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RELATIVE CONSEQUENCES OF TRANSPORTING HAZARDOUS MATERIALS*

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INTRODUCTION

The transportation of hazardous materials has become a matter of increasing public interest and concern which has been voiced in requests for improvements in shipping systems and increased protection from the hazards resulting from such shipments. Included within the term hazardous materials are basic categories of materials which exhibit anoxic, corrosive, explosive, flammable, radioactive or toxic effects or characteristics. The media has expanded its coverage of accidents and incidents involving hazardous materials and there has been an increase in the number of laws and regulations governing such shipments. These rules have been promulgated because of the accidents and incidents which have occurred, and because of the increased numbers, volumes and types of materials involved. These additional rules have resulted in greater complexities of transporting, storing, and disposing of hazardous materials. Industry has responded with modifications to (or acquisition of new) equipment which has significantly improved performance of some transport systems in accidents. In addition, companies have been founded to clean up spills of hazardous materials and to return the routes and transport systems to operational status.

One aspect of the awakened interest in hazardous materials transport is reflected in the numbers of analyses describing the potential harm and risks involved. Many analyses and techniques have been developed to show the quantitative risk that accrues from transporting these materials. A number of these studies have been used to show that transportation is "safe" but some of the same studies have also been used to show how many problems and potential disasters are waiting to occur. This paradox is especially interesting to those involved in radioactive materials transportation. They weigh the objective record of no deaths or injuries from 30 years of transporting radioactive materials against that of any other category or class of hazardous material and then observe which industry "enjoys" the principal attention of the public, media, regulators and lawmakers at all levels of government. The problem here is the public's perception of the relative hazards posed by a material and their perception of the relative benefits they receive from it. The understanding of this process is part of the program at the Transportation Technology Center (TTC), and this paper deals with the relative hazards portion of the problem.

The objective of this paper is to discuss methods under study at TTC to develop a perspective on how technical measures of hazard and risk relate to perception of hazards, harm, and risks associated with transporting hazardous materials.

This paper is concerned with two major aspects of the relative hazards problem and is based on a study performed by Science Applications, Inc. The first

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aspect is the analyses of the possible effects associated with exposure to hazardous materials as contained in the following two parts: (1) outlines of possible problems and controversies that could be encountered in the evaluation and comparisons of hazards and risks and (2) description of the various measures of harm (hazards or dangers) and subsequent comparisons thereof. The second aspect of this paper leads into a presentation of the results of a study which had the following purposes: (1) to develop analytical techniques for a consistent treatment of the phenomenology of the consequences of a release of hazardous materials, (2) to reduce the number of variables in the consequence analyses by development of transportation accident scenarios which have the same meteorological conditions, demography, traffic and population densities, geographical features and other appropriate conditions and (3) to develop consistent methods for presenting the results of studies and analyses that describe the phenomenology and compare hazards. The results of the study are intended to provide a bridge between analytical certainty and perception of the hazards involved.

ANTICIPATED PROBLEMS

There are many possible problems associated with performing relative comparisons of hazards. The most important problem is how the results of a particular comparative study will be received by the public. Typically a statement comparing hazards becomes an advocacy position whether explicitly stated or implicitly indicated. For example, comparisons of natural disasters to hazards of transportation may be informative, but are of little value, because there is a benefit associated with one and not the other. Development of econometric measures of possible effects also may be informative, but will certainly create similar disagreements because of difficulties in setting prices on injuries or fatalities. Analyses of the harmful effects associated with the manufacture, processing, use or transportation of one hazardous material are often stated to be superior or safer than the same activities associated with another material. As a result, those advocating the maligned material or activity quickly assemble their resources and outline deficiencies in the original analysis. In concluding this cycle, it can be stated that both "sides" in this controversy end up with reduced credibility and the public and the decision makers have increased skepticism about both materials and activities.

An example of a problem and resulting controversy created by comparisons of the risks of nuclear power with other energy systems is described by a study performed by Inhaber.[1] The concept of risk to human health divided by the net energy produced by the energy system considering the total energy cycle was used as the comparative resource in this study. The goals of the study were to (1) assess the risks of nuclear power, and (2) place the results of the study into perspective. The results of this study showed that risks (total deaths per megawatt year) for solar power (space heating, thermal, and phhotovoltaic) were eight to forty times greater than nuclear power when the entire energy cycle was considered (acquisition of raw materials, fabrication of building materials, construction and operation). However, the problems of storage and disposal of nuclear wastes were not considered in this analysis. Regardless of whether the storage and disposal of nuclear wastes pose an actual risk to public health, the exclusion of these activities in the risk assessment violated one of the ground rules of the study by not considering an entire energy cycle. This exclusion is significant because these storage and disposal activities have been the focus of interest groups in criticism of the plans, procedures, and policies developed for nuclear wastes. An evaluation of this study indicates that its results were informative but that the relative safety of nuclear power to solar power or other energy forms was not "proven" conclusively and that the benefits of this analysis to the safety of both solar and nuclear power were questionable. Inhaber's study is typical of many that have been performed which result in adverse or construed advocacy positions for a system or material. It is sufficient to state that so many analyses have been performed to prove whatever particular result was desired that it has become difficult to perform objective analyses and develop methods to compare hazards. These analyses should be performed only under carefully controlled conditions, with stated objectives, and for selected audiences.

MEASURES OF HAZARDS AND HARM

A variety of methods have evolved or been developed to estimate harm and hazards to people and the environment. Risk assessment activities have resulted in the strongest technical analyses of these hazards. With continued interest in protecting man and the environment from possible adverse effects of hazardous materials, the perception of harm, hazards and risks has led to many positions and regulations which have little basis on the technical facts. In order to place the harm, hazards and risks in perspective, some methods have been developed which define risks in terms of cartesian coordinates. These range, in descriptive terms, from involuntary and certain fatal consequences to voluntary and certain non-fatal effects. Using such descriptions it is possible to plot activities, processes or industries on these scales.[2] Another definition set indicates whether an activity is acceptable by technical analyses and accepted by the public or is unacceptable by technical analyses and not accepted by the public.[3] The relationship of these and other imprecise measures of the perception of risk, hazards and harms to technical analyses is the goal of the study reported in this paper. The problem is extremely complicated because of the many effects that must be considered as possible results of exposure to a release of hazardous materials (e.g., death, injury, illness, birth defects, latent health effects, acute effects, genetic effects, monetary losses for cleanup and reconstruction, contamination, facility denial, evacuation, property damage, species extinction, loss of recreation, reduced aesthetic effects, social impacts in terms of disruption of social processes and reduction in the quality of life). Development of comparative criteria which places appropriate weighting factors on each of these effects has not been universally successful, but is frequently achieved in small groups by decision analyses.

Indexes of harm do provide for comparative analysis and decision procedures. These indexes can be developed with different criteria (scales) describing and linking any of the seventeen considerations noted above or other appropriate effects. An example of using such index of harm and subsequent comparison is outlined later in this paper. Until some acceptance of some quantitative methods emerges, the methodology contained in this paper may be used to provide insight (from a technologist's point of view) into this problem of relative hazards and comparisons of harm in transporting hazardous materials.

CONSEQUENCE ANALYSES

The consequences calculated in this paper are for the effects created by a spill of hazardous materials. The emphasis is on fatalities only, but the methodology developed is applicable to and can account for various other measures of hazard (i.e., injuries, property damage and social effects) previously outlined. The effects of a release of hazardous materials and the consequences associated with the spill are summarized in a flow chart shown in Figure 1.

A general relationship was developed from the various equations describing the possible effects of various hazardous material on human health as follows: (all categories of materials previously indicated are described by this equation with the exception of corrosives).

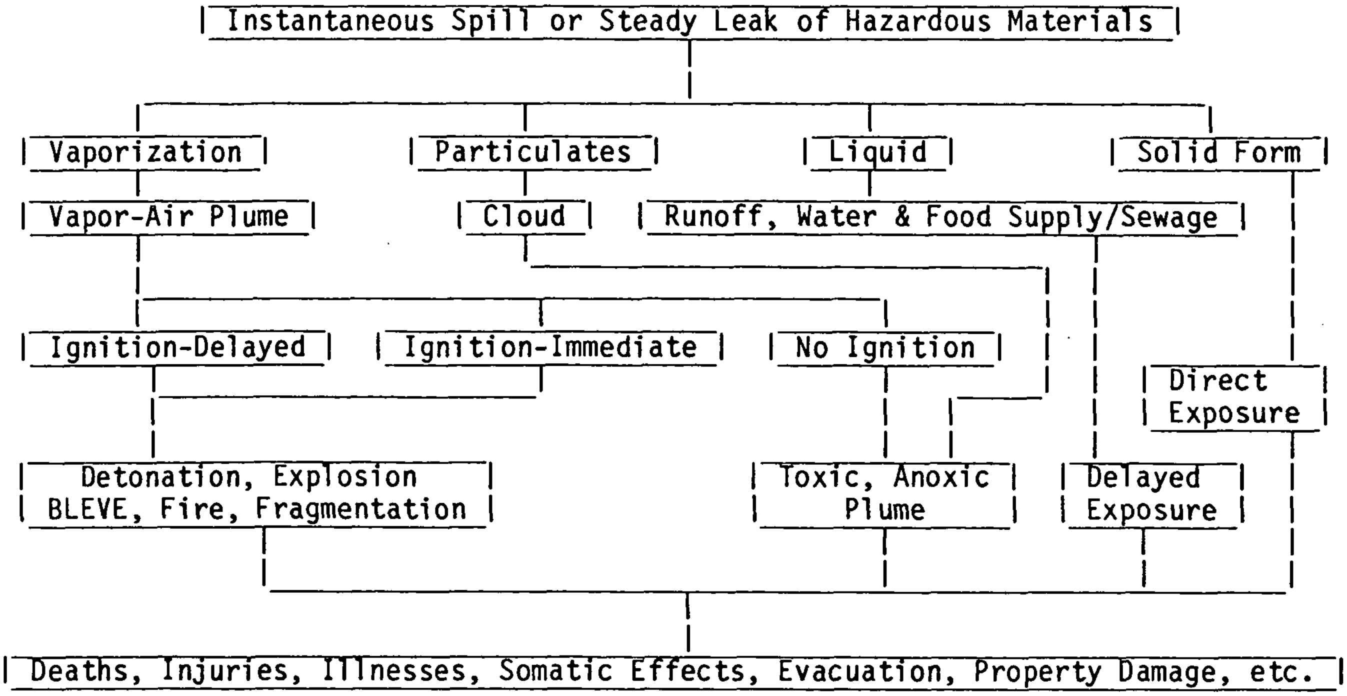

Figure 1. Flow Chart of Possible Effects Resulting from a Spill of Hazardous Materials

$$C = ABF(m)^{f}/d^{a} \qquad (1)$$

where

- C = Consequence (fatalities, injuries, property damage, etc.)
- A = Fraction of population, property, etc., within an area affected by the released material (0.0 < A < 1.0, 1.0 - A is fraction protected by natural or man-made features)
- B = Population density, property value, or other appropriate measure of people or geography
- F = Constant (threshold factor for fatalities, injuries, damage, etc.)
- m = Mass of hazardous material released
- f = Factor depending on category of hazardous material
- d = Distance from release point
- a = Relationship for dilution

Equation (1) is applicable for immediate effects caused by exposure to a fireball, blast overpressure and toxic materials where the cloud produced by instantaneous release is basically spherical in form. With the population density (B) and an estimate of the people shielded from the effects (A) known for an affected area, the consequences resulting from an instantaneous release of materials can be calculated. (For example, for flammable materials, the consequence C is equal to the heat loading $q(Btu/ft^2)$ to cause fatalities within distance x from a source, K is equal to 7785, m is equal to the weight of the material in kilograms and f is equal to 5/6. This product, multiplied by the population density of the affected area and the fraction of the population affected by the released material, established analytical estimates of the consequences.)

As the released materials begin to be affected by the meteorological conditions and terrain, Equation (1) requires redefinition of and additional terms to describe these more complicated conditions. Among the factors which will help define these conditions that must be considered are the following: (1) dispersion of materials which are usually in vapor-air or particulate cloud forms and including the effect of buoyancy, (2) mitigating or enhancement effects offered by natural or man-made features which aid dilution or concentration of the materials, (3) the nature of the release (instantaneous or continuous) and (4) the type of effects created by the released materials (immediate, latent, genetic, etc.)

Restricting the discussion to health effects (with the continued implied application to other effects), the major contribution to these effects is the dispersion over a wide area of vapor-air-particulate cloud of sufficient concentrations to cause hazards to the public. This dispersion and dilution depends upon the meteorological conditions and whether the material is instantaneously or continuously released. The relationship describing consequences as a function of the materials released is shown in Figure 2. Relationships between the consequences and time are shown in Figure 3.

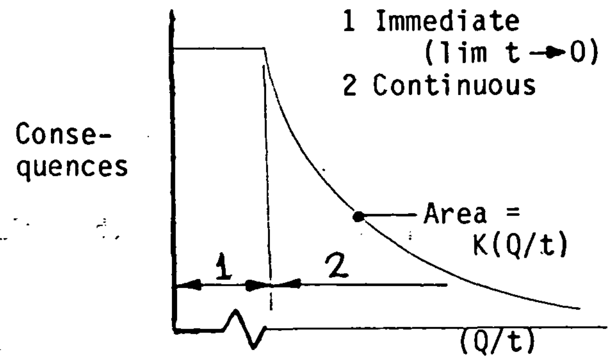

Figure 2. Relationship between consequences of release of hazardous material and mass and duration of materials released.

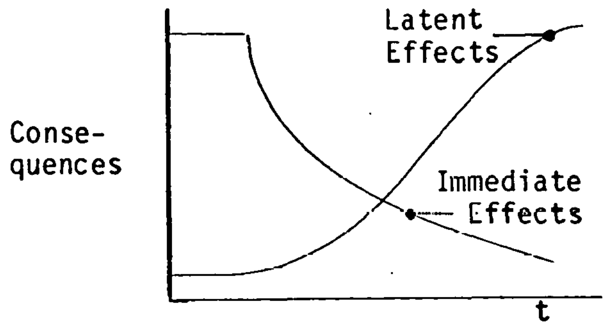

Figure 3. Possible relationships between time for health effects to occur and consequences.

To account for the various factors and relationships for dispersion and dilution, Equation (1) requires modification and redefinition as follows to describe continuous releases:

$$C = ABKQ^{m}(t)^{n} \quad (2)$$

where

C = Consequences of release of hazardous materials
A,B = Previously defined
Q = Volume of material released
t = Time
m,n = Exponents describing meteorological conditions and material released
K = f (material spilled and area involved) with the Area under the curve in Figure 2 = K (Q/t) because at a given time, Area, Q, n are known as shown in Figure 2 and K is the intercept which can be calculated.

SIMULATED ACCIDENT CONDITIONS

Two accident scenarios (urban and rural) were postulated to develop quantitative comparisons of health effects produced by releases of various hazardous materials. In addition, the two cases would provide a uniform set of conditions to evaluate the methodology and eliminate as much subjectivity in the analyses as possible. The scenarios offer the available pathways (direct exposure, airborne, aquatic and food chain) for possible health effects to occur. The rural location consisted of a freeway overcrossing a state highway adjacent to a river as shown in Figure 4. Also in the immediate area were a gasoline station and a food market. The traffic densities were 20 and 100 vehicles per hour on the state highway and freeway, respectively. The prevailing wind of 2 m/sec was directed toward a town 3 km away which had a population density of 2400 people/km^2. The urban scenario was also a freeway overcrossing a city street (Figure 5). The traffic density was 8000 vehicles per hour on the freeway and 1000 per hour on the city street. The population densities ranged from 35,000 people/km^2 near the source to 20 people/km^2 at 80 km with an approximate geometric decay between. A wind speed of 2 m/sec existed. Tall buildings and other features (e.g., pedestrians) were included.

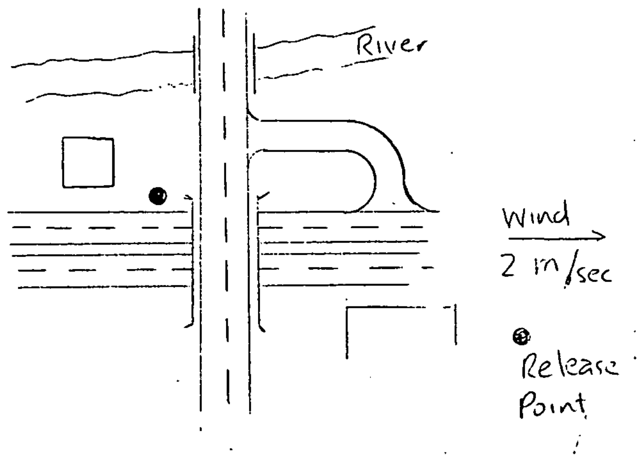

Figure 4. Rural accident location.

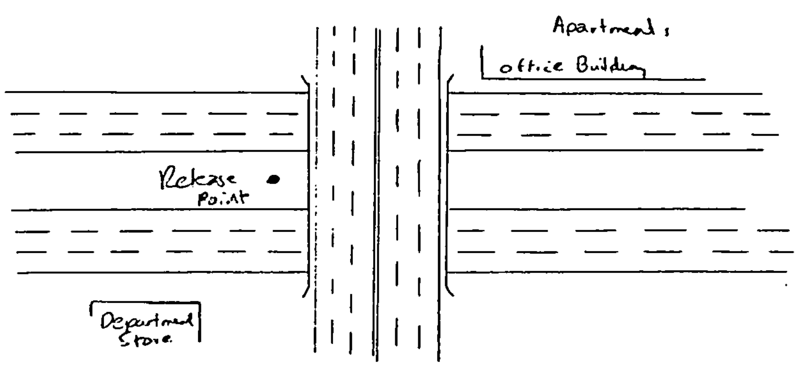

Figure 5. Urban accident location.

RELATIVE CONSEQUENCES

Deatiled calculations were made of health effects produced from releases in these two situations using specialized and detailed techniques. Equations (1) and (2) were used as models to relate the results of the more detailed calculations to the determination of the consequences of spills of the following materials: anoxic (chlorine, which is also toxic), high explosives, flammable (LNG and LPG), radioactive (spent fuel) and toxic (parathion and toxaphene). These individual materials were selected as representative of their particular category and because basic characteristics and data describing the materials were available.

Analyses and subsequent comparisons of the results were accomplished through a variety of methods. One of the approaches is outlined in the following schematic as shown in Figure 6. Here, the object is to develop a relationship between the measures of harm for materials A and B when shipments are subjected to similar accident environments in similar settings. The central plot of Figure 6 contains measures of harm for materials A and B and the other diagrams indicate the conceptual flow of the calculation. Beginning in the lower left with material A, accident severities (categories I through VIII from NUREG-0170) are related to package response as indicated. The release of materials (if it occurs) is related to the consequences as calculated using the appropriate form of Equations (1) and (2) and either of the two scenarios described. These consequences (in this case health effects only) form the measure of harm. The numbers on the scales merely indicate increasing values. Beginning in the upper right with material B, a similar analytical procedure is outlined in Figure 6. With sufficient calculations for analysis of the effects of various accident severities, a curve comparing the measures of harm of two materials is described as a "figure of merit". Analysis of this "figure of merit" plot can indicate (through deviation from a diagonal line) significant differences in the regulatory climate or risk perceptions of the two materials.

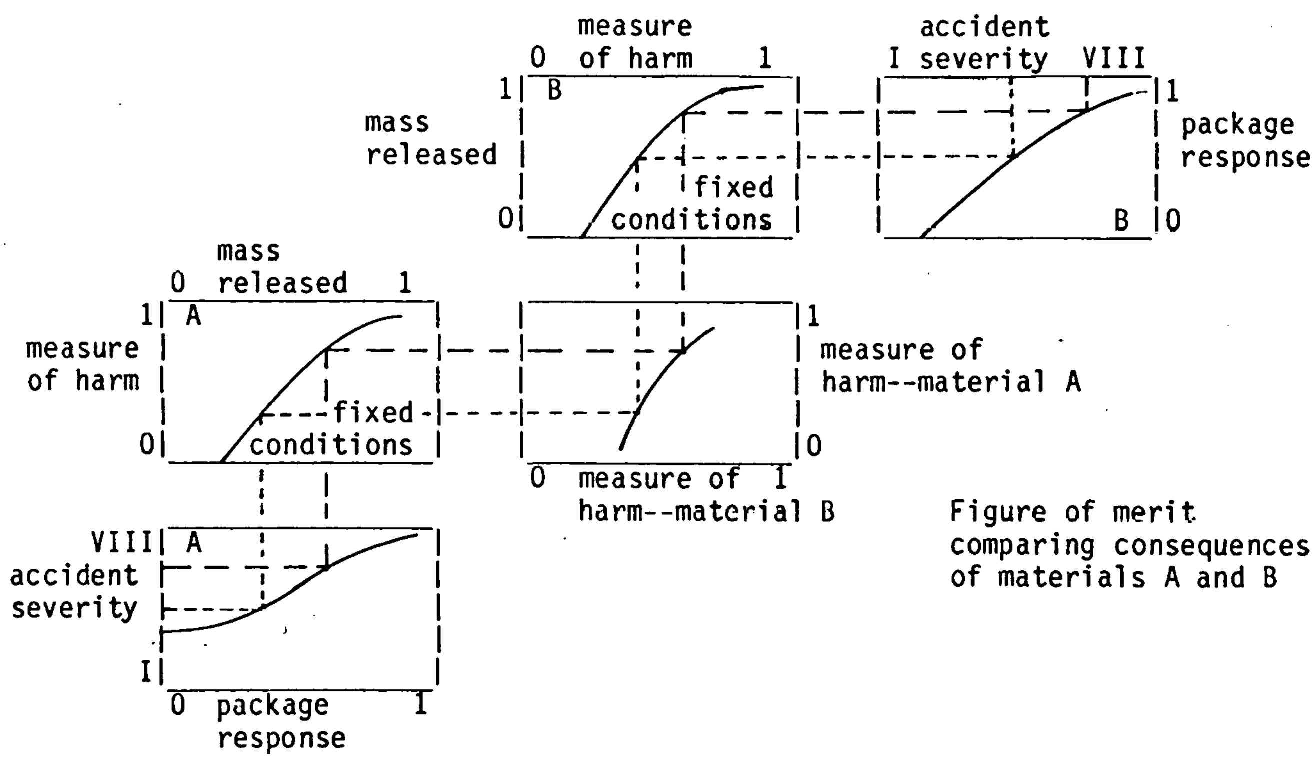

Figure 6. Schematic for Comparisons of Hazards from Two Materials

CONCLUSIONS

Understanding the differences in perception of hazards resulting from transport of various hazardous materials is fraught with difficulties in isolating the qualitative and quantitative features of the problem. By relating the quantitative impacts of material hazards under identical conditions, it is hoped that the perceived differences in material hazards can be delineated and evaluated.

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