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**ESTIMATING THE MAGNITUDE OF
MACRO-HAZARDS**

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ABSTRACT

Flammable liquids and vapors being stored, transported, or used, present potential hazards of catastrophic scale. In this paper, the author examines the physical behavior of unconfined vapor cloud explosions (UVCE), boiling-liquid expanding-vapor explosions (BLEVE), and massive flammable liquid fires. Rules of thumb for calculating their effects are offered. The property damage and injury potentials of overpressure blast waves are discussed, as is the usefulness of the TNT equivalency analysis. Factors affecting the severity of UCVEs, BLEVEs, and massive spill fires are considered.

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Introduction

Transportation, storage, and use of flammable and explosive materials have been responsible for a number of catastrophes involving large losses of life and property. There appears to be an increasing number of such incidents with macro-hazard potential. This may be the result of increased population congestion, environmental control, and energy availability. Macro-hazard incidents, however, are not new. In 1915, ignition of a vapor cloud from a venting tank car in Ardmore, Oklahoma, caused structural damage 1,200 ft. away. Detonation of a common fertilizer, ammonium nitrate, caused the three largest industrial disasters in history. In 1921, three-quarters of the town was destroyed and 430 people died in such an explosion in Oppau, Germany. Twenty-one years later, 250 people died at Tessenloot, Belgium, and 570 were killed in a similar disaster at Texas City, Texas, in 1947.

Other large disasters have involved the massive release of flammable vapors. The 1944 spillage of about 400,000 lb. of liquified natural gas in Cleveland cost about 130 lives and destroyed 79 dwellings and many industrial and commercial buildings. In 1948, failure of a tank in Ludwigshafen, West Germany, released about 65,000 lb. of dimethyl

ether; 209 people died in the subsequent explosion. Two years ago, over 200 people were burned to death in a polypropylene tanker accident on the Mediterranean coast of Spain. These examples represent some of the worst disasters to date. There have been many more where the loss was lower only because the incident was remote or because there was sufficient warning for evacuation.

This paper covers some typical macro-hazards associated with flammable liquids and presents rules-of-thumb for estimating the magnitude of these hazards. Cryogenic fluids and gas pipeline transport are not included.

The specific macro-hazards covered will be:

Unconfined vapor cloud explosions (UVCE) which can produce an over-pressure blast wave, dangerous missiles, and a fireball.

Boiling-liquid expanding-vapor explosions (BLEVE) which produce both a fireball and dangerous missiles.

Massive flammable or combustible liquid fires which produce a continuous high level of radiant heat.

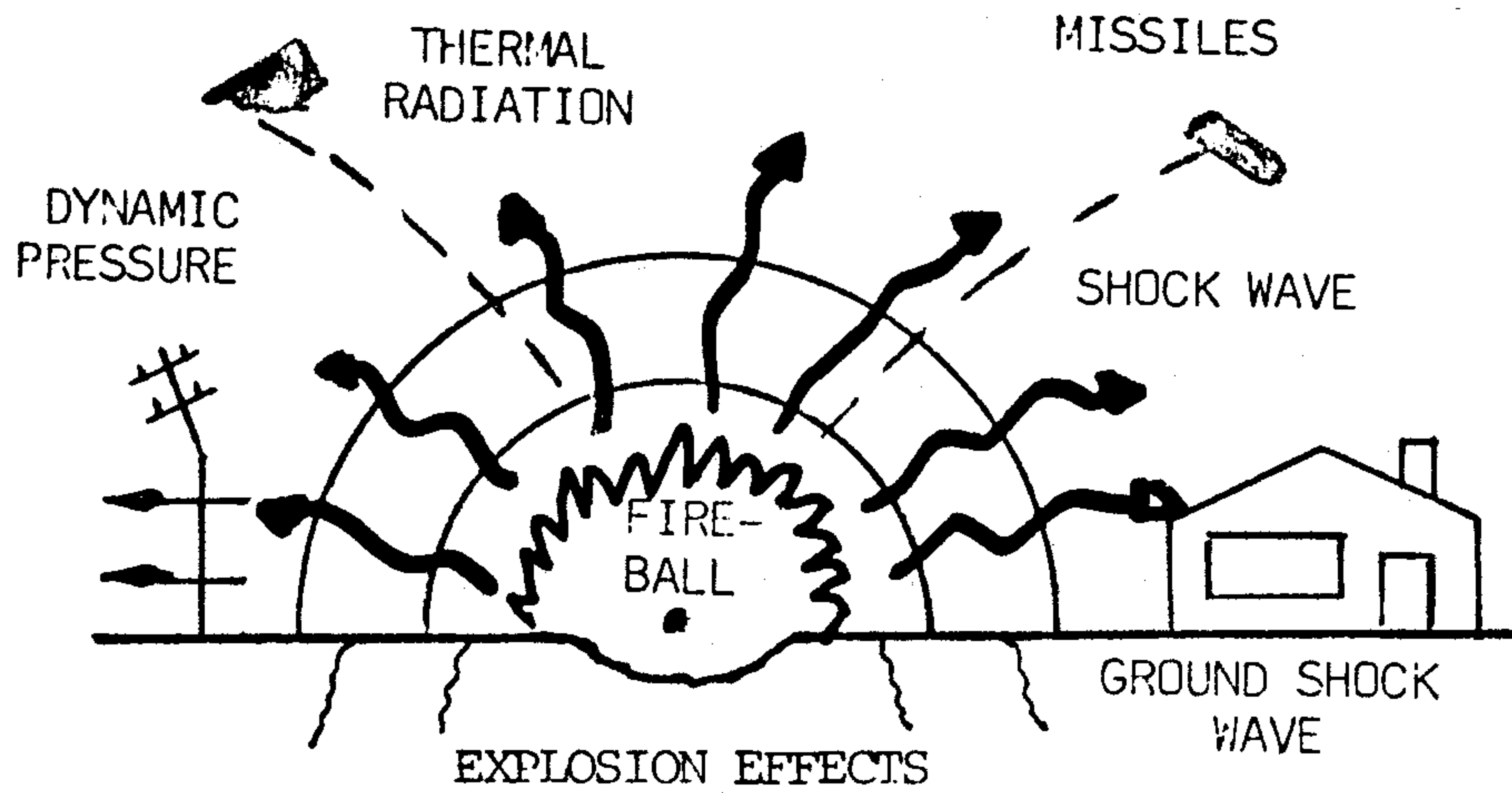


Figure 1

The emphasis herein is on the hazard, what can happen, not on the risk, what probably will happen. These relationships represent approximate, but realistic, maximums based on current knowledge. They are intended as a first step in evaluating a potential hazard and in seeing whether a more detailed risk analysis is justified. The concern is only with the far-field effects of macro-hazards. Close-in, the loss of buildings, equipment and people without special protection is highly probable. Assessment of these hazards is useful for:

- . Selecting the level of protection.

- . Protecting critical or high-value facilities.
- . Facility location and design.
- . Comparing hazards with levels currently found acceptable.
- . Calculating risks.

Unconfined Vapor Cloud Explosion (UVCE)

A cloud of a fuel can be formed whenever there is a rapid release of a flammable gas, vapor, or mist without immediate ignition. If ignited before the fuel is diluted below its flammable limits, it may burn rapidly (deflagrate), or burn so as to produce over-

pressure damage characteristic of a detonation.

The principal dangerous result of a deflagration will be the massive fireball similar to that associated with a BLEVE. The hazard potential of this fireball will depend on the weight of fuel vapor in the cloud that is above the lower flammable limit.

The unconfined vapor cloud explosion, UVCE, often represents the maximum potential hazard associated with flammable gases, vapors and mists. Vapor-cloud ignitions have caused overpressure blast wave damage characteristic of a detonation rather than a deflagration. Most flammable gases and vapors, in the proper concentration in air, will detonate when confined in particular geometric enclosures. The detonation limits are narrower than the flammable limits. However, a UVCE refers to the combustion of an unconfined fuel-air mixture which produces damaging pressure with far-field characteristics of a detonation. The fuel may be a gas, vapor, or mist. There is still a scientific controversy as to whether the UVCE is a true detonation, supersonic combustion propagation process, or some other not as yet defined phenomenon.

Interest in UVCE phenomena has increased considerably in hazard analysis of petrochemical facilities, transportation and storage, and in application of this phenomenon as a fuel-air explosive (FAE) weapons system. The LP gases, monomers, and hydrogen appear to detonate more readily than other hydrocarbons. Methane is believed not capable of detonation in a cloud, but natural gas composed of methane and heavier hydrocarbons may detonate under some circumstances. Most UVCE have involved several thousand pounds of fuel, though a number have occurred with a cloud of under 1,000 lb.

A high-explosive detonation produces many damaging effects as illustrated in

Figure 1. However, the UVCE does not produce all the effects of a high-explosive detonation; the flame front must accelerate and, therefore, detonation does not occur during the complete reaction. Cratering and ground shock waves, characteristic of high-explosive detonation, have not been observed in accidental UVCEs. The far-field overpressure effects (e.g. below 10 to 20 psi overpressure) follow the same general rules as for a detonation but the near-field effects are less severe than those of a high-explosive detonation. Dynamic pressures are produced by a UVCE but in the far-field, they will be significantly less than the blast overpressure. In addition to the overpressure blast wave, the UVCE also produces a thermal fireball and missiles which present a definite far-field danger.

BLEVE

The boiling-liquid expanding-vapor explosion, BLEVE, is the most common of fire and explosion macro-hazards. BLEVE is used to describe the results of the sudden rupture of a container containing a liquified gas whose vapor pressure is above ambient pressure. When the container fails, the liquified gas is suddenly exposed to atmospheric pressure. Since the vapor pressure is higher than atmospheric pressure, it wants to boil away. However, in order to vaporize, the liquid must absorb heat (heat of vaporization). Heat comes from cooling down some of the liquid and from the environment. As the pressurized vapor is released, the newly vaporized liquid expands. This explosive-like expansion propels liquid droplets cooled from vaporization and container fragments along with the expanding vapor into a huge cloud.

BLEVEs are most often associated with fire exposure on a liquified gas container. When the temperature of the steel exceeds about 750°F its strength starts decreasing. The heat also raises the pressure of the liquified gas which

