Application of Quantitative Risk Assessment Techniques in the U.S. Coast Guard Regulatory Process (1982)

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THE APPLICATION OF QUANTITATIVE RISK ASSESSMENT TECHNIQUES IN THE U.S. COAST GUARD REGULATORY PROCESS

Report of the
Panel on Risk Analysis for
Marine Transport of Hazardous Materials

Cttee on Maritime Hazardous Materials

NATIONAL MATERIALS ADVISORY BOARD
Commission on Engineering and Technical Systems
National Research Council

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The report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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ABSTRACT

The potential was examined for use of modern risk analysis techniques in developing U.S. Coast Guard (USCG) regulations to minimize the public risk from marine transport of bulk chemical cargoes. Consideration also was given to the usefulness of these techniques in setting priorities and support levels for USCG safety research programs.

The principal conclusion of the study is that risk assessment techniques could be, and to some limited extent have been, used with success within the USCG regulatory framework. Since the resources available for regulation are limited, they must be used in a cost-effective manner. The specific recommendations call for:

1. Selected studies on shipments of new substances with a potentially large impact on the public if released into the environment.

2. Selected studies on certain ports and locations along inland waterways that appear to have a high incidence of accidents.

3. Delineation of key variables and establishment of the types of data to be collected before and after promulgation of a regulation to determine the effectiveness of the issued regulation.

4. Sponsorship of retrospective risk studies to estimate the potential for high consequence-low probability events with familiar but potentially hazardous cargoes.

5. Review of existing regulations in a selected area (e.g., marine transport of bulk chemical cargoes on inland waterways) to gain insight into the consistency of regulations and to learn if any gaps or contradictions exist.

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Application of Quantitative Risk Assessment Techniques in the U.S. Coast Guard Regulatory Process

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Descriptors: *Regulations; *Risk; *Hazardous materials; Materials handling; Assessment; National government; Accident prevention; Safety

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PREFACE

As part of its effort to ensure that hazardous materials are transported safely, the U.S. Coast Guard (USCG) contracted with the National Research Council (NRC) to form the Committee on Maritime Hazardous Materials. This NRC committee provides advice to the sponsor through the efforts of a number of panels appointed to investigate various aspects of the safety issues concerning the marine transport of bulk materials.

The Panel on Risk Analysis for Marine Transport of Hazardous Materials was established to examine the usefulness of modern risk analysis techniques in developing regulations that will minimize the risk to the public from the marine transport of bulk chemical cargoes. Any recommendations concerning the use of risk analysis methods were to be accompanied by descriptions of the limitations and reliability of the methods. The panel also was to determine whether such techniques would be useful in setting priorities for USCG safety research programs. The panel is composed of individuals possessing expertise in risk assessment, USCG procedures and practices, practical shipping experience, ship design and structure, materials science, and toxicology and health effects. (See Appendix C for biographical sketches of panel members.)

To accomplish its task, the panel reviewed the legislated responsibility of the USCG to promote and enforce maritime safety during the shipment of hazardous cargo. The panel also reviewed present and past methods used by the USCG in developing regulations and studied systems where risk analysis methods could be used by the Coast Guard in carrying out its responsibilities. Because the panel had limited time and resources, it restricted its inquiry to the movement of bulk liquid cargoes and the regulations set forth in Title 46 Code of Federal Regulations, (CFR), Parts 30-40 and Parts 150-155 (see page 21). The panel considered both the requirements for self-propelled vessels and for barges and barge movement on inland waterways.

The chairman would like to express his appreciation to the members of the panel for their concerted efforts during the course of this study. Thanks also are extended to the USCG liaison representatives to the panel and to Stanley M. Barkin who provided excellent NRC staff support.

Robert Erdmann
Panel Chairman

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FOR MARINE TRANSPORT OF HAZARDOUS MATERIALS

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Chapter 1

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Current regulations concerning the shipment of bulk liquid hazardous cargoes are based on many years of development work and study in the United States by government, industry, and the public and, internationally, by the Safety of Life at Sea Conferences and the International Maritime Organization (formerly IMCO, the Intergovernmental Maritime Consultative Organization). The impetus for regulation has and continues to come from a variety of sources such as industry requests, maritime casualties, technological improvements, or the public or Coast Guard perception of a safety problem.

A system safety process approach has been used in the past in the maritime industry and has continually evolved into more sophisticated procedures. This process often employs quantitative analyses, especially using engineering, design, and operational information, for studying all phases of a specific system to identify hazards related to the failure of that system and to initiate responses to prevent or control these hazards. Risk analysis is broader in scope and, consequently, can be sometimes useful in both industrial and regulatory planning and decision-making.

Although risk assessment has been practiced for many years, its development into a formal methodology including the use of risk models and specialized techniques is recent. The use of risk assessment methods now is required of federal regulatory agencies and the results of their application must be made known as part of the rulemaking process.

A risk assessment or analysis can be considered to consist of a risk estimate and a risk evaluation. A risk estimate is the statistical and/or analytical modeling process that leads to a quantitative (sometimes qualitative) estimate of a given risk; a risk evaluation is the appraisal of the significance of the risk estimate.

A risk estimate is made by acquiring and using the data needed to develop estimates of the probabilities of occurrence and the magnitude of impact of undesired events. The risk evaluation attempts to assess the significance of the risk estimate in terms of its acceptability, how it compares to risk estimates of alternatives, or the cost of reducing the risk to a lower level. The general principles can be applied in several ways depending on the situation or system under scrutiny.

Risk assessment as now practiced is an orderly process that can be an important tool in decision-making. It is, however, subject to uncertainties. This important shortcoming is due in part to the fact that data available for use in a risk estimate often are insufficient or possibly erroneous, thereby requiring that simplified assumptions and surrogate information be used. The acquisition of pertinent data is costly, and a time-consuming activity. Oftentimes, data are impossible or difficult to obtain. Because of this shortcoming, the panel cannot specify at this time a consistent quantitative risk assessment approach to safety regulations for a field as diverse as water transportation of hazardous materials. It was able, however, to identify the criteria and some situations for useful applications of risk assessment methodology by the Coast Guard.

The content and structure of this report reflect the relative amount of effort devoted to each of the panel's tasks. Chapter 2 provides a brief review of risk assessment techniques as applied in the shipping of hazardous materials; Chapter 3, a discussion of existing regulations and their genesis; and Chapter 4, a survey of the data sources on quantities and types of materials shipped, hazards of the cargoes, and past shipping incidents. By integrating these three streams of thought, the conclusions and recommendations presented below were formulated. Chapter 5 presents a very preliminary example of event tree application to potential river barge accidents to exhibit some of the organizational power and comprehensiveness of the tools of risk assessment.

This report contains a large amount of material on the subjects of vessel design, operating methods, and previous Coast Guard work and a lesser amount of material on risk analysis. This choice was made to emphasize the firm basis for the panel's recommendations and it reflects the effort made to assure that risk techniques could be helpful, if difficult to implement.

The following conclusions and recommendations are the result of the collective judgment of the panel. They are based upon discussions held during meetings, upon presentations and documents received (included as references in this report) and the personal expertise of the members.

CONCLUSIONS

1. The USCG has been using risk assessment techniques in various ways for a number of years. It has carried out studies on the consequences of potential spills; collected failure rate and operational data on the shipping of hazardous materials; and performed informal, qualitative risk analyses. In specific cases, quantitative risk assessments have been carried out by various groups and reviewed by USCG personnel.

2. There is good potential for utilizing the methodology of risk assessment in estimating the value of current and pending USCG regulations. Although it may not be possible now to perform general risk evaluations for a given set of regulations, it is possible that regulations can be evaluated to determine their risk reduction potential in various applications.

3. The overall safety record for the shipment of bulk hazardous materials is good; however, objective evidence for the efficacy of a specific regulation or action cannot be documented. In addition, because high consequence-low probability events are sparse or nonexistent in the record of experience, it cannot be stated categorically that the safety trend is a positive one. It may be that because of good fortune certain accidents that have occurred on major U.S. waterways have not had more dire consequences.

4. The mandate to use risk analysis in the USCG decision-making process exists. Even though this type of analysis cannot guarantee avoidance of erroneous decisions, its orderly method cannot help but improve upon ad hoc or visceral decision-making in the area of public safety.

5. There is no level of safe operation to which the industry and the USCG is comparing its current activities or regulations.

RECOMMENDATIONS

1. For shipments of new substances that have a potentially large impact on the public if released into the environment, selective risk type studies should be performed to determine the value of existing regulations and how they might be changed (either reduced or augmented) to allow for safe shipments at acceptable hazard levels.

2. Specific regulations should be evaluated through the use of risk assessment techniques for certain ports and certain locations along inland waterways that appear to have a high incidence of accidents. Local geography, traffic density and weather conditions should be taken into account to eliminate these incidents, or reduce their frequency of occurrence.

3. The key variables in any risk assessment should be delineated so that the relevant regulations are examined in relation to each one. These variables include: vessel and containment characteristics; chemical properties and their effects; environmental effects, including river flow patterns; and human factors and communications. Limiting conditions of operation based upon these key variables and the regulations relevant to the local area should also be considered.

4. Gathering data is costly and it is possible to use risk assessment techniques to help decide what types of data are worth collecting. Once a risk assessment application is selected, the identification of key data type and amount should be ascertained. At this stage, the data can be gathered. Furthermore, since lack of data is usually one of the limitations in any risk study, the USCG should plan and start an orderly process for monitoring events before and after a regulation is issued.

Data should also be acquired on other risks that maritime workers or the public face. Therefore, the U.S. Coast Guard should collect data on comparable local and regional risks of an occupational as well as an involuntary nature.

5. The USCG should sponsor several retrospective risk studies to estimate the potential for high consequence-low probability events with existing shipments of familiar but potentially hazardous cargoes. These studies would provide some quantitative link between regulations and operational risk levels. They would also allow the U.S. Coast Guard to develop a risk assessment procedure that would be acceptable to industry as well as to the government when a risk analysis of a new substance is being contemplated. There exist potential third-party effects and liabilities in the bulk shipment of hazardous materials, and these retrospective risk assessments would help provide some direction and/or quantification of these factors.

6. A review of sequences of past incidents should be undertaken with the thought of uncovering alternate and possibly more severe paths to the ones actually observed. This undertaking would lead to an assessment of the potential for severe events, the types of regulations inherent in the sequences studied, and the degree of risk reduction the current operational framework provides. Risk assessment techniques would help in such an evaluation.

7. Existing regulations should be correlated within the various phases of a risk assessment. Insight would be gained on the consistency of the regulations and any gaps or contradictions would be revealed.

8. Some effort should be expended to determine what constitutes an adequate level of safe operation for the transport of hazardous materials.

9. The effectiveness (from a risk reduction standpoint) of a given regulation should be determined from studies conducted during the pre- and post-time periods from the date of issuance of the regulation.

IMPLEMENTATION

In making its recommendations, the panel clearly realized that a great deal of time and resources will be needed to carry them out. The panel does not recommend that the USCG abandon entirely its current approach to managing and reducing risks from the transport of hazardous materials. The panel does recommend, however, that some steps be taken based on the results of risk analyses to prioritize the formulation of regulations of bulk hazardous cargo shipments.

One point not discussed extensively is the potential value of using simulators coupled with risk analysis to train personnel involved in shipping. Incorporation into simulators of all the various conceivable sequences developed with risk assessment procedures could assist in the development of a work force possessing the experience needed to handle the events that might occur in the future. Such studies, possibly carried out on simulators prior to drafting regulations, may also point out the potential benefits and shortcomings of a given regulation.

Chapter 2

RISK ASSESSMENT PROCEDURES AND PRACTICES

Much risk assessment work has been done concerning the shipment of hazardous materials and a great deal of information relevant to such studies has been collected. There also exists a vast amount of literature on risk assessment in other fields.

This chapter contains a brief review of risk assessment applications in shipping. The various segments of a risk analysis are discussed first and then the information needed for performing an analysis is identified. Finally, the types of output one can expect are mentioned. The accuracy and uncertainty of this type of analysis are addressed as are the lack of completeness and the predictive applications of the methodology.

THE COMPOSITION OF A RISK ASSESSMENT

In a 1979 study the PRC Systems Services Co. describes risk assessment in marine transportation in terms of four elements:

> The first element is the probability of a vessel casualty; that is, collision, ramming, grounding, fire, explosion, etc. The second element is the probability of a spill, given that a casualty has occurred. Next, the physical reactions of the spilled material with the water and air must be determined. This reaction may result in a toxic cloud, oil pool, vapor cloud, fire, or explosion, depending upon the material characteristics and the environment. Finally, the damage caused by the spill is determined from the spill phenomenology and the resources at risk. This may be measured in terms of fatalities, injuries, property loss, or ecological damage.

USCG regulations governing the transport of hazardous materials traditionally have addressed the prevention of accidents that could result in potentially hazardous chemical spills. However, as the variety and volume of chemicals shipped by sea have grown so has the potential for serious public health and environmental consequences in the event of spillage and leakage due to accidents. This has been complicated by the increased body of knowledge about the acute, chronic, and subtle toxicities of both familiar and newly developed chemicals being shipped by water.

The PRC (1979) assessment of the alternate ways of determining casualty probability states:

> The statistical method uses historical data on vessel casualties and vessel traffic to develop casualty probabilities. The analytic

method involves kinematic equations expressing the probability of collision or ramming in terms of pertinent system variables. Computer simulation of ship movement can be used to estimate the probability of collision, ramming, or grounding. For the fault tree approach, trees are developed that indicate the logical sequences of events that lead to a casualty. Probabilities are assigned to basic events, such as a component failure, and the probability of system failure is computed from these basic event probabilities. The subjective approach develops probabilities from the results of questionnaires or from interviews of knowledgeable personnel. Finally, the casualty report analysis approach is based upon detailed evaluation of narrative casualty reports to estimate the proportion of casualties that might have been prevented by a specified safety measure.

USCG RISK ANALYSIS TOOLS

The USCG has developed a family of risk analysis tools: the Chemical Hazards Response Information System (CHRIS)(Allan and Harris 1976), the Hazard Assessment Computer System (HACS), and the Population Vulnerability Model (PVM)(Perry and Articola 1979, Rausch et al. 1977a and b, Tsao and Perry 1979). All three are of the consequence analysis type, all are completely deterministic; the first two facilitate emergency response efforts and all can be used for a wide range of planning purposes including site selection, placement of vessel traffic services* (VTS) etc. The PVM is based on HACS, which is a computerized version of the CHRIS hazard assessment manuals. CHRIS and HACS permit a user to calculate the distance and direction a spilled cargo and its effects will travel independent of the spill location. The PVM permits a user to calculate the potential human and property losses from a spill occurring in a specific location. Several factors (e.g., terrain) have not yet been integrated into these systems.

CHRIS was developed as an emergency response tool and is the foundation of the USCG's ongoing risk analysis effort. The CHRIS user takes the on-scene reports of an impending or actual accident and, through tables and charts and very simple hand calculations, rapidly computes the location of the chemical and its effects (e.g., thermal radiation as a function of time and distance from the spill origin). Due to the need for speed, the basic equations have been arranged to make emergency response feasible. HACS, a computerized version of CHRIS, is based on the same models and equations that were used in developing the CHRIS tables and charts. Computerization is intended to increase the speed of response as well as to improve accuracy.

* A VTS is a communications system that processes and disseminates traffic information and advisories to and from participating vessels in the area being serviced. The system provides vessels with advanced information on other vessel movements and any additional information that may affect safety.

CHRIS and HACS are based on a series of mathematical models, each of which describes a single step in the development of a spill. One or more models in sequence make up a module that describes a distinct phase of a spill. The simulation of a spill requires one or more modules. This building block approach characterizes the systems.

The process of spill simulation using CHRIS or HACS can be illustrated by the following example: A ship's tank of refrigerated, unpressurized liquefied petroleum gas (LPG) is penetrated at the waterline, and cargo begins to escape. Local USCG personnel want to know how far downwind the vapor cloud could travel before becoming completely diluted below the lower flammable limit (LFL). This is important because the ship has grounded six miles offshore with an onshore wind of 3 miles per hour. In the two hours before the vapor cloud reaches the moderately populated land, the residents could be evacuated. Since evacuation presents significant risks to the evacuees as well as major logistical problems, predicting whether the cloud is still dangerous when it reaches the shoreline is important.

In solving this problem, the CHRIS or HACS user first executes the Rate of Release module because the cargo release is continuous in time rather than sudden and complete. The results of this module give the input data necessary for the next module, Spreading Rate and Movement (primarily the quantity of cargo released as a function of time). Execution of the Boiling Rate and Vapor Dispersion modules completes the simulation, and the results tell whether evacuation is necessary. Generally, errors are in the conservative direction (i.e., on the side of safety).

There usually are sufficient physical property data in the CHRIS and HACS data bases for a typical run. If not, the user can enter the specific missing data or default values will be provided by the system. If the user believes that his data are superior to those in the data base, he can enter his data instead. The user must provide information unique to the simulation (e.g., tank dimensions, weather conditions, and simulation pathway). If the results of a specific module are already known (e.g., the actual cargo spill rate), the module need not be executed, which saves time and eliminates unnecessary calculational errors.

The Population Vulnerability Model (PVM) includes information on the impact a hazardous cargo release would have on people and property. The PVM user starts by applying the HACS models to give the location of the cargo and of some of its effects (e.g., thermal radiation) as a function of time; the effects of the cargo spill on people and property then are calculated. The PVM output organizes the number of people and number of structures and their dollar value by census tract. All of the resources at risk are assumed to lie at the center of the census tract for modeling purposes. Only a few geographical locations are within PVM currently.

In general, the PVM requires much the same input data as HACS. The simulation is divided into two parts: In Phase I the location of a released cargo and/or its effects is calculated at the user specified intervals after the release--usually at a two-minute interval of simulated time. At each interval, the concentration of the spilled material or the intensity of one or more of its effects (e.g., blast overpressure, thermal radiation intensity, or vapor concentration) are calculated at the center of each census tract. In Phase II, the impact of the released chemical on the people and property within each census tract is calculated. Property losses are reported as the number of structures destroyed and the dollar loss; human losses are reported as the number of fatalities, the number of injuries (permanent), and the number of irritated individuals (nonpermanent injuries such as eye watering or nausea).

Phase II results are given for each time interval and for each census tract. The numbers also are expressed as the percentage affected in each census tract. Since the damaging effect on people outdoors is much different from that on those indoors, the PVM calculations are performed separately for each group; 50 percent arbitrarily are assumed to be outdoors and 50 percent indoors. Since the results are reported at each time interval, the PVM user can follow the progress of a vapor cloud as it moves downwind.

In those cases when a toxic vapor cloud is being simulated and the spill source is continuous, an alternative method that permits a "once through" approach is to execute Phases I and II only once for the time as well as a more accurate representation of the dynamics of a cargo spill. The PVM user also can experiment to determine how effective one safety measure or another might be (e.g., to determine how people and property would suffer as a result of an accident if a loading terminal was located in a populated area or to determine if there would be any significant benefit to restricting the size of ships and land storage.) It is even possible to vary the physical situation (e.g., to determine the differences between the effects of an LPG vapor cloud deflagration and an LPG vapor cloud detonation). The PVM is not restricted to the marine mode; a shore tank releasing vapor is treated no differently than a ship's tank.

The accuracy of CHRIS, HACS, and the PVM is not known at this time. Large-scale experiments are difficult to run, and there have been very few large-scale accidental releases of hazardous materials. In a few simulations of actual accidents, CHRIS, HACS, and the PVM have shown at least qualitative agreement with experience.

There are, no doubt, other tools that could or have been used in risk assessment of marine transport. In the panel's short existence, it was unable to collect and review these tools for their adequacy, limitations, or reliability of results. However, the panel does feel that methods can, if necessary, be developed or augmented to analyze both the probability of occurrence and the consequence of any event sequence, given the existence of data to support the analysis.

MATERIALS PROPERTIES

A number of USCG-supported studies have concentrated on the physical reaction of spilled hazardous material with the environment and the consequent damage from such spills. There exists a great number of materials that are transported in bulk and the properties of these materials need to be known for accurate consequence estimates. Information on acrylonitrile, for example, can be found in data sources identified in Table 1. A sample from CHRIS is presented as Figure 1.

Because of the wide variety of shipped materials, groupings by hazard type and severity have been attempted. Although these groupings would not be very useful in the risk assessment of a specific shipment, they may have use when considering an overall river system or an integrated port system. For example, one grouping has been suggested by the Committee on Hazardous Materials (1974). In its report, the committee reviewed almost 400 chemicals and rated them using the grading system shown in Table 2.

Because of the vast array of chemicals being shipped, it is unlikely that all effects of potential releases are being considered. Continuous updating is needed to ensure that adequate consideration is given to both acute and chronic effects as well as to environmental and property loss estimations. These considerations are important if a risk study is to have bearing on a potentially hazardous location.

The panel is aware of the value of considering toxic consequences to the public and to the environment from chemical spills. As noted above, Table 2 is one example of a rating system that has been used to categorize the toxic hazard of chemicals being shipped by the marine mode. More elaborate systems may be developed that consider the potentially toxic effects of chemical release, and this panel believes that the further development and use of this type of evaluation is warranted as appropriate information becomes available.

A large number of risk studies have been carried out for one specific substance, liquefied natural gas (LNG). They can be categorized as follows (National Materials Advisory Board 1980):

1. Site-specific risk assessments,

2. Site-specific evaluations of the probability of an accident leading to the release of LNG,

3. Site-specific evaluations of the consequences of an LNG release,

4. Non-site-specific safety studies for the water transportation of LNG (generally these are models such as CHRIS and HACS), and

5. Acceptability-of-risk, risk-perception, and risk-benefit studies of a general nature.

These LNG risk studies were conducted because of the large amount of material involved, the threat to population centers, and the lack of experience in shipping this material. The potentially great consequences of the situation led naturally to risk studies as they did in the nuclear

TABLE 1 Examples of Sources of Information on Acrylonitrile

Author or Editor, Date	Publication
American Conference of Governmental Industrial Hygienists 1982	TLVs, Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment with Intended Changes for 1982
National Fire Protection Association 1977	Fire Hazard Properties of Flammable Liquids, Gases, Volatile Solids
National Institute for Occupational Safety and Health 1977	Registry of Toxic Effects of Chemical Substances
National Institute for Occupational Safety and Health and Occupational Safety and Health Administration 1978	Pocket Guide to Chemical Hazards
National Institutes of Health, and the Environmental Protection Agency Information System 1980	Oil and Hazardous Materials Technical Assistance Data System (OHMTADS)
Sax 1979	Dangerous Properties of Industrial Materials
U.S. Coast Guard (see Allan and Harris 1976)	Chemical Hazard Response Information System (CHRIS)[a]
U.S. Coast Guard 1976	Chemical Data Guide for Bulk Shipment by Water

[a] Volume I, Condensed Guide to Chemical Hazards, presents general data on fire, explosion, pollution, and safety for more than 900 substances. Volume II, Hazardous Chemical Data Manual, contains chemical, physical, and toxicological data in addition to that included in Volume I. Volume III, Hazard Assessment Handbook, provides for assessing the extent of damage due to spills and is the basis of HACS. Volume IV, Response Methods Handbook, contains methods of containment and sources of clean-up equipment. (The four manuals are available from the Government Printing Office.)

ACN	ACRYLONITRILE

Common Synonyms	Watery liquid — Colorless to light yellow — Irritating odor
	Floats on water. Poisonous, flammable vapor is produced.

AVOID CONTACT WITH LIQUID AND VAPOR. KEEP PEOPLE AWAY.
Wear goggles, self-contained breathing apparatus and rubber overclothing (including gloves).
Shut off ignition sources and call fire department.
Stop discharge if possible.
Stay upwind and use water spray to "knock down" vapor.
Evacuate area in case of large discharge.
Isolate and remove discharged material.
Notify local health and pollution control agencies.

Fire

FLAMMABLE.
POISONOUS GASES MAY BE PRODUCED IN FIRE.
Flashback along vapor trail may occur.
Vapor may explode if ignited in an enclosed area.
Wear goggles, self-contained breathing apparatus, and rubber overclothing (including gloves).
Combat fires from a safe distance or protected location.
Extinguish with dry chemical, alcohol foam, or carbon dioxide.
Water may be ineffective on fire.
Cool exposed containers with water.

Exposure

CALL FOR MEDICAL AID.

VAPOR
POISONOUS IF INHALED.
Irritating to eyes.
Move to fresh air.
If breathing has stopped, give artificial respiration.
If breathing is difficult, give oxygen.

LIQUID
POISONOUS IF SWALLOWED.
Irritating to skin and eyes.
Remove contaminated clothing and shoes.
Flush affected areas with plenty of water.
IF IN EYES, hold eyelids open and flush with plenty of water.
IF SWALLOWED and victim is CONSCIOUS, have victim drink water or milk and have victim induce vomiting.
IF SWALLOWED and victim is UNCONSCIOUS OR HAVING CONVULSIONS, do nothing except keep victim warm.

Water Pollution

HARMFUL TO AQUATIC LIFE IN VERY LOW CONCENTRATIONS.
Fouling to shoreline.
May be dangerous if it enters water intakes.
Notify local health and wildlife officials.
Notify operators of nearby water intakes.

1. RESPONSE TO DISCHARGE
(See Response Methods Handbook, CG 446-4)

Issue warning — poison; highly flammable
Restrict access
Disperse and flush

2. LABELS

3. CHEMICAL DESIGNATIONS

3.1 **Synonyms:** Cyanoethylene
Fumigrain
Ventox
Vinyl cyanide

3.2 **Coast Guard Compatibility Classification:** Substituted allyl

3.3 **Chemical Formula:** $CH_2{=}CHCN$

3.4 **IMCO/United Nations Numerical Designation:** 3.1/1093

4. OBSERVABLE CHARACTERISTICS

4.1 **Physical State (as shipped):** Liquid

4.2 **Color:** Colorless

4.3 **Odor:** Mild, pungent, resembling that of peach seed kernels

5. HEALTH HAZARDS

5.1 **Personal Protective Equipment:** Air-supplied mask, industrial chemical type, with approved canister for acrylonitrile in low (less than 2%) concentrations, rubber or plastic gloves; cover goggles or face mask, rubber boots, slicker suit, safety helmet.

5.2 **Symptoms Following Exposure:** Similar to those of hydrogen cyanide. Vapor inhalation may cause weakness, headache, sneezing, abdominal pain, and vomiting. Similar symptoms shown if large amounts of liquid are absorbed through the skin; lesser amounts cause stinging and sometimes blisters; contact with eyes causes severe irritation. Ingestion produces nausea, vomiting and abdominal pain.

5.3 **Treatment for Exposure:** Skilled medical treatment is necessary; call physician for all cases of exposure. INHALATION: remove victim to fresh air. (Wear an oxygen or fresh-air-supplied mask when entering contaminated area.) INGESTION: induce vomiting by administering strong solution of salt water, but only if victim is conscious. SKIN: remove contaminated clothing and wash affected area thoroughly with soap and water. EYES: hold eyelids apart and wash with continuous gentle stream of water for at least 15 min.
If victim is not breathing, give artificial respiration until physician arrives. If he is unconscious, crush an amyl nitrite ampule in a cloth and hold it under his nose for 15 seconds in every minute. Do not interrupt artificial respiration while doing this. Replace ampule when its strength is spent and continue treatment until condition improves or physician arrives.

5.4 **Toxicity by Inhalation (Threshold Limit Value):** 20 ppm

5.5 **Short-Term Inhalation Limits:** 40 ppm for 30 minutes

5.6 **Toxicity by Ingestion:** Grade 3; LD_{50} 50 to 500 mg/kg (rat, guinea pig)

5.7 **Late Toxicity:** Data not available

6. FIRE HAZARDS

6.1 **Flash Point:** 30°F C.C.; 31°F O.C.

6.2 **Flammable Limits in Air:** 3.05% – 17.0%

6.3 **Fire Extinguishing Agents:** Dry chemical, alcohol foam, carbon dioxide

6.4 **Fire Extinguishing Agents Not to be Used:** Water or foam may cause frothing

6.5 **Special Hazards of Combustion Products:** When heated or burned, ACN may evolve toxic hydrogen cyanide gas and oxides of nitrogen.

6.6 **Behavior in Fire:** Vapor is heavier than air and may travel a considerable distance to a source of ignition and flash back. May polymerize and explode.

6.7 **Ignition Temperature:** 898°F

6.8 **Electrical Hazard:** Class I, Group D

6.9 **Burning Rate:** Data not available

7. CHEMICAL REACTIVITY

7.1 **Reactivity with Water:** No reaction

7.2 **Reactivity with Common Materials:** Attacks copper and copper alloys; these metals should not be used. Penetrates leather, so contaminated leather shoes and gloves should be destroyed. Attacks aluminum in high concentrations.

7.3 **Stability During Transport:** Stable

7.4 **Neutralizing Agents for Acids and Caustics:** Not pertinent

7.5 **Polymerization:** May occur spontaneously in absence of oxygen or on exposure to visible light or excessive heat, violently in the presence of alkali. Pure ACN is subject to self-polymerization with rapid pressure development. The commercial product is inhibited and not subject to this reaction.

7.6 **Inhibitor of Polymerization:** Methylhydroquinone (35-45 ppm)

8. WATER POLLUTION

8.1 **Aquatic Toxicity:**
100 ppm/24 hr/all fish/100% killed/fresh water
0.05-1 ppm/24 hr/bluegill/lethal/salt water

8.2 **Waterfowl Toxicity:** Not pertinent

8.3 **Biological Oxygen Demand (BOD):** 70%, 5 days

8.4 **Food Chain Concentration Potential:** None noted

9. SELECTED MANUFACTURERS

1. E. I. duPont de Nemours & Co., Inc.
Electrochemicals Dept.
Wilmington, Del. 19898
2. Monsanto Co.
Monsanto Polymers & Petrochemicals Co
800 North Lindbergh Blvd
St. Louis, Mo. 63166
3. Vistron Corp.
Cleveland, Ohio 44115

10. SHIPPING INFORMATION

10.1 **Grades or Purity:** Technical: 98-100%

10.2 **Storage Temperature:** Ambient

10.3 **Inert Atmosphere:** No requirement

10.4 **Venting:** Pressure-vacuum

11. HAZARD ASSESSMENT CODE
(See Hazard Assessment Handbook, CG 446-3)

A-P-Q-R-S-Z

12. HAZARD CLASSIFICATIONS

12.1 **Code of Federal Regulations:** Flammable liquid

12.2 **NAS Hazard Rating for Bulk Water Transportation:**

Category	Rating
Fire	3
Health	
Vapor Irritant	3
Liquid or Solid Irritant	1
Poisons	3
Water Pollution	
Human Toxicity	4
Aquatic Toxicity	3
Aesthetic Effect	2
Reactivity	
Other Chemicals	3
Water	0
Self-Reaction	3

12.3 **NFPA Hazard Classifications:**

Category	Classification
Health Hazard (Blue)	4
Flammability (Red)	3
Reactivity (Yellow)	2

13. PHYSICAL AND CHEMICAL PROPERTIES

13.1 **Physical State at 15°C and 1 atm:** Liquid

13.2 **Molecular Weight:** 53.06

13.3 **Boiling Point at 1 atm:** 171°F = 77.4°C = 350.6°K

13.4 **Freezing Point:** −118°F = −83.6°C = 189.6°K

13.5 **Critical Temperature:** 505°F = 263°C = 536°K

13.6 **Critical Pressure:** 660 psia = 45 atm = 4.6 MN/m²

13.7 **Specific Gravity:** 0.8075 at 20°C (liquid)

13.8 **Liquid Surface Tension:** Not pertinent

13.9 **Liquid-Water Interfacial Tension:** Not pertinent

13.10 **Vapor (Gas) Specific Gravity:** 1.8

13.11 **Ratio of Specific Heats of Vapor (Gas):** 1.151

13.12 **Latent Heat of Vaporization:** 265 Btu/lb = 147 cal/g = 6.16 × 10⁵ J/kg

13.13 **Heat of Combustion:** -14,300 Btu/lb = -7950 cal/g = −332 × 10⁵ J/kg

13.14 **Heat of Decomposition:** Not pertinent

13.15 **Heat of Solution:** Not pertinent

13.16 **Heat of Polymerization:** Not pertinent

(Continued on pages 5 and 6)

5. HEALTH HAZARDS (Cont'd.)

5.8 **Vapor (Gas) Irritant Characteristics:** Vapor is moderately irritating such that personnel will not usually tolerate moderate or high vapor concentrations.

5.9 **Liquid or Solid Irritant Characteristics:** If spilled on clothing and allowed to remain, may cause smarting and reddening of the skin. Large amounts may be absorbed through the skin and cause poisoning.

5.10 **Odor Threshold:** 21.4 ppm (Sense of smell fatigues rapidly)

FIGURE 1 Chemical hazard response information system (CHRIS).

REVISED 1978

TABLE 2 Outline of Rating System

Column:	I	II	III	IV	V	VI	VII	VIII	IX	X
	FIRE	HEALTH			WATER POLLUTION			REACTIVITY		
		Vapor Irritant	Liquid or Solid Irritant	Poisons	Human Toxicity	Aquatic Toxicity	Aesthetic Effect	Other Chemicals	Water	Self-reaction
Grade 0	No Hazard	No effect	No effect	No effect	Nontoxic; LD_{50} 15 g/kg	Acute threshold limits above 10,000 ppm	No significant pollution; gases and odorless liquids	Inactive; may be attacked by Grade 4	No reaction	No reaction
Grade 1	Closed cup; Flash point above 140°F	Slight effect	Causes skin smarting	Slightly toxic	Practically non-toxic: LD_{50}5-15 g/kg	Threshold limits 1,000 to 10,000 ppm	Mild-odored light oils and soluble chemicals	React only with Grade 4	Mild reaction; unlikely to be hazardous	Mild self-reaction under some conditions
Grade 2	Flash point 100 to 140°F	Moderate irritation; temporary effect	First-degree burns, short exposure	Intermediat toxicity	Slightly toxic; LD_{50} 0.5 to 5 g/kg	Threshold limits 100 to 1,000 ppm	Mild-odored, colorless, water-insoluble oils; B.P. 150-450°F	React with Grades 3 and 4	Moderate reaction	Will undergo self-reaction if contaminated; do not require stabilizer
Grade 3	Flash point below 100°F B.P. above 100°F	Irritating; cannot be tolerated	Second-degree burns, few minutes exposure	Moderately toxic	Moderately toxic; LD_{50}50-500 mg/kg	Threshold limits 1 to 100 ppm	Light-colored high-boiling oils; odorous water-soluble compounds	React with each other and with those of Grades 2 and 4	More vigorous reaction; may be hazardous	Vigorous self-reaction; require stabilizer
Grade 4	Flash point below 100°F B.P. below 100°F	Severe effect; may do permanent injury	Second-degree and third-degree burns	Severely toxic	Toxic chemicals; LD_{50}50 mg/kg	Threshold limits below 1 ppm	Heavy oils, colored or malodorous	React with each other and all other grades	Vigorous reaction; likely to be hazardous	Self-oxidizing chemical; capable of explosion or detonation

SOURCE: Committee on Hazardous Materials 1974 industry (Atomic Energy Commission 1975). However, because of the newness of the LNG technology and the efforts at cargo protection and ship safety, data concerning potentially large catastrophic events are lacking. Thus, these risk studies have inherent limitations because they cannot be verified experimentally.

Given this lack of verification, it is essential that all failure data relevant to equipment and human performance in shipping be reviewed for applicability in a given risk assessment. These data include information on historical accident sequences of a nature similar to the ones under consideration, information on component part failures and on severe environments, and estimates of the projected frequency of occurrence of the situation under consideration.

SHORTCOMINGS

A risk assessment involves both methodology to determine the probability of an event sequence and a physical and chemical hazard analysis to determine the impact of such a sequence. The risk assessment can be a comprehensive one covering all types of incidents at a port or along a river system or it can be sequence specific.

A risk assessment requires extensive calculations and supporting data; therefore, a risk analyses will inevitably have some shortcomings.* The principal shortcomings can be as follows:

1. The data base is insufficient. The historic record of casualties (e.g., ship collisions) may not provide sufficient detail concerning cause and effect to permit reliable probabilities to be assigned to events. This is especially so when new systems or technologies are introduced for which little experience exists.

2. The consequence model is inaccurate. To quantify the risk resulting from accidental release of hazardous materials into the marine environment, use is made of models of the physical, chemical, and biological processes by which the hazardous materials affect the environment in which they are disseminated. Often these models are a very much simplified and approximate description of the real process, which can be quite complex. In some cases, it may not be known how reliable a model may be.

3. Human factors are difficult to quantify because experience is limited and/or the variability of human behavior is wide-ranging. Underestimating human error could lead to a lack of emphasis on preventive training. An overestimate of these human error rates could lead to undue emphasis on elimination of the human operator.

*A concise discussion of risk assessment with respect to the transport of hazardous materials is given by Philipson et al. (1982). In their report various commonly used terms are defined and both technical and ethical concerns are discussed and various shortcomings are documented.

4. The risk analyst is biased. In selecting event probabilities or using consequence models, judgments often must be made regarding which conflicting data or calculations are most suitable to the problem at hand. Because many such choices may be necessary, the analyst may exhibit a consistent bias toward minimizing or maximizing the calculated risk.

Risk analyses have been used for many purposes, some of which are controversial. Although it is natural to expect that risk analyses used to support policy choices or political decisions will be examined closely and criticized, it is important to recognize the difficulties which encumber the application of risk analyses to the solution of practical problems. Some are:

1. Reduction of principal risks. There is considerable agreement that risk analyses can help determine the relative risks of the various failure modes and thus delineate the most profitable paths for reducing risk.

2. Risk-benefit analysis. There are two problems associated with evaluating the benefits of a proposed action vis-à-vis the risks. Since the benefits and risks are usually experienced by different populations, it is not clear how these aspects are to be weighed relative to each other. The conversion of risks to costs (for the purpose of comparing to benefits) is also controversial, especially when human life or health is at risk and the exposure is involuntary.

3. Acceptability of risk. The concept of the acceptability of risk is not at all well defined. In addition, controversy invariably accompanies the use of absolute risk levels as criteria for public acceptability. This is especially the case when high consequence, low probability events are being considered.

4. Perception of risk. There can be substantial differences between risks perceived by the public and risks assessed objectively in a risk analysis. To the extent that public perceptions will affect public policy, risk analysis may be only one aspect of the decision-making process.

With these concerns in mind, a National Research Council panel on LNG safety (National Materials Advisory Board 1980) made several recommendations, and although related specifically to LNG, these recommendations have wider applicablity. The panel recommended that:

1. Risk assessments should be updated periodically, because new knowledge of changing conditions during the lifetime of a project can affect the conclusions of the original assessment.

2. Additional accident examples having high consequence-low probability events should be evaluated for risks. Risk assessments should be performed not only for the high consequence-low probability events, as is currently the practice, but also for the lower consequence-higher probability events. Public acceptance of LNG can be affected adversely by less-than-catastrophic events (e.g., spills during transfer operations or shipboard fires).

3. The risks associated with water transportation of LNG and with other hazardous materials should be compared. The USCG in consultation with an advisory group should establish the basis for risk comparisons (e.g, cargoes and ports to be studied). The applicability of risk-benefit analysis should be evaluated.

4. Better input data should be developed to increase the reliability of risk analyses. A worldwide incident-reporting system, including coverage of minor incidents and near misses, would help to provide relevant data. Data from tests at a ship-simulator facility should be collected. Such data will increase the reliability of synthesized probability data for ship collisions at specific sites. Risk assessments should provide confidence levels and discussions of uncertainties when probability data are used.

PRESENT DAY ATTITUDES TOWARDS SAFETY

From this brief review of the risk-related literature in shipping, two paths of activity appear to have evolved. First, the shipping industry and its regulators have attempted to reduce losses by improving their equipment and procedures for operation. This process has been, until recently, reactive for the most part, i.e., transport systems were improved after failure occurred. Some effort at regulation prior to adverse incidents has been attempted, based upon the experience of the community with similar cargoes and their attendant hazards.

The second path of activity stems from an awareness that a systematic approach to safety based on risk analysis has been evolving in other fields as well as in shipping, and that large catastrophic events, although not having yet occurred, may indeed be possible. This leads one to believe that the historical approach to safety in shipping either may not have led to adequate regulation or may have led to counterproductive regulation for potentially large events.

This latter set of concerns is exemplified in the British literature on Mossmorran Bay (Rice and Sutcliffe 1979; Sutcliffe 1980). A review of the hazards to persons and property at this site (near Edinburgh) was found to be large in comparison to other levels of risk imposed upon the populace. This occurred partly because the situation was one of gradual growth, and only when a comprehensive review was performed was the integrated risk level made apparent. While this study was performed for an overseas port, there is enough similarity to suggest that port studies be performed in the U.S. using risk asssessment techniques.

A second example of regulatory inadequacy can be found in the Maritime Transportation Research Board report on reducing tankbarge pollution (1981). It is suggested there that regulations may not have universal applicability and that they are not necessarily cost effective in all instances (e.g., alternatives to double hulls as a means of reducing oil spills in tank barges may lead to reasonable ways of reducing pollution but these suggested alternatives may be less than universally applicable).

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Chapter 3

REGULATIONS

The panel's study was limited to liquid cargoes carried in bulk including the combustible and flammable materials regulated under Title 46 CFR, Parts 30-40 (Chapter 1, Subchapter D, Tank Vessels) and the toxic, reactive and corrosive liquids, liquefied gases, carcinogens, and other hazardous materials regulated under Title 46 CFR, Parts 150-155 (Chapter 1, Subchapter O, Certain Bulk Dangerous Cargoes). Subchapter D regulates bulk liquid and liquefied gas cargoes that have conventional burning characteristics (e.g, petroleum products) whereas Subchapter O regulates cargoes that have hazardous properties other than or in addition to flammability.

Several of these parts are discussed next using the yearly issues of CFR Title 46 dated October 1, 1981 without consideration of subsequent changes that may have been issued via the Federal Register.

Part 150 classifies the hazardous cargoes into 22 reactive groups and 14 cargo groups. It indicates, for example, which groups are incompatible and must not be carried in adjacent tanks.

Part 151 applying to unmanned barges includes general requirements, definitions, and detailed regulations, as well as Table 151.05, Summary of Minimum Requirements. Hazardous materials not listed are not approved for shipment in bulk. Manned barges require special individual consideration.

Part 153 presents the safety rules for self-propelled vessels carrying hazardous liquids. This part includes 37 pages of general requirements, definitions, detailed rules and regulations, and Table 1--Table of Minimum Requirements, which lists hazardous cargoes and minimum requirements.

Part 154 presents the safety standards of self-propelled vessels carrying bulk liquefied gases. This part includes 64 pages of general requirements, definitions, detailed rules and regulations, and Table 4--Summary of Minimum Requirements, which lists the liquefied gases and minimum requirements.

Part 154a presents interim regulations for issuance of letters of compliance to barges and existing liquefied gas vessels. This Part of 9 pages establishes a procedure for evaluating and regulating the safety of foreign flag barges carrying any of the cargoes listed in Annex A, and foreign flag vessels carrying the liquefied gases of Table 4 of part 154. This procedure would be used for barges and vessels built prior to the effective date of Parts 151, 153, and 154.

The scope of the detailed rules and regulations in Parts 151, 153, and 154 are summarized in the tables of minimum requirements. These tables generally include the specific requirements for each hazardous cargo in terms of ship or hull type, cargo tank type, cargo containment system, control of cargo tank vapor space, vapor leak detection, gauging, venting and vent height, cargo segregation, cargo transfer piping and control, environmental control of cargo tank and cargo handling space, electrical hazard, fire protection, temperature control, special requirements, and tank inspection.

Most of the regulations are designed to preserve the integrity of the cargo containment system and to protect the ship's crew and other workers. The regulations designed to protect the general public are those that minimize the probability of a spill of considerable magnitude. In this regard, the major factors are the ship or hull type, cargo tank type, and cargo containment system including the requirements for ship side and bottom protection of the cargo tanks, and the ability of the ship to survive damage and remain afloat in a stable condition. Based on studies of ship collisions, rammings and groundings, the location of the cargo tanks with respect to the ship's side and bottom is specified, and criteria for the probable extent of damage are established as a basis for damage stability and survivability calculations.

The degree of protection required is not the same for all hazardous cargoes. The highest standard of physical protection, Ship Type I, is required for those substances considered to pose the greatest hazard, those whose release would have wide-reaching effects. Ship Type II is required for those cargoes considered to pose a significant hazard but whose release would not have as wide-reaching effects. Ship Type III covers products considered to pose a still lesser hazard and is similar in concept to normal tankships carrying, for example, gasoline although increased survivability is required. Thus, the intent of the regulations is to provide a degree of safety equivalent to that found acceptable in the transportation of gasoline.

REGULATION DEVELOPMENT

These regulations are based on many years of development work and experience by government, industry, and the public within the United States, and internationally by the Safety of Life at Sea Conferences and IMCO.

Halvarsen (1975) documents the USCG's involvement with hazardous materials. Historically, the first federal regulation of hazardous materials is found in the Steamboat Inspection Act of 1852, which contained requirements concerning the transport of flammable and combustible liquids on steam passenger vessels . An act in 1871 sought to improve safety in the transportation of such materials as oil of vitriol, nitrol, camphene, nitroglycerine, naphtha, benzene, crude oil, and refined petroleum. The USCG first entered the area of hazardous materials regulation with the Dangerous Cargo Act of 1940. In 1942 the Coast Guard assumed the functions of the Bureau of Marine Inspection and Navigation, which had been formed in 1936 by combining the Steamboat Inspection Service and the Bureau of Navigation.

The Morro Castle and Mohawk passenger ship disasters in September 1934 and January 1935, respectively, resulted in a thorough congressional investigation of maritime regulations, and more marine legislation was enacted in 1936 and 1937 than during the previous 20 years. The Tank Vessel Act of 1936 subjected all tank vessels carrying dangerous liquid cargoes in bulk to inspection by the Bureau of Marine Inspection and Navigation and authorized the promulgation of regulations regarding their construction, inspection, and operation (Shepheard 1943). The American Bureau of Shipping (ABS), the American Petroleum Institute (API), and other groups participated in drafting the regulations that resulted in Subchapter D.

The late 1950s saw the movement of bulk cargoes of considerable variety, including the initial experimentation with the transport of cryogenic products by barges on U.S. rivers (U.S. Coast Guard 1976). In response to this and other technological advances in water transportation, the USCG established its Chemical Engineering Branch to provide for the evaluation of the hazards of unconventional cargoes. In addition, a special USCG task group was established to formulate plans and concepts for new regulations for unconventional cargoes. In 1963, a committee was formed with representatives from the API, the Manufacturing Chemists Association (now CMA), the Compressed Gas Association (CGA), the Chlorine Institute (CI), and others to assist the USCG in formulating regulations for the bulk transport of hazardous cargoes.

The 1961 sinking in the Mississippi River near Natchez of a barge carrying 1200 tons of chlorine in four independent tanks and the subsequent publicity and successful salvage operation, "were the catalysts by which the corrective measures (for barge hulls) were initiated in the form of new regulations" (Steinman and Carman 1966). These new regulations were published in the Federal Register on February 1, 1963, June 5, 1964, and March 9, 1965 and ultimately were incorporated in comprehensive new regulations in Subchapter O.

During the same period, the Committee on Hazardous Materials (established in 1962 by the National Academy of Sciences at the USCG's request) carried out various studies on technical aspects of hazardous materials safety. One of these resulted in a method of evaluating the hazards of bulk liquid and liquefied gas cargoes that is published in Committee on Hazardous Materials 1973. The method, with accompanying specific ratings, permitted correlation of barge structural and operational requirements with the type and degree of hazard of individual cargoes. The committee's initial report covered 156 industrial chemicals and was expanded to cover 363 industrial chemicals. Later changes, mostly minor, resulting from technical information and comments received from specialists concerned with the safe handling of hazardous materials were included.

A significant trade from American petrochemical plants to Europe and Japan in ships of foreign registry began in the early 1960s. Concerned that these ships did not possess the safeguards to assure containment of the cargo, the USCG in 1964 required that any ships to be operated in this trade from U.S. ports should submit for review and approval plans of the cargo containment area and related piping and electrical systems. This procedure for review and approval of ships of foreign registry was a significant departure from accepted international practice and was based on the method established by the Safety of Life at Sea Convention (1960) in regard to the port and population hazard presented by nuclear propelled merchant ships.

In 1967 the United States requested that IMCO create a subcommittee to develop an international system of regulations under which the government of registry would oversee the requirements of ship construction. This resulted in the IMCO Code for the Construction and Equipment for Ships Carrying Dangerous Chemicals in Bulk (1971) and the Code for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (1975). Since the U.S. regulations provided the model for these two codes and since a concerted effort was made to keep them consistent with the international standards as they were developed, the requirements of the IMCO codes were incorporated in the Code of Federal Regulations with moderate revisions.

Among the important and far-reaching laws concerning the transport of hazardous materials enacted in recent years are the Federal Water Pollution Control Act of 1972, the Ports and Waterways Safety Act of 1972, the Transportation Safety Act of 1974, the Deepwater Ports Act of 1974, and the Port and Tanker Safety Act of 1978.

THE USCG REGULATORY PROCESS

Prior to about 1960, marine legislation and safety regulations generally resulted from marine casualties. With the initiation of the Nuclear Merchant Ship Program in 1957 and the beginning of the bulk shipment of hazardous materials, it was recognized that a marine accident in ports or waterways could result in casualties to the general population. Consequently, safety recommendations, guides, and regulations were drafted concurrently with the development of new technologies.

Hazardous materials, pollution, and other safety regulations are promulgated as a result of maritime casualties, industry requests to USCG, statutes calling for regulations, technological developments, USCG recognition of a safety problem, Presidential directives, or public perceptions of a problem area.

The in-house process used by the Coast Guard in promulgating regulations is presented in the December 1980 issue of Proceedings of the Marine Safety Council and is summarized in Appendix A of this report. Establishing minimum requirements for the transport of hazardous materials is an ongoing process since new industrial chemicals or products are being proposed continually (22 in the first half of 1981). For each product, data are required to be submitted on Form CG-4355, Characteristics of Liquid Chemicals Proposed for Bulk Water Movement. The data submitted are reviewed, compared with similar information available from other sources, and evaluated in comparison with currently regulated materials for equivalent safety. The IMCO Criteria for Hazard Evaluation of Bulk Chemicals also is used in the evaluation process.

The USCG staff then determines which is the appropriate category for the product:

1. Unregulated;

2. Combustible or flammable (Subchapter D);

3. Toxic, reactive, corrosive, liquefied gases, etc. (Subchapter O);

4. Not permitted in bulk on manned vessels but permitted on unmanned barges; or

5. Not permitted to be shipped in bulk except by special individual action.

At this point the proposed rulemaking process starts (see Appendix A).

OPERATIONAL CONTROLS, FACILITIES, AND PERSONNEL

For safety and environmental protection, the USCG regulates the design, construction, and testing of ships and barges carrying hazardous cargoes, the operation of ships and barges in the navigable waters of the United States, the waterfront facilities, and personnel certification. The USCG has statutory authority to regulate and control port safety under the Magnuson Act (50 USC 191) and the Ports of Waterways Safety Act of 1972 (33 USC 1221 et seq). The regulations are found in Title 33 CFR. All bulk liquids operations are regulated under Part 126 thereof.

Under 33 CFR, Part 160, authority has been delegated to the USCG District Commanders and Captains of the Ports to issue orders and directions regulating the operational controls of vessels carrying hazardous materials when entering, moving within, moored in, or leaving a U.S. port (see Patterson 1978 for example). Approximately 40 materials now are designated as cargoes of particular hazard (COPH). Vessels carrying these cargoes are subject to additional requirements under 33 CFR, Part 124.

In specific cases the regulatory responsibilities of some government agencies overlap. To delineate the exact areas of each agency's responsibility, Memoranda of Understanding (MOU) are developed. For example, the USCG has authority over ships, piers, and associated storage tanks while the Materials Transportation Bureau (MTB) has authority over natural gas transportation and storage. The agencies signed an MOU, "Regulation of Waterfront Liquefied Gas Facilities" (U.S. Coast Guard 1978), giving the USCG responsibility for establishing regulatory requirements for:

1. Facility site selection as it relates to the management of vessel traffic in and around a facility;

2. Fire prevention and fire protection equipment, systems, and methods for use at a facility;

3. Security of a facility; and

4. All other matters pertaining to the facility between the vessel and the last manifold (or valve) immediately before the receiving tank.

MTB is responsible for all other matters, e.g., design and construction of the facility.

The USCG's traditional responsibility for safety of life and property at sea and its more recently assigned responsibility for protection of the marine environment permit it to establish the qualifications for licensing and certifying marine personnel for service aboard U.S. merchant vessels. These regulations are contained in 46 CFR, Subchapter B, Parts 10-16, and Subchapter P, Part 157.

Because of the prevalence of foreign flag ships in the hazardous cargo trade into and out of U.S. ports, the USCG has been vigorously promoting the development of international standards for the officers and crew of these vessels through its U.S. representation in IMCO. (As of November 1981, these IMCO standards had not been established.)

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Chapter 4

A REVIEW OF SOURCES OF INFORMATION

QUANTITIES AND VARIETIES OF MATERIALS SHIPPED

Bulk liquids moved by water are not subject to Interstate Commerce Commission (ICC) or other federal rate regulations. As a consequence, the statistical background information available defining the quantities and varieties of materials shipped is neither extensive nor detailed. However, carriers are required to report (monthly) the quantities and types of commodities moved over various segments of the federally maintained waterways system to the U.S. Corps of Engineers (COE). The COE publishes summary information about the quantities and types of cargoes moved with about a two-year lag after the date of shipment (U.S. Army Corps of Engineers 1978). This information is available for the total waterways system and often by waterway segment as well.

The COE information is presented in 30 commodity groups with 146 commodity classification numbers. These commodity numbers are not as useful as they might be because they frequently include many products that do not fall into the hazardous cargo category. General terms like "basic chemicals and basic chemical products" become catch-alls and a list of COE commodity classification numbers applicable to each commodity on the USCG hazardous cargo lists would be helpful. Nevertheless, the COE data provide some perspective concerning the volume of hazardous materials moved in waterborne commerce. The data in Table 3 indicate the approximate quantity of some selected hazardous cargoes:

TABLE 3 Quantities of Some Selected Commodities Shipped Per Year

Class Number	Name	Amount (in thousands of tons/yr)
1493	Liquid sulfur	8,560
2810	Sodium hydroxide	5,188
2813	Alcohols	4,277
2817	Benzene and toluene	3,994
2818	Sulfuric acid	2,344
2819	Basic chemicals and products[a]	35,092
2912	Liquefied gases	5,288
	Subtotal	64,743
	Total Waterborne Commerce	2,021,350

[a]Not entirely hazardous, but other hazardous commodities are possibly included under commodity class numbers 2871, 2872, 2873, 2876, 2879, 2917.
SOURCE: U.S. Army Corps of Engineers 1978.

The American Waterways Operators (AWO) use the COE data as the basis for an AWO publication (American Waterways Operators 1978). This document presents data by waterway segment and also summarizes the data to provide overall numbers to show within product categories the tons and ton-miles of products shipped throughout the domestic inland waterways system.

The Maritime Administration also publishes information about the quantities and varieties of materials shipped in domestic waterborne commerce (Maritime Administration 1980). These data are published annually with five-year increments of information. The most recent one available shows statistics for 1975 through 1979.

These publications contain information which is largely related to the domestic commerce of the United States. Information about the foreign commerce of the United States by water is contained in volume I of the Corps of Engineers' Waterborne Commerce of the United States and the information is gathered by the Corps from information provided by the Bureau of Census from reports of customs entrance and clearance forms filed for inward and outward foreign tonnage.

The Bureau of Census data are computerized and generated tabulations may be obtained in a form most usable for a particular project. These can show tons and value of imports and exports carried on U.S. and foreign ships, of the liner, tanker, or tramp types, by 2, 3, or 4 digit classification basis. Such a tabulation on a 4 digit basis for the year 1979 lists about 700 commodities and required 71 pages. Two of these pages which include data for some bulk liquid hazardous cargoes are reproduced in Appendix B. The data may also be tabulated on an area to area basis (to or from 9 U.S. areas, and to or from 20 foreign areas).

Individual carrier and shipping companies maintain their own records of tons and ton-miles of cargoes shipped. This information generally is categorized by the generic name of the particular cargo involved in the case of chemicals and petroleum products; therefore, it tends to encompass the broad spectrum of hazardous materials.

Information on the volumes carried by an individual carrier is not at all indicative of the total quantity of a particular cargo moved in commerce on a relative basis because individual carriers may gain or lose important contracts from year to year and this will change the relative importance of particular cargoes in the corporate mix. However, these individual company statistics do tend to list the primary hazardous materials moved in commerce through inland waterways of the United States, and they may be helpful in identifying specific chemicals frequently seen in commerce, thereby supplementing the more general categories contained in the COE statistics. For instance, a carrier's or a shipper's statistics will show the tons and ton-miles of products like chlorine, anhydrous ammonia, acrylonitrile, acetone cyanohydrin, caustic soda, and other cargoes commonly found in domestic commerce that are lost in the groupings in the COE statistics. Unfortunately, individual company statistics are not generally available.

CHEMICAL HAZARD DATA

A number of publications provide useful information on the magnitude and type of hazard involved in the shipment of specific hazardous materials. One is the USCG's Chemical Data Guide for Bulk Shipment by Water (1976). This guide, which has been updated from time to time, contains individual page listings for each of 279 chemical cargoes, all of which involve some type of hazard. The magnitude and type of hazard for the cargo is given and a brief emergency response procedure is outlined in the event of a spill, a fire, or other some casualty involving that cargo. This information is intended for use by nontechnical personnel in their response to emergencies involving these cargoes. The USCG publishes similar information in A Condensed Guide to Chemical Hazards which is part of CHRIS (U.S. Coast Guard 1974).

Another guide to the magnitude and type of hazard involved with individual chemicals is the Committee on Hazardous Materials' Evaluation of the Hazard of Bulk Water Transportation of Industrial Chemicals--A Tentative Guide (1973). This guide was developed under contract for the USCG and was used by the Coast Guard in the grouping of various individual chemical cargoes to assign barge and ship hull types for the carriage of those cargoes and in determining the need for specialized equipment (e.g., gauging and venting equipment as well as firefighting equipment and spill containment equipment) for individual cargoes.

The various standard chemical and petroleum engineering references, such as the Handbook of Chemistry and Physics and Chemical Dictionary, are frequently used for detailed information about the nature, magnitude, and type of hazard involved with a particular product. Similarly, various manufacturers publish manuals that describe in detail the characteristics of the cargoes which they manufacture.

INFORMATION ON OPERATING VESSELS

The USCG's Marine Safety Information System (MSIS) contains a record of important information about U.S. flag ocean-going vessels as well as foreign flag ships visiting U.S. ports. In the past, some records were kept at the individual ports and some at USCG Headquarters, which made it difficult to find out about a vessel's history. The MSIS is intended to remedy this situation since its data base is accessible to each port and can be added to by each port.

There are several groups of data in the MSIS. For a foreign flag chemical carrier, the first data group defines the vessel by giving the ship's name, former names, reference numbers, flag, dimensions, owner, and date of construction. The next group contains Safety of Life at Sea (SOLAS) information and the next, Letter of Compliance (LOC) data including the expiration date and the list of cargoes approved for carriage. The Certification of Financial Responsibility has become important in recent years and the appropriate data are listed next. This is followed by an entry dealing with reported casualties that gives the date, location, case number, and a short description. Finally, boarding history is described in terms of the date, location, results and type of boarding. With this listing, any deficiencies noted on one visit to a port are always available. Boardings are placed in off-line storage after 18 months and violations, after 3 years. USCG units must update these entries. Provision is made for short messages calling attention to a specific problem with a ship, which effectively alerts all concerned parties.

The regulations governing the transportation of a new cargo are established provisionally by the Hazard Evaluation Branch at USCG Headquarters. Up to three years pass before these regulations are published in the Code of Federal Regulations (CFR) because of the due process requirements in developing regulations. With the MSIS, a few minutes after a proposed cargo requirement is approved by the Chief of the Cargo and Hazardous Materials Division, every port has access to it. Another module of MSIS will have chemical and physical data on over 100 cargoes that can be updated at any time.

SHIP AND BARGE DESIGN

As noted in Chapter 3, the USCG regulates the design, construction, and operation of barges and tankers used for the bulk transport of hazardous materials. Many vessels have been built in accordance with the regulations and, in some cases, concurrently with the development of the regulations. The Coast Guard has published from time to time a volume entitled, List of Inspected Tank Barges and Tankships (1977), which includes all tank vessels certificated by the USCG. The listing designates the various cargoes regulated under 33 CFR, Subchapters D or O, that a particular vessel is certificated to carry. It shows a great many tank vessels certificated to carry Grade A and lower petroleum products and far fewer vessels certificated to carry the various chemicals that must be listed by name on the certificate of inspection of the particular vessel. A listing of hazardous materials barges and the cargoes for which each is certificated also is included.

The design and development of some of these special purpose vessels have been described in the technical literature. Examples of these technical papers are those by Connors (1978), Creelman (1971), Cuneo et al. (1980), de Frondeville (1977), Foster and Coward (1965), Howard (1972), McAlear and Nierberg (1979), Neal (1976), Phillips and Kelly (1979), Shearer (1979), Steinman and Carman (1966), Symon (1981), and Thomas and Schwendtner (1971).

In addition to Subchapter O and Subchapter D, the Coast Guard regulates through its engineering regulations the equipment to be utilized within and aboard these tank vessels. Further, it spells out through its tankerman regulations and its manning regulations the manner in which these vessels will be crewed and operated by certificated and licensed personnel. The

USCG's involvement with tank vessels of all kinds begins during design and continues through the construction period with regular inspection at each step by trained USCG personnel until the vessel is completed and ultimately certificated by the USCG for its intended use.

Subsequent to that time, the USCG carries out a life cycle inspection program. The program basically is a biannual inspection with an interim mid-term inspection so that the vessel generally is inspected by USCG personnel at least once a year and more comprehensively every two years. The regulations also require certain drydocking periods and internal tank inspection periods that vary depending on the trade in which the vessel is engaged and the cargoes being handled.

USCG regulations are not static; they are constantly reviewed and amended to keep them up to date and to correct deficiences that may become apparent as new cargoes and new operations enter the picture. In order to facilitate this continous review of regulations, the USCG consults various industry advisory groups and committees that make available to USCG technical personnel the broad operating experience of industry professionals.

In addition to the USCG publications spelling out construction and operating standards, there are, of course, the Rules and Regulations of the Classification Societies, and a broad range of texts on ship and barge design and structural analysis that are used by the community of naval architects and marine engineers in the development of designs that ultimately will attain USCG and classification society approval. Some of these publications are sponsored by the Society of Naval Architects and Marine Engineers and others are produced by various technical publishers.

OPERATOR TRAINING

Personnel training is available in many forms. The federal government operates the U.S. Merchant Marine Academy at Kings Point, New York, to train deck and engine officer personnel, and there are various state schools established for the same purpose. The state schools presently in operation are Maine Maritime, Massachusetts Maritime Academy, New York State Maritime Academy, Texas Maritime Academy, and the California Maritime School. In addition to officer training schools, a number of marine schools have been established by both the government and various unions to train personnel for entry level positions on ships and towboats and to upgrade entry level personnel to more skilled positions in the deck, engine, and steward's departments of vessels. Some private vocational schools provide training for certification for a variety of marine personnel categories. A notable private school is the National River Academy in Helena, Arkansas, which trains pilot house personnel, engineering personnel, deckhands, tankermen, and mates for inland river towboats. The objective of all of these schools, in addition to training qualified personnel, is to produce graduates who will pass the USCG license and certificate examinations.

Many of the major towboat, barge, and shipping firms operate in-house training programs. These programs generally are intended to familiarize personnel with company policy concerning operating and safety procedures and the use of safety equipment. They also attempt to familiarize personnel with the cargoes handled by that particular company.

DATA ON PAST INCIDENTS

The U.S. Coast Guard (1980) publishes annually a statistical summary of commercial vessel casualties. Although a great deal of information is included, it is presented in a way that makes it difficult to extract information about hazardous materials incidents. Part of the reason for this is that until recently a hazardous materials incident had to be reported only if monetary damage exceeded $1500 or if death to personnel or if loss of time because of injury were involved. The statistical summary information is based on data from USCG Casualty Investigation Reports and the accident report forms (Form CG-2692) filed by operators for each reportable incident. Supplementing these are the records of the Marine Inspection Office that has cognizance over the repairs. Unfortunately, this reporting process is not set up to make it particularly useful for obtaining a summary of information involving hazardous materials incidents. Also it is not possible to gather information on casualties at a particular location, for instance, at a dangerous bridge or a difficult lock or a crossroad where numerous accidents have occurred.

Significant water transport casualties are the subject of the USCG hearing procedure wherein a hearing board is established and a detailed written report of the conclusions of the hearing is made. In the case of serious accidents these USCG hearing reports are reviewed by the National Transportation Safety Board (NTSB) and the NTSB files its own report that usually contains recommendations for USCG implementation. In addition to these reports, various ports (i.e., New York, New Orleans, Houston, San Francisco, Puget Sound, and Valdez, Alaska) maintain vessel traffic systems and compile their own records but do not publish summary information. These records appear to be a useful research resource yet to be tapped.

Obviously, hazardous materials transport incidents can have a significant impact on the economic fortunes of the companies involved. Consequently, the individual operating companies maintain detailed records and analyses of the experience of their fleets. This information generally is kept confidential and considered proprietary but from time to time it is made available in technical articles or speeches written by corporate personnel.

Various studies of hazardous materials transport experience have been conducted. For example, Arthur D. Little (1974) prepared a model economic and safety analysis of the transportation of hazardous substances in bulk and, the Committee on Hazardous Materials (1973a) prepared a long-range forecast concerning the bulk transportation of hazardous materials by water which includes a case study of risk exposure factors for hazardous materials flow in intracoastal waterways.

Card (1975) reports on a study of the effectiveness of double bottoms in preventing spills, based on the records of 30 tank vessel casualties which occurred in U.S. waters between January 1969 and April 1973. This study showed that if the tankers involved had been fitted with double bottoms of 1/15 the beam (B) in height, 90 percent of the spills would not have occurred. If the double bottom height had been 2.0 meters, only 1 case in the 30 would have spilled. The regulations for Types I and II chemical ships specify B/15 or 6 m, whichever is less, and for Types I and II gas ships B/15 or 2 m, whichever is less.

The Maritime Transportation Research Board (1981) has reported the results of some studies of penetration of single- and double-hull tank barges due to collisions, rammings, and groundings. One analysis of loaded double-hull barge accidents showed that penetration of the inner hull was avoided in nearly 90 percent of the accidents involving penetration of the outer hull. Another analysis, comparing single- and double-hull barges indicated even higher effectiveness. Over 50 percent of the hazardous cargoes listed in 46 CFR, Table 151.05, require double hulls or single hulls with independent cylindrical cargo tanks. In spite of sévere accidents to some of the latter, which carry cargoes such as chlorine and anhydrous ammonia, there have been no cargo spills from this barge type.

With respect to gas ships, through the end of 1980 there have been 5,420 voyages (10,840 loaded port transits) of LNG ships without a spill due to collisions, rammings, or groundings. (There have been small spills during cargo transfer.) There have been two significant groundings of large LNG tankers with no penetration of the inner bottom and no spill. Of the 5,420 voyages, 254 were to the United States, 373 were from Alaska to Japan, 1,549 were to Japan, and 3,334 were to Europe (private communication from the Society of International Gas Tanker and Terminal Operators, Ltd.). The number of voyages of liquefied gas ships carrying LPG, ethylene, etc., is estimated to be ten times that of LNG. Data on spills are not available.

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Chapter 5

APPLICATION OF RISK ASSESSMENT METHODS

POTENTIAL USCG APPLICATIONS

The scope of potential applications for quantitative risk analysis by the USCG is quite large as illustrated by the following examples:

1. Bulk shipments of hydrogen peroxide are not permitted today. Should hydrogen peroxide be permitted aboard ship in bulk? Should the USCG approve a request to ship hydrogen peroxide of 60 to 70 percent concentration, given the nature of its hazards?

2. Safety relief devices prevent tank overpressurization during a fire, reducing the chance of a large and rapid cargo release. Since, on occasion, safety valves do leak, small releases must be expected. Thus, there is a trade-off between small infrequent releases and large releases during fires. For very hazardous chemicals (e.g., chlorine), should safety relief devices be required? The United States requires them, but other countries disagree.

3. Chlorine is restricted to bulk shipment in barges with no more than 4 tanks, each no larger than 300 tons. Currently, it is prohibited aboard ship in bulk. Is this reasonable? Should chlorine be prohibited aboard ship?

4. Vapor recovery systems return cargo vapors to shore during tank loading. The alternative is to release the vapors to the atmosphere. Long vapor return pipes when filled with flammable fuel-air mixtures can transform a fire into a more dangerous detonation. Which are safer, vapor recovery systems or venting directly to the atmosphere?

5. Barges can remain in service for 50 years or more and tank vessels for 40 years or more. Should liquefied gas carriers be permitted to sail when they are decades old? Should the USCG establish mandatory scrapping dates for liquefied gas carriers? Is there anything about liquefied gas carriers that requires a maximum lifetime? Can one distinguish between the cargo containment portion and the rest of the ship?

6. How many back-up systems should the USCG require for chemical cargoes? To prevent tank overfilling, for example, the Coast Guard could require a trained tankerman, a high level alarm, and an overflow valve.

7. How much redundancy should the USCG require in electronic navigation devices? Radars, for example, can fail. Should two be installed? Should there be more than two?

8. Which is superior in maximizing crew safety, forward or aft deckhouses? USCG regulations now favor aft deckhouses. Which arrangement gives the crew more protection?

9. Which provides more protection during tank loading, automatic or manual shutdowns? Automatic shutdowns can fail and crewmen may not pay attention. If both types are used, the automatic shutdown may not be maintained and/or the crewmen may fail to pay attention, counting on the automatic device to prevent overflow.

10. With open gauging, the crew is exposed to cargo vapors but is able to monitor closely the liquid level in the cargo tank. With closed gauging the crew is protected from vapors but the liquid level measurement depends on equipment that could fail, causing overflow, that could pollute the air and water. Which is safer overall, open or closed gauging?

11. For molten cargoes, high vent risers may become blocked if, during the loading, the tank is overfilled and the liquid cools and solidifies. If blocked, a vent riser cannot relieve overpressure and the cargo tank may rupture. Are high vent risers safe for use with molten cargoes?

12. If a tank is stowed on deck, it can be cooled during a fire by water spray, but its fire exposure factor is high. The fire exposure factor is related to the amount of thermal radiation received. If stored in a cargo hold, the fire exposure factor is much lower, but the tank cannot easily be cooled by spray. Where should portable tanks be located?

13. Towboats are classed as uninspected although they move large tonnages of cargo (including hazardous materials) through major cities on waters that require high and reliable performance. Should towboats be inspected in a manner analogous to ocean-going vessels?

14. Should quantitative risk analysis be undertaken for all significant casualties on inland waterways? Such analyses might reveal other or contributing risks, items that should be considered in future casualty investigations, and additional items that should be included in the Maritime Safety Information System.

15. Should a minimum ratio of towboat horsepower to tow tonnage be etablished to assure adequate manueverability under widely varying conditions?

16. Although the USCG does not have prime responsibility for site approval, it does have responsibility for determining if and in what manner vessels may utilize a facility. Is the present qualitative method of determining the suitability of a new hazardous materials facility site adequate?

17. Does a particular port area require a vessel traffic control system (VTS) to improve safety? Would the installation prove to be cost effective?

These representative applications range from simple systems composed of relatively few elements to large complex systems with many elements, from low consequence to high consequence events, and from moderate probability to extremely low probability for the occurrence of an incident.

The most difficult regulations to be developed and enforced by the USCG--and probably the most important for public safety--are those related to low probability-high consequence events in certain systems and situations. These regulations characteristically are based on little or no direct experience and as a result quantitative results of a risk analysis may well lack credibility and utility. There still may be benefits from qualitative risk analysis because the methodology requires orderly, structured thinking that reduces the probability that a significant element in the overall risk will be overlooked.

However, in the absence of an overall quantitative analysis, the problem of deciding the acceptability of the estimated risk becomes much more difficult because, at this stage in the evolution of quantitative risk analysis as a regulatory tool, the only approach is to compare results with other risks that are being accepted. Without overall quantification, the comparison becomes a matter of judgment or educated guessing. Although regulatory decisions also should be based on consideration of corresponding benefits and on who bears the risks for those benefits, a consistent, quantitative approach to these considerations is not feasible at this time for a field as diverse as water transportation of hazardous materials.

Given this situation, it appears that applications of quantitative risk analysis by the Coast Guard should include those that meet the following criteria:

1. the situation or system being analyzed can be defined so all significant elements are identified,

2. the objective or purpose of the analysis is understood, and

3. potential consequences warrant a careful analysis.

A SAMPLE APPLICATION

It was not feasible for the panel to undertake a risk analysis for any of the real decisions facing the Coast Guard because of time and input data limitations. However, a hypothetical casualty sequence developed by another National Research Council group (Marine Board 1979) provided a convenient means of illustrating the use of some quantitative risk analysis methods. This hypothetical event was based on an actual casualty (U.S. Coast Guard 1972).

A brief description of the hypothetical incident is as follows: A towboat pushing four barges of refrigerated anhydrous ammonia (NH_3), while proceeding downstream on the Ohio River at flood stage, strikes a highway bridge in the vicinty of Louisville, Kentucky, as the result of a steering failure. The two lead barges separate from the tow without cargo tank damage and break apart. One barge grounds without incident, but the other proceeds downstream and goes over the McAlpine Dam with subsequent massive release of cargo.

Although a complete analysis would consider other possible consequences (e.g., tow does not break up, both barges go over the dam, the grounded barge sinks instead of grounding), the assumed sequence has a large resultant consequence and is deserving of analysis to determine its probability.

Figure 2 is a preliminary event tree for the hypothetical sequence imbedded in other possible sequences. The purpose of the risk analysis in this case is to estimate the probability of a massive release of ammonia due to the coexistence of the highway bridge and the McAlpine dam.

Probabilities in Figure 2 were assigned by panel members on the basis of experience and judgment. In all likelihood they are reasonable, but they are presented here for purposes of illustration only. Although the hazardous material in this hypothetical casualty was anhydrous ammonia, actual probabilities would not change greatly for barges carrying other hazardous materials as long as the sequence description was the same. However, if the analysis were extended to include risk to the public, there would be major differences between cargoes because of widely differing types and degrees of hazard (e.g., flammability, vapor toxicity, pollution of potable water, detonability).

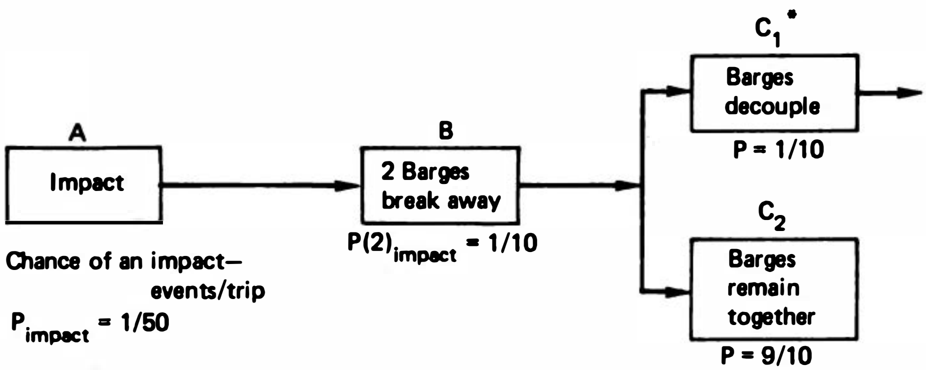
The assumed sequence of events is indicated by asterisks in Figure 2. The overall probability is obtained by multiplying the elemental probabilities as follows:

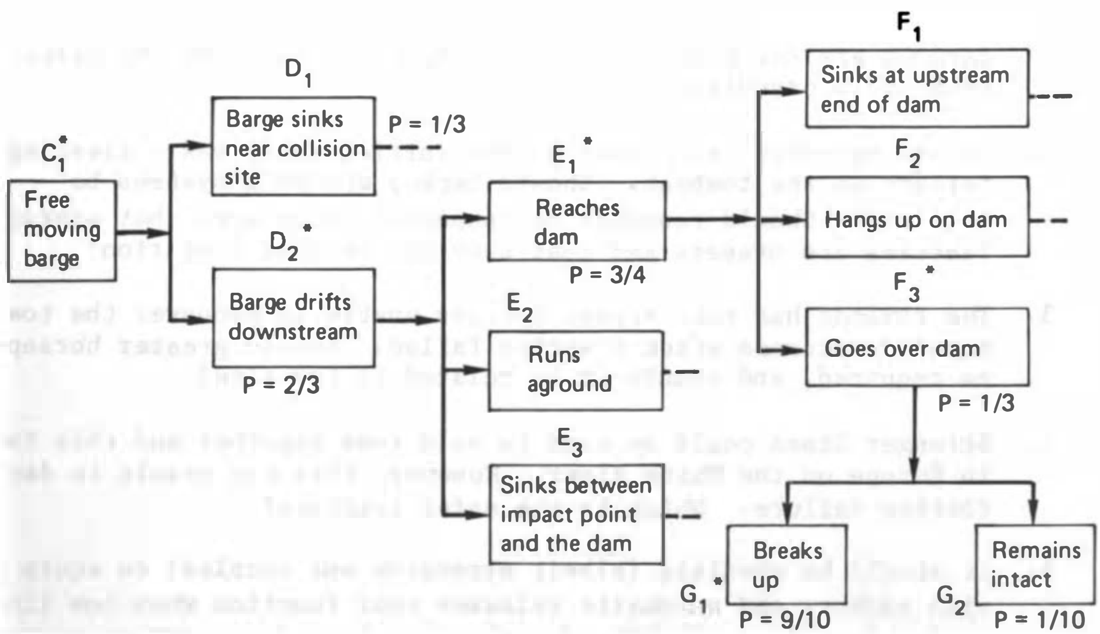
$$P = P_A P_B P_{C_1} P_{D_2} P_{E_1} P_{F_3} P_{G_1} = (1/50)(1/10)(1/10)(2/3)(3/4)(1/3)(9/10)$$

$$= 3 \times 10^{-5}$$

where P = probability of massive release per trip.

This is an extremely simple example of one tool used in quantitative risk analysis as it might be applied in casualty studies. If the USCG PVM





*Sequence under consideration

FIGURE 2 Event tree for hypothetical casualty sequence.

or HACS (described earlier) were utilized, the analysis could be extended to estimate risk to the public from this sequence. Also, other event elements and other post-ramming sequences could have been analyzed.

Various other tools from the risk assessment field could be applied to this sequence but were not because of time constraints. The intent of this very brief example is to show some of the power of the techniques in disciplining the analysis, thereby making safety possibly more quantifiable and certainly making safety analysis more verifiable, reproducible, and comprehensive.

Even this simple analysis can be used to identify actions that may be deserving of (further) consideration. Examples are:

1. Only the lead barges broke away and, intuitively, they appear to be the most vulnerable. Should lead barges be restricted to less hazardous cargoes? (Note that barges carrying the more hazardous cargoes are designed to provide more protection for the cargo in the event of a casualty.)

2. In the hypothetical casualty, the initial event was a steering failure on the towboat. Should backup steering systems be required? Should towboats be inspected to be sure that appropriate features are present and that they are in good condition?

3. The towboat had twin screws but was unable to maneuver the tow while bound downstream after steering failed. Should greater horsepower be required, and should it be related to tow size?

4. Stronger lines could be used to hold tows together and this is done in Europe on the Rhine River. However, this can result in deck fitting failure. Which is the safer practice?

5. It should be possible (albeit expensive and complex) to equip barges with anchors and automatic releases that function when tow lines part. Is this worthwhile for the more hazardous cargoes to prevent uncontrolled drifting?

6. A standby towboat could be provided upstream of dams during periods of high water and swift currents to corral drifting hazardous cargo barges. Is this practical and economically feasible?

This short illustration does not do justice to the power of risk assessment and the techniques of which it consists. Similar studies of data, fault tree analysis, and common mode considerations would yield other insights into the sequences typified by the one considered herein.

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Appendix A

THE USCG PROCESS FOR PROMULGATING REGULATIONS[a]

The process by which the USCG promulgates regulations is slow and methodical. Each proposal is reviewed, presented for public comment, and discussed and reviewed again before becoming final. There are three identifiable stages in this process: the conceptual stage, the proposal stage, and the final rule stage. The impetus for the regulation can come from various sources: public awareness of a problem area, a Presidential directive, a statute calling for regulations (such as the Port and Tanker Safety Act of 1978) or, most sadly, a maritime casualty.

Once the need for corrective action is demonstrated, a project manager is selected at USCG Headquarters. The project manager examines the problem and looks at alternative solutions. He decides whether a regulation is the proper solution or whether some other answer might be more appropriate. Most problems which come to the USCG for consideration are handled in some other way than by regulation. If a regulation seems to be the best answer, however, the project manager develops a work plan.

The project manager sets forth the following points in his work plan:

1. The need for the regulation (i.e., what prompted the regulatory activity);

2. The objectives to be accomplished and the means of accomplishment, stated as explicitly as possible;

3. The alternatives considered and the various impacts the proposed alternatives will have on the economy, the environment, small businesses, the cities, local governments, consumers, the regulated parties, and the general public;

4. The major problems or issues expected to be encountered in preparing the regulation;

5. The authority for the regulation;

6. How the public input will be accommodated; and

7. Recommended priority and proposed timetables for preparation.

[a] From the Proceedings of the Marine Safety Council, 37(1980):158-9.

The work plan is given a preliminary legal review to determine whether there appears to be statutory authority to carry out the proposal; it then is reviewed by the officials responsible for the program area concerned. When the program director of the regulation--a USCG Admiral--is satisfied that there is a need for the regulation and that the proposal is the best of the available alternatives, the work plan is submitted to the Marine Safety Council (MSC) for consideration.

The Marine Safety Council consists of seven Admirals and is chaired by the Chief Counsel. Included on the MSC are the program directors responsible for the major regulatory areas--merchant marine safety, marine environmental protection, boating, public and consumer affairs, and the other offices which have an interest in regulations development.

The MSC reviews all the factors considered in the work plan. Each member brings to bear the expertise of his staff and the particular concern of his office. Only when the MSC is convinced that a genuine need for the regulation exists and that the concept represents the best available alternative in terms of accomplishing the desired objectives does it give its approval to proceed with the project.

If the proposal involves a significant regulation, the work plan must receive the Commandant's approval and eventually be reviewed by the Secretary of Transportation and his staff. A significant regulation is one which will have extensive economic impact, usually on the order of $100 million or more, or otherwise be of substantial public interest.

Once a work plan is approved, the second stage of the regulatory process begins: the preparation of a proposal. A project team is assigned for this task, and a docket is opened. The project team usually consists of the project manager and a project counsel, although in more complex projects additional individuals also participate.

The first task of the project team is to draft proposed regulations that would apply to the area of concern. The proposal may take two forms: an Advance Notice of Proposed Rulemaking (ANPRM) or a Notice of Proposed Rulemaking (NPRM). An ANPRM is usually a tentative suggestion of possible approaches that might be taken in regulating an area of concern. Even though detailed specific proposals may be made at this step, an ANPRM is published solely to generate more informed comment regarding a specific issue. All comments received are carefully reviewed to determine whether there is sufficient cause and justification to proceed with further rulemaking. An NPRM is published in lieu of an advance notice when the Coast Guard has a good idea of how the final rule should be stated.

Various administrative laws and regulations set forth the regulatory procedure that must be followed in preparing regulatory proposals. Basically, these laws and regulations say that the public normally must be given the opportunity to comment before a regulation can be made final and effective. There are very few exceptions to this rule.

Once the regulatory proposal is completed by the project team, it is sent out for internal USCG clearance. Interested parties are given an opportunity to review and revise the proposal before it is published. When all required clearances have been received, the appropriate USCG officer signs the proposal and it is printed in the Federal Register for public comment.

Because most people do not follow the daily Federal Register, the USCG also publishes notice of regulatory actions in the "Keynotes" section of the Proceedings of the Marine Safety Council. By doing this, the USCG is able to reach many more interested parties than it would if it adhered only to the requirement to publish in the Federal Register.

The comment period is a most important one. Parties view the proposed regulation for the first time and can tell the USCG what they think. Responsive comment by the public, particularly by affected parties, is necesssary if the final product is to be an effective, meaningful regulation. Comments are usually in the form of a written response to the proposal published in the Federal Register; however, public hearings also may be held to allow oral comments to be presented.

After comments have been received, they are analyzed in detail by the project team. After all applicable inputs have been reviewed and considered, the next stage is entered.

If the proposal was an ANPRM, an NPRM is drafted. If the proposal was an NPRM, a final rule is prepared. If an NPRM receives sufficient negative comment, however, the USCG may withdraw the proposal entirely or may amend the notice so extensively that another notice will be published and more public comment solicited. Most regulations are published first as NPRMs and then as final rules.

Once the final rule is prepared, it goes through the same screening process as the notice. It is more closely scrutinized during the review, however. All input in response to an NPRM is considered seriously.

Once a final rule is signed by the Commandant or another appropriate official, the final regulation is published in the Federal Register. It should be noted that the project team drafts a preamble to accompany the regulation. In the preamble, the comments received after publication of a notice are discussed. It explains why some parts of the regulation were changed and why some were not. The thoughts and policy behind the regulation will be explained. It is a good idea to retain this part of the Federal Register, as this information will not be published in the Code of Federal Regulations. Usually, the regulation will become effective 30 days after publication.

Appendix B

COMMODITY TONNAGE AND MONETARY VALUE

APPENDIX B

1979 Census Data - Inbound Tanker

Code	Commodity Name	Total Tons	U.S. Tons	Foreign Tons	U.S. %	Total Value
3330	Crude Petroleum	248510937	8454197	240056740	3	35492725800
3344	Fuel Oils, N.E.S.	46640439	2193533	44446906	5	5391447135
3410	Nat. Gas, Propane, etc.	7279493	1539803	5739690	21	522153750
3345	Lubricating Oils, etc.	7115581	443385	6672196	6	1537614493
3341	Gasoline, Jet Fuel, etc.	6195809	254110	5941699	4	1439144623
3343	Gas Oils	3889156	499218	3389938	13	762119402
3352	Mineral Tars & Products	1375526		1375526		142877777
3225	Metallic Oxides, NEC	1344166		1344166		119778535
3354	Asphalt, Btum. Mixtures	1302038	14371	1287667	1	120170088
0615	Molasses	1301633	48870	1252763	4	104663793
5221	Chem. Elements, Inorganic	1082510	229382	853128	21	68496684
5171	Coal Tar Derivatives	537187		537187		226214671
4243	Cocoanut Oil	455266		455266		407514107
5174	Hydrocarbons	345286	279347	317349	8	127075003
5175	Alcohols, Mono. & Poly.	222235	13697	208538	6	72689621
4242	Palm Oil	138110		138110		83808358
5621	Nitrogenous Fertilizers	106770		106770		12948772
5622	Phosphatic Fertilizers	106426		106426		10971536
2732	Gypsum, Plaster, Limestone	81318		81318		360639
4244	Palm Kernel Oil	71518		71518		61327173
5985	Chem. Compounds & Products	61879		61879		25355893
3232	Coke of Coal for Fuel	56706	15618	41088	28	5861615
5222	Inorganic Acids, etc.	55772		55772		2033033
5178	Nitrogenous Compounds	54293		54293		87890355
5172	Chemicals, Indstrl. Orgnc.	38635		38635		29692328
5176	Epoxides, Ethers, etc.	36833		36833		20406080
5177	Organic Acids	28653		28653		20954979
5623	Potassic Fertilizers	25166		25166		1565285
6411	Newsprint Paper	23272		23272		8208182
9311	Spec Transactions N. Clas	14885		14885		11407998
5910	Pesticide, Herbicide, etc.	14121		14121		43944809
5542	Washing Preparations, NES	13788		13788		12635718
5260	Inorganic Chems., NES	12325		12325		209078
2320	Rubber, Gums, Unprocessed	9304	5177	4127	56	9267550
3353	Pitch of Coal Tar	7888		7888		565595
6712	Pig Iron, Cast Iron, Spieg	6982		6982		913741
1124	Dstld. Alcoholic Bevgs	5876	16	5860		5167934
3351	Mineral Waxes & Pet. Jellies	5782		5782		1620130
5884	Resins & Resin Materials	5445		5445		5044762

APPENDIX B (continued)

1979 Census Data - Inbound Tanker

Code	Commodity Name	Total Tons	U.S. Tons	Foreign Tons	U.S. %	Total Value
4231	Rapeseed Oil	4182		4182		3371651
2331	Rubbers, Synthetic	3511		3511		2018639
5981	Wood & Resin Chem. Products	2953		2953		941161
4111	Fats & Oils of Fish	2889		2889		595632
0620	Sgr. Confec. No. Choc., etc.	2862		2862		337048
6786	Steel Pipe, Tubes, etc.	2506	154	2352	6	1367459
7810	Passngr Autos & Vehicles	2396		2396		10453495
4248	Vegetable Oils, N.E.S.	2020		2020		2270715
5179	Organic Chemicals, N.E.S.	1763		1763		2367532
5173	Chemicals, Finished, Organic	1675		1675		1798687

Code	Commodity Name	Total Tons	U.S. Tons	Foreign Tons	U.S. %	Total Value
3355	Coke, Pitch, Anthra Oil	8279056	14742	8264314		472032050
5253	Spec Inorganic Compounds	2419147	91540	2327607	4	167558592
5173	Oth Spec Acyc Organ Cmpd	2210470	756	2209714		928410754
3345	Lubricating Oils, Greases	2184712	113218	2071494	5	319533695
0810	Feed for Anml Ex Unm Crl	1790275	110	1790165		329726783
0440	Corn or Maize--Unmilled	1452547	164352	1288195	11	174765769
2222	Soybean, Ex Coffee Subst	1300222	63109	1237113	5	350375812
5112	Cyclic Hydrocarbons	1179951	1428	1178523		627513866
0410	Wheat & Meslin--Unmilled	1128654	239385	889269	21	159569337
5257	Sodm Nitr Ptssm Sulf, etc.	1099281		1099281		211319388
3410	Gas-Nat & Mfd	1080990		1080990		126820482
4113	Anml-Fat, Oil, Inc. Wl Grease	969390	1424	967966		525601053
4232	Soybean Oil Ex Hydrogena	854820	4871	849949	1	558946831
5113	Halogen Deriv--Hydrocarb	424158		424158		148189290
5171	Oth Spec Cyclic Org Chem	421587		421587		157543300
5621	Ammon Nitr, Sulf, etc.	410836	47094	363742	11	36086198
3344	Heavy Fuel Oils	379183	19285	359898	5	44362278
5982	Var Additive Preps	290059	282	289777		317258364
3341	Gas, Naphtha Der & Jetfuel	275019		275019		80545855
2743	Sulfur-Ntve Elem or Recc	266342	7379	258963	3	14906151
5172	Oth Spec Inter Chem Cmpd	254351		254351		202464538
4233	Cottonsd Oil Ex Hydrognt	235345		235345		159498075
0615	Molasses	189738		189738		16009512
3343	Mtr Fuel Fueloil-Lght #4	185403	43575	141828	24	21535326
2713	Phosphates--Crude & Apatit	182929		182929		5535421
5629	Fertilizer, NSPF	132941	10098	122843	8	24544513
5111	Acyclic Hydrocarbons	128869		128869		61231164
5252	Inorganic Acids	98483		98483		8333286
3352	Coal Tar, Oils-Creo, etc.	93742		93742		6548818
4111	Menha Oil, Mar-Anml Oil	86115		86115		37621628
5988	Misc Chem Prod NSPF	82205	2931	79274	4	33701908
3351	Petr Jelly, Wax, Paraf Wax	57891		57891		15471048
5178	Plasticizers, etc.	51077		51077		43465266
5981	Turpentine, Resins, Pitch	46191		46191		15054193
0430	Barley-Unmilled	42140	42140		100	4105784
5881	Thermoplastic Resins	41385	6	41379		41205210
4250	Unmix Oil--Corn Fix Veg	39913		39913		31976523
5622	Phosphatic Ftlzr, etc.	38451		38451		6606116
5179	Fatty Substances	35521		35521		22600003
5174	Alcohol Mix, Monohyd, Acyc	28601		28601		24240767

APPENDIX B (continued)

1979 Census Data - Outbound Tanker

Code	Commodity Name	Total Tons	U.S. Tons	Foreign Tons	U.S. %	Total Value
4236	Sunflower Seed Oil	28084		28084		18402196
0459	Buckwht, Oth Cerls--Unmld	25797	25747	50	100	2731362
4400	Hydr Anml, Veg Oil & Fats	25264		25264		17334599
2471	Sawlogs, Veneer Logs-Soft	23127		23127		1473820
0421	Rice in Husk or Husked	22987		22987		8060649
9310	Spec Trans, Nt Classfd	20184	7688	12496	38	524239
5544	Cleaning Preparations	18196		18196		11291741
0422	Rice-Semi or Whol Milled	12085		12085		4408981

Appendix C

BIOGRAPHICAL SKETCHES OF THE PANEL MEMBERS

ROBERT C. ERDMANN received a B.S. and an M.S. from Newark College of Engineering and the University of California at Los Angeles (UCLA), respectively. He obtained his Ph.D. in applied mechanics and physics at the California Institute of Technology and then joined the faculty at UCLA. His present position is at Science Application Inc. where his technical interests include nuclear reactor safety and reliability analysis and risk analysis in engineering.

WILLIAM A CREELMAN JR. received a B.S. from the U.S. Merchant Marine Academy. After various positions with Lake Tankers Corporation and National Oil Transport Corporation he joined The National Marine Service. He is now president of the company.

JAMES A. FAY obtained a B.S. from Webb Institute of Naval Architecture, an M.S. from the Massachusetts Institute of Technology (M.I.T.), and a Ph.D. in mechanical engineering from Cornell University. After being a professor at Cornell University he became a professor of mechanical engineering at M.I.T. Gaseous detonations, plasma physics, air and oil pollution, and liquefied gas safety are among his research interests.

GEORGE W. FELDMANN received A.B., B.S., and Ch.E. degress from Columbia University. After forty years with E. I. du Pont de Nemours and Co. he retired and became a consultant. His expertise is in rubber chemicals, fluorine and titanium process development, marine engineering, and movement of bulk dangerous products by barge and vessel.

JAMES P. FLYNN obtained a B.S. from Bucknell University and a Ph.D. in chemistry from Iowa State University. Since graduation he has been employed by The Dow Chemical Company and is presently a research associate. His technical expertise comprises the evaluation of chemical hazards, hazardous waste disposal, and health and environmental regulations.

DOUGLAS C. MacMILLAN graduated from the Massachusetts Institute of Technology with a B.S. in naval architecture. He has worked for the Federal Shipbuilding and Dry Dock Company, George G. Sharp, and the Quincy Shipbuilding Division of General Dynamics Corporation. After his retirement he became a consultant in naval architecture. Mr. MacMillan is a member of the National Academy of Engineering.

WILLIAM E. McCONNAUGHEY received a B.S. in chemical engineering from the University of Nebraska. He worked for various research and development groups in the Department of the Navy before employment with the U.S. Coast Guard where he was involved in safety issues relevant to hazardous materials transportation. Now retired, Mr. McConnaughey is a consultant to industry.

FREDERICK W. OEHME received B.S. and D.V.M. degrees from Cornell University, an M.S. from Kansas State University, and a Ph.D. in toxicology from the University of Missouri-Columbia. His current position is professor of toxicology at Kansas State University where he is also the Director of the Comparative Toxicology Laboratory. His research involves biotransformation and biochemical action of toxicants, clinical and diagnostic toxicology, and public health aspects of toxicants.

J. REED WELKER obtained B.S. and M.S. degrees from the University of Idaho and a Ph.D. in chemical engineering from the University of Oklahoma. He was employed by the Research Institute of the University of Oklahoma and later became a vice president of University Engineers, Inc. His present position is President of Applied Technology Corporation. His expertise is in fire research, atmospheric dispersion, and liquefied natural gas plant safety.

BIBLIOGRAPHIC DATA SHEET	1. Report No. NMAB-402	2.	3. Recipient's Accession No.
4. Title and Subtitle The Application of Quantitative Risk Assessment Techniques in the U.S. Coast Guard Regulatory Process			5. Report Date
			6.
7. Author(s) Panel on Risk Analysis for Marine Transport of Hazardous Materials			8. Performing Organization Rept. No. NMAB-402
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			14.

15. Supplementary Notes

16. Abstracts

The potential was examined for use of modern risk analysis techniques in developing U.S. Coast Guard (USCG) regulations to minimize the public risk from marine transport of bulk chemical cargoes. Consideration also was given to the usefulness of these techniques in setting priorities and support levels for USCG safety research programs.

The principal conclusion of the study is that risk assessment techniques could be, and to some limited extent have been, used with success within the USCG regulatory framework. Since the resources available for regulation are limited, they must be used in a cost-effective manner. The specific recommendations call for:

1. Selected studies on shipments of new substances with a potentially large impact on the public if released into the environment.

2. Selected studies on certain ports and locations along inland waterways that appear to have a high incidence of accidents.

17. Key Words and Document Analysis. 17a. Descriptors

Risk assessment
U.S. Coast Guard regulations
Hazardous chemical cargoes

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 58
	20. Security Class (This Page) UNCLASSIFIED	22. Price

ABSTRACT (continued)

3. Delineation of key variables and establishment of the types of data to be collected before and after promulgation of a regulation to determine the effectiveness of the issued regulation.

4. Sponsorship of retrospective risk studies to estimate the potential for high consequence-low probability events with familiar but potentially dangerous cargoes.

5. Review of existing regulations in a selected area (e.g., marine transport of bulk chemical cargoes on inland waterways) to gain insight into the consistency of regulations and to learn if any gaps or contradictions exist.