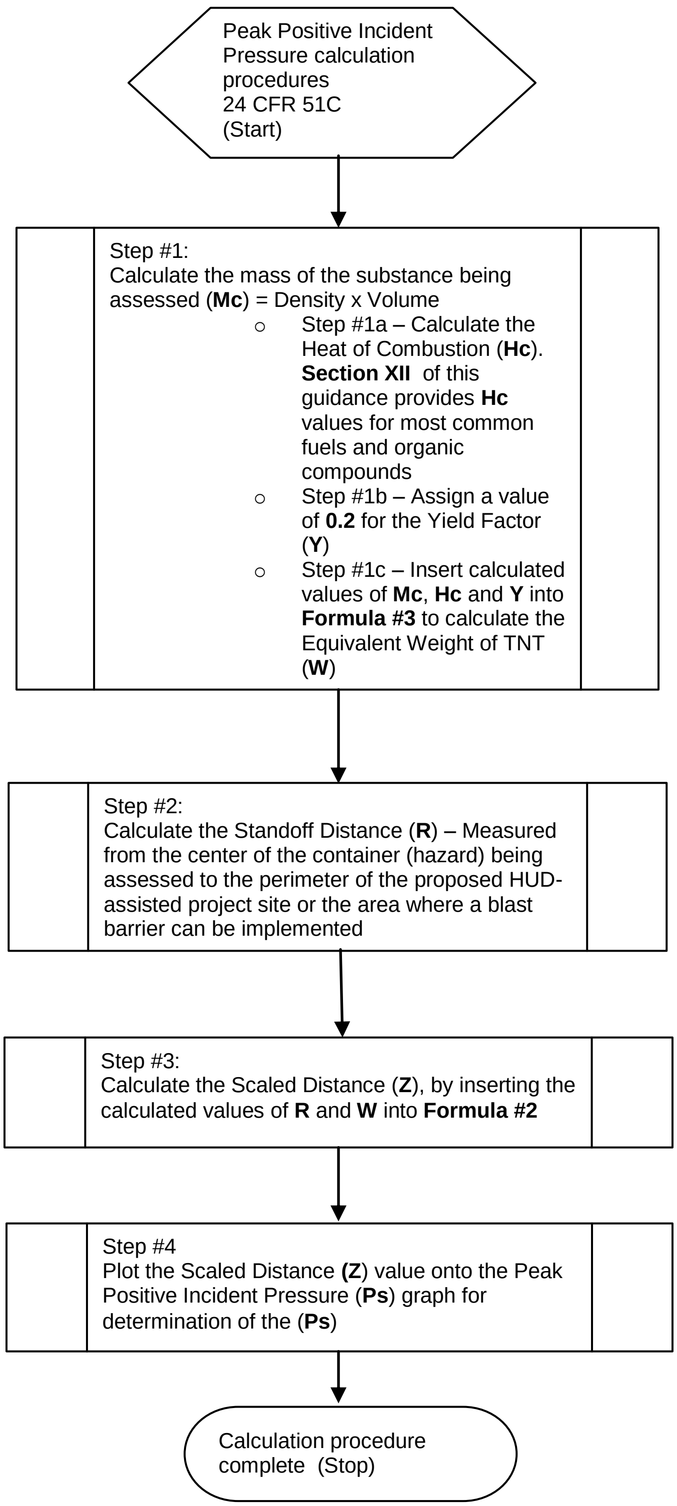
<u>Table 2</u> provides unit conversion factors for length calculation.

Step 3 - Once the standoff distance (R) has been determined, the scaled distance (Z) can be calculated by inserting the values of R and W (equivalent weight of TNT) in **Formula #2**.

Step 4 – Once the scaled distance has been calculated, the value can be plotted in the following graph for the determination of the peak positive incident pressure (Ps).



Flowchart illustrating Peak Positive Incident Pressure calculation procedures for a hazard



d. If there are no natural or man made barriers between the HUD proposed project site and the hazard and the last resort is to design and implement a barrier,

What information must be known and provided to the structural engineer for the design of the subject barrier?

For inquiries regarding the design and implementation of barriers, the following site information is required:

- A project layout map (for better analysis of the hazard(s) in relation to the proposed HUD-assisted project location)
- Site map (preferably a topographic map with elevations)
  - Digitized topographic maps:
    - Free digital topographic maps for general public use are available from the following sources:
      - Yahoo maps, http://developer.yahoo.com/maps/
      - Google Earth, http://earth.google.com/

    Note: HUD does not endorse any of the referenced electronic sources of information
  - Address of the HUD-assisted project and the facility with the hazard(s)
- Using the site map, and a mile as a radius parameter distance, plot a perimeter from the center of the proposed HUD-assisted project site, to delineate a project boundary where facilities inside that boundary that store, manufacture or process substances of explosive or fire prone nature must be evaluated for ASD determination
    - Within those identified facilities, if there are containers for storage of chemicals of fire prone or explosive nature, identify and list the following characteristics for each container:
      - Chemical name (not the trade name).
      - Type (above ground only) and size (volume capacity in gallons) of each of the containers on site.
      - If containers are diked or undiked. If diked, provide the dike area in square feet.
  - If containers are storing pressurized (gases) or unpressurized (liquids) substances.
  - Standoff distance for calculation of the peak positive incident pressure or thermal heat flux.

d.1. For stationary containers, storing substances under pressure of explosive nature (fire may or may not be an additional product of the explosion, depending on the flammability of the substance being assessed)

What information is required to be provided to the structural engineer for the design and implementation of a blast barrier?

The peak positive incident pressure

Once the peak positive incident pressure has been calculated, a structural engineer can design and implement a blast barrier to withstand that peak positive incident pressure emitted from a hazard.

What information is required to be provided to the structural engineer for the design and implementation of a fire barrier (if the substance being assessed has flammable properties)?

The thermal heat flux
The thermal heat flux is the heat from combustion emitted from a hazard

Once the thermal heat flux has been calculated, a structural engineer can design and implement a fire barrier to withstand that thermal heat flux.

d.2. For stationary containers, storing substances not under pressure of fire-prone nature, what procedure should be followed to address the required information to be provided to the structural engineer for the design and implementation of a fire barrier?

1. *To calculate the thermal heat flux (Q),from substances bearing the specified conditions as stated in d.2, please contact Headquarters* (Office of Environment and Energy, Nelson A. Rivera – 202-402-4455)*. The thermal heat flux effects on the proposal need to be calculated on a case by case basis, and depending on the results of the analysis, if a fire mitigation wall is required it may not be feasible for the developer due to the size requirements to mitigate the fire ball produced by the hazard.*

e. Has the project been rejected or have mitigation options other than barrier construction (e.g., the hazard will be buried) been identified?

- If the project has been rejected – no further action is required
- If the hazard will be buried – no further action is required
- If another site, that does not have hazards, will be used to meet the project goal – no further action is required

X - Mitigation Example:

Site information:

Calculate the peak positive incident pressure (Ps) from a 1000 gallon container of liquid propane gas, at 3 ft, 9 ft, 50ft and 100ft distance, for a HUD housing development that is planned to be built at 50 ft from the subject container.

Note: Barriers should be constructed as close to the hazard source as possible. In this example, we are calculating the peak positive incident pressure (Ps) at various distances from the hazard to demonstrate that the Ps value decreases depending on how far this pressure is measured from the hazard. In this example, the barrier will be designed at 3 ft from the hazard.

Since the barrier will be implemented at 3 ft from the hazard and propane gas can produce blast overpressure and thermal radiation, we also must calculate the thermal heat flux (Q) at 3 ft from the subject container.

There are no man made or natural barriers between the location of the HUD project site and the hazard (container). There is a clear line of sight from the hazard to the location of the proposed HUD site for a housing development.

Site mitigation analysis:

In accordance with Worksheet # 4, located at page 12 of the HUD ASD Guidance, (Siting of HUD-Assisted Projects Near Hazardous Facilities) the Acceptable Separation Distance for blast overpressure for the container of this example is 220 ft.

In accordance with Worksheet # 3, located at page 11 of the HUD Guidance (Siting of HUD-Assisted Projects Near Hazardous Facilities) the Acceptable Separation Distance for thermal radiation for the container of this example is 50 feet for buildings and 275 for people.

The location for the proposed HUD site for development meets the department's acceptable separation distance requirement for thermal heat flux for buildings but not for people.

The location for the proposed HUD site for development does not meet the department's acceptable separation distance requirement for blast overpressure for buildings.

The location for the proposed site does not allow a new building design configuration for protection of the building occupants from the heat or blast overpressure emitted from the hazard, there are no natural or man-made barriers between the hazard and the location of the HUD proposed site and because of environmental regulations, the container (hazard) cannot be buried.

As a last resort, if a barrier was to be designed and implemented between the hazard and the location of the HUD proposed site for development, the thermal heat flux (from the heat of combustion emitted from the hazard) and the peak positive incident pressure (blast overpressure) are required to be provided to the structural engineer, for the protection of the people and buildings related to the HUD-assisted project.

Peak Positive Incident Pressure Calculation:

Substance being assessed = Liquid Propane Gas

The density of propane in liquid form is 493.53 Kg/m^3 **– Section XI** of this guidance

The container with liquid propane gas has a volume of 1000 gallons. Such volume in units of m^3 (cubic meters) is 3.7854.

To change from gallons to cubic meters:
(1000 x 1.6387×10^{-5} x 231)

Density = mass / volume

Mass = density x volume

Mass of chemical being analyzed (Mc) = 493.53 x 3.7854 = 1,868.20 kg

Heat of combustion for propane = Hc (For liquid propane gas) = 46.357 MJ/kg – **Section XII** of this guidance.

Heat of combustion for propane changed from MegaJoules/kilograms (MJ/kg) into kilocalories/kilograms (kcal/kg) = 46.357 MJ/kg = 11,070 kcal/kg

To change from MegaJoules/kilograms to kilocalories/kilograms:
(46.357 x 238.8)

Y is the yield factor (the fraction of the mass of chemical that contributes to the explosion, which is 0.02 for fuel gas explosions)

The values of Mc, Hc and Y are used in **Formula #3** to calculate the equivalent weight of TNT (W) as follows:

W = 1,868.20 x (11,070/1155) x 0.02

W = 358.11 Lbs

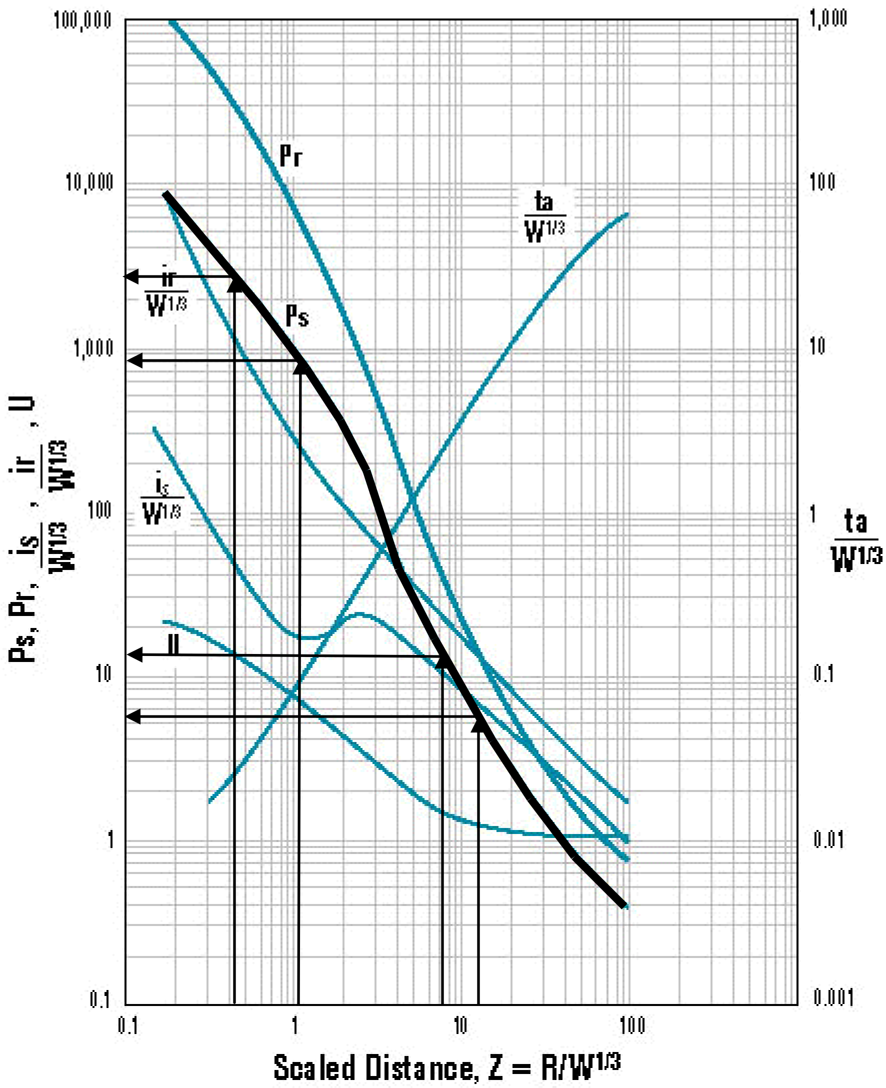
The following are the standoff distances (R) where the scaled distances will be calculated:

At 3 feet, 9 feet, 50 feet and 100 feet

The scale distances (Z) can be determined by using the previous stated standoff distances in **Formula #2** as follows:

At 3 feet standoff distance: $Z = R/(W)^{1/3} = 3/(358.11)^{1/3} = 0.423$
At 9 feet standoff distance: $Z = 9/(358.11)^{1/3} = 1.27$
At 50 feet standoff distance: $Z = 50/(358.11)^{1/3} = 7.04$
At 100 feet standoff distance: $Z = 100/(358.11)^{1/3} = 14.08$

Once the scaled distances have been calculated, the values are plotted in the following graph for the determination of the peak positive incident pressures (Ps)



The peak positive incident pressures (Ps) are as follow:
At 3 feet standoff distance: Z = 0.423, the Ps = 2,800 psi
At 9 feet standoff distance: Z = 1.27, the Ps = 800 psi
At 50 feet standoff distance: Z = 7.04, the Ps = 15 psi
At 100 feet standoff distance: Z = 14.08, the Ps = 5.6 psi

The substance being assessed (propane gas) poses the following hazards:

- Blast overpressure (calculated for a barrier design specification as the peak positive incident pressure)
- Thermal radiation (calculated for a barrier design specification as the thermal heat flux)

The thermal heat flux at 3 ft from the hazard (liquid propane gas container) can be calculated as follows:

The vapor density of propane is 1.60 kg/m^3 – **Section XIII** of this guidance

Volume of liquid propane vapor = Volume of container where the liquid propane is stored = 1,000 gallons x 0.15 = 150 gallons = 0.5678 m^3

To change from gallons to cubic meters:
(150 x (1.6387x10^{-5}) x 231)

Using **Formula #1.1**,

Mass of Vapor of the Substance being Assessed = Volume of Vapor of the Substance being Assessed x Substance vapor density (kg/m^3)

Mass of vapor of liquid propane = 0.5678 x 1.60 = 0.9085 kg

Using **Formula #1.2a**,

Fire ball flame height = 12.73 x (Volume of liquid propane vapor (m^3))$^{1/3}$

Fire ball flame height = 12.73 x 0.5678$^{1/3}$ = 10.54 m

The distance at ground level to the origin = 3 feet = 0.9144 m

To change from feet to meters:
(3 x 0.3048)

Using **Formula #1.2**,

Standoff Distance = [(Fire ball flame height) (m))^2 + (Distance at ground level to the origin (m))^2]$^{0.5}$

Standoff Distance = [10.54^2 + 0.9144^2]$^{0.5}$ = 10.58 m

By inserting the calculated values of the mass vapor of liquid propane and the standoff distance into **Formula #1**,

Thermal Heat Flux = Q = (828 x (mass of vapor of liquid propane)$^{0.771}$) / (Standoff distance)^2

$Q = (828 \times 0.9085^{0.771}) / (10.58)^2 = 6.87$ kw/m^2 = 2,178.18 BTU/ft^2-hr

To change from kw/m^2 to BTU/ft^2-hr:
(6.87 x 317.0781)

Suggested design criteria for a barrier, to be provided to the structural engineer, would be as follows:

"A barrier, made out of a material to withstand a calculated thermal heat flux of 2,178.18 BTU/ft^2-hr and peak positive incident pressure of 2,800 psi must be designed and implemented between the hazard and the proposed project, shielding all points of the project, from line of sight exposure to the container (hazard), so the subject hazard can be appropriately mitigated."

XI - The following table provides the density of most common hazardous and not hazardous substances including fuels. The table does not include the "universe" of substances, but it includes the most used in industry.

Liquid	Temperature (Degrees C)	Density (kg/cubic meter)
1,1,2-Trichlorotrifluoroethane	25	1564
1,2,4- Trichlorobenzene	20	1454
1,4 - Dioxane	20	1033.60
2-Methoxyethanol	20	964.60
Acetic Acid	25	1049.10
Acetone	25	784.58
Acetonitrile	20	782.20
Alcohol, ethyl	25	785.06
Alcohol, methyl	25	786.51
Alcohol, propyl	25	799.96
Ammonia (aqua)	25	823.35
Analine	25	1018.93
Automobile oils	15	880-940
Beer (varies)	10	1010
Benzene	25	873.81
Benzil	25	1079.64
Brine	15	1230
Bromine	25	3120.40
Butyric Acid	20	959
Butane	25	599.09
n-Butyl Acetate	20	879.60
n-Butyl Alcohol	20	809.70
n-Butyl Chloride	20	886.20
Caproic Acid	25	921.06
Carbolic Acid	15	956.30
Carbon disulfide	25	1260.97
Carbon tetrachloride	25	1584.39
Carene	25	856.99
Castor oil	25	956.14
Chloride	25	1559.88
Chlorobenzene	20	1105.80
Chloroform	20	1489.20
Chloroform	25	1464.73
Citric Acid	25	1659.51
Coconut oil	15	924.27
Cotton seed oil	15	925.87
Cresol	25	1023.58
Creosote	15	1066.83
Crude Oil, 48degrees API	60F	790
Crude Oil, 40degrees API	60F	825
Crude Oil, 35.6degrees API	60F	847
Crude Oil, 32.6degrees API	60F	862
Crude Oil, California	60F	915

Crude Oil, Mexican	60F	973
Crude Oil, Texas	60F	873
Cumene	25	860.19
Cyclohexane	20	778.50
Cyclopentane	20	745.40
Decane	25	726.28
Diesel Fuel 20 to 60	15	820-950
Diethyl ether	20	714
o-Dichlorobenzene	20	1305.80
Dichloromethane	20	1326.00
Diethylene glycol	15	1120
Dichloromethane	20	1326.00
Dimethyl Acetamide	20	941.50
N,N-Dimethylformamide	20	948.70
Dimethyl Sulfoxide	20	1100.40
Dodecane	25	754.63
Ethane	-89	570.26
Ether	25	72.72
Ethylamine	16	680.78
Ethyl Acetate	20	900.60
Ethyl Alcohol	20	789.20
Ethyl Ether	20	713.30
Ethylene Dichloride	20	1253.00
Ethylene glycol	25	1096.78
Fluorine refrigerant R-12	25	1310.95
Formaldehyde	45	812.14
Formic acid 10% concentration	20	1025
Formic acid 80% concentration	20	1221
Freon 11	21	1490
Freon 21	21	1370
Fuel oil	60	890.13
Furan	25	1416.03
Furforol	25	1154.93
Gasoline, natural	60	711.22
Gasoline, Vehicle	60	737.22
Gas oils	60	890
Glucose	60	1350-1440
Glycerin	25	1259.37
Glyme	20	869.10
Glycerol	25	1126.10
Heptane	25	679.10
Hexane	25	654.83
Hexanol	25	810.53
Hexene	25	671.17
Hydrazine	25	794.52
Iodine	25	4927.28
Ionene	25	932.27

Isobutyl Alcohol	20	801.60
Iso-Octane	20	691.90
Isopropyl Myristate	20	853.20
Kerosene	60	817.15
Linolenic Acid	25	898.64
Linseed oil	25	929.07
Methane	-164	464.54
Methanol	20	791.30
Methyl Isoamyl Ketone	20	888.00
Methyl Isobutyl Ketone	20	800.80
Methyl n-Propyl Ketone	20	808.20
Methyl t-Butyl Ether	20	740.50
N-Methylpyrrolidone	20	1030.40
Methyl Ethyl Ketone (MEK)	20	804.90
MEK	25	802.52
Milk	15	1020-1050
Naphtha	15	664.77
Naphtha, Wood	25	959.51
Napthalene	25	820.15
Ocimene	25	797.72
Octane	15	917.86
Olive oil	20	800-920
Oxygen (liquid)	-183	1140
Palmitic Acid	25	850.58
Pentane	20	626.20
Pentane	25	624.82
Petroleum Ether	20	640.00
Petrol, natural	60	711.22
Petrol, Vehicle	60	737.22
Phenol	25	1072.28
Phosgene	0	1377.59
Phytadiene	25	823.35
Pinene	25	856.99
Propane	-40	583.07
Propane, R-290	25	493.53
Propanol	25	804.13
Propylene Carbonate	20	1200.60
Propylene	25	514.35
n-Propyl Alcohol	20	803.70
Propylene glycol	25	965.27
Pyridine	25	978.73
Pyrrole	25	965.91
Rape seed oil	20	920
Resorcinol	25	1268.66
Rosin oil	15	980
Sabiname	25	812.14
Sea water	25	1025.18
Silane	25	717.63
Sodium Hydroxide(caustic	15	1250

soda)		
Sorbaldehyde	25	895.43
Soya bean oil	15	924-928
Stearic Acid	25	890.63
Sulphuric Acid 95%	20	1839
Sunflower oil	20	920
Styrene	25	903.44
Terpinene	25	847.38
Tetrahydrofuran	20	888.00
Toluene	20	866.90
Toluene	25	862.27
Triethylamine	20	727.60
Trifluoroacetic Acid	20	1489.00
Turpentine	25	868.20
Water, pure	4	1000.00
Water , sea	77	1021.98
Whale oil	15	925
o-Xylene	20	880.20

XII – The following table provides the heat of combustion for common fuels and for some organic compounds

Heat of Combustion (MJ/kg)	
Fuels	**MJ/kg**
Hydrogen	120.971
Gasoline	47
Diesel	45
Ethanol	28.865
Propane	46.357
Butane	45.752
Wood	15
Coal	15-27
Natural Gas	54
Organic Compounds	**MJ/kg**
Methane	50.009
Ethane	47.794
Pentane	45.357
Hexane	44.752
Heptane	44.566
Octane	44.427
Nonane	44.311
Decane	44.240
Undecane	44.194
Dodecane	44.147
Isobutane	45.613
Isopentane	45.241
2-Methylpentane	44.682
2,3-Dimethylbutane	44.659
2,3-Dimethylpentane	44.496
2,2,4-Trimethylpentane	44.310
Cyclopentane	44.636
Methylcyclopentane	44.636
Cyclohexane	43.450
Methylcyclohexane	43.380
Ethylene	47.195
Propylene	45.799
1-Butene	45.334
cis-2-Butene	45.194
trans-2-Butene	45.124
Isobutene	45.055
1-Pentene	45.031
2-Methyl-1-pentene	44.799
1-Hexene	44.426
1,3-Butadiene	44.613
Isoprene	44.078
Nitromethane	10.513

Nitropropane	20.693
Acetylene	48.241
Methylacetylene	46.194
1-Butyne	45.590
1-Pentyne	45.217
Benzene	40.170
Toluene	40.589
o-Xylene	40.961
m-Xylene	40.961
p-Xylene	40.798
Ethylbenzene	40.938
1,2,4-Trimethylbenzene	40.984
Propylbenzene	41.193
Cumene	41.217
Methanol	19.937
n-propanol	30.680
Isopropanol	30.447
n-Butanol	33.075
Isobutanol	32.959
Tertiobutanol	32.587
n-Pentanol	34.727
Methoxymethane	28.703
Exoxyethane	33.867
Propoxypropane	36.355
Butoxybutane	37.798
Methanal	17.259
Ethanal	24.156
Propionaldehyde	28.889
Butyraldehyde	31.610
Acetone	28.548
Carbon (graphite)	32.808
Carbon monoxide	10.112
Ammonia	18.646
Sulfur	4.639

XIII – The following table provides the fuel vapor density for common hydrocarbon fuels

Fuel Vapor Densities (kg/m^3)	
Fuel	**kg/m^3**
Acetone	2
Acetylene	0.90
Benzene	2.80
Butane	2.00
Carbon Monoxide	1.00
Cyclohexane	29.00
Ethanal	1.50
Ethane	1.00
Ethylene	1.00
Gasoline	3.49
Heptane	3.50
Hexane	3.00
Hydrogen	0.10
Methane	0.60
Methanol	1.10
Octene	3.90
Propane	1.60
Propylene	1.50
Styrene	3.60
Toluene	3.10
Xylene	3.70

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