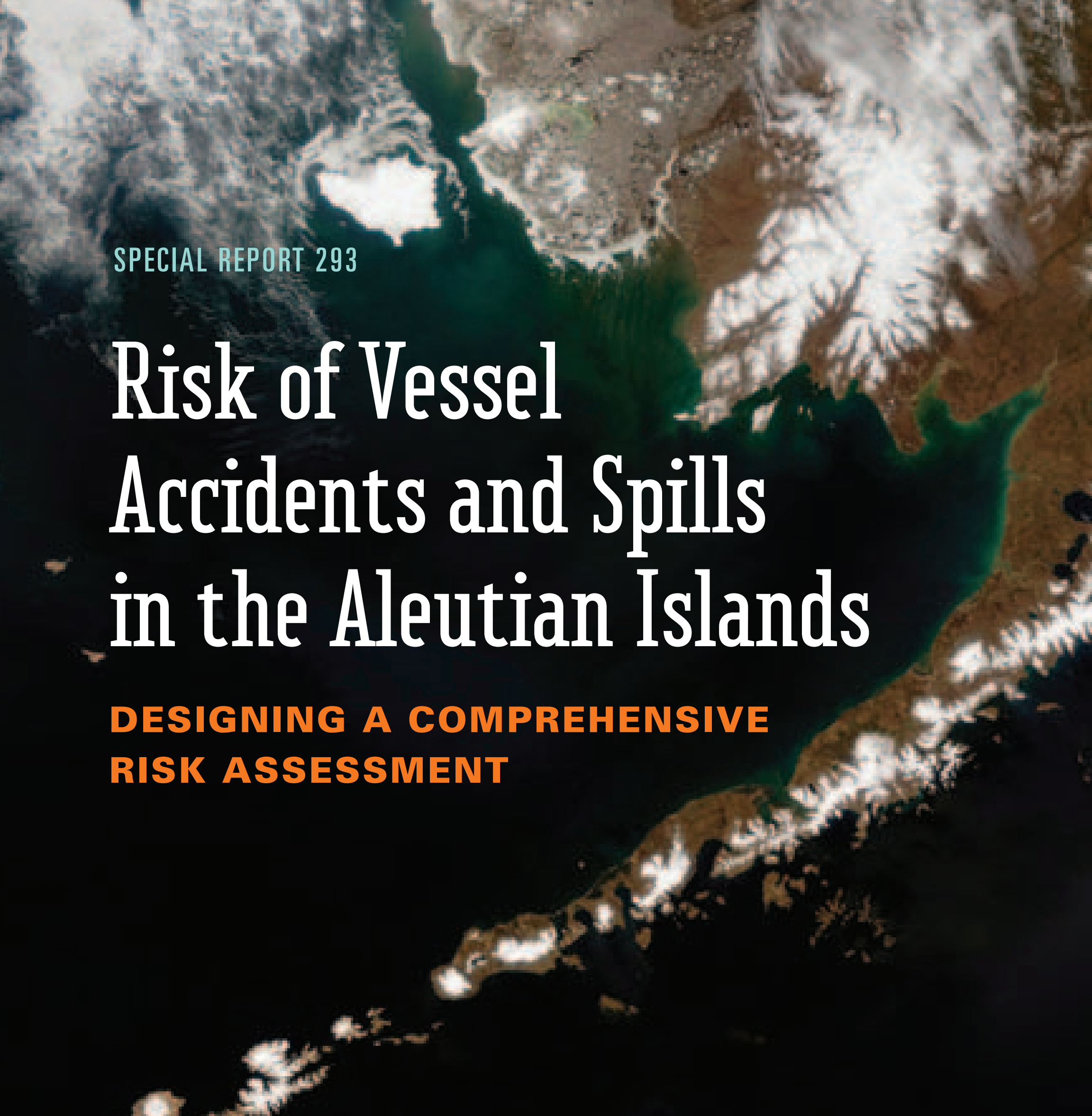

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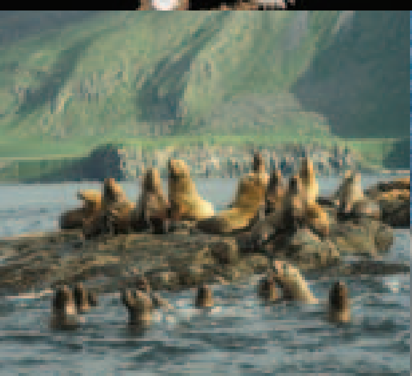
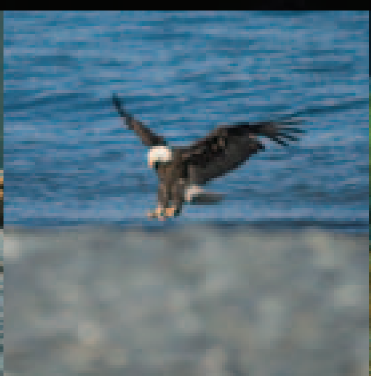
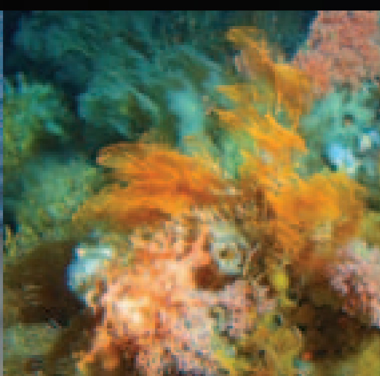
DESIGNING A COMPREHENSIVE RISK ASSESSMENT

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SPECIAL REPORT 293

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Committee on the Risk of Vessel Accidents and Spills in the Aleutian Islands: A Study to Design a Comprehensive Assessment

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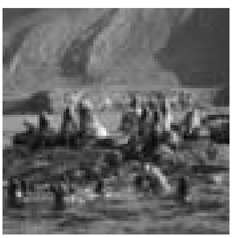

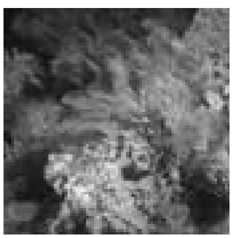

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competencies and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to the 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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Committee on the Risk of Vessel Accidents and Spills in the Aleutian Islands: A Study to Design a Comprehensive Assessment

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Preface

The Aleutian Islands are home to natural resources found nowhere else in the world, and the regional economy is dominated by commercial fishing. Protection of the region's natural resources is therefore a paramount public concern.

The Aleutian region is intersected by major commercial marine shipping routes—a large and growing international fleet of ships carrying various cargoes from the west coast of North America to Asia along the North Pacific Great Circle Route. With the exception of a few containerships that call on the port of Dutch Harbor, most of these commercial ships transit through or near the Aleutians and do not stop except for emergencies. Some accidents involving these ships have resulted in oil spills that have had serious environmental consequences. Indeed, history has shown that oil spill accidents in the Aleutians are not uncommon, in large part because of the frequent and sudden storms, high winds, and severe sea conditions to which the region is subject. Response to these events is often ineffective because of the severe weather and a lack of appropriate infrastructure.

A commercial vessel accident and large oil spill in 2004 focused public attention on the risks inherent in commercial shipping in the region. The court settlement resulting from this accident established funding for a comprehensive risk assessment and directed the U.S. Coast Guard to take actions necessary to conduct this assessment.

Risk assessment is a systematic approach used to evaluate the level of safety of a complex system and to identify appropriate safety improvements. It is an established engineering discipline and has been used in the maritime industry in the past with varying degrees of success. Both the State of Alaska and the U.S. Coast Guard have had experience with maritime risk assessments, and both understand the complexity of the problem at hand, as well as the need for a well-designed process that will ensure a successful outcome. Consequently, they asked the National Academies to examine the available data and develop a framework and the most appropriate and scientifically rigorous approach possible for the mandated comprehensive risk assessment, and to design the assessment with a logical sequence of building blocks so that it could be conducted in discrete steps.

To conduct this study, the Transportation Research Board (TRB) within the National Academies empaneled the Committee on the Risk of Vessel Accidents and Spills in the Aleutian Islands: A Study to Design a Comprehensive Assessment. The committee included individuals with expertise in risk assessment methods and practices; risk assessment data and analyses; risk analyses, with emphasis on evaluation and prevention of ship accidents; commercial shipping, with emphasis on North Pacific operations; navigation safety and voyage planning; U.S. Coast Guard missions and operations related to waterway management and accident response; environmental protection; and regulatory approaches to ship safety and accident prevention. (Biographical sketches of the committee members can be found at the end of the report.) This report presents the committee's analysis of the problem; reviews the available data; describes the structure and design of an appropriate risk assessment; and presents the committee's recommendations for organizing, managing, and conducting a comprehensive assessment of the risk of vessel accidents and spills in the Aleutian Islands.

The committee met three times. During a multiday meeting (October 29–November 2, 2007) in Alaska with a site visit to Dutch Harbor, the committee heard from stakeholders and reviewed available data pertinent to its charge. Stakeholders discussed specific hazards presented by Aleutian shipping operations and a range of possible mitigation measures they believed should be considered for implementation. At its second meeting, held January 7–8, 2008, the committee received presentations on the following topics:

- Related maritime risk assessments, including the following:
  - Methodologies and approaches in recent and ongoing assessments in the United States (Puget Sound and San Francisco)

  - Methodologies and approaches in recent assessments in Europe
  - Methodologies employed in limited-scope risk analyses
- Spill response and environmental impacts:
  - Vessel casualties and oil outflow modeling
  - Impacts from spills of persistent oils
- Commercial vessel operations and practices
- Spill risk from a shipowners Protection and Indemnity (P&I) Club perspective
- Available and accessible U.S. Coast Guard data

At its third meeting, held March 13–16, 2008, at the Beckman Center of the National Academies in Irvine, California, the committee reviewed draft sections of this report, finalized the report structure, discussed its conclusions and recommendations, and continued drafting the text. In addition to these full committee meetings, a subgroup of the committee met during the last week of March, and members of the committee held numerous conference calls.

ACKNOWLEDGMENTS

The work of this committee was greatly facilitated by the thoughtful advice and background information provided by all of the presenters at its meetings, as well as other individuals with relevant technical expertise, stakeholder groups, and government and industry officials who were consulted during the study. The committee also gratefully acknowledges the contributions of time and information provided by the sponsor liaisons. The committee is especially indebted to liaisons Leslie Pearson, manager of the Prevention and Emergency Response Program in the Division of Spill Prevention and Response at the Alaska Department of Environmental Conservation; and CDR James Robertson of U.S. Coast Guard District 17 (Alaska region), who responded promptly and with a generous spirit to the committee's numerous requests for information.

In addition, the committee thanks the many industry, trade association, and state and local government representatives and other individuals who provided input for this study: Sam Albanese, National Oceanic and Atmospheric Administration (NOAA); Dave

Aplin, World Wildlife Fund; Capt. Dave Artz, Alaska Marine Pilots; Jim Ayers, Oceana; Bill Benning, Marine Exchange of Alaska; Poppy Benson, Alaska Maritime National Wildlife Refuge, Fish and Wildlife Service (FWS); Catherine Berg, FWS; Rich Berkowitz, Transportation Institute, Seattle; Vernon Byrd, Alaska Maritime National Wildlife Refuge, FWS; LCDR Xochitl Castañeda, U.S. Coast Guard, Washington, D.C.; Paul Cojeen, U.S. Coast Guard, Washington, D.C.; Bubba Cook, World Wildlife Fund; Capt. Mark DeVries, U.S. Coast Guard, Captain of the Port for Western Alaska; Dustin Dickerson, local fisherman, Dutch Harbor; Lt. Ben Duarte, U.S. Coast Guard Marine Safety Detachment, Dutch Harbor; Cheryl Eldemar, Oceana, Juneau; Diana Evans, North Pacific Fishery Management Council, NOAA; Gary Folley, Alaska Department of Environmental Conservation; Tim Fowler, DNV Energy, United Kingdom; Capt. Pete Garay, Alaska Marine Pilots; John Gardenier (retired), Pragmatica Corp.; Turkan Gardenier, Pragmatica Corp.; Capt. Tom Gemmell (U.S. Coast Guard, ret.), Marine Conservation Alliance; Martha Grabowski, Rensselaer Polytechnic Institute and LeMoyne College; Rodney Gregory, Business Transformation Agency, Reston; Scott Habberstad, Manager Regional Sales, Alaska, Alaska Airlines; Tim Hall, DNV Energy; Geoffrey Harben, Alaska Department of Environmental Conservation; Bruce Harland, Crowley Marine Services, Alaska; John R. (Jack) Harrold, George Washington University; Larry Hartig, Commissioner, Alaska Department of Environmental Conservation; Bob Heavilin, Alaska Chadux Corporation; Jon Heifetz, NOAA; Kris Holderied, NOAA Kasitsna Bay Laboratory; Amy Holman, NOAA Alaska Regional Collaboration Team; Chris Jones, Maritime Operations Project Manager, Prince William Sound Regional Citizens' Advisory Council; Ian Jones, Memorial University of Newfoundland; ADM Robert Kramek (U.S. Coast Guard, ret.), American Bureau of Shipping; Christopher Krenz, Oceana; Kathy Kuletz, Migratory Bird Management, FWS; Tom Lakosh, Parker & Associates, Anchorage; LCDR James Larson, U.S. Coast Guard Headquarters; John LeClair, Alaska Chadux Corporation; LCDR Vivianne Louie, U.S. Coast Guard, Washington, D.C.; Karl Lumbers, UK P&I Club, London; Dan Magone, Magone Marine Services, Inc.; Shirley Marquardt, Mayor, City of Unalaska; Molly McCammon, Alaska Ocean Observing System; Deborah French McCay, Applied Science Associates, Inc.; Jimmer MacDonald, Dutch Harbor local diver and commercial fisherman; Jason Merrick, Virginia Common-

wealth University; Colin Moore, Herbert Engineering Corporation; David Moore, Minerals Management Service, Department of the Interior (DOI); Doug Mutter, Office of Environmental Policy and Compliance, DOI, Anchorage; CDR Christopher Myskowski, U.S. Coast Guard; Capt. Ed Page (U.S. Coast Guard, ret.), Marine Exchange of Alaska; Leslie Pearson, Alaska Department of Environmental Conservation; Dimitri Philemonof, Aleutian Pribilof Islands Association; Todd Ripley, Maritime Administration; CDR James Robertson, U.S. Coast Guard, District 17; Carolyn Rosner, North Pacific Research Board, Alaska Ocean Observing System; Bob Schoephoester, Alaska Chadux Corporation; Carven Scott, NOAA; CDR Sandra Selman, District Legal Officer, U.S. Coast Guard; Whit Sheard, Pacific Environment; Capt. Julio Soares, American President Lines; Mike Sollosi, U.S. Coast Guard, Washington, D.C.; Rick Steiner, Shipping Safety Partnership; Barry Strauch, National Transportation Safety Board; Kent Sundseth, Alaska Maritime National Wildlife Refuge, FWS; Tyanc Thayer, U.S. Coast Guard, Washington, D.C.; Kirsi Tikka, American Bureau of Shipping; Jeremy Weiss, U.S. Coast Guard, Washington, D.C.; Carter Whalen, Alaska Marine Pilots; John Whitney, NOAA; and Bruce Wright, Aleutian Pribilof Islands Association.

The committee also thanks the crews of the tug *Gyrfalcon* [one of the local rescue assets in Dutch Harbor that has responded to various emergencies in and around the harbor and whose crew has been trained with the Emergency Towing System (ETS)] and the tug *James Dunlop* (another local responder whose crew has been trained with the ETS and is on call around the clock for emergency response). Thanks are extended as well to employees of Magone Marine Services, a local company with more than 30 years of experience in diving, underwater demolition, and vessel recovery in the Aleutian Islands; employees of NC Machinery, diesel mechanics for fishing vessels, tugs, and ships with experience in safety maintenance, severe-weather shutdowns, and mechanical emergencies that arise at sea; and the members of the City Council of Unalaska, who took time from their busy schedules to share their knowledge and insights with the committee during its site visit to Dutch Harbor.

This study was performed under the overall supervision of Stephen R. Godwin, TRB's Director of Studies and Special Programs. The committee gratefully acknowledges the work and support of Beverly Huey, who served as project director, and Peter Johnson, under whose guidance this study was initiated, both of whom provided invaluable assistance to the committee during the information gathering, data analysis, report writing, and report review stages. The committee expresses its admiration and appreciation of Peter Johnson's continued commitment to the success of this effort, even after his retirement at the end of 2007. The committee also acknowledges the work and support of Suzanne Schneider, Associate Executive Director of TRB, who managed the review process; Rona Briere, who edited the report; Alisa Decatur, who prepared the manuscript; Jennifer J. Weeks, TRB Editorial Services Specialist, who formatted and prepared the prepublication files for website posting; Senior Editor Norman Solomon, who provided editorial guidance; Juanita Green, Production Manager, who coordinated the design, typesetting, and printing; and Javy Awan, Director of Publications, under whose supervision the report was prepared for publication.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

The committee thanks the following individuals for their review of this report: Gregory Baecher, University of Maryland, College Park; Duane Boniface, ABS Consulting, Arlington, Virginia; Warner Chabot, Ocean Conservancy, San Francisco, California; John Lee, University of Iowa, Iowa City; Molly McCammon, Alaska Ocean Observing System, Anchorage; Jacqueline Michel, Research Planning, Inc., Columbia, South Carolina; Danny Reible, University of Texas at Austin; and Steve Scalzo, Marine Resources Group, Seattle, Washington. Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the report's findings and conclusions, nor did they see the final draft before its release.

The review of this report was overseen by Marcia McNutt, Monterey Bay Aquarium Research Institute, Moss Landing, Cali-

fornia. Appointed by NRC, she was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

—R. Keith Michel, *Chair*
Committee on the Risk of Vessel Accidents and Spills in the Aleutian Islands: A Study to Design a Comprehensive Assessment

Glossary

Following are the definitions of a number of terms used in this report.

Accident. An unintended event leading to loss of life, property, or damage to the environment. Examples of marine accidents include collisions, powered groundings, drift groundings, fire and explosion, and founderings (see the definitions below).

Alaska Marine Highway (System). A ferry service operated by the State of Alaska along the state's south-central coast, the eastern Aleutian Islands, and the Inside Passage of Alaska and British Columbia, Canada. The ferries (which can transport people, freight, and vehicles) also serve communities in southeastern Alaska that lack road access.

Allision. The impact of a vessel with a fixed object other than the bottom of the body of water (e.g., a bridge, pier, or offshore platform).

Area to be avoided (ATBA). An area with defined limits where either navigation is particularly hazardous or it is exceptionally important to avoid casualties. All ships or certain classes of ships may be instructed to avoid these areas.

Automatic identification system (AIS). A communications medium that automatically provides vessel position and other data to other vessels and shore stations and facilitates the communication of vessel traffic management and navigational safety data from designated shore stations to vessels.

Beaufort scale. A method for estimating wind strengths without the use of instruments, developed in 1805 by Sir Francis

Beaufort. It is still used for this purpose, as well as for combining various components of weather (wind strength, sea state, and observable effects) into a unified picture. Force 6 winds range from 22 to 27 knots on the scale, with sea heights of 9.5 to 13 feet. At Force 7, winds range from 28 to 33 knots, with sea heights of 13.5 to 19 feet. Force 8 winds are 34 to 40 knots, with seas from 18 to 25 feet high. In Force 9 conditions, winds range from 41 to 47 knots and sea heights from 23 to 32 feet. At Force 11, winds are 56 to 63 knots and seas from 37 to 52 feet high.

Bunkers. Fuel used for ship propulsion and power. Bunkers may be heavy residual fuel oils (referred to as HFO), or lighter refined oils, such as diesel oil (DO) and marine gas oil (MGO).

Causality. The precursor event to an incident. Examples include failure to take appropriate precautions, inattention, and component failure.

Collision. The impact of a vessel under way with another vessel under way.

Consequence. The outcome of an event or accident.

Deadweight (DWT). The difference between the displacement of a ship in water at a specific gravity of 1.025 at the assigned summer load waterline and the lightship weight, generally measured in metric tons. The lightship is the displacement of a ship without cargo, consumables (e.g., fuel, fresh water), ballast water, passengers, or crew.

Diurnal tides. One high tide and one low tide each tidal day.

Drift grounding. The impact of a vessel with the ground when the vessel loses its ability to navigate (e.g., through loss of propulsion, steering, or towline separation) and is blown aground before it can get under way or is taken under tow.

Foundering. Loss of a vessel from flooding, which may be due to insufficient stability or inadequate freeboard.

Frequency. The likelihood of an event or accident (number of events per unit time).

Great circle route. The shortest distance between two places on the earth's surface. The route follows a line described by the intersection of the surface with an imaginary plane passing through the earth's center.

Gross ton (GT). A unit of measurement calculated in accordance with international conventions and national requirements; a function of a vessel's space within the hull and of enclosed spaces above deck.

Groundfish. Any marine fish except halibut, smelt, herring, and salmon.

Hazard. An agent that can harm life, property, or the environment.

Incident. An event in which a vessel or its contents are put at risk. Examples are loss of propulsion, loss of steering, and navigational errors.

Innocent passage. The right of vessel passage through a state's territorial sea when not calling at a port in that state (up to 12 nautical miles from the baseline).

International Maritime Organization (IMO). The United Nations' specialized agency responsible for improving maritime safety and preventing pollution from ships.

International strait. A strait used for international navigation between one part of the high seas or an exclusive economic zone and another part of the high seas or exclusive economic zone.

Invasive species. With respect to a particular ecosystem, any species (including its seeds, eggs, spores, or other biological material capable of propagating that species) that is not native to that ecosystem and whose introduction does or is likely to cause harm to the economy, the environment, or human health.

Long-range identification and tracking system (LRIT). A maritime domain awareness initiative that will allow member states to receive position reports from vessels operating under their flag, vessels seeking entry to a port within their territory, or vessels operating in proximity to the state's coastline.

Nonpersistent oil. As used herein, No. 2 diesel oil and other light refined products, which tend to evaporate and disperse more readily than persistent oils (see below) when spilled.

Oil. As used herein, all petroleum oils, such as crude oils, fuel and residual oils, and waste oils.

Particularly sensitive sea area (PSSA). An area that needs special protection through action by the International Maritime Organization because of its significance for recognized ecological, socioeconomic, or scientific reasons and that may be vulnerable to damage by international maritime activities.

Persistent oil. Crude and residual oils, which tend to result in more widespread contamination when spilled and are more difficult to clean up than nonpersistent oils (see above).

Powered grounding. The impact of a vessel with the ground or shoreline while the vessel is under power.

Risk. The combination of the likelihood of an event and its consequences.

Scenario. A sequence of events leading to an accident.

Semidiurnal tides. Two high tides and two low tides of approximately equal height per tidal day.

Spill event. An accident resulting in oil or chemical outflow into the environment.

Strait. A natural, constricted channel of water that connects two larger bodies of water.

Traffic separation scheme (TSS). A vessel-routing scheme separating opposing streams of traffic by separation zones. Within international waters, TSSs are established by the International Maritime Organization.

Transit passage. The right of passage through an international strait that is used for international navigation between one part of the high seas or an exclusive economic zone and another part of the high seas or an exclusive economic zone.

Vessel traffic system (VTS). A vessel traffic management system whereby authorities monitor vessel movements within a waterway by radar surveillance and disseminate navigational information with regard to potential hazards.

Contents

Summary

Risk assessment is a systematic approach used to evaluate the level of safety of a complex system or operation and to recommend appropriate safety improvement measures. It is an established engineering discipline with application in many industrial enterprises for which safety is a paramount concern, such as nuclear reactors, large chemical plants, and the airline industry. Risk assessment is also widely used in the marine industry by government and private authorities to help manage safe shipping operations. Assessing risk involves addressing three key questions: What can go wrong? How likely is it? and What are the impacts? These questions are organized systematically into discrete steps that involve identifying hazards (or creating risk scenarios), determining the likelihood of their occurrence, and identifying their consequences. The present study applies such classic fundamentals of risk assessment to the question of how to minimize vessel accidents and spills in the Aleutian Islands and recommends an appropriate framework for conducting a comprehensive risk assessment for such events.

The Aleutian Islands are a 1,200-mile chain of small volcanic islands in the North Pacific stretching westward from the Alaska Peninsula to Russia. In addition to their biological, cultural, and ecological significance, these islands have long been politically and

economically important. The Aleutians are located along the shortest transportation route for commercial vessels traveling between northwestern North America and Asia. More than 4,500 large commercial vessels annually now traverse Unimak Pass at the eastern end of the Aleutians—a number that has steadily risen in recent years and is anticipated to continue to grow with increases in vessel traffic between Asia and North America, including the Arctic as well as the Aleutians Islands.

In December 2004, the grounding and breakup of the bulk carrier M/V *Selendang Ayu* during a severe storm focused public attention on the oil spill risks posed by vessels transiting the Aleutians. The accident caused the death of six crew members when a U.S. Coast Guard (USCG) rescue helicopter crashed. It also resulted in a spill of 336,000 gallons of heavy fuel oil near the shore of Unimak Island. While this incident was particularly severe, other accidents, spills, and near misses have taken place and continue to occur in the region. The court settlement following the M/V *Selendang Ayu* accident specified that funds be allocated for a comprehensive risk assessment of ship accidents and spills in the Aleutians and for conduct of projects identified by the risk assessment.

This study, conducted by a committee empaneled by the Transportation Research Board of the National Academies, was initiated to provide guidance for the conduct of that assessment. The charge to the committee was to examine available data and evidence about the risk of spills from vessels transiting the Aleutian Islands, determine the information needed to conduct a comprehensive risk assessment, recommend a framework for the most appropriate and scientifically rigorous risk assessment approach possible given available data and modeling capability, and identify how the risk assessment could be conducted in a logical sequence of discrete steps.

The risk posed to people and the environment by shipping in the Aleutians is greatly influenced by the region's unique setting, harsh environment, and difficult operating conditions. Such factors as geography, climate, regulatory regime, population and its cultural base, ecology, and industrial activities all combine to define this special operating environment. Assessing the risk in this environment requires a full understanding of these conditions and factors as they are at present and as they may change over time.

This report reviews and evaluates available information on the current system and operating environment for shipping in the Aleutian Islands. It presents the committee's proposed design for a comprehensive risk assessment for the evaluation of vessel accidents and spills in the Aleutians and recommendations for an appropriate framework for the conduct of that assessment. These recommendations identify a logical sequence of building blocks that can be used to conduct the assessment in discrete steps so that early decisions can be made regarding the most important safety improvements and risk mitigation options can be considered in the order of their priority.

STUDY CONTEXT

The Aleutian Islands: Resources and Infrastructure

Central to the public concern about improving the safety of shipping in the Aleutian Islands are the unique and valuable natural resources in the region that could suffer damage from vessel accidents. Indeed, history has shown that oil spill accidents in the Aleutians are not uncommon, in large part because of the frequent and sudden storms, high winds, and severe sea conditions to which the region is subject. Response to these events is often ineffective as a result of the severe weather conditions and a lack of adequate salvage and spill response infrastructure (for example, there are no large rescue-capable tugs).

The Aleutian region is home to natural resources found nowhere else in the world. Because of the vast diversity of species over a broad area, most of the Aleutian Island chain has been designated as a national wildlife refuge. Few marine areas in the world match the Aleutians in marine productivity, and Dutch Harbor is the leading U.S. fishing port in tonnage landed.

Large commercial vessels engaged in the substantial and growing maritime trade between northwestern North America and northern Asia travel the North Pacific Great Circle Route that traverses the Aleutian Islands. The 4,500 vessels that transit Unimak Pass annually are a mix of large containerships, bulk carriers, car carriers, tankers, and others—the majority foreign flagged and on "innocent passage" through these waters. These vessels carry large quantities of fuel oil and various cargoes, including chemicals and other hazardous materials. The spill risk they pose will grow as their traffic volume increases and as new shipping routes emerge to serve future resource development in Alaska and other Arctic regions.

The volume of vessel traffic through Unimak Pass is roughly double that calling on all ports in the 17th USCG District (Alaska). Vessels entering those major ports are subject to a set of controls, whereas similar vessels traveling on innocent passage through the Aleutians need not meet comparable requirements.

Vessel Accidents and Spills

In the region near Dutch Harbor, large commercial ship traffic is concentrated in and near Unimak Pass, and the local fishing fleet, tugs and barges, ferries, and other small vessels often cross the large-ship traffic lanes. Farther out in the Aleutian chain, the traffic is more dispersed, but hazards are always present. Since 2005, because of new automatic identification system (AIS) carriage requirements and the installation of AIS stations in the area, the Marine Exchange of Alaska has been collecting data on ship transits through Unimak Pass for USCG. These data identify and characterize each vessel transit, and the annual reports produced from the data can be combined with incident/accident reports to determine historical patterns.

Historical data on accidents and spills near the Aleutian Islands show that fishing vessels account for the majority of the accidents, most of these resulting in small spills, while the large commercial fleet has experienced only a few major accidents but with much larger spill volumes. Over the past 20 years, about 20 fishing vessel accidents with spills in excess of 1,000 gallons were recorded, while just two commercial cargo vessel accidents (the M/V *Selendang Ayu* in 2004 and the M/V *Kuroshima* in 1997) spilled 336,000 and 40,000 gallons, respectively.

Data for the past 20 years on response to spills in the Aleutians have also shown that almost no oil has been recovered during events in which recovery attempts have been made by the responsible parties or government agencies and that in many cases, weather and other conditions have prevented any response at all. This evidence and other data on the difficulty of recovering oil from the sea in open ocean environments and severe weather conditions lead the committee to suggest that accident and spill prevention be given high priority in considering risk reduction options.

Safety Infrastructure

The 1,200-mile-long Aleutian Island chain is remote and sparsely populated. It has few sizable harbors and minimal maritime infrastructure—especially with respect to the ability to respond to vessels in distress. Given this limited infrastructure and the harsh climate and other hazards to shipping that characterize the region, mariners are challenged to maintain safe operations. The committee therefore reviewed the existing infrastructure and safety measures (such as practices on board and in port, regulations, and the use of vessel monitoring and tracking systems) to identify key areas for improvement that should be considered in assessing the risk of vessel accidents and spills in the Aleutian Islands.

Reliable communications are vital to safe shipping, and the committee found that there are significant gaps in coverage within the Aleutian study area. Moreover, several accident reports cite poor communications as a factor contributing to a chain of events leading to serious problems. Vessel monitoring and tracking systems also can enhance safe operations. The advent of AIS technology has improved traffic management capabilities and offers the potential for active monitoring and early identification of problems. Beginning January 1, 2009, vessel tracking capability will be further improved by International Maritime Organization (IMO) regulations requiring cargo ships above 300 gross tons to transmit long-range identification and tracking technology (LRIT) data.

When vessels at sea do experience problems, it is important to have an effective response capability. Tug capability for assisting large vessels in distress does not exist in the Aleutians. Only small harbor tugs are stationed in Dutch Harbor, and they are not rescue-capable. While Dutch Harbor authorities have prepared Emergency Towing System packages that represent an important step toward improving shipping safety in and near the harbor, their coverage is primarily local; other areas in the Aleutians remain more vulnerable. None of the existing measures are adequate for responding to large vessels under severe weather conditions, and the substantial funding normally required for such a capability has not been identified.

RECOMMENDATIONS

Risk Assessment Framework

The committee developed a risk assessment framework for analyzing the commercial shipping system in the Aleutian region, both in its current state and projected into the future, with respect to accidents and spills resulting in harm to people and the environment. The proposed framework can be used to evaluate hazards, identify current levels of risk, investigate risk reduction measures, analyze the costs and benefits of those measures, and justify safety improvements to the system.

The committee recommends that a structured risk assessment be performed with two major phases—a Phase A Preliminary Risk Assessment and a Phase B Focused Risk Assessment. This process would include a specific, stepped approach to collecting and categorizing available data; development of a logical sequence of events defining key scenarios; and use of a risk matrix for an initial qualitative evaluation of risk levels.

The Phase A Preliminary Risk Assessment should begin with semiquantitative studies aimed at traffic characterization and projections, spill estimates, and identification of the highest risks. This information should then be used for a qualitative assessment and prioritization of risk reduction options.

The Phase B Focused Risk Assessment should entail detailed, in-depth assessments of individual risk reduction options in order of priority. The time and resources dedicated to Phase A should be limited to ensure that it is completed in a timely manner and that sufficient resources have been reserved for Phase B. Phase B should be accomplished in discrete steps as necessary in accordance with the priority of measures to be investigated and the level of risk reduction possible. The committee believes that this framework would enable risks to be evaluated effectively and efficiently within the resources available. It would also allow for explicit and comparative evaluations of risk reduction measures using more analytical techniques, such as modeling and cost–benefit studies, when warranted.

The committee also recommends that the risk assessment include a quantitative fate and effect consequence analysis to yield an understanding of the damage to natural resources and socioeconomic

impacts associated with different hazards, sizes of spills, and accident locations. The committee believes that a preliminary consequence analysis should be conducted in Phase A and a more detailed analysis, including biological impacts, in Phase B.

Organization of the Risk Assessment Study

An effective study organization is vital to the success of a risk assessment. The committee reviewed various risk assessment approaches and techniques, including those employed in recent marine risk assessments that are relevant to the problem at hand. This experience points to the importance of certain elements: the problem should be clearly defined, and a contractor should be provided with the specific scope of the study and explicit goals; a peer review group should be given responsibility for reviewing and commenting on the study methodology and the handling of uncertainties; and a stakeholder group should be included in framing the issues, identifying local expert knowledge, suggesting risk reduction measures, and reviewing final results.

The committee recommends that the risk assessment be organized and managed by a team consisting of USCG, its designated fund management organization (the National Fish and Wildlife Foundation), and the State of Alaska. The Management Team should provide oversight of the contractor(s) conducting the risk assessment.

The committee recommends that the Management Team appoint a Risk Assessment Advisory Panel with a facilitator and members consisting of experts and key parties with an interest in furthering the goals of the risk assessment. Recognizing the importance of stakeholder involvement to the success of the risk assessment, the committee suggests that the Advisory Panel represent all major Aleutian Islands stakeholders, who would provide relevant local knowledge and expertise to the contractors. The panel should review and comment on the framing of the study and its conduct at key stages and help identify and provide input on the risk reduction measures to be evaluated.

The committee also recommends that the Management Team appoint a Risk Assessment Peer Review Panel with a facilitator and members consisting of experts in the techniques and methodologies of risk assessment to ensure that the study will be conducted

with sufficient attention to completeness, accuracy, rigor, and transparency.

Finally, the committee's charge was to develop the framework for a risk assessment. The committee believes that ongoing risk management is a critical part of the risk assessment process. Thus, the framework proposed in this report is structured to ensure effective implementation of the most cost-effective risk reduction measures by establishing Phase B as a detailed risk management project.

Interim Actions to Enhance the Assessment

During its review of existing data, the definition of the problem, and the current state of safety in the system, the committee identified interim actions that would help ensure a successful risk assessment. The committee is aware of the urgency of taking actions to improve the safety of shipping operations in the Aleutian Islands, and early actions that would provide additional data to build a solid risk assessment foundation should also be considered.

The committee recommends that USCG take appropriate action to expand the AIS tracking network along the Aleutian chain and covering the southern North Pacific Great Circle Route. The process for taking this action is already in place, and USCG has the authority to proceed as funding is made available. It would be valuable to implement these systems and to make available the data they yield as soon as possible so the complete traffic system can be described and analyzed with confidence as part of the risk assessment. Collection of additional AIS data should not delay this risk assessment. If it is not possible to install additional receivers and collect sufficient data to contribute to the study, the augmentation of the AIS system should be given careful consideration when the Phase A study results become available. When LRIT data become available, USCG should take steps to utilize these data to further improve vessel tracking in and around the Aleutian chain.

Having an adequate rescue tug capability in the region has been identified in the past as a risk reduction option with obvious benefits for responding to large commercial vessels in distress. This capability has been established in other locations where the potential for maritime accidents exists, and local stakeholders in the Aleutians have advocated this solution for many years. While the committee has not evaluated the costs and benefits of this option, it has concluded that such an evaluation could not begin without more information about costs and possible financing mechanisms. Therefore, **should the Phase A assessment conclude that rescue tugs have potential risk reduction benefits, the committee recommends that USCG and the State of Alaska be ready and available to investigate funding levels, sources, and mechanisms for an Aleutian Rescue Tug, with the expectation that the Risk Assessment Management Team and Advisory Panel might request this information for early consideration within the risk assessment process.**

The committee further recommends that USCG be ready and available to investigate the possible structure and costs of a Vessel Traffic Information System within and near Unimak Pass and Dutch Harbor, with the expectation that the Risk Assessment Management Team and Advisory Panel might request the information thus generated early in the risk assessment process. This action would facilitate the risk assessment and provide needed data for cost–benefit analyses of selected options.

Subject to the findings of the Phase A Preliminary Risk Assessment, the committee also recommends early consideration of options for tracking and monitoring vessel traffic in certain congested areas, as well as for employing some common traffic management schemes that have shown merit in similar locations worldwide. Implementing voluntary vessel traffic systems, establishing traffic lanes, and identifying particularly sensitive sea areas or areas to be avoided are among the measures that USCG could pursue without new authority. Some of these measures might require IMO consideration, while others might be adopted unilaterally.

CONDUCT OF THE RISK ASSESSMENT STUDY

Building on the recommendations presented above, the committee has outlined the process and specific steps it believes should be followed to conduct a successful risk assessment for shipping operations in the Aleutian Islands.

Problem Definition, Scope, and Budget

The primary goal of the risk assessment is to determine whether risk reduction measures are necessary and then to recommend the

TABLE S-1 Hazardous Substances

Type	Marpol Annex or Other Code	Name	Example
Oil	Annex I	Oil cargo	Crude oil, asphalt-blending stocks, fuel oil no. 4, fuel oil no. 5, fuel oil no. 6, diesel oil
	Annex I	Biofuels and base petroleum fuels	
	Annex I	Bunkers	Diesel oil, lube oil, heavy fuel oil
Chemicals	Annex II and IBC Code (Chapters 17 and 18)	Noxious liquids in bulk and noxious liquid substances	Vegetable oils, oil-like substances
	Annex II and IBC Code	Biofuels	Biodiesel, fatty acid methyl esters, B100 and ethanol, ethyl alcohol E100
Other hazardous substances	Annex III	Dangerous goods in package form and invasive species	Microorganisms, rats

Note: IBC = international bulk container.

implementation of effective and efficient risk reduction measures. To achieve this goal within available resources, the study must focus on the specific problem at hand—risks related to accidental spills from vessels operating in the study region. To provide the needed focus, the committee has defined the types of hazardous substances, types of accidents, geographic region, and time frame to be considered for the study. Table S-1 identifies the hazardous substances that need to be addressed, while Figure S-1 illustrates the study region, which includes the entire Aleutian Island chain and encompasses the region traversed by commercial vessels on the North Pacific Great Circle Route.

Because the system and the problem are so complex, the committee recommends that the study be conducted in phases—beginning with qualitative and semiquantitative analyses and assessments, followed by selected detailed quantitative assessments of significant risks and most promising risk reduction measures. The prioritization of potential risk reduction measures should be an ongoing, iterative process throughout all of these efforts, reflecting analysis results as they become available, changing circumstances, and emerging technologies and opportunities.

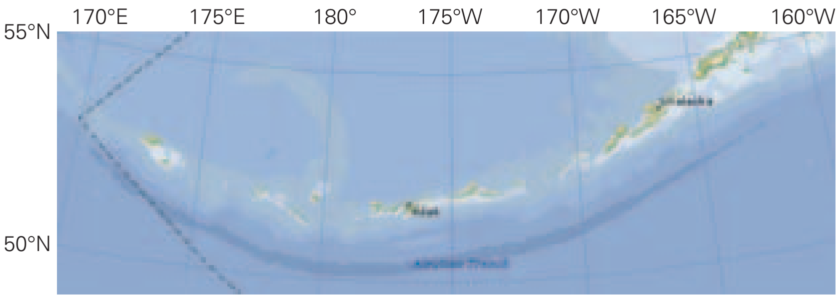

FIGURE S-1 Complete Aleutian chain.

The Advisory Panel should be structured to build trust, clarify the values and goals for the assessment, provide local knowledge, and identify needed organizational learning and policy changes. It should also help establish tolerance parameters for risk and, together with the Management Team, perform an initial prioritization of risk reduction measures. The committee has concluded that, regardless of how rigorous it may be, an analytical approach to risk assessment alone is insufficient for decision making. The needs and values of stakeholders play a key role and must be considered in the decision-making process.

The basic steps and time line for the risk assessment are shown in Figures S-2 and S-3. The figures show the relationships among the four groups involved in management, oversight, and conduct of the risk assessment and the primary responsibilities of each. The committee believes that approximately 2 years will be required for the full assessment. The process is structured so that a qualitative prioritization of risk reduction measures will be available after the first year, which may allow for earlier implementation of those measures that stand out as particularly effective.

In accordance with the court settlement resulting from a commercial vessel accident and large oil spill in 2004, $3 million has been set aside for the overall risk assessment and projects identified by the assessment. The committee is confident that the available funds are more than sufficient to cover the costs of a credible comprehensive risk assessment; however, the Management Team must control the scope of the effort to ensure that the work is done in a timely fashion and that early efforts are not devoted to detailed analyses that will not influence the final decisions.

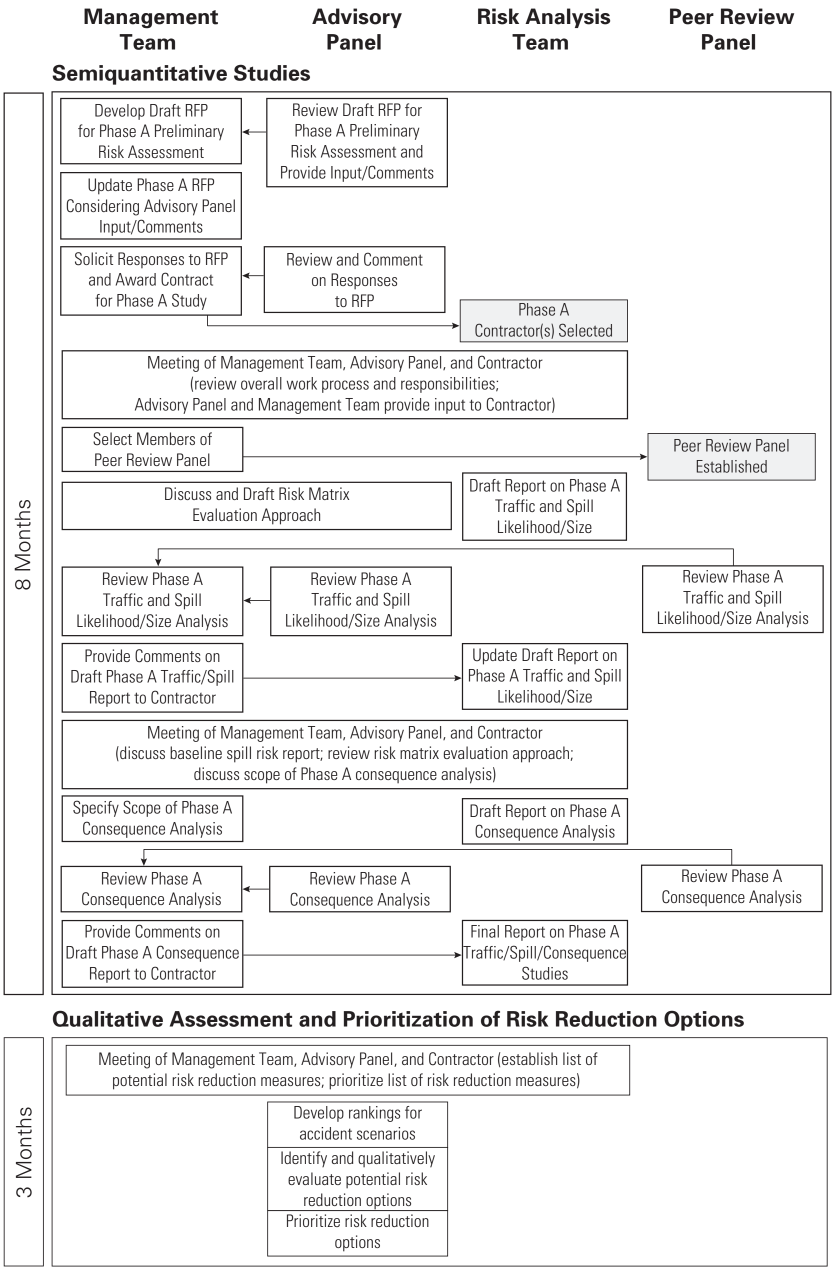

FIGURE S-2 Phase A Preliminary Risk Assessment. (RFP = request for proposals.)

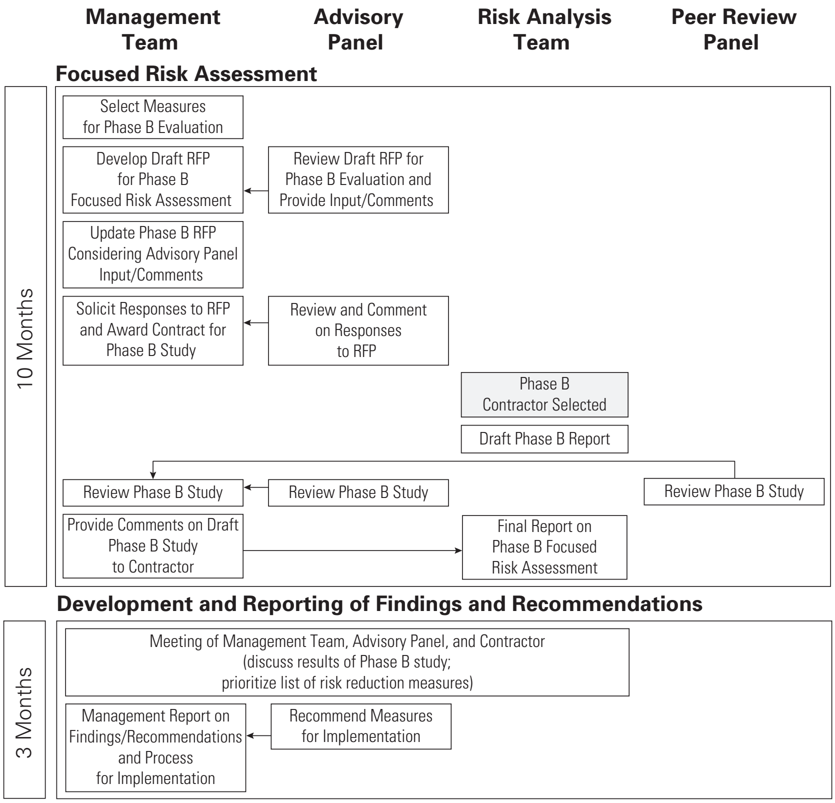

FIGURE S-3 Phase B Focused Risk Assessment.

The Phase A characterization of risk is needed for the initial qualitative assessment of risk reduction measures and should serve as a baseline for the focused quantitative risk reduction investigations. Care must be taken to avoid spending too much of the budget on the Phase A effort; the committee believes that this effort can be completed for about 25 percent of the overall budget. In the Phase B analysis, there may be a natural tendency to assess more options in greater detail than resources allow, so the scope and schedule should be defined and adhered to as closely as practicable. If additional studies are deemed desirable, they should be considered after the study has been completed as part of the ongoing effort of risk management.

Technical Approach

The committee's proposed technical approach for conducting the risk assessment begins with the Phase A Preliminary Risk Assessment. The semiquantitative portions of the Phase A analysis (i.e., traffic characterization and projections and spill estimates) should rely on historical data supplemented by results of prior risk studies and expert opinion. This analysis should help identify geographic locations and spill scenarios for a limited number of focused environmental impact investigations. The Phase A study should identify the highest risks in terms of the types of spills and vessels involved, the types of accidents and their likely causes and scenarios, and the spill sizes and likely locations, and it should provide some sense of the environmental impacts. The intent is to provide sufficient information with which to prioritize risk reduction measures on a qualitative basis.

The committee recommends the following specific steps to accomplish the semiquantitative portions of Phase A:

- *Traffic study:* Characterize the existing fleet and traffic and the quantities of hazardous cargoes moved. Project growth in trade, changes in vessels, and impacts of expected regulatory changes. Project the fleet makeup over a 25-year study period.
- *Spill baseline study:* Develop an oil spill baseline over the study period on the basis of projected movements of oil and hazardous materials and estimated spill rates and frequencies. The projection should provide an understanding of the most important hazards and serve as a baseline for later assessment of benefits.
- *Identification of high-risk accidents:* Identify the hazardous substances, representative spill sizes, and locations of spills associated with the highest-risk accidents.
- *Phase A consequence analysis:* For representative high-risk accidents, perform a high-level spill trajectory and fate analysis to gain an understanding of the relative impacts of spill size, type, and location.
- *Accident scenario and causality study:* Determine representative accident scenarios to develop probabilities for their principal causes and associated consequences.

The Phase A Preliminary Risk Assessment should end with a qualitative assessment of risk reduction options that should lead to the identification of certain measures that merit immediate implementation, some that are unjustifiable, and others that warrant more detailed analysis.. The Advisory Panel and Management Team should populate risk matrices, compile lists of potential risk reduction measures, qualitatively assess the benefits and costs of each measure, and prioritize the measures. The Risk Analysis Team should be available during these deliberations to provide background information and insight into the Phase A investigations. Figure S-4 illustrates a risk matrix that the committee recommends using as a structured process for reaching conclusions and establishing priorities for risk reduction measures.

In the Phase B Focused Risk Assessment, the assessment approaches and techniques should be applied in more detailed, quantitative analyses to determine whether particular measures are justified and to understand their secondary effects. A variety of techniques, such as numerical simulations, as well as expert elicitation, should be used to quantify the likelihood and consequences of an accident with and without a risk reduction measure in place. Uncertainty and sensitivity analyses should help bound the confidence level of the characterization of risks and benefits. Such quantitative assessments should also supply data needed for cost–benefit analyses.

The Phase B risk analysis should follow the basic steps of Phase A. The specific modeling and analysis methods may differ because the analysis needs to be more focused, with sufficient detail, precision, and data quality to allow more robust decisions on the selection, design, and implementation of cost-effective risk control measures. As noted, to the extent possible, Phase B should be a quantitative assessment. Other characteristics of the Phase B risk analysis should include the use of hybrid modeling methods for risk scenarios; more detailed causal modeling; consideration of human factors and adoption of human-error analysis techniques; evaluation of rare, high-consequence events; advanced modeling; formal use of expert opinion; and rigorous uncertainty and sensitivity analyses.

The final step in the committee's proposed approach is decision making and implementation of risk reduction measures. Implementation of risk reduction measures will involve many challenges, including establishing sources for funding and reaching agreement with the various agencies and stakeholders that will influence the failure or success of a measure. Risk management is not a one-time solution; it requires continuous monitoring and reassessment. Thus, the committee stresses the need for a mechanism to ensure that the risk management plan remains a living document.

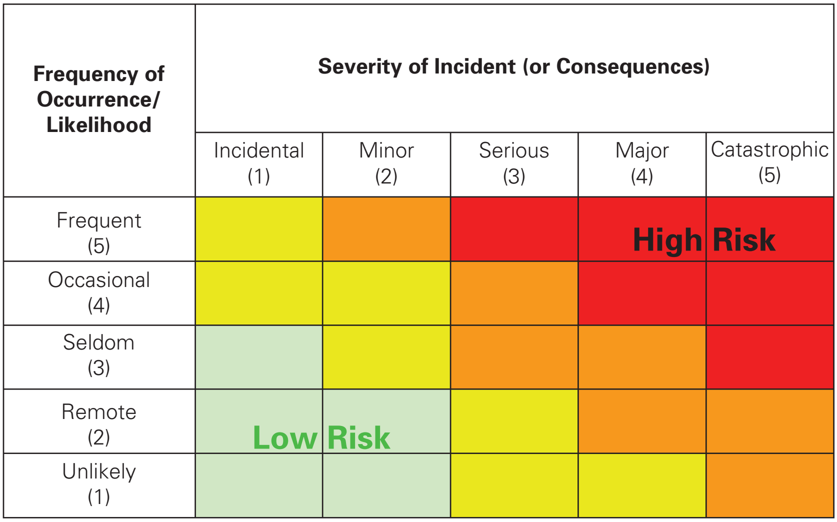

FIGURE S-4 Proposed risk matrix.

Implementation of Risk Reduction Measures

The development of risk reduction measures for implementation will require consideration of who the decision makers are and what capacities they have to effect recommended changes. For example, USCG rulemaking depends on consideration of benefits relative to costs. The State of Alaska and local municipalities also have specific decision-making roles. Securing federal funds will involve other U.S. government branches, and IMO will have a role if changes to international regulations are desired. Successful implementation of certain initiatives may require the collaboration of various government decision makers, the support of stakeholders, and a relatively longer time.

Need for Transparency

If the objectives of the risk assessment study are to be met, its final report should be fully transparent, describing the study process and all relevant assumptions:

- Hazards and risks should be clearly identified. For risk reduction measures that merit detailed analysis, benefits and costs should be clearly defined.
- All sources of data should be documented and assumptions explained. Models and methodologies should be explained in suf-

ficient detail to allow a third party to understand the assessment's basic assumptions and limitations.

- Judgments applied during the assessment should be explicitly stated. The process for elicitation and analysis of expert opinion should be explained.
- Uncertainty and associated sensitivity analyses should be clearly documented and explained. Results should be presented in a way that does not create a false sense of precision.
- The analyses should be of sufficient depth to address the needs and expectations of those with expertise in risk assessment while being understandable to the layperson.

CONCLUSION

Despite the complexity of the system and the open-ended nature of the problem, the committee is confident that a rigorous and comprehensive risk assessment of shipping in the Aleutian Islands can be conducted within the available resources and that needed safety improvements can be justified in the process. The committee also understands that, while certain historical and time-series data are limited, they can be enhanced and supplemented by relevant worldwide data and local expertise and judgment. This report presents a framework for conducting such a risk assessment, explaining the underlying principles and offering guidelines for applying both qualitative and quantitative techniques where appropriate. Finally, throughout this report, the committee emphasizes principles that are key to ensuring a successful outcome. These include keeping the work focused on a clear definition of boundaries and scope, designing the assessment process to incorporate continuous involvement of local stakeholders, and applying a phased approach to set priorities for early action and allocate resources efficiently.

CHAPTER 1

Introduction

Several vessel accidents and spills of oil and other fuels in recent years near the Aleutian Islands have focused attention on the potential risks posed by vessels operating in the region. The most serious of these incidents, occurring in December 2004, was the grounding and breakup of the M/V *Selendang Ayu,* a large bulk grain carrier, which resulted in a spill of 336,000 gallons of heavy fuel oil and six fatalities. Such incidents are of concern because of the biological, cultural, and economic significance of the Aleutian Islands, as well as their geopolitical importance for the United States. Vessel accidents and spills can have serious negative impacts on the region's ecosystem, devastating endemic and migrating wildlife and plant species and the economies that depend on the region's rich resources.

STUDY CONTEXT

Vessel Traffic in the Aleutian Islands

Commercial shipping between the west coast of North America and Asia is substantial and growing. Over the past decade, it has increased by approximately 5 percent annually, and it is forecast to continue to grow at a similar rate in the coming decade. Most of these ships use the North Pacific Great Circle Route—the most direct transit route between Pacific coast ports of the United States and Asia—which brings them through or near the Aleutians. Unimak Pass at the eastern end of the Aleutian Islands sees about 4,500 vessel transits annually.

Growth of commercial traffic in the region is expected because of both an increase in maritime trade and expanded economic activity in the Arctic that will open up new shipping routes through the Aleutians. Economic activity is expected to increase in the Arctic as the southern extent of the summer ice pack thins, enabling ice-capable ships to travel through the region. According to a recent report of the National Research Council (NRC), "Those deploying fishing fleets, cruise ships, mining, and the associated ore transit ships, as well as petroleum recovery and tanker ship transport, anticipate increased operations in the region. When current orders for ice-strengthened tankers have been filled, the worldwide fleet of these vessels will double in number" (NRC 2007, 5). Some of these tankers will be transiting through the Aleutian region.

Given current trends in both maritime trade and climate change, growth in vessel traffic in the Aleutian Islands is expected to continue for the foreseeable future. All other factors remaining constant, this growing traffic will result in an increased risk of vessel accidents and spills.

In addition to commercial ships that transit the region, fishing vessels, ferries, cruise ships, tugs, and barges operate in and around the Aleutians. Because some fishing grounds are at the north end of Akun Island, fishing vessels must cross the commercial traffic lanes. Moreover, two or three large cruise ships operate annually in the Aleutians, 10 cruise ships visit Dutch Harbor every summer, and about 20 trips are made each year via the Alaska Marine Highway. These numbers are also expected to increase, adding more north–south vessel traffic through the region.

Safety Concerns

The Aleutian Island chain, consisting of approximately 300 volcanic islands, extends westward about 1,200 miles from the southwestern tip of the Alaska Peninsula toward the Kamchatka Peninsula and occupies an area of about 6,820 square miles. The region is remote and contains few large harbors. Responding to emergencies is difficult because capable vessels and equipment are located great distances away. For example, the nearest U.S. Coast Guard (USCG) base with search and rescue capabilities is located at Kodiak, Alaska, almost 500 miles east of Unimak Pass at the eastern end of the island chain.

Many factors in the Aleutian region converge to raise public concern about the risk of vessel accidents. A central factor is the unique and valuable natural resources of the region that could suffer damage from vessel accidents. The Aleutians contain one of the most important marine ecosystems in the world (including the Alaska Maritime National Wildlife Refuge). They are home as well to the largest and most valuable commercial fishing grounds of the United States, and the local economy depends heavily on the fishing industry. The region is also characterized by a substantial variety of maritime industrial activities, with large ships carrying hazardous cargoes, and a history of accidents and spills with inadequate response. This study is intended to address these concerns by developing a framework for assessing the future risks of vessel accidents and spills in the Aleutians and providing the justification for appropriate safety improvements.

Vessel Accidents in the Aleutians

On December 8, 2004, the bulk grain ship M/V *Selendang Ayu*, which had lost power and been adrift for about 53 hours in heavy seas and winds ranging from Beaufort force 7 (near gale) to force 11 (violent storm), grounded and subsequently broke up during a storm on the north side of Unalaska Island. The ship spilled about 336,000 gallons of fuel oil and diesel fuel and oiled portions of 70 miles of coastline, affecting commercial fish habitats and subsistence hunting, gathering, and fishing areas and killing seabirds (NOAA 2007). The incident drew international attention because six crew members were lost when a helicopter attempting to evacuate the crew crashed into the sea. This incident helped focus attention on the oil spill risks posed by vessels transiting the Aleutian Islands.

The M/V *Selendang Ayu* incident, however, was not isolated. Each year, accidents and near accidents occur in the Aleutians with the potential for significant environmental and economic consequences. For example, between 1981 and 1999 there were 41 oil spill incidents in the Aleutians for which USCG requested assistance from the National Oceanic and Atmospheric Administration's (NOAA's) Hazardous Materials Response Unit (NOAA 2000). According to NOAA, "for the past 25 years, the Aleutian Islands have averaged nearly one oil spill of 1,000 gallons or more per year" (NOAA 2007, 1). Moreover, between 1991 and 2004, 45 casualties due to vessel incidents were reported throughout the Aleutian Island chain; of these casualties, 16 resulted from incidents involving loss of maneuverability. By comparison, during the same period, 415 casualties were reported for all U.S. vessels, most of which were fishing vessels.

Before the M/V *Selendang Ayu* incident, the largest, most expensive, and most prolonged spill response in the Aleutians was to the 1997 grounding on Unalaska Island of the M/V *Kuroshima*, a 368-foot frozen-seafood freighter. The ship broke its anchorage during a storm and ran aground. It was estimated that the vessel released 39,000 gallons of heavy fuel oil that affected approximately 3,500 feet of ocean shoreline and about 1.6 miles of shoreline in Summer Bay Lake (ADEC 1997a; ADEC 1997b). Because this spill was adjacent to the communities of Dutch Harbor and Unalaska, the grounded vessel and oil pollution were relatively accessible. However, the cleanup effort lasted more than a year, and the spill negatively affected biological resources, human subsistence, and recreational resources (NOAA 2000).

Shortly after the grounding of the M/V *Kuroshima*, the containership *Hanjin Barcelona* collided with the *Alaska-1*, a catcher–processor vessel, north of Dutch Harbor. The *Alaska-1* sank, although its entire crew was rescued.

CURRENT RISK REDUCTION MEASURES

The M/V *Selendang Ayu* accident highlighted the lack of knowledge about the extent and nature of vessel traffic transiting the North Pacific Great Circle Route between the west coast of North America and the Far East and sharing waters used by local marine traffic. It also served as a catalyst for action by the State of Alaska and USCG to mitigate the potential risks involved. The Alaska Department of Environmental Conservation and USCG, which "have a responsibility to minimize the potential for incidents and to be prepared for any contingency," either jointly or individually, have recently initiated a number of measures to this end, including the following (ADEC 2006, 1):

- Automatic identification systems (AIS) capability has been installed at Scotch Cap to track vessels transiting Unimak Pass.
- Stakeholder input is sought to establish priorities, objectives, and action plans as part of the emergency response process.
- Potential places of refuge are being identified and plans developed so that vessels in distress can be anchored safely while undergoing repair.
- Geographic response strategies—site-specific spill response methods to protect sensitive coastal areas—are being developed and will provide first responders with guidance for the rapid implementation of preidentified actions to protect these areas.
- A Ports and Waterways Safety Assessment (PAWSA) for the Aleutian Islands was sponsored to examine preventive measures for improving safety in the region.
- A multistage risk assessment of maritime transportation in the Bering Sea and the Aleutian archipelago is being planned.

The United Nations Convention on Law of the Sea (UNCLOS), which entered into force in 1994, provides authority for coastal states to manage vessels on innocent passage through territorial seas; however, USCG and the State of Alaska remain unclear about their specific authority to regulate ship traffic directly through U.S. waters in the Aleutians. While foreign vessels on innocent passage are not subject to regulation by coastal states with respect to hull construction, manning, and equipment, coastal states do have the right under UNCLOS to impose regulations regarding such matters as safe navigation, maritime traffic, pollution prevention, and establishment of sea lanes and traffic separation schemes (see Chapter 3). Until the M/V *Selendang Ayu* incident, estimates of the volume of marine traffic were not being made, although USCG had conducted traffic counts during two months in 2004. Since being installed, the AIS monitoring devices at Scotch Cap have provided data that allow estimation of transits made by vessels over 300 gross tons on international voyages through the pass by date and in association with prevailing weather conditions.

In July 2006, USCG hosted a workshop for the PAWSA of the Aleutian Islands in Anchorage (USCG 2006). The workshop included broad representation from waterway users, regulatory authorities, and various stakeholders with a vested interest in the safe and efficient use of the Aleutian Islands for commercial and recreational purposes. Participants examined a wide variety of options for helping to prevent and respond to vessel incidents at or near Unimak Pass and the eastern Aleutians. (The geographic region addressed was limited to 168°W longitude to the east; 162°W longitude to the west, including Dutch and Akutan Harbors; the portion of the Bering Sea bounded by the Great Circle Route to the north; and the Unimak Pass traffic fairway and Unalaska Island to the south.) Other options besides those considered for the PAWSA have been proposed, a number of which were presented to the committee at its October 29–30, 2007, meeting in Anchorage. (See Appendix A for a list of risk mitigation options presented to the committee by representatives of federal, state, and local governments, as well as industry and stakeholder organizations.)

In addition, the State of Alaska commissioned a study (Nuka Research and Planning Group 2006) for which records from a variety of sources were assembled to estimate the scale and nature of vessel traffic and the frequency of vessel incidents in the Aleutian region, and to evaluate gaps in existing data and recommend needed improvements. The pertinent results of that study are described in more detail in later chapters of this report.

On August 14, 2007, following the M/V *Selendang Ayu* accident investigation, IMC Shipping Company PTE Ltd., the owner of the ship, pled guilty to two counts of illegal discharging and one count of killing migratory birds. Under the plea agreement, IMC is required to pay $3 million to the National Fish and Wildlife Foundation "for the purpose of conducting an Aleutian Islands risk assessment of the shipping hazards for that area as well as projects identified by the risk assessment" (*Selendang Ayu* Settlement 2007, 12). (See Appendix B for the complete plea agreement.)

On September 30, 2007, USCG and the National Fish and Wildlife Foundation executed a memorandum of agreement establishing the Vessel Source Pollution Prevention and Compliance Fund, under which the Aleutian Islands risk assessment will be undertaken. The fund will "receive monies to be used to protect coastal and marine habitats and species by improving general understanding and knowledge of and promoting compliance with marine environmental protection laws of the United States" (USCG 2007, 1).

The National Fish and Wildlife Foundation, established in 1984, is a nonprofit corporation that is directed to undertake activities to further the conservation and management of fish, wildlife, and plant resources for present and future generations. It is authorized to accept funds from any legal source to further its mission. A subaccount was established for specific activities required under the settlement for the M/V *Selendang Ayu* case.

A multistage risk assessment of maritime transportation in the Bering Sea and the Aleutian archipelago is being planned. The National Academies study that is the subject of this report represents the beginning of a long-term risk assessment and mitigation strategy.

STUDY OBJECTIVES AND SCOPE

Following the *Exxon Valdez* spill, a comprehensive risk assessment of shipping through the Prince William Sound region was undertaken. An NRC committee subsequently conducted a review of that study and identified a number of concerns with regard to its methodology, use of expert elicitation, and treatment of uncertainty (NRC 1998). The NRC report had minimal influence because it was published after the assessment had been completed.

When the decision was made to conduct a risk assessment for the Aleutian Island region, the State of Alaska and USCG proactively solicited the National Academies' input in advance of conducting the study. They requested that this committee develop a framework and procedure for the risk assessment, as described in the committee's statement of task:

> to examine available data and evidence about the risk of spills from vessels transiting the Aleutian Islands, determine the information needed to conduct a comprehensive risk assessment, recommend the appropriate framework for such an assessment, and identify how a comprehensive risk assessment could be conducted in discrete steps. The framework would establish the most appropriate and scientifically rigorous risk assessment approach possible given available data and modeling capability. The steps would provide a logical sequence of building blocks toward a comprehensive assessment that could be conducted as future funding becomes available.

In carrying out its charge, the committee identified a sequence of phases and steps for a comprehensive risk assessment that can be undertaken as funding becomes available.

While it is recognized that shipping through the Aleutian Islands poses risks to people, habitats, and the environment, the extent of those risks is not well understood because a comprehensive risk assessment has never been conducted for this area. Risk is inherent in this as in any system—it can be reduced and managed, but it cannot be eliminated. Risk assessment is widely used in the marine industry by government and private authorities to help manage the risks associated with shipping operations. Assessing risk involves addressing three key questions: What can go wrong? How likely is it? and What are the impacts? Efforts to answer these questions are organized systematically into discrete steps that involve identifying hazards (or creating risk scenarios), determining the likelihood of their occurrence, and identifying their consequences (NRC 1997; NRC 1994). The present study describes the fundamental steps of risk assessment and applies them to the question of how to minimize vessel accidents and spills in the Aleutian Islands.

Many stakeholder groups in the Aleutians should be knowledgeable about the risks associated with shipping operations in the region so that informed guidance can be provided. Involvement and a shared commitment among these parties, along with effective communication, training, and procedures, can make efforts to manage the risks of vessel accidents and spills more effective.

STRUCTURE OF THE REPORT

The remainder of this report is organized into six chapters. Chapter 2 describes the fundamentals of risk assessment, including the methodology, how the assessment is usually structured and managed, and how the committee used these principles to develop a recommended approach for the Aleutian assessment. Chapter 3 describes the region's local assets and their vulnerability, its climate, and its maritime infrastructure. Chapter 4 presents available information on vessel traffic, movement of hazardous goods, accidents, and spills in the Aleutians, as well as the regulatory framework for navigation in the region. Chapter 5 presents the committee's recommended organization of the risk assessment, while Chapter 6 describes the proposed technical approach for conducting the assessment. Finally, Chapter 7 contains the committee's conclusions and recommendations.

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Abbreviations

ADEC	Alaska Department of Environmental Conservation
NOAA	U.S. National Oceanic and Atmospheric Administration
NRC	National Research Council
USCG	United States Coast Guard

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CHAPTER 2

Fundamentals of Risk Assessment

Risk is the combination of the likelihood and consequences of an undesirable event. For example, the risk of pollution from a vessel accident could be expressed as the likelihood of a spill combined with the impact of that spill. As noted in Chapter 1, to calculate risk, situations must be evaluated to answer the following questions:

- What can go wrong?
- How likely is it?
- What are the impacts?

The first question involves creation of a risk scenario; the second, determination of likelihood; and the third, specification of consequences.

The process for answering these three questions is called "risk analysis," and the answers derived, for all possible scenarios, are a complete expression of the risk being assessed. This chapter provides an overview of risk assessment; describes the overall organization of and approach to risk assessment; and summarizes the committee's proposed approach for a risk assessment of shipping operations in the Aleutian Islands, which is detailed in Chapters 5 and 6.

OVERVIEW OF RISK ASSESSMENT

Risk assessment combines risk analysis with risk management, the latter term denoting the processes of establishing risk tolerance criteria and selecting and implementing risk reduction measures. Risk assessment is a rational and structured approach for identifying hazards, analyzing risk, and identifying risk reduction measures. Properly implemented within an organization that follows a long-term risk management process, it provides a cost-effective basis for maintaining risk within appropriate limits.

In the marine industry, various risk assessment frameworks exist. One established approach is the International Maritime Organization's (IMO's) Formal Safety Assessment (FSA). FSA is described by IMO as a "rational and systematic process for assessing risks relating to maritime safety and the protection of the marine environment" (IMO 2002, 1). This process is also used by IMO for evaluating the cost and benefits of options for reducing risks (IMO 2002). The results of risk assessments, including those employing FSA approaches, can be used to compare options, weigh costs against benefits, and aid in making decisions among options. Figure 2-1 outlines the FSA process.

Most risk assessment processes, including those applied in other fields, such as the aviation and nuclear power industries (NRC 1997; NRC 1994; NRC 1983), use the same overall approach as FSA and generally comprise the following steps:

- Hazard identification,
- Risk analysis,
- Risk control options,
- Cost–benefit assessment, and
- Recommendations for decision making.

Step 1: Hazard Identification

The hazard identification step, in the IMO approach, might more properly be called the hazard and accident scenario identification step. Hazards are materials or conditions with the potential to result in harm to human life or health, property, or the environment. During this preliminary hazard identification stage, analysts use a combination of techniques aimed at identifying all relevant hazards

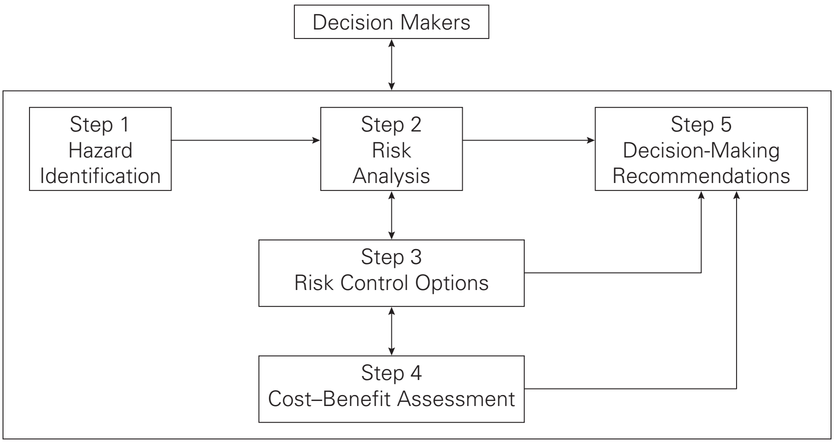

FIGURE 2-1 IMO's FSA process.

(Source: IMO 2002.)

and associated scenarios within the scope of the risk assessment study. In the case of shipping operations, the objectives of hazard identification are to

- Identify specific hazards involved in shipping that have the potential to harm human life and health, property, or the environment;[1]
- Identify accident types (e.g., drift groundings, powered groundings, collisions) and scenarios and provide an understanding of the causal factors (e.g., loss of steering, inadequate stability) and conditions (e.g., sea state, weather, current) leading to these accidents;
- Provide an understanding of the likelihood and consequences of these accidents and scenarios; and
- Identify the high-risk scenarios and conditions under which they may occur.

Hazard identification generally involves both high-level analytical and qualitative assessments. Various techniques are applied, such as checklists, HaZID (Center for Chemical Process Safety 2008), and expert judgment. (The formal use of expert opinion and evidence is summarized in Appendix C. The discussion covers the use of expert opinion, the "facilitator," and the issue of controlling bias.) The analytical assessment helps ensure that historical expe-

[1] All other consequences of concern to stakeholders that are discussed later in this report are direct impacts of such harm or fear that it will occur.

rience and accident data are taken into account; it is performed at a coarse level, sufficient to help identify the principal hazards and scenarios. The hazard identification should not be restricted to situations that have occurred in the past; rather, the approach used should allow for creative thinking such that potential hazards not previously encountered are also postulated. Keeping the analysis as broad as possible at this stage is essential to a quality assessment (Atwood et al. 2003; DNV 2002; NRC 1994; O'Hara et al. 2004).

Step 2: Risk Analysis

Once hazards and accident scenarios have been identified, detailed analysis of risks can begin. This step involves more rigorous investigations into the conditions and causes of the most significant scenarios. It commonly includes processing and analyzing large quantities of data and performing modeling. The analysis relies on historical experience, analytical methods, and expert knowledge or judgment.

To conduct a risk assessment, analysts must make practical decisions about the techniques to be used, such as hazard and operability analysis (HaZOP) (CCPS 2008), event and fault trees, elicitation of expert judgment, human reliability analysis (discussed in Appendix D), simulation, and consequence (fate and transport) analysis. Analysts must also determine the effort necessary to achieve a level of precision from the risk analysis that will ultimately result in beneficial, usable results for all concerned or potentially affected. Thus analysts must determine whether quantitative, semiquantitative, or qualitative techniques or a combination thereof will provide the most appropriate risk estimates. Regardless of what techniques are used, careful identification of the sources of uncertainty is required, along with estimates of the uncertainty in stated results (Atwood et al. 2003; DNV 2002; O'Hara et al. 2004). (Appendix E examines issues associated with uncertainty, including sources of uncertainty, sensitivity analysis, propagation of uncertainty, and Bayesian statistical analysis.)

The choice of techniques is influenced by the nature of the available information and the precision necessary to determine a credible risk value. Figure 2-2 illustrates how qualitative or quantitative techniques can be used for risk analysis (ABS 2000). Regardless of the techniques chosen, the goal of the analysis remains the same: to derive

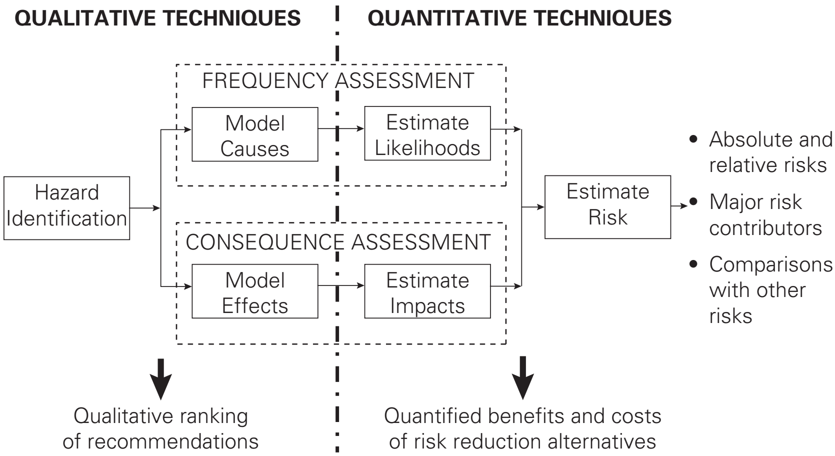

FIGURE 2-2 Risk analysis techniques.

(Source: ABS 2002.)

estimations of risk and to provide detail sufficient for examining risk reduction measures that can achieve a tolerable level of risk (NRC 1989). The output of the risk analysis should be a refined characterization of scenarios, their likelihood, and their consequences, allowing risks to be ranked in order of consideration for risk control options.

Scenarios

Scenarios are initially narrative descriptions of what can happen. In the case of shipping operations, developing scenarios requires extensive experience in those operations, good engineering knowledge, and a grasp of the modeling required to develop scenarios that can be analyzed efficiently. (See Appendix F for a detailed description of event sequence diagram methodology and risk scenario development.) Figure 2-3 illustrates the primary aspects of marine scenarios. The scenario begins with an initiating cause, such as a loss of propulsion, a fire, or adverse weather. The next step is to develop a sequence of events that represents the response of the "system" (the ship, its hardware and software, its crew) to the cause. The safeguards in place (barriers, operational controls, and risk control options) are delineated. If the cause is not controlled by the safeguards, failures may occur (hardware failures, human and organizational failures, or failures caused by environmental stressors). This

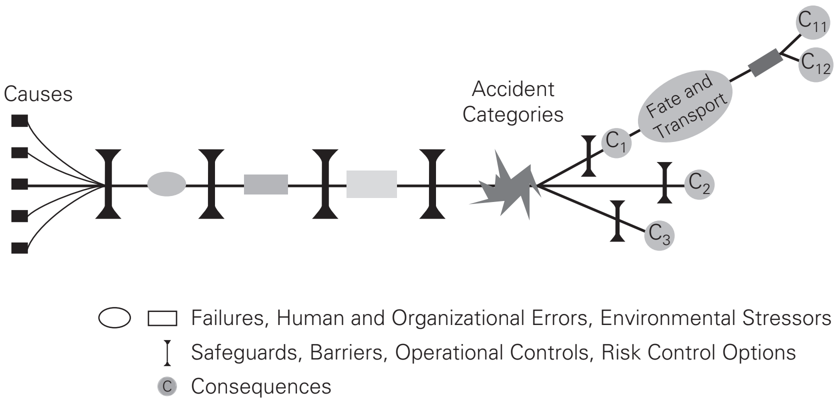

FIGURE 2-3 Primary aspects of marine scenarios.

sequence of events either is arrested or leads to an accident that can have immediate consequences, such as loss of life, physical damage to the ship, and spills of hazardous materials. If a spill is involved, the scenario continues through transport of the material and its deposition in the environment. Should a spill occur, mitigation measures (additional safeguards) can limit the environmental and subsequent economic and social consequences. Remediation, or cleaning up the contamination, can limit harm to life in the area.

Likelihood

Estimates of the likelihood of the identified scenarios come first from experienced judgment and second from simple statistics based on analysis of accident reports. Finally, when needed, likelihood estimates are derived from evaluation of detailed models of the scenarios.

Consequences

The consequences of concern to stakeholders are identified through literature reviews and interactions with stakeholders (NRC 1994; NRC 1989). For the present study, the committee identified preliminary consequences of concern following a series of informational meetings (see the "Risk Assessment Approach" section later in this chapter). Analysts will need to refine this list. Historical consequences related to loss of life and damage to ships and cargoes can be quantified from accident data. Consequences to the environment can be identified through modeling efforts. The few historical events with significant consequences can indicate the potential extent of consequences but are not adequate for prediction purposes.

One aim of the risk analysis is to determine and characterize the risk levels of various scenarios. Often this characterization will use categories such as the following to determine the importance of risk reduction for a given scenario:

- Negligible—no risk reduction methods required;
- Tolerable—risk should be reduced to "as low as reasonably practical"; and
- Intolerable—risk reduction must be undertaken irrespective of cost.

Such characterization allows comparison across scenarios and risks and provides a means for properly considering risk reduction for situations outside acceptable boundaries given the concerns and needs of the various stakeholders.

Step 3: Risk Control Options

The next step is to identify possible risk control measures, prioritize and identify those that are more promising, and analyze their effectiveness. The results of the screening process associated with hazard identification and the risk analysis of the existing system allow the assessment of risk control measures to focus on scenarios identified as having the highest risk, considering the combination of likelihood of occurrence and consequences. However, it is also important to consider scenarios identified as having the highest likelihood of occurrence even if their consequences are modest, and scenarios having the highest consequences even if their likelihood is small. Once screened, the more promising risk control measures are subjected to risk analysis as described in Step 2 above to quantify their impact on the likelihood and consequences of accidents.

Step 4: Cost–Benefit Assessment

The purpose of cost–benefit assessment is to provide an additional tool for decision making that identifies the implementation costs and the expected benefits of risk reduction measures. Cost-effectiveness is often expressed in terms of net cost per unit reduction in risk, enabling the ranking of risk reduction measures. While determining implementation costs and understanding the relationship between costs and benefits yield valuable input for the decision-making process, that process is inevitably more complex than simply selecting the most cost-effective solutions. For example, certain benefits, such as damage to natural resources and societal impacts, are difficult to quantify in monetary terms yet need to be considered in the overall assessment.

In cost–benefit assessment, costs usually are discounted to present value. Benefits generally are not discounted; rather, the cumulative benefits over the study period are applied. Thus, a cost-effectiveness index for a risk reduction measure is calculated as the net cost of the measure divided by its gross benefits. For shipping operations, typical indices are dollars per fatality avoided or dollars per gallon of oil spill avoided. Alternatively, a multidimensional comparison of costs and risk curves or risk matrices (described later in this chapter) can be more informative than calculation of a cost–benefit ratio.

Step 5: Recommendations for Decision Making

The final step in IMO's FSA methodology is to present decision makers with a set of well-defined recommendations. Those recommendations should reflect all relevant findings, including the following:

- Comparison and ranking of the hazards and risk scenarios,
- Comparison and ranking of risk control measures as a function of costs and benefits, and
- Consideration of risk control measures that keep risks as low as reasonably practical.

Documentation of the recommendations should include a description of the evaluation criteria used in ranking the risks and risk reduction measures. It should also include an explanation of significant uncertainties associated with the recommendations (NRC 1989)—in the case of costs, for example, the interest rate used for discounting (see the discussion of addressing uncertainty in Appendix E).

ORGANIZATION OF RISK ASSESSMENT

Definition of the Problem

Before beginning a risk analysis, it is important to define the problem carefully. The purpose of problem definition is to identify objectives and set the bounds for and focus of the analysis. As an example of defining the problem at hand, the risk assessment addressed by the present study focuses on accidents and spills rather than intentional operational releases. This is but one of many dimensions that must be defined for this risk assessment. The charge to the committee and this report define the problem and scope of the approach for this risk assessment study.

Management of the Assessment

The previous section described the sequence of steps to be followed in a risk assessment. Other important analytical choices include whether the assessment should be tiered in a way that permits broad-brush qualitative aspects of risk to be examined first, on the chance that easily identified risks can be addressed by measures that are relatively easy to implement, saving both time and expense. If this approach is applied, measures with high benefit and relatively low implementation costs may prove sufficient in some circumstances, obviating the need to extend the assessment into areas of greater precision whereby quantitative estimates of risk are developed.

When a risk assessment is intended to aid decision makers in identifying and reducing technological risks of considerable public concern, some elements of how best to organize the study are matters of choice that are not easily prescribed. Primary among these is the relationship to be developed among managers and decision makers, analysts, those with local knowledge of the technological system undergoing analysis, others with a detailed understanding of the potential local environmental and socioeconomic impacts associated with the risks of concern, and the broader stakeholder community of interested and affected parties. The modern approach to risk assessment increasingly emphasizes formal roles for all these parties.

Stakeholder Engagement

Recent years have seen a trend in risk assessment toward extensive engagement of stakeholders throughout the process of defining and analyzing risks and identifying risk reduction measures (Bonano et al. 2000; NRC 1996; Presidential/Congressional Commission on Risk Assessment and Risk Management 1997; Omenn 2006). For example, the Presidential/Congressional Commission on Risk Assessment and Risk Management (1997) divided the risk assessment and management process into six stages. Only the final "evaluation" stage (which involves assessing the effectiveness of measures adopted to address the identified risks) is cited as being appropriately conducted without explicit stakeholder involvement (see Figure 2-4).

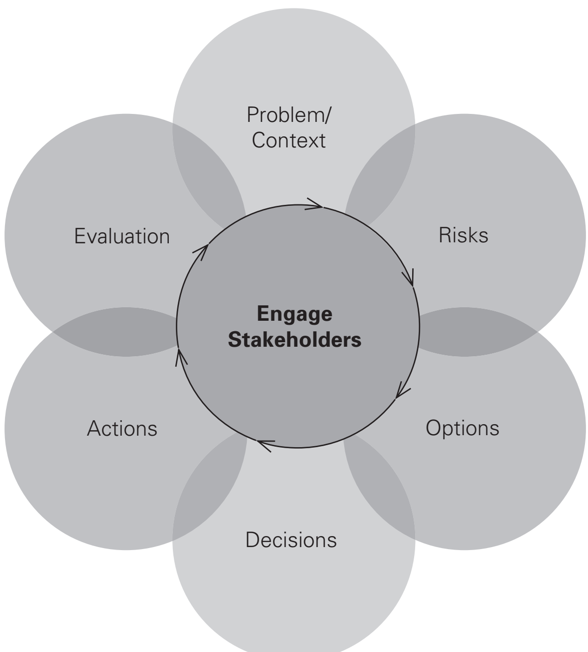

FIGURE 2-4 Engagement of stakeholders in the risk assessment and management process.

(Source: Omenn 2006. Reprinted with permission from the American Association for the Advancement of Science.)

Engaging stakeholders, decision makers, and analysts—typically contractors—in the design and conduct of a risk assessment has been termed "collaborative risk assessment" (Charnley 2000). This was the approach taken in the Prince William Sound Risk Assessment Study (PWS study) (Merrick et al. 2002), in which a "highly interactive and cooperative" steering committee (NRC 1998) played a significant role in shaping the overall study through frequent meetings with the analytical team. The steering committee operated by means of consensus decision making. In the end, although it had begun as an advisory body with many members skeptical about the outcome of the study, it fully endorsed the study results and volunteered to be the publisher of record for the final study report (Merrick et al. 2002; PWS Steering Committee 1996).

The PWS study's steering committee was constituted to be broadly representative of the main groups with an interest in risk reduction in Prince William Sound, groups that, in the aftermath of the 1989 *Exxon Valdez* oil spill, had highly adversarial relationships. The committee's unanimous acceptance of the study results, together with self-reports by the study team (Merrick et al. 2002), suggest that stakeholder engagement accomplished an important goal of collaborative risk assessment—organizational learning that led not only to new understanding of the nature of risks within the system but also to a new collaborative decision-making approach to managing the identified risks. Stakeholders contributed resources, knowledge, and information to the study, and the resulting collaborative learning induced not only policy but also organizational change (Busenberg 2000).

In the PWS study, local stakeholders played another important role—supplying substantive domain expertise that helped the study team quantify the relative importance, in terms of relative conditional probabilities, of various situational factors that could influence risk in the Prince William Sound shipping system (Merrick et al. 2002). A group consisting of pilots, deck officers, and shipboard engineers who had worked aboard trade vessels of the Trans-Alaska Pipeline System rated the relative likelihood of a large number of different scenarios resulting in accidents. The results of questionnaires in which 120 scenarios were rated (Merrick et al. 2002) became a primary data source for the PWS study.

Identification of Stakeholders

The question of whom to consider stakeholders, and by extension whom to invite to be engaged in the analytic and deliberative phases of a risk assessment, is ultimately answered in part by the nature of the problem and in part by the extent to which the decision-making organization views itself as inclusive (Mitchell et al. 1997). The modern tendency in environmental management is certainly in the direction of inclusiveness—in the words of Mikalsen and Jentoft (2001, 282), going "from user groups to stakeholders."

The basis for stakeholder identification should not be closeness to the problem itself (i.e., user groups) but rather who has *power, legitimacy,* and *urgency* given the problem's defining characteristics, particularly the distribution of benefits and costs in relation to the problem as it stands today or might stand in the future (Mikalsen and Jentoft 2001; Mitchell et al. 1997). By these measures, stakeholders can be identified as *definitive* (having unequivocal claims by virtue of direct engagement in the problem domain, in other words, possessing all three of the above attributes); *expectant* (having legitimate expectations to be involved because they possess two of the three attributes); or *latent* (possessing just one of the three attributes) (Mikalsen and Jentoft 2001). The implication is that groups geographically removed from the problem arena may nevertheless have a stake in addressing the problem (e.g., fishing companies headquartered in the lower 48 states or national and international nongovernmental organizations representing environmental interests), just as may local populations, such as native communities or immigrant workers in local seafood processing operations.

As is clear from Ritchie and Gill's (2006) study of the potential social impacts of the M/V *Selendang Ayu* spill and the committee's meetings with community leaders in Dutch Harbor, the Dutch Harbor community has enjoyed considerable economic benefit from its position as home port to major Bering Sea–Gulf of Alaska fisheries that are among the most economically valuable in the world. These economic benefits have translated into substantial social and cultural benefits to the community at large, making it a place that residents value for the high quality of life it now affords (Ritchie and Gill 2006). In the end, however, these community attributes and the economic activity that supports them underscore the high degree of resource dependency on the Bering Sea–Gulf of Alaska fisheries, rendering both the local community and the fisheries themselves highly vulnerable to the effects of oil spills.

As the above discussion suggests, some aspects of stakeholder vulnerability to oil spills are difficult to quantify given the approaches typically used to account for and value social impacts in risk assessments (Murphy and Gardoni 2006). The least-connected latent stakeholders—perhaps immigrant workers in seafood-processing plants with comparatively low levels of both power and legitimacy but high levels of urgency—are most likely to be subject to undercounting with respect to the losses they would suffer were a large oil spill with major detrimental impacts on local fisheries to occur. Methods derived from the field of economic development have been proposed as means of accounting for such impacts in risk analysis (Murphy and Gardoni 2006), but their utility has yet to be demonstrated through application.

Possible Limitations and Biases

Stakeholder engagement in risk assessment clearly confers many benefits. These include, as noted above, trust building, clarification of the values and goals that should inform the assessment, the provision of local information and knowledge that would otherwise be easily missed, and potentially a path to organizational learning and policy change that might not otherwise be available. Stakeholder engagement also comes with potential limitations, however. Frequent interactions with stakeholders can compromise the study team's objectivity, lead to "common denominator" study framing when analytical understanding might indicate different choices, and introduce bias into the analysis (NRC 1998). The heavy reliance on poorly controlled and documented elicitation of expert views in the PWS study, for example, led to results that proved difficult to validate (Merrick et al. 2002). The choice was made to pursue this path because the study's steering committee insisted that only local data be used in the study, rather than the worldwide data often used to support estimates of the likelihood of rare events in risk studies.

Reliance on individuals with knowledge of or direct involvement in previous incidents, such as those involving the *Exxon Valdez* or M/V *Selendang Ayu*, can introduce "availability bias," by which repeat events are deemed highly likely simply because they have already occurred (Merrick et al. 2002). In the Aleutians' maritime system, for example, transiting cargo ships and freighters are easily identified as the risk "problem" given that vivid imagery of the M/V *Kuroshima*, M/V *Selendang Ayu*, and *Cougar Ace* accidents is fresh in local memory. The fishing fleet is more easily seen as vulnerable to spills associated with vessels in the cargo trade, rather than a source of additional risk. Yet in the PWS study, the primary source of collision risk was found to be a collision between a fishing vessel and a Trans-Alaska Pipeline System trade tanker, a risk traceable to the large number of fishing vessels present within Prince William Sound during fishing seasons.

RISK ASSESSMENT APPROACH

This section presents a brief exposition of the general ideas behind risk assessment to set the stage for discussion of the specific tasks required for the risk assessment of shipping operations in the Aleutian Islands. Recall that the approach to risk assessment begins with risk analysis, a systematic process for answering the three questions posed at the beginning of this chapter:

- What can go wrong?
- How likely is it?
- What are the impacts?

The formal definition of a risk analysis proceeds from these simple questions, where a particular answer is S_i, a particular scenario; p_i, the likelihood of that scenario; and C_i, the associated consequences.

In mathematical parlance, this answer is known as the risk triplet $<S_i, p_i, C_i>$, and the complete set of answers—that is, all possible scenarios—is, in fact, the "risk analysis" (NRC 1997). The analysis describes and quantifies every scenario. The calculational link between the full set of triplets and the "risk curve" (e.g., the risk matrix) that displays summary results for frequency versus consequences is developed later in this section.

Approaches used for defining the scenarios always begin with qualitative descriptions. These descriptions become more thorough, detailed, and analytical as structured search and analysis tools are applied. Estimations of likelihood and consequences generally begin with rough ideas based on experience and judgment. They then progress, stepwise, through ranges taken from event records;[2] to statistics based on the data; and finally to full-fledged analysis based on logic models, engineering and physics calculations, simulation, human performance modeling, and fate and transport modeling. In some cases, the analysis may end with qualitative techniques if risks do not lend themselves to quantification, if discrete or sufficient credible data required for quantitative assessments are unavailable, or if obtaining or analyzing data is not cost-effective.

Analysis results include qualitative descriptions of the scenarios (narratives), their likelihood (e.g., frequent, infrequent, rare), and their consequences (e.g., mild, moderate, severe, catastrophic). As the analysis is extended, it produces models of the scenarios; calculations of the frequencies of particular events, outcomes, and classes of scenarios; and estimates of specific consequences (oil spills, deaths and injuries, damage to natural resources, socioeconomic impacts, and damage to reputation). These outputs become more quantitative and the uncertainty of the results is narrowed as more detailed information is developed.

Summary measures of risk are presented in qualitative, semiquantitative, and quantitative formats, becoming more quantitative as the level of analysis deepens. However, results in all of these formats should be reported because they speak to different audiences and to different purposes. One popular format for presenting the results of qualitative risk analysis is a matrix (see Figure 2-5) with columns corresponding to various levels of consequence and rows to different levels of likelihood. The number of columns and rows depends on the depth of the completed analysis and the intended use of the results. Risk scenarios analyzed are placed in the cells of the risk matrix according to their level of likelihood and consequences. Color schemes are used to indicate different risk levels (e.g., red for high risk). The risk scenarios are thereby placed in a limited number of risk categories for ranking and comparison in risk management, also on the basis of qualitative acceptance criteria. Sometimes numerical scales (e.g., 1 through 5) are used for one or both dimensions of the matrix, but the numbers are not meant

[2] These ranges must be tempered with judgment to allow for the limited nature of historical events: not every possible scenario has yet happened, and some have happened so seldom that one can have little confidence that the observed range is fully representative of the possibilities.

Frequency of Occurrence/ Likelihood	**Severity of Incident (or Consequences)**				
	Incidental (1)	Minor (2)	Serious (3)	Major (4)	Catastrophic (5)
Frequent (5)				**High**	**Risk**
Occasional (4)					
Seldom (3)					
Remote (2)	**Low**	**Risk**			
Unlikely (1)					

FIGURE 2-5 Example risk matrix.

to be estimates of actual frequencies of scenarios or the magnitude of their consequences. Note that uncertainty can be represented in the risk matrix by having results span multiple cells rather than being scored in a single cell (NRC 1997).

A number of formats can be used to represent results of quantitative risk analysis. One is the "expected value" of risk. If scenario S_i has a consequence of magnitude C_i and a probability of p_i, then the scenario risk (R_i) is defined as $R_i = p_i * c_i$, and the total risk is calculated by summing over all risk scenarios: $R = \Sigma\, p_i * c_i$. A major drawback of this format is that it masks the potentially important difference between "low probability–high consequence" and "high probability–low consequence" scenarios when they result in the same values for probability times consequence.

A far better method for representation of risk is known as a "risk curve" or "risk profile." The risk curve is developed from the complete set of risk triplets. The triplets are presented in a list of scenarios rearranged in order of increasing consequences, that is, $C_1 \leq C_2 \leq C_3 \leq \cdots \leq C_N$, with the corresponding probabilities. A fourth column is included showing the cumulative probability, P_i (uppercase P), as shown in Table 2-1.

When the points $<C_i, P_i>$ are plotted, the result is the staircase function illustrated in Figure 2-6. Since the scenarios in Table 2-1

TABLE 2-1 Risk Table

Scenario	Probability	Consequences	Cumulative Probability
S_1	p_1	C_1	$P_1 = P_2 + p_1$
S_2	p_2	C_2	$P_2 = P_3 + p_2$
$\vdots$	$\vdots$	$\vdots$	$\vdots$
S_i	p_i	C_i	$P_i = P_{i+1} + p_i$
$\vdots$	$\vdots$	$\vdots$	$\vdots$
S_{N-1}	p_{N-1}	C_{N-1}	$P_{N-1} = P_N + p_{N-1}$
S_N	p_N	C_N	$P_N = p_N$

Source: NRC 1997.

generally are really categories of scenarios, one could argue that the staircase function should be regarded as a discrete approximation of a nearly continuous reality. If a smooth curve is drawn through the staircase, that curve can be regarded as representing the actual risk, and it is the risk curve or risk profile (Figure 2-6).

Often a combination of qualitative and quantitative analyses is needed to establish risk estimates when the problem under analysis is diverse and complex. Indeed, the majority of risk assessments fall

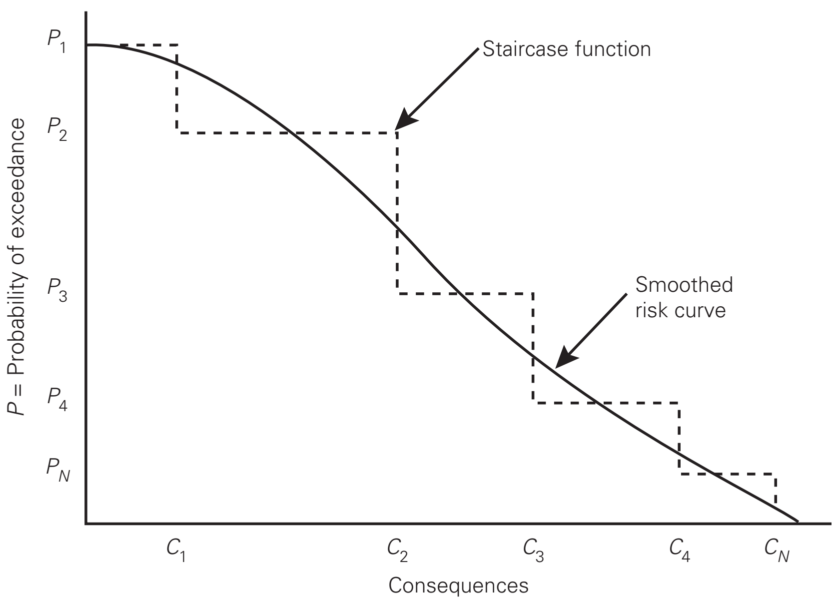

FIGURE 2-6 Risk curve.

(Source: NRC 1997.)

into this category. In some cases, actual numerical values are used to discriminate among different levels of likelihood or consequences expressed with qualitative descriptors (NRC 1997).

The first activity in the actual risk analysis step is the analysis of historical events. In the case of the present study, accidents that have occurred in the Aleutians are of primary concern, and if these historical data were sufficient, they would be all the analysis would examine. Because of special conditions that occur in the Bering Sea, the signature of accidents in that region differs from worldwide averages. However, to ensure that limited data for the Aleutians do not cause the risk analysis to ignore rare, high-consequence events, those data must be supplemented by worldwide data. The most appropriate way to integrate the data is by using Bayes' theorem, as described in Appendix E. In the preliminary assessment, however, results for the Aleutians may be adjusted by using expert judgment, on the basis of information extracted from the worldwide data.

Reviewing historical data on accidents and spills provides a picture of the accident types likely to occur and an indication of the types that pose the greatest risk. To characterize the risks and begin to understand how the likelihood and consequences of spills can be mitigated, it is then necessary to understand the accident scenarios, that is, the series of steps leading up to these dominant accident types. The development of accident scenarios begins with identification of the conditions that affect the progress of the scenarios and limit their consequences. As shown in Figure 2-7, for each ship type (including fuels and cargoes), the analyst asks what causes can lead to various accident categories and subsequent damage.

Qualitative methods (such as checklists, HaZID, and HaZOP) can be used to help identify hazards and scenarios of concern. These methods can also be useful screening tools. Screening is particularly important since hazard identification and accident scenario identification can yield numerous scenarios that could result in losses. Since analyzing all such scenarios in detail may not be realistic or even possible, high-level risk screening may be desirable. Screening allows

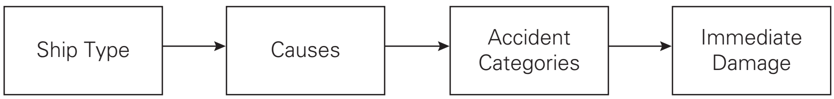

FIGURE 2-7 Simplified accident scenarios.

analysts to review various scenarios and risk controls and safeguards in place and to compare them against broad risk criteria with established thresholds to determine which scenarios require further assessment. The further assessment can be conducted with either qualitative or quantitative methods, again depending on the nature of the information available and the level of precision required. At the same time, it is important to retain the list of screened scenarios. In fact, it is better to think of this process as one of setting priorities, because assumptions used in the screening process need to be tested later in the analysis to ensure that important scenarios have not been set aside. In addition, new information often emerges that challenges early assumptions.

Analysts must expand the potentially important, high-level, simplified accident scenarios with detailed information from the available data sources. To extract the most useful information from the historical record, a model is needed. For this purpose, the committee proposes an extension of the simplified accident scenario model illustrated in Figure 2-7. It begins with the three elements shown in Figure 2-8 that represent the initial or boundary conditions for the scenario: the ship type (including its fuel and cargo); its location in the Aleutian chain; and the conditions, such as sea state and weather, before and during the sequence of events of the accident.

All ship types must be considered; those of importance will surely include tankers, containerships, service and refueling support ships, fishing boats, local commercial ships, and passenger ships. As for locations, the Risk Analysis Team will likely need to break up the areas near the Aleutians into zones mapped onto the sea, identifying areas of similar hazard and sensitivity, such as passes and harbors (see Figure 2-9). Conditions of importance identified by the committee include weather (sea state, freak waves, icing, wind, rain, and fog), traffic, season of the year, and time of day.

Incorporated next are the additional elements identified in the simplified accident scenario of Figure 2-7: the cause, the accident

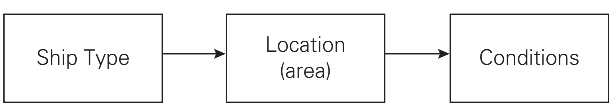

FIGURE 2-8 Initial conditions.

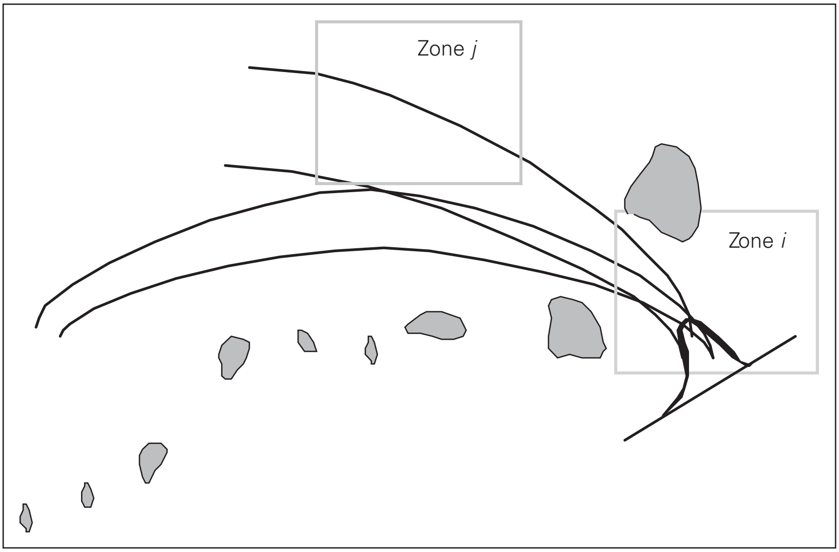

FIGURE 2-9 Illustrative zones in the Aleutians.

category, and the immediate damage. Adding the opportunities for crew/rescuer control, the environmental consequences, and possible remediation yields the basic scenario model for the risk analysis (see Figure 2-10). This model can be used in several ways to facilitate the risk analysis, as described below. The elements of the model can be defined as follows:

- Cause [fire or explosion, flooding, human error, loss of propulsion, loss of steerage, and weather (from the conditions identified earlier)].
- Accident category (drift grounding, powered grounding, collision, allision, structural failure).

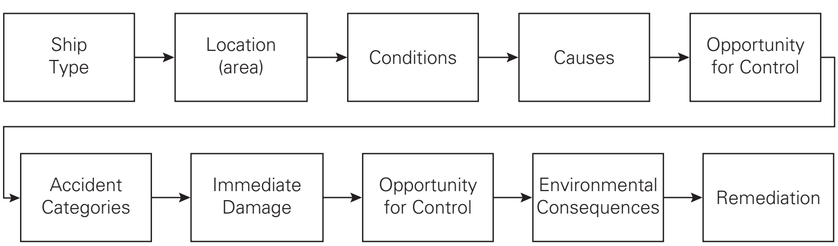

FIGURE 2-10 Basic scenario model for Aleutian shipping risk analysis.

- Immediate damage [spill (material, amount, rate, duration), loss of life (crew and rescuers), physical damage to property].
- Opportunities for control. [Crew and rescuers usually have multiple opportunities to control the accident, and the analysis team must identify and model them. They are grouped into two general types in the basic scenario model: the opportunity to control events (*a*) before the causal event actually becomes an accident and (*b*) after the accident has caused immediate damage but before subsequent consequences accrue.]
- Environmental consequences. (Because of the rare nature of serious spills, modeling is needed to evaluate environmental and subsequent socioeconomic damage; anecdotal evidence is available in the data.)
- Possible remediation (the final opportunity to control long-term losses).

Event analysis proceeds with cataloging of the results of the review of accident records within the framework of the scenario model. For this purpose, a table with headings corresponding to the elements of the scenario model can be used (see Table 2-2). Once analysts have populated the table (referred to as the event database) by using the available data, they will find that many of the cells are empty because of incompleteness in the accident reports. Nevertheless, a variety of useful analyses can be performed:

- Major accident categories can be grouped on the basis of events in the database.

TABLE 2-2 Elements of the Scenario Model

Event	Ship Type and Cargo	Location	Conditions	Cause	Opportunity for Control	Accident Category	Immediate Damage	Opportunity for Control	Environmental Consequences	Remediation
Event 1										
Event 2										

- The frequencies of representative sequences of events through immediate damage can be determined by combining data from the Aleutian events table, the generic (worldwide) table, and expert judgment.
- Pairs of consequences and conditions can be examined, and conditional probability estimates can be developed, such as the likelihood of drift groundings involving bad weather or collisions occurring in passes compared with other locations.

Finally, the basic scenario model provides a useful structure for evaluating and comparing risk control options. Figure 2-11 illustrates how risk control options can intervene at every stage of the scenario. Interventions before the accident occurs are known as "prevention" and are clearly preferred. However, it is impossible, economically and in principle, to prevent every accident. Some unanticipated events will occur, and one must be able to control such events. Moreover, in many cases it is more feasible and economically viable to control an event than to try to prevent it. Therefore, the best approach is to distribute risk control options throughout the scenario, some offering prevention and others providing mitigation of accident consequences (Atwood et al. 2003; DNV 2002; O'Hara et al. 2004; USNRC 1981).

An approach for evaluating competing options qualitatively is to evaluate each option against each stage of the model. In this process, favored solutions must be considered on the same

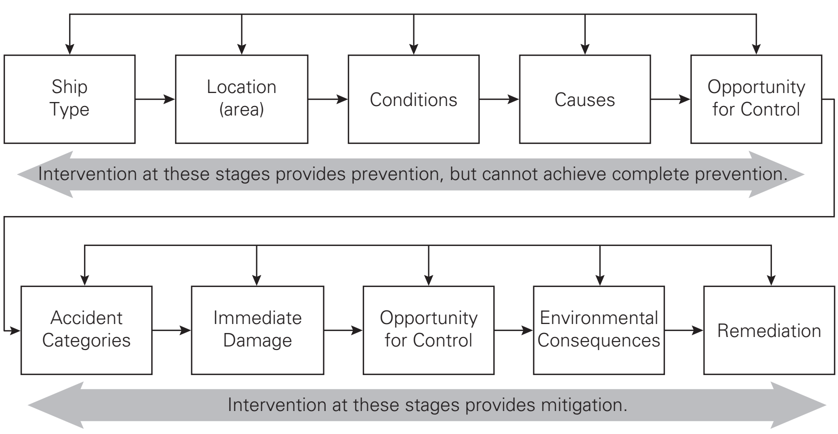

FIGURE 2-11 Risk control can intervene at every stage of the scenario.

basis as all others. Overstated claims must be proved. Table 2-2, based on the scenario model, provides a tool for this evaluation. As each option is considered, analysts ask for which scenarios and where in each the option offers improvement. They then enter in the table the effectiveness of the option versus the stages. Also included are the basis for that claim and the feasibility and practicality of the option and its expected costs. These evaluations can be based on judgment, but it must be informed and documented judgment. Many proposed options can be expected to be seen as offering improvements for similar effects. In such cases, it is likely that only one of the competing options should be instituted. Careful cost–benefit analysis will suggest which one to choose.

Note that after qualitative analysis and preliminary quantitative analysis, it may be possible to select some particularly obvious options for implementation. In most cases, however, more thorough, detailed models and quantification will be required.

RISK ASSESSMENT OF ALEUTIAN SHIPPING OPERATIONS

The approach for the Aleutian Islands risk assessment proposed by the committee encompasses all the steps in IMO's FSA identified earlier in Figure 2-1: hazard identification, risk analysis, risk control options, cost–benefit assessment, and recommendations for decision making. However, the organization and sequencing of the specific tasks necessary to complete these steps need to reflect lessons learned from many previous risk assessments. The progress of the PWS study illustrated many problems that need to be avoided. Risk analysts tend to attack the problem in bottom-up fashion, attempting to perform the best and most complete analysis possible. By the time they make their first attempt to quantify their model, the majority of the available funding has been spent. Many corrections, reframings, and additions are required, but there are no resources to complete the work. Experience has revealed that a phased approach can avoid many of these problems, better focus the detailed analysis effort, and provide useful results at an early stage.

The committee's plan for the risk assessment of Aleutian shipping operations begins with a Phase A Preliminary Risk Assessment that structures the overall problem. It is as complete as possible in formulating the range of possible scenarios, but modeling is limited. The Phase A assessment relies heavily on data analysis and expert judgment. The follow-on Phase B Focused Risk Assessment is aimed at providing careful and detailed comparisons of risk before and after risk control options are applied.

The committee proposes an organizational structure for the risk assessment consisting of four groups or panels—a Management Team, an Advisory Panel, a Risk Analysis Team, and a Peer Review Panel. The Management Team would assume overall responsibility for ensuring that the work is carried out in an effective and useful way. The Advisory Panel would consist of stakeholders and experts who could provide local knowledge and expertise. The Risk Analysis Team would be provided by the contractor. Finally, the Peer Review Panel would provide technical oversight. The four groups would interact to move the project through the risk management process shown in Figure 2-12. Details are provided in Chapters 5 and 6.

The entire risk assessment must encompass the steps outlined in Figure 2-13. The work begins with the Phase A risk analysis, which provides a high-level estimate of the likelihood and consequences of

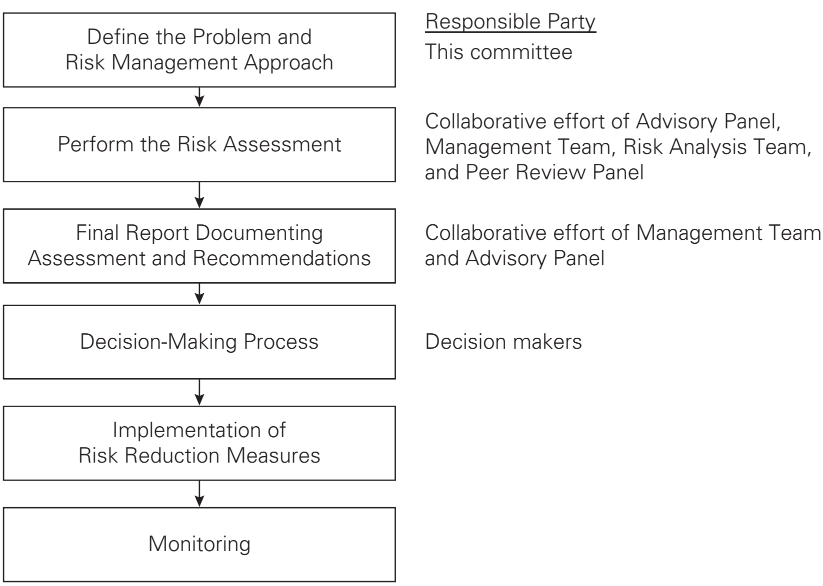

FIGURE 2-12 Steps in the risk management process for the Aleutian Islands.

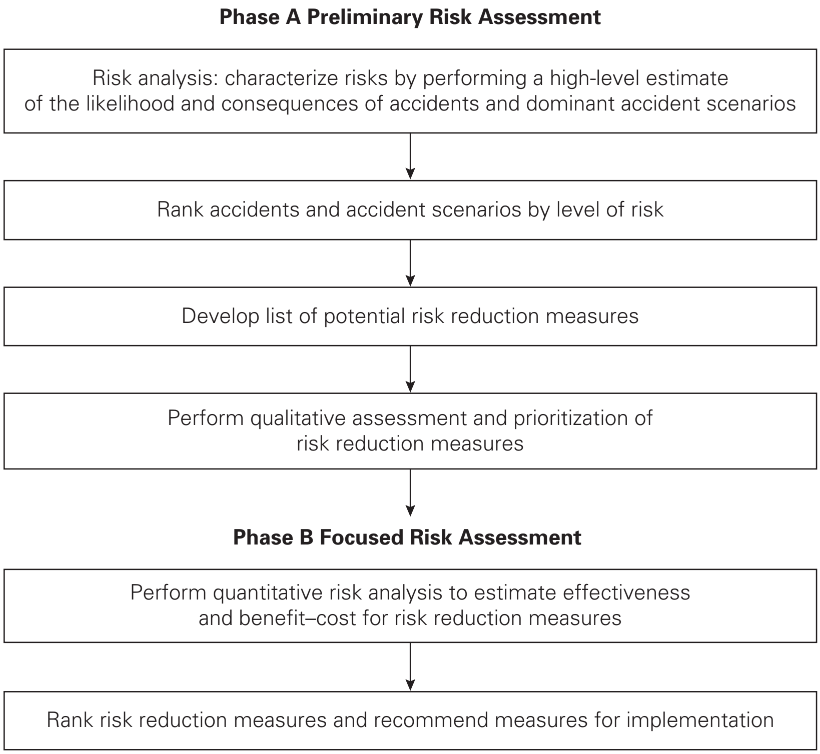

FIGURE 2-13 Steps in the proposed tiered risk management process.

accidents and dominant accident scenarios. This is followed by a ranking of accidents and accident scenarios by level of risk and development of a list of potential risk reduction measures. Next are a qualitative assessment and prioritization of risk reduction measures. In Phase B, detailed analysis provides more rigorous comparisons of risk with and without specific risk control measures. The analysis includes quantitative risk analysis to estimate the effectiveness and benefit–cost of risk reduction measures, ranking of the measures, and the recommendation of measures for implementation. To avoid misleading results, groups of control measures must be examined to ensure that the potential improvements offered by one measure are not already provided by others.

The basic task structure of the proposed risk assessment approach is shown in Table 2-3, which indicates how the Aleutian Islands risk assessment tasks relate to IMO's FSA steps. Phase A includes the

TABLE 2-3 How the Tasks of the Aleutian Islands Phased Risk Assessment Relate to the Steps in IMO's FSA

Task	IMO FSA Step				
	1. Hazard Identification	2. Risk Analysis	3. Risk Control Options	4. Cost–Benefit Assessment	5. Decision-Making Recommendations
Phase A Preliminary Risk Assessment					
1. Traffic Study					
2. Baseline Spill Study					
3. Identification of High-Risk Accidents					
4. Phase A Consequence Analysis					
5. Accident Scenario and Causality Study					
6. Development of Rankings for Accident Scenarios					
7. Development of List of Potential Risk Reduction Options					
8. Evaluation of Risk Reduction Options					
9. Prioritizing of Risk Reduction Measures					
10. Peer Review					
Phase B Focused Risk Assessment: Comparative Analysis of Risk Control Options					
1a. Detailed Risk Comparison: Base Case Versus Option Set 1					
1b. Cost–Benefit Assessment: Base Case Versus Option Set 1					
2a.					
. . .					
Decision-Making Recommendations					

FSA's hazard identification step; the qualitative and initial quantitative portions of the risk analysis step; and preliminary portions of the risk control options, cost–benefit assessment, and decision-making recommendations steps. Upon completion of Phase A, the risk analysts will have identified the major accident categories and estimated their likelihood. The analysts will have defined the full range of scenarios that may be of interest and investigated the fate of a representative set of spills in a representative set of locations along the Aleutian chain. Local experts and stakeholders will have proposed a set of risk reduction options, evaluated their feasibility and potential impacts on each element of the scenarios, and made preliminary recommendations for prioritizing the options.

This approach will ensure that a well-defined subset of the full risk assessment with a closely controlled scope is performed initially. Phase A will provide useful preliminary results and a sound basis for scoping future work while retaining a substantial portion of the budget for specific analyses. Phase B is expected to be performed in a series of follow-on tasks aimed at refining the Phase A results for evaluation of specific risk reduction options.

Organizing the steps of a risk assessment in a series of phases is a well-tested approach for improving the quality and cost-effectiveness of the endeavor. Careful structuring of tasks is required to ensure that the initial phase provides useful information, does not mask important aspects of the problem, and does not bias future work (Atwood et al. 2003; DNV 2002; O'Hara et al. 2004).

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Abbreviations

ABS	American Bureau of Shipping
CCPS	Center for Chemical Process Safety
DNV	Det Norske Veritas
IMO	International Maritime Organization
NRC	National Research Council
PWS	Prince William Sound
USNRC	U.S. Nuclear Regulatory Commission

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CHAPTER 3

The Aleutian Islands

FRAMING THE ISSUES

The Aleutians are a chain of small volcanic islands forming an island arc in the North Pacific Ocean, extending about 1,200 miles westward from the Alaska Peninsula toward the Kamchatka Peninsula in Russia. In addition to their biological, cultural, and economic significance, these islands have long been geopolitically important to the United States, most notably during World War II, but more recently with the advent of the global shipping industry. Today the Aleutians are located along the shortest transportation route for vessels traveling between northwestern North America and Asia (see Figure 3-1). Along that route, Unimak Pass in the eastern Aleutians is heavily used by vessels traveling between ports such as Vancouver and Seattle and those in East Asia, such as Shanghai and Yokohama. Although navigational hazards exist near the islands and severe weather and sea conditions are common, the pass's main channel is relatively wide, deep, and unobstructed. More than 4,500 vessels now traverse Unimak Pass annually—a number that has steadily risen in recent years and is anticipated to continue to grow with increases in vessel traffic in Asia and North America, including the Arctic as well as the Aleutian Islands.

The risk posed to people and the environment by shipping in the Aleutians is greatly influenced by the region's unique setting,

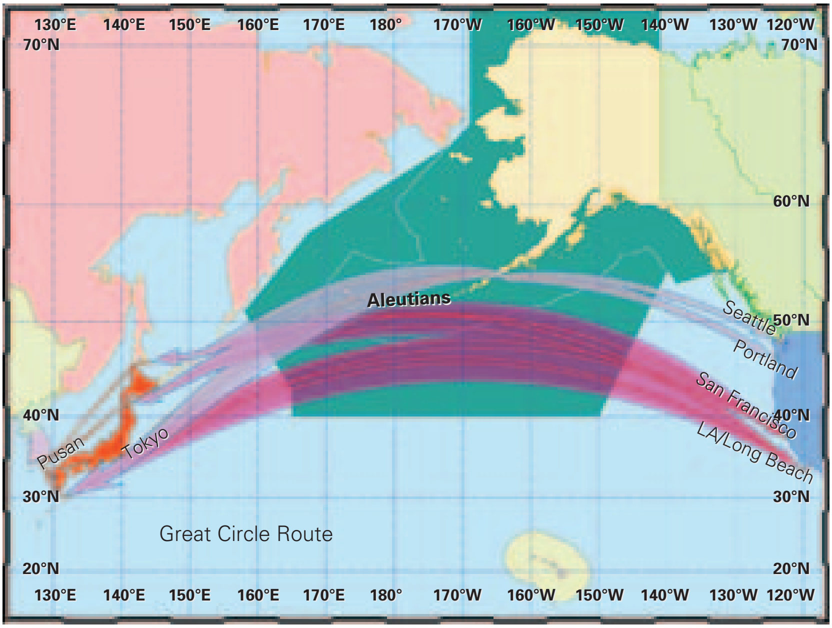

FIGURE 3-1 Map depicting vessel transits along the northern and southern North Pacific Great Circle Route. (The light blue line indicates an exclusive economic zone.)

(Source: Nuka Research and Planning Group 2006.)

harsh environment, and difficult operating conditions. Such factors as geography, climate, regulatory regime, population and its cultural base, ecology, and industrial activities combine to define this special operating system. Assessing the risk posed by shipping operations requires a full understanding of these factors and conditions as they are at present and as they may change over time.

This chapter reviews the data and information available to the committee concerning these topics and provides an initial overview of how these issues can be framed within a risk assessment of shipping operations in the Aleutians. Discussed in turn are the region's environmental and ecological assets; its economic assets; its cultural and social values; its geology, oceanography, and climate; and its supporting maritime infrastructure.

LOCAL ASSETS AND THEIR VULNERABILITY[1]

Environmental and Ecological Assets

The Aleutian Islands archipelago comprises more than 200 islands covering an area of about 1.1 million hectares. Formed by volcanic action, the islands today are still characterized by regular, frequent volcanic and seismic activity. Many of the chain's 57 volcanoes (13 of which exceed 1,500 meters in height) are active. Most of the islands are mountainous, with numerous lakes, ponds, and streams. Plant life is diverse and characterized by species from both North America and Eurasia.

The Aleutian Islands have long been recognized for their importance as a haven for biological diversity. As early as 1913, the Aleutians were designated by President William Taft as the Aleutian Islands Reservation. The reserve was created primarily for the conservation of seabirds and sea otters, the latter having been nearly extirpated as a result of the fur trade throughout the North Pacific. Pioneering biologists such as Olaus Murie and Bob "Sea Otter" Jones conducted early seminal studies that still guide science and conservation in the region today. In 1980 the wildlife reservation of the Aleutians was combined with several others in Alaska, establishing the Alaska Maritime National Wildlife Refuge.

The islands' important role in the preservation of natural and cultural heritage has been recognized through other designations:

- More than 60 percent of the refuge is considered wilderness according to the Wilderness Act of 1964. "Wilderness" designation in this context can be afforded to areas of ecological, geological, historical, scientific, or other value.
- In 1976, the World Conservation Union, now known as the International Union for Conservation of Nature, designated the Aleutian Islands an International Biosphere Reserve, a status conferred under the aegis of the United Nations.
- Several sites within the Alaska Maritime National Wildlife Refuge have been designated as natural or historical under the National Park Service's National Natural and Historical Landmark Programs.

[1] The committee gratefully acknowledges the information on Aleutian history and culture provided by Poppy Benson of the Alaska Maritime National Wildlife Refuge and on invasive species provided by Dave Aplin of the World Wildlife Fund.

- The National Audubon Society has identified more than 20 sites in the Aleutians and neighboring islands as Important Bird Areas, an international designation used in more than 150 countries to indicate that an area harbors bird species of special concern, species with restricted home ranges, and species that are vulnerable because they exist in high concentrations and therefore could suffer significant negative impact from a single event.
- The World Wildlife Fund and the Nature Conservancy of Alaska consider several regions within the Aleutians to be high conservation priorities because of their global importance in harboring marine mammals, seabirds, and unique island ecosystems. These areas include the Golden Triangle, the marine and island ecosystems that extend from Unalaska and the Bogoslof Islands to the Pribilofs and Izembek Lagoon.
- One of the unique aspects of the Alaska Maritime National Wildlife Refuge is the inclusion of international research and conservation in its mission statement. This is particularly important given the biogeographical proximity of the Aleutian Islands to Russian waters and their inclusion of Russia's Commander Islands Biosphere Reserve, an archipelago that makes up the westernmost extent of the Aleutian chain.
- In recognizing the importance of the Aleutian Islands, the North Pacific Fishery Management Council has developed a pilot Fishery Ecosystem Plan for the region. The goals are to integrate data, identify ecosystem indicators that can be used to evaluate the health of the Aleutians over time, and provide a proactive tool for setting management goals and understanding cumulative effects (North Pacific Fishery Management Council 2007).

The islands' many outstanding ecological features include more than 30 species of nesting seabirds, numbering approximately 40 million—a figure representing 80 percent of all seabirds found in North America. Buldir Island alone is considered the most diverse seabird breeding area in the northern hemisphere. The Aleutian chain also provides important wintering areas for such species as the emperor goose and whiskered auklet, which winter almost exclusively in the Aleutians.

Hundreds of thousands of marine mammals breed on the islands, including endangered Steller sea lions and endangered northern sea otters, and together, Bogoslof and the Pribilof Islands host the world's largest rookeries for northern fur seals. Other marine mammals that traverse the rich waters surrounding the Aleutians include various cetacean species, such as the sperm, humpback, Baird's beaked, fin, killer, and Stejnegers' beaked whales. For many marine mammals, one of the islands' passes, Unimak Pass, provides a critical migratory corridor between the North Pacific Ocean and the Bering Sea. Indeed, Unimak Pass is a veritable marine mammal superhighway, used by humpback whales, sea lions, fur seals, and many other wildlife species moving between the two water bodies.

Few areas in the world match the Aleutians in marine productivity. Thanks to its proximity to the Bering Sea "green belt"—a region of high primary productivity along the Bering Sea shelf break—and the bathymetry of the Bering Sea, the Aleutian chain reaps the benefits of tidal mixing of cold nutrient-rich waters and high levels of phytoplankton and zooplankton, building blocks of the marine food web.

The Aleutians' high species richness and productivity are evident in numerous habitat types that are both representative of and unique to the Bering Sea. Among them are rich eelgrass beds and kelp forests. Just west of the Aleutians, on the northern side of the Alaska Peninsula, Izembek Lagoon is home to one of the world's largest expanses of eelgrass, a marine grass that provides substrate and shelter for invertebrates and fish and is an important source of nutrition for waterfowl.

In the western Aleutians, scientists have recently invested special effort in documenting the presence of cold-water corals. In so-called "coral gardens" are more than 100 species known to form a rich undersea habitat for numerous fish and invertebrates (Stone 2006). In fact, current science indicates that the Aleutians may be home to the highest species diversity of cold-water corals, with at least 25 species of hydrocorals and gorgonians being endemic to the region (occurring nowhere else in the world) (Heifetz et al. 2005). The Aleutians' coral gardens provide shelter for rockfish and shrimp and breeding habitat for species such as golden king crab. Other species assemblages, such as sponges, anemones, snails, and sea stars, often accompany coral gardens. New species are continually being discovered in the Aleutians. In summer 2007, during an expedition surveying 1,000 miles in the western region, from Attu to Tigalda Island in the Aleutian chain, two species of anemone thought to be new and one new kelp species—named Golden V Kelp for its v-shaped lobe—were discovered (*Dutch Harbor Fisherman* 2007). In June 2007, because of concern about potential damage to the western Aleutian corals by bottom-trawling fishing gear, the North Pacific Fishery Management Council closed 180,000 square miles in the western Aleutians to this form of fishing.

The Aleutians are also home to important ecological processes that sustain the richness of the waters surrounding the islands, as well as Alaska's cold and productive marine waters. The islands' passes, for example, channel the flow of nutrient-rich water to the Bering Sea and provide important forage for seabirds and mammals (Stabeno et al. 2005). Island passes, Unimak Pass in particular, also serve as marine mammal corridors for whales and pinnipeds traveling between the North Pacific Ocean and the Bering Sea each year.

Economic Assets

The ecological state of the Aleutians is tied in many ways to the health of the region's economy. The Bering Sea and Aleutian Islands are known for harboring some of the richest fish stocks in the world, including walleye pollock, Pacific Ocean perch, Pacific cod, Pacific herring, halibut, sablefish, pelagic and demersal rockfish, Atka mackerel, and salmon. The harvesting of these fish, particularly pollock, forms the basis of a vibrant economy that generates approximately $2 billion per year. Given the region's location on the North Pacific Great Circle Route and as the center of one of the most productive fisheries in the world, much of its economy is based on fishing, processing, fleet services, and shipping (ADEC 2007). At the center of this industry is Dutch Harbor, a port on the island of Unalaska. In 2007, for the 18th year in a row, Dutch Harbor was the leading port in the United States in terms of volume of fish landed (brought into the docks), while it ranked second in value, at $162 million, behind New Bedford, Massachusetts (Welch 2007). The communities of Atka and Adak are also developing their harvesting and processing capacities, respectively. In 2005 the Aleutian Islands region contributed 216 million pounds of fish, representing an estimated ex-vessel value (i.e., the value before processing) of $60 million (North Pacific Fishery Management Council 2007).

In 2006 there were 7,000 active fishing permit holders in Alaska, at least 2,876 of whom had Alaska wage and salary employment in addition to their fish harvesting jobs. Gross fisheries earnings for this group exceeded $285 million, while wage and salary earnings were $71.5 million (Wink et al. 2007). Although it is difficult to determine how many of those people are located in the Aleutian Islands, 80.5 percent of the private-sector workforce[2] (27.4 percent in fish harvesting and 53.1 percent in seafood processing) in the Aleutian and Pribilof Islands region was employed in the seafood industry in 2005.

Cultural and Societal Values

The early ancestors of the Unangans, or Aleuts, came to the Aleutian Islands more than 11,000 years ago. They built villages along the seacoast and developed intricate societies supported by the abundant marine mammals, fish, seabirds, marine invertebrates, and seaweed. Their population numbers reached between 15,000 and 25,000. Evidence of their ancient villages still exists on nearly every island. Today, Aleut villages are found on Atka, Adak, Umnak, Akatan, and Unimak Islands in the Aleutians and on St. Paul and St. George in the Pribilof Islands, as well as on Bering Island in Russia's Commander Islands.

The Russian "voyages of discovery" were launched with the first expedition of Vitus Bering in 1741, as the Russian empire sought to explore and exploit resources in the easternmost reaches of the Eurasian continent. With the discovery of plentiful fur-bearing mammals, such as sea otters and fur seals, a wave of fur traders soon swept the area, bringing disease and subjugation to the Aleuts and colonizing some of the islands as part of Russian America. The traders wantonly overharvested sea otters, and they introduced foxes to many of the islands, which would have a negative impact on the islands' bird life for the ensuing two centuries. Human societies were also destroyed: by the 1780s the Unangan/Aleut population had declined to about 2,000.

In 1867 the Aleutians were included as part of Russia's sale of Alaska to the United States. A Russian presence remained in Aleut communities, particularly through the Russian Orthodox Church, to which many local people had been converted during the period of Russian dominance. Today Aleut/Unangan communities throughout

[2] Workforce refers to the number of workers employed in an industry for any amount of time during the year.

the chain participate in commercial fisheries and other industries while maintaining customary and traditional subsistence practices. Communities throughout the Aleutian and Pribilof Islands harvest a variety of marine resources from the rich waters of the Bering Sea, including Steller sea lions and northern fur seals, sea ducks, seabird eggs, and other products. In addition to traditional activities, Aleutian and Pribilof residents participate in the Bering Sea fishery, a centerpiece of the region's economy. The community-based halibut fishery, in which residents directly participate through an Individual Fishing Quota system, is a significant income generator. Pribilof and Aleutian Island communities also participate in the North Pacific fishery through the Community Development Quota program. Shareholder profits are administered by the Central Bering Sea Fishermen's Association on St. Paul Island and the Aleutian Pribilof Islands Community Development Association, which represents St. George Island and five communities in the Aleutians.

Another influential factor in the islands' history and culture is the legacy of World War II. During the war, the Japanese swept into the Aleutians, bombing Dutch Harbor and seizing the islands of Kiska and Attu. Allied forces fought the long and bloody Aleutian Campaign to recapture the islands. The military remained after the war, later testing three underground nuclear bombs on Amchitka Island. Active bases continued to exist at Shemya and Adak through the Cold War into the 1990s. Relicts of the Cold War and World War II, including guns, buildings, and debris, remain on many islands. Isolation has prevented the degradation of such sites at Kiska and Attu, which are now considered some of the best-preserved World War II sites in the world.

GEOLOGY, OCEANOGRAPHY, AND CLIMATE

Geology and Oceanography

The Alaskan archipelago is a chain of volcanic islands along a seismic subduction zone and thus experiences frequent volcanic activity and earthquakes. The volcanic activity has been known to change water depths substantially and has been responsible for undersea mountain ranges and a deep ocean trench.

The productivity discussed in the previous section can be attributed in large part to the nutrient-rich currents that are driven northwards along the west coast of Canada and southeast Alaska, join the Alaskan stream as it follows the Continental Shelf break westward past Kodiak Island and along the southern side of the Aleutians, and finally flow through the oceanic passes into the Bering Sea. The inflow through the Aleutians creates an eastward flow along the north side of the islands, known as the Aleutian North Slope Current, and is the source for the Bering Slope Current. The water depth through Near Strait is about 2,000 meters, and the inflow of the Alaskan Stream through this passage provides most of the mass needed for upper-ocean circulation in the western Bering Sea (NOAA 2000). Figure 3-2 depicts the current flow in the Aleutian Islands region.

The tides along the southwestern end of the Alaskan Peninsula are semidiurnal, while those from Unimak Island westward throughout the entire Aleutian chain are a combination of diurnal and semidiurnal. The maximum tidal range at Cold Bay is around 8 feet, while the entire Aleutian Island chain has a range of about 4 feet.

Water usually flows with the channel (i.e., southeast to northwest and vice versa). A current of 3 to 5 knots is common in Unimak Pass,

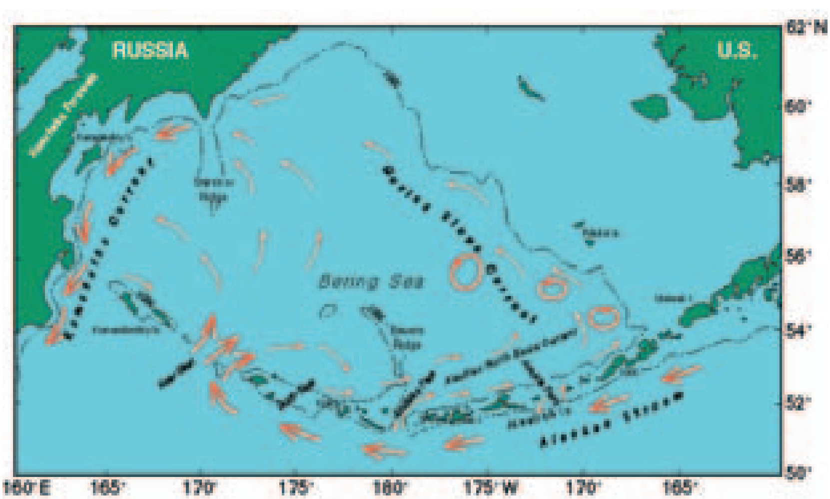

FIGURE 3-2 General circulation through and around the Aleutian Islands.

(Source: Presentation to the committee by J. Whitney, October 29, 2007.)

but currents greater than 7 knots do occur. Unimak Pass is 10 miles across, with a 4-mile safety fairway. The sea bottom is rocky outside of fairways (e.g., Unimak Pass and Dutch Harbor). There is a limiting draft of 42 feet from Iliuliuk Bay into Dutch Harbor caused by a bar near a sea buoy (USCG 2006).

On the north side of Unalaska Island—in the vicinity of the M/V *Selendang Ayu* incident—as in other remote areas in the Aleutians, "little is known of how currents, open ocean swells, wind waves, and bathymetry/geography interact." This lack of information will hinder future efforts to respond to accidents until more is learned (Scott et al. 2008, 5).

Climate

The Aleutian Islands are characterized by moderate and fairly uniform temperatures and heavy rainfall. For example, the average annual temperature in Unalaska is about 38°F–30°F in January and about 52°F in August.

> The highest and lowest temperatures recorded on the islands are 78°F and 5°F, respectively. The average annual rainfall is about 80 inches and Unalaska has about 250 rainy days per year. Wind speed is typically high in the Aleutians. A [typical] storm track along the Aleutian Island chain and all of the coastal area of the Gulf of Alaska exposes these parts of the state to a large majority of the storms crossing the North Pacific, resulting in a variety of wind problems. Direct exposure results in the frequent occurrence of winds in excess of 50 mph during all but the summer months. In the western end of the Aleutian Islands, winds have reached an estimated 139 mph (estimated because the wind recorder pen could only record up to 128 mph). Wind velocities approaching 100 mph are not common but do occur, usually associated with mountainous terrain and narrow passes. For years, strong winds have taken their toll of both merchant and fishing vessels. (www.wrcc.dri.edu/narratives/ALASKA.htm)

Poor weather in the Aleutian region (e.g., rain and sleet) commonly reduces visibility to half a mile 15 to 20 percent of the time, and foggy conditions persist from late spring through early fall. Fog usually clings to islands on the Bering Sea side more than to those on the Pacific side.

Each year from late summer through early spring sees semipermanent low pressure in the Aleutians, causing difficult sea conditions and resulting in the storm season. "Low pressure systems that develop over the western Bering Sea (off the coast of Eastern Siberia) often track east along the Aleutian Islands before impacting mainland Alaska. Storms, especially in the winter, are characterized by weather conditions that are extremely variable over very short time periods and distances" (Scott et al. 2008, 2). Weather conditions can change drastically "from sunny to snowy and from calm to hurricane-force winds, all within a few hours" (Scott et al. 2008, 2) and are known to change radically within a quarter mile. The impact of severe weather on the safety of ship operations was emphasized in a number of presentations to the committee.

SUPPORTING MARITIME INFRASTRUCTURE

Most of the infrastructure in place to monitor climate, vessel traffic, and rescue and salvage operations is centralized in Dutch Harbor, Unalaska, though infrastructure associated with fishing has increased on Adak Island in recent years. The National Oceanic and Atmospheric Administration (NOAA) has installed several offshore weather/wind sensory buoys, but the Physical Oceanographic Real-Time System is not installed in this area. NOAA invests many resources in trying to understand water circulation in the Aleutian region and has conducted numerous drifter studies to obtain data on current trajectories. (See Figure 3-3 for examples of some drifter trajectories in the region.) These studies use drifter buoys—buoys weighted down so that their movements are driven by the water currents and minimally influenced by the wind. Until relatively recent years, only two moored buoys were in place in the Aleutian Islands because of many factors, including freezing spray and frequent strong current speeds through the passes that made the buoys difficult to maintain.

There are tide and current tables, including Coast Pilot; tide height sensors are installed at Sennett Point and Unimak Pass; and tugboats currently report sea conditions by using standardized forms. Unalaska Island has a handful of permanent observational platforms; however, all instrumentation is located in the vicinity of Dutch Harbor, some 50 miles away from the site of the M/V *Selendang Ayu* incident—on "the opposite side of the island from the incident in a completely different meteorological and oceanographic regime"

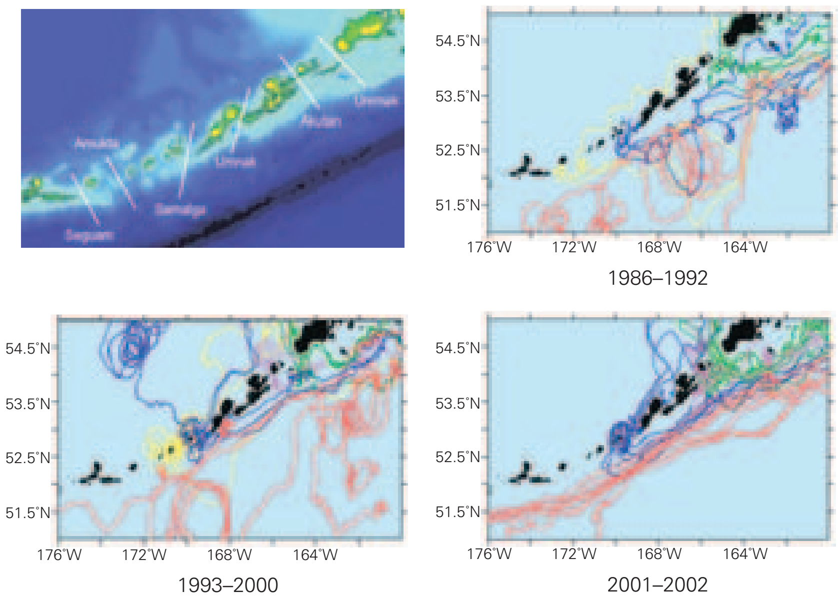

FIGURE 3-3 Drifter trajectories during three different time periods over 17 years, using 53 drifters. Sixty percent of the buoys went through either Unimak Pass or Samalga Pass; 26 percent did not go through any passes.

(Source: Presentation to the committee by J. Whitney, October 29, 2007.)

(Scott et al. 2008, 2). Weather monitoring is also provided by RADARSAT-1, a polar-orbiting satellite with high-resolution images (about 0.1 km) that offer "good indicators of surface wind speed and direction. Because RADARSAT utilizes surface roughness to estimate wind information, RADARSAT could also provide high resolution insight into the extent of any oil spill because oil tends to minimize surface roughness relative to ocean surfaces that are not oil covered" (Scott et al. 2008, 5).

In recent years, the loss of power on commercial ships, leading to drift groundings, has been identified as a frequent cause of major oil spills; therefore, a number of U.S. states have established prepositioned rescue tugs. In terms of capacity for rescue and oil spill response in the Aleutian region, however, the physical infrastructure needed to respond to large vessels in distress along the North Pacific Great Circle Route—including Unimak Pass—is generally minimal and is insufficient under severe weather conditions. Dutch Harbor is the only commercial port in the Aleutians with facilities suitable for large vessels. However, only small harbor tugs are permanently stationed there. In 2004, during the M/V *Selendang Ayu* accident (near Dutch Harbor), none of the rescue vessels that were able to reach the scene [a U.S. Coast Guard (USCG) cutter and two commercial towing vessels] were capable of rendering needed assistance because they were too small and had limited towing power. Indeed, USCG has no tugs capable of assisting large vessels in distress. This is a long-standing problem in the region, and various stakeholders have strongly advocated upgrading the rescue tug capability in the Aleutians for as long as the need has been recognized.

USCG has a presence in Dutch Harbor and provides valuable safety oversight and communications capability for the region, especially with respect to fishing and commercial vessels calling at Dutch Harbor and the substantial maritime activity based in this port. USCG does not, however, operate any vessel traffic monitoring or management system for commercial ships transiting nearby Unimak Pass or for foreign vessels in general using the Great Circle Route through the Aleutian region.

The Alaska Marine Pilots—licensed state pilots whose primary duty is to maintain the safe navigation of a vessel at all times while in transit or maneuvering in compulsory pilotage waters—also have a base in Dutch Harbor. There they have the capability to track vessels through a link to automatic identification system stations. This capability helps them communicate with and follow vessels with which they work during port calls to Dutch Harbor. They do not have the authority to manage traffic in Unimak Pass, but they have developed some proposals to that effect and could be consulted about how such a capability might operate. The general rule for determining the boundaries of compulsory pilotage in the Aleutian Islands is consistent with that for other regions of Alaska. Pilotage is compulsory at all entrances from seaward to Alaska bays, sounds, rivers, and straits where the passage is within 3 nautical miles of the shore. Vessels requiring a licensed state pilot include those that are of foreign origin, those over 300 gross tons that are registered in the United States, and those over 65 feet long that are propelled by machinery. There are exemptions for towing vessels; Canadian naval vessels; U.S. and Canadian fishing vessels; pleasure craft of U.S. registry; and vessels engaged in coastwise trade between Alaska, Hawaii, and Canada.

Other commercial assets for emergency response are also stationed in Dutch Harbor. A local salvage firm, Magone Marine Service, Inc., has operated in the harbor since 1978 and performed many valuable response operations for casualties involving fishing vessels, tug-barges, and cargo vessels; however, it, too, lacks the assets needed to assist large commercial ships in distress (see Appendix G). Recognizing the need for additional response assets, local authorities and industries in Dutch Harbor developed an Emergency Towing System (ETS) in 2007 that is now located in Unalaska (see Box 3-1). The

BOX 3-1

Dutch Harbor ETS

The ETS is described as follows:

> Following the near grounding of the *Salica Frigo* on March 9 [2007], the Mayor of Unalaska convened a Disabled Vessel Workgroup to discuss issues and proactive solutions, which prompted the ETS workgroup. The goal of the workgroup is to develop an emergency towing capability for disabled vessels in the Aleutians subarea utilizing locally available tugboats and an emergency towing system. Emergency towing equipment and trained personnel stationed in Unalaska will decrease response time and may preclude a disabled vessel from grounding.
>
> The ETS consists of a towline capable of towing a distressed vessel, a messenger line to assist in deploying the towline, a line-launcher, a buoy, and chaffing gear. The ETS may be deployed to a disabled ship from the stern of a tugboat or airdropped to the deck of the ship via helicopter. Two ETS will be purchased to cover most vessels found in the Aleutian Islands. The City of Unalaska has purchased a system suitable for vessels up to 50,000 DWT and the Alaska Department of Environmental Conservation is purchasing a system capable of towing vessels greater than 50,000 DWT.

Source: Aleutians Emergency Towing System for Aleutians, Alaska. www.dec.state.ak.us/spar/perp/aiets/home.htm.

ETS is deployable from either a rescue vessel or a disabled vessel and has been tested in local exercises. It is a much-needed interim measure, but local stakeholders do not consider it a substitute for a large, capable standby rescue tug (committee meetings in Dutch Harbor, November 1–2, 2007, with mayor and city council of Unalaska, Alaska Marine Pilots, Magone Marine). Furthermore, while innovative and commendable, the system is intended to be deployed primarily in Dutch Harbor and therefore is geographically limited in its application.

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Abbreviations

ADEC	Alaska Department of Environmental Conservation
NOAA	National Oceanic and Atmospheric Administration
USCG	United States Coast Guard

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CHAPTER 4

Vessel Traffic, Accidents, and Spills in the Aleutians

This chapter summarizes available historical information on vessel traffic, movement of hazardous goods, accidents, and spills in the Aleutian region. These data, while not all-inclusive, serve as a starting point for the committee's recommended Phase A Preliminary Risk Assessment. This chapter also reviews the sources of these data, the quality and reliability of the data, and the potential availability of additional data for use in future risk assessment efforts. Finally, the chapter summarizes the regulatory framework for navigation in the Aleutian region.

VESSEL TRAFFIC

Vessel Types

A variety of vessels operate in the Aleutian Islands, ranging from small local supply barges, to vessels associated with the fishing trade, to cargo vessels transiting the area to or from Pacific Coast ports. For purposes of a risk assessment of shipping operations in the Aleutians, this vessel traffic can be divided into two broad categories.

The first category results from the substantial and growing maritime trade between the United States and Asia. Many of the vessels trading between northern Asia and the northern Pacific Coast ports of the United States and Canada follow the Great Circle Route through Unimak Pass at the eastern end of the Aleutian Islands chain. The pass is just west of Unimak Island, 1,300 miles west of Juneau and 800 miles southwest of Anchorage. The vessels involved in this trade are a mix of large commercial ships classed as containerships, bulk carriers, car carriers, tank vessels, and others. They are mainly foreign-flagged and on innocent passage through these waters.

Weather, distance, and other factors combine to influence the most efficient route chosen by shippers when voyages are planned. According to the latest tracking data available (discussed in detail below), about 4,500 large commercial vessels transit Unimak Pass annually. About 3,600 of these vessels are westbound because the majority of eastbound vessels follow more favorable currents by using the route south of the Aleutians. Although similar tracking data are lacking for the southern route, it is assumed for present purposes that the number of vessels traveling in each direction is equal; thus the total number of large commercial vessel transits in both directions would be about 7,200 annually.

The second category of vessels of interest to a risk assessment of Aleutian shipping operations includes local fishing vessels and supply, work, or service vessels calling on Alaskan ports. Vessels in this category are smaller than those in the first category, carry less fuel and cargo, are typically on shorter voyages, and are usually of U.S. registry. For example, 400 to 500 fishing vessels operate in and around the Aleutians.[1] Also in this category are numerous ferries, cruise ships, tugs, and barges. Fishing vessels operate mainly out of Dutch Harbor; local tug–barges, small cargo vessels, and work boats operate out of either Dutch Harbor or other, smaller Aleutian ports in addition to making up some north–south traffic to and from more distant Alaskan locations.

[1] Many of these vessels operate out of Dutch Harbor and typically make two or more transits (two transits is one round-trip) from Dutch Harbor to the fishing grounds each season.

Volume of Traffic

A comprehensive review of vessel traffic in the Aleutian region through mid-2006 can be found in a report prepared for the state of Alaska by Nuka Research and Planning Group (2006). This report summarizes commercial and local vessel transits through Unimak Pass by using the first 9 months of U.S. Coast Guard (USCG) data from recently installed automatic identification system (AIS) tracking stations. It also estimates fishing vessel traffic by using data from the National Marine Fisheries Service fisheries observers and summarizes USCG data on casualties and Alaskan data on oil spills from vessel accidents. As an aid to estimating the future risks of spills, the report calculates the volumes of oil carried by the various types of commercial vessels that use the Great Circle Route through the Aleutians, thereby estimating the volumes and types of oil moved through the region.

To supplement the Nuka report, the committee requested and received from USCG 2 years of AIS vessel tracking data for Unimak Pass (covering fiscal years 2006 and 2007, and thus expanding the Nuka data set) (USCG 2007). The data indicate about 3,500 vessel transits through the pass from October 1, 2005, through September 30, 2006, and about 4,500 from October 1, 2006, through September 30, 2007.

Table 4-1 shows the types of vessels that make up the total for fiscal year 2007—the two largest categories being containerships (40 percent) and bulk carriers (35 percent). The AIS data include detail on each vessel tracked, including its name, flag, port of departure, and date and time of transit, that could be used to investigate other characteristics and historical data on these vessels from public sources. The following are some additional aspects of the AIS data (USCG 2007):

- Among the 4,470 transits of large commercial vessels through Unimak Pass following the Great Circle Route in fiscal year 2007,
  - 3,580 vessels were westbound (85 percent);
  - 890 vessels were eastbound (15 percent);
  - 3,130 vessels were bound to or from U.S. ports (70 percent); and
  - 1,340 vessels were bound to or from Canadian ports (30 percent).

TABLE 4-1 Vessels Transiting Unimak Pass, October 1, 2006, Through September 30, 2007

Vessel Type	Number of Vessel Transits[a]
Containerships	1,800
Bulk carriers	1,550
Car carriers	300
Reefers	175
General cargo ships	175
Chemical tankers	125
Crude and product tankers	40
Liquid natural gas and liquid petroleum gas tankers	40
Wood chip carriers	50
Roll-on/roll-off	50
Other	165
Total	4,470

[a]Numbers are adjusted for missed days and rounded up.

Source: USCG 2007.

- The number of transits of vessels involved in local trade tracked in and around Unimak Pass in fiscal year 2007 was 1,720 (1,435, or 80 percent of the total, were fishing vessels[2]).

During fiscal year 2007, AIS was operational and appeared to be tracking vessels transiting the pass about 98 percent of the time. Although a few reports of noncompliance with the AIS carriage requirements were received, the actual rate of compliance is unknown. Since large commercial vessels transiting this route call on both U.S. West Coast and Canadian ports, efforts to learn more about them or to exercise port state control over their operations would have to involve both U.S. and Canadian authorities. In contrast, the roughly 1,700 local vessel transits are mainly U.S.-registered fishing vessels, so USCG can exercise its authority over them more readily, and additional particulars on their operations may be available from U.S. authorities.

[2] This is the number of fishing vessel voyages that are tracked by AIS in the region covered. It could be any number of individual vessels making any number of transits each during the year. However, not all fishing vessels are equipped with AIS transponders; thus, the actual number of fishing vessel transits is much larger than that captured in these data.

Additional vessel traffic data could be collected given further time and effort. USCG continues to collect and analyze AIS data for Unimak Pass on a regular basis—a third year of such data will be available in October 2008, facilitating efforts to determine trends over time and project future traffic patterns. In addition, more AIS stations could be installed to track vessels on the southern route or farther along the Aleutian chain. And, as noted in Chapter 3, in 2009 a worldwide long-range identification and tracking (LRIT) system for ships will become operational and may supply further useful data.

Finally, several other types of vessels may operate in or transit the Aleutians in the future with the development of the oil and gas businesses. They include offshore supply vessels, offshore drilling units, seismic exploration vessels, and anchor handling tugs. The risk assessment would need to account for these and other additions to vessel traffic over the assumed time period.

MOVEMENTS OF OIL, CHEMICALS, AND OTHER HAZARDOUS GOODS

Cargo Carried

Since reports on vessel traffic based on AIS data identify ship types and names, one could estimate the amounts and types of fuel oil carried, as well as possible cargoes of petroleum and other hazardous materials. In its report, Nuka Research and Planning Group (2006) estimates fuel oil carried by certain vessel types; the report also totals chemical tankers and liquefied natural gas carriers, oil barges, and so forth and estimates the materials they carry. According to the report, tankers may carry, on average, 400 million gallons of oil as cargo and fuel, while large containerships and bulkers typically carry 1.6 million and 0.5 million gallons of oil as fuel, respectively. The fuel used varies with the type of vessel: large commercial vessels typically use heavy residual oils (thick oils that persist in the environment), while fishing vessels, tugs, and the like generally use diesel fuel, which is lighter and more volatile and evaporates rapidly but is more toxic when released. [For a detailed examination of the nature and impact of releases of petroleum (crude oil and the products refined from it) to the environment, see *Oil in the*

Sea III: Inputs, Fates, and Effects (NRC 2003)]. More accurate estimates of the amounts and types of oil carried as cargo or fuel by vessels transiting the Aleutians can be derived from AIS data.

While data on operational discharges from vessels transiting through the Aleutians are not readily available at present, they could perhaps be estimated by using worldwide data on similar vessels. Whether these data would be useful to the risk assessment that is the subject of this study depends on specifics of the work scope, yet to be determined.

Nonnative and Invasive Species

Shipping as a vector for introducing alien species into the marine environment is another risk to the Aleutian Islands, one that is exacerbated by globalization and increased trade. The costs can be high in both ecological and monetary terms. For example, an invasion of the European green crab—anticipated to be a competitor for Alaskan native species—could be extremely costly to the $117 million shellfish industry (Union of Concerned Scientists 2001). While the cost to the U.S. economy of the introduction of terrestrial and aquatic invasive species is difficult to determine, one study estimates the damages at $137 billion annually (Pimentel et al. 2000). Of note in the present context, of the more than $600 million spent in 2000 to address this problem, the U.S. Department of Agriculture received approximately 90 percent for predominantly land-based efforts, while less than 1 percent was dedicated to combating invasive species (U.S. General Accounting Office 2002).

Aquatic species move through the marine environment by means of a variety of human-mediated pathways—shellfish importation, aquaculture, aquariums, horticulture, and the pet industry, to name a few (U.S. Commission on Ocean Policy 2004). Also of concern is the introduction of invasive species through ship ballast water carrying viable organisms from one water body to another. More than two-thirds of recent introductions of nonnative species in U.S. marine and coastal areas were likely due to shipborne vectors, and transport and discharge of ballast water is the most ubiquitous of these. Alaska, like all mainland coasts of the United States, has felt the effects of successful invasions of aquatic species (EPA 2008).

Introductions of terrestrial species have also dramatically affected the Bering Sea region. Given the importance and uniqueness of avian diversity in the Aleutians, a major concern is the threat to bird life posed by the introduction of rats. Rats prey on live nesting birds as well as eggs and can quickly destroy entire seabird colonies. A Japanese shipwreck in 1780 introduced the first Norway rat to Alaska, and by 1790 one of the Aleutians was named Rat Island. Rats have now invaded some 30 Alaskan islands and many additional areas, coastal and inland. Once established, rats devastate seabirds and other species. In certain locations and at certain times, rat "spills" (rats swimming to land from shipwrecks or walking from docked ships to land on ropes or gangplanks) are considered to be more ecologically damaging than oil spills.[3] Today the Fish and Wildlife Service and its partners are working to control the spread of rats to uninfected islands through education and outreach activities, as well as to eradicate rats from islands where they have become established.

VESSEL ACCIDENTS

A significant number and variety of vessel accidents have occurred in the Aleutian region over the past few decades, and several data sources can be consulted to determine their causes, circumstances, consequences, and trends. Two key sources are accident reports prepared by the National Transportation Safety Board (NTSB) following its investigations of major marine accidents and USCG's Marine Safety Management System (MSMS) database.

Only a few NTSB accident reports have been completed for the Aleutian region in recent years. Besides the M/V *Selendang Ayu* accident in 2004, the NTSB database since 1985 includes accidents involving one passenger vessel, one tug–barge unit, and 20 fishing vessels. The much larger USCG database contains reports of marine incidents and accidents spanning 40 years, from which the committee reviewed data for the Aleutians from 1991 through 2008. Appendix H contains selected summary information derived from MSMS data for the Aleutians from 1991 to 2000 (more than 3,000 incidents) and from Marine Information for Safety and Law Enforcement (MISLE) data for 2000 to 2003. In addition, the appendix contains a table

[3] Personal communication, A. Archibeque, Union of Concerned Scientists Report, 2002.

indicating most frequent causal factors from more than 1,400 MISLE incident reports for the Aleutians from 1995 to 2008.

The committee was able to draw only initial observations from these data. For one thing, fishing vessels accounted for the vast majority of individual incidents in the database. The reasons for this imbalance cannot be discerned from the data themselves, but one possibility cited elsewhere (e.g., Nuka Research and Planning Group 2006) is that U.S.-flagged fishing vessels may have a higher reporting rate than foreign-flagged vessels on innocent passage. In addition, as can be seen from the oil spill data presented below, the fishing vessel fleet appears to be responsible for a larger number of relatively small incidents, while the large commercial fleet has experienced a few major incidents.

Although the committee was unable to review other accident data because of time and resource constraints, additional data are available that could be used for the risk assessment. One recent study by the Government Accountability Office summarizes major spills for the entire United States from 1990 through 2006.[4] Accident data are available as well from other countries and international bodies for similar categories of vessels and operational environments. More detail on specific incidents could also be developed from several other sources, such as responders to incidents and salvage firms.[5] It is clear that many common types of ship accidents have occurred in the Aleutians. The historical data illustrate the frequency of these events, as well as the difficult nature of emergency response in this remote and hostile environment. Box 4-1 summarizes circumstances and events for five selected vessel accidents in the Aleutians illustrating a variety of conditions, vessel types, causal factors, and consequences. These examples illustrate some key issues related to recent vessel incidents in the region and can serve as a first approximation of some typical accident scenarios for use in the Phase A Preliminary Risk Assessment, along with others as appropriate.

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[4] The report defines major spills as those involving damage claims of at least $1 million. There were 51 such spills recorded during the period among a total of about 3,400 spills. There were no discernible trends for the 51 large spills over the 15-year time frame; in other words, one to five large damaging vessel spills appeared to occur each year, with a random pattern from year to year.

[5] See Appendix G for a sample list of salvage incidents in the region near Dutch Harbor taken from a private database maintained by a local salvage firm.

BOX 4-1

Circumstances and Events Surrounding Five Selected Vessel Accidents in the Aleutian Region

M/V *Selendang Ayu*

- Vessel: Malaysian-registered bulk carrier, 738 ft, 40,000 gross tons
- Carrying: 60,000 tons of soybeans and 1,000 tons of fuel oil
- Casualty: Lost power; vessel ran aground and broke up after drifting 100 miles to land
- Date: November–December 2004
- Location: North shore of Unalaska Island
- Consequences: Six fatalities, one serious injury; $12 million vessel loss; rescue helicopter crashed; 336,000 gallons of heavy fuel oil spilled
- Causal factors:
  - Main engine failure; crew unable to repair and restart
  - Severe weather and high winds and seas contributing to problems with repair work and rescue operations
  - Failure to notify authorities and seek assistance in a timely manner
  - Lack of adequate emergency towing and anchoring gear
  - Inadequate prior engine maintenance
  - Lack of adequate rescue/towing vessel and equipment in the region
  - Lack of proper survival equipment for crew

M/V *Kuroshima*

- Vessel: Japanese-registered freighter, 367 ft
- Carrying: Fisheries cargo and bunker fuel oil
- Casualty: Vessel dragged anchor in harbor and ran aground
- Date: November 1997
- Location: Dutch Harbor
- Consequences: One fatality; vessel damage; 40,000 gallons of heavy fuel oil spilled onto beach and freshwater lake

(*continued*)

BOX 4-1 (*continued*)

Circumstances and Events Surrounding Five Selected Vessel Accidents in the Aleutian Region

- Causal factors:
  - Severe storm, high winds and seas
  - Inadequate emergency anchoring system
  - Lack of adequate tow/rescue tug in region

M/V ***Cougar ACE***

- Vessel: Singapore-registered car carrier, 654 ft
- Carrying: 4,800 vehicles, 180,000 gallons of fuel
- Casualty: Vessel heeled over 80 degrees, was adrift without power for a few days
- Date: July 2006
- Location: South of Aleutians
- Consequences: One fatality; vessel damage; vessel able to be towed to Dutch Harbor for repairs; near-miss polluting event
- Causal factors: Investigations under way

T/B ***Foss 256***

- Vessel: U.S.-registered tug–barge unit
- Carrying: Fuel oil cargo for Navy facility in western Aleutians
- Casualty: High winds pushed barge over rocks while oil was being transferred to shore; vessel ran aground, and several cargo tanks were penetrated
- Date: January 1989
- Location: Amchitka Island, western Aleutians
- Consequences: 84,000 gallons of diesel oil spilled; no cleanup
- Causal factors:
  - Severe weather
  - No emergency response equipment in the area
  - Other factors unknown

(*continued*)

F/V *Phoenix*

- Vessel: U.S.-registered fishing vessel out of Dutch Harbor
- Carrying: 7,000 gallons of diesel fuel
- Casualty: Vessel lost power and control when fishing gear became entangled in rudder; vessel drifted to Unimak Island shore, grounded, and was penetrated
- Date: April 1993
- Location: Unimak Island just west of Unalaska
- Consequences: All 7,000 gallons of diesel fuel spilled; no cleanup
- Causal factors:
  - Inadequate attention paid to handling of fishing gear
  - Heavy weather
  - Lack of available emergency response

Source: ADEC 2006; NOAA 2000; NTSB 2006.

SPILLS OF OIL AND OTHER HAZARDOUS SUBSTANCES

The committee reviewed available data on oil spills in the Aleutian region and noted that these data are comprehensively compiled and reported (see Figure 4-1). In 2007 the Alaska Department of Environmental Conservation (ADEC) issued a report on oil spills from 1996 to 2004, which contained a section on the Aleutians. The data show just two significant vessel spills (i.e., more than 10,000 gallons) during the past 10 years, by far the largest of these being that of the M/V *Selendang Ayu* at 336,000 gallons. An additional review of the past 20 years of spill data shows about 22 spills of more than 1,000 gallons in the Aleutians. A report of the National Oceanic and Atmospheric Administration (NOAA) indicates that almost no oil has ever been recovered from these vessel spills in the Aleutians (NOAA 2000).

As noted above, the data show that in the recent past, fishing vessels have contributed to the largest number of spills compared with all other vessel categories, although the largest volume

FIGURE 4-1 Recent oil spills in Alaska's Maritime National Wildlife Refuge.

(Source: Pacific Environment, presented at committee meeting on October 30, 2007.)

spilled has been from just a few significant commercial vessel incidents. Figure 4-2 shows the number of incidents by vessel type from 1981 through 1999 for which NOAA has provided response assistance.

Figure 4-3 is a map with detail on spills of at least 1,000 gallons from 1981 to 2006 throughout the Aleutian chain. It shows a wide

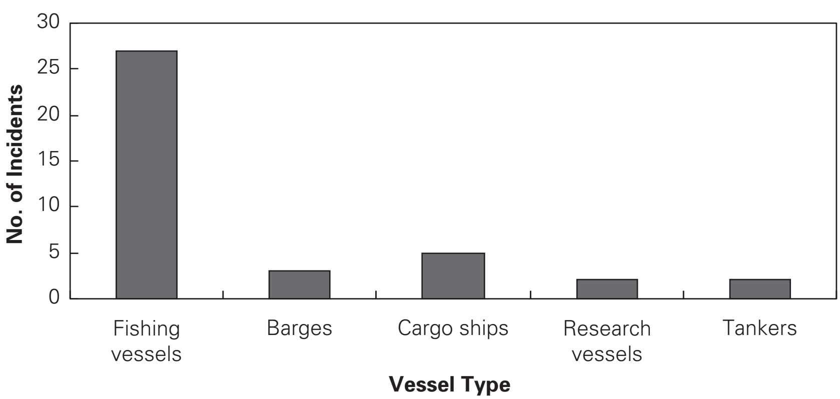


FIGURE 4-2 Number of oil spill incidents by source for which NOAA has provided response assistance in the Aleutians, 1981–1999.

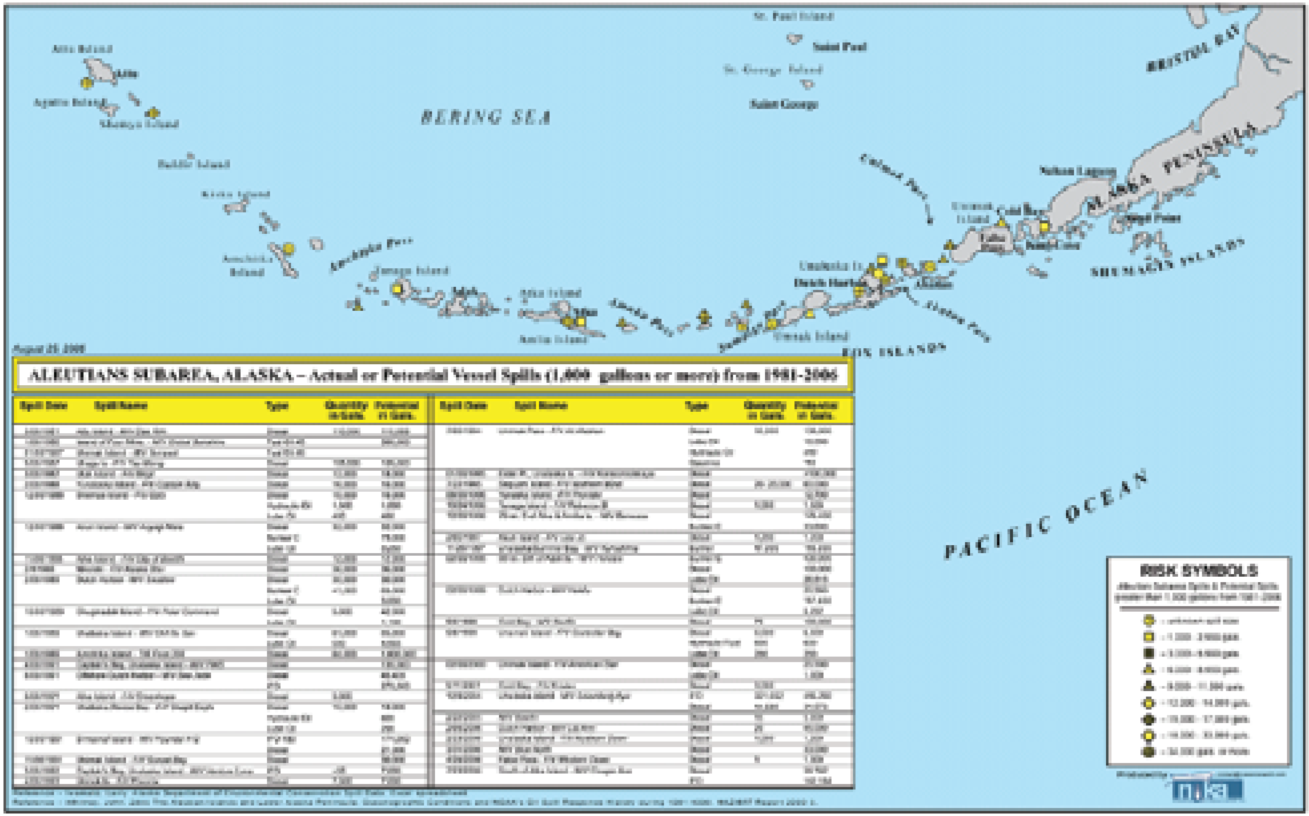


FIGURE 4-3 Map with detail on spills of at least 1,000 gallons from 1981 to 2006 throughout the Aleutian region.

(Source: Nuka Research and Planning Group 2006.)

distribution of spill locations and a large range of incident types. Figures 4-4, 4-5, and 4-6 present detail on various characteristics of spills between 1996 and 2005.

The ADEC report summarizes discernible trends from these spill data (see Figure 4-4). First, it concludes that the total number of spills in the region appears to have been on a general decline during this 10-year period (Figure 4-4*a*). Also, the frequency of spills appears to decline during October through January, possibly because of the timing of the fishing season (Figure 4-4*b*). Trends with regard to the number of spills per year may be somewhat misleading because of the overwhelming numbers of small spills compared with just two very large spills—those from the *Kuroshima* in 1997 and the *Selendang Ayu* in 2004.

Compared with all oil spills in the Aleutians, spills from vessels were the most common and accounted for almost half the total number and 88 percent of the total volume (see Figure 4-5*a*). The spill causes recorded were roughly evenly distributed among human factors, structural/mechanical, and other relative to the number of spills, but in terms of volume released, human factors dominated (Figure 4-5*b*). Finally, 98 percent of the number of spills were of noncrude oil, indicating that most of these spills were of either vessel fuels or refined products being delivered to island locations (Figure 4-5*c*).

The following are initial conclusions drawn from vessel spill data for the time period 1981–2005 (ADEC 2007):

- There were 26 known vessel spills of more than 1,000 gallons during the 25-year period, an average of approximately one per year.
- With so few large spills per year, there is no obvious pattern over time.
- There were seven vessel spills of more than 35,000 gallons:

Date	*Ship*	*Diesel or Heavy Oil*	*Amount (gallons)*
Dec. 26, 1988	Tank Barge 283	Diesel	2,041,662
Dec. 8, 2004	M/V ***Selendang Ayu***	Heavy oil	335,732
March 5, 1981	M/V ***Dae Rim***	Diesel	109,998
Jan. 17, 1989	T/B ***Foss 256***	Diesel	83,958
Jan. 11, 1989	M/V ***Chil Bo San***	Diesel	60,984
Nov. 26, 1997	M/V ***Kuroshima***	Heavy oil	38,976
Feb. 1, 1988	F/V ***Alaska Star***	Diesel	35,952

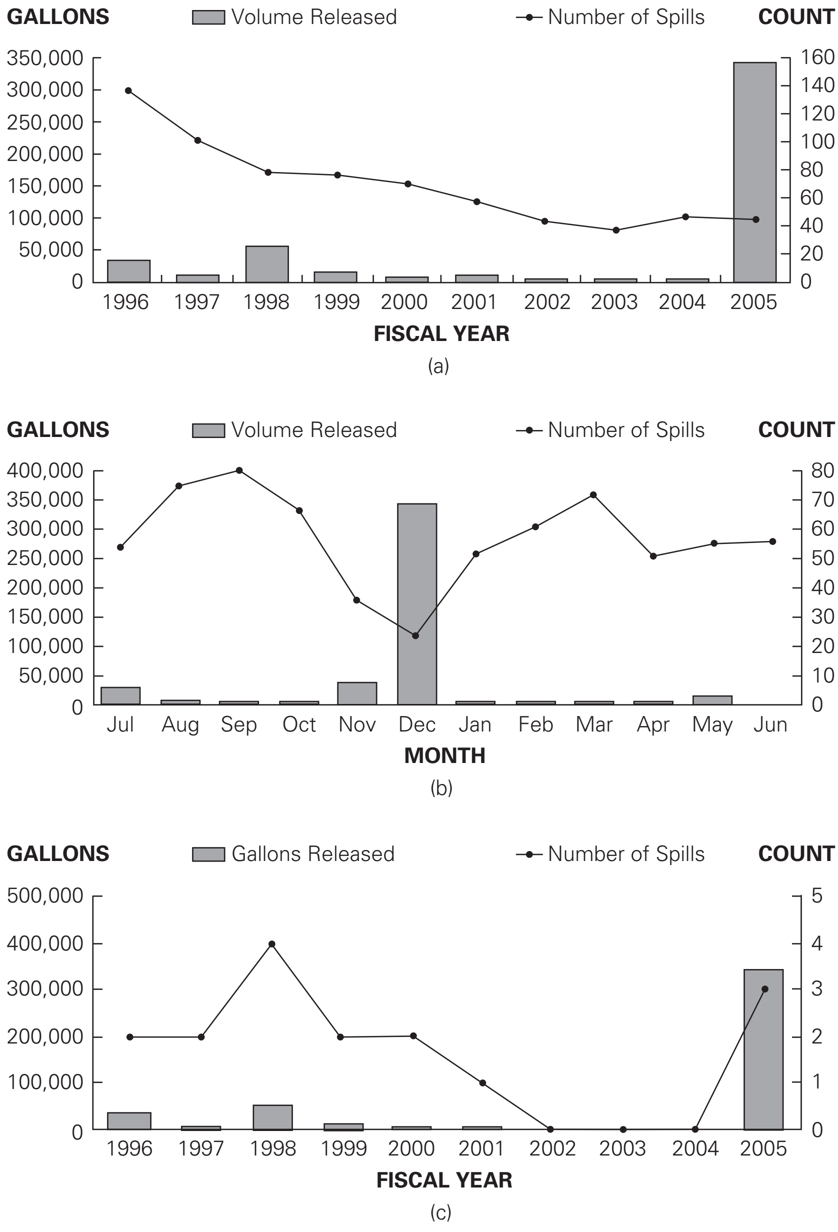


FIGURE 4-4 Spill trends in the Aleutians by fiscal year, month, and size, 1996–2005: (*a*) all spills by fiscal year; (*b*) all spills by month; (*c*) spills > 1,000 gallons.

(Source: ADEC 2007.)

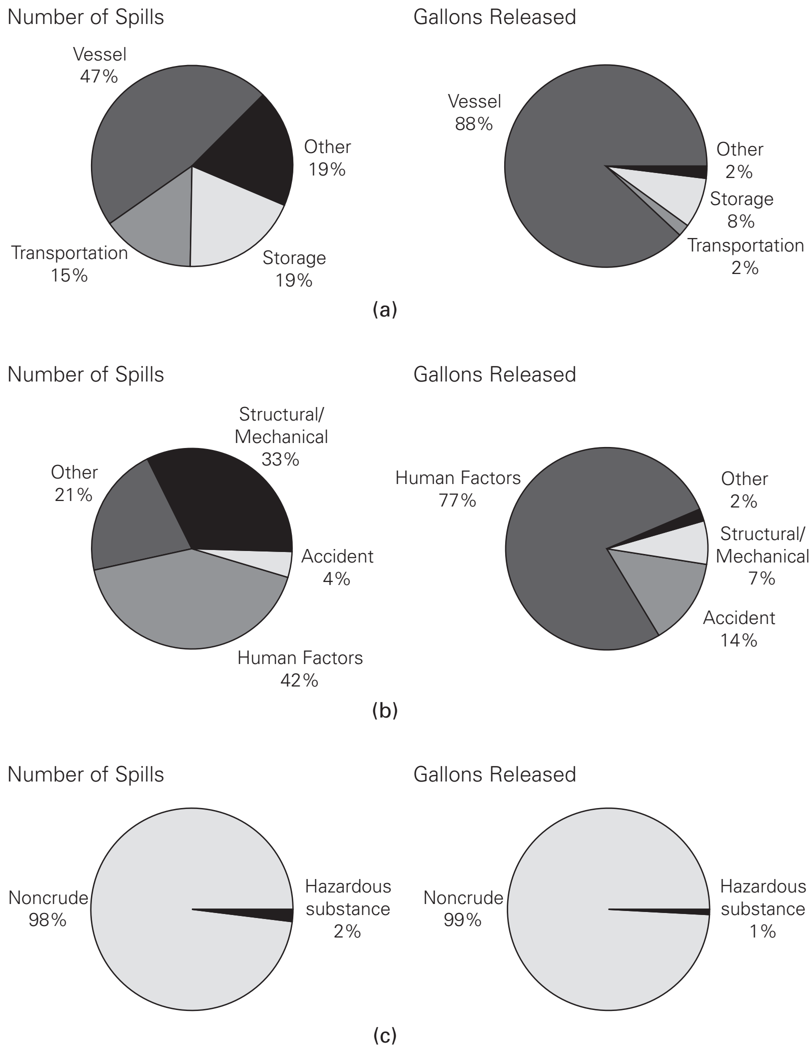
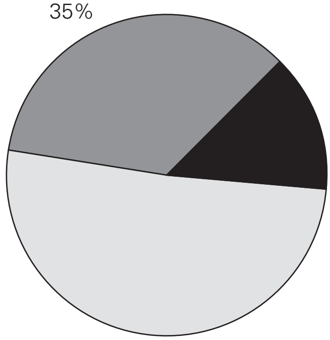


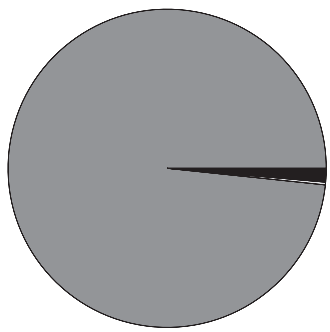
FIGURE 4-5 Spills in the Aleutians by (*a*) facility type, (*b*) cause, and (*c*) product, 1996–2005.

(Source: ADEC 2007.)

[In the Tank Barge 283 incident (USCG MP88008565), the tank barge foundered and broke up in the Shumagin Islands, at the upper end of the Aleutian chain. Because no investigation report is available on this incident that would provide detailed information on the sequence of events leading to the incident as there is for the M/V *Selendang Ayu* and the other accidents



(a)



(b)

FIGURE 4-6 Contribution of spills of various sizes to total number of spills and total volume released, 1996–2005: (*a*) percentage of total number of spills represented by spills of various sizes and (*b*) percentage of total volume released attributable to spills of various sizes. (More than half of the spills reported during the 10-year period were less than 10 gallons in size. More than 98 percent of the total volume released was attributable to spills with a volume of greater than 99 gallons.)

(Source: ADEC 2007.)

described in Box 4-1 that resulted in large spills, the box does not include a description of this incident.]

- Of the 26 known spills, 16 were from fishing vessels (the largest are listed above).
- Of the 10 cargo vessel spills, two were from tank barges, seven from self-propelled ships, and one from a vessel designated simply as a tank vessel.

REGULATORY FRAMEWORK

The United States has sovereignty over the waters of the Aleutian Islands out to 12 nautical miles, which constitutes its territorial sea; it also exercises some authorities to the outer edge of the exclusive economic zone (EEZ), which extends 200 nautical miles seaward of the baseline from which the territorial sea is measured. International law gives each coastal state broad jurisdictional authority to prescribe and enforce within its territorial seas, subject to the right of innocent passage. Since Unimak Pass is an international strait, foreign vessels enjoy the right of transit passage through it, as well as through waters north and south of the Aleutian Islands. While the United States could establish a traffic separation scheme or impose other requirements on shipping related to navigational safety within its territorial sea with the approval of the International Maritime Organization (IMO), it may not take unilateral action that would hamper or restrict international transit rights. However, if a foreign vessel is bound for a port or other location in the United States, the United States may impose additional requirements, such as a vessel oil spill response plan (VRP) for tankers, as a condition of entry. Such plans must include a geographic-specific appendix for each USCG Captain of the Port (COTP) jurisdiction to be transited; this includes transits to the outer edge of the EEZ (USCG 2007).

Several international legal regimes might be applied to manage shipping and shipping traffic in the region. These include the 1982 United Nations Convention on the Law of the Sea (UNCLOS); IMO provisions concerning vessel traffic services, vessel routing and reporting systems, and particularly sensitive sea areas (PSSAs); and U.S. statutes and regulations. These legal regimes are interrelated.

In March 1983, President Reagan declared that the United States would respect and follow the navigational provisions of UNCLOS as customary law. UNCLOS was signed by the United States in 1994, but to date it has still not been ratified by the U.S. Senate. Nonetheless, the United States has taken advantage of the provisions of UNCLOS, claiming a 200-nautical-mile EEZ in 1983, a 12-nautical-mile territorial sea in 1988, and a 24-nautical-mile contiguous zone in 1999.

As noted above, then, for international and many domestic purposes, the United States now exercises sovereignty out to 12 nautical miles from each of the islands in the Aleutian Island chain, as well as some authorities to the outer edge of the EEZ. The exercise of this authority, however, is subject to the inclusive rights of the international community to innocent passage. Several of the UNCLOS articles (Numbers 17, 18, 19, 37, and 38) define this right of innocent passage and explain how it applies for all nations to vessels transiting territorial seas and international straits (UNCLOS 1982).

Before the territorial sea in the Aleutians was extended to 12 nautical miles, the international community had a "high-seas corridor" through Unimak Pass. Now, however, the territorial sea of the United States entirely overlaps the waters of Unimak Pass. To constitute an "international strait" under international law, a body of water must first constitute a strait—a natural, constricted channel of water that connects two larger bodies of water. The right of transit passage applies to international straits "which are used for international navigation between one part of the high seas or an exclusive economic zone and another part of the high seas or an exclusive economic zone" (UNCLOS 1982, Article 37). States may not hamper or suspend the right of transit passage through straits in their territorial sea (UNCLOS 1982, Article 44). Because Unimak Pass is used for international navigation and connects two large bodies of water, it clearly constitutes an international strait.

While transit passage refers to the right of passage through an international strait, innocent passage refers specifically to the right of passage through a territorial sea when not calling at a port (for the United States, up to 12 nautical miles from the baseline). With respect to the application of Title 33 of the Code of Federal Regulations (CFR) Part 155, Subpart D, concerning VRPs, there is no real difference between U.S. and foreign vessels in the applicability of the requirement to carry such a plan; however, there is now a specific provision that this subpart does not apply to certain types of vessels, including foreign-flagged vessels engaged in innocent passage [33 CFR § 155.1010(c)(7)] and not calling at a U.S. port. Although transit passage is not specifically mentioned as an exception, it is certainly included by implication and practice for foreign-flagged vessels not calling at a U.S. port.

When President Reagan issued a proclamation extending the U.S. territorial sea to 12 nautical miles, he stated, "In accordance with international law, as reflected in the applicable provisions of [UNCLOS], within the territorial sea of the United States, the ships of all countries enjoy the right of innocent passage and the ships and aircraft of all countries enjoy the right of transit passage through international straits" (Presidential Proclamation 5928 of December 27, 1988). Coastal states have considerably less jurisdiction over foreign-flagged vessels engaged in transit passage than those engaged in innocent passage. Thus by inference, the innocent passage exception of 33 CFR § 155.1010(c)(7) applies equally to vessels engaged in transit passage through Unimak Pass.

A number of measures, based on both international law and U.S. statutes and regulations, are available to manage ship traffic and operations in the U.S. territorial sea around the Aleutian Islands. If vessels are U.S.-flagged, or if they have plans to engage in the transfer of oil or other cargo in a port or place subject to the jurisdiction of the United States on a particular voyage, the Oil Pollution Act of 1990 (OPA 90) requires that they carry a VRP with a geographic-specific appendix for each COTP zone through which they will pass. (See Box 4-2 for discussion of an important provision of OPA 90 relative to shipping operations in the Aleutians.) USCG has also given priority to developing VRP regulations for nontank vessels. Part of the purpose of the geographic-specific appendix is to identify oil spill response organizations (OSROs) with which vessel operators have contracted to respond to an actual or potential oil spill. The closest OSRO to Unimak Pass and the Aleutian Island chain is in Cook Inlet, about 1,200 nautical miles from the pass.

IMO has the authority to review and approve sea lanes, traffic separation schemes, PSSAs, and other restrictions on navigation. The organization seeks to promote maritime safety and security and to protect the marine environment while ensuring uniformity and consistency worldwide. To this end, it has established guidelines and procedures for reviewing and approving such proposals. While many of the laws governing navigation, environmental protection, drug trafficking, customs, immigration, and fiscal matters apply to the waters of the Aleutian Islands, no specific traffic management regulations apply to Unimak Pass. Nonetheless, other rules of international navigation, such as the International Regulations for Preventing Collisions at Sea, apply (UNCLOS 1982, Article 39). Also, under recent changes to IMO's 1974 Convention on Safety of Life at Sea (SOLAS 74), most ships are now required to carry an AIS, which provides the ship's position within VHF–FM radio range to other ships thus equipped and to shore station receivers. Ship-to-ship AIS is an effective tool for collision avoidance. The Unimak Pass

BOX 4-2

Double-Hull Requirements in Alaskan Waters

Following the *Exxon Valdez* spill in Prince William Sound, the U.S. Congress passed OPA 90, which mandated the phase-out of single-hull tankers and tank barges. As stated in 33 CFR § 157.08(n)(5), however, tank barges weighing less than 1,500 gross tons operating in the waters of the Aleutian Islands are specifically exempted from the double-hull provisions of OPA 90. (A tank barge of 1,500 gross tons will have a cargo capacity of roughly 900,000 gallons.) This was considered to be a practical solution to the delivery of oil to small, remote villages with confined waterways and extremely shallow water depth, which may not be able to sustain double-hull configured barges because of their size, weight, and reduced carrying capacity during ice-free, high–low water navigation periods. As a result, there are currently single-hull tank barges moving petroleum products within the Aleutian region that have no mandated retirement date. The risks related to operating single-hull tank barges in this relatively pristine region, known for its severe and changeable weather, need to be understood. It is important that tank barges be evaluated in this risk assessment.

region is equipped with shore-based AIS receivers, which enables tracking of vessels through the area and provides statistical data on vessel traffic. This region is the exception; most of the Aleutian Island chain is not covered by AIS shore-based receivers. In addition, IMO is currently working on the implementation of ship LRIT and is working with SOLAS parties to determine how such data will be managed and distributed to coastal, port, and flag states. IMO agreed to an amendment to SOLAS 74 requiring LRIT capability for certain ships; this amendment went into effect on January 1, 2008, and those ships must comply by December 31, 2008. Although the United States has not yet done so, it could propose that the environmentally sensitive Aleutian Islands, or parts thereof, constitute a PSSA and require special protection against oil spills and other navigational mishaps.

U.S. law[6] provides broad authority to limit or otherwise control the movements of any ship in the U.S. territorial sea, including the use of vessel traffic services, safety zones, and regulated navigation areas. This authority could apply to the sea areas surrounding the Aleutian Islands out to 12 nautical miles from the baseline as defined in UNCLOS.

Although the United States could impose unilateral requirements within its territorial sea, it is reluctant to impose burdensome requirements on foreign vessels on innocent passage through those waters. This reluctance is reflected in 33 CFR § 160.103 ("Applicability"), relative to the control of vessel operations, which exempts from compliance ships in innocent passage through the territorial sea of the United States or transiting navigable waters of the United States that form part of an international strait. As previously noted, however, if a foreign-flagged vessel is en route to a port or other place within the United States, additional requirements, such as a vessel spill VRP for a tanker carrying oil in bulk that includes a Geographic Specific Appendix (GSA) for each COTP zone being transited out to the EEZ, would apply; these COTP zones would include the Aleutians. As noted earlier, a regulatory effort is also under way to develop VRP requirements for nontank vessels.

Finally, given that the Unimak Pass area is heavily trafficked and vulnerable to environmental degradation, other options for regulating or monitoring vessel traffic transiting through it could be considered. Such options might include a traffic separation scheme or a PSSA.

REFERENCES

Abbreviations

ADEC	Alaska Department of Environmental Conservation
EPA	Environmental Protection Agency
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NTSB	National Transportation Safety Board

[6] The Ports and Waterways Safety Act, as laid out in Chapter 25 of Title 33, United States Code, Sections 1221–1232, and as implemented in 33 CFR Parts 155 and 160.

UNCLOS	United Nations Convention on the Law of the Sea
USCG	United States Coast Guard

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CHAPTER 5

Organization of the Aleutian Islands Risk Assessment

This chapter provides details on the organization of the Aleutian Islands risk assessment introduced in Chapter 2. The goal of the risk assessment is the implementation of effective and efficient risk reduction measures. To achieve this desired outcome within available resources, it is critical for the study to stay focused on the specific task at hand—assessment of risks related to accidental spills from vessels operating in the study region. The first section of this chapter sets the bounds for the study. The proposed Management Team should take care to ensure that the study remains within these established bounds.

Formulating an effective risk assessment approach that combines input from stakeholders, experts in risk analysis and risk assessment, and decision makers is also necessary to success. The second section of this chapter describes the committee's recommended approach, which involves close cooperation among a Management Team representing decision makers, an Advisory Panel consisting of stakeholders and interested experts, a Risk Analysis Team made up of one or more contractors, and a Peer Review Panel providing technical review of the risk assessment.

The assessment of risks associated with maritime transportation can be extremely complex. The complexity arises from a multitude of factors. There are currently some 10,000 shipping companies flying the flag of 150 different countries, operating a world commercial shipping fleet of roughly 50,000 vessels. Many of these vessels transit the Aleutian Islands. Regulatory control of these vessels is divided among many entities, including the International Maritime Organization, flag states, port states, and classification societies. Jurisdictional issues are complex—the legal right of transit and the right of innocent passage limit the intervention measures available to state and federal agencies. The quality of vessel design and construction, crew training and experience, and the management standards of operating companies are inconsistent across the fleet. Classes of vessels are designed for specific commodities and services, leading to a large number of ship types and sizes carrying a wide variety of hazardous substances (see Chapter 4). The Aleutian region is subject to severe and highly changeable weather; it is remote, creating challenges for access and communications; and it is home to relatively unspoiled and unique habitats and extensive biodiversity (see Chapter 3).

In view of this complexity, it is appropriate for the risk assessment to begin with qualitative and semiquantitative analyses and assessments and then to focus detailed quantitative assessment on the most significant risks and the more promising risk reduction measures. For this reason, the committee recommends that the study be divided into two phases: a Phase A Preliminary Risk Assessment and a Phase B Focused Risk Assessment. Assessment and prioritization of potential risk reduction measures would be undertaken by the Advisory Panel and Management Team during and immediately after each phase. Technical details and background on each of these steps are provided in Chapter 6.

PROBLEM DEFINITION

The proposed risk assessment for shipping operations in the Aleutian Islands specifically addresses the risk of spills from marine vessels transiting through and servicing the region. The recommended bounds for the study are described below.

Hazardous Substances to Be Considered

The risk assessment should consider spills of petroleum products, bulk chemicals, and packaged hazardous containerized cargoes moving through the Aleutians (see Table 5-1). Risks related to the introduction of invasive species should be considered on a qualitative basis.

Types and Sizes of Vessels to Be Considered

All marine vessels weighing more than 300 gross tons (GT) carrying hazardous substances as defined above and all smaller vessels having a fuel oil capacity of at least 10,000 gallons should be considered. Vessels transiting the North Pacific Great Circle Route between the west coast of the United States and Canada and the Far East constitute the traffic flow of primary public concern, since the largest oil spills in recent years were the result of accidents involving cargo ships on innocent passage through Unimak Pass. However, other vessel types pose risks that should not be ignored in a comprehensive risk assessment. In the region, for example, fishing boats account for

TABLE 5-1 Hazardous Substances

Type	Marpol Annex or Other Code	Name	Example
Oil	Annex I	Oil cargo	Crude oil, asphalt-blending stocks, fuel oil no. 4, fuel oil no. 5, fuel oil no. 6, diesel oil
	Annex I	Biofuels and base petroleum fuels	
	Annex I	Bunkers	Diesel oil, lube oil, heavy fuel oil
Chemicals	Annex II and IBC Code (Chapters 17 and 18)	Noxious liquids in bulk and noxious liquid substances	Vegetable oils, oil-like substances
	Annex II and IBC Code	Biofuels	Biodiesel, fatty acid methyl esters, B100 and ethanol, ethyl alcohol E100
Other hazardous substances	Annex III	Dangerous goods in package form and invasive species	Microorganisms, rats

Note: IBC = international bulk container.

the largest number of spills greater than 10,000 gallons in size (see Chapter 4). Single-hull tank barges, known to pose relatively high oil spill risks, supply products to the outer Aleutian Islands. Therefore, the risk assessment should consider all vessels above 300 GT, which include but are not limited to the following types:

- Containerships,
- Bulk carriers,
- General cargo vessels,
- Gas carriers,
- Roll-on/roll-off vessels and pure car carriers,
- Cruise ships,
- Crude oil carriers,
- Product tankers,
- Tank barges,
- Chemical carriers,
- Fish processors,
- Fishing vessels,
- Tugs, and
- Government vessels.

The study should include vessels currently transiting the region, as well as those that can reasonably be anticipated to do so during the 25-year study period (the study period is discussed below). For example, oil production in the Bering Sea, the Chukchi Sea, and other northern areas may lead to increased traffic of exploration and production vessels, such as offshore supply vessels, drill ships, mobile offshore drilling units, and icebreakers.

Accident Types to Be Considered

The risk assessment and proposed risk reduction measures should focus on spills from accidents. Major accident categories to be considered are collisions, allisions, powered groundings, drift groundings, founderings, structural failures, and fires and explosions. Spills from drift groundings and collisions have been responsible for the major spills from cargo ships in the Aleutian region and clearly must be given careful consideration. However, it is important that the Phase A Preliminary Risk Assessment be comprehensive and not limited solely to those types of accidents that have occurred in Alaskan waters in recent years and that may be perceived as having the highest risk. In recent years, for example, catastrophic structural failure has led to a number of very large oil spills (e.g., the *Prestige* and the *Erika*).

The risk assessment should exclude operational and intentional discharges from ships. Although it is recognized that the latter likely exceed the oil spillage from accidents (NRC 2003), the committee believes that limiting the study to accidents leading to spills and excluding discharges, which are smaller and chronic in nature, offers the most promise for significant risk reduction.

Geographic Region to Be Considered

Vessel traffic operating in the following geographic region should be considered:

- North boundary, 55°30′ N;
- South boundary, 50° N;
- West boundary, 170° E and international date line; and
- East boundary, 160° W.

The study region (see Figure 5-1) is intended to cover vessels transiting in the vicinity of the Aleutian Islands; those calling on ports in the Aleutian chain; and fishing boats, processors, and other vessels operating within the region. This includes vessels on innocent passage transiting immediately to the south of the Aleutian chain. Should drift grounding simulation indicate that vessels transiting outside the above boundaries pose a significant risk to the Aleutian Islands, the boundaries should be adjusted accordingly. Whereas the assessment of vessel traffic and the locations of spill accidents should be

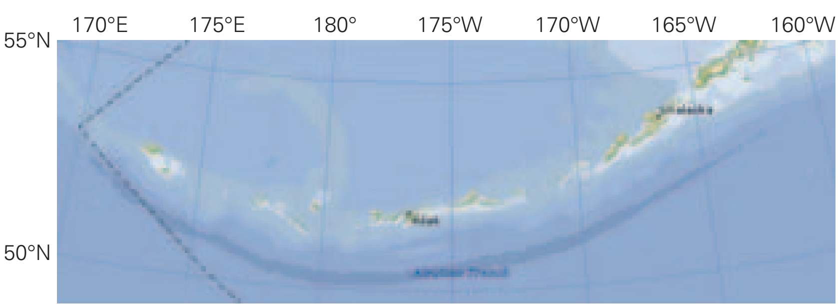

FIGURE 5-1 Complete Aleutian chain.

restricted to the study region, the environmental and socioeconomic consequences of these spills may extend outside the study region, depending on the fate of the spill.

Time Frame to Be Considered

The study period should be 25 years, from 2009 to 2033. The study period needs to be sufficiently long to provide a basis for life-cycle cost–benefit analysis and to reflect anticipated changes in vessel traffic and vessel types and designs, as well as the impact of known and reasonably expected regulatory changes.

ASSESSMENT ORGANIZATION AND MANAGEMENT STRUCTURE

The committee proposes an organization and management structure for the Aleutian Islands risk assessment consisting of four groups: a Management Team, an Advisory Panel, a Risk Analysis Team, and a Peer Review Panel.

Management Team

The Management Team would consist of those agencies responsible for allocating the funds for the risk assessment, as well as for ensuring that the work is carried out in an effective and useful way. The following agencies should have representatives on the Management Team:

- The U.S. Coast Guard (USCG),
- The Alaska Department of Environmental Conservation and Department of Natural Resources, and
- The National Fish and Wildlife Foundation (NFWF).

This team should work in a collaborative manner to

- Oversee the use of funds;
- Refine the study work scope, issue requests for proposals, and award contracts for the risk analysis;
- Establish the Advisory Panel and appoint its facilitator;

- Establish the Peer Review Panel and appoint its chairperson;
- Work collaboratively with the Advisory Panel to establish risk tolerance guidelines and prioritize risk reduction measures; and
- Prepare a final summary of findings, conclusions, and recommendations, written in collaboration with the Advisory Panel.

As described in Chapter 1, the courts have given responsibility for allocation of funding for the risk assessment to NFWF. NFWF has in turn signed a cooperative agreement with USCG giving USCG responsibility for contracting for and overseeing the risk assessment. Therefore, although the Management Team should work on a collaborative basis and seek consensus in reporting its findings and recommendations, the ultimate responsibility rests with USCG.

Advisory Panel

The idea of the Advisory Panel is to take advantage of experience gained through the Presidential/Congressional Commission on Risk Assessment and Risk Management, the Prince William Sound study, and other collaborative risk assessment efforts discussed in Chapter 2 while avoiding the potential limitations resulting from frequent interactions with stakeholders that can compromise the study team's objectivity. The Advisory Panel would represent a structured stakeholder-participatory approach intended to build trust, clarify the values and goals that should inform the assessment, incorporate local information and knowledge that would otherwise be easily missed, and potentially provide a path to organizational learning and policy change that might not otherwise be available.

The Advisory Panel would consist of stakeholders and experts who would offer local knowledge and expertise on all issues pertinent to the assessment, such as local infrastructure, relevant industries, waterways and their navigation, weather, and habitats. The panel should include representatives from the following:

- Municipalities;
- Environmental organizations and interests;
- Subsistence users;
- Landowners and managers (e.g., the Maritime National Wildlife Refuge);
- Different sectors of the fishing industry;

- Industry (including salvors, pilots, mariners, and port authorities);
- Government agencies offering special expertise (e.g., the National Oceanic and Atmospheric Administration); and
- Others with expertise in local weather, habitats, waterways, infrastructure, and so forth.

The Advisory Panel would provide stakeholders' perceptions of current risks, assist in identifying hazards and offer local knowledge critical to proper characterization of the risks, brainstorm on potential risk reduction measures, help establish tolerance parameters for risks, and perform an initial prioritization of risk reduction measures. It should be recognized that, regardless of how rigorous a risk assessment may be, no analytical approach alone will be sufficient for decision-making purposes. The needs and values of stakeholders will play a key role in understanding the issues and must be considered in the decision-making process.

The Advisory Panel is intended to operate as an independent entity, although the Management Team should generally be invited to its meetings as nonvoting participants. The Management Team should also allocate funds for meeting facilities and administrative expenses, as well as for the cost of a facilitator. The facilitator should ensure that the Advisory Panel has adequate representation from the full range of stakeholders and sufficient expertise in risk assessment and the local environment. The committee envisions the Advisory Panel as a volunteer group, although some compensation for travel expenses may be necessary to ensure the desired representation of stakeholders.

Risk Analysis Team

The Risk Analysis Team would perform the risk analysis under the direction of the Management Team, be called upon to make presentations to the Management Team and the Advisory Panel, and present the technical basis for its work to the Peer Review Panel. The Risk Analysis Team should consist of one or more contractors with demonstrated expertise in the following:

- Maritime transportation and qualitative and quantitative spill risk assessment, including human factors analysis and uncertainty analysis;
- Marine traffic analysis and modeling;

- Environmental impact studies;
- Spill cleanup and socioeconomic and cultural impact assessments; and
- Human factors.

The contractor(s) should have a proven record in preparing reports and presentations suitable for both technical and nontechnical audiences and the ability to communicate effectively with stakeholders and the public.

Peer Review Panel

The Peer Review Panel would consist of approximately five experts (in the areas of marine risk assessment, environmental modeling and assessment of socioeconomic impacts, and human factors evaluation) appointed by the Management Team after consultation with the Advisory Panel. It could be expanded, however, if the members determined at the first meeting that crucial expertise necessary for the activity was lacking. It should have collective expertise in all aspects of marine risk assessment. Its role would be to perform a peer review of the approaches, methodologies, models, and algorithms used by the Risk Analysis Team to ensure that assumptions are based on the best available data, that uncertainties have been properly described, that analyses have the appropriate rigor for the level of assessment, that the work is of a consistently high quality, and that findings are properly justified.

Risk Assessment Tasks and Time Line

The basic steps and time line for the risk assessment are shown in Figures 5-2 and 5-3. The diagrams show the relationships among the above four groups with respect to management, oversight, and conduct of the risk assessment. The primary responsibilities of each group are indicated in the respective columns. The committee believes that approximately 2 years will be required for the full assessment. The process is structured so that a qualitative prioritization of risk reduction measures will be available after the first year, which may allow earlier implementation of those measures that stand out as particularly effective.

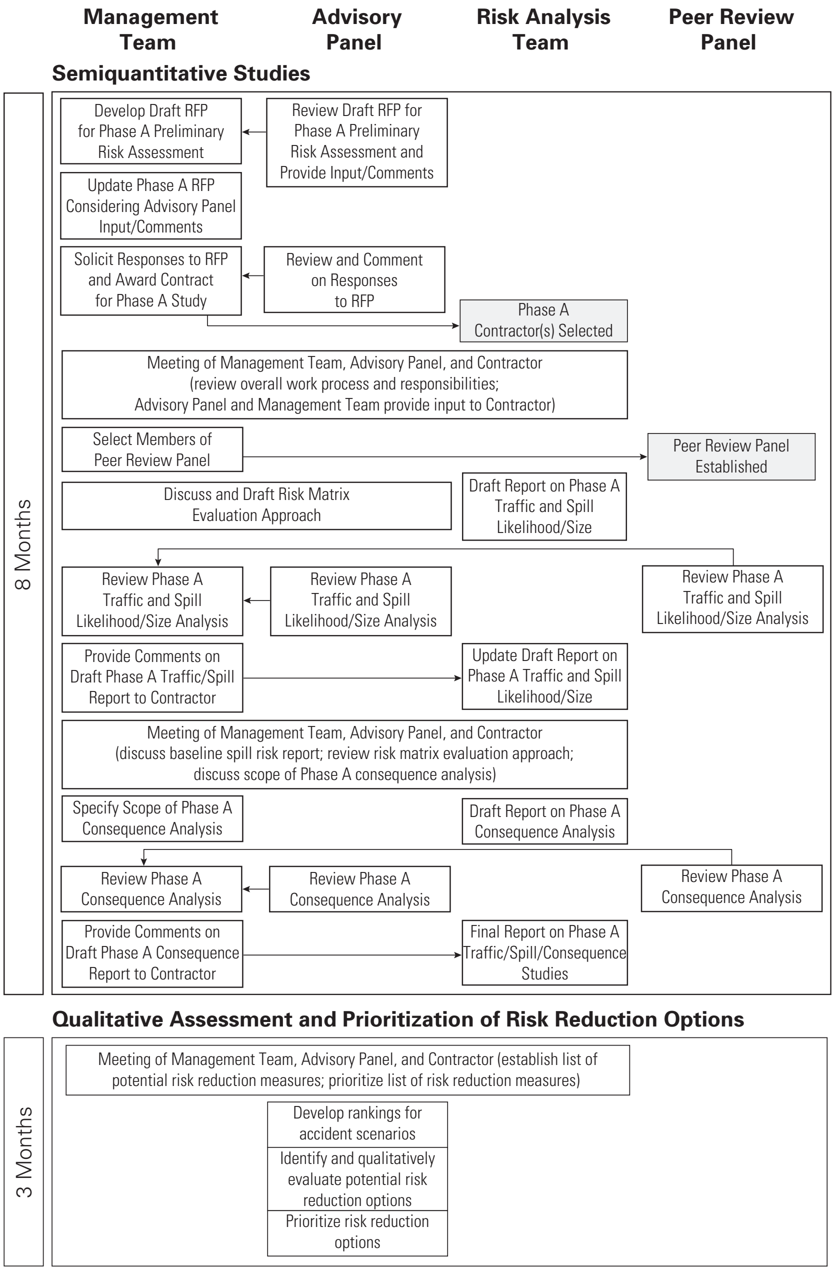

FIGURE 5-2 Phase A Preliminary Risk Assessment. (RFP = request for proposals.)

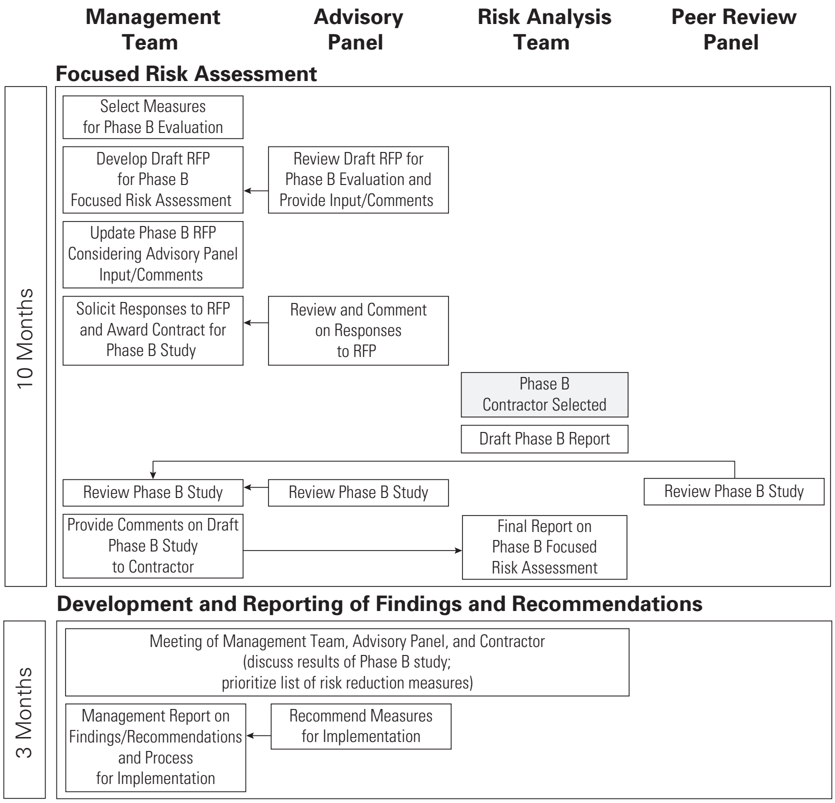

FIGURE 5-3 Phase B Focused Risk Assessment.

The risk assessment has four main stages:

- Phase A semiquantitative studies,
- Phase A qualitative assessment and prioritization of risk reduction options,
- Phase B Focused Risk Assessment, and
- Phase B development and reporting of findings and recommendations.

The estimated times for completion of each stage are approximate and subject to refinement. However, the Management Team should attempt to keep the risk assessment generally on schedule. There is a sense of urgency to the study given the high level of traffic through the area, combined with the limited infrastructure in place for mitigating risks (e.g., the lack of traffic separation and vessel traffic services) and for providing effective responses to incidents (e.g., the lack of rescue-capable tugs). Recognizing this sense of urgency, the proposed schedule is purposively aggressive. Meeting the schedule will require careful management of parallel work efforts, avoidance of scope creep, and attention to work package delivery dates. The importance of meeting the schedule is ultimately the responsibility of the Management Team and should be emphasized from the beginning of the project.

At a minimum, the Management Team, Advisory Panel, and Risk Analysis Team should meet after each major step to review assumptions and findings; these meetings are shown in the figures. It is likely that more frequent meetings will be needed. However, the Risk Analysis Team will be able to take full advantage of the knowledge and expertise of the Advisory Panel and the Management Team.

Although collaboration is necessary for the success of this study, each group has specific responsibilities, and some independence is therefore required. The Management Team is responsible for defining the work scope of the Risk Analysis Team. The Management Team, Advisory Panel, and Risk Analysis Team are encouraged and expected to share expertise and knowledge. However, the Risk Analysis Team must perform its specified tasks in an unbiased manner, without predisposition toward any particular outcome. One of the concerns expressed by the National Research Council committee reviewing the Prince William Sound study was that the study was "less an independent analysis of risk than a mutually agreed upon description of issues and recommendations for mitigating risk" (NRC 1998, 2). A balance must be struck between the obvious benefits of close collaboration and consensus building and the need for independent and critical thinking. The role of the Peer Review Panel is less collaborative—its job is to ensure that the science is right. Nevertheless, the critiques prepared by the Peer Review Panel should be instructive and constructive, with the goal of improving the final product.

Budgetary Considerations

In accordance with the *Selendang Ayu* court settlement, $3 million has been set aside for the overall risk assessment and projects identified by the risk assessment (*Selendang Ayu* Settlement 2007). The committee is confident that the available funds are more than sufficient to cover the costs of a credible comprehensive risk assessment. Funds remaining at the end of the assessment can be applied to risk reduction measures. Principal expenses for the risk assessment include the following:

- Administration and meetings,
- Facilitator for the Advisory Panel,
- Peer Review Panel, and
- Phase A and Phase B analyses by the contractor(s).

The Management Team must control the scope of the work to ensure that it is conducted in a timely fashion, without early effort being expended on detailed analyses that will have little or no influence on the final decisions.

The Phase A analysis involves the characterization of risks, needed as background for the qualitative assessment of potential risk reduction measures and as a baseline for the focused quantitative assessment of risk reduction measures. As noted earlier, care must be taken to avoid spending too much of the budget on the Phase A analysis, leaving inadequate resources for the Phase B assessment. The committee's best estimate is that about one-quarter of the overall budget should be allocated to the Phase A effort. Approximately two-thirds of that portion of the budget should be allocated for the traffic, spill likelihood and size, and causality studies, and one-third for the spill consequence studies. The budgeted amount should be adhered to, and expansion of the scope of these efforts should be avoided.

In Phase B, there may be a natural tendency to assess more risk reduction options in greater detail than resources allow. Again, the scope of the work should be defined and adhered to as far as is practical. Contingencies should be provided for in the budget and time line to ensure that the final report is delivered without undue delay. If additional studies are deemed desirable, they should be considered following completion of the study as part of the ongoing effort of risk management.

REFERENCES

Abbreviation

NRC	National Research Council

NRC. 1998. *Review of the Prince William Sound, Alaska, Risk Assessment Study.* National Academy Press, Washington, D.C.

NRC. 2003. *Oil in the Sea III: Inputs, Fates, and Effects.* National Academies Press, Washington, D.C.

Selendang Ayu Settlement. 2007. United States of America vs. IMC Shipping Co. PTE Ltd. Aug. 13.

CHAPTER 6

Technical Approach to the Aleutian Islands Risk Assessment

This chapter details the technical approach proposed by the committee for conducting the Aleutian Islands risk assessment. The first section describes the first five steps in the Phase A Preliminary Risk Assessment, aimed at characterizing the risk of accidental spills from maritime transportation in the Aleutian Islands region. These semiquantitative portions of the Phase A assessment, such as traffic characterization and projections and estimation of spill rates and sizes, will rely heavily on historical data and, where appropriate, experience from prior risk studies and expert opinion. The traffic and spill risk studies will help the Management Team and Advisory Panel identify geographic locations and spill scenarios for a limited number of focused environmental impact investigations, to be carried out in the Phase A consequence analysis. As noted in Chapter 5, avoiding extensive simulations and modeling and limiting the extent of the consequence assessment will control the cost of the Phase A study, allowing the majority of resources to be concentrated on the focused assessment of spill prevention and mitigation measures.

The Phase A work should yield a basic understanding of where the highest risks lie with respect to the types of hazardous substances and vessels involved, the types of accidents and the likely causes of and scenarios leading to those accidents, the sizes and likely locations for spills, and the environmental impact of those spills. The intent of these studies is to provide the Management Team and Advisory Panel with sufficient information with which to identify and prioritize risk reduction measures on a qualitative basis during the continuation of Phase A.

The committee wishes to emphasize that the ultimate goal of the risk assessment is to identify measures that can be taken to reduce the risk of vessel accidents and spills in the Aleutian region. As discussed below, the committee has compiled an initial list of risk reduction options than can be used by the Management Team and the Advisory Panel as a starting point for working toward this goal. Although the risk assessment is structured into discrete phases and steps, the identification and prioritization of risk reduction options should be an ongoing, iterative process throughout all of these efforts, reflecting analysis results as they become available, changing circumstances, and emerging technologies and opportunities.

The second section of this chapter describes the Phase A effort to evaluate the identified risks, develop a list of potential risk reduction measures, and prioritize those measures. On the basis of this qualitative assessment, the Management Team, in collaboration with the Advisory Panel, may be able to identify certain measures as appropriate for immediate implementation. Some measures will be discarded as unjustifiable, and others will be designated for more detailed analysis.

The third section of the chapter describes the approaches and typical techniques to be applied in the more detailed, quantitative analyses of Phase B that are needed to justify certain measures and understand their secondary effects on the overall system. These analyses will likely involve examination of a variety of risk reduction options, numerical simulations, and elicitation of information from expert witnesses to quantify the likelihood and consequences of the accidents identified in Phase A with and without the risk reduction measures in place. Uncertainty and sensitivity analyses will provide a sense of the confidence warranted in the characterization of risks and the benefits to be realized. The quantitative assessment also will supply data needed for cost–benefit analyses.

The final section describes the steps needed to develop and report final recommendations for decision makers on the risk reduction measures to be implemented. There are many challenges to implementation, including establishing sources of funding and reaching agreement with the various agencies and stakeholders that will influence the failure or success of a measure. The risk management process is not a one-time solution; it requires continuous monitoring and reassessment. Thus, the need for a mechanism to ensure that the risk management plan remains a living document is discussed.

PHASE A PRELIMINARY RISK ASSESSMENT: SEMIQUANTITATIVE STUDIES

The purpose of this portion of the Phase A Preliminary Risk Assessment is to identify the more significant risks related to spills from shipping and provide a basis for the identification and initial ranking of possible risk reduction measures. These semiquantitative studies are intended to provide a high-level understanding of relative risks, taking into consideration types of vessels and hazardous substances and locations where discharges are most likely to occur.

Results of these studies should allow the Advisory Panel and Management Team to perform a preliminary ranking of risk control measures, taking into account such factors as effectiveness, amenability to implementation through regulatory or voluntary means, and costs. Some measures assessed as having a high level of effectiveness may be proposed for immediate implementation. For those measures for which the justification for implementation is not conclusive, more detailed assessments will likely be required to better quantify the likelihood of the accidents that would be addressed and the extent to which the measures would reduce their frequency and consequences. These additional analyses would be undertaken in Phase B.

The Preliminary Risk Assessment should utilize relatively simple tools, avoiding detailed event tree analyses and complex simulation models to the extent practical. These Phase A studies will rely primarily on historical data, expert opinion, and lessons learned from prior studies. Some of the initial analyses will be qualitative in nature, with increasing levels of quantification in subsequent analyses as necessary.

The basic steps in this portion of the Phase A assessment are listed below and described in more detail in the ensuing text.

1. *Traffic study*: Perform a vessel traffic study to characterize the existing fleet and traffic in the region and the quantities of oil and other hazardous cargoes being moved. Project growth in trade, changes in vessel design and size, and the impacts of known and reasonably expected regulatory changes. Use this information to project the fleet makeup over the study period.
2. *Spill baseline study*: Develop the spill baseline over the 25-year study period as the product of the projected movements of oil and other hazardous cargoes and the estimated average spill rates. Frequency is developed in terms of accident return period for each type of ship and accident. Consequence is initially expressed in terms of the expected or average spill outflow, which together with the spill frequency defines the spill rate. This projection will provide an understanding of the most important hazards and serve as a baseline for later assessment of benefits. Related information, such as the maximum expected outflow (upper limit), type of substance spilled, and safety implications in terms of loss of life and serious injuries, is developed to assist in the Step 3 and Step 5 assessments.
3. *Characterization of spills from the highest-risk accidents*: Taking into consideration the traffic and baseline spill analysis, identify the hazardous substances, representative spill sizes, and locations of spills from the highest-risk accidents. This information will be used as input for the Phase A consequence analysis (Step 4 below). Determine which accidents (types of accidents, predominant vessel types, geographic locations) are of sufficient concern to merit assessment of risk reduction measures. This information will be used during the brainstorming of potential risk reduction measures and as input into the accident scenario and causality analysis (Step 5 below).
4. *Phase A consequence analysis*: Perform a preliminary spill trajectory and fate analysis for the spills and locations identified in Step 3 above. The intent is to gain an understanding of the relative environmental consequences of spill size, type of hazardous substance spilled, and spill location. Perform a qualitative assessment of the potential resource damage and socioeconomic impact of these representative spills.

5. *Accident scenario and causality study*: For the dominant accident types identified in Step 3, determine representative accident scenarios. Develop probabilities for the principal causes and associated consequences of the significant scenarios.

Where possible, historical data should be used to determine traffic and commodity flows, as well as the likelihood and size of spills. Care must be taken when applying these historical data. Reporting standards are rarely consistent within a given database, and no single database is comprehensive. Although data specific to the local region are generally preferred, the sparseness of accident and spill data for large vessels in the study region will necessitate use of national and international data on spill frequency and size to generate statistically significant estimates. When data are unavailable or characterized by considerable uncertainty, the use of expert judgment, simulations, and other analytical models may be required. For instance, drift grounding simulation may be needed to gain an understanding of the likelihood of a disabled vessel drifting aground, particularly for vessels transiting to the south of the Aleutian Islands. However, the use of simulations or expert opinion to predict the likelihood of major spill events should be minimized to the extent possible. The uncertainty of the estimates derived should be carefully assessed, and sensitivity analyses should be carried out as appropriate.

The baseline projection developed in Step 2 should assume full implementation of the Oil Pollution Act of 1990 (OPA 90) and International Maritime Organization (IMO) regulations that have already been adopted. Examples of regulations that will affect the environmental performance of ships built during the study period include the International Convention for the Prevention of Pollution from Ships (MARPOL), Annex I, Regulation 23, *Accidental Oil Outflow Performance*, which specifies subdivision requirements for the cargo spaces of oil tankers, and MARPOL, Annex I, Regulation 12A, *Oil Fuel Tank Protection*, which specifies double-hull or equivalent protection for fuel tanks. The baseline projection should also account for future regulations that can reasonably be anticipated. For example, it is expected that IMO will implement air emission regulations that will mandate increased use of nonpersistent fuel oils. The baseline projection should assume that no additional risk reduction interventions or measures will be implemented during the study period. Thus, the baseline will represent a hypothetical future without the potentially beneficial effects of the risk reduction options being investigated in the Aleutian Islands risk assessment. (Future benefits from operational requirements such as International Safety Management and Standards of Training, Certification, and Watchkeeping should be considered only if compliance with those requirements can be fully documented and quantified.)

1. Traffic Study

1a. Determine the makeup and traffic patterns of the fleet transiting the Aleutian Islands or operating within the study region.

An analysis of traffic though the study area should be developed on the basis of the best available data. As described in Chapter 3, automatic identification system (AIS) vessel tracking data have been compiled for transits through Unimak Pass since 2006. These data provide the most accurate information on the number, types, and routing of larger vessels transiting the Great Circle Route through the Aleutians. Data for ships transiting immediately south of the Aleutian chain are less reliable. (Satellite AIS data would be useful if available as an additional data source for the assessment.) To the extent practical, other data sources, such as the U.S. Coast Guard (USCG) Puget Sound vessel tracking system (VTS) and the Canadian Coast Guard Tofino VTS should be used. These data sets provide tracking information for vessels arriving at and departing from the Seattle and Vancouver areas, respectively, and should provide an indication of the routing of vessels calling on these regions and whether tank vessels are laden or in ballast. Communication with weather routing services and shipping companies may also be required to augment these data. Determinations of concentrations of fishing vessels, locations of seafood processors, movements of barges transporting refined products to the outer Aleutian Islands, and other local vessel movements will require review of local data sources, such as the Marine Exchange and the Alaska Commercial Fisheries Entry Commission, as well as communication with pilots and industry representatives.

The various data sources should be used to develop best estimates of traffic for vessels carrying at least 10,000 gallons of fuel or other oil product or significant quantities of hazardous cargo. These estimates should provide a picture of traffic patterns, categorized by vessel type, amounts and types of hazardous substances (e.g., persistent oil, nonpersistent petroleum products, hazardous chemicals), and seasonality. Ship data should be evaluated to determine design characteristics required for the risk analysis, such as the percentage of single-hull versus double-hull tank vessels, the extent of double-hull protection provided for fuel tanks, and the range of bunker tank capacities applicable to the various vessel types.

The categories of vessel types and sizes should be sufficiently fine-grained to allow assessment of measures that may be particular to a given trade or vessel type. The committee envisions that the vessel categories will include at least the following: product tankers (laden and in ballast), crude oil carriers (laden and in ballast), tank barges (laden and in ballast), liquefied natural gas carriers, containerships of less than 4,500 twenty-ft equivalent units (TEUs), containerships of more than 4,500 TEUs, bulk carriers of less than 60,000 tonnes deadweight tonnage, bulk carriers of more than 60,000 tonnes deadweight tonnage, roll-on/roll-off vessels and vehicle carriers, other cargo ships, government vessels, fishing vessels, tugboats, and other smaller vessels.

1b. Estimate the current movements of cargo oils, containers, bulk cargoes, bulk chemicals, and other commodities through the study region, and develop yearly estimates for the movement of cargoes through the region over the 2009–2034 study period.

Commodity movements through the Aleutian Islands should be estimated on the basis of fleet and traffic data, together with data from the various national port databases documenting trade. For instance, the U.S. Army Corps of Engineers compiles statistical data on waterborne commerce covering vessels that call on U.S. ports, and Statistics Canada maintains a similar database for Canadian ports. Considerable uncertainty exists because of global climate change and peak oil concerns, and alternative growth scenarios (e.g., new oil and gas fields) should be investigated (NRC 2007).

Historical growth in trade should also be reviewed. To forecast oil and dry cargo transport quantities for the period 2009–2034, data should be solicited from the various trade organizations, the U.S. Department of Energy, the Maritime Administration, ports, and other sources.

1c. Project the fleet makeup over the study period, anticipating likely changes in vessel size and design.

Over the 25-year study period, changes in the design of ships transiting the Aleutian Islands can be anticipated. For example, only a few containerships greater than 8,000 TEUs in size are currently in operation, but more than 100 ultralarge containerships are on order, ranging in capacity from 8,000 to 13,000 TEUs. The growth in ship size may reduce the number of vessels trading, but the average fuel tank capacity of ships will increase. Because containerships represent a significant portion of the vessels on innocent passage through Unimak Pass, the growth in vessel size will have a bearing on longer-term spill risks.

Regulations adopted by IMO and applicable to the international fleet also will influence the design and arrangement of ships. These regulations may apply only to newly constructed vessels, or if applicable to existing vessels, may have a phase-in period. The impact of these regulations on ships expected to transit the Aleutians during the study period should be considered:

- By 2009, the OPA 90 and MARPOL double-hull regulations for tankers will have been largely implemented. Any further phase-in of double hulls should be considered.
- For large commercial vessels, the majority of fuel oil tanks are arranged adjacent to the side or bottom shell. For new vessels contracted for after 2008, MARPOL Regulation 12A requires that the fuel tanks be double-hulled or that the tank arrangement be analyzed to demonstrate an equivalent level of expected mean outflow from accidents.
- A previous Transportation Research Board study (TRB 2001) found that certain double-hull tankers, particularly those with single-tank-across configurations, are prone to large accidental oil outflows. IMO subsequently implemented MARPOL Regulation 23, which requires all newly built tankers to meet specified outflow performance requirements.

1d. Develop yearly estimates for vessel traffic and the movements of ship's fuel oil (bunkers), cargo oil, and hazardous chemicals through the study region for the 2009–2034 period. Forecast growth in the fishing fleet.

The understanding of existing vessel traffic gleaned from Step 1a above, the forecasts of growth in trade and commerce derived from

Step 1b, and the characterization of the future fleet obtained from Step 1c should be used to project the traffic flow and fleet makeup for the study period. When projecting movements of petroleum products, consideration should be given to the anticipated increase in exploration for and production of gas and oil in the Bering Sea, the Chukchi Sea, and other Arctic regions.

2. Spill Baseline Study

2a. Estimate the spill frequency and projected spill size distribution by vessel type.

The accident types most likely to lead to large spills are collisions, powered and drift groundings, structural failures, and fires and explosions. In the Aleutian waters, groundings and collisions, particularly those occurring during inclement weather, are frequently the cause of large oil spills. Major spills from drift groundings in the waters around Unimak Pass (e.g., the M/V *Kuroshima* and M/V *Selendang Ayu* incidents) have heightened public awareness of and concern about drift groundings.

The spill baseline study should include the following accident types: collisions, drift groundings, powered groundings, allisions, structural failures, founderings, and fires and explosions. Historical spill statistics for the study area should be used to determine the distribution of spill sizes and the frequency of accident scenarios leading to the outflow of oil and other hazardous cargoes. Data from USCG, the State of Alaska, and salvors, as well as other local records, should be reviewed. Given the scarcity of significant spill events in the region, it will be necessary to augment the local spill data with data on U.S. and international spill events.

Because of the scarcity of data and the evolution of ship designs, it will be necessary to use expert opinion and limited numerical simulations to determine accident frequency. The scarcity of data on outflow from cargo tanks on double-hulled tankers as well as double-hulled bunker tanks means that probabilistic oil outflow analysis based on historical damage data or simulation will likely be needed to develop spill size distributions for collisions and groundings. These estimates should be verified against historical data for reasonableness.

The overall estimate of spillage should be subdivided among major ship categories. At a minimum, the following categories should be considered: tank ships, tank barges, containerships, other large commercial vessels, fishing vessels, and other small craft. Separate statistics should be provided for persistent and nonpersistent oils. Multiplying the frequency of spills by the average spill size will yield an overall estimate of spillage (in terms of barrels per year).

This spill study should also provide the information needed for Step 3 and Step 5 assessments. The types of accidents and the vessels involved should be mapped against indicators of consequence, such as the types of hazardous substances spilled, the distribution of spill size, the likely locations of spills, the seasonality (likely time of year) of spills, and safety implications in terms of loss of life and serious injuries.

2b. Develop the oil spill baseline over the 25-year study period as the product of the projected movements of oil and other hazardous materials and the estimated average spill rates.

The product of the projected quantities of oil and other hazardous materials moved over the 25-year study period by each vessel type and the spill rate for that vessel type provides the oil spill baseline.

3. Characterization of Spills from the Highest-Risk Accidents

Using the findings of the traffic and baseline spill studies, the Risk Analysis Team should produce a matrix that identifies for the higher-risk accidents the following information:

- Type of accident (e.g., drift grounding, collision),
- Type of vessel involved (e.g., containership, tank barge, fishing boat),
- Type of hazardous substance spilled (e.g., heavy fuel oil, marine gas oil),
- Representative spill sizes (50th and 95th percentile spill volumes),
- Likely geographic locations, and
- Seasonality (likely time of year).

In the Phase A consequence assessment (Step 4 below), spill trajectory studies will be performed to assist in assessment of the environmental and socioeconomic impacts of spills. Each combination of inputs from the above list represents a single assessment. On the basis of available resources, it is anticipated that between 10 and 15 such assessments can be carried out in the Phase A consequence analysis. The Management Team and Advisory Panel, in consultation with the Risk Analysis Team, should select a representative mix of spill events for the Phase A consequence analysis and identify the dominant accident types. The latter will be subject to further causality analysis and will receive the most attention when the Advisory Panel deliberates on potential risk reduction measures and their effectiveness.

4. Phase A Consequence Analysis

Although spill size serves as an indicator of consequences, it does not by itself define consequences to the extent that it can be used to compare reliably the risk posed by certain accidents and risk control measures. The type of oil or other hazardous substance, the location of the spill, and the time of year the spill occurs influence the extent of damage to natural resources, cleanup costs, and socioeconomic costs, and they should be considered along with spill size when consequences are evaluated.

To illustrate the importance of substance type, spills of persistent oils, such as the heavy fuel oil used for bunkers of large commercial ships, have properties different from those of the diesel oil and marine gas oil used for propulsion of smaller craft, such as fishing boats. The lighter refined products are more volatile, and their evaporation reduces the amount of oil remaining on the surface. Compared with spills of heavy oil, spills of diesel oil and marine gas oil generally have much lower cleanup and socioeconomic costs. Spills of diesel oil and marine gas oil also generally have less impact on seabirds and mammals, cause less shoreline contamination, and have lower cleanup costs than spills of heavier oils. On the other hand, the lighter oils dissolve and disperse more readily into the water column and can be expected to have greater impacts on fish and invertebrates in the water and on demersal fish and invertebrates in the benthic zone.

Likewise, the impacts and costs of spills are highly area dependent. Those impacts and costs are influenced by a range of factors, such as environmental conditions (tide, current, wind, sea state), sensitivity and exposure of natural resources, and the extent of economic and societal reliance on the sea and coastal regions. To provide an understanding of the relative influence of substance type, spill size, and location on spills in the study region, a scoping spill consequence analysis should be performed as part of the Phase A Preliminary Risk Assessment. At this stage, the consequence analysis should be a high-level assessment of natural resource vulnerability rather than a comprehensive assessment of biological impact and costs of natural resource damage. As necessary, more detailed analyses can be carried out when risk reduction measures are assessed.

The Phase A consequence analysis, then, should cover a mix of spill sizes, substance types, and locations. As noted in the preceding section, the specific parameters to be addressed by the analysis should be determined on the basis of the results of the traffic, spill baseline, and spill likelihood and size studies. The following scope is suggested for the analysis:

- Spills of two to four types of substances should be evaluated. At a minimum, heavy fuel oil and diesel oil should be evaluated. On the basis of the projected spill rate data developed during the spill baseline study, it may be decided that certain chemicals or other products, such as crude oil, marine gas oil, or gasoline, merit inclusion in the consequence analysis.
- Three to five geographic spill locations should be evaluated. These locations should include those where spills (particularly larger ones) are likely to occur and where environmental or economic impacts are expected to be most severe.
- Two or three sizes of spills should be evaluated, including the 50th and 95th percentile spill volumes (a typical and a large spill).

The physical fate model used should be three-dimensional and capable of calculating mass balance for relevant spaces, including the water surface, the shoreline, the water column, and sediments. The model should permit evaluation over time of the surface oil distribution and concentrations of oil in the water column and sediments. The environmental conditions (wind, currents, tides, and waves) input to the models should be derived from local long-term statistical data, with the date and time varied randomly to provide a range of weather conditions.

For this preliminary consequence analysis, the extent and concentrations of oil should be used as a surrogate for impact on natural resources. To provide an indicator of impact on seabirds and mammals, exposure should be expressed in terms of water surface area oiled, geographic extent of shoreline oiling, and percentage of oil washed ashore. To provide an indicator of impact on fish and invertebrates, the volume of water affected above thresholds of concern, as well as the area of bottom sediment contamination, should be determined.

In the detailed consequence analysis that may be required for assessment of risk reduction measures or for cost–benefit analysis, a biological model should be applied to measure exposure of aquatic habitats and wildlife to the substances spilled. Such a model should determine the impact of the substances on populations, given abundance data for the species of interest. It is important for the fate and biological modeling tools to be well established and calibrated against actual spill data.

During this preliminary consequence analysis, assessment of socioeconomic impacts should be qualitative. Such impacts are difficult to quantify, especially during the preliminary stages of a risk assessment, but are a significant part of the overall consequences of a spill. Studies (e.g., McCay et al. 2003) indicate that when all impacts are quantified, the socioeconomic costs alone can exceed the aggregate cost of property damage, cleanup, and resource damage for some scenarios. The Aleutian region is characterized by a high level of resource dependency (see Chapter 3) and therefore a high level of community vulnerability to spills of oil and other hazardous substances. (See Appendix I for further discussion of resources at risk, resource dependency, and community vulnerability in the region.)

5. Accident Scenario and Causality Study

From the preceding studies, dominant accident types should now be identified. For example, it might be found that the important accidents are collisions and drift groundings involving cargo ships operating in and around Unimak Pass, drift groundings of tank barges, and founderings and groundings of fishing vessels operating in particularly environmentally sensitive regions. For each of the dominant accident types, the Risk Analysis Team should develop representative accident scenarios. These scenarios will by their nature describe principal causes. Probabilities of occurrence for these scenarios should be assigned and presented with the associated consequences (in terms of expected spill sizes and types of hazardous substance spilled). The confidence level in the probability figures should be clearly stated, since many of these figures will have a high level of uncertainty.

To the extent practical, the historical data used in the baseline spill study should serve as the basis for these probabilities. In many casualty and incident reports, however, cause is not clearly specified. Therefore, analysts will need to rely on sources from outside the Aleutian Islands, other risk assessments, and expert opinion in conducting this study of accident scenarios and probabilities.

PHASE A PRELIMINARY RISK ASSESSMENT: QUALITATIVE ASSESSMENT AND PRIORITIZATION OF RISK REDUCTION OPTIONS

To complete the Phase A preliminary risk assessment, a qualitative assessment of risk reduction options should be performed by the Advisory Panel and Management Team. This effort should include populating the risk matrices, compiling a list of risk reduction options, qualitatively assessing the benefits and costs of those options, and prioritizing the options. The Risk Analysis Team should be available during these deliberations to provide background information and insight into the Phase A investigations. It is recommended that the methodology used for this qualitative portion of the Part A assessment be similar to that presented in the USCG publication *Marine Operations Risk Guide*.

6. Development of Rankings for Accident Scenarios

6a. Develop frequency and consequence categories and risk matrix format.

As discussed in Chapter 2, a typical risk matrix may have three columns and three rows or perhaps six columns and six rows. Typically, the rows represent levels of likelihood (ranges of probability of occurrence of the scenarios or accidents), and the columns represent consequences (ranges of severity of consequences). Table 6-1 contains example criteria for likelihood, and Table 6-2 contains example criteria for consequences.

It is not straightforward to combine consequences that are often quite different in nature and difficult to quantify (e.g., loss of life, damage to the environment, socioeconomic impact). It can be helpful to assign severity levels by type of consequence and then combine these values into an overall consequence rating. Tables 6-2 and 6-3 support this type of an approach. However, special care must be taken in performing this type of subjective prioritization. Although an overall risk rating is a helpful tool for comparing and prioritizing

TABLE 6-1 Example Criteria for Likelihood

	Frequency Category	Description
5	Very frequent	From 10 to 100 events per year
4	Frequent	From 1 to 10 events per year
3	Occasional	From 1 event every 10 years to 1 event per year
2	Infrequent	Less than 1 event every 10 years
1	Rare	Not expected to occur

alternatives, it can be misleading when consequences and their likelihoods of occurrence have significantly different magnitudes.

Tables 6-1, 6-2, and 6-3 are presented as examples only. The Advisory Panel, in consultation with the Management Team and Risk Analysis Team, should determine the frequency and consequence categories that are appropriate and the criteria to be applied for each category. These criteria are for purposes of ranking scenarios and accidents by level of risk and eventually effectiveness of risk reduction options and will not necessarily be the basis for the final decision on which options will be implemented. That final

TABLE 6-2 Example Criteria for Consequences

	Severity	Safety Impact	Environmental Impact	Economic Impact	Mission Impact
3	Major	One or more deaths or permanent disabilities	Releases that result in long-term disruption of the ecosystem or long-term exposure to chronic health risks	At least \$3,000,000	At least \$3,000,000
2	Moderate	Injury that requires hospitalization or lost workdays	Releases that result in short-term disruption of the ecosystem	At least \$10,000 and less than \$3,000,000	At least \$10,000 and less than \$3,000,000
1	Minor	Injury that requires first aid	Pollution with minimal acute environmental or public health impact	At least \$100 and less than \$10,000	At least \$100 and less than \$10,000

Source: USCG 2008, Chapter 2, p. 6.

TABLE 6-3 Example Criteria for Consequences by Consequence Category

Consequence	1—Incidental	2—Minor	3—Serious	4—Major	5—Catastrophic
Natural resources	No significant wildlife kill or habitat impact				Destruction of unique or rare habitat
Health and safety of public	No significant exposure				Significant exposure for many people
Health and safety of crew	Minor injury at most				Multiple fatalities or permanent disabilities
Release of oil or cargo	Recordable event with no outside notification (e.g., onboard containment, placarding, mistowage)				Significant release or irreparable damage with long-term effects
Socioeconomic impact	No significant disruption of industry or society				Total loss of asset/multiple industries affected; multi-generational community impact
Damage to reputation	No adverse news coverage				International adverse news coverage

choice rests with decision makers rather than the Advisory Panel or the Management Team.

6b. Assign frequency and consequence categories to each scenario.

The Risk Analysis Team should make an initial attempt to assign frequency and consequence categories to each scenario. In doing so, the team should consider the results of the semiquantitative Phase A studies, as well as the uncertainty of the data. The Advisory Panel, in consultation with the Management Team and Risk Analysis Team, should review these tables and make adjustments where deemed appropriate.

6c. Assign risk numbers (risk priority scores).

The frequency and consequence categories can now be combined to form a risk priority score. Figure 6-1 shows an example from the *Marine Operations Risk Guide*, where the risk for each hazard or accident falls into one of four groups: very high (VH), high (H), moderate (M), or low (L). Alternatively, risk numbers can be used to define the risk groups (e.g., 1 through 5, where 5 is the highest risk level). The Advisory Panel, in consultation with the Management Team and Risk Analysis Team, should develop a risk priority matrix format suitable for this assessment.

Frequency of Occurrence (or Likelihood)	**Consequences (Severity of Accident)**				
	Incidental (1)	Minor (2)	Serious (3)	Major (4)	Catastrophic (5)
Frequent (5)	M	H	VH	VH	VH
Occasional (4)	M	M	H	VH	VH
Seldom (3)	L	M	H	H	VH
Remote (2)	L	L	M	H	H
Unlikely (1)	L	L	M	M	H

HIGH RISK

LOW RISK

FIGURE 6-1 Example risk priority matrix. L = low risk; M = moderate risk; H = high risk; VH = very high risk.

6d. Rank accident scenarios by level of risk.

Using the priority risk matrix, scenarios should be consolidated into four or five risk categories. The Advisory Panel, in consultation with the Management Team and Risk Analysis Team, should attempt to further rank the accident scenarios within each group, producing an overall ranking of accident scenarios.

7. Development of List of Potential Risk Reduction Options

Central to the ultimate purpose of a risk assessment is the identification and implementation of appropriate measures to reduce the risk of accidents to acceptable levels. The committee has compiled an initial list of potential risk reduction options by using several sources, beginning with preliminary work accomplished by stakeholder groups and government agencies in Alaska over the past few years of analyzing the problem. The list also includes suggestions made by stakeholders at the committee's meetings in Anchorage and Dutch Harbor. Appendix A contains this initial list, grouped within a few general categories. The committee attempted to include all ideas that were advanced; the list has not been vetted or prioritized.

Some of these options have already been investigated, and some have apparent benefits as well as implementation paths that have been described. For example, several Alaskan organizations have proposed approaches for improved vessel tracking and some forms of VTS for Unimak Pass. The Marine Exchange of Alaska has put forth a proposal to build and operate additional AIS receiving sites and an operations center to track and communicate with vessels and identify potentially unsafe vessel transits. The Alaskan Marine Pilots have suggested the development of formal VTS for Unimak Pass and its vicinity and have prepared a paper describing the elements of such a service and explaining how it would work.

In addition, USCG has in the past implemented VTS in a number of ports and waterways in the United States on the basis of analyses of vessel accident risks in these locations. For these existing USCG-authorized VTS installations, various approaches are used, including USCG owned and operated, marine pilot operated, and marine exchange operated, all under USCG waterways management authority. Current vessel traffic in and around Unimak

Pass is substantial; thus a careful investigation by USCG of the advisability of establishing VTS in the Unimak Pass area appears warranted.

Another risk reduction option for which there has been some investigation and evaluation is providing emergency towing equipment that can be delivered to vessels in distress if and when needed. The City of Unalaska, in cooperation with industry and government partners, recently developed a towing package that could be used to aid vessels in distress in the region near Dutch Harbor and Unimak Pass. As more information on vessel traffic is developed, local authorities may refine this option to make it more effective.

The committee suggests the list in Appendix A as a starting point for evaluating options as part of the risk assessment process. This list should be reviewed, expanded upon, and refined, preferably by the Advisory Panel. Many of the likely members of that group are responsible for measures on the committee's list of potential risk reduction options, and many have local knowledge of the waterways, the environment, the infrastructure, and shipping in the Aleutian region. They have the expertise and the interest to augment the work of the Risk Analysis Team in this important way. It is anticipated that other stakeholders, the Management Team, and the Risk Analysis Team will offer additional suggestions.

This work can begin in parallel with earlier steps in the Phase A risk assessment, although the list should be revisited and possibly expanded upon when the results of the vessel traffic, spill baseline, and Phase A consequence studies are available. The rankings of accidents and scenarios should also prove useful in identifying potential risk reduction options.

8. Evaluation of Risk Reduction Options

In this step, the effectiveness, order-of-magnitude cost, and ease of implementation of the risk reduction options are evaluated. The Risk Analysis Team should make an initial, qualitative effort to estimate the benefits and costs of the options. The Advisory Panel, in consultation with the Management Team and Risk Analysis Team, should review these estimates and adjust them where deemed appropriate.

8a. Estimate the benefits of the risk reduction options.

A risk control measure is effective if it reduces the frequency of an accident, the consequences of the accident, or both. For instance, the example shown in Figure 6-2 reduces the frequency category by two levels and the consequences category by one level. This can be represented as an overall relative risk reduction score (e.g., 1 + 2 = 3), which can be used to rank the effectiveness of the risk reduction options identified in Step 7. It should be remembered that a given risk reduction measure may be effective for a number of different accident types, and the cumulative impact of measures must be considered when they are ranked.

8b. Estimate the cost of the risk reduction options and the cost–benefit ratio.

During this step of the Phase A assessment, costs should be estimated by category. For instance, the cost of implementation might be assigned a rating from 1 to 4, where 1 is little or no cost, 2 is minimal cost, 3 is significant cost, and 4 is major investment. The Advisory Panel, in consultation with the Management Team, should develop the cost categories and the range of costs assigned to each category. The Risk

Frequency of Occurrence (or Likelihood)	**Consequences (Severity of Accident)**				
	Incidental (1)	Minor (2)	Serious (3)	Major (4)	Catastrophic (5)
Frequent (5)	M	H	VH	VH	VH
Occasional (4)	M	M	H	Risk without measure	VH
Seldom (3)	L	M	H	H	VH
Remote (2)	L	L	Risk after measure	H	H
Unlikely (1)	L	L	M	M	H

FIGURE 6-2 Risk priority matrix. L = low risk; M = moderate risk; H = high risk; VH = very high risk.

Analysis Team can then make an initial attempt to assign cost categories to the risk reduction options. Costs should include industry compliance costs, costs borne by the public, and enforcement costs. For this level of analysis, avoided costs related to injury and death, property damage, resource damage, and socioeconomic impacts should be considered as part of the qualitative benefit assessment in Step 8a above. A cost–benefit ratio can be developed by dividing the relative risk reduction score determined in Step 8a by the cost rating.

8c. Assess the ease of implementation of risk reduction options.

The practicality of implementing and enforcing a risk reduction measure should also be evaluated. Questions to be considered include the following: Who can implement the measure (e.g., government agency, industry, international agreement, multiple parties)? How feasible is it to implement? How likely is it to succeed? How much time is required for implementation? As with benefits and costs, ease of implementation can be assigned a category rating.

9. Prioritization of Risk Reduction Options

The final step in the Phase A assessment is ranking the risk reduction options taking into account all factors, including the benefits realized, the cost–benefit ratio, and ease of implementation. The cost–benefit results must be viewed with care, since the options exhibiting the lowest ratios may not be those providing the highest net benefits. This effort will require the collective judgment of the Advisory Panel and the Management Team.

When the proposed risk reduction measures are reviewed in this way, it will become apparent that some are much more likely to provide significant benefit than others. It will also become clear that many are aimed at the same kind of improvement, such that the benefit of some will be provided more effectively by others. This culling process will therefore produce a more focused set of potential measures. It will also enable expert judgment to provide a check on the data-driven analysis performed by the Risk Analysis Team.

On the basis of this prioritization effort and the recommendations of the Advisory Panel, the Management Team may decide that there is sufficient justification to recommend immediate implementation of some of the potential risk reduction measures. In these cases, the Management Team should document the fact that uncertainty in the estimates of frequencies and benefits have been accounted for. This could be achieved, for example, by demonstrating that assumptions are conservative.

Other criteria could also be used for prioritization. The cost–benefit ratio is important and USCG is one of the federal agencies that is required to consider costs and benefits in risk prioritization, but it might be useful to augment this with a consideration of uncertainty because a highly promising strategy may not merit additional investigation if the Phase A analysis provides definitive evidence regarding its efficacy. In contrast, if there is another strategy that has a moderate expected value but high uncertainty (it could be extremely effective, but there is not enough evidence to judge), this strategy might be a higher priority for investigation in Phase B. Because one goal of Phase B is to reduce uncertainty and to identify the most promising strategies, it might be effective to prioritize strategies on the basis of risk reduction potential.

At this stage, it will be possible to screen some measures out as insignificant or ineffective. Other measures will be identified as demonstrating sufficient promise, and these will be assessed in detail in the Phase B Focused Risk Assessment.

PHASE B FOCUSED RISK ASSESSMENT

The Phase B Focused Risk Assessment involves a more in-depth look at the potential risk reduction measures identified in Phase A, aimed at quantifying their benefits and costs and better understanding their secondary effects on both the overall system and the net benefits of other measures. The results of this effort should provide the Management Team and Advisory Panel with sufficient information to make recommendations with regard to the implementation of risk reduction measures and produce a report documenting the justification for these recommendations.

The potential risk reduction measures identified during Phase A as warranting further study will largely dictate the scope of the Phase B assessment. Therefore, this section does not explicitly define the Phase B study, but rather describes the expectations for the effort and some of the tools and techniques that can be applied in carrying it out.

When preparing the request for proposals for the Phase B assessment, the Management Team should balance the level of rigor and sophistication to be specified for the analyses with the needs of the assessment. In general, the depth of the analyses should be commensurate with the level of the risks being investigated. Resources must be directed at accomplishing the overall goal of the risk assessment—to reduce risk of spills to an acceptable level. Phase B can be accomplished in discrete steps as necessary on the basis of the priority of the measures to be investigated and the level of risk reduction possible.

The level of rigor needed and the types of analysis techniques to be applied may depend not only on the level of risk being investigated but also on the complexity of the system, the role of human factors in the dominant scenarios, the uncertainty of the analysis techniques, and the extent of historical precedents and the availability of similar studies. The particular geographic area may also be a factor. Dynamic risk models incorporating comprehensive system simulations generally provide the most insight into system behavior, the influence of system changes (e.g., increases in vessel movements), and unexpected consequences of changes to the system. The dynamic nature of the system should not be underestimated. The quantities and types of cargo movements, the design of vessels, weather and environmental conditions, and regulatory requirements are some of the many factors undergoing constant changes. This complex system must be modeled with sufficient rigor and evaluated over an extended period of time to capture the implications of these changes for the risk of spills from vessels. Dynamic risk models are expensive to develop, however, and should focus on geographic areas of particular interest. Human factors analysis can also be resource-intensive and should focus on those areas where high risk has been identified and where potential risk reduction measures are practical and enforceable.

Phase B Analysis and Techniques

The Phase B risk analysis should follow the basic steps outlined for Phase A. The specific modeling and analysis methods may differ, however, because the analysis needs to be more focused, with sufficient detail, precision, and data quality to allow more robust decisions on the selection, design, and implementation of cost-effective risk reduction measures. To the extent possible, Phase B should be a quantitative assessment. Other characteristics of the Phase B risk analysis methods are described below.

Possible Need for Use of Hybrid Modeling Methods to Develop the Risk Scenarios

Hybrid modeling used to develop Phase B risk scenarios may employ the following techniques:

- Event sequence diagrams for the development of categories of risk scenarios at an appropriate level of abstraction (see Appendix F for further discussion of event sequence diagrams and their use in developing risk scenarios);
- Fault trees, Bayesian belief networks, or similar logic modeling methods as necessary to add causal detail to the events of the event sequence diagrams; and
- Physical models and simulation, particularly for environmental consequence analysis (modeling the fate and effects of spilled substances) and system simulation (capturing the complex interactions of vessel traffic and the changeable conditions in which the vessels operate).

Need for More Detailed Causal Modeling, Particularly in Areas Where Risk Reduction Measures Are Being Considered

Normally, the level of detail of risk analysis is influenced by data availability. When certain details are essential to understanding how risk reduction measures work, however, such details should be added even in the absence of data so that sensitivity analysis (see below) can be performed. Doing so usually requires a combination of modeling techniques (e.g., event sequence diagrams, fault trees) or system simulation supplemented by elicitation of expert opinion.

Need to Consider Possible Human Errors in Critical Phases of Risk Scenario Evolution

In the case of marine accidents, causality can often be traced to human factors, making evaluation of human error (e.g., in causing accidents, in implementing response plans and rescue operations) a critical part of the overall risk assessment. This analysis, at a minimum, should include identification of human failure events, with assessment of corresponding human error probabilities. A more detailed human reliability analysis may be necessary in some cases. See Appendix D for further discussion of human error and human reliability analysis methods.

Consideration of Rare, High-Consequence Events as Well as More Frequent, Lower-Consequence Events

Both types of events need to be examined. The methods used to study each type may differ.

Use of Advanced Methods for Estimation of Model Parameters

Such methods may encompass, for example, probabilities of events, projection of vessel traffic into the future, and metrics for the effectiveness of risk controls. They may also include Bayesian inference, a well-established technique for assessing rare and catastrophic events. See Appendix E for further discussion of Bayesian statistical analysis methods.

Use of Formal Methods for Employing Expert Opinion

Study of the risks associated with complex man-made and natural systems always involves subjects for which data or models either do not exist or are not cost-effective. In such cases, expert opinion becomes an important resource for the analyst. Formal methods for the use of expert opinion include guidelines and techniques for selection of subject matter experts, elicitation of their opinions, and use of those opinions (e.g., methods for aggregating probability estimates obtained from multiple experts). See Appendix C for further discussion of the elicitation and use of expert opinion.

More Rigorous and Comprehensive Uncertainty and Sensitivity Analyses

Conservatism is often used to offset the higher levels of uncertainty expected in the preliminary, highly qualitative stages of risk assessment. The more detailed assessments of the Phase B focused analyses should necessitate less reliance on conservative assumptions. The findings of the analysis need to be carefully scrutinized and the level of uncertainty explicitly stated, however, so that decision makers will not inadvertently be left with a false sense of precision.

All important sources and types of uncertainty need to be considered in generating and reporting the findings of the Phase B risk analyses. These include uncertainties stemming from the structure and form of the models employed, generally referred to as *model uncertainty,* and uncertainties in the model parameters, generally known as *parameter uncertainty.* In the Phase B analyses, uncertainty should be quantified when practical. Doing so imposes discipline and requires the analyst to scrutinize the robustness of each assumption made.

Sensitivity analysis is a technique for assessing the influence of varying inputs on analysis results. Sensitivity analysis is appropriate for evaluating the impact of significant model assumptions and highly uncertain model parameters on the development of risk scenarios, modeling of consequences, and evaluation of the role and effectiveness of risk reduction measures. See Appendix E for further discussion of uncertainty and sensitivity analyses.

Consequence Analysis

The extent of additional consequence analysis required for the Phase B assessment will be influenced by the types of risk reduction measures to be evaluated and the possible need for monetizing of benefits, such as avoidance of natural resource damage and socioeconomic costs. Both spill outflow analysis and biological consequence modeling may be necessary.

Spill Outflow Analysis

In the Phase A assessment, the size of spills is based primarily on historical data. During Phase B, it may be desirable to obtain more detailed estimates of the distribution of spill sizes for certain accident scenarios. Moreover, changes in vessel design and size and the size of bunker tanks may make it difficult to predict spill size entirely on the basis of historical data, in which case analytical techniques should be applied.

A number of approaches are available for calculating spill size given a particular vessel design and type of accident. These include simulation of groundings and collisions and assessment of structural damage based on energy balance (TRB 2001, 250–255), as well as probabilistic methods based on historical damage (TRB 2001, 195–198). A broad range of factors influence outflow, such as the structural arrangement of the ship, the characteristics of the struck object, the speed of the vessel, and weather conditions. The complexity of the problem necessitates the use of many simplifying assumptions, which in turn reduces the confidence level of the results. If these approaches are applied in the Phase B analysis, their results should be benchmarked against historical spill data to the extent practical.

Biological Consequence Modeling

The physical fate of a number of representative spill scenarios (e.g., type of oil, size, location) is investigated in the Phase A assessment. For that analysis, the concentrations of the spilled substance contaminating the water, sediment, and shoreline are used as an indicator of environmental damage. Additional model runs may be needed during Phase B, because other locations or spill sizes may require evaluation. Where particularly sensitive habitats are endangered, estimates of fatalities to fish, invertebrates, seabirds, and mammals may be desired. For these analyses, a biological model is applied together with the fate model to determine exposure of habitats and organisms to lethal levels of spill components and to estimate mortality and ecological losses. Estimating natural resource damage requires compilation of abundance data for species of interest (e.g., fish, invertebrates, seabirds, otters).

Cost–Benefit and Cost-Effectiveness Analysis

The Phase A assessment includes a high-level look at costs and benefits, which involves assigning categories of costs and benefits largely through qualitative analysis. In Phase B, the costs and benefits should be quantified to the extent possible.

The Office of Management and Budget (OMB) provides guidance for regulatory analysis of federal regulations (Circular A-4, September 17, 2003). Although not all of the risk reduction measures being considered would require federal intervention, the procedures for cost–benefit analysis and cost-effectiveness analysis should be applied to all the measures to facilitate decision making.

In cost–benefit analysis, both costs and benefits are monetized. The results make it possible to compare all risk reduction measures according to a common metric and reduce reliance on the use of professional judgment to compare benefits qualitatively. Cost–benefit analysis should be performed to the extent practical when benefits can reasonably be monetized. Cost-effectiveness analysis is applied when it is difficult to monetize benefits, particularly when safety and health assessments come into play. For instance, cost-effectiveness can be expressed as cost per fatality avoided or cost per barrel of oil spill avoided. Results of cost-effectiveness analysis can be misleading, however, when the effectiveness measure does not properly map consequences or when disparate types of benefits are combined. For example, the consequence of an oil spill is influenced by the type of oil spilled and the size and location of the spill; this makes it difficult to compare different accidents and risk reduction measures on the basis of barrel of oil spill avoided. Furthermore, a risk reduction measure may improve safety (i.e., reduce serious personal injury or fatality rates) while reducing the likelihood or size of a spill.

OMB recommends that costs and benefits be quantified whenever possible. Where costs or benefits cannot be monetized, they should be expressed in physical units. If they cannot be expressed in physical units, a qualitative description of the costs and benefits should be provided. Key elements of the regulatory analysis approach recommended by OMB are as follows:

- Document how a risk reduction measure will provide expected benefits.
- Compare costs and benefits against a *no action* baseline.
- Identify the expected undesirable side effects and ancillary benefits of the risk reduction measure, and add them to the direct benefits and costs as appropriate.

The baseline spill projection developed during Phase A and subsequently refined during Phase B should be used as a basis for the *no action* baseline. An annualized stream of costs and benefits should be developed relative to this baseline and then discounted to present value for comparison purposes. The OMB guidelines provide procedures for discounting costs and benefits.

In prior maritime regulatory assessments, USCG has frequently expressed cost-effectiveness in terms of *barrels of spilled oil averted*. For example, the methodology applied in an assessment of the use of rescue and escort tugs to avoid oil spills in the Puget Sound area (USCG 1999) assumed the following. Where a risk reduction measure was deemed effective in avoiding accidents and consequently reducing vessel damage, cargo loss, time loss, human injuries, or loss of life, these avoided losses were treated as benefits. These *avoided costs* were subtracted from the *cost of compliance and enforcement* to obtain the *net costs. The net cost-effectiveness* equaled the *benefits* (present value of the number of barrels of oil not spilled) divided by the *net cost*. In this case, a *value of statistical life* was applied to monetize fatalities, thereby allowing benefits to be expressed in terms of *barrels of oil spill averted*.

The committee recommends that a similar approach for quantifying cost-effectiveness be applied for all the risk reduction measures evaluated in Phase B. Again, it should be remembered that cost-effectiveness ratios alone are not sufficient for decision making but should be supplemented by quantified benefits, including estimates of spill size distribution, as well as mean spill size and numbers of fatalities and serious injuries avoided. The oil spill trajectory models and spill fate assessments will assist in the qualitative assessment of different spill sizes and spill types. With this approach, cleanup costs, costs of natural resource damage, and socioeconomic costs are treated as part of the qualitative assessment.

A number of approaches and techniques are available for monetizing cleanup costs, costs of natural resource damage, and socioeconomic costs. In one approach for estimating costs of natural resource damage, for example (McCay et al. 2003), a biological model is applied as described in the section on consequence analysis. The basis for estimating these costs is the cost to restore equivalent resources. Another example is an approach described for estimating cleanup and socioeconomic costs for spills in San Francisco Bay (Etkin 2003). See Appendix I for further discussion of resource vulnerability and natural resource damage.

Evaluating the costs of natural resource damage can be expensive, depending in part on the availability of the necessary biological data. After reviewing the Phase A results, the Management Team, in consultation with the Advisory Panel and Risk Analysis Team, should decide on the extent to which the costs of natural resource damage and socioeconomic costs will be evaluated. This information may be needed to compare the relative impact of spills of different sizes or different oil and chemical types, or to justify risk reduction measures involving particularly high implementation costs.

DEVELOPMENT AND REPORTING OF RECOMMENDATIONS FOR DECISION MAKERS ON RISK REDUCTION MEASURES TO BE IMPLEMENTED

The recommendation of risk reduction measures for implementation by decision makers requires consideration of who the decision makers are in the risk management system and their capacities, both individually and collectively, to implement recommended measures. An additional consideration is the type or packaging of information needed by decision makers given their specific regulatory roles or mandates. For example, USCG rulemaking depends on consideration of benefits relative to costs, as described above. Within the bounds of their respective jurisdictions, USCG, the State of Alaska, and local municipalities all have decision-making roles. Securing federal funds involves other U.S. government branches, and IMO will have a role as well if changes to international regulations are recommended. For the more costly and far-reaching measures, successful implementation may well require a collaborative agreement among decision makers and the support of stakeholders, and some such measures, such as those that require the involvement of IMO, may take longer to implement than changes that can be made at the local level.

The Management Team and the Advisory Panel should prepare a final report providing recommendations to decision makers in a way that documents the basis for those recommendations in the risk assessment. According to IMO's Formal Safety Assessment (see Chapter 2), the purpose of this final stage of the risk assessment is

> to define recommendations which should be presented to the relevant decision makers in an auditable and traceable manner. The recommendations would be based upon the comparison and ranking of all hazards and their underlying causes, the comparison and ranking of risk control options as a function of associated costs and benefits, and the identification of those risk control options which keep risks as low as reasonably practical.

To meet the objectives of the risk assessment, the final report should be fully transparent, describing the risk assessment process and all relevant assumptions. It should show that the full range of relevant hazards and risks was adequately investigated, describe major uncertainties that affect the robustness of the conclusions reached, and demonstrate that the analysis was of sufficient rigor to represent benefits and costs accurately to the extent practical. The following should be found in the final report:

- Hazards and risks should be clearly identified. For risk reduction measures that merit detailed analysis, costs and benefits should be clearly defined.
- All sources of data should be documented and assumptions explained. Models and methodologies should be described in sufficient detail that a third party can understand the basic assumptions and limitations of the assessment.
- Judgments applied during the assessment should be explicitly stated. The process for elicitation and analysis of expert opinion should be explained.
- Uncertainty and associated sensitivity analyses should be clearly documented and explained. Results should be presented in a way that does not create a false sense of precision.
- The report should be of sufficient depth to address the needs and expectations having those with expertise in risk assessment while being understandable to the layman.

Ideally, all stakeholders and decision makers will reach consensus on measures to be implemented. Past experience in risk management indicates that this is not always possible, however, since some stakeholders may have strong positions on which they are unable or unwilling to compromise, or uncertainties may cloud the true worth of some risk reduction measures or the true costs associated with their implementation. When consensus cannot be reached, the report should present the differing opinions, thereby assisting decision makers in understanding the various sides of the issues.

As discussed in Chapter 2, risk can be characterized as negligible, tolerable, or intolerable. The goal of the risk assessment that is the subject of this report is to improve the level of safety related to spills from ships operating within the Aleutian Islands region. The implementation of risk reduction measures identified by this assessment should result in risk falling at or below the tolerable level (although it may not be possible to define such a level with precision), and decision makers must decide which measures or which combination thereof will achieve this goal. In so doing, they must balance the level of investment required to implement the measures against the projected safety level of the system that would result.

Although the decision as to which measures will be adopted ultimately rests with the decision makers, the Management Team and Advisory Panel must attempt to address the concept of acceptable risk in formulating their recommendations. The acceptable level of risk will vary among different stakeholders. A collaborative effort will be necessary to understand the viewpoints of different stakeholders and meld them into an acceptance criterion.

Once decisions have been made and risk reduction measures implemented, there should be a process for monitoring the effectiveness of the measures and the overall acceptability of system risk. The final report should include a proposed structure for this ongoing risk management process, which should include metrics for the continuous monitoring of risk. Specific institutional arrangements will likely be necessary to foster continued discussion among a broad range of stakeholders regarding the residual risk in the system and the adequacy of the measures instituted to control that risk. Experience with other systems having the complexity of shipping through the Aleutian Islands suggests that risk cannot be reduced to zero by risk reduction measures that can feasibly be undertaken.

REFERENCES

Abbreviations

NRC	National Research Council
TRB	Transportation Research Board
USCG	U.S. Coast Guard

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CHAPTER 7

Conclusions and Recommendations

The committee's charge was to design a comprehensive risk assessment for evaluating the risk of vessel accidents and spills in the Aleutian Islands and to recommend an appropriate framework for conducting that assessment. To fulfill this charge, the committee reviewed and evaluated available data and information on the current system and the operating environment. The recommendations presented in this report are intended to provide a logical sequence of building blocks that can be used to conduct the assessment in discrete steps so that early decisions can be made about the most important safety improvements and risk reduction options can be considered in priority order. This approach will allow for an efficient and focused study.

During its review of historical data on maritime operations in the Aleutian region and accidents that have occurred, the committee identified a number of areas of concern with respect to the safety of the existing system. Recent trends in vessel traffic in the region, combined with accident data, difficulties in responding to incidents, and the lack of infrastructure that explains many of those difficulties, made it possible to identify where improvements in each of these areas could be considered. Where appropriate, then, the committee developed findings related to accident prevention and mitigation whose implementation could simultaneously enhance the risk assessment process and contribute to safer shipping operations.

CONCLUSIONS

The Aleutian Islands: Natural Resources and Maritime Operations

Central to the public concern about improving the safety of shipping in the Aleutian Islands are the unique and valuable natural resources in the region that could suffer damage from shipping accidents. The region also is subject to frequent and sudden storms, high winds, and severe sea conditions that create operational challenges for all mariners. History has shown that spills in the Aleutians have been geographically widespread and that efforts to recover the oil have been ineffective.

In its review of existing data on the Aleutians and their environment, the committee found that ***the area is home to globally unique natural resources.*** The vast diversity of species over an expansive region is well documented, and most of the Aleutian Island chain has been designated as a national wildlife refuge. Few marine areas in the world match the Aleutians in marine productivity, and Dutch Harbor is the leading fishing port in the United States in terms of volume. ***The economy of the Aleutians relies on the fishing industry, which accounts for more than 80 percent of private-sector employment.***

Large commercial vessels engage in the substantial and growing maritime trade between northwestern North America and northern Asia traveling the North Pacific Great Circle Route, which traverses the Aleutian Islands. About 4,500 ships transit Unimak Pass annually, averaging 12 per day, and a similar number travel just south of the Aleutians annually as well. This number represents a significant increase in just the 2 years since the State of Alaska Department of Environmental Conservation published a report on vessel traffic through Unimak Pass, in which it was estimated that 3,100 ships per year passed westbound through the Aleutians. The ship traffic in the region comprises a mix of large containerships, bulk carriers, car carriers, tankers, and others—most of which are foreign-flagged and on innocent passage through these waters. These vessels carry large quantities of fuel oil and various cargoes, including chemicals and other hazardous materials. A few significant accidents in recent years have heightened public concern about the risks posed by these vessels, especially as traffic has grown in both volume and complexity.

Vessel traffic through Unimak Pass is roughly double that calling on all ports in the 17th U.S. Coast Guard (USCG) District (Alaska). Yet vessels entering those major ports are subject to a set of controls, whereas similar vessels traveling on innocent passage through the Aleutians need not meet comparable requirements.

Vessel Accidents and Spills

Fishing vessels transit the region near Dutch Harbor, while large commercial ship traffic on the North Pacific Great Circle Route is concentrated in and near Unimak Pass, as are the local fishing fleet, tugs and barges, ferries, and other small ships. Farther out in the Aleutian chain, the traffic is more dispersed, but hazards are always present. Since 2005, USCG has been able to track commercial ships transiting Unimak Pass, and these data can be combined with incident/accident reports to determine historical patterns.

Historical data on accidents and spills in the Aleutians show that fishing vessels account for the majority of accidents, resulting mainly in small spills, while the large commercial fleet has experienced only a few major incidents, but involving much larger spill volumes. Over the past two decades, about 20 fishing vessel accidents with spills in excess of 1,000 gallons have been documented, while just two commercial vessel accidents (the M/V *Selendang Ayu* in 2004 and the M/V *Kuroshima* in 1997) spilled 336,000 gallons and 40,000 gallons, respectively. These and other accident and spill data are valuable input for the risk assessment process. In addition, data for the past 20 years on response to spills in the Aleutians have shown that almost no oil has been recovered as a result of attempts made by the responsible parties or government agencies and that in many cases weather and other conditions have prevented any response at all. This evidence and other data on the difficulty of recovering oil from the sea in open ocean environments and severe weather conditions lead the committee to conclude that ***accident and spill prevention should be given high priority when risk reduction options are selected for evaluation.***

Safety Infrastructure and Its Limitations

The 1,200-mile-long Aleutian Island chain is remote and sparsely populated, with few sizeable harbors and minimal maritime infrastructure, especially of the kind that can respond to vessels in distress. Together with a harsh climate and other hazards to shipping, these conditions challenge mariners to maintain safe operations. The committee therefore reviewed the current status of safety measures (such as practices on board and in port, regulations, and the use of vessel monitoring systems and tracking) and infrastructure in the region to ascertain key areas for improvement that should be considered in assessing risks.

Reliable communications are vital to safe shipping. ***In the Aleutian Islands region, however, reports of radio network gaps that hinder both ship-to-ship and ship-to-shore communications are frequent.*** Several accident reports cite poor communications as a contributing factor in a chain of events leading to serious problems. As noted, the committee also reviewed the status of vessel monitoring and tracking systems, which can enhance safe operations in remote areas such as the Aleutians. The advent of automatic identification system (AIS) and long-range tracking technologies has opened up new traffic management opportunities and has the potential to allow active monitoring of the system and early identification of problems. In the Aleutians, the placement of a single AIS station on Scotch Cap at Unimak Pass has produced valuable information and demonstrated this potential.

Finally, history has shown that when vessels at sea do experience problems, it is important to have an effective response capability. ***Tug capability for assisting large vessels in distress does not exist in the Aleutians, and there is no oil spill response organization (OSRO) in the area; the closest OSROs are in Kodiak and Anchorage.*** The small harbor tugs stationed in Dutch Harbor are not capable of responding to vessels in distress; they are not rescue-capable. Dutch Harbor authorities have prepared emergency towing packages that can be deployed when needed. While this Emergency Towing System (ETS) represents an important step forward in improving shipping safety in Dutch Harbor, its coverage is primarily local, and other areas in the Aleutians remain vulnerable. Furthermore, the ETS is not adequate to respond to large commercial vessels in distress outside of the harbor.

RECOMMENDATIONS

Risk Assessment Framework

The committee developed a risk assessment framework for analyzing the commercial shipping system in the Aleutian region, both in its current state and projected into the future, with respect to accidents and spills resulting in harm to people and the environment. The proposed framework can be used to evaluate hazards, identify current levels of risk, investigate risk reduction measures, analyze the costs and benefits of those measures, and justify safety improvements to the system.

The committee recommends that a structured risk assessment be performed with two major phases—a Phase A Preliminary Risk Assessment and a Phase B Focused Risk Assessment. This process would include a specific, stepped approach to collecting and categorizing available data; development of a logical sequence of events defining key scenarios; and use of a risk matrix for an initial qualitative evaluation of risk levels.

The Phase A Preliminary Risk Assessment should begin with semiquantitative studies aimed at traffic characterization and projections and spill estimates, and identification of the highest risks. This information should then be used for a qualitative assessment and prioritization of risk reduction options.

The Phase B Focused Risk Assessment should entail detailed, in-depth assessments of individual risk reduction options in order of priority. The time and resources dedicated to Phase A should be limited to ensure that it is completed in a timely manner and that sufficient resources have been reserved for Phase B. Phase B should be accomplished in discrete steps as necessary in accordance with the priority of measures to be investigated and the level of risk reduction possible. The committee believes that this framework would enable risks to be evaluated effectively and efficiently within the resources available. It would also allow for explicit and comparative evaluations of risk reduction measures using more analytical techniques, such as modeling and cost–benefit studies, when warranted.

The committee also recommends that the risk assessment include a quantitative fate and effect consequence analysis to yield an understanding of the damage to natural resources and socioeconomic

impacts associated with different hazards, sizes of spills, and accident locations. The committee believes that a preliminary consequence analysis should be conducted in Phase A and a more detailed analysis, including biological impacts, in Phase B.

Organization of the Risk Assessment Study

An effective study organization is vital to the success of a risk assessment. The committee reviewed various risk assessment approaches and techniques, including those employed in recent marine risk assessments, that are relevant to the problem at hand. This experience points to the importance of certain elements: the problem should be clearly defined, and a contractor should be provided with the specific scope of the study and explicit goals; a peer review group should be given responsibility for reviewing and commenting on the study methodology and the handling of uncertainties; and a stakeholder group should be included in framing the issues, identifying local expert knowledge, suggesting risk reduction measures, and reviewing final results.

The committee recommends that the risk assessment be organized and managed by a team consisting of USCG, its designated fund management organization (the National Fish and Wildlife Foundation), and the State of Alaska. The Management Team should provide oversight of the contractor(s) conducting the risk assessment.

The committee recommends that the Management Team appoint a Risk Assessment Advisory Panel with a facilitator and members consisting of experts and key parties with an interest in furthering the goals of the risk assessment. Recognizing the importance of stakeholder involvement to the success of the risk assessment, the committee suggests that the Advisory Panel represent all major Aleutian Islands stakeholders, who would provide relevant local knowledge and expertise to the contractors. The panel should review and comment on the framing of the study and its conduct at key stages and help identify and provide input on the risk reduction measures to be evaluated.

The committee also recommends that the Management Team appoint a Risk Assessment Peer Review Panel with a facilitator and members consisting of experts in the techniques and methodologies of risk assessment to ensure that the study will be conducted with sufficient attention to completeness, accuracy, rigor, and

transparency. This panel would also help identify and consider the consequences of uncertainties.

Finally, the committee's charge was to develop the framework for a risk assessment. The committee believes that ongoing risk management is a critical part of the risk assessment process. Thus, the framework proposed in this report is structured to ensure effective implementation of the most cost-effective risk reduction measures by establishing Phase B as a detailed risk management project.

Interim Actions to Enhance the Assessment

During its review of existing data, the definition of the problem, and the current state of safety in the system, the committee identified interim actions that would help ensure a successful risk assessment, in particular by providing data to build a better foundation for the assessment process. The committee is also aware of the urgency of taking actions to improve the safety of shipping operations in the Aleutian Islands.

Accordingly, the committee recommends that USCG take appropriate action to expand the AIS tracking network along the Aleutian chain and covering the southern North Pacific Great Circle Route. The process for taking this action is already in place, and USCG has the authority to proceed as funding is made available. It would be valuable to implement these systems and to make available the data they yield as soon as possible so the complete traffic system can be described and analyzed with confidence as part of the risk assessment. Collection of additional AIS data should not delay this risk assessment. If it is not possible to install additional receivers and collect sufficient data to contribute to the study, the augmentation of the AIS system should be given careful consideration when the Phase A study results become available. When long-range identification and tracking data become available, USCG should take steps to utilize these data to further improve vessel tracking in and around the Aleutian chain.

Having an adequate rescue tug capability in the region has been identified in the past as a risk reduction option with obvious benefits for responding to large commercial vessels in distress. This capability has been established in other locations where the potential for maritime accidents exists, and local stakeholders in the Aleutians have advocated this solution for many years. The committee has not evaluated the costs and benefits of this option, and such an evaluation could not begin without more information about costs and possible financing mechanisms. Therefore, **should the Phase A assessment conclude that rescue tugs have potential risk reduction benefits, the committee recommends that USCG and the State of Alaska be ready and available to investigate funding levels, sources, and mechanisms for an Aleutian Rescue Tug, with the expectation that the Risk Assessment Management Team and Advisory Panel might request this information for early consideration within the risk assessment process.**

The committee further recommends that USCG be ready and available to investigate the possible structure and costs of a Vessel Traffic Information System within and near Unimak Pass and Dutch Harbor, with the expectation that the Risk Assessment Management Team and Advisory Panel might request the information thus generated early in the risk assessment process. This action would facilitate the risk assessment and provide needed data for cost–benefit analyses of selected options.

Subject to the findings of the Phase A Preliminary Risk Assessment, the committee also recommends early consideration of options for tracking and monitoring vessel traffic in certain congested areas, as well as for employing some common traffic management schemes that have shown merit in similar locations worldwide. Implementing voluntary vessel traffic systems, establishing traffic lanes, and identifying particularly sensitive sea areas or areas to be avoided are among the measures that USCG could pursue without new authority. Some of these measures might require International Maritime Organization consideration, while others might be adopted unilaterally.

FINAL THOUGHTS

Despite the complexity of the system and the open-ended nature of the problem, the committee is confident that a rigorous and comprehensive risk assessment of shipping in the Aleutian Islands can be conducted within the available resources and that needed safety improvements can be justified in the process. The committee also understands that, while certain historical and time-series data are limited, they can be enhanced and supplemented by relevant worldwide data and local expertise and judgment. This report presents a framework for conducting such a risk assessment, explaining the underlying principles and offering guidelines for applying both qualitative and quantitative techniques where appropriate. Finally, throughout this report, the committee emphasizes principles that are key to ensuring a successful outcome. These include keeping the work focused on a clear definition of boundaries and scope, designing the assessment process to incorporate continuous involvement of local stakeholders, and applying a phased approach to set priorities for early action and allocate resources efficiently.

APPENDIX A

Potential Risk Reduction Options

Central to the ultimate purpose of a risk assessment process is the identification and implementation of appropriate measures to reduce the risk of accidents to acceptable levels. The committee developed an initial list of potential risk reduction options by using several sources, beginning with preliminary work accomplished by stakeholder groups and government agencies in Alaska in analyzing the problem over the past few years. Box A-1 shows this initial list grouped within a number of general categories so they can be readily reviewed. The list includes all ideas presented to the committee and has not been vetted or prioritized by the committee.

Each of these options can be analyzed to determine its potential benefits relative to its costs and its likelihood and difficulty of implementation. An early step in analyzing each option is to address the questions listed below. This step can be accomplished independently of other tasks involved in the risk assessment and may result in an understanding of which options can be implemented with minimal or reasonable time and effort.

- What is included in the option (i.e., descriptive details)?
- Who can implement the option (e.g., government agency, industry, signatories to an international agreement, multiple parties)?
- How feasible is it to implement? How likely is it to succeed?
- How much time is needed for its implementation?
- What is the cost of its implementation (i.e., cost to each involved party)?

BOX A-1

Initial List of Risk Reduction Options

Waterways Management and Traffic Control

- Enhance or expand vessel tracking and communication systems (a voluntary vessel traffic information system for Unimak Pass or a mandatory traffic management scheme).
- Expand the existing automatic identification system (AIS) network to encompass a larger region (especially the southern route).
- Build and operate more AIS receiver stations throughout the Aleutians and possibly along the southern route by using weather buoys for mounting.
- Enhance and optimize the aids to navigation currently in place throughout the Aleutians.
- Enhance requirements for voyage planning and safety features for vessels calling at U.S. and Canadian ports and transiting the Aleutians.
- Update charts and coast pilots, and improve weather and sea state forecasting systems for the region.
- Implement a traffic separation scheme in or near Unimak Pass.
- Implement speed restrictions in shipping lanes.
- Establish restrictions for certain sensitive areas of operation.
- Implement long-range vessel tracking, and use it to identify potential problems.

Inspection and Enforcement

- Increase inspection and enforcement of safety requirements on vessels (especially older vessels) calling at U.S. and Canadian ports and transiting the Aleutians.

Vessel Personnel and Pilotage

- Enhance requirements for vessel safety equipment and crew training, and enforce existing requirements.
- Expand pilotage areas and pilot services to Unimak Pass and other possible locations.
- Establish an incident and near-miss reporting system with safeguards for mariners.

(*continued*)

- Enhance oil spill response capabilities and training.
- Conduct emergency training and salvage drills.

Vessel Equipment and Design

- Require redundant steering and propulsion for tankers.
- Require redundant steering and propulsion for tugs towing tank barges.
- Require redundant steering and propulsion for all vessels.
- Require double-hull protection for fuel tanks.
- Require double-hull protection for cargo tanks on tank barges.
- Raise liability limits.

Emergency Operations and Procedures

- Station adequate salvage and lightering equipment and capabilities at key locations.
- Finalize U.S. Coast Guard (USCG) salvage and firefighting requirements.
- Provide standby rescue tugs to respond to vessels in distress (large enough for prevailing conditions and ships in trade).
- Enhance the tug-of-opportunity network.
- Station a multipurpose vessel in Dutch Harbor with rescue tug capabilities but other uses as well (e.g., research) to help pay the cost.
- Provide escort tugs for certain vessels and conditions in Unimak Pass.
- Implement storm and severe weather rules for Unimak Pass and the greater Aleutians.
- Enhance and expand USCG response capabilities for vessels in distress (e.g., response teams, rescue vessels, and helicopters).
- Require pollution response plans for all large vessels transiting sensitive areas, similar to requirements for vessels calling at Alaska ports.
- Require all large vessels to have emergency tow packages.
- Expand on emergency towing equipment currently implemented in Dutch Harbor.
- Identify a network of places of refuge, and develop plans for their use.

Some of the options listed in Box A-1 have already been investigated to a certain degree, and some have obvious benefits and implementation paths that have been described. For example, several Alaskan organizations have proposed approaches for improved vessel tracking and some forms of vessel traffic service (VTS) for Unimak Pass. The Marine Exchange of Alaska has put forth a proposal to build and operate additional automatic identification system (AIS) receiving sites and an operations center to track and communicate with vessels and identify potentially unsafe vessel transits. The Alaskan Marine Pilots have suggested the development of a formal VTS for Unimak Pass and vicinity and prepared a paper describing the elements of such a service and explaining how it would work.

In addition, the U.S. Coast Guard (USCG) has in the past implemented VTS in a number of ports and waterways in the United States on the basis of analyses of vessel accident risks in these locations. Various approaches are used for these existing USCG-authorized VTS, including USCG owned and operated, marine pilot operated, and marine exchange operated, all under USCG waterways management authority. Current vessel traffic in and around Unimak Pass is substantial compared with that in other regions with established VTS; thus a careful investigation by USCG of the advisability of establishing a VTS in the area appears warranted.

Another risk reduction option for which there has been some investigation and evaluation is providing emergency towing equipment that can be delivered to vessels in distress if and when needed. The City of Unalaska, in cooperation with industry and government partners, recently developed a towing package that could be used in an emergency situation to aid vessels in distress in the region near Dutch Harbor and Unimak Pass. As more information on vessel traffic is developed, local authorities may further refine this option to make it more effective.

The committee proposes the list in Box A-1 as a starting point for evaluating risk reduction options within the risk assessment process. This initial list should be reviewed, refined, and then expanded as appropriate by the Advisory Panel. A detailed analysis of the costs and benefits of selected options would be one of the desired results.

APPENDIX B

Selendang Ayu Plea Agreement

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IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF ALASKA

UNITED STATES OF AMERICA,	)	No.
	)	
Plaintiff,	)	
	)	**PLEA AGREEMENT**
v.	)	
	)	
IMC SHIPPING CO. PTE. LTD.,	)	
	)	
Defendant	)	

IMC PLEA AGREEMENT

Unless the parties jointly inform the Court in writing of any *additional agreements, this document in its entirety contains the* terms of the plea agreement between the defendant and the United States. This agreement is limited to the District of Alaska and the Environmental Crimes Section of the Department of Justice; it does not bind other federal, state, or local prosecuting authorities.

I. TERMS OF THE AGREEMENT

A. Terms of Agreement

The defendant, IMC SHIPPING CO. PTE. LTD (IMC), agrees to plead guilty to a three-count information in this case. Any agreements the parties have on sentencing recommendations and guideline applications are set forth in Section III. IMC will waive all rights to appeal the conviction and sentence imposed under this agreement, and will waive all rights to collaterally attack the conviction and sentence, except on the grounds of ineffective assistance of counsel or the voluntariness of the plea.

B. Federal Rule of Criminal Procedure 11

Under the terms of this agreement IMC will plead guilty to a three-count information charging IMC in Counts 1 and 2 with discharges in violation of the Refuse Act, 33 U.S.C. §§ 407, 411; and in Count 3 with killing migratory birds in violation of the Migratory Bird Treaty Act, 16 U.S.C. §§ 703, 707(a). The parties expressly agree that this plea agreement is entered into pursuant to Rule

11(c)(1)(C) of the Federal Rules of Criminal Procedure as discussed below. Under the terms of this agreement, the parties may only withdraw from this agreement if the Court deviates from the sentencing recommendations made by the parties as outlined in this agreement in Section III.

C. Waiver of Claim for Attorney Fees and Costs

Because this is a negotiated resolution of the case, the parties waive any claim for the award of attorney fees and costs from the other party.

D. Breach

The parties agree that if the Court finds that IMC has breached this agreement, or if IMC's guilty pleas are rejected, withdrawn, set aside, vacated or reversed, at any time, the United States will be free to prosecute IMC on all charges covered by this agreement, including any charges that might have been brought but for this agreement.

E. Full Description of Conduct

This agreement does not limit the rights of any party to provide the Court with a full description of the Defendant's conduct, correct inaccuracies at any time, or speak at the time of sentencing consistent with the recommended provisions set forth in the agreement. The parties agree to allocute at sentencing in favor of the joint recommendation regarding the appropriate sentence, as set *forth in this agreement at Section III.*

II. CHARGES, ELEMENTS, FACTUAL BASIS AND STATUTORY PENALTIES

A. Charges

IMC agrees to plead guilty to a three-count information charging IMC in Counts 1 and 2 with discharges in violation of the Refuse Act, 33 U.S.C. §§ 407, 411; and in Count 3 with killing migratory birds in violation of the Migratory Bird Treaty Act, 16 U.S.C. §§ 703, 707(a).

B. Elements

The elements of the misdemeanor charges to which IMC is pleading guilty are as follows:

1. **Counts 1 and 2, Refuse Act:**

   First, the defendant did discharge refuse from a ship;

   Second, the discharge was into a navigable water;

   Third, the defendant did not have a permit to make the discharge.

2. **Count 3, MBTA:**

   First, the defendant caused the death of migratory birds;

   Second, the defendant did not have permission, nor was it authorized by law, to kill the birds.

C. Factual Basis

The United States has conducted an extensive investigation into the facts surrounding the grounding of the M/V Selendang Ayu. This investigation involved many technical and complex issues, and the investigation included depositions taken of witnesses by the U.S. Attorney's office, as well as numerous interviews conducted by agents of the U.S. Environmental Protection Agency Criminal Investigation Division, the U.S. Coast Guard, and the Federal Bureau of Investigation, as well as evidence collection by the U.S. Fish and Wildlife Service Office of Law Enforcement, and review of voluminous records and documents, and consultation with IMC's and the government's experts. The National Transportation Safety Board (NTSB) also conducted a casualty investigation.

Under the Clean Water Act, it is a misdemeanor to negligently discharge oil into waters of the United States, and federal courts have held that the United States need only prove that ordinary negligence caused a discharge to sustain a conviction for a negligent discharge of oil.The United States believes it is in a position to seek an indictment of IMC charging a false statement count for the actions of the ship's crew regarding the initial statements made by agents of IMC, including the vessel's captain, to the U.S. Coast Guard and the NTSB regarding the casualty, and charging a misdemeanor count for a negligence violation of the

Clean Water Act for the actions of the company and crew leading up to the grounding.

IMC, for its part, recognizes its vicarious liability for the crew's misstatements to the NTSB and the U.S. Coast Guard in some of the initial interviews, but disputes that the grounding was the result of any negligence on the part of IMC or any of its affiliates or agents. In recognition of the cooperation of IMC in the investigation by the United States, and consistent with the policies of the Department of Justice set out in the Principles of Federal Prosecution of Business Organizations, and the Environmental Crimes Section's Voluntary Disclosure Policy, the United States has agreed to forego False Statement and Clean Water Act charges against IMC.

The parties agree that in December 2004, the M/V Selendang Ayu, operated by IMC, was traveling the Great Circle Route through the Aleutian chain in Alaska when it went aground near the north shore of Unalaska Island, west of Skan Bay in the Bering Sea. Unalaska Island is within the Alaska Maritime National Wildlife Refuge (Refuge). On December 6, 2004, the discovery of a crack in the engine's number three cylinder liner led the crew to shut down the engine. The ship drifted for three days in high winds and heavy seas while the crew attempted to repair the engine. The crew was never able to restart the engine.

On December 8, 2004, the M/V Selendang Ayu ran aground on the north shore of Unalaska Island, Alaska west of Skan Bay.

The Refuge where the ship went aground hosts the largest nesting population of seabirds in North America. The Refuge is a significant site for migratory seabirds both nationally and internationally. The Refuge's primary functions are to facilitate scientific research regarding the health of the ocean and promote conservation of seabirds. As a result of the grounding of the Selendang Ayu, approximately 340,000 gallons of bunker oil spilled into the ocean killing migratory birds in numbers into the thousands, and oiling 20 miles of coastline and spilling thousands of metric tons of soy beans into the Bering Sea.

The parties disagree about the cause of the crack in the cylinder liner of the engine on the M/V Selendang Ayu. The government believes its evidence would show that the crack in the cylinder that precipitated the engine shutdown and subsequent inability to restart the engine was caused by improper maintenance and inappropriate operation of the engine exacerbated by the forecasted heavy weather experienced by the ship along the Great Circle Route. IMC disagrees with the government's conclusions regarding the maintenance and operation of the ship's engine and believes that the evidence would show that the crack in the cylinder liner was not caused by improper maintenance or inappropriate operation of the engine.

The parties agree that since the incident IMC has acted in a responsible manner by cooperating with the investigation by the United States. It cooperated as requested in the NTSB investigation into the Selendang Ayu casualty, making witnesses available to the NTSB, and providing the NTSB with documents relating to the vessel. When IMC learned that Captain Singh, the master of the vessel, had made false statements to the NTSB regarding the incident, and had instructed other crew members to do so as well, IMC insisted that the crew-witnesses correct their statements and made all of the crew available to the NTSB for further questioning. The NTSB has indicated that as a result of IMC's intervention the master's actions did not hinder the investigation.

IMC also cooperated as requested in the investigation conducted by the U.S. Attorney's Office into the M/V Selendang Ayu casualty. It voluntarily accepted subpoenas and produced thousands of pages of documents to the United States relating to the vessel. It made foreign witnesses available to the United States in Singapore and in Anchorage, who would otherwise have been beyond the subpoena power of the United States, and voluntarily shared technical information regarding the incident with federal investigators.

IMC has also cooperated as and whenever requested by state and federal authorities overseeing the cleanup of oil spilled as a result of the incident.

D. Statutory Penalties

The maximum statutory penalties applicable to the charges to which the organizational defendant is pleading guilty, based on the facts to which the defendant will admit in support of the guilty pleas, are as follows:

Counts 1, 2 and 3:

- two times the pecuniary loss caused by the offense pursuant to the Alternative Fines Act, 18 U.S. C. § 3571(d);
- five years probation;
- restitution;
- a $125 mandatory special assessment for Counts 1 and 2 charging Class A misdemeanors, and $50 for Count 3 charging a Class B misdemeanor, pursuant to 18 U.S.C. § 3013.

III. JOINT SENTENCING RECOMMENDATION

A. Sentencing Guidelines

The parties agree that the version of the advisory United States Sentencing Guidelines (U.S.S.G.) incorporating guidelines amendments through November 1, 2002, shall cover these offenses to the limited extent that the guidelines apply in this context. The parties further agree that pursuant to U.S.S.G. § 8C2.1

(commentary) and § 8C2.10 of the United States Sentencing Guidelines, which pertain to the sentencing of organizations, the guidelines do not determine fine range in environmental cases, but rather leave such determination to the sound discretion of the Court in accordance with 18 U.S.C. §§ 3553, 3571 and 3572.

B. Sentence Recommendation

1. Agreed upon Sentence

The parties agree, pursuant to Fed. R. Crim. P. 11(c)(1)(C), that the following is an appropriate disposition of this matter:

- $10,000,000 penalty to be paid as specified below in paragraph III.B.2;
- A three year term of probation during which IMC must comply with special conditions of probation set forth in paragraph III.C below; and
- A $300 special assessment.

The parties agree that no amount of the criminal penalty shall reduce IMC's civil liability to any person or entity, including any federal, state or local government agency. The parties agree that IMC is bound only by facts specifically admitted by IMC in this agreement.

2. Method of Payment

In regard to the imposition of the $10,000,000 penalty and special assessments of $300 at sentencing, the parties agree that only $9,000,000, in penalties and $300 in special assessments for a total of $9,000,300, will be due in full and that the remaining $1,000,000 of the total $10,000,000 penalty will be held in abeyance as follows: if IMC fails, in a material manner, to implement special conditions of probation set forth in paragraph III.C below, the Court may order IMC to pay an amount up to the $1,000,000 of this penalty held in abeyance. Additionally, if IMC violates, in a material manner, any of the terms of probation then the Court may order as penalties for probation violations any amount up to the $1,000,000 held in abeyance.

No later than two business days prior to sentencing, as scheduled by the Court, IMC shall notify the U.S. Attorney's Office that IMC's counsel is in possession of $9,000,300, in its client funds account with which to pay IMC's penalties and special assessments. The total criminal penalty will be paid as set out below:

a. Count I charging a violation of the Refuse Act, 33 U.S.C. §§ 407, 411, totaling $3.5 as follows:

(1) $1,500,000 fine to be paid in full on the day of the entry of the pleas to the Clerk of Court;

(2) $1,500,000 to be paid in full within ten days of the entry

of the pleas to the National Fish and Wildlife Foundation for the purpose of conducting an Aleutian Islands risk assessment of the shipping hazards for that area as well as projects identified by the risk assessment. This amount is to be paid as community service pursuant to U.S.S.G. § 8B1.3 and in furtherance of satisfying the sentencing principles provided for under 18 U.S.C. § 3553(a);

(3) $500,000 fine to be held in abeyance and paid only in the event the Court orders a penalty pursuant to a probation violation in any amount up to $500,000.

b. Count 2 charging a violation of the Refuse Act, 33 U.S.C. §§ 407, 411, totaling $3.5 as follows:

(1) $1,500,000 fine to be paid in full to the Clerk of Court on the day of the entry of the pleas;

(2) $1,500,000 to be paid in full within ten days of the entry of the pleas to the National Fish and Wildlife Foundation for the purpose of conducting an Aleutian Islands risk assessment of the shipping hazards for that area as well

as projects identified by the risk assessment. This amount is to be paid as community service pursuant to U.S.S.G. § 8B1.3 and in furtherance of satisfying the sentencing principles provided for under 18 U.S.C. § 3553(a);

(3) $500,000 fine to be held in abeyance and paid only in the event the Court orders a penalty pursuant to a probation violation in any amount up to $500,000.

c. Count 3 charging a violation of the Migratory Bird Treaty Act, 16 U.S.C. §§ 703, 707(a) totaling $3,000,000, as follows:

(1) $2,000,000 fine to be paid in full on the day of the entry of the pleas to the Clerk of Court; by operation of law, specifically, 16 U.S.C. § 406(b), this fine amount shall be directed to the Department of the Interior to carry out approved wetlands conservation projects;

(2) $1,000,000 to be paid in full within ten days of the entry of the pleas to the National Fish and Wildlife Foundation for the purpose of funding projects for the Alaska National Marine Wildlife Refuge system. This amount is

to be paid as community service pursuant to U.S.S.G. § 8B1.3 and in furtherance of satisfying the sentencing principles provided for under 18 U.S.C. § 3553(a).

3. Community Service

As discussed above $4,000,000 of the criminal penalty is to be paid to the National Fish and Wildlife Foundation (NFWF) by IMC as community service pursuant to U.S.S.G. § 8B1.3 and in furtherance of satisfying the sentencing principles provided for under 18 U.S.C. § 3553(a). The monies paid to the NFWF shall be directed to the Alaska Maritime National Wildlife Settlement Fund and used for the purposes set forth above and accounted for to Congress in annual reports required by 16 U.S.C. § 3706(b). The explicit goal of IMC's required community service is to fund an assessment of risks associated with the shipping industry traveling through the areas near or affecting the Alaska National Maritime Refuge, and projects identified to minimize those risks (Counts 1 and 2), and other environmental projects and initiatives authorized by the NFWF designed for the benefit, preservation and restoration of the coastal environment and ecosystems in the Alaska National Maritime Refuge, specifically projects affecting the Aleutian Islands Unit of the Refuge (Count 3).

The NFWF is a congressionally-mandated, charitable and nonprofit corporation, established pursuant to 16 U.S.C. §§ 3701–3709. Its purposes include the acceptance and administration of "private gifts of property for the benefit of, or in connection with, the activities and services of the United States Fish and Wildlife Service," and the performance of "such other activities as will further the conservation and management of the fish, wildlife, and plant resources of the United States, and its territories and possessions, for present and future generations of Americans." Id. § 3701(b)(1), (2). The NFWF is empowered to "do any and all acts necessary and proper to carry out" these purposes, including, specifically, solicitation, acceptance, and administration of "any gift, devise or bequest . . . of real or personal property." Id. § 3703(c)(1), (7).

The payments made by IMC for community service as set out above are made as a condition of probation incidental to a criminal conviction. As such, IMC agrees it will not characterize, publicize or refer to the payment as anything other than payment of a criminal penalty.

C. Special Conditions of Probation

IMC will serve a three year period of probation with a special condition that IMC will hire an auditor approved by the United States to review engine maintenance /performance—including trending and analysis of data collected and how that data is collected—of the IMC fleet and report findings and recommendations during the probation period to the U.S. Attorney's Office and the U.S. Probation Office (U.S.P.O.). IMC will also appoint a Responsible Corporate Officer to ensure compliance with this special condition of probation.

1. Auditor

a. IMC will retain an auditor approved by the U.S. Attorney's Office at IMC's expense prior to the time of sentencing;

b. IMC will submit a copy of the contract between the auditor and IMC to the U.S. Attorney's Office that details the scope of the audit. IMC agrees to give the auditor full access to IMC's records, employees, facilities and vessels necessary to make a meaningful evaluation of IMC's current operations;

c. The auditor will prepare a draft report of his findings and furnish it to the U.S.P.O. and the U.S. Attorney's Office at the same time it is given to IMC no later than one year from the date of sentencing;

d. The parties may deliver comments about the draft report to the auditor who may consider these comments. The auditor will prepare a final report of his findings and recommendations and will furnish them to the U.S.P.O., IMC, and the U.S. Attorney's Office within six months of submitting the draft report;

e. IMC will submit a written response to the U.S.P.O. and the U.S. Attorney's Office specifying what actions IMC will take to correct any noted deficiencies within six months of the final report;

f. The auditor will submit quarterly reports to the U.S.P. O. and the U.S. Attorney's Office detailing the implementation of measures to address noted deficiencies. Compliance with the recommendations of the audit will remain under the supervision of the Court for the duration of the term of probation.

2. Responsible Corporate Officer

a. IMC will appoint an IMC employee as a responsible corporate officer ("RCO"), who will have requisite knowledge of IMC obligations under this agreement and the authority to insure that the obligations are fully implemented, and who will be directly responsible for overseeing the audit and implementing the recommendations;

b. The U.S. Attorney's Office must approve the selection of the RCO. IMC will identify the RCO to the Court at the time of sentencing;

c. The RCO will review and sign all submissions to the Court and U.S.P.O. relevant to the audit and compliance process.

D. Corporate Authorization

One week prior to the execution of this plea agreement, IMC will provide to the U.S. Attorney's Office and to the Court written evidence, in the form of a resolution of its Board of Directors sufficient under the laws of Singapore, certifying that the defendant is authorized to plead guilty to the information in this case, and to enter into and comply with all provisions of this agreement. The resolution shall further certify that an identified individual is authorized to take these actions and that all corporate formalities, including but not limited to, approval by defendant's directors, required for such authorization have been observed.

The defendant agrees that Yuelin Yang, as General Counsel for IMC, will be authorized to appear on its behalf, to enter its guilty pleas and to represent it for imposition of its sentence.

IV. WAIVER OF TRIAL, APPELLATE RIGHTS, AND COLLATERAL ATTACK RIGHTS

A. Trial Rights

Being aware of the following, IMC waives these trial rights:

-- The right to a speedy and public trial by jury on the factual issues establishing guilt or any fact affecting the mandatory minimum and statutory penalties, and any issue affecting any interest in any assets subject to forfeiture;

-- The right to object to the composition of the trial jury;

-- The right to plead not guilty or to persist in that plea if it has already been made;

-- The right to be presumed innocent and not to suffer any criminal penalty unless and until the defendant's guilt is established beyond a reasonable doubt;

-- The right to be represented by counsel at trial and if necessary to have counsel appointed at public expense to represent the defendant at trial -- the defendant is not waiving the right to have counsel continue to represent the defendant during the sentencing phase of this case;

-- The right to confront and cross examine witnesses against the defendant, and the right to subpoena witnesses to appear on the defendant's behalf.

B. Appellate Rights

The defendant waives the right to appeal the convictions resulting from the entry of guilty pleas to the charges set forth in this agreement. The defendant further agrees that if the Court imposes the sentence as contemplated in this agreement the defendant waives without exception the right to appeal on all grounds contained in 18 U.S.C. § 3742 the sentence the Court imposes.

C. Collateral Attack Rights

The defendant agrees to waive all rights to collaterally attack the resulting convictions and/or sentence—including terms or conditions of, and any fines, community service, or restitution—the Court imposes. The only exceptions to this collateral attack waiver are as follows: 1) any challenge to the conviction or sentence alleging ineffective assistance of counsel, based on information not now known to the defendant and which, in the exercise of reasonable diligence, could not be known by the defendant at the time the Court imposes sentence; and 2) a challenge to the voluntariness of the defendant's guilty pleas.

V. ADDITIONAL AGREEMENTS BY UNITED STATES

The United States agrees that it will not prosecute the defendant or its affiliates or agents, including but not limited to Ayu Navigation Sdn Bhd, Wawasan Bulk Services Sdn Bhd and IMC Transworld Ltd. further for any other offense now known arising out of the subject of the investigation related to the charges brought in the information in this case and the defendant's admissions set forth in Section II C. Provided, however, if the defendant's guilty pleas are rejected, withdrawn, vacated, reversed, or set aside, or if the defendant's sentence is vacated, reversed, set aside, or modified, at any time, in any proceeding, for any reason, the United States will be free to prosecute the defendant and its affiliates and agents on all charges arising out of the investigation of this case.

VI. DEFENDANT'S ACCEPTANCE AND UNDERSTANDING OF THE TERMS OF THIS PLEA AGREEMENT

On behalf of IMC, being of sound mind and under no compulsion or threats, or promises not otherwise contained in this document, knowing that I will be put under oath at the entry of plea hearing to tell the truth, do hereby state IMC's agreement to and understanding of this agreement as follows:

A. IMC wishes to enter a plea of guilty to Counts 1, 2, and 3 of the

Information filed in this case in which IMC is charged with discharges in violation of the Refuse Act, 33 U.S.C. §§ 407, 411, in Counts 1 and 2; and killing migratory birds in violation of the Migratory Bird Treaty Act, 16 U.S.C. §§ 703, 707(a), in Count 3.

B. IMC's attorney has explained the charges to which IMC is pleading guilty and the necessary elements, and the consequences of the guilty pleas.

C. IMC is admitting that the allegations against IMC in Counts 1, 2 and 3, of the information and the factual basis for IMC's plea are true.

D. IMC's understands that by pleading guilty IMC gives up and waives the following rights:

-- The right to plead not guilty or to persist in that plea if it has already been made;

-- The right to a speedy and public trial by a jury on the issue of guilt;

-- The right to object to the composition of the petit jury;

-- The right to be presumed innocent and not to suffer any criminal penalty unless and until IMC's guilt is established beyond a reasonable doubt;

-- The right to be represented by a lawyer at trial and if necessary to have a lawyer appointed to represent IMC at trial—IMC understands it is not waiving the right to have counsel represent IMC during the sentencing phase of the case;

-- The right to confront and cross examine witnesses against IMC, and the right to subpoena witnesses to appear on IMC's behalf.

E. IMC is fully aware that if IMC were convicted after a trial and sentence were imposed on IMC thereafter, IMC would have the right to appeal any aspect of the conviction and sentence. Knowing this, IMC voluntarily waives the right to appeal its conviction and sentence, as described above. Furthermore, IMC also knowingly and voluntarily agrees to waive the right under 18 U.S.C. § 3742 to appeal any aspect of the sentence imposed in this case, if the Court imposes a sentence within the parameters of this agreement. Furthermore, IMC knowingly and voluntarily waives the right to collaterally attack any aspect of the conviction, judgment or sentence, except for a challenge based upon ineffective assistance of counsel, based on information not now known by IMC and which, in the exercise of due diligence, could not be known by IMC by the time the Court imposes the sentence, which information affected either the guilty plea or the sentence imposed by the Court. IMC is fully satisfied with the representation given by its attorney. IMC has discussed all possible defenses to the charges with its attorney. He has investigated the case and followed up on any information and issues IMC has raised with him to IMC's satisfaction and has taken the time to fully explain the legal and factual issues involved in IMC's case to IMC's satisfaction. IMC and its attorney have discussed how the United States Sentencing Commission Guidelines have a limited application in this case, as well as the statutes applicable to IMC's offense and any other factors that will affect the sentence calculation in this case.

F. IMC further understands that if IMC pleads guilty, there will not be a trial and that the Court will ask me under an oath to answer questions about this offense on behalf of IMC. I understand that I may be prosecuted if I make false statements or give false answers.

G. IMC understands that the Court has the ultimate discretion to either accept or reject this agreement. IMC understands that it will only be allowed to withdraw from this agreement if the Court deviates from the sentencing agreement made between the parties.

H. IMC understands that anything that it discusses with its attorney is privileged and confidential, and cannot be revealed without IMC's permission. Knowing this, IMC agrees that this document will be filed with the Court.

I. This document contains all of the agreements made between IMC and the United States regarding IMC's plea. There are no other promises, assurances, or agreements between IMC, IMC's attorney, and the United States that have affected IMC's decision to change its plea or to enter into this agreement. If there were, I would so inform the Court. IMC understands that if the Court finds that IMC has breached this agreement, the United States will be free to prosecute IMC on all charges arising out of the investigation of this case and any charges not brought as a result of this agreement.

J. I have read this plea agreement carefully and understand it thoroughly. I know of no reason why the Court should find me incompetent to enter into this agreement or to enter a plea on behalf of IMC. IMC enters into this agreement knowingly and voluntarily. I therefore wish to enter a plea of guilty on behalf of IMC to the information filed in this case in which IMC is charged with Refuse Act, 33 U.S.C. §§ 407, 411 in Counts 1 and 2; and with killing migratory birds in violation of the Migratory Bird Treaty Act, 16 U.S.C. §§ 703, 707(a) in Count 3.

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[Signatures on the following page.]

DATED: 8/14/07

YUELIN YANG
General Counsel IMC
On behalf of the Defendant IMC

As counsel for the defendant, I have discussed with IMC the terms of this plea agreement, have fully explained the charges to which IMC is pleading guilty and the necessary elements, all possible defenses, and the consequences of these pleas. Based on these discussions, I have no reason to doubt that the defendant is knowingly and voluntarily entering into this agreement and entering pleas of guilty. I know of no reason to question the competency of IMC to make these decisions. If, prior to the imposition of sentence, I become aware of any reason to question the defendant's competency to enter into this plea agreement or to enter pleas of guilty, I will immediately inform the Court.

DATED: 8/14/07

ROBERT BUNDY
Attorney for IMC

On behalf of the United States, the following accept IMC's offer to plead guilty under the terms of this plea agreement.

DATED: 8/13/07

ANDREA T. STEWARD
Assistant U.S. Attorney
District of Alaska

DATED: 8/13/07

for ROBERT ANDERSON
Senior Trial Attorney
DOJ, Environment Crimes Section

[Signatures continued on next page.]

DATED: 8/13/07

KAREN LOEFFLER
Criminal Chief
District of Alaska

DATED: 8/9/2007

NELSON P. COHEN
United States Attorney
District of Alaska

APPENDIX C

Expert Judgment

THE USE OF EXPERT OPINION

An expert is an individual with specialized knowledge or skill in some specific domain. While in principle any degree of knowledge of a subject qualifies one as an expert to that degree, a person is called an expert only when he or she is believed to be much more knowledgeable than a layperson about the subject of interest.

Expert opinion can be viewed as an expression of the judgment of an expert on a subject or issue. An opinion is usually regarded as an impression, personal assessment, or subjective estimation of a quality or quantity of interest. Expert opinion, in contrast to factual information, is a judgment or a belief that, at least in the mind of the receiver of the opinion, is based on uncertain information or limited knowledge.

The primary reason for eliciting expert opinion is to deal with uncertainty with regard to selected technical issues. Issues most suited to elicitation of expert opinion involve significant uncertainty, are controversial or contentious, are complex, and can have a significant effect on risk. Elicitation and use of expert opinion should be regarded as a heuristic and not a scientific tool for exploring such issues that would otherwise be inaccessible.

Two measures of quality for the elicitation and use of expert opinion are "substantive goodness" and "normative goodness." Substantive goodness refers to the knowledge of the expert relative to the problem at hand. Normative goodness, on the other hand, refers to the expert's ability to express that knowledge in accordance with the calculus of probabilities and in close correspondence with his or her actual opinions. Depending on the situation, one or the other type of goodness predominates.

Questions that need to be considered with regard to the use of expert opinion fall into two categories: (*a*) elicitation (e.g., how to select the experts, how many to select for a given issue, and how to elicit their opinions) and (*b*) how to use the elicited opinions and information about the experts to estimate the unknown quantity.

It has been widely documented that judgmental estimates are subject to a number of potential biases. Two biases that are particularly important in the practice of risk assessment are (*a*) the possibility of systematic overestimation or underestimation and (*b*) overconfidence, or the tendency for people to give "overly narrow confidence intervals which reflect more certainty than is justified by their knowledge about the assessed quantities" (Tversky and Kahneman 1974).

The following are helpful points to consider when expert opinion is used:

- It is important to select good domain experts and train them in normative aspects of the subject.
- Aggregating the opinions of multiple experts tends to yield more accurate results than using the opinion of a single expert.
- Mathematical methods of aggregation are generally preferable to behavioral methods for reaching consensus.
- The quality of expert judgments can be substantially improved by decomposing the problem into a number of more elementary problems.
- Significantly better overall results are obtained if the initial problem definition and decomposition are performed with care and in consultation with the experts.
- Expert opinions are subject to bias and overconfidence. Effective means of reducing overconfidence are (*a*) using calibration techniques and (*b*) encouraging experts to actively identify evidence that tends to contradict their initial opinions (see the discussion below on bias).
- Sources of strong dependency among experts should be identified. Weak dependency does not appear to have a major impact on the value of multiple expert judgments.

THE FACILITATOR

A facilitator is an expert with the interpersonal skills needed to control the elicitation process and ensure that all available information emerges, that the experts are fairly heard, and that their views are not subsumed by those of others. To these ends, it is important not only that the experts selected represent a range of expertise but also that the facilitator challenge them to explain the basis for their judgments. A facilitator can directly address any biases. For example, representativeness bias involves replacing a careful evaluation of the available information with quick conclusions based on partial information or allowing irrelevant information to affect one's conclusions. The facilitator must have the skill to sense when an individual is exercising such bias.

Moreover, it is important to understand the heuristics people often use to develop subjective probability distributions and the associated biases. Knowing which framings for eliciting distributions cause problems makes it possible to use those that work better. Because the facilitator is familiar with the potential biases associated with the subject at hand, he or she can test the group's ideas and lead them in the right direction. The following strategies should be used either explicitly or implicitly through the facilitator's questioning (Budnitz et al. 1998; see also Tversky and Kahneman 1974):

- Construct simple models of the maximum and minimum points of the distribution, avoiding focus on the central tendency until the end points are studied to avoid anchoring; test these models to examine the evidence supporting them rather than relying on opinion alone.
- Seek consensus on the evidence considered by the analysis team.
- Test distributions by asking whether the assessor agrees it is equally likely for the real answer to lie between the 25th and 75th percentiles or outside them, or between the 40th and 60th percentiles and outside the 10th and 90th percentiles. Sometimes these questions must be phrased in ways that avoid suggesting the answer.
- Use a strong facilitator who ensures that each participant individually puts his or her evidence on the table and justifies it (Budnitz et al. 1998). The facilitator must use judgment in

deciding when to push the participants rather than going through a long and tedious checklist.

- Exercise care in assessing parameters that are not directly observable. The distribution is supposed to reflect the analyst's evidence concerning a particular parameter. If the analyst has little direct experience with the parameter, it can be difficult to justify an informative prior distribution.

CONTROLLING UNINTENTIONAL BIAS IN USING EXPERT OPINION

One of the most important concerns associated with the use of a consensus expert judgment process is that of unintentional bias. In the subjective process of developing probability distributions, strong controls are needed to prevent bias from distorting the results (i.e., to prevent derivation of results that fail to reflect the team's state of knowledge). Perhaps the best approach is to understand thoroughly how unintended bias can occur. With that knowledge, the facilitator and team can guard against its influence in their deliberations.

A number of studies present substantial evidence that people [both naive analysts and subject matter (domain) experts] are not naturally good at estimating probability (including uncertainty in the form of probability distributions or variance) (Cooke 1991; Hogarth 1975; Mosleh et al. 1988). For example, Hogarth (1975) notes that, according to psychologists, people have only limited information-processing capacity. This implies that their perception of information is selective, that they must apply heuristics and cognitive simplification mechanisms, and that they process information in sequential fashion. These characteristics in turn often lead to a number of problems in assessing subjective probability. Evaluators often are subject to the following:

- They ignore uncertainty (this is a simplification mechanism). Uncertainty is uncomfortable and complicating and beyond most people's training.
- They lack an understanding of the impact of sample size on uncertainty. Domain experts often give more credit to their experience than it deserves (e.g., if they have not seen something

happen in 20 years, they may assume it cannot happen or that its occurrence is much more unlikely than once in 20 years).

- They lack an understanding of or fail to think hard enough about independence and dependence.
- They have a need to structure the situation, which leads them to imagine patterns even when none exist.
- They are fairly accurate at judging central tendency, especially the mode, but may significantly underestimate the range of uncertainty (e.g., in half the cases, people's estimates of 98 percent intervals fail to include the true values) and are influenced by beliefs of colleagues and by preconceptions and emotions.
- They rely on a number of heuristics to simplify the process of assessing probability distributions. Some of these heuristics introduce bias into the assessment process.

Examples of this last problem include the following:

- Representativeness: People assess probabilities by the degree to which they view a known proposition as representative of a new one. Thus stereotypes and snap judgments can influence their assessment. In addition, representativeness ignores prior probability (Siu and Kelly 1998), that is, what one's initial judgment of the probability of a new proposition would be before considering new evidence—in this case, one's assumption about the representativeness of the known proposition. Clearly the prior should have an impact on the posterior probability, but basing one's judgment on similarity alone ignores that point. This also implies that representativeness is insensitive to sample size (since one jumps to a final conclusion on the basis of the assumption of similarity alone).
- Availability: People assess the probability of an event by the ease with which instances can be recalled. This availability of the information is confused with its occurrence rate. Several associated biases have been observed:
  - Biases from the retrievability of instances (recency, familiarity, and salience),
  - Biases from the effectiveness of a search set (the mode of search may affect the ability to recall), and
  - Biases of imaginability (the ease of constructing inferences is not always connected with the probability).

- Anchoring and adjustment: People start with an initial value and adjust it to account for other factors affecting the analysis. The problem is that it appears to be difficult to make appropriate adjustments. It is easy to imagine being locked in to one's initial estimate, but anchoring is much more sinister than this alone. A number of experiments have shown that even when one's initial estimates are totally arbitrary and represented as such to the participants, the effect is strong. Suppose that two groups are each told that a starting point has been picked randomly from which to work; the one given the higher arbitrary starting point generates higher probability. One technique found helpful is to develop estimates for the upper and lower bounds before addressing most-likely values.

Rather than concluding prematurely that people are irredeemably poor at generating subjective estimates of probability, one should realize that many such applications have been successful. Hogarth (1975) points out that studies of experienced meteorologists have shown excellent agreement with facts. Thus, it is essential to understand what techniques can help yield good assessments.

Winkler and Murphy (1978) make a useful distinction between two kinds of expertise or "goodness." "Substantive" expertise refers to knowledge of the subject matter of concern, while "normative" expertise is the ability to express opinions in probabilistic form. Hogarth (1975) points out that the subjects in most studies reviewed were neither substantive nor normative experts. A number of studies have shown that normative experts (whose domain knowledge is critical) can generate appropriate probability distributions but that substantive experts require significant training and experience or assistance (such as that provided by a facilitator) to do well.

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APPENDIX D

Human Reliability Analysis

Human error can originate or surface in all phases of a system's life cycle, including design, construction, operation, and management. Since risk management requires an understanding of the causes of and contributors to the risk so that effective safeguards can be developed, human causes of accidents must be explicitly considered in the analysis of risk (see Box D-1). Human risk factors are defined as those factors that can be attributed to the people in the system and "include both factors that cannot be directly changed (e.g., age, gender, personality, information processing, cognitive ability) and those that can (e.g., experience levels; training, education, and qualifications; substance use; compliance; peer pressure)" (TRB 2002, 118). One technical discipline that provides the methods and tools for modeling and analyzing human contributions to risk is known as human reliability analysis (HRA). Objectives of HRA are to (*a*) identify human failure events in the context of risk scenarios, (*b*) estimate human error probabilities, and (*c*) provide a causal explanation for the errors to support the development of preventive or mitigating measures. As a multidisciplinary domain, HRA uses techniques and insights from cognitive psychology, behavioral sciences, human factors engineering, organizational behavior, and historical event records.

HRA methods (e.g., Bieder et al. 1998, Macwan and Mosleh 1994, Swain and Guttman 1983, Swain 1987) generally identify errors through some type of task analysis, preferably done in the context of

BOX D-1

The Role of the Human Element in Maritime Safety

The importance of the human element in maritime safety is increasingly being recognized by the shipping and offshore communities and is receiving increased levels of attention due to the efforts of organizations such as the United States Coast Guard, the United Kingdom's Health and Safety Executive, and the International Maritime Organization (IMO). IMO's primary efforts have concentrated on human element issues relating to management, training, and personnel, as reflected by the *International Management Code for the Safe Operation of Ships and for Pollution Prevention* in 1993 and the update of the *International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers* in 1995. The human element, however, includes other areas of application, which, if systematically considered and treated, will decrease the potential human error and improve safety, productivity, and efficiency.

Elements that affect safety and efficiency in job performance include: vessel design and layout considerations, workplace ambient environmental elements, management and organizational issues related to operations, and the personnel who operate the vessel or offshore installation. Insufficient attention to any of these elements may adversely affect safety, productivity, and efficiency. . . . The workplace design may increase the likelihood of human error. Additional training, operations, and maintenance manuals and more detailed written procedures cannot adequately compensate for human errors induced by poor design.

Source: ABS 2003.

the risk scenarios being considered. In the absence of a widely accepted causal model of human error, HRA methods typically rely on performance shaping factors (PSFs) to relate the context and conditions to human errors. Examples are environmental factors (e.g., limited visibility), the physical state of the crew (e.g., fatigue), and the psychological state of the crew (e.g., stress, high workload). The set of PSFs is sometimes extended to include organizational factors (e.g., poor quality of procedures, lack of training, poor safety culture). Depending on the industry and level of fidelity of HRA models, error probabilities are estimated on the basis of field data, simulator experiments, quantification models, and expert judgment.

A recent report (Kolaczkowski et al. 2005) identifies good practices associated with quality HRA, and a follow-on study (Forester et al. 2006) evaluates the extent to which some of the more popular methods incorporate those good practices. A common view today is that human error is often a symptom of trouble deeper within a system (Dekker 2002; Reason 1997). In fact, from this point of view, "error" is not the right term. These human actions are seen as reasonable responses given the context in which people find themselves. Reason speaks of "organizational accidents" that occur in complex systems possessing a wide variety of technical and procedural safeguards. These occurrences arise from the insidious accumulation of delayed-action failures lying mainly in the managerial and organizational spheres. Such latent conditions (or latent failures) are like resident pathogens within the system. Organizational accidents can result when these latent conditions combine with active failures (errors or violations at the "sharp end") and local triggering factors to breach or bypass the system defenses. These events have the following characteristics:

- The accident sequence begins with the negative consequences of organizational processes (i.e., decisions concerned with planning, forecasting, designing, managing, communicating, budgeting, monitoring, auditing, and the like). Another influential factor is the system's safety culture.
- The latent conditions thus created are transmitted along departmental and organizational pathways to the various workplaces, where they manifest as conditions that promote errors and violations (e.g., high workload, time pressures, inadequate skills and experience, poor and unreliable equipment).

- At the level of the individual at the "sharp end," these local latent conditions combine with psychological error and violation tendencies to create unsafe acts. Many unsafe acts will be committed, but few of them will penetrate the numerous defenses and safeguards to produce bad outcomes.
- The fact that engineered safety features, standards, administrative controls, procedures, and the like can be deficient because of latent conditions as well as active failures reflects the connection between organizational processes and defenses.

Some more recent methods are an attempt to address many of these issues from a more fundamental perspective that views the identification of "errors" and determination of their causes as two sides of the same coin. Some HRA methods offer a taxonomy of error types that, depending on the orientation and origin of the method, may cover such issues as action failures (e.g., failing to start an engine in a timely manner or skipping a procedural step), cognitive errors (e.g., misdiagnosis), and violations (e.g., violation of rules and regulations, sometimes with the best of intentions).

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Abbreviations

ABS	American Bureau of Shipping
TRB	Transportation Research Board

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APPENDIX E

Uncertainty, Sensitivity, and Bayesian Methods

SOURCES OF UNCERTAINTY

Risk analysis involves modeling, explicitly or implicitly. As such, it is subject to error and uncertainty. Model error is the difference between reality and its representation in the form of a model. Symbolically, $\Delta = r - m$, where Δ is the error, r is the reality (actual behavior), and m is its representation (or prediction) by the model. Models are usually created for a purpose, and the level of accuracy or the correspondence between the model and reality should be reviewed in the context of that purpose. A model could be accurate with respect to one aspect of reality and in relation to a certain purpose but inadequate in a different context. Any risk model has a "form" (or structure) and a set of "parameters." Therefore, the assessment of the magnitude of Δ is subject to two sources of uncertainty—one stemming from the structure and form of the model, generally referred to as *model uncertainty*, and another due to uncertainty in the model parameters, generally known as *parameter uncertainty*.

Uncertainties exist for many reasons, including randomness, incomplete knowledge with regard to phenomena, inaccuracies in determination of the values of quantities and parameters (e.g., a probability value), high sensitivities of system performance to specific conditions, and omission of important factors (e.g., a basic event) from an analysis. Such sources of uncertainty should be documented in the risk analysis, whether qualitative or quantitative. Given these multiple sources, discussions of uncertainty can easily become complex.

All of these sources of uncertainty can be portrayed in an analysis by means of a probability density function (pdf). This is a normalized function that portrays the relative likelihood that an uncertain variable will be observed within a particular interval.

It is helpful in a practical way to characterize several classes of uncertainty, because careful thinking about the character of sources of uncertainty leads to a better understanding of the problem and better representation of the associated pdfs. Three classes of uncertainty should be considered:

- Deterministic case—there is no variability or there is no imperfect state of knowledge that leads to variability in the results;
- Aleatory uncertainty—there is random variability in any of the factors that leads to variability in the results; and
- Epistemic uncertainty—the state of knowledge about the effects of specific factors is less than perfect.

To help understand these terms, a more operational point of view is that uncertainty is aleatory if

- It is (or is modeled as) irreducible;
- The uncertainty is observable (i.e., repeated trials yield different results); or
- Repeated trials of an idealized thought experiment will lead to a distribution of outcomes for the variable, and thus this distribution is a measure of the aleatory uncertainties in the variable.

The uncertainty is epistemic if

- One is dealing with uncertainties in a deterministic variable whose true value is unknown;
- Repeated trials of a thought experiment involving the variable will result in a single outcome, the true value of the variable; or
- It is reducible (at least in principle).

The approach for treating uncertainty implements the subjective framework for treating probabilities in analysis described by Apostolakis (1990) (see the discussion of Bayesian methods below). This approach provides the benefit of a clearer (and potentially simplified) elicitation-based quantification process. This benefit arises from the subjective framework's distinction between aleatory and epistemic uncertainties, which requires a careful examination of the factors contributing to uncertainty, resulting in a clearer definition of the issues being addressed during the elicitation. It provides a clear way to tell the truth about what is and is not known. For this reason and with clear documentation, the analysis or elicitation can be well defended.

The implications of the different values the uncertain variable might take and their corresponding probabilities of being true can be propagated to the ultimate answer obtained concerning the risk level (see the discussion of uncertainty propagation below).

The main way in which incompleteness-related uncertainty can be treated by using a pdf relates to the magnitude by which an analysis could be in error because of omission of an important structural element. The possibility of an omission is treated in terms of the magnitudes of the consequences within an analysis to which such an omission is considered likely to contribute.

SENSITIVITY ANALYSES AND UNCERTAINTY PROPAGATION

Once the magnitudes of uncertainties of the factors of a risk analysis have been determined, they can be used either to examine the *sensitivities* of the results to variations in the factors within the stated domain or to *propagate* the effects of the uncertainties to ultimate risk results. Both types of analysis are important in performing risk assessment, since uncertainties typically cannot be eliminated (although their magnitudes can be reduced) and should be addressed.

In *sensitivity analyses,* the influences of different values of a factor on ultimate answers are estimated. This is done to identify the factors of greatest sensitivity and to obtain a rank ordering of such sensitive factors. This knowledge can be valuable in identifying the factors for which improvement in performance would be most valuable and those for which degradation of performance is most important to avoid. This knowledge is also valuable to the analyst in helping to resolve or understand the epistemic uncertainty involved. In fact, there is a trade-off between the cost of an analysis or experiment and the potential impacts of living with resolvable epistemic uncertainty.

In *propagation of uncertainties*, the pdfs discussed above are used in selecting the individual values of the uncertain factors on the basis of the Monte Carlo technique in order to propagate to the ultimate answers the influences of the important uncertain factors, considered in combination. In one such sample, a value of each factor is selected randomly, reflecting the influences of its pdf. Then, the set of such values obtained from all factors is used to obtain the values of the individual performance measures of the system. When this procedure is repeated N times, it will produce a set of N values of each performance measure. Then, the relative abundance of values of a particular measure found within a specified interval of measure values provides an approximate estimate of the magnitude of the pdf of that measure corresponding to the interval specified. As the magnitude of N increases, the error of this estimate will decrease asymptotically toward zero.

Thus, one can obtain an approximate estimate of the range of the measure consistent with a stated confidence value. Since this estimate reflects both subjective and objective factors, it should be viewed as a statement of the estimator's belief about the figure of merit (e.g., the level of risk).

BAYESIAN STATISTICAL ANALYSIS

For risk assessment, the Bayesian approach offers important advantages: all kinds of evidence are used, uncertainty bands are narrower, and evaluating data with zero occurrences of events in N trials is straightforward. The foundation of Bayesian statistical inference is Bayes' theorem. The basic idea is simple. From the calculus of probability, we know that the probability of the joint occurrence of two events A and E is the following:

$$P(A \cap E) = P(A) \cdot P(E|A) = P(E) \cdot P(A|E)$$

which is a simple, uncontroversial statement. The Rev. Thomas Bayes (1958) went a step further by rearranging the above as

$$P(A|E) = \frac{P(A) \cdot P(E|A)}{P(E)}$$

and interpreting these terms as follows:

$P(A|E)$ = "posterior" probability of A, after collecting evidence E (say, the result of an experiment);

$P(A)$ = "prior" probability of A; and

$P(E|A)$ = "likelihood" of the evidence (if the evidence can take on several values $E_1, E_2, \ldots$, the likelihood is the probability of getting evidence E_i, given the prior).

This Bayesian switch (called inverse probability) allows the use of something that is known or can be calculated (the likelihood of the evidence) to determine the value of *P(A)* (given all the evidence at hand). It leads to a meaningful definition of subjective or state-of-knowledge probability. Details of the approach can be found in many standard sources (De Finetti 1975; Jefferies 1961).

E can be historical data, results of experiments, or expert opinion, all of which may be subject to uncertainty and ambiguity. Generalized forms of Bayesian inference developed in recent years provide ways of using such information in developing epistemic uncertainty distributions for risk model parameters.

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APPENDIX F

Event Sequence Diagram Method and Risk Scenario Development

The event sequence diagram method is a simple and powerful modeling tool for developing possible risk scenarios. It enables visualization of the logical and temporal sequence of causal factors leading to various states of the system. Figure F-1 illustrates the event sequence diagram method. The figure depicts the change of state of a vessel initially operating within the "safe functional/physical zone" (shaded area). At Point A, an event (e.g., equipment failure) occurs, causing deviation from the normal operating zone and putting the vessel in an undesired state (Point B). Another event (e.g., crew recovery action) is initiated at that point, and depending on whether it succeeds or fails, the vessel returns to the safe zone (Point C), or an accident occurs (Point F). The sequence of events from A (the initiating event) to the end states (C or F) forms two simple scenarios. These scenarios provide the context within which the events and their causes are evaluated as potential hazards or sources of risk.

In event sequence diagramming, a set of graphical symbols is used to describe the various elements of a scenario. Figure F-2 shows a simple event sequence diagram. The diagram starts with a circle symbolizing the initiating event or condition. The possible events or conditions (rectangles in the diagram) that can follow the initiating event are then listed in the proper temporal or logical order, connected by lines, forming various possible strings or sequences of events that ultimately end with a diamond symbol representing their end states. Pivotal events have a single input line and a (Yes/No) pair

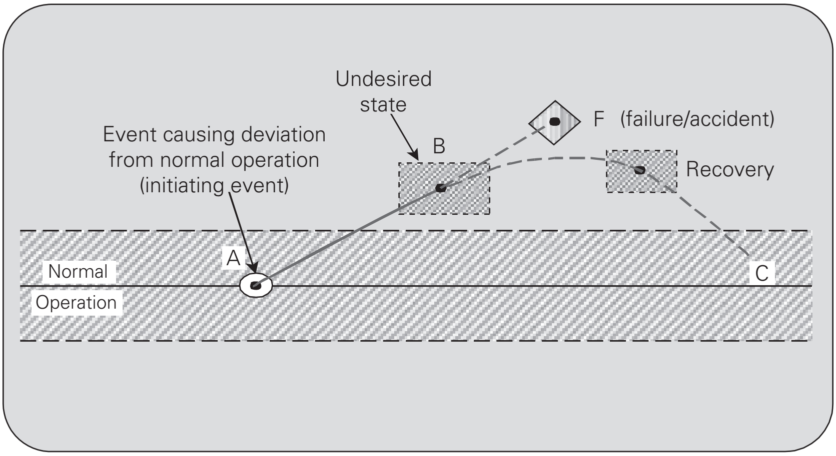

FIGURE F-1 Event sequence diagram method.

of output lines, depending on whether the pivotal event occurs (Yes output) or otherwise (No output). The same applies in the case of conditions where Yes means the condition is satisfied and No means the opposite.

An event sequence diagram, therefore, is a visual representation of a set of possible risk scenarios originating from an initiating event. Each scenario consists of a unique sequence of occurrences and non-occurrences of pivotal events (Point B or C in Figure F-1). Each scenario eventually leads to an end state, which designates the severity of the outcome of that scenario.

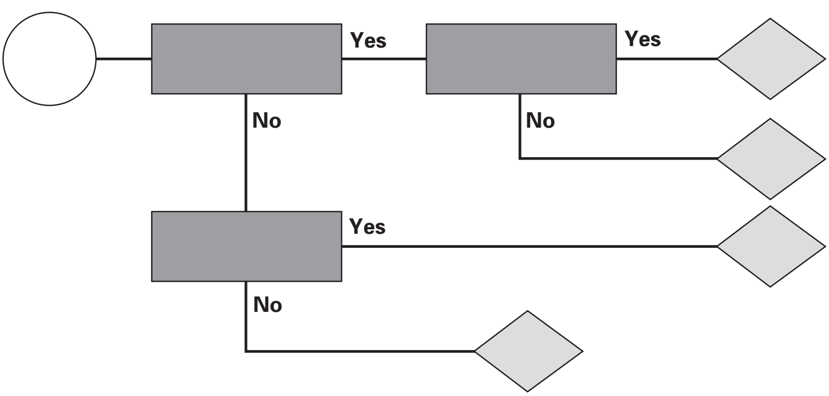

FIGURE F-2 Event sequence diagram concept.

Figure F-3 is an example of a simple event sequence diagram where, given the occurrence of the initiating event, the state of System 1 (a pivotal event) determines whether the sequence leads to success (end state S), when it works, or a human action is required, when it fails. Given the success of human action, another pivotal event (state of System 2) will determine the final outcome: success state (S) if System 2 works or failed state (F) if it fails. The failure of human action also leads to failed state F. Therefore, this simple event sequence diagram depicts four possible risk scenarios, two leading to success and two leading to a failed state (accident).

Event sequence diagrams are extremely versatile and can be used to model many situations, ranging from the behavior of purely static systems to that of many types of dynamic systems. Historically, event sequence diagramming has been loosely defined and has been used in a variety of industries for different purposes. It has been used in probabilistic risk analyses by the nuclear power industry to develop and document the basis for risk scenarios, as well as to communicate risk assessment results and models to designers, operators, analysts, and regulators. Event sequence diagrams have also been used in the aviation industry as part of safety and reliability analyses of aircraft systems. The National Aeronautics and Space Administration has used event sequence diagrams to help identify accident scenarios. In all three applications, the diagrams have been used both qualitatively for identification of hazards and risk scenarios and quantitatively to determine probabilities of risk scenarios.

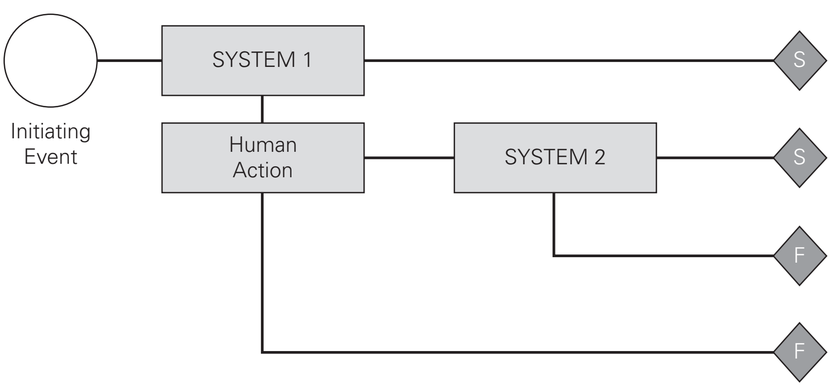

FIGURE F-3 Simple event sequence diagram.

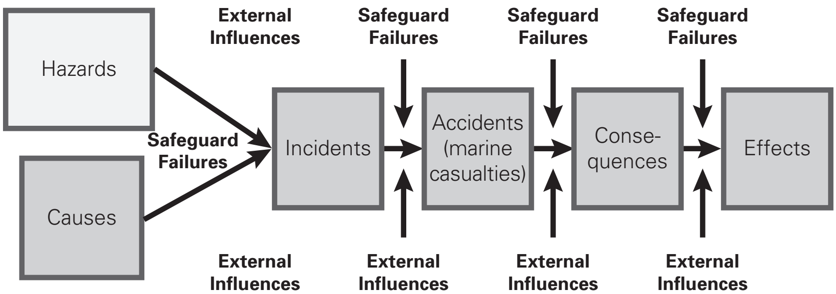

FIGURE F-4 Characterization of elements of marine risk scenarios.

Developing scenarios that can be analyzed efficiently requires good engineering knowledge, extensive experience in systems operation, and familiarity with modeling. Figure F-4 characterizes the main aspects of marine scenarios. The scenario begins with an initiating cause, for example, a fire, flooding, or adverse weather. What happens next is a sequence of events that represents the response of the "system" (the ship, its hardware and software, its crew) to the cause and the safeguards in place (barriers, operational controls, and risk control options). The cause can be controlled by the first safeguard; if not, failures may occur (hardware failures, human and organizational failures, or failures caused by environmental stressors). This sequence of events either is arrested or leads to an accident that can have immediate consequences, such as loss of life, physical damage to the ship, or a spill of hazardous materials. If a spill is involved, the scenario continues through transport and deposition of the material in the environment. Mitigation measures (additional safeguards) can limit the damage before environmental and subsequent economic and social consequences accrue. Remediation measures can limit harm to life in the area by cleaning up the contamination.

APPENDIX H

Summary Incident and Casualty Data from U.S. Coast Guard's Marine Safety Management System, 1991–2000, and Marine Information Safety and Law Enforcement System, January 2000–March 2003

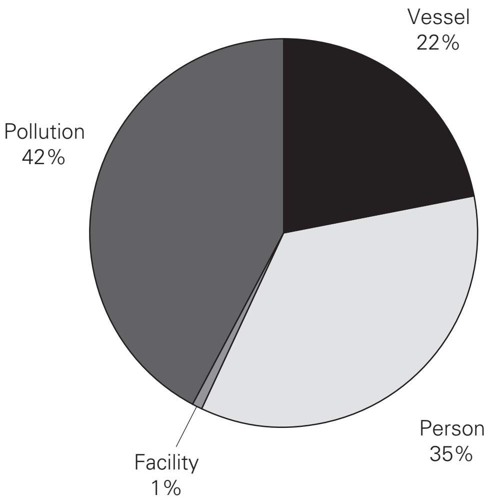

FIGURE H-1 Primary nature of incident (damage): all vessel types.

(Source: Marine Safety Management System.)

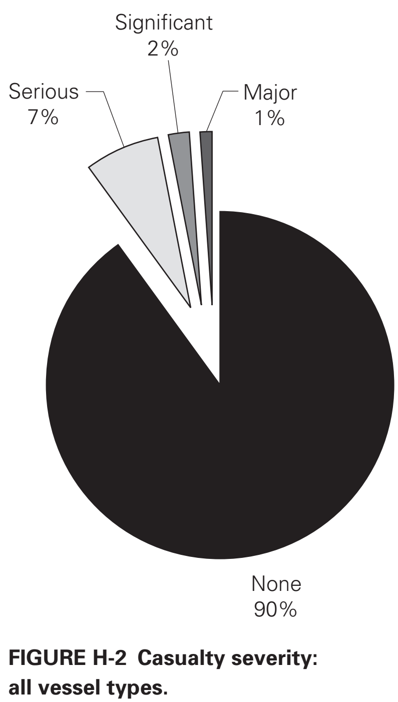

FIGURE H-2 Casualty severity: all vessel types.

(Source: Marine Safety Management System.)

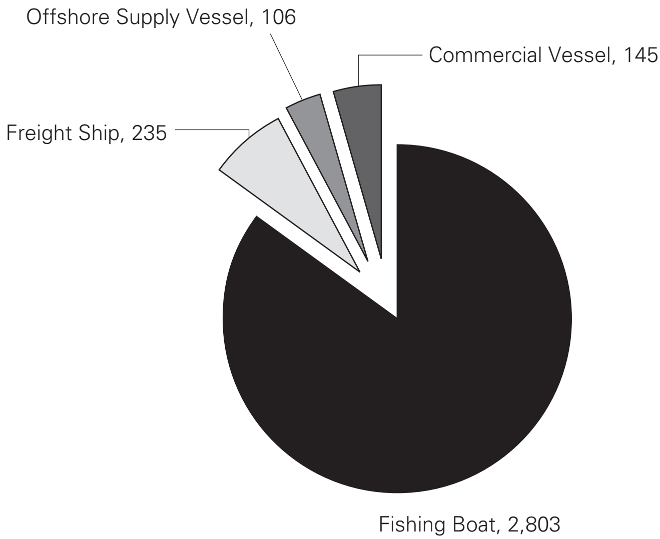

FIGURE H-3 Incidents by vessel type.

(Source: Marine Safety Management System.)

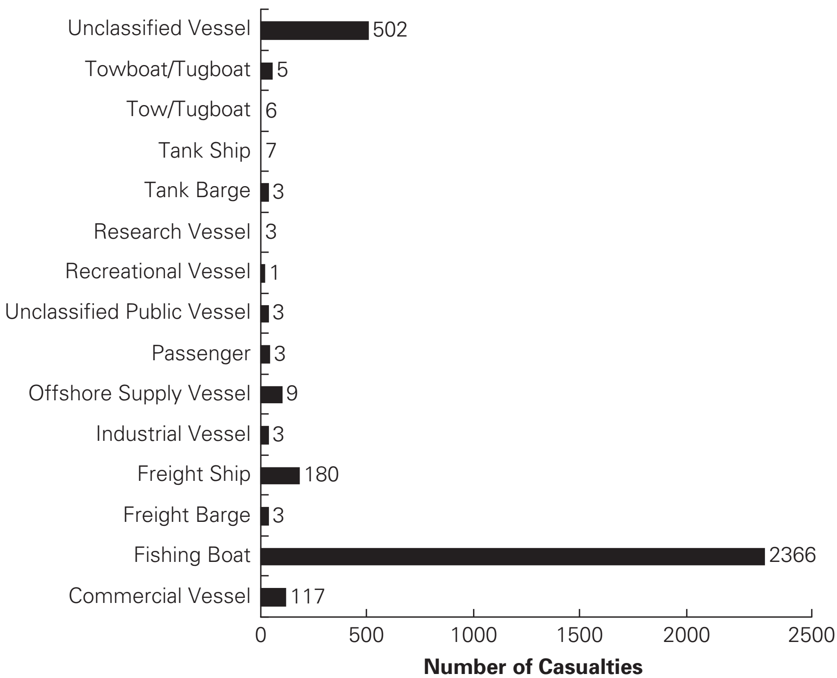

FIGURE H-4 Casualties by vessel type.

(Source: Marine Safety Management System.)

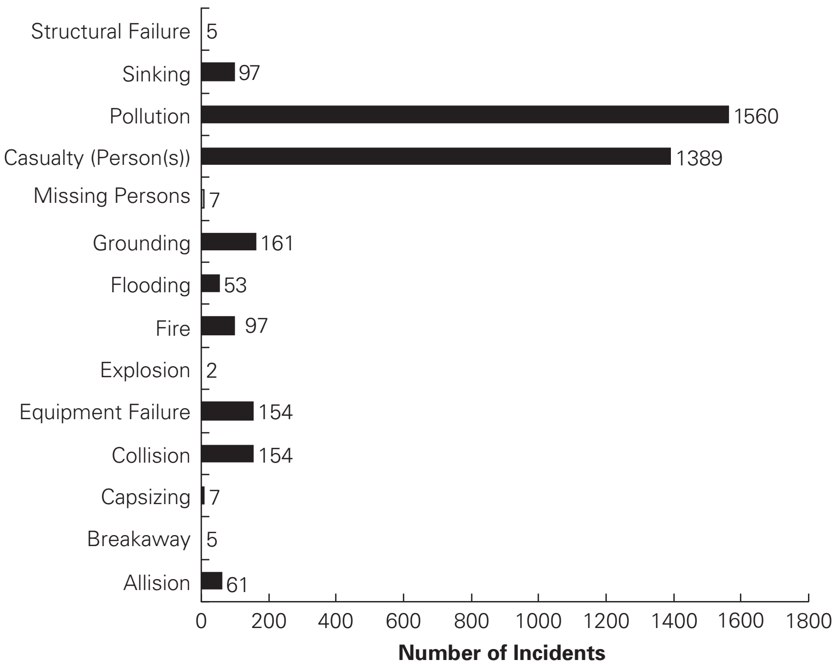

FIGURE H-5 Primary nature of incident: all vessel types.

(Source: Marine Safety Management System.)

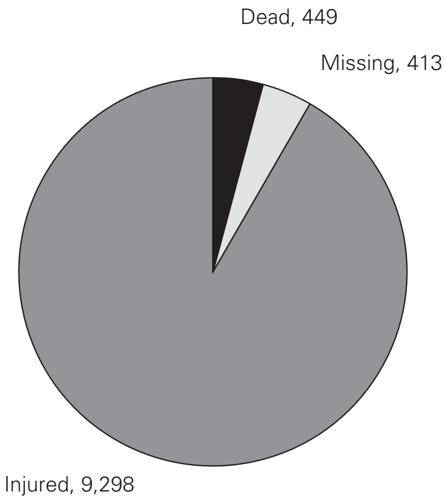

FIGURE H-6 Dead, missing, and injured crew: fishing boats.

(Source: Marine Safety Management System.)

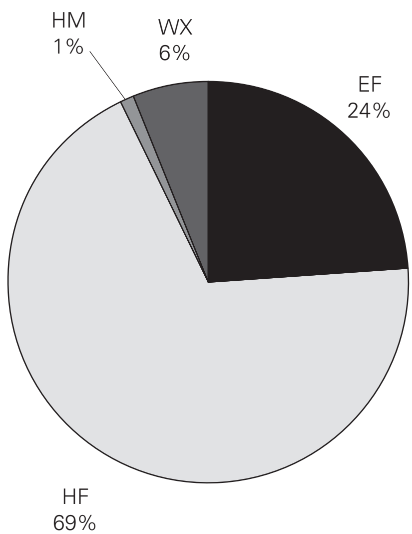

FIGURE H-7 Primary cause of incident: fishing vessels only. EF = equipment failure; HF = human factors; HM = hull material; WX = weather conditions.

(Source: Marine Safety Management System.)

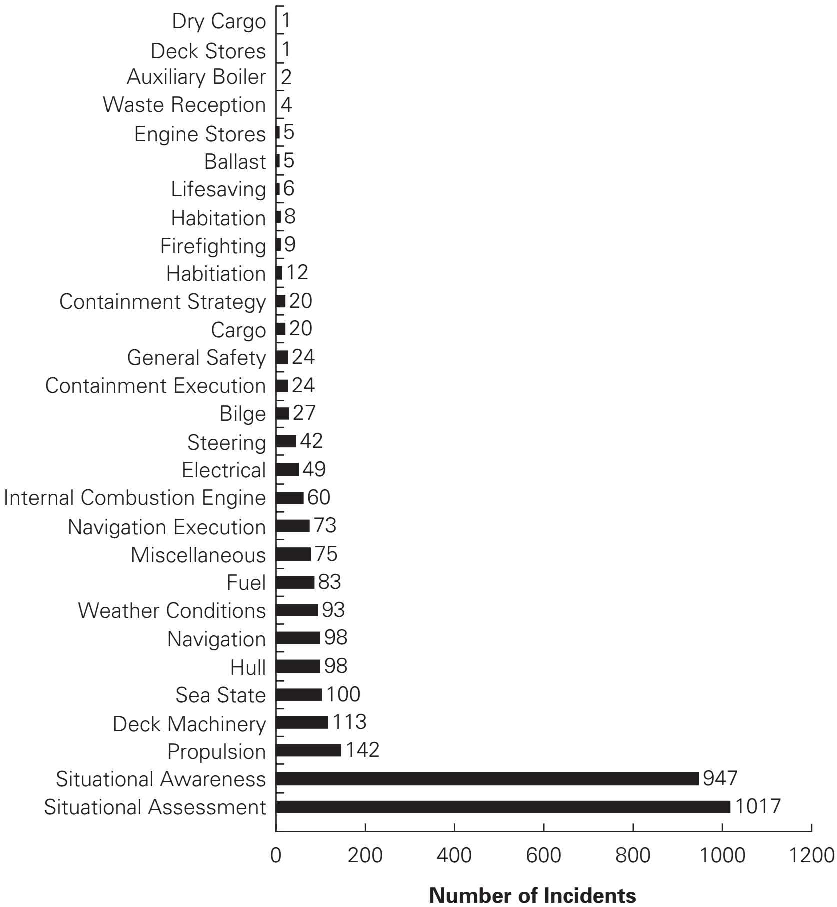

FIGURE H-8 Top-level root causes of incidents: all vessel types.

(Source: Marine Safety Management System.)

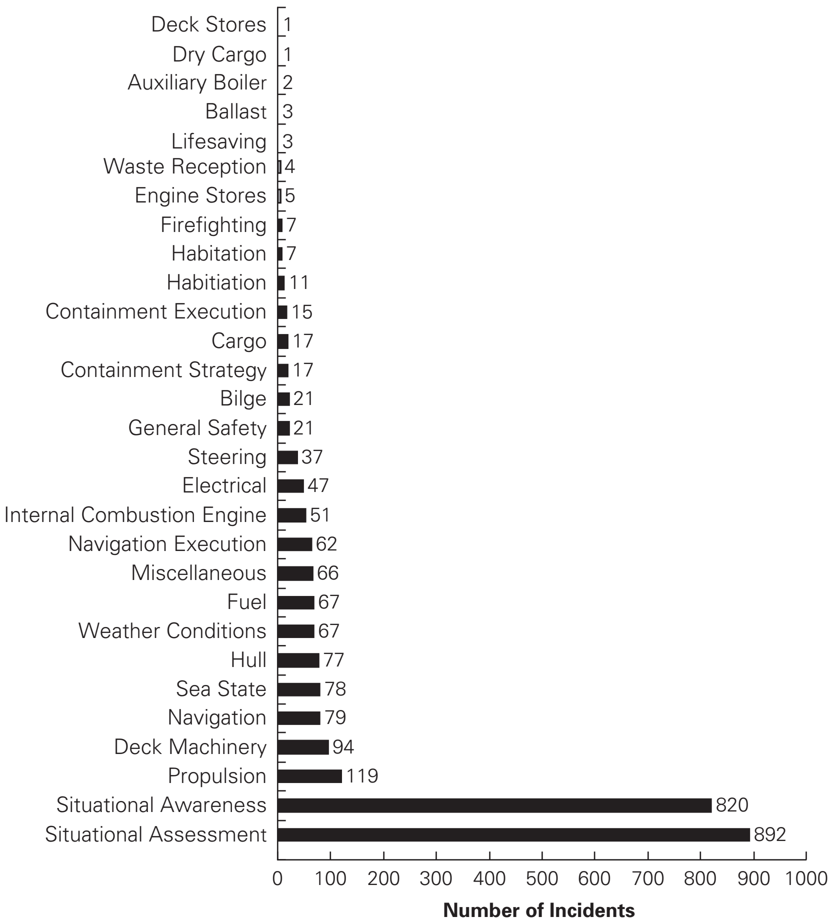

FIGURE H-9 Top-level root causes of incidents: fishing vessels.

(Source: Marine Safety Management System.)

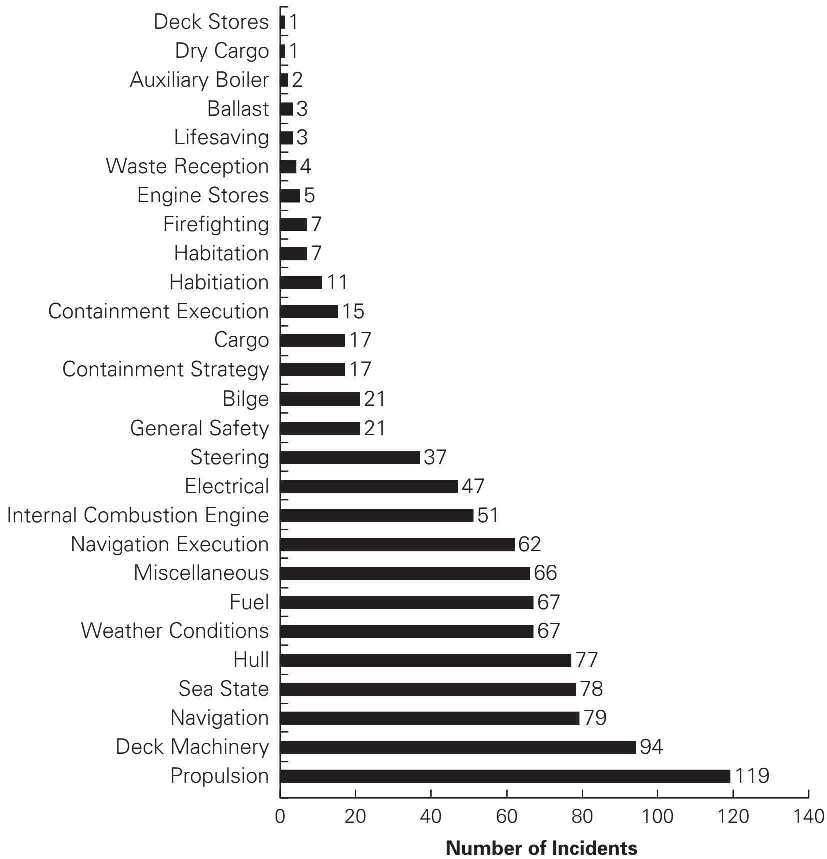

FIGURE H-10 Top-level root causes of incidents, removing situational awareness factors: fishing vessels.

(Source: Marine Safety Management System.)

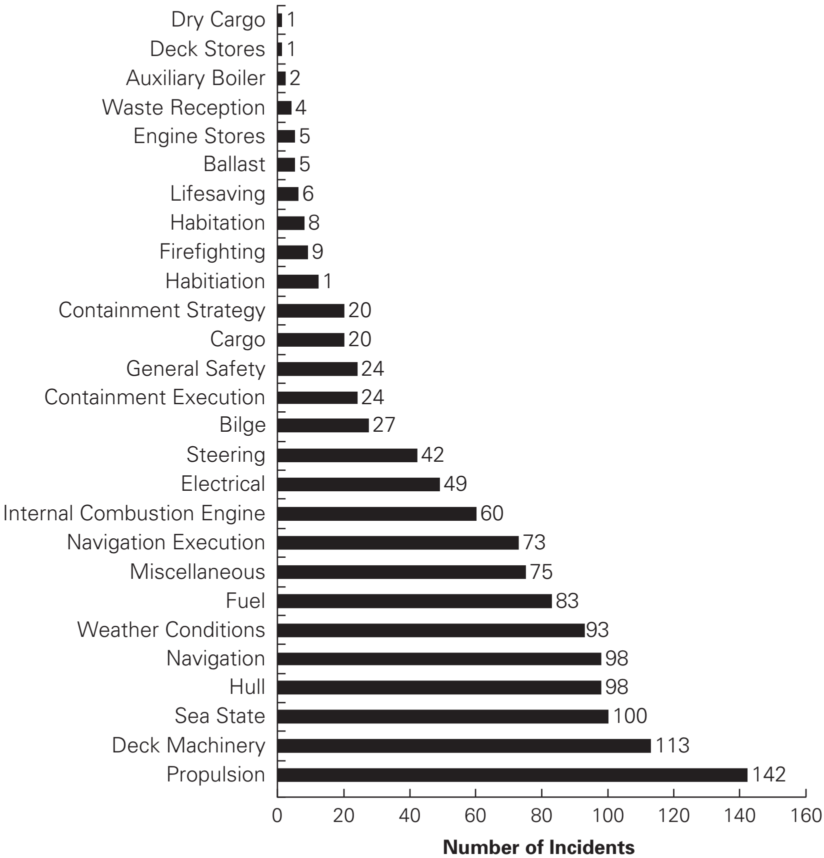

FIGURE H-11 Top-level root causes of incidents, removing situational awareness factors: all vessels.

(Source: Marine Information Safety and Law Enforcement System.)

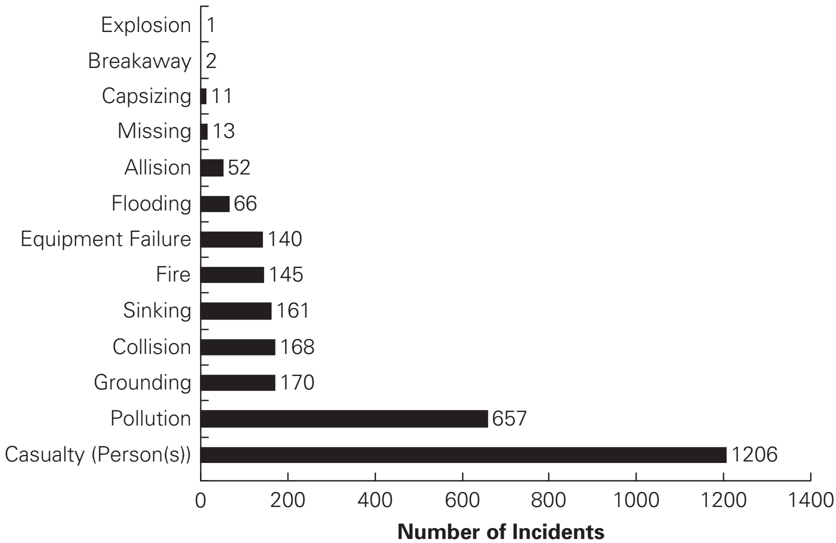

FIGURE H-12 Primary nature of incident: fishing vessels only.

(Source: Marine Information Safety and Law Enforcement System.)

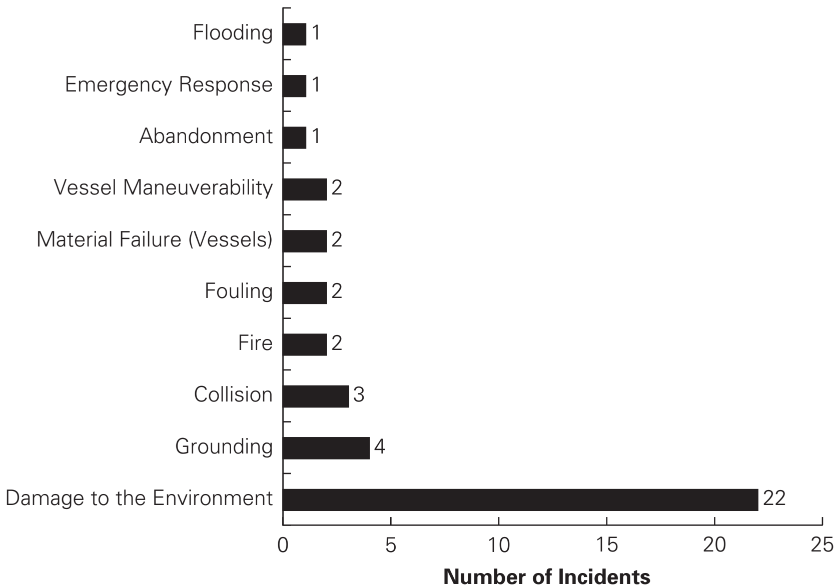

FIGURE H-13 Primary nature of incident: all vessels.

(Source: Marine Information Safety and Law Enforcement System.)

APPENDIX I

Resource Dependency and Community Vulnerability

Resources of great commercial, subsistence, and natural value are at risk from spills of oil and other hazardous substances in the Aleutian Islands. These resources have economic and other significance for the people of the Aleutians, Alaska, the United States, and, arguably, the world. In some cases their value is easy to measure economically; an example is the Bering Sea–Aleutian Islands whitefish fishery, the largest in the world. The method used to calculate this value, called market valuation, is based on the use of market prices. Other values are more difficult to capture in economic terms, and so-called "nonmarket" value estimation techniques must be used. For example, the nutritional and cultural values of subsistence fisheries and other marine resources are difficult to reduce to dollars and cents, as those heavily engaged in subsistence activity have "income" of a nonmarket variety and enjoy other difficult-to-quantify benefits of cultural significance.

The Alaska Maritime National Wildlife Refuge encompasses many of the region's extraordinary resources of natural and biodiversity value. The importance of these resources can be measured by the calculation of an "existence" value. Existence values are derived through random sample surveys employing appropriately framed questions to identify individuals' willingness to pay for the resources in question. This valuation technique, known as contingent valuation, was used to estimate the economic value of damages caused by the *Exxon Valdez* oil spill. Those studies estimated that the "aggregate lost passive use value" (the American public's willingness to pay to prevent another *Exxon Valdez*–type spill under the scenario laid out in the survey) ranged from $2.8 billion to $7.19 billion (in 1990 dollars) (Carson et al. 2003). The relatively wide variation of such estimates underscores the uncertainty inherent in decisions about which models to use in extrapolating survey results to conclusions about values of the general population through techniques such as contingent valuation.

It is also important to consider future or potential values that have not yet been assigned to the natural resources of the region. Biodiversity harbored in the marine waters of the Aleutian Islands may have future economic value that is not understood today. For example, yet-to-be-discovered compounds extracted from marine organisms could have value in treating human disease. Indeed, new species continue to be discovered in Aleutian waters not yet explored, some of them close to shore (*Dutch Harbor Fisherman* 2007). Because such future values are uncertain today, economists call them *option values.* They are not distinct from the other types of values described above, but they have resonance with people today that depends on how future conditions are likely to affect the availability of the resources, as well as people's income level and attitudes about risk (NRC 2004). Common today is the practice of recognizing "ecological goods and services" provided by particular ecosystems or resources as essential to supporting human life and thereby having economic value. As the recent United Nations–sponsored Millennium Ecosystem Assessment showed, the planet's ecosystems are sources of numerous essential ecological goods and services of value to humankind in supporting life (MEA 2005). Thus the Aleutians are not only rich in biodiversity but also relatively unexplored, and they could provide economic and other benefits to society that as yet are undiscovered.

The region's commercial fishery is by far its greatest source of standard economic value. The Bering Sea–Aleutian Islands groundfish fishery has an estimated wholesale value of more than $2 billion per year, while the crab fishery represents an additional $300 million to $500 million per year. Together they make up the largest fishery in the world, with hundreds of thousands of tons landed per year (Sepez et al. 2003). As noted in Chapter 3, landings in Dutch Harbor had a value in 2006 of $162 million, the second-highest value and the highest volume of landing of any U.S. fishing port, and generated thousands of jobs in the seafood industry. The dominance of seafood-related employment, however, is not limited to Dutch Harbor; a significant portion of the ownership of Bering Sea–Aleutian Islands vessels and fish processing is based in Seattle. Thus, catastrophic events affecting Dutch Harbor would likely have much broader consequences in the northwest Pacific, and indeed in the nation.

In addition, the income derived by migrant laborers from fish processing is of great value in the foreign nations from which many of these workers come. The phenomenon of circular migration is of substantial economic importance to many developing nations. Because of the diversity and geographic distribution of fisheries in the Aleutians, there is considerable economic and subsistence value dispersed throughout the region. On the commercial side, valuable individual quotas are held in the halibut fishery, and a system of community development quotas (CDQs) in the crab, pollock, halibut, and Pacific cod fisheries provides a mechanism for allocating income to shareholders in participating coastal communities through designated CDQ groups. Again, because a high proportion of local harvest vessels and processing facilities is owned by interests outside of Alaska, incidents that harm the industry are likely to have reverberations far beyond the Aleutian region. In addition, the fishing industry provides revenues that support a high quality of life in Unalaska and Dutch Harbor, one that would be threatened in the event of a spill resulting in the closure of fisheries, as was evident in the *Exxon Valdez* oil spill of 1989 (Ritchie and Gill 2007). Even if there is no contamination, fisheries can be closed, with substantial loss of income due solely to the perception of contamination (Alaska Oil Spill Commission 1990).

The above discussion illustrates a high level of resource dependency on commercial and subsistence fisheries in the Aleutians—conditions that translate into local populations that are highly vulnerable, both socially and economically. Events such as oil spills can threaten the resource base on which community health and well-being depend, creating social vulnerability. Vulnerability refers to "inherent characteristics of a system that create the potential for harm but are independent of the probabilistic risk of occurrence of any particular hazard or extreme event" (Sarewitz et al. 2003, 805). It is important to consider vulnerability separately from risk. The concept highlights the importance of considering both *event risk* (e.g., the occurrence of large spills) and *outcome risk* (e.g., the loss of access to important subsistence resources or the closure of segments of commercial fisheries on which the whole community or significant subgroups depend).

Communities reduce their vulnerability by investing in strong social institutions with the capacity for learning and adaptation. Robust institutions have the ability to facilitate major transformation should this become necessary to lessen resource dependency and enhance community resilience (Adger 2000). Subgroups within a resource-dependent community with little political influence (entitlement) or few resources (endowment) may prove less adaptable than the community at large, possibly leading to social justice concerns. Ritchie and Gill (2006) illustrate the many ways in which unfortunate events such as oil spills can result in outcomes that lower community resilience. An important finding in social studies of communities that experience natural or technology-induced disasters is that under some circumstances, communitywide patterns of stress can develop that permanently alter a community's sense of itself. Such impacts are difficult to quantify and easily overlooked.

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Abbreviations

MEA	Millennium Ecosystem Assessment
NRC	National Research Council

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Study Committee Biographical Information

R. Keith Michel, *Chair,* is former President and current Board Chairman of Herbert Engineering Corporation. In more than 25 years with the company, he has worked on design, specification development, and contract negotiations for containerships, bulk carriers, and tankers. Mr. Michel has served on numerous industry advisory groups developing guidelines for alternative tanker designs, including groups advising the International Maritime Organization and the U.S. Coast Guard. His work has included the development of methodology, vessel models, and oil outflow analyses. He was a project engineer for the U.S. Coast Guard report on oil outflow analysis for double-hull and hybrid tanker arrangements, which was part of the U.S. Department of Transportation's technical report to Congress on the Oil Pollution Act of 1990. He has also worked on the development of salvage software used by the U.S. and Canadian Coast Guards, the U.S. Navy, the National Transportation Safety Board, the Maritime Administration, the American Bureau of Shipping, Lloyd's, and numerous oil and shipping companies. Mr. Michel was Chair of the Marine Board of the National Research Council (NRC) from 2002 through 2004 and has served on several NRC committees. He holds a BS in naval architecture and marine engineering from the Webb Institute of Naval Architecture.

Dennis C. Bley is President of Buttonwood Consulting, Inc. He has more than 30 years of experience in nuclear and electrical engineering, reliability and availability analysis, data analysis, plant and human modeling for risk assessment, expert elicitation, treatment of uncertainty, decision analysis, expert systems, and technical management. He conducts research in human reliability analysis, probabilistic risk assessment of technological systems, modeling of uncertainties in all areas of risk analysis and risk management, extension of applications to new industries, and enhancement of technical risk communication. Dr. Bley has a PhD in nuclear engineering from the Massachusetts Institute of Technology (MIT) and a BSEE from the University of Cincinnati. He is recognized for developing probabilistic risk assessments and applying them to a wide range of engineered facilities, and he has lectured at universities, businesses, and government organizations on all aspects of risk assessment. He has also authored many papers and reports on risk assessment techniques and methods. He has served on NRC and government committees evaluating such diverse topics as railroad safety, nuclear energy systems, disposal of chemical weapons in the Army's stockpile, airport operations, the space shuttle, and chemical facilities.

Thomas M. Leschine is Director of the University of Washington School of Marine Affairs and specializes in environmental policy, with an emphasis on the use of scientific and technical information in environmental decision making. His research interests include coastal ecosystem and marine pollution management; maritime safety, including oil spill prevention and response; and the long-term management of hazards associated with radioactive and other long-lived wastes. He chaired the NRC Committee on Remediation of Buried and Tank Wastes, whose work culminated in the publication of *Long-Term Institutional Management of U.S. Department of Energy Legacy Waste Sites* (2000), a comprehensive examination of the Department of Energy's planning for long-term stewardship at defense nuclear sites. That work led to publication of the edited volume *Long-Term Management of Contaminated Sites* (2007) in the Elsevier JAI Academic Series *Research in Social Problems and Public Policy*. Dr. Leschine served previously as a member of the Marine Board's Committee on Risk Assessment and Management of Marine Systems, which produced the *Review of the Prince William Sound, Alaska, Risk Assessment Study* (1998). He received his PhD in mathematics from the University of Pittsburgh, where he specialized in mathematical logic. He made the transition to a career in marine affairs through postdoctoral research and staff appointments at the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts, and briefly at the National Center for Atmospheric Research in Boulder, Colorado.

Henry S. Marcus is Professor of Marine Systems in the Ocean Engineering Department at MIT, where he has held teaching and research positions for more than 35 years. He has also been a marine transportation consultant to many government agencies and various maritime industries. Dr. Marcus earned a BS in naval architecture from Webb Institute, two MS degrees from MIT (in naval architecture and shipping management), and a DBA from Harvard Business School. He was a member of the National Academies' Marine Board in the 1990s, has served on several Marine Board committees, and chaired a Marine Board Committee on Tank Vessel Design that reviewed ship design approaches to oil spill prevention. He has served as a member of the Federal Transportation Advisory Group and as a member of the Marine Transportation Systems National Advisory Council. He has authored or coauthored six books and numerous articles on various aspects of the marine industry. His current research interests include ocean transportation systems and international logistics, maritime transportation policy, and Arctic marine transportation. He currently directs the Ocean Systems Management Program in MIT's Center for Ocean Engineering in the Department of Mechanical Engineering.

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