POTENTIAL SAFETY AND ENVIRONMENTAL CONCERNS IN PETROLEUM TRANSPORTATION

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INTRODUCTION

Petroleum has become the major energy source in the United States. However, by 1985, it is projected that the U.S. will be importing almost half of its oil requirements from foreign nations. Most petroleum imports will travel by tanker. Recent oil tanker accidents resulting in massive oil spills have focused public concern on the safety of petroleum transportation systems. This paper presents results of a study conducted for the Department of Energy by Pacific Northwest Laboratory to provide early recognition of and prioritize potential problems in petroleum transportation. Early identification of significant problems can contribute to the lead time needed to implement problem solutions and to plan appropriate research, development and systems engineering to mitigate potentially adverse effects. Other objectives of this study are to identify possible gaps in the coverage of ongoing programs and recommend necessary action to mitigate the potential impact of identified problems.

Potential problems in petroleum transportation were identified by the analysis and prioritization of current issues. Additional information and insight were gained from contact with experts in government and in the petroleum and transportation industries. The relative priorities of problem concerns were judged on the basis of their potential impact on the whole transportation system and the potential immediacy of that impact.

The diversity of potential problems affecting energy material transportation has suggested the use of a special format for presenting the results of this study. Each specific potential problem is discussed in a subsection that describes the concern, identifies the basis for the concern and discusses in an appraisal format the overall perspective on the concern as a guide to
recommending action. Ongoing or planned programs investigating problem solutions are summarized, when possible, as related work. Recommendations are then made for actions that address potential problems according to their apparent needs and importance under current conditions.

The concerns highlighted in this paper have been extracted from a much larger study, which covered a broader range of concerns. The full report includes a discussion of over twenty-five problem issues, with topics ranging from safety and environmental concerns to transportation logistics and legal, regulatory and institutional problems. Perceived problems and concerns currently being resolved by ongoing programs are also identified in the complete study.

The remainder of this paper presents summaries of selected safety and environmental concerns in petroleum transportation. Each of these potential problems is discussed below, together with recommendations for actions that address the problem. The concerns addressed in this paper deal with 1) gaps in oil spill prevention technology and practices and, 2) assessing the effects of oil spills that occur.

EFFECTS OF MARINE OIL POLLUTION

Public doubts concerning the effectiveness of oil spill cleanup methods and uncertainty regarding ecological effects of marine oil pollution may create pressure for regulatory requirements that do not effectively mitigate adverse environmental impacts, yet impose unreasonably high costs upon the industry.

Approximately 50 percent of the total oil release in the oceans comes from river and urban runoff, atmospheric fallout and natural seeps. The other 50%, approximately 3.5 million tons/year, stems from industry-related sources. Transportation is responsible for more than half of this amount. The actual damage to marine life from an oil spill depends upon the volume, composition and toxicity of the released oil, weather conditions, ecosystems, the physiography of the oil spill area and man's ability to clean up the spill. Field studies present conflicting opinions regarding the threshold limits for damage to marine life from petroleum.
Many companies manufacture oil spill cleanup equipment and materials, including oil skimmer systems which remove oil from a water surface, containment booms which prevent spreading of the oil, and absorbents which remove oil from water. However, with the exception of USCG and EPA programs, most oil spill cleanup developments are designed for rivers, harbors and ponds, not oceans. These devices are fairly ineffective in even moderate sea, current and wind conditions.

Oil spills are the most frequent type of accident during petroleum transportation. Although the actual spill may not constitute an immediate hazard to human life, the effects of oil on ecological systems may be substantial. While all damages may not be permanent, long term ecological disruption may occur. Extensive laboratory and field studies on oil pollution effects have been performed, although results are varied and often contradictory. However, the extent of this work does not appear to have been effectively communicated to the public. An assessment of the adequacy of current U.S. pollution prevention capabilities and contingency plans and the potential environmental consequences of oil spill incidents is required. The results of this assessment should be used to provide the public with credible information on the status of U.S. abilities to cope with marine oil pollution. An increased public awareness of the state-of-the-art should reduce pressure for costly and ineffective regulation.

**OIL SPILL TRAJECTORY MODELING**

Current modeling techniques for predicting the movement of oil spills are often inadequate. Inaccurate forecasting of oil slick transport and spreading can hinder clean-up efforts and lead to public reaction.

When an oil spill occurs, measures to minimize environmental impacts require a capability to forecast the short and long term behavior of the spilled oil. Accurate predictions of arrival times, locations and sizes of oil slicks are necessary to facilitate measures to protect beaches or areas of special biological significance. Imprecise forecasting can delay the implementation of protective measures.
Predictions of oil spill trajectories and the ultimate fate of oil in the marine environment are based on mathematical simulations of the many physical, chemical, and biological processes and phenomena which interact in the event of an oil spill. Forecasts are limited by an inadequate understanding of these complex interrelationships. Even the more sophisticated probabilistic models do not consider all of the transport processes of petroleum in the marine environment. These incomplete models may yield misleading predictions regarding the movement of oil slicks. Restraints on predictive abilities also stem from the large amounts of localized data required in order to realistically operate the mathematical simulations; even if available, the accuracy of input data for some model parameters is questionable.

Large scale oil spills throughout the world have had major local effects on the ecology of the ocean and coastlines near these spills. There is a growing worldwide concern over the environmental damage that can be caused by accidental releases of petroleum. Oil spill drift forecasting models can be instrumental in identifying areas of maximum environmental threat and directing efficient containment action.

Models have been developed that can predict the spreading, transport and potential impacts of some actual spills. A new oil spill model is also being developed at the University of Southern California (USC), funded by the American Petroleum Institute. The USC model integrates present knowledge concerning the major physical, chemical and biological processes that are likely to affect oil spilled in the marine environment. However, only spills that occur at the water surface will be modeled, and different shoreline terrains upon which the oil may impact are not taken into account.

Generally, the development of oil spill models has surpassed the availability of the detailed data required to reliably operate the simulations. Physical and chemical properties of the oil, the motion and composition of the water beneath the slick, and climatological conditions above the slick are all important in analyzing oil slick transformations. Most models, however, do not attempt to consider the full range of potential interactions because of the complexity of the relationships involved. For many of these processes, there is also a
significant lack of data suitable for testing the basic hypotheses of modeling efforts.

Present techniques for predicting oil slick growth yield no better than order-of-magnitude estimates for slick size and configuration. None of the present models consider oil accumulation in bottom sediments, which may have ecological impacts on marine organisms and the shoreline. Current modeling techniques are most adequate when applied to relatively protected sites such as harbors and bays, where processes for which little is known (such as dispersion, weathering and wave influence) can usually be neglected for the short travel times involved. In more exposed environments, however, these processes must be considered.

Effective oil spill cleanup efforts require an accurate forecasting of the oil spill pathway. Only surface instantaneous spills have as yet been modeled with any degree of success. Continuous surface oil spills may be partially modeled by approximating the spill as a series of discrete instantaneous releases. No methods presently exist for modeling subsurface spills, such as from an offshore pipeline. More research is necessary to incorporate subsurface transport models, the accumulation of toxic oil ingredients in particulates and sediments, and the long-term effects of decay processes in drift models. More accurate models should result in improved oil spill response capabilities. An improved knowledge of the ultimate fate of oil in the marine environment will also clarify effects of oil pollution and diminish costly and time-consuming environmental debates.

ENVIRONMENTAL IMPACT OF PIPELINE LEAKS

Pipeline leaks that escape immediate detection may result in environmental damage. Leak detection devices monitoring fluctuations in pressure and flow are regularly used for petroleum pipeline systems. With this type of continued monitoring, leaks are generally detected within twenty-four hours. However, at the lower limits of the detection range, the metering may not be sensitive
to pressure and flow fluctuations caused by proportionally small leaks. Leak detection limits vary between 0.1 to 1 percent of the pipeline flow depending on the age of the system and flow conditions. Improved leak detection on the Trans-Alaska Pipeline is provided by metering systems sensitive to 0.1 percent of rated capacity flow. However, with a flow rate of one million barrels per day, the 0.1 percent sensing limit could allow losses of up to 1,000 barrels per day to go undetected.

Thousands of barrels of Prudhoe Bay crude oil were released by a sabotage attempt on the Alaska pipeline on February 15, 1978. The leak detection system did not detect the leak, which was eventually reported by a private pilot flying over the line. Estimates of the peak rate of oil flow from the leak ranged up to three barrels (126 gallons) per second. The oil was contained in an area 600 feet in diameter around an aboveground section of the pipe about 6 miles east of Fairbanks. Up to 20,000 barrels of oil could have been released if the line had leaked all the oil in the affected section.

Routine pipeline surveillance and maintenance are important aspects of pipeline safety and accident prevention. During inspection and maintenance, pipelines are shut down while the pressure is monitored. A pressure drop may indicate a leak. However, there is normally at least a two-week interval between inspections. A leak occurring below the detection limit of the flow metering can usually be spotted visually. Pipeline personnel trained in ground and aerial surveillance can spot small pipeline leaks by indications such as a visible oil patch, a yellow vegetation area over the pipeline, a melted patch of snow or an oil sheen on water. Infrared film is also used in aerial surveillance of pipelines for determination of hot and/or cold spots that could indicate a pipeline leak.

Leaks occurring below the detection limit of the flow instrumentation are generally located by routine surveillance. The quantity of oil lost, however, is sometimes difficult to estimate. Small oil spills on land are rarely of significant environmental concern. However, an oil pipeline leak that can reach ground water, waterways or the marine environment may cause environmental damage before it is noticed.
Oil releases from offshore pipelines\(^{(a)}\) can also result in environmental damage. Six of eighteen oil spills from pipeline ruptures or leaks reported to the USGS during 1967-1976 were considered to be major pollution incidents.\(^{(b)}\) Breaks in pipelines are primarily caused by ship anchors and seismic activity.

There is a general lack of technical specifications for offshore pipelines. Although the Offshore Technology Conference provides some evidence of ongoing research and development, there is no major research and development program for offshore pipelines. Environmental effects of the lines seem to be dealt with on a case-by-case basis. Environmental impact statements for offshore construction, including drilling operations and deepwater ports, must specifically address the impacts of any offshore pipelines included in the facility.

Although pipelines are considered one of the safest methods of transporting petroleum, leaks can occur and may not be detected in time to prevent environmental damage. Not all leaks are required to be reported and the quantity of oil lost is sometimes difficult to assess. Because some pipeline leaks escape detection for a limited period of time, there is a need to ascertain the maximum amount of oil which could be lost (or intentionally diverted) without triggering the detection system. The potential environmental impacts and energy loss significance of such undetected leaks should be evaluated to determine whether the development of new pipeline operation and control techniques are warranted to address this problem. A pipeline system safety and environmental effects analysis is also needed to provide information about marine life pattern changes associated with offshore petroleum pipelines. This study should also assess the adequacy of current technology for offshore pipelines, including corrosion control, inspection methods and repair procedures. An analysis of the environmental impacts of pipeline leaks could also reduce planning and construction leadtimes for new pipeline projects.

\(^{(a)}\) These include pipelines required for deepwater port operations.
\(^{(b)}\) Major spills are defined as those of more than 2,380 barrels of oil.
COST-EFFECTIVE TANKER SAFETY DESIGN STANDARDS

Recent legislation mandates tanker safety design standards for crude oil and product tankers. These requirements may not provide the most cost-effective means of preventing tankers being a source of marine oil pollution and may result in unnecessary increases in oil shipment costs.

Public Law 95-494 sets up a list of design requirements for new and existing petroleum tankers. New crude oil carriers of 20,000 DWT or greater must be fitted with segregated ballast tanks (SBT), crude oil washing \(^{(a)}\) (COW) and inert gas (IGS) systems. Separate water-and oil-ballast tanks prevent the mixing of oil and water in the same tank and eliminate the need to fill cargo tanks with sea-water ballast. At present, the release of oily ballast water before reloading accounts for about 1.5 out of the 1.8 million tons of oil discharged annually into the sea from ships.\(^{(4)}\) Tank washing systems that use sprayed oil instead of water also reduce mixing of oil and water and resultant ocean pollution. Inert gas systems pump an inert or nonflammable gas into partially empty tankers to avoid fuel-vapor explosions.

Other requirements of the new law include the following: 1) existing crude oil carriers of 40,000 DWT or greater \(^{(b)}\) must have clean ballast tanks (CBT), SBT or COW systems; IGS must also be installed according to a timing schedule set by ship size; and 2) petroleum product tankers greater than 40,000 DWT \(^{(b)}\) (and new product tankers over 30,000 DWT) must be equipped with CBT or SBT and have IGS installed. Standards for inspection and certification, backup radar and improved emergency steering are also included for existing tankers.

\(^{(a)}\) Crude oil washing uses the force of crude oil circulating in the cargo tanks to remove heavy residues and to sweep away oil left sticking to surfaces.

\(^{(b)}\) The design standards also apply to existing tankers between 20,000 and 40,000 DWT which were more than 15 years old in April 1978.
The use of segregated ballast tanks will diminish oil pollution resulting from routine ballasting and tank-cleaning operations and the spills occurring as a result of human error or poor operating procedures during these processes. However, cargo tanks would still require cleaning in case of ship repairs or to carry some cargos, such as refined products, or even special crudes, which might be contaminated by the residues of other crude oil.

The use of separate tanks to prevent the mixing of ballast water and the lighter petroleum cargo floating on top of it is an expensive pollution prevention alternative. Converting existing tankers to segregated ballast tanks would reduce oil-carrying capacity by about 15 percent, and may cost between $300,000 and $3 million per vessel. There may also be a possibility of ships being unable to reach design speeds because of a reduced draft when sailing under ballast. Introducing segregated ballast tanks to the existing world tanker fleet will inevitably increase the cost of oil delivered by sea, perhaps by as much as 2 percent. There may also be difficulties in establishing monitoring equipment for oil/water mixtures and providing shore-based reception and disposal facilities for oily mixtures and residues which could not be discharged at sea.\(^4\)

A simpler, and less costly approach might be to allow the mixture of oil and water to settle for a few days in calm weather and then discharge relatively clean water. Another approach is to discharge dirty ballast into dockside "slop" tanks, as many U.S. tankers do.

This concern suggests the need for an overall system study on the cost-effectiveness of tanker safety options and pollution prevention alternatives. Although segregated ballast is effective in limiting oil pollution from routine cleaning operations, it does not prevent releases in an accident situation. Furthermore, the new safety regulations will not be fully implemented for another five years. Interim prevention measures and the
development of future oil pollution prevention standards and techniques should consider all available alternatives on the basis of acceptable public risk and cost/benefit assessments. Tanker safety options should address the real risk areas in marine petroleum transportation.

TRAINING OF WATERWAY PERSONNEL

Human error is a causal factor in 80 to 85 percent of all waterway casualties. Inadequately trained and/or poorly motivated waterway personnel may contribute to higher than acceptable vessel casualty rates. The waterway transportation industry is concerned about this problem and is lobbying to increase the qualification requirements of inland waterway personnel to obtain higher competence levels. The only licensed officer aboard a tow or tugboat has traditionally been the operator.

The industry has become involved with schools offering marine training programs, such as Seattle Community College and Lundeburg School of Seamanship. Some companies offer in-house training to their marine operations personnel. The growing sophistication of marine petroleum transport vessels and equipment such as fathometers, dual radars, radios, and speaker systems, increases the need for formal training programs. Training courses provide new employees with the basic procedures and techniques of marine operations, and review procedures or teach new skills to more experienced employees.

Programs are offered in fire-fighting, hazardous cargo transfer, equipment operations, safety procedures and other areas. Most marine operations personnel belong to unions, which also provide training programs for deckhands, engineers, mechanics and tankermen.

The USCG is presently involved in revising personnel qualification regulations. Regulations that increase qualification requirements would increase the number of licensed personnel aboard petroleum transport vessels and should thus lead to reductions in marine casualties. Also, stricter standards must be developed and enforced regarding the number of hours one may stand on watch, and the testing and retraining of personnel. Although endorsements and licenses do not necessarily guarantee efficient personnel, they may result in an improved awareness of safety precautions and procedures.
While most aspects of this problem are being addressed in current programs, it is recommended that emphasis be placed on identifying the human risk factors in marine petroleum transportation. This could be one task in a major program on the cost-effectiveness of various casualty prevention practices and devices. It is important to determine the real causes of marine casualties and implement systems that address those causes.

**INSUFFICIENT COAST GUARD MANPOWER**

The number of vessel and facility inspections and accident investigations is increasing as a result of the increasing number of regulations requiring enforcement by the USCG. This trend may reduce the Coast Guard manpower available for monitoring other aspects of waterway transport; this in turn may encourage a lower level of safety consciousness on the part of maritime operators.

The USCG is the principal enforcement agency for regulations governing the operation of vessels in coastal and inland waterways. The many regulations pertaining to petroleum cargo vessels require the USCG to use its limited manpower by establishing priorities for inspection and investigation of incidents. As both regulations and traffic increase, the USCG enforcement function may become too thinly spread to remain fully effective in encouraging all aspects of safe operation on U.S. waterways. Some operators, as a result, may risk reducing their compliance with safety regulations and thereby increase the probability of accidents.

The USCG enforces a large number of regulations pertaining to marine vessels and facilities, crew size and qualifications, and navigation. Inspections and investigations proceed according to priorities which are established by the basic responsibilities of the USCG for safety of life at sea and protection of the marine environment. These priorities must often be changed to accommodate new requirements. In areas that have a small number of USCG personnel, this often means that investigations will require more time and inspections will be less frequent. The USCG is also responsible for overseeing oil spill-control operations if local authorities are unable to effectively handle or coordinate response activities. The USCG may have as few as half the personnel needed to effectively deal with marine accidents and oil spills.
It appears that USCG manpower shortages may result in a decreased level of environmental protection to the U.S. Outer Continental Shelf and coastal areas. Although we recognize that most enforcement agencies are forced to operate at a less than optimal manpower level, public concern regarding marine safety and environmental effects of oil spills dictates a reevaluation of USCG priorities. We recommend that the USCG allocate available manpower to ensure a minimum level of environmental protection to coastal areas. A realignment of responsibilities among other agencies may be necessary to achieve satisfactory levels of protection.

CONCLUSIONS

The above group of concerns suggests the need for a program to trace the paths of petroleum in the oceans from the source of the spill to where effects on marine organisms are observed. There are two complementary parts to this program. The first part should generate oil spill event trees for each mode of oil transport and estimate the number of oil spills or percentage of spillage related to each source of petroleum release. This work would reveal those areas where preventive measures might be most cost-effective. The second major portion of the recommended program should provide a more complete data base regarding the fate and effects of oil releases in the ocean environment.

An improved understanding of oil spill pathways should offer a sound basis for evaluating the level of environmental protection offered by various spill prevention techniques and devices. This data base could also help to evaluate the cost-effectiveness of implementing new environmental protection methods specific to particular spill sources. It is essential that pending and future decisions on oil production and development be made with a clear understanding of problem causes and potential effects of alternative remedial actions. Knowledge generated by this program should be useful in guiding policy decisions and determining the direction of future development efforts.
REFERENCES


