Tic

PSEG

Public Service Electric and Gas Company 80 Park Place Newark, N.J. 07101 Phone 201/622-7000

September 30, 1974

Docket 50354--113
" - 50355--113

RECEIVED OCT 2 1974

Mr. A. Giambusso
Deputy Director for Reactor Projects
Directorate of Licensing
U. S. Atomic Energy Commission
Washington, D. C. 20545

Dear Mr. Giambusso:

REPORT - ANALYSIS OF POTENTIAL EFFECTS
OF WATERBORNE TRAFFIC ON PLANT SAFETY
HOPE CREEK GENERATING STATION
DOCKET NOS. 50-354 AND 50-355

Included in "Additional Information - Site and Environment" submitted to the staff by letter dated January 4, 1974, was a commitment by Public Service Electric and Gas Company to conduct a study to estimate the probability of impairment of function to safety related structures or components resulting from the accidental explosion of waterborne ship cargo in the vicinity of the Hope Creek plant. This commitment was in response to the requirement stated by the staff in Question 2.47 transmitted by letter dated December 21, 1973.

The subjects of explosives carried on the Delaware River including Anchorage No. 2 and the ability of the plant to withstand the detonation of such cargo was addressed in "Applicant's Answer to Staff's Interrogatories Dated April 11, 1974", transmitted to the staff on April 25, 1974. The conclusion, as stated in the abovementioned document, is that safety related structures and equipment can withstand a detonation in the river channel or Anchorage No. 2 of the largest quantity of explosives permitted to be shipped.

In discussions with the ACRS on February 8, 1974, Public Service Electric and Gas Company agreed to study the effects of numerous additional types of potentially hazardous occurrences on the river. In their report on the Hope Creek plant dated February 12, 1974, the ACRS stated that the matter of potential effects on plant safety due to waterborne traffic on the Delaware River should be resolved in a manner satisfactory to the Regulatory Staff.

MASTER

10157

BLANK PAGE

A comprehensive study has been conducted by Arthur D. Little, Inc. to determine the potential effects of a broad spectrum of waterborne traffic on plant safety. Enclosed are ten (10) copies of the report of that study, entitled "Analysis of Potential Effects of Waterborne Traffic on the Safety of the Control Room and Water Intakes at Hope Creek Generating Station".

The results of the study show the probability of risk to plant safety due to waterborne traffic is sufficiently low that no special provisions or additional requirements need be included in the Hope Creek Generating Station design to insure the ability to safely shutdown or maintain the plant in a safe shutdown condition.

Very truly yours,

R. L. Mittl
General Manager - Projects
Engineering and Construction Department

CC G. Lear, Atomic Energy Commission
W. Butler, Atomic Energy Commission

Docket - 50354--113
" - 50355--113

ANALYSIS OF POTENTIAL EFFECTS OF WATERBORNE TRAFFIC ON THE SAFETY OF THE CONTROL ROOM AND WATER INTAKES AT HOPE CREEK GENERATING STATION

to

PUBLIC SERVICE
ELECTRIC AND GAS COMPANY
80 PARK PLACE
NEWARK, NEW JERSEY 07101

SEPTEMBER 1974

77289

MASTER

Arthur D. Little, Inc.

FINAL REPORT

relating to

ANALYSIS OF POTENTIAL EFFECTS OF WATERBORNE TRAFFIC ON THE SAFETY OF THE CONTROL ROOM AND WATER INTAKES AT HOPE CREEK GENERATING STATION

to

Public Service Electric and Gas Company
80 Park Place
Newark, New Jersey 07101

September 1974

77289

MASTER

Arthur D Little, Inc.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

1.0 INTRODUCTION

1.1 BACKGROUND

During the course of their review of the construction permit application for Hope Creek Generating Station, the Atomic Energy Commission Staff stated the requirement that a determination be made of the probability of accidental explosion of waterborne ship cargo in the vicinity of Artificial Island, and the associated probability of impairment to safety-related structures or components essential to achieve a safe shutdown. The Advisory Committee on Reactor Safeguards recommended that the study also include the probability of spills or resulting fires of oil or LNG and barge collision with the service water intake structure. Public Service Electric and Gas Company (PSE&G) agreed to conduct such a study and provide a report of the results to the AEC Staff.

In order to comply with this commitment, PSE&G retained Arthur D. Little Incorporated (ADL) to conduct the required study.

This report provides a description and the results of the study.

1.2 OBJECTIVE

The objective of this study is to quantify the risks presented to the Hope Creek Station safety-related structures and equipment due to maritime traffic on the Delaware River in the vicinity of Artificial Island. The potential risks presented by the maritime activities considered are those due to flammable vapor dispersion, toxic vapor dispersion, pool fires, explosions, corrosive chemicals, and ramming and blockage of the intake structure.

1.3 APPROACH

The waterfront structure, by virtue of its proximity to the river, is more vulnerable to the effects of waterborne hazards. However, since occupancy of the intake structure is not required for maintenance of plant safety, hazards effecting only personnel occupancy were not considered.

The possibility of a ship or barge colliding with the intake structure was studied and an estimate of damage was made. The possibility of blockage of the intake structure due to a marine accident was also studied.

The remaining plant equipment and structures important to safety are located over 800 feet from the river, therefore most of the river traffic accidents considered would have no effect. The probability of accidents resulting in the release of flammable or toxic vapor was considered due to the potential risk to occupancy of the station control room.

The estimates of risk presented in this report were developed in accordance to the following steps:

1. The traffic history along the Delaware was established by utilizing data from the Corps of Engineers, Waterborne Commerce of U.S. data base (supplemented by information from the Philadelphia Maritime Exchange).
2. The probability of a collision occurring of sufficient severity to cause major release of several types of cargo was estimated using the U.S. Coast Guard accident records, world-wide tanker experience and a simplified statistical model.
3. For each major type of cargo, the distance from the plant within which the accident could pose a threat was estimated.
4. The probability of each type of cargo presenting a risk to plant safety was determined.

In evaluating the many estimates of risk, several simplifications and assumptions were made. However, these simplifications and assumptions were made in a conservative fashion so as not to underestimate the risk.

1.4 PRESENTATION

The results of this study are presented in Section 2. The detail data and calculations in support of the results are presented in Sections 3, 4, 5, and 6 plus appendices.

2.0 RESULTS

This section contains the results regarding risks presented to the water intakes and the control room at Hope Creek by waterborne traffic on the Delaware. The risk considerations are arranged by category of traffic. For barge related spill risks, hazards presented by spills that result in fire, toxic or flammable vapor clouds, explosive and corrosive chemicals are considered and the actual risk quantified. Similarly, for tanker related spills, we have presented risks due to spillage resulting in fire, toxic or flammable vapor clouds, explosives and corrosive chemicals. In addition to the spill related risks, maritime traffic could potentially pose problems of ramming the intakes and/or blocking of intakes. The risk presented to the intakes by these occurrences is evaluated. Non-collision related shipping hazards are also considered and the risk presented to Hope Creek evaluated. Finally, the risk presented to Hope Creek by possible future shipments of liquified natural gas on the Delaware is also evaluated. There is presently no shipment of LNG on the river.

2.1 BARGE RELATED SPILL RISKS

2.1.1 Fire Risks

The following calculation yields the risk of fire from barge accidents. The ignition of a spill of five million gallons or more of a flammable liquid within one mile of the water intakes (catchment distance of 2 miles) is required to pose a potential threat to the water intakes.

Annual barge trips of flammable cargo	390
Catchment distance (miles)	X 2
Accidents per barge mile	X 0.42×10^{-6}
Spills per accident	X 0.45
Spills of 5×10^{6} gallons or more/spill	X 1.2×10^{-3}
Ignition per barge spill*	X 7×10^{-2}
Probability of critical incidents/year =	1.2×10^{-8}

Risk of Severe Fire at Intake = 1.2×10^{-8} occurrences/year

*"The Probability of Transportation Accidents," W.A. Brobst, Chief-Transportation Branch, U.S. Atomic Energy Commission, Washington D.C. Paper presented at the 14th Annual Explosives Safety Seminar, New Orleans, Louisiana, Nov. 10, 1972.

This occurrence presents a risk only to the intakes. The control room is too far removed from the water to be affected by spill fires.

2.1.2 Vapor Dispersion Risks

Liquified or compressed gases present a potential risk to the intake structure and the control room if they are flammable and a potential risk to the control room if they are flammable or toxic. Whereas both flammable and toxic liquefied gases are shipped by Artificial Island in propelled vessels, there is no known barge shipment of liquefied or compressed gases past Artificial Island.

2.1.3 Explosion Risks

No high explosives are known to move in the vicinity of Artificial Island. This has been verified by searching the records kept by the U.S. Corps of Engineers and the Bureau of Customs. In addition, the U.S. Coast Guard offices in Philadelphia and New York confirmed this fact. Finally, no known industry or military activities in that region would warrant shipment of high explosives by barge. Anchorage 2, which is northwest of Artificial Island, has been designated as suitable for ships carrying not more than 800 tons of explosives. In the past, ships have anchored there and explosives were loaded from barges. However, there are no plans to ship explosives on the Delaware of use Anchorage 2 for any loading of explosives. Several letters confirm the above statements. (See Appendix 3.)

2.1.4 Corrosive Chemical Risk

The only corrosive liquid moving in barges by the Hope Creek site is dilute sulfuric acid. As shown in Section 5.4, the catchment distance for sulfuric acid is one-half mile and the spill must occur within 200 feet of the shore line to work its way into the intake. The calculation for corrosive liquid ingestion is as follows:

Annual barge trips (sulfuric acid)	160
Catchment distance (miles)	X 0.5
Correction for nearness to shoreline	X 0.02
Probability of accident per barge mile	X 0.42×10^{-6}
Spills per accident	X 0.45
Spills of 10^6 gallons or more/spill	X 7×10^{-3}

Probability of critical incident/year =	$2.1X10^{-9}$

Risk of Ingesting Corrosive Liquid = $2.1X10^{-9}$ occurrences/year

2.2 SHIP/TANKER RELATED SPILL RISKS

2.2.1 Fire Risks

A total of 1440 loaded tanker trips of flammable liquid cargos pass Artificial Island each year. Once again, as in the case of barges, only spills and ignition of five million gallons of fuel or more are potentially threatening to the water intakes. The fire risks presented by flammable material shipping is calculated as follows:

Annual tanker trips	$1.44X10^{3}$
Tanker accidents per mile	X $1.5X10^{-6}$
Catchment distance (miles)	X 2.0
Spills per accident	X 0.20
Spills of 5 x 10^6 gallons or more/spill	X $4X10^{-3}$
Probability of ignition/large spill	X $1X10^{-2}$
Probability of critical fire/year	= $3.4X10^{-8}$

Risk of Large Fire at Water Intakes = $3.4X10^{-8}$ occurrences/year

This occurrence presents a risk only to the water intakes. Note that there have have been very few tanker related spills of flammable materials where cargo in excess of 5 million gallons was released. In the limited number of such spills that have occurred (on a world wide basis) there is no record of the spill having ignited. In attempting to determine the probability of ignition of spill given a release of over 5 million gallons discussions were held with several offices of the U.S. Coast Guard. The consensus of opinion was that the probability of ignition for such cases was under 5%. In the calculation above, a 1% probability of ignition has been assumed. If a probability of ignition of 5% had been utilized the risk of a critical fire would have been $1.7X10^{-7}$ occurrences per year.

2.2.2 Vapor Dispersion Risks

There are two classes of vapor dispersion risks: those due to flammable vapors, and those due to toxic vapors.

2.2.2.1 Flammable Vapor Cloud

The two liquefied gases, butane and LPG, are shipped by Artificial Island. They constitute a total of 12 loaded ship movements per year. Based on this traffic, the risk of having a flammable vapor cloud covering the plant is calculated as follows:

Annual tanker trips	12
Tanker accidents per mile	X 1.50×10^{-6}
Catchment distance (miles)	X 22
Spills per accident	X 0.02
Probability of cloud not having ignited prior to arrival over plant	X 0.1
Probability of the lethal wind direction	X 2.8×10^{-2}
Probability of adverse weather condition	X 0.5
Probability of critical incident/year	= 1.1×10^{-8}

Risk of Flammable Vapor Cloud Over Plant = 1.1×10^{-8} occurrences/year

This occurrence presents a risk to both the control room and the water intakes.

Note that unlike the gasoline products, liquefied gases are highly volatile. They vaporize rapidly and the probability of ignition due to collision itself is likely to be high.* If ignition occurs at the accident site, the gas would be consumed quickly and there would be no vapor dispersion problem. Furthermore, even if the cloud did not ignite immediately, the probability of the flammable vapor cloud's igniting prior to moving any significant distance, is great. Any ignition source (such as a match or a motor boat) could ignite the cloud and eliminate further downwind travel.

2.2.2.2 Toxic Vapor Cloud

The only toxic gas shipped by Artificial Island is liquid ammonia. Three loaded ships, each carrying about 7000 tons of liquid ammonia, move by Artificial Island each year. The risk due to such movement is the accumulation of gaseous ammonia in the control room, in the event of an accident that results in a gaseous cloud over the plant. The calculation of risk is as follows:

*See statement of Admiral W.M. Benkert under his comment u. as reported in the Federal Power Commission Final Impact Statement on Docket Nos. CP73-47, CP73-88, CP73-139, CP73-197, CP73-199, August 1974.

Annual tanker trips	3
Tanker accidents per mile	X 1.5×10^{-6}
Catchment distance, based on 400 ppm	X 28
Spills per accident	X 0.02
Probability of lethal wind direction	X 2.8×10^{-2}
Probability of adverse weather condition	X 0.5
Probability of critical incident/year	= 3.5×10^{-8}

Risk of Ammonia Cloud (400 ppm) over Plant = 3.5×10^{-8} occurrences/year

This occurrence presents a risk only to the control room. Note that the human nose can detect ammonia at 20 ppm, well below the 400 ppm level that is severely irritating and that would require personnel to leave the control room. The risk calculated above is based on a realistic toxic concentration of 400 ppm. The risk calculated on the very conservative catchment distance corresponding to a 100 ppm concentration would be 8.8×10^{-8} occurrences per year.

2.2.3 Explosion Risks

No high explosives are known to move by ship in the vicinity of Artificial Island. This has been verified by searching the records kept by the U.S. Corps of Engineers and the Bureau of Customs. The U.S. Coast Guard offices in Philadelphia and New York also confirmed this fact. Finally, no known industrial or military activities in that region would warrant shipment of high explosives by ship. Anchorage 2, which is northwest of Artificial Island, has been designated as suitable for ships carrying not more than 800 tons of explosives. In the past, ships have anchored there and explosives were loaded from barges. However, there are no further plans to ship explosives on the Delaware or use Anchorage 2 for any loading of explosives. Several letters (see Appendix 3) confirm the above statements.

2.2.4 Corrosive Chemical Risk

Whereas large tonnages of sulfuric acid are barged by Artificial Island, there is no record of corrosive chemicals being moved by ship on the Delaware by Artificial Island.

2.3 RAMMING OF INTAKES

The size of the ships which could conceivably ram into the water intake structure is limited by the tidal conditions. Under the normal tidal range, ships in excess of

approximately 15,000 tons would likely ground on the shoal areas outside the river channels before reaching the intake structure. Under extreme tidal conditions, however, such as the design high-water level corresponding to hurricane conditions, the largest ships transiting the Delaware could reach the intake without grounding.

The kinetic energy levels associated with these postulated rammings have been determined to be of the same order of magnitude as those from major ship collisions. From ship collision studies, however, it can be argued that the expected structural damage from ship rammings of the intake structure will be mostly damage to the ship structure, and furthermore, that the damage will not be extensive enough to block the intake with structural rubble.

A further qualitative comparison of the seismic design input and the inertial loadings of the intake structure and its components caused by rammings indicates that the intake structure will likely suffer only local damage from the ramming accident. Details are provided in Appendix 5.

2.4 BLOCKING OF INTAKES

Our analysis has concluded that blockage of the intake structure opening by a runaway ship or barge is not possible. Under the most extreme low-water conditions assumed in the design of this facility, the water intake area required to maintain non-cavitating flow during any plant operating mode is less than the area provided by the fish escape opening. Since these openings are at the sides of the intake structure, they cannot be blocked simultaneously with the blocking of the main intake area. Furthermore, consideration of the main intake area alone showed that the required blockage (97% of the area in the extreme low-water level condition) could not be accomplished by a conventional vessel with hull curvature, nor by any barge currently transiting the Delaware River near the Artificial Island site. Further details are provided in Section 6 and Appendix 6.

2.5 NON-COLLISION RELATED SHIPPING HAZARD

The most frequent source of risk presented by maritime activity is collision between two vessels, between a vessel and a bridge or pier, between the vessel and the water intakes, or between vessel and the river bottom (grounding). There is, however, one other

potential source of risk – problems that a ship may encounter from internal causes while it is underway. Examples of this are fire in the living quarters of the crew or an engine-room fire. If the fire gets out of hand, it could result in a release of hazardous cargo material. Such a release, may in turn, pose a potential threat to the water intakes or to the control room.

In the years 1968-1973 there have been no reported incidents of cargo release due to internal causes while a ship was underway on the Delaware. On the average, 9500 cargo ships moved by Artificial Island each year. Even if an internal problem, such as an engine-room fire, were to occur and cause the release of some cargo, it is doubtful that a large release would occur. Every large spill in U.S. waters (over 100,000 gallons) recorded by the U.S. Coast Guard for the period 1970-1972 was caused either by collision or grounding (see Appendix 9) and not as a result of internal problems on the ship. As a result of these observations, we conclude that the probability of a non-collision related shipping hazard threatening the water intakes or the control room is negligibly small.

2.6 RISKS PRESENTED BY LNG TRANSPORTATION

At present no liquefied natural gas (LNG) is transported by barge or by ship on the Delaware River. However, proposals to import LNG have been filed with the Federal Power Commission by both El Paso Eastern Co. and Transco Energy Co. Under these proposed projects up to 106 LNG ships would enter the Delaware and move by Artificial Island each year to a Transco terminal in Gloucester County (Raccoon Island), N.J.

In the remote event of an accident's releasing large quantities of LNG on water, a double hazard exists. First, the LNG release could be accompanied by immediate ignition, in which case a large pool fire of short duration would result, second, ignition could be delayed, in which case a large vapor cloud will form and disperse downwind. The large pool fire would last less than 5 minutes and would not threaten the water intakes or the control room. If a fire did not occur as a result of the LNG spill and a vapor cloud of methane were formed, a small possibility exists that a flammable vapor cloud could cover the plant.

The risk of a flammable methane vapor cloud's covering the plant can be calculated as follows:

Annual LNG tanker trips	106
Catchment distance/trip (miles)	X 24
Collisions/mile	X 1.5×10^{-6}
Spills/collision	X 5.0×10^{-3}
Probability of lethal wind direction	X 2.8×10^{-2}
Probability of cloud not igniting prior to arrival over plant	X 0.1
Probability of adverse weather condition	X 0.5
Probability of flammable vapor incident/year	= 2.7×10^{-8}
Risk of flammable methane vapor covering the plant	= 2.7×10^{-8} occurrences/year

This occurrence presents a potential risk to both the water intakes and the control room. Note that the above estimate of risk of flammable methane vapor's covering the plant is a conservative overestimate. If a collision severe enough to release LNG were to occur, there is a good possibility that immediate ignition would occur as a result of the collision itself.* Even if immediate ignition did not occur, the chances are that the flammable vapor cloud would ignite prior to reaching the plant. Any ignition source, such as a lit match, could ignite the cloud, causing the cloud to be consumed quickly and precluding any further travel. Further, under current USCG plans for bringing LNG ships into a harbor†, a great deal of traffic control is imposed in the harbor and a USCG boat actually escorts the LNG ship into its berth. Under these imposed conditions of traffic safety it is most unlikely that a large LNG release could occur on the Delaware.

---

*See Statement of Admiral W.M. Benkert (USCG) under his comment u. as reported in the Federal Power Commission Final Impact Statement on Docket Nos. CP73-47, CP73-47, CP73-88, CP73-139, CP73-197, CP73-199, August 1974.

†See, for example, the Captain of the Port Contingency Plan (USCG) for LNG and LPG ships coming into Boston, New York or Providence Harbors.

3.0 TRAFFIC/ACCIDENT DATA BASE

This section contains the basic data needed to estimate the potential hazards that may be imposed on the Hope Creek power plant by the maritime traffic in the Delaware River. We selected 1972 statistics for analysis because these are the latest years for which complete data are available. In this section we first develop a description of the hazardous material traffic past Artificial Island in 1972. Next, we examine the relevant accident data over a five-year period to obtain estimates of accident probabilities. Finally, we analyze the available information on spills of hazardous materials to estimate the likelihood of spills big enough to potentially affect the operations of the nuclear power plant adversely.

3.1 TRAFFIC ON THE DELAWARE RIVER BY HOPE CREEK

3.1.1 General Background

The maritime traffic that passes Artificial Island consists of the following:

1. Ships from foreign ports which proceed directly up the Delaware to ports north of Artificial Island.
2. Ships from domestic ports which proceed directly up the Delaware to ports north of Artificial Island.
3. Tankers from foreign ports which discharge some of their cargo at Anchorage "A" in order to match their drafts (currently crude oil) to that of the Delaware.
4. Barges (non-self-propelled) which transport lightered cargo from Anchorage "A" to refineries north of Artificial Island.
5. Barges (both self-propelled and non-self-propelled) which carry clean petroleum products and sulfuric acid between ports on the Delaware and ones beyond the Delaware Capes.
6. Ships between ports on the Delaware and ones outside the Delaware Capes. These include breakbulk cargo vessels, tankers in ballast and tankers with clean petroleum products.
7. Foreign and domestic coastwise traffic which uses the Delaware River in trips to and from the Schuylkill or the Delaware and Chesapeake Canal.

There are no ports of any significance whatsoever between Artificial Island and the Delaware Capes. Moreover, except for pleasure craft, there is no small-vessel commercial traffic such as fishing boats in the area. Furthermore, except for the barges which lighter tankers at Anchorage "A", no internal[1] traffic passes the island.

Some observations about operations within the Delaware north of Artificial Island are relevant to understanding the data. Iron ore is a major commodity on the river. Some of this ore is lightered north of Artificial Island to reduce vessel draft or is transshipped to railroad at Philadelphia. Neither distillate nor residual fuel oil is lightered south of the island. Residual is often discharged directly to consumers from a single tanker that makes a number of stops. Distillate is often lightered from tankers at anchorages well north of Artificial Island.

The exposure of the cold water intakes of Hope Creek on Artificial Island depends upon the numbers and types of vessels which pass the island and the commodities which they carry. No single sources supply this information. Consequently, the description of the traffic must be built up from the incomplete information which is available. The approach to this building up was first to obtain a general picture of shipping in the Delaware from local shipping interests. The next step was to determine annual commodity flow by analyzing the data collected by the Corps of Engineers and reported in their publication "Waterborne Commerce of the United States." Data from the Philadelphia Maritime Exchange, supplemented by information from the Interstate Oil Transport, was used to convert commodity flow into numbers of trips for the various commodities of interest. The result is a table showing for the principal hazardous commodities, the annual trips, and the average lot size. In the following sections we will describe the data base from which the calculations were made, describe how the calculations were carried out, and finally present the results.

3.1.2 Data Sources

The principal data resources were the "Waterborne Commerce of the United States" and the Philadelphia Maritime Commission. "Waterborne Commerce" is published annually

---

[1] "Internal" is defined by the Corps of Engineers as traffic which originates and terminates within a single waterway.

by the U.S. Corps of Engineers and contains two sets of tables for the various individual waterways of the nation; one set showing annual freight traffic according to a four-digit commodity classification and the other set showing annual movements in the waterways by vessel draft. Examples of these two data sets are given in Figures 3.1 and 3.2.

The Corps of Engineers collects data for every movement of vessels within U.S. waters. Carriers are legally required to report information and are subject to penalties if they do not. Data for foreign vessels are supplied to the Corps of Engineers by the Bureau of the Census based on Customs Bureau receipts. The responsibility for submitting information about domestic movements rests with the shipping operator. The Corps reports unofficially that it pursues vigorously operators who do not fully meet its requirements and that 10% would be a very liberal estimate of unreported freight traffic. The standard forms (Figure 3.3) prepared by the operators are mailed to the local division of the Corps, which then forwards them to New Orleans where the final processing is done for publication.

The Philadelphia Maritime exchange, located at 7th and Chestnut Streets in Philadelphia, maintains logs on all ships that call at the Port of Philadelphia to discharge goods of foreign origin. The Exchange receives information when the vessel enters the Delaware Capes from the sea. The logs contain the name of the vessel, its registry, and the kind and amount of its cargo to be discharged in Philadelphia. The logs for the entire year of 1972 were provided to ADL by the Exchange. As mentioned before, this information applies only to Philadelphia. No other harbor on the Delaware maintains such data. Therefore, by itself it does not provide the entire data base for determining the traffic in the Artificial Island area.

The Exchange's data for 1972 correlates very well with the Corps of Engineers data for the same year, although some discrepancies were apparent. For example, fuel oil from the Virgin Islands appears as foreign in the Exchange's logs whereas the Corps classifies it as domestic coastwise. Moreover, foreign cargo that is lightered from a ship after entering the Delaware is treated as an internal receipt by the Corps whereas the Exchange's data indicates it to be foreign. However, the few important discrepancies that appeared were readily resolved.

The third major source of information we used was the Interstate Oil Transport, Inc. This company, with headquarters at 6 Penn Center Plaza, Philadelphia, provides most of the

WATERBORNE COMMERCE OF THE UNITED STATES, 1972

PHILADELPHIA, PA., DISTRICT

DELAWARE RIVER, TRENTON, N. J. TO THE SEA
(CONSOLIDATED REPORT)

COMPARATIVE STATEMENT OF TRAFFIC

YEAR	TONS	PASSENGERS	ADDITIONAL TRAFFIC: RAILROAD FREIGHT CARS EMPTY	ADDITIONAL TRAFFIC: RAILROAD FREIGHT CARS LOADED	AUTOMOBILES ACCOMPANYING PASSENGERS	YEAR	TONS	PASSENGERS	ADDITIONAL TRAFFIC: RAILROAD FREIGHT CARS EMPTY	ADDITIONAL TRAFFIC: RAILROAD FREIGHT CARS LOADED	AUTOMOBILES ACCOMPANYING PASSENGERS
1963--	104,807,353	1,407,686	10,876	11,814	616,945	1968--	115,998,841	4,372,488	8,450	9,534	1,087,010
1964--	108,987,739	1,748,260	9,619	9,754	712,795	1969--	120,480,017	4,530,925	7,757	7,887	1,154,430
1965--	107,315,410	2,681,155	11,081	11,042	833,569	1970--	123,975,124	4,529,863	6,856	6,910	1,193,926
1966--	113,443,385	3,824,889	11,336	11,310	984,349	1971--	123,543,497	4,276,820	4,743	4,480	1,137,469
1967--	115,531,355	4,116,882	8,632	8,023	1,087,168	1972--	127,287,387	4,675,514	4,814	4,742	1,291,736

FREIGHT TRAFFIC, 1972

OCEANGOING

(SHORT TONS)

COMMODITY	TOTAL	FOREIGN: IMPORTS	FOREIGN: EXPORTS	FOREIGN: THROUGH UPBOUND	FOREIGN: THROUGH DOWNBOUND	DOMESTIC COASTWISE: RECEIPTS	DOMESTIC COASTWISE: SHIPMENTS	DOMESTIC COASTWISE: THROUGH UPBOUND	DOMESTIC COASTWISE: THROUGH DOWNBOUND
TOTAL	99,323,234	56,890,645	3,286,775	3,769,138	923,264	23,358,244	7,287,385	2,256,449	2,411,334
0101 COTTON, RAW	411	377	34	---	---	---	---	---	---
0103 CORN	1,037,577	---	348,077	---	689,100	---	---	400	---
0105 RICE	208	5	4	---	7	---	---	197	---
0106 SORGHUM GRAINS	1	---	1	---	---	---	---	---	---
0107 WHEAT	82,510	---	78,112	---	4,398	---	---	---	---
0111 SOYBEANS	245,454	---	161,974	---	82,709	---	---	771	---
0119 OILSEEDS, NEC	164	139	20	5	---	---	6	---	---
0121 TOBACCO, LEAF	27,300	23,447	41	345	273	489	2,713	---	---
0122 HAY AND FODDER	1,834	1,557	---	277	---	---	---	---	---
0129 FIELD CROPS, NEC	745	460	247	9	29	---	---	---	---
0131 FRESH FRUITS AND TREE NUTS	17,512	12,169	17	283	---	43	---	---	---
0132 BANANAS AND PLANTAINS	71,189	1,623	---	69,566	---	---	---	---	---
0133 COFFEE	12,619	12,465	38	106	---	---	---	---	10
0134 COCOA BEANS	230,351	226,633	3,073	389	260	---	---	---	---
0141 FRESH AND FROZEN VEGETABLES	1,594	531	234	441	388	---	---	---	---
0161 ANIMALS AND PRODUCTS, NEC	48,155	43,417	2,073	2,475	184	---	6	---	---
0191 MISCELLANEOUS FARM PRODUCTS	519	342	145	32	---	---	---	---	---
0841 CRUDE RUBBER AND ALLIED GUMS	3,740	3,450	89	168	---	---	42	---	---
0861 FOREST PRODUCTS, NEC	45,858	40,514	1,523	3,797	24	---	---	---	---
0911 FRESH FISH, EXCEPT SHELLFISH	2,925	2,538	149	6	2	---	185	45	---
0912 SHELLFISH, EXCEPT PREPARED	2,980	---	---	---	---	---	2,980	---	---
1011 IRON ORE AND CONCENTRATES	10,192,051	10,044,039	49,286	98,726	---	---	---	---	---
1051 ALUMINUM ORES, CONCENTRATES	44,910	39,082	20	5,828	---	---	---	---	---
1061 MANGANESE ORES, CONCENTRATES	102,425	101,402	1,023	---	---	---	---	---	---
1091 NONFERROUS ORES, CONCENT, NEC	89,761	29,373	1,404	58,960	1	---	23	---	---
1121 COAL AND LIGNITE	975,614	---	967,491	---	---	7,438	85	---	---
1311 CRUDE PETROLEUM	46,702,467	34,389,765	217	551,214	---	11,491,240	16,116	333,915	---
1411 LIMESTONE	1,192,117	824,505	3	367,586	23	---	---	---	---
1412 BUILDING STONE, UNWORKED	21	21	---	---	---	---	---	---	---
1442 SAND, GRAVEL, CRUSHED ROCK	14,582	13,101	1,267	---	51	---	163	---	---
1451 CLAY	64,692	2,744	53,466	8,377	---	---	15	---	---
1471 PHOSPHATE ROCK	7,573	6,832	362	---	379	---	---	---	---
1479 NATURAL FERTILIZER MATS, NEC	20,870	20,870	---	---	---	---	---	---	---
1491 SALT	36,708	---	403	36,176	129	---	---	---	---
1492 SULPHUR, DRY	5,308	4,283	923	---	102	---	---	---	---
1493 SULPHUR, LIQUID	210,375	---	---	---	---	163,697	---	28,723	17,955
1499 NONMETALLIC MINERALS, NEC	278,938	207,475	23,277	47,970	206	---	10	---	---
1911 ORDNANCE AND ACCESSORIES	283	251	2	---	---	---	---	---	30
2011 MEAT, FRESH, CHILLED, FROZEN	130,772	79,893	3,264	93,753	1,824	19	19	---	---
2012 MEAT AND PRODUCTS, NEC	25,740	23,387	227	393	71	35	1,627	---	---
2014 TALLOW, ANIMAL FATS AND OILS	48,153	---	40,049	---	7,568	---	---	538	---
2015 ANIMAL BY-PRODUCTS, NEC	5,024	960	3,818	68	96	20	42	---	---
2021 DAIRY PRODUCTS, NEC	9,571	3,860	3,440	2,081	174	---	16	---	---
2022 DRIED MILK AND CREAM	1,739	---	1,585	---	---	---	154	---	---
2031 FISH AND SHELLFISH, PREPARED	23,018	10,948	325	399	66	11,280	---	---	---
2034 VEGETABLES AND PREP, NEC	52,045	42,327	1,497	296	53	---	7,872	---	---
2039 PREP FRUIT AND VEG JUICE, NEC	8,485	7,843	970	79	5	1	378	---	---
2041 WHEAT FLOUR AND SEMOLINA	6,442	18	6,170	4	250	---	---	---	---
2042 PREPARED ANIMAL FEEDS	16,087	2,283	1,845	---	199	5,554	926	---	---
2049 GRAIN MILL PRODUCTS, NEC	13,974	72	11,388	---	1,488	---	545	---	489
2061 SUGAR	899,827	899,803	2	---	---	---	22	---	---
2062 MOLASSES	14,981	11,487	---	---	---	---	208	3,306	---
2081 ALCOHOLIC BEVERAGES	29,520	23,571	319	3,553	198	1,909	248	23	31
2091 VEGETABLE OILS, MARG, SHORT	7,384	2,400	2,753	25	16	---	135	1,946	21
2092 ANIMAL OILS AND FATS, NEC	5,572	862	---	---	---	---	---	---	4,710
2099 MISCELLANEOUS FOOD PRODUCTS	76,764	57,151	1,737	15,494	84	52	2,037	130	79
2111 TOBACCO MANUFACTURES	899	21	356	2	6	402	72	---	---
2211 BASIC TEXTILE PRODUCTS	52,312	35,263	7,048	8,595	50	---	1,356	---	---
2212 TEXTILE FIBERS, NEC	13,625	13,459	64	17	---	74	11	---	---
2311 APPAREL	4,170	2,651	244	12	55	1,167	49	---	---
2411 LOGS	1,847	409	191	27	1,220	---	---	---	---
2413 FUEL WOOD, CHARCOAL, WASTES	8	---	---	---	---	---	8	---	---
2414 TIMBER, POSTS, POLES, PILING	5	5	---	---	---	---	---	---	---
2416 WOOD CHIPS, STAVES, MOLDINGS	1,378	1,361	17	---	---	---	---	---	---
2421 LUMBER	703,473	380,674	779	213,729	188	60,101	---	19,075	24,009
2431 VENEER, PLYWOOD, WORKED WOOD	157,685	156,837	24	824	---	---	---	---	---
2491 WOOD MANUFACTURES, NEC	8,548	5,541	2,659	61	175	6	57	43	---
2511 FURNITURE AND FIXTURES	9,332	8,451	290	61	3	217	530	31	---
2611 PULP	1,373	1,128	207	---	28	---	---	---	---
2621 STANDARD NEWSPRINT PAPER	89,733	88,421	1,312	---	---	---	---	---	---
2631 PAPER AND PAPERBOARD	51,209	33,469	17,291	23	209	---	121	---	---

FIGURE 3.1

PHILADELPHIA, PA., DISTRICT

TRIPS AND DRAFTS OF VESSELS

HARBOR OR WATERWAY	DIRECTION						DIRECTION					
DRAFT (FEET)	SELF PROPELLED VESSELS			NON-SELF PROPELLED VESSELS		TOTAL	SELF PROPELLED VESSELS			NON-SELF PROPELLED VESSELS		TOTAL
	PASSENGER AND DRY CARGO	TANKER	TOWBOAT OR TUGBOAT	DRY CARGO	TANKER		PASSENGER AND DRY CARGO	TANKER	TOWBOAT OR TUGBOAT	DRY CARGO	TANKER	
DELAWARE RIVER, TRENTON, N. J. TO THE SEA (CONSOLIDATED REPORT) FOREIGN AND COASTWISE			UPBOUND						DOWNBOUND			
46	9	42				71		1				1
45		15				19						
44	1	34				35						
43	2	34				36		1				1
42	2	41				43		2				2
41	3	53				56		2				2
40	63	130				193	5	8				13
39	32	161				193	1	6				7
38	18	155				173		9				9
37	68	203				271	2	9				11
36	25	216				241	6	19				25
35	24	139				163	11	75				86
34	32	92				124	19	50				69
33	39	78				117	30	52			12	94
32	52	99				151	24	59			14	97
31	67	62				129	31	78			6	115
30	78	55		1	1	135	47	90			1	138
29	43	35				78	53	42			1	96
28	64	32				96	79	86			1	166
27	81	34				115	100	81				181
26	142	36		4		182	159	138		1		298
25	207	49				256	241	301			1	543
24	264	42				306	366	253			6	625
23	253	41				294	293	254		1	23	571
22	306	55			3	364	391	221		1	19	632
21	323	87		1	3	414	244	196			6	446
20	281	49	1		8	339	367	76			17	460
19	242	19	2		7	270	283	48			32	363
18 AND LESS	749	256	760	59	527	2,351	1,708	194	777	60	437	2,676
TOTAL	3,470	2,364	763	65	540	7,211	3,762	2,356	777	63	978	7,936
DELAWARE RIVER, TRENTON, N. J. TO THE SEA (CONSOLIDATED REPORT) INTERNAL			UPBOUND						DOWNBOUND			
37		2				2		1				1
36		9				9						
35		12				12		1				1
34		4				4		1				1
33		4				4		3				3
32		7				7		4				4
31	1	5				6		5				5
30		7				7		5				5
29		3				3		2				2
28		8				8	1	10			1	12
27		9				9		7				7
26		5			2	7		4				4
25		10			1	11		6			1	7
24	1	5			4	10	1	3			1	5
23		9			15	24	5	2			1	8
22	1	5			13	19	4	11			2	17
21		2			9	11	1	10			3	14
20	1	5		6	35	47		20			15	35
19		3		58	66	127	1	50			74	125
18 AND LESS	32,642	376	22,999	4,418	7,796	67,811	34,101	391	22,405	4,424	7,775	69,096
TOTAL	32,656	498	22,999	4,482	7,941	68,138	34,114	536	22,405	4,424	7,873	69,352
DELAWARE RIVER BETWEEN PHILADELPHIA, PA., AND TRENTON, N. J.			UPBOUND						DOWNBOUND			
41		1				1						
40	10	1				11	1					1
39	6	6				12		1				1
38	8	18				26						
37	51	32				83	1	2				3
36	18	14				32						
35	16	4				20		2				2
34	3	13				16	1	2				3
33	5	8				13	3	3				6
32	17	3				20	1	2				3
31	13	3				16	8	5				13
30	16	6				22	10	5				15
29	12	4				16	18	3				21
28	14	10				24	20	17				45
27	19	11				30	26	12				38
26	21	6				27	25	11				36
25	28	15			1	44	40	40				80
24	31	11			1	43	57	31				88
23	35	15			3	53	63	24		1		88
22	42	9			3	54	56	24		1	1	82
21	42	3			2	47	55	12				67
20	59	6		6	10	81	71	9			9	89
19	48	4		50	32	134	62	5			35	102
18	78	9		18	84	113	44	2			12	58
17	19		9	387	71	486	27	4	8		19	58
16	27	1	1	2	32	63	20	3	1		15	39
15	8	3	390	11	66	447	11	1	390		25	399
14	5	8	10	4	146	173	6	1	9		60	76
13	3	1	409		316	729	3	5	402	1	291	702
12 AND LESS	46	5	5,626	3,400	1,002	10,057	46	21	5,350	3,021	1,770	11,020
TOTAL	642	232	6,414	3,808	2,229	13,415	663	246	6,130	3,024	2,219	13,004

FIGURE 3.2

TRIP NO. (One way) ______________ 19____

NAME OR NO. OF VESSEL

NET REGISTER TONS | FLAG

VESSEL OPERATION REPORT

STATEMENT OF FREIGHT AND PASSENGERS CARRIED

Form Approved.
Budget Bureau No. 49-R268.9.

TYPE OF VESSEL *(Check One)*

- ☐ SELF PROPELLED, DRY CARGO AND PASSENGER
- ☐ SELF PROPELLED, TANKER
- ☐ TOWBOAT OR TUGBOAT
- ☐ NON-SELF PROPELLED, DRY CARGO
- ☐ NON-SELF PROPELLED, TANKER
- ☐ OTHER

DEPARTED FROM—				ARRIVED AT—					CARGO DATA *(If light, so state)*				*LEAVE BLANK*
PORT OR LOCALITY	DOCK	DATE	ACTUAL DRAFT	PORT OR LOCALITY	DOCK	DATE	ACTUAL DRAFT	SERVICE [1]	COMMODITY	QUANTITY	UNIT [2]	WEIGHT PER UNIT	NET TONS

LOCALITIES ENTERED FOR: REFUGE | REPAIRS

FUELED AT: PORT | DOCK

KIND OF FUEL: OIL / COAL / GAS ☐ BBL. ☐ TONS ☐ GAL.

PROJECT CHANNELS USED *(Where a choice exists, indicate waterways, exit and/or entrance channels used.) (See inside cover.)*

1—*For each cargo movement show "1" if common or contract carriage subject to regulation by the Interstate Commerce Commission; "2" if exempt, for hire; "3" if private.*
2—*Net tons, Gross tons, Bushels, etc.*

I hereby certify that this is a complete and accurate report.

SIGNED | TITLE

OPERATOR | ADDRESS

ENG Form 3925 — FEB 67 — Replaces ENG Form 1, 1 Nov 65, which is obsolete.

CORPS OF ENGINEERS—DEPARTMENT OF THE ARMY

FIGURE 3.3

barge services on the Delaware River, including the lightering operations in Delaware Bay for the crude oil tankers with drafts too large for the upper Delaware channels. Interstate Oil gave us information on the sizes of the vessels which it operates in the vicinity of Artificial Island and also estimates for other carriers which use that stretch of the river.

Finally, the U.S. Coast Guard, Philadelphia, confirmed the general picture we developed of the ship traffic in the area of interest.

3.1.3 Commodity Movements Past Artificial Island

Several commodities were selected as a basis for determining annual freight volumes in the Artificial Island area. These volumes are not given directly in any single one of the "Waterborne Commerce" tables but must be inferred from all the tables for the Delaware River. There are several reasons for this. For example, the table "Delaware River, Trenton to the Sea, Foreign and Coastwise" contains data about traffic which enters the Delaware River through the Chesapeake and Delaware Canal and then proceeds north, thereby bypassing the Artificial Island stretch of the river. However, crude oil that is lightered from tankers at Anchorage "A" appears in the "Internal" table which follows the one cited above. The analysis of the Waterborne tables necessary to obtain the required numbers is described in detail in Appendix 8.

Commodity volumes were converted into vessel trips by dividing them by the average shipment size for that commodity on the Delaware. Average shipment size was derived mainly from the Maritime Exchange data. Foreign and domestic crude were treated separately because smaller ships are used for domestic movement of this commodity. Crude oil also passes Artificial Island in barges and this was taken into account. For domestic movement of refined petroleum products, the average shipment size was based on information given to us by Interstate Oil Transport.

Table 3.1 summarizes the results of the analysis. This table contains for each of the commodities deemed potentially hazardous of spills, the numbers of vessel trips, the average lot size and the total 1972 tonnage as derived from the Corps of Engineers data. The commodities shown in Table 3.1 represent over 83% of the tonnage on the Delaware during the year in question.

TABLE 3.1

HAZARDOUS MATERIAL TRAFFIC PAST ARTIFICIAL ISLAND - 1972

	Number of Vessels	Average Lot Size[1] (thousands of tons)	Annual Tonnage[2] (millions)
TANKERS			
Foreign Crude Oil	710	49	34.9
Domestic Crude Oil	470	25	11.8
Fuel Oil[3]	1,024	25	25.6
Gasoline	212	25	5.3
Butane	10	13	0.1[4]
TANK BARGES			
Clean Products	210	8	1.7
Crude - Lighters	850	5.8	4.9
Jet Fuel	180	1.4	0.2
Sulfuric Acid	160	0.8	0.1
OTHER			
Ammonia[5]	3	7	0.021
Naphtha	20	18	0.3
Benzene & Toluene	20	10	0.2
Liquid Sulfur	20	10	0.2
Basic Chemicals	70	10	0.7
Kerosene	40	10	0.4
Lubricating Oils & Greases	110	10	1.1
Asphalt, Tars & Pitches	70	10	0.7
LPG	2	12	0.02

[1] Philadelphia Maritime Exchange - 1972 Data.

[2] Corps of Engineers, "Waterborne Commerce of the U.S., 1972," Delaware River, Trenton, N.J., to the sea (adjusted).

[3] Distillate Fuel Oil and Residual Fuel Oil. Includes 5.3×10^6 tons appearing as "internal" traffic in "Waterborne Commerce."

[4] Liquefied Gases.

[5] Delaware River Port Authority.

3.1.4 Dimensions of Barges Operating in the Vicinity of Hope Creek on the Delaware

Interstate Oil Transport, Inc., furnished us with the names of the barges that operate in the Hope Creek region of the Delaware. The Coast Guard Register provided data on the dimensions of these vessels. These data are shown in Table 3.2.

3.2 ACCIDENT DATA FOR THE DELAWARE RIVER

3.2.1 Ships

The accident data are derived from U.S. Coast Guard investigations of all accidents involving either loss of life or damage amounting to $1,500 or more. We have obtained the data, in the form of abstracts maintained on magnetic tape, covering the period 1 July 1968 to 1 July 1973. The 5-year history contains 302 individual records, with one record for each vessel involved in an accident. The records on tape do not specify the exact location of the accident, beyond noting that it occurred in the Delaware River. The narrative files, referenced on the tape by serial number, do specify the precise location.

Most of the incidents involve single vessels only, and these in miscellaneous difficulties. The significant incidents, from the present viewpoint, amount to the following:

<u>Collisions between Moving Vessels:</u>

Tanker-Tanker	1
Tanker-Freighter	2
Tanker-Other	2
Freighter-Other	2
Tank Barge-Cargo Barge	3

<u>Groundings, Capsizings, and Founderings:</u>

	Groundings		Capsizings & Founderings	Total
	Without Damage	With Damage		
Barges	4	4	6	14
Tankers	21	7	0	28
Other	24	2	4	30
Total	49	13	10	72

TABLE 3.2

BARGES OPERATING IN HOPE CREEK AREA OF THE DELAWARE RIVER[1]

	Gross Tons	Length	Beam	Depth	Draft[2]
Ocean 250	15,000	546	85	41	32
90	6,400	400	66	28	22
96	6,300	400	66	28	22
Tide Mar 19	7,200	390	68	40	32
Rob. Poling	4,200	333	64	24	19
Albany Sun	2,300	300	43	22	18
Toledo Sun	2,300	300	43	22	18
Geo. Tilton	500	130	40	11	9
Prov. Getty	3,200	311	48	22	18
Offshore 2401	1,400	236	50	14	11
ArGoil 185	1,150	210	42	14	11
175	931	200	43	12	10
150	931	200	43	12	10
130	820	196	40	13	10
Interstate 50, 52, 53, 54, 55	3,200	300	62	21	17
48	2,940	310	63	18	14
38, 37, 35	2,700	285	60	19	15
34	2,000	255	54	17	14
30	1,800	240	58	16	13
19	1,100	220	42	15	12
18	1,100	215	42	15	12
17	1,000	210	42	14	11
12	1,000	230	42	13	10
8	800	190	40	13	10

[1]Source: Interstate Oil Transport, Inc.
[2]Draft assumed equal to 80% of depth.

The "Other" category includes vessels of all sorts not in the first two classes, i.e., freighters, dredges, pleasure boats, ferries, etc.

Consequently, during the five years from July 1, 1968, through June 30, 1973, there were three collisions of big ships with one another, or on the average 0.6 collision per year. This value agrees well with the value computed by the method developed by ADL and submitted in evidence before the Federal Power Commission in the Eascogas and Distrigas hearings (Dockets Nos. CP-73: 47, 88, 132, 148, 230, 122); that is, according to the more general theory the expected number of collisions per year in the Delaware River is 0.7. We therefore take the 5-year experience as valid for the derivation of empirical constants.

In computing the number of collisions we must include not only the three occurring between big ships, but also the two collisions with dredges and other such vessels. This brings the 5-year total to 7. The number of ship trips per year can be taken as 9,553* and the length of the Delaware River as 100 miles. Then the number of collisions per ship-mile is 1.5×10^{-6}.

3.2.2 Barges

Historical accident experience in the Delaware River cannot be used to derive useful accident rate estimates for barges, because exposure data in such terms as annual miles of travel in the river is impossible to obtain. An ocean-going ship moves directly up and then down the river between the Philadelphia-Wilmington area and the Delaware Capes. Since the "Waterborne Commerce" provides the number of annual trips for such ships, an annual mileage estimate is possible. However, barges on the Delaware vary considerably in size, and in the distance which they move on the river. Consequently, there is no way to infer their annual mileage from Corps of Engineers data.

In connection with a study for the Maritime Administration† on the Inland Waterways of the United States we found that the nature of the barge traffic was such that estimates of annual exposure data were reasonably feasible. We found that the accident rate varied

---

* Self-propelled vessels with drafts greater than 18 feet accounted for in "Waterborne Commerce," 1972.

† "A Model Economic and Safety Analysis of the Transportation of Hazardous Substances in Bulk" by Arthur D. Little, Inc. July 1974. Study prepared for Office of Domestic Shipping, Maritime Administration, Department of Commerce, Washington, D.C.

from 0.099 to 2.4 per million miles with an average of 0.42 per million miles. The spill rate per accident was 0.45. We propose to use these values for the Delaware River.

3.2.3 LNG Ships

No historical data are available on the accident of LNG ships for the simple reason that no accident has yet occurred to them. Inasmuch as they are large ships, we have assumed that their accident rate is the same as for tankers and freighters. Such a rate is probably high for LNG carriers for several reasons. First, these ships have many safety features not usually found in the average tanker or freighter. Second, special procedures are required by the Coast Guard when these ships enter ports. In Boston, for example, they have to move in daylight under good visibility conditions and with all other traffic movements forbidden.

3.3 SPILL STATISTICS

3.3.1 Barges

The distribution of spill sizes was determined from the data furnished by the U.S. Coast Guard covering the period 1970-1972 (Appendix 9). The spill size was assumed to be independent of the nature of the cargo and of the cause of the accident. Those spills for which the size is unknown were assumed to be less than 1000 gallons. The resulting spill size distribution is approximately log-normal with a median of about 1000 gallons and a standard deviation of 2.8. The estimated probability of a five million-gallon spill, given that a spill has occurred is 1.2×10^{-3}. That is, in about one spill out of 1000 at least five million gallons will be released.

3.3.2 Tankers (Other than LNG and LPG)

Porricelli, Keith, and Storch ("Tankers and the Ecology," SNAME Transactions, Vol. 79, 1971) reported on 338 tanker collisions that occurred during the calendar years 1969 and 1970 while the tankers were underway. Eighty-two of these collisions resulted in pollution. Since 13 were regarded as minimal, we will take the probability of a spill due to collision of 69/338 or 0.20.

In *An Analysis of Oil Outflows Due to Tanker Incidents* (delivered to a Joint Conference Prevention and Control Oil Spills, March 1973) Keith and Porricelli present detailed data, including spill size, for 22 of these incidents. The distribution of spill size appears

to be log-normal with a median of 53,800 gallons and a standard deviation of 1.70. If we assume (as Keith and Porricelli do) that the other spills were less than 100,000 gallons, the probability of a spill greater than 5 million gallons is 4.0×10^{-3} and the overall probability that a collision results in such a spill is 8.0×10^{-4}. These results are not inconsistent with U.S. Coast Guard data of Appendix 9.

3.3.3 Tankers (LNG)

The spill probabilities of these ships in collision are different from those for tankers. The probabilities used in this report result from an analysis which considered striking velocity, angle of impact and the *actual* construction of the LNG ship and its tankage.

Taking into account the geometry of the Delaware Channel our estimate of the probability of a spill following a collision is 5.0×10^{-3}. The effect of the geometry is to limit the possible angles of impact to those within ±45° of the bow and stern where the ship is not resistant to penetration.

3.3.4 Tankers (LPG, Anhydrous Ammonia, etc.)

These vessels are placed in Class IIG in the proposed International Maritime Consultive Organization Gas Code. According to this code, they must be able to sustain stranding or minor side damage without release of cargo and remain afloat no matter what happens. The U.S. Coast Guard has already imposed this code on all such ships which seek entry to U.S. waters.

Since LNG tankers belong in this category, it would probably be appropriate to use the same spill probability for all the Class IIG ships. However, our LNG analysis was done with respect to ships that use the latest technology for cargo containment and ship safety. Also, the LNG ships are much larger and subject to certain Coast Guard operational procedures which do not necessarily apply to the other Class IIG tankers. Therefore, if a larger spill probability would seem justified. In Section 3.3.2 the probability of a spill in a tanker collision was estimated to be 0.20. This is to be contrasted with 0.005 for the LNG ship in the Delaware Channel, cited above. The value for Class IIG ships, other than tankers, should lie between these values. We are setting it at 0.02, four times greater than that for LNG, to reflect the smaller size of these ships and an enlargement of possible

impact angles to cover all 360°. It is also a factor of ten less than for petroleum tankers to reflect the very significant differences in the construction of these two classes of ships (double bottoms vs single, stronger tankage, etc.).

4.0 EFFECTS OF VIOLENT WEATHER UPON ACCIDENT PROBABILITIES

In the previous chapter we presented calculations which led to the:

probability per mile of an accident,

probability per accident of a spill, and

probability per spill of a large spill.

These probabilities were calculated for both barges and large ships. The question arises of the extent to which violent weather phenomena such as hurricanes or tornados could change these probabilities. This chapter presents some semi-quantitative observations on this question.

The first observation to be made is that all these probabilities are based on historical data except for LNG type ships where the second and third probabilities were based on theoretical considerations. The question then becomes with respect to the other probabilities of the degree to which violent weather occurrences would modify them.

The probability most likely to be affected by violent weather is that for accident per mile for large ships. The data period for this probability was 1967 to 1972. It can be safely assumed that for most of the common types of violent weather – such as wind storms, thunderstorms, snow and ice – these were not particularly abnormal years and therefore, the effect of them is already inherent in the probabilities.

As far as we know, there were neither hurricanes nor tornados in the Artificial Island area of the Delaware during that time. Nevertheless these events sometimes occur in this area, so how much should we modify the probability to take them into account? First let us consider the tornado. The Continental United States with 3.6 x 10^6 square miles is visited by approximately 1000 such storms a year. Let us assume the average tornado has a footprint of 2.5 square miles (1/4 mile wide and 10 miles long). Assuming tornadoes are equally probable throughout the United States (which they are not), the probability that a given point in the nation will experience one annually is

$$\frac{2.5 \times 100}{3{,}600{,}000} = 7 \times 10^{-4}$$

Hence, of the 100 miles by 1/3 mile channel area of the Delaware, 2.31×10^{-2} miles would annually experience tornados on average. On the basis of 10,000 large ship movements per year up and down the Delaware and a speed of 8 knots, the density of ships is

$$\frac{10{,}000}{365 \times 24 \times 8} = 0.14 \text{ ship per mile}$$

which is equivalent to 1/2 ship per square mile of channel. If we finally assume that a ship visited by a tornado would appear in our accident statistics, the annual contribution made by tornados to these would be

$$0.14 \times 7 \times 10^{-4} = 10^{-4} \text{ ship per year.}$$

The accident statistics of Section 3 for large ships were based on seven accidents over a 5-year period. Tornados would add only 0.0005 to this figure. Consequently we can dismiss them as a factor in our large ship accident calculations.

Hurricanes were not a factor in our large-ship data base because none occurred in the time period. Now the average number of big ships in the river at a given time is approximately 14. Let us assume one hurricane per 50 years which would involve the entire 100-mile stretch of the river from the Delaware Capes to Philadelphia and that every one of these 14 ships was a casualty. This would only change our annual casualty rate of 1.40 to 1.68, a change which would have no effect upon our conclusions.

Finally, we consider the other probabilities – barge accident rates and the spill rates and sizes for both large vessels and barges. The data on which these are based come from all parts of the United States (but mostly east of the Rockies) and therefore, have embedded in them the effects of all the varieties of weather which North America is capable of producing. It may be argued that the Delaware is different from the rest of the nation insofar as weather is concerned. This is probably true. However, the Delaware is probably on the benign side for it generally escapes the hurricanes which plague the Gulf Coast and certainly escapes the tornados of the Mississippi Valley. Tsunamis, seiches, earthquakes, icebergs and severe floods have never played any significant role on Delaware maritime traffic in modern times. We therefore conclude that for probability calculations our data base already adequately includes the effects of violent weather phenomena assuming no major climactic changes occur in the next 50 years.

It should be noted that the above estimates of the effects of violent weather on accident probabilities assume that shipping continues as normal even though severe weather warnings have been issued. The path of hurricanes can be predicted with a fair degree of certainty and warnings issued several hours before arrival of the hurricane. If a hurricane were imminent in the Delaware region the Captain of the Port of Philadelphia could exercise extraordinary powers granted him under the Code of Federal Regulations (Title 33, part 6) pertaining to "Protection and Security of Vessels, Harbors and Waterfront Facilities" and prevent any further traffic in the channel. Ships in the outer harbor could be asked to go out to sea or seek other harbors. Ships and barges in the inner harbor could be asked to stay at berth. With these safety measures in force the likelihood of severe collisions in inclement weather will be minimized.

5.0 ASSESSMENT OF HAZARD

5.1 DEFINITION OF CATCHMENT DISTANCE

In Section 3, probabilities of spills of hazardous chemicals occurring on the Delaware River were derived on a per-mile-of-riverway basis. However, we are interested only in spills which occur close enough to the plant to pose potential problems to the water intake system or the main control room. Depending on the chemical released and the quantity released, there is a maximum distance within which the spill must occur to pose a potential threat. This maximum distance, which varies with chemical and quantity spilled, is referred to here as the "catchment distance." The catchment distance, then, defines the distance, upstream and downstream from the water intakes, within which the release of a certain quantity of a chemical would be potentially harmful to the plant.

In assessing the hazards presented by maritime activity on the Delaware we will consider the known variety of chemicals shipped and will evaluate a catchment distance for each generic class of chemical which presents a hazard. Catchment distances are evaluated for pool fires, toxic and flammable vapor dispersion, soluble corrosive chemicals in intake, and explosions. A non-chemical related hazard is the potential blockage of the water intakes caused by barge collision and sinking in the close vicinity of the intakes. Catchment distances for blockage of intakes by barges are not presented because the design of the intake structure makes blockage impossible. (See Appendix 6.)

5.2 CATCHMENT DISTANCES FOR POOL FIRES

Should an accident release a flammable, lighter-than-water chemical on water, a potential pool fire hazard exists. Gasoline, liquefied natural gas (LNG), certain oils, and methanol are examples of chemicals which present a pool fire hazard. When the chemical is released on water, it will spread on the water surface. If it is ignited immediately upon release, the chemical will be consumed at a high rate and a high-intensity but short-duration fire will result. If unignited upon release, the chemical will spread on the surface until it is spread so thin (or has evaporated completely, as in the case of LNG) that it will no longer support a stable flame in the liquid pool.

The hazard presented by a pool fire is limited to a potential threat to the intake structure, the control room being too far from the river bank to be threatened by such fires. As far as the water intake structure is concerned, the ignited pool cannot be drawn into the pump bays because of the presence of skimmers at the bay entrance. However, if the ignited pool were to remain in the vicinity of the intake structure long enough, the fire could eventually threaten the concrete intake building.

The type of intake structure planned for Hope Creek can withstand envelopment in a fire (of effective black body emitting temperature of 1600°F) for over 20 minutes.* Under conditions of instantaneous spill and immediate ignition 5 million gallons of gasoline would be required for a fire of about 20 minutes† duration fine. We need only be concerned, therefore, by spills involving 5 million gallons or more of a flammable chemical in the immediate vicinity of the intakes. Furthermore, since most flammable liquid pool fires that can be expected on the Delaware have physical characteristics and severity levels similar to or less than those presented by gasoline, we need consider only gasoline.

The catchment distance for the 5-million-gallon spill would be somewhat less than 2 miles. Instantaneous spills as large as 5 million gallons are theoretically possible, and for this case the catchment distance is taken as 2 miles. However, spills occurring more than 1 mile from the intake, if immediately ignited, would not continue to burn for 20 minutes after reaching the intake, even with the most favorable river current. If ignition were delayed until the spill moved to the intake, sufficient spreading would have occurred to reduce subsequent fire duration to less than 20 minutes.

So far, we have only been discussing instantaneous spills. If a somewhat slower leak were to occur near the intakes, fires of longer duration would result. For example, if a barge carrying 5 million gallons of gasoline were to strike the intake structure and release gasoline at 50,000 gallons per minute and if immediate ignition were to occur, a 100-minute fire could result. However, fires involving small quantities of fuel can be easily controlled and simple water spray can protect the intake building. Manually operated water spraying capability will be available at the Hope Creek plant. Furthermore, the catchment distance

---

*See Appendix 7.

†See Appendix 1.

for these slowrate continuous spills is small (on the order of a hundred feet). Consequently, the probability of such events occurring is rare.

For purposes of quantifying the risk from pool fires, we have considered only spills of 5 million gallons or more occurring within 1 mile of the water intake structure. Details of the spread and fire calculations are presented in Appendix 1.

5.3 VAPOR DISPERSION

If an accident on the Delaware were to release a cold liquefied gas or a compressed gas, a vapor cloud of the gas would form and disperse downwind. Vapor clouds that contain toxic gases could pose a threat to operators in the control room and a vapor cloud of flammable gas could pose a fire hazard of sufficient severity to threaten the security of the control room. The gases that are currently shipped on the Delaware by Hope Creek and that pose a flammable-vapor dispersion problem are butane, LPG, and potentially LNG.

Anhydrous ammonia is the only toxic liquefied gas being shipped by Artificial Island. It is estimated that some 21,000 tons of liquefied ammonia are moving in ships with each ship carrying about 7,000 tons. There is no known movement of chlorine.

5.3.1 Flammable Vapor Dispersion (other than LNG)

Rather than treat each flammable gas separately, we will consider the risks presented by the worst case, which is represented by the 123,000 tons of LPG cargo. This cargo represents 12 ship movements a year with a maximum forseeable spill of 10,000 tons per ship. Under the most adverse weather conditions, an instantaneous 10,000-ton release of LPG would form a vapor cloud which could disperse up to 11 miles downwind prior to dilution below its lower flammability limit. In this case, the catchment distance for an LPG spill resulting in a flammable vapor cloud over the plant is 22 miles. Details of the dispersion methodology are presented in Appendix 2.

5.3.2 Toxic Vapor Dispersion

The only gas of concern in this category of hazard is ammonia. The total annual traffic consists of three shipments of 7,000 tons each. Under the most adverse wind conditions, an instantaneous release of 7,000 tons of ammonia would result in a vapor cloud that could disperse 35 miles downwind before the ground level concentration diminished

to a level below the AEC suggested* toxic limit of 100 ppm. In this case, the catchment distance for an ammonia spill resulting in a toxic vapor cloud over the plant would be 70 miles. However, a more realistic toxic limit is 400 ppm. This limit is more in keeping with practices in industrial safety. The catchment distance for a 400 ppm vapor cloud is 28 miles. Details of the dispersion methodology used are presented in Appendix 2.

5.4 CATCHMENT DISTANCES FOR CORROSIVE LIQUIDS

Spills of soluble corrosive liquids could work their way into intakes and into the cooling water system. The only chemical shipped on the Delaware that poses this problem is sulfuric acid. The concentrations of sulfuric acid necessary to cause various levels of corrosion to carbon steel pipes are reported in the Corrosion Handbook. Modeling studies** of water flow into the Salem intakes have shown that all the water entering the intakes comes from within 200 feet of the intakes in the normal direction. The same should apply to Hope Creek if a sulfuric acid spill were to occur within a quarter of a mile upstream or downstream of the intake it would be diluted in approximately 5.3×10^6 ft^3 of water.† The largest spill would constitute 800 tons or about 1.3×10^4 ft^3. The concentration of sulfuric acid being shipped by Artificial Island is low, generally below 50% by volume. Consequently, the concentration entering the water intakes would be $1.3 \times 10^4 \times 0.5 \div 5.3 \times 10^6$ or 0.12% volume. If sulfuric acid of this concentration (0.12% by volume) were to pass through the service water system the maximum amount of material removed on the pipe walls because of corrosion would be less than 0.003 mm (0.2 mil). (See Figure 5.1.) This degree of degradation is very small and for all practical purposes we may consider the catchment distance for sulfuric acid to be 1/4 mile. Only spills within 1/4 mile of the intake and within 200 feet of the bank pose potential problems.

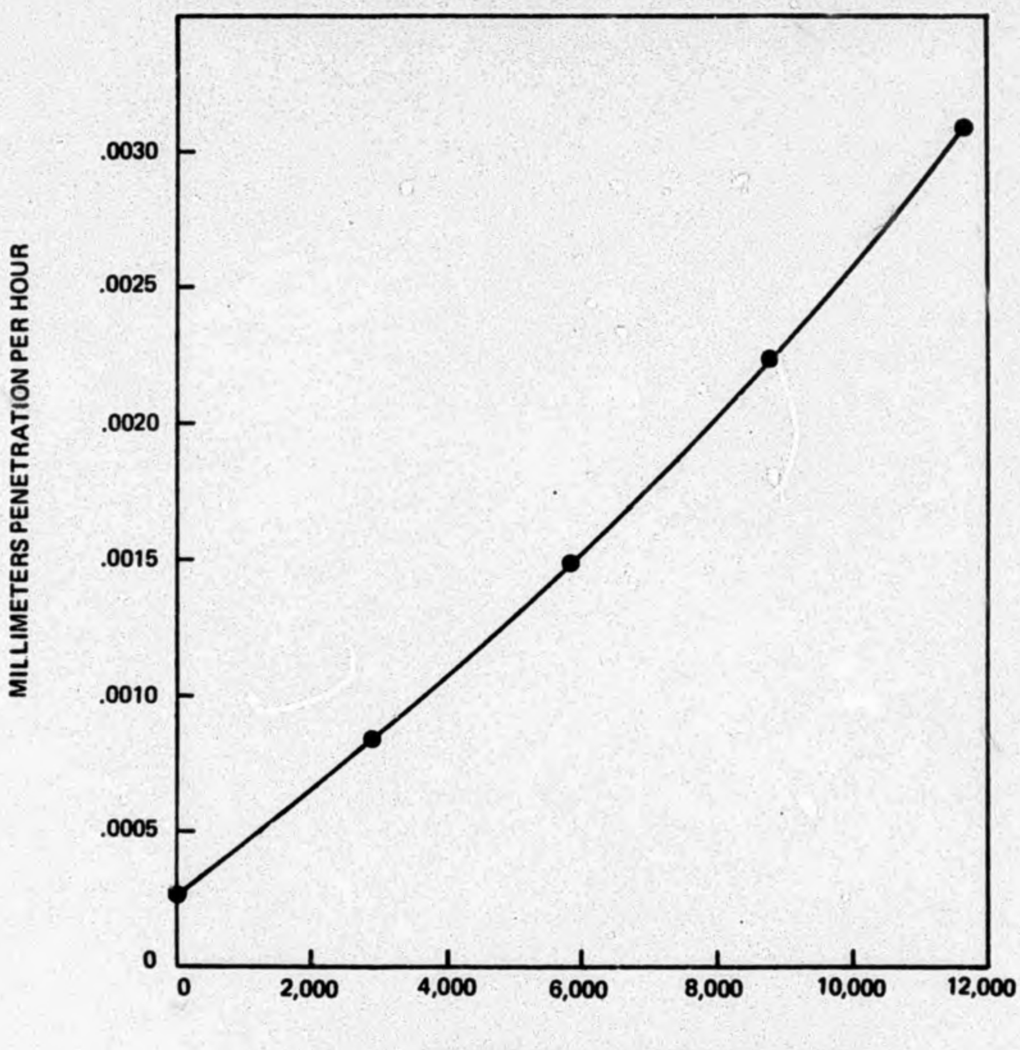
---

*See AEC document "Regulator Guide 1.78," June 1974.

**"Circulating Water Intake Hydraulic Mode Studies" Salem Station Hydro-Research-Science. USAEC Docket Nos. 50-272, 50-311. August 1969.

†Good mixing would occur as sulphuric acid is about twice as heavy as water and would tend to sink. However, as it is highly soluable in water, it would mix well as it moves down.

"CORROSION RATE OF CARBON STEEL BY 0.12 VOLUME PERCENT SULFURIC ACID AS A FUNCTION OF FLOW-RATE INSIDE 20-INCH I.D. TUBE."*



*W. Whitman, R. Russell, C. Welling, and J. Cochrane, *Ind. Eng. Chem.*, *15*, 672 (1923).

FIGURE 5.1

5.5 CATCHMENT DISTANCE FOR LNG SPILLS

At present, there is no movement of liquefied natural gas (LNG) on the Delaware. However, El Paso Natural Gas, Inc., has filed plans for a major importation project with the Federal Power Commission* which could result in up to 106 ships carrying LNG moving by Artificial Island in the future. As a result of these known plans for LNG importation, the risks due to LNG shipment are also evaluated.

The release of a large quantity of LNG on water presents two basic hazards. Either the spill will be accompanied by immediate ignition, in which case a pool fire will result, or else a vapor cloud of methane will form and disperse downwind. In the event of an accident and immediate ignition of 10,000 tons of LNG, a high-intensity, short-duration fire will result. Because of the rapid spread and evaporation of LNG, the fire duration will be about 5 minutes. Neither the water intake system nor the control room will be adversely affected by the fire.

In the event of an accident resulting in the instantaneous release of 10,000 tons (one tank of a typical, new, LNG ship) of LNG without ignition, a large vapor cloud will form. This vapor cloud will be flammable wherever the concentration of methane in air is between 5 and 15% by volume. The cloud will disperse downwind and dilute itself as more air is entrained into the cloud. Under the most adverse weather conditions a 10,000-ton release of LNG could produce a vapor cloud that remains flammable for a distance of 12 miles downwind. Of course, the chances of the cloud's igniting as it moves downwind are great, and once the cloud ignites it will burn rapidly and all further hazard will be alleviated. However, since the cloud could remain flammable for 12 miles the catchment distance for an LNG vapor cloud covering the plant is 24 miles. Details of the LNG vapor dispersion calculations are shown in Appendix 2.

---

*FPC Docket No. CP-73-258.

6.0 BLOCKING AND RAMMING OF INTAKES

6.1 GENERAL BACKGROUND

Some of the potential hazards to the service water intake structure are due to ramming collisions or groundings of the ships transiting the Delaware River. In a grounding collision, the water intake structure might not be able to provide cooling water under emergency conditions because blockage of the intake area has reduced the water inflow below critical limits, or has significantly impaired the pump efficiency by reducing the water head below the net pressure suction head (NPSH) of the pump. Similarly, a ramming collision could conceivably penetrate the intake structure to a sufficient depth to impact and destroy the pumps themselves, or create enough structural rubble to block the entry of water in sufficient quantities.

6.2 BLOCKING OF INTAKES

Blockage of the intake structure by a sunken or grounded vessel could restrict the normal access of water to the pump inlet, and thereby reduce the head available to the pump. If the loss of head due to blockage is sufficient to reduce the head available at the pumps to less than the net positive suction head (NPSH) requirements of the pumps, cavitation could result, water flow could decrease sharply, and destructive damage could be caused to the pump. The criterion established for safe operation, therefore, has been set as the blockage which reduces the head available to the pumps to their NPSH requirements, in the case in which the river tidal level is at its minimum credible low low water. (See Appendix 4.)

Two cases have been examined: one for continuous safe operation of the plant, with each of the eight service water pumps delivering its normal design flow rate of 10,875 GPM; and the other for the safe operation requirements during plant shutdown in the LOCA mode.

The results of these analyses, which are described in Appendix 6, indicate that the minimum flow area required for normal continuous plant operations is 35 ft^2, while that required for the plant shutdown condition is 12 ft^2. These correspond, respectively, to about three percent and one percent of the total intake area at the design low low water condition.

These values suggest that it is just about impossible to block the intake structure to the degree necessary to produce an unsafe plant operational situation because of insufficient

service water flow. This degree of blockage would require a vessel, the draft of which is equal to or shallower than the water level at the intake structure, to penetrate up to the intake structure without grounding on the dredged side slopes, turn parallel with the intake opening, and in the case of those vessels with drafts shallower than the water depth, sink immediately in front of and close up against the intake opening. The length of these vessels must be less than 125 feet so that they can maneuver into the appropriate position, but longer than approximately 75 feet to block three of the four intake bays.

There is no conceivable circumstance under which a conventionally-shaped ship, with hull curvature at the bow and stern, could block the intake structure to the necessary degree. The curvature itself would prevent it.

Barges with squared bows and sterns and with essentially flat rectangular sides could conceivably block the frontal intake area. A listing of those barges which make up the bulk of the barge traffic past Artificial Island was obtained from the Interstate Oil Transport Company of Philadelphia. This listing (presented in Table 3-2) is comprised of 30 barges, ranging in size from 500 to 15,000 gross tons. Out of these 30, only one is less than 200 feet long. This particular one, the George Tilton, is 130 feet long, but is only 11 feet in total height and hence could block the water intake structure only if the water level were lower than the lowest level ever recorded.

Two of the specific design features of the intake structure, which have not been considered in the analysis or discussion up to this point, would essentially preclude the possibility of blockage of the water inflow to the degree necessary under any conceivable situation. These design features are the fish escape area and the marine dock bumpers. The proposed design of the intake structure for the Hope Creek Station incorporates fish escapes at the sides of the structure. This arrangement is possible because the intake structure extends 25 feet into the river past the shoreline. Thus, even if the frontal area of the intake structure opening were completely blocked, water could flow into the intake through the fish escape areas. These areas, one on each side, are approximately 5 feet wide, and are open up to an elevation corresponding to approximately mean high water level. At the design low low water level, used in the blockage analysis, about 40 ft^2 of flow area would be available through each of the two fish escape areas – an amount considerably greater than the minimum flow areas required for safe plant operation.

The marine dock bumpers are resilient structures normally positioned at several elevations on each of the protruding structural walls or buttresses to prevent impact damage from service ships. These bumpers, which typically extend 2 or 3 feet from the concrete wall, could also serve to hold a stranded or grounded vessel away from the intake structural walls, and hence provide a water flow area around and under the vessel. Conceivably some of these bumpers may be broken or sheared off by the oncoming vessel; it is not likely, however, that a sufficient number of them would be damaged to the degree required for the vessel to approach the intake for close-to-total blockage of the frontal intake area.

6.3 RAMMING OF INTAKES

Impact of the intake structure by a ramming ship could conceivably destroy some of the pump systems or block the water intake opening sufficiently to impair the efficiency of the water inflow.

Ramming collisions would be, as discussed in Appendices 4 and 5, limited to relatively shallow draft vessels under the normal range of tidal conditions, since the larger ships would likely ground on the shoal areas outside the river channels. The analysis of the potential for such groundings indicates that the largest vessel capable of reaching the intake for tides up to the high high water level (i.e., the highest tidal level ever recorded in the vicinity of Artificial Island) would have a displacement of approximately 100 million ft-lb. (See Appendix 5.) At a mean tide level, the largest vessel capable of reaching the intake without grounding would have a displacement of approximately 9000 tons, and a maximum kinetic energy of about 60 million ft-lb. At low low water conditions the largest vessel would be approximately 3000 tons and have a kinetic energy of about 30 million ft-lb. At the extreme design high water condition, corresponding to potential hurricane tidal levels occurring once in a thousand years, the largest vessels transiting the Delaware River would be capable of reaching the intake without grounding. These, as indicated in Appendix 5, could impact the intake structure with as much as 200 million ft-lb of kinetic energy. Thus, the analysis indicates that even over these extreme tidal conditions the magnitude of the kinetic energy of such potential ship ramming incidents would be in the 20 to 200 million ft-lb with the most probable value being on the order of 100 million ft-lb.

The resistance of the intake structure to this energy input during impact will be developed by various energy storage and dissipative mechanisms, such as elastic and plastic strain energy in the structural components, shear and frictional forces in the soil-structure interface, and shear and compressive forces in the underlying and surrounding soil materials.

An analysis of the response of the intake structure to such ramming inputs – severe enough to produce plastic or elasto-plastic behavior, or some mode of structural failure – cannot be determined analytically in a straightforward manner. First, most of the mechanical work, or absorption of the impact energy, takes place in the plastic region of the structural materials, so the applicability of analytical techniques is limited. Second, the actual mechanisms of the structural failure are complex; they involve bending, twisting, buckling, crushing, etc. and frequently progress from one of these failure modes to another.

Two approaches have been used to study the structural deformation effects of ship collisions: (1) empirical methods using data about actual collisions to define relationships between the energy of the collision and the degree of structural damage, and (2) model studies, in which scaled structural models simulating vessel bows in collision with vessel sidewalls or other structures have been fabricated and tested in the laboratory.

Each of these approaches has produced results which have applicability to the present study. The empirical approach by Minorsky* evaluated the extent of structural damage in major ship collisions and the magnitude of the energy lost in those collisions. The energy of the major collisions which occurred over a 12-year period was determined to be between 100 and 400 million ft-lb. As an example of the relation between energy and structural damage, one case, which involved approximately 270 million ft-lb of energy, consisted of a high-speed collision at sea of a 22,000-ton vessel and a 20,000-ton vessel, and resulted principally in the destruction of a 60-foot by 60-foot portion of the 7/8-inch thick main deck of the struck vessel. From this case, it is apparent that a considerable amount of energy can be absorbed by plastic deformation of structural elements, particularly if such elements have an appropriate configuration and orientation for effective input resistance.

---

*"An Analysis of Ship Collisions with Reference to Protection of Nuclear Power Plants," by V.U. Minorsky, J. of Applied Research, October 1959.

When the collision energy and the extent of damage from this ship collision are compared to the energy potentially available for ramming collisions of the intake structure, it can be concluded that the degree of damage required for a hazardous blocking or destruction of the water intake structure is unlikely to result from the magnitude of the energies available from the postulated ramming conditions.

The model studies, particularly those by the Japanese investigators,* have shown that in the collision of two deformable bodies, the distribution of the structural damage between the two bodies was quite sensitive to the relative strength or resistance of the two bodies, with the weaker of the two absorbing most of the energy and hence being destroyed one-sidedly. On this basis, it would seem reasonable to conclude that if a vessel collided with the relatively massive reinforced concrete intake structure, most of the impact energy would be dissipated in damage to the vessel. In such a case, the essential hazard would arise from blocking of the intake by the structural failure and deformation of the vessel components and the resulting rubble and debris. As indicated in Section 6.2, the intake opening cannot be blocked to the degree necessary to prevent safe operation of the plant during its normal or shutdown conditions, even under the relatively ideal blocking configuration provided by a flat-sided barge. Structural rubble would be relatively inefficient in this regard. Furthermore, the magnitude of the input energy, as indicated earlier, is related to the largest size of the vessel reaching the intake, which in turn is a function of the tidal level. Thus, the effective intake opening (intake width times height of water level) will increase as the magnitude of the impact energy available to create structural rubble increases.

Another approach that can provide a qualitative assessment of the structural resistance of the service water intake structure is to compare the accelerations due to the ramming with the seismic design requirements. The intake structure has been designed as a seismic Class I structure in keeping with its vital role in the safe operation of the facility. As such, its design is based, in addition to the usual structural loading conditions, on a dynamic analysis utilizing earthquake response spectra and/or earthquake time-history ground impact. The peak acceleration ground motion input values in the horizontal direction are 0.10g for

---

*"A Study on Collision by an Elastic Stem to a Side Structure of Ships" by Y. Akita and K. Kitamura, Journal of the Society of Naval Architects of Japan, Vol. 131, June 1972.

the Operating Basic Earthquake. In the vertical direction, the general motion input values are specified as two-thirds of the horizontal input values, acting simultaneously. For reinforced concrete structures, the damping is specified as two percent of critical damping for the Operating Basic Earthquake, and seven percent for the Design Basic Earthquake.

The acceleration response spectra to these inputs indicate that over certain frequency ranges, these input values will be amplified by as much as a factor of 3.7 in the case of the Operating Basic Earthquake, and by 2.1 in the case of the Design Basic Earthquake. Under these inputs, the structural components and the structural system as a whole must not develop stresses above specified limits.

Structural loadings due to impact from a ramming collision are of course quite different from system ground motion inputs from seismic forces. One of the major differences is that while seismic inputs are applied to the entire structure through soil-structure interaction, the impact loads due to collision are essentially local and progressive as the penetration or deformation proceeds to adjoining structural elements. With this type of structural loading pattern, many complex structures, including many vessels and configurations such as the intake structure, which consist of a large number of interconnected structural components in grid-like or honeycomb designs, will exhibit a relatively constant resisting force, and hence produce a relatively constant deceleration of the ramming ship and of the impacted structure. Assuming the case of constant deceleration, the deceleration magnitude is given simply by the relation

$$a = v^2/2s$$

where:

a = deceleration, ft/sec^2

v = ramming velocity, ft/sec

s = maximum penetration, ft

Using this formulation, one can determine the value of deceleration of the ramming ship for prescribed penetration depths and ramming velocities. For example, for penetration sufficiently deep into the intake structure to directly affect the pumps requires that s be about 55 ft. Assuming a high high water condition, with a maximum vessel size of 26,000

tons and speed at six knots, leads to a deceleration of about 0.03g. For a maximum penetration of, say, 10 feet, the deceleration is about 0.16g.

The corresponding accelerations imparted to the intake structure would be extremely difficult to determine because the effective mass of the intake structure, including the surrounding earth and foundation, resisting the impact force is not easily determinable. It would appear intuitively clear, however, that the velocity, and hence acceleration, imparted to the entire intake structure would be much less, perhaps orders of magnitude less, than that of the ramming ship.

On the basis of this qualitative argument, damage to the structural elements of the intake structure due to inertial loadings is not a conceivable occurrence from a ship-ramming accident. Whatever damage is incurred by the intake structure is more likely to arise from stress development as a result of local loadings from the impact. From prior arguments, however, it is not conceivable that ramming collisions by such local loadings and structural failure could cause the magnitude of damage to the service water intake system necessary to preclude safe operation of the plant during its normal or shutdown modes.

APPENDIX 1

ANALYSIS OF SPREAD AND IGNITION OF FLAMMABLE LIQUIDS ON WATER

Prior to determining the probability that a spill of volume V or greater, at a location x miles from the water intakes, will arrive at the intake while still flammable, it will be necessary to examine the physics of oil spread on water.

The spread of most flammable liquid materials on water is similar to that of oil. The movement of oil and other petroleum products released in waterways is controlled by three basic mechanisms: (1) the propensity of oil to spread because of density and surface tension effects, (2) the effects of wind, and (3) the effects of water current. Depending on the size of spill, the nature of the waterway, and the time frame of interest, one or more of these mechanisms would play a dominant role in determining extent of spread. While spreading, the oil can evaporate and even sink, provided it combines with enough contaminants to become effectively heavier than water. In general the released oil will spread (because of density and surface tension effects) to a minimum thickness of about 0.1 mm for most common oil and petroleum products. When an oil slick hits the shore line it starts being absorbed by the boundary at a relatively slow rate depending on the kind of soil involved. For short periods this absorption can be neglected.

A. PHYSICS OF OIL SPREAD

The natural tendency for oil to spread on water by virtue of density and surface tension effects has been the subject of much study. Fluids with viscosities much larger than water (such as oil) spread in three phases: (1) gravity-inertia; (2) gravity-viscous; and (3) surface tension-viscous. For an instantaneous spill of volume V the radius of spill r, these phases can be expressed* as

$$r = 1.14\,[GV]^{1/4}\,t^{1/2} \qquad \text{Gravity-inertia}$$

$$r = 0.98\,[G^2 \frac{V^4}{\nu}]^{1/12}\,t^{1/4} \qquad \text{Gravity-viscous}$$

$$r = 1.6\,[\frac{\sigma}{\rho\sqrt{\nu}}]^{1/2}\,t^{3/4} \qquad \text{Surface tension-viscous}$$

---

*Fannelop, J.K., and Waldman, G.D., "Dynamics of Oil Slicks", *AIAA Journal*, Volume 10, April 1972, p. 506.

where ρ is the density of water, t is the time after spill, ν is the kinematic viscosity of water and G is the gravitational constant multiplied by the non-dimensional density defect.

B. SAMPLE CALCULATION

Consider the spill of one million gallons of oil in a wide river (no shore lines effects) with mean current of 1.5 knots and wind of 30 knots from one direction. Let us track the movement of the oil spill in the first hour after spill (Figure A-1). The spill occurs at site X at time t = 0. We show the current direction and wind direction by sectors at the site. One hour later the slick is at site Y. It has spread to a radius of 1330 feet because of density effects and moved 1.5 nautical miles in the current direction and 0.9 nautical mile (30 x 0.03) in the wind direction. The dotted lines show the net movement of the oil.

C. OIL MOVEMENT IN THE FLAMMABLE RANGE

In order to assess the probability of oil fires in plant water intakes, we need to determine the condition of flammability of oil on water and apply this to determine the likelihood of oil in intakes while it is still flammable.

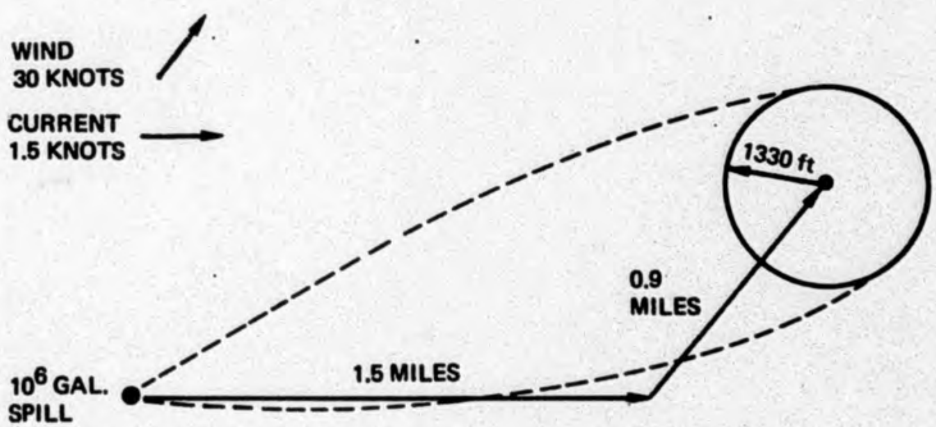
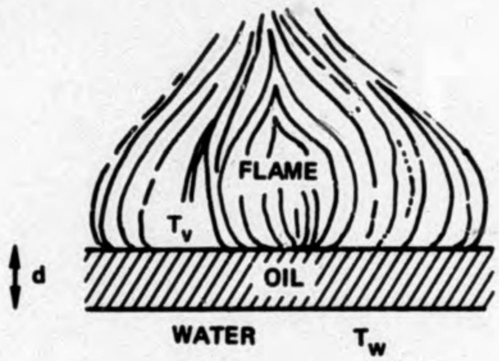


FIGURE A-1. SCHEMATIC OF OIL MOVEMENT

When oil is spilled on water it spreads, thereby causing the constant volume slick to become thinner. Eventually the slick becomes too thin to be ignited and support a stable fire. In this appendix we calculate the critical thickness for burning of oil on water and use the time a given volume takes to achieve this thickness as the flammable life time of the oil. On the basis of this time, we evaluate the probability of oil's reaching the intake while still flammable.

D. CALCULATION OF THE CRITICAL THICKNESS FOR BURNING FUEL OIL ON WATER

Consider a pool of oil burning on top of a water base. A critical thickness is achieved when the heat radiated from the flame to the surface (which goes into evaporating the fuel) is equal to the heat conducted through the oil film into the water; that is



$$I_{rad} = \frac{\kappa(T_v - T_w)}{d_c}$$

where:

- I_{rad} = intensity of radiation from the flame to the surface (cal sec^{-1} cm^{-2})
- κ = thermal conductivity of the fuel oil (cal sec^{-1} cm^{-1} °C^{-1})
- T_v = vaporization temperature of the oil (°C)
- T_w = water temperature (°C)
- d_c = critical thickness of the oil slick (cm)

When burning is taking place at steady state, the back radiation from the flame to the pool equals the heat needed to evaporate an amount of oil equal to that burning in the flame; that is:

$$I_{rad} = v\rho\Delta H_v$$

where:

v = linear regression rate of the surface (cm sec^{-1})

ρ = density of the oil (gm cm^{-3})

ΔH_v = latent heat of vaporization (cal gm^{-1})

For a typical oil on sea water we can substitute the following values:

v = 4 mm/min* = 0.0067 cm sec^{-1}

ρ = 0.9 gm cm^{-3}

ΔH_v = 80 cal gm^{-1}

κ = 3.7×10^{-4} cal sec^{-1} cm^{-1} $°C^{-1}$

T_v = 240°C

T_w = 10°C

The critical thickness can then be evaluated as

$$d_c = \frac{\kappa(T_v - T_w)}{v\rho\Delta H_v}$$

$$= \frac{3.7 \times 10^{-4}\ (240 - 10)}{0.00667 \times 0.9 \times 80}$$

$$= 0.18 \text{ cm}$$

This checks very well with the value of d_c = 0.13 cm found experimentally* for butanol, isopentanol and hexanol layers on water.

It is clear then that an oil slick on fire will not burn to a slick thickness less about 0.2 cm. We utilize this result to hypothesize that oil slicks thinner than 0.1 cm (for a conservative estimate) will not sustain stable combustion.

E. CALCULATION OF TIME TO REACH CRITICAL THICKNESS

Utilizing the equations governing the spread of oil on water, we calculated the time necessary to reach a critical thickness of 0.1 cm. The results are shown in Table A-1.

---

*Blinov, V.I. and Khudjakov, G.N., "Diffusion Burning of Liquids", Moscow Academy of Sciences, 1961, translated by Dept. of the Army, Corps of Engineers, Fort Belvoir, VA, Report No. T-1490 a-c, 63-15670.

TABLE A-1

TIME TO REACH CRITICAL THICKNESS

Spill size (gallons)	10^2	10^3	10^4	10^5	10^6
Time (hours)	0.038	0.175	0.81	3.6	17.0
Radius at this time (meters)	11.0	34.7	110	347	1100

F. SIMULTANEOUS SPREADING AND BURNING

Although a million gallon release of fuel oil may remain flammable on water for several hours, in the event of ignition the fire would burn out in very short time. Fire duration for flammable liquid spills with immediate ignition can be calculated utilizing the relationship:*

$$t = 0.67 \left[\frac{V}{G\,\dot{r}^2}\right]^{1/4}$$

where:

- t = time for burning complete pool (sec)
- V = volume of spilled fuel (ft^3)
- G = effective gravity, $g(1-\rho_{fuel}/\rho_{water})$, (ft/sec)
- $\dot{r}$ = regression rate of burning fuel (ft/sec)

A typical regression rate for gasoline and other petroleum products is 0.36 in./sec whereas a typical ratio of fuel density to water density is 0.7. Utilizing these values, we calculated the time for fire duration of various sized spills shown in Table A-2.

---

*"Assessment Models in Support of the Hazard Assessment Handbook", Technical Report by Arthur D. Little, Inc., Cambridge, Massachusetts to U.S. Coast Guard. Office of Research and Development, Washington DC, Report No. CG-D-65-74, January 1974.

TABLE A-2

TYPICAL TIME TO COMPLETELY BURN GASOLINE
(Simultaneous Spread and Ignition)

Volume spilled (gallons)	10^4	10^5	10^6	5×10^6
Time to burn out (seconds)	140	250	430	660

As can be seen from Table A-2, a million gallon spill, if immediately ignited, will burn out in about 7 minutes. As a conservative estimate, we have postulated that a million gallon spill may present a fire hazard of over 10 minutes duration. A five million gallon spill, if immediately ignited, will burn for about 11 minutes. As a conservative estimate we have postulated that a five million gallon spill may present a fire hazard of over 20 minutes. The intake structure can withstand much more than 20 minutes of envelopment in a fire (see Appendix 7) but once again, we have conservatively estimated that a fire of over 20 minutes duration is a potential threat. As a result of these considerations, only five million gallon spills within one mile of the intake are considered hazardous. Spills outside the one-mile distance may still be flammable (or burning, if already ignited) when they reach the intake, but in that case, the fire duration will be less than 20 minutes.

APPENDIX 2
VAPOR DISPERSION

A. INTRODUCTION

Of the many chemicals transported on water, quite a few are cryogenic liquids which vaporize when heated to atmospheric temperatures. Other liquids are highly reactive with water and produce toxic gases. Therefore, if one is to assess their inherent hazard one must know to what extent these released gases are dispersed. The model used in the prediction of vapor concentrations at various locations and times is presented here.

The primary agent that will disperse a vapor cloud released into the atmosphere is the atmospheric turbulence. Molecular diffusion caused by concentration gradients represents a much smaller effect than turbulent mixing. Therefore, wind conditions and the air temperature gradient (in effect, the local meteorological conditions) have considerable influence on the dilution of the cloud. The uncertain and unpredictable character of the atmospheric condition, the differences in topography of a particular locale, and the differences in the physical properties of the vapor released make it difficult to give a general dispersion model applicable to all circumstances and locations. However, some models have been proposed in the literature, all of which have their roots in the Fickian diffusion equation based on turbulent diffusion coefficients. In almost all of the models the vapor released is assumed to have the same density as the local air (neutrally buoyant), and it is further assumed that during the dispersion process neither the wind direction, nor its velocity, nor other meteorological conditions change. In most cases the effects of heat transfer from the surrounding air and ground are neglected.

The model presented here is the one most widely used in practice for concentration predictions.

B. DETAILS OF THE MODEL FOR LPG AND LNG RELATED DISPERSION

The model presented is based on the Gaussian diffusion models of Pasquill and others.[1] The origin of the x,y,z coordinates is on the ground directly beneath the source point (and, in the case of area sources, it is the center of the area on the ground). The x direction is defined as the direction of the wind and z is the vertical direction. (See Figures A-3 and A-4.)

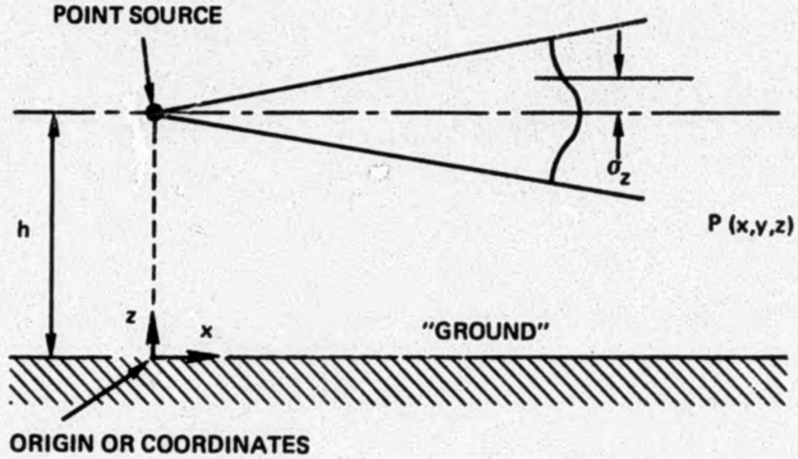


FIGURE A-3. SCHEMATIC DIAGRAM OF A CONTINUOUS POINT SOURCE

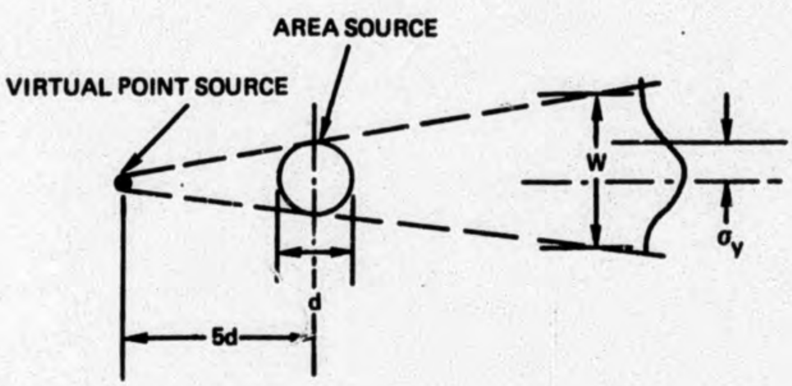


FIGURE A-4. SCHEMATIC DIAGRAM OF A CONTINUOUS AREA SOURCE

1. Point Source

For vapor released instantaneously, the following equation is used:

$$C(x,y,z,t) = \frac{m}{(2\pi)^{3/2}\ \sigma_x \sigma_y \sigma_x} \text{Exp-} \left[\frac{(x-Ut)^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2}\right] + \left[\text{Exp} - \frac{(z-h)^2}{2\sigma_z^2} + \text{Exp} - \frac{(z+h)^2}{2\sigma_z^2}\right] \quad (1)$$

where $\sigma_x, \sigma_y, \sigma_z$ = variances of the Gaussian concentration profiles in the respective directions.

The terms σ_y and σ_z are a functions of downwind distance. For use in Eq. (1) we assume $\sigma_x = \sigma_y$.

If the concentration is expressed in mole fraction (C_f) of the air vapor mixture, then:

$$C_f = \frac{1}{[1 + \rho_a/C\ M_v/M_a]} \quad (2)$$

where ρ_a = the density of air at standard conditions (15°C, 1 atm).

2. Area Sources

The proper procedure for obtaining the concentration at any point due to an area source is to add the contributions from each infinitesimal point source in the area toward the concentration. This is illustrated by Eq. (3).

$$C_a(x,y,z,t) = m/A \int_{\bar{x},\bar{y} \text{ over the source area A}} C_p(x-\bar{x}, y-\bar{y}, z \quad , t-\bar{x}/U)\ d\bar{x}\ d\bar{y} \quad (3)$$

where

C_a = concentration at (x,y,z) due to area source;

C_p = concentration at the same point due to a point source at $\bar{x},\bar{y}$; and

A = area of source.

In general, the evaluation of the above integral is difficult. However, for estimating the concentration at large distances (greater than two equivalent diameters of the source area) the following simple analysis suffices for most engineering purposes.

The area source is replaced by a virtual point source of the same total strength, but displaced upwind by a suitable distance. It is found that this "suitable distance" is a function of the concentration itself. However, a reasonable estimate of this upwind origin-shift distance is about 5 diameters. Hence, for area source calculations we use:

$$x' \doteq x + 5d \qquad (4)$$

and substitute this x' in Eq. (1), instead of x, to obtain the concentration at point x.

C. APPLICATION TO LPG AND LNG

The dispersion theory discussed here is the one used in calculating distances of flammable vapor travel for both LPG and LNG generated vapors. The catchment distance is merely two times the maximum distance of flammable cloud travel. The actual distances as a function of volume spilled is shown in Table A-3.

TABLE A-3

MAXIMUM DISTANCE OF FLAMMABLE CLOUD TRAVEL
(Atmosphere F)

Case 1: LNG				
Spill Quantity (tons)	100	500	5,000	10,000
Pool Radius (feet)	200	380	860	1,120
Evaporation Time (secs)	76	110	200	240
Maximum Extent of Travel (miles)	1.5	3.2	8.9	12
Case 2: LPG				
Spill Quantity (tons)	100	500	5,000	10,000
Pool Radius (feet)	210	390	940	1,230
Evaporation Time (secs)	140	220	380	450
Maximum Extent of Travel (miles)	1.3	2.8	8.2	11

Because of type of construction of LNG and LPG tankers, any spill is likely to release the contents of an entire tank. Typical tank size on these tankers is 10,000 tons.

In the event of 10,000-ton releases of LNG and LPG the catchment distance would be 24 and 22 miles, respectively.

D. MODEL FOR AMMONIA DISPERSION

Unlike LPG and LNG generated vapor, ammonia vapor is lighter than air and will tend to rise. The model for ammonia dispersion used in this study is based on the results obtained in a recent U.S. Coast Guard sponsored project on ammonia spills on water.[2] When ammonia is spilled on water, approximately half of the quantity released dissolves to form ammonium hydroxide whereas the remaining half vaporizes and disperses downwind. The vapor dispersion problem can be adequately treated as a combination of standard dispersion theory and buoyant plume theory. Full details of the prediction method and experimental verification of the theory are presented in Reference 2.

Based on the predictive methods in Reference 2, the extent of ammonia cloud travel prior to diluting the cloud below 100 ppm and 400 ppm are as shown below:

MAXIMUM CLOUD TRAVEL DISTANCES
VARIOUS AMMONIA CONCENTRATIONS
(Atmosphere F)

Spill Quantity (tons)	100	500	3,000	7,000
Downwind Distance for 100 ppm (miles)	5.6	11	24	35
Downwind Distance for 400 ppm (miles)	3	5	11	14

Once again, in the event of a tanker related spill, the most likely spill quantity would be the entire tank content of 7,000 tons. The catchment distance is 28 miles.

REFERENCES FOR APPENDIX 2

(1) "Meteorology and Atomic Energy"; U.S. Atomic Energy Commission, Division of Technical Information, Slade, D.H., Editor, July 1968, Ch. 3, pp. 65-116.

(2) "Prediction of Hazards of Spills of Anhydrous Ammonia on Water" Report by Arthur D. Little, Inc., Cambridge, Massachusetts to U.S. Coast Guard, Office of Research and Development, Washington D.C. Report # CG-D-74-74. AD779400. January 1974.

NOMENCLATURE

Symbol	Description	Formula or Value	Units
C	concentration of vapor		kg/m^3
C_f	molar vapor concentration		fraction or %
d	equivalent diameter of area source		m
h	height of source above the ground		m
m	mass of vapor released		kg
$\dot{m}$	rate of release of vapor		kg/s
M_a	molecular weight of air	28.9	kg/kmole
M_v	molecular weight of vapor		kg/kmole
t	time		s
U	wind velocity		m/s
W	width of vapor plume at any point		m
x	downwind distance		m
y	crosswind distance		m
z	vertical distance		m
ρ_a	density of air at 15°C, 1 atm	1.22	kg/m^3
$\sigma_x, \sigma_y, \sigma_z$	variances of Gaussian concentration profile		m

APPENDIX 3

SHIPMENT OF HIGH EXPLOSIVES ON THE DELAWARE

Small quantities of high explosives used to ship on the Delaware and Anchorage 2 was used for unloading purposes. However, we have been unable to find any documentation of use of Anchorage 2 for explosives since 1969. We firmly believe that no explosives are now shipped or are likely to be shipped by Artificial Island in the near future. Brief descriptions of telephone conversations and actual correspondence with certain major companies are attached as exhibits to substantiate the above facts. Some of the reported telephone conversations were initiated by Arthur D. Little personnel whereas others were initiated by PSE&G.

Telephone Conversations

1. Name of Company: Pilots Association for the Bay & River Delaware
   Telephone Number: (215) 925-7165
   Date of Contact: April 15, 1974
   Summary of Telcon:
   - Anchorage has not been used for explosives since late 1960's.
   - Used to handle in general cargo freighters #C2 and C3; 6500 Ton to 7300 Ton.
   - Asosciation handles all vessels to and from foreign ports and some coastal cargos.

2. Name of Company: Frankford Arsenal
   Telephone Number: (215) 831-6011
   Date of Contact: April 15, 1974
   Summary of Telcon:
   - All shipments by air or road.
   - Do not expect to ever ship by water.

3. Name of Company: Atlas Corporation

Telephone Number: (302) 478-6200

Date of Contact: April 16, 1974

Summary of Telcon:

- Explosives plant is in Reynolds, PA
- All shipments are by rail and truck
- Any water shipments are from Kings Bay, GA
- Absolutely no shipments of explosives in or out on Delaware River.

4. Name of Company: U.S. Coast Guard District Headquarters, New York

Telephone Number: (212) 264-4916

Date of Contact: September 9, 1974

Summary of Telcon:

- Does not know of any recent explosives movement by water on Delaware.
- A change of status plan to make Anchorage 2 a non-explosive anchorage is under file.

5. Name of Company: U.S. Coast Guard, COTP Office

Telephone Number: (215) 923-4320

Date of Contact: September 9, 1974

Summary of Telcon:

- No explosives unloading since 1969
- COTP Philadelphia has requested a change in status of Anchorage 2 to make it a non-explosive anchorage.

LETTERS OF SUPPORT

Several letters are attached

HERCULES INCORPORATED

TRAFFIC DEPARTMENT · WILMINGTON, DELAWARE 19899

April 23, 1974

PROJECT MANAGER
Electric Engineering Department
J. T. BOETTGER
Noted JTB
APR 25 1974
Refer to FML
Copies to JTB
☐ Follow
☑ File

Mr. John T. Boettger
Project Manager - Hope Creek
Public Service Electric and Gas Company
80 Park Place, Room 314 MP
Newark, New Jersey 07101

Dear Mr. Boettger:

HOPE CREEK GENERATING STATION
SHIPPING OF EXPLOSIVES

We refer to your letter of April 18 which was just received by the undersigned today.

From 1966 through 1974 to date, Hercules Incorporated has not used or made a shipment through the Explosive Anchorage off Artificial Island in the Delaware River. In 1965 we made two shipments as follows:

50#/case

1) 2,600 cases Dynamite and 75 cases Primacord to Liberia on the Farrell Line vessel S/S AFRICAN MOON, November 30.

2) 2,000 cases Dynamite and 125 cases Primacord to Liberia on the Farrell Line vessel AFRICAN GROVE, September 24.

As we informed Mr. Linn, there are very few places in the United States where it is possible to load export shipments of commercial explosives. We have just recently secured permission from the Navy to load some shipments of commercial explosives on vessels at their Earle, New Jersey, facility. As long as permission is granted by the Navy to use their facility, we can see no reason or necessity to use the Anchorage off Artificial Island. As you know, however, the Navy can withdraw permission at any time.

If Earle, New Jersey, and Artificial Island, Delaware River, were both closed to us, the only other known facility on the East and Gulf Coasts of the United States is Kings Bay, Georgia.

Very truly yours,

R. C. Stout, Traffic Manager
Export/Import Division
Traffic Department

Reading PE
Apr. 29, '74
Stout - Linn

RCS/jmp

PI-1178

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
WILMINGTON, DELAWARE 19898

POLYMER INTERMEDIATES DEPARTMENT

April 24, 1974

HOPE CREEK GENERATING STATION
SHIPPING OF EXPLOSIVES

Re: Your Letter of April 16, 1974

PROJECT MANAGER
Electric Engineering Department
J. T. BOETTGER
Noted JTB
APR 26 1974
Refer to FM LINN
Copies to JTB
☐ Follow
☒ File

Mr. John T. Boettger
Project Manager - Hope Creek
Public Service Electric and Gas Company
80 Park Place, Room 314 MP
Newark, New Jersey 07101

Dear Mr. Boettger:

As requested in the reference letter, we have reviewed what information we do have pertaining to shipments of explosives on the Delaware River over the past ten years. As Mr. Linn found with Coast Guard records, our records beyond three years have also been destroyed.

To the best of our recollection, Du Pont Company has not shipped any Class "A" or Class "B" explosives from the Delaware River in the years 1969 through the present time. In the years 1964 through 1968, approximately four shipments per year were made from Artificial Island, averaging approximately 150M lbs. each. Shipments were made in commercial motor and/or steam ship vessels of approximately 5000 gross tons and larger. No other port on the Delaware River was used by Du Pont for shipment of Class "A" and Class "B" explosives.

Small amounts (under 5M lbs.) of Class "C" explosives were shipped over the docks of Philadelphia in the years 1964 through 1967. As far as we can recollect, no shipment of Class "C" explosives has been made in the years 1968 through 1973 across the Philadelphia docks.

We do not foresee any change in the pattern of shipments from the Delaware River in the next few years.

Very truly yours,

C. J. Doubt

C. J. Doubt
Physical Distribution

CJD:cmz

PROJECT MANAGER
Electric Engineering Department
J. T. BOETTGER
Noted
APR 25 1974
Refer to FML
Copies to JTB
☐ Follow
☑ File

DEPARTMENT OF THE NAVY
COMMANDANT, FOURTH NAVAL DISTRICT
PHILADELPHIA, PA. 19112

N46:MLM:bs
8000
23 April 1974

Mr. F. W. Schneider
Manager of Engineering
Public Service Electric and
  Gas Company
80 Park Place
Newark, New Jersey 07101

Subj: U. S. Navy Shipping Of Ordnance
on the Delaware River

Dear Mr. Schneider:

In reply to your letter of 16 April 1974, you are advised the Navy does not ship any type explosives to the Naval Base or Philadelphia area in freighters or freighter-type vessels.

Normal ship's ammunition which include ASROC, torpedoes, gun ammunition, small arms and pyrotechnics for safety at sea are carried on Navy ships which visit or are home ported at the Philadelphia Naval Base. Ships entering the Naval Shipyard are required by regulation to be free of ammunition.

The Commandant, 4th Naval District/Commander, Naval Base, Philadelphia, has no record of any accident or incident involving U. S. Navy ships during the past ten years.

If we can be of further assistance to you, please feel free to call on this command.

Sincerely,
M L McMillan
M. L. McMILLAN
District Ordnance Officer
Fourth Naval District

Copy to:
Mr. J. T. Boettger - Project Manager
Hope Creek

READING COMPANY

MARKETING DEPARTMENT
READING TERMINAL
PHILADELPHIA, PA. 19107

CHIEF STRUCTURAL ENG'R.
ELEC. ENG. DEPT.
☐ WLC ☑ RAA
MAY 30 1974
Noted
☐ SFF ☐ WC ☐
☐ ☑ FML

May 23, 1974
File: 28921-1-G

PROJECT MANAGER
Electric Engineering Department
J. T. BOETTGER
Noted JTB
MAY 1974
Refer to FML
Copies to DJJ, JCR
☐ Follow
☐ File

Mr. J. T. Boettger, Project Manager
Hope Creek Public Service
Electric & Gas Company
80 Park Place, Room 314 MP
Newark, N. J. 07101

Dear Mr. Boettger:

Please refer to your letter of April 19, wherein you inquired of us to furnish you with information concerning past, present, and future Explosive shipments from our railroad facilities in the Wilmington, Del., area to Artificial Island in the Delaware River; which information is required in connection with your plans for construction of the Hope Creek Generating Station on Artificial Island.

In order to respond to your specific inquiries, we also called upon the services of our Operating/Transportation and Sales Departments, who furnished us the following information in part:

1. Concerning the number, size, and type of Explosive shipments handled in the last 10 years, our records indicate the following:

Cars

1962	1963	1964	1965	1966	1967	1968
35	64	10	6	3	1	None

1969	1970	1971	1972	1974 (4 Months)
1	None	None	None	None

All of these shipments moved through Pigeon Point, Del., to Artificial Island.

At this juncture we regret that we are not able to furnish you with more detailed information relative to size of shipments as well as type of Explosives as to develop these factors would entail a substantial time consuming process and, further, as you will note, we have not handled any movements since 1969 or, for that matter, are there any prospects of participating in future shipments, we do not understand why this type of detailed information concerning past movements would be required in connection with your project.

2. In regard to our tariff naming rates on Explosives from the Wilmington, Del., area to Artificial Island, we would advise that we have filed a proposal to cancel same which cancellation should be effective around July 1, 1974.

3. We can respond to your question concerning our plans and capabilities to handle future shipments of Explosives on the Delaware River by stating that we are no longer interested in participating in these movements particularly when factors of high risk and excessive expenses are involved.

We would point out that the decision to cancel our Explosives Tariff culminated from studied we recently made on this type of traffic movement.

In addition, we have retired much of our floating equipment (lighters, barges, etc.) and that which remains is in continual use. Therefore, we have no desire to tie-up this equipment in any possible future Explosives movements which we might be offered, as certainly this would be to the detriment of our normal traffic handlings.

We sincerely hope our responses to your inquiries will be of benefit to you and, if we may be of further assistance to you in this matter, please do not hesitate to contact us.

Very truly yours,

C W Jewell

C. W. JEWELL
Product Manager

CWJ/jt

GENERAL COUNSEL OF THE DEPARTMENT OF DEFENSE

WASHINGTON, D. C. 20001

24 Apr 1974

Troy B. Conner, Jr., Esq.
Conner, Hadlock and Knotts
Suite 1050
1747 Pennsylvania Ave., N. W.
Washington, D. C. 20006

Dear Mr. Conner:

This letter confirms the telephone discussion of April 18th between Mr. Reynolds of your Office and Major Briggs of my Office concerning the possible shipment of munitions on the Delaware River, near Salem, New Jersey.

The only regular shipments by ocean vessel of munitions by the Department of Defense on the East Coast of the United States involve the ports at Sandy Hook, New Jersey and Sunny Point, North Carolina. There is no information to indicate that the Department of Defense is shipping munitions on the Delaware River.

I trust that the above information will be of assistance to you.

Sincerely,

Martin R. Hoffman

RETYPED COPY OF ORIGINAL

APPENDIX 4
SHIP GROUNDING

A. RESISTING MECHANISMS

When a ship runs aground, several energy-absorbing mechanisms can develop, depending upon the character of the sea bottom and of the ship's hull construction. These mechanisms include structural deformation of the hull (especially if the bottom is hard or rocky); frictional resistance between the hull and the bottom material; displacement of the bottom material (particularly for heavy and strong-hulled ships moving in soft bottom material); or rigid-body motions of the ship, such as trim changes (the bow rises) or vertical translation (the entire ship moves up).

In the vicinity of Artificial Island, the bottom material is characterized as consisting "largely of silt-size materials,"[1] with a few areas of fine sand. For these types of generally soft materials, the probability of ship bottom deformation as a major energy absorption mechanism would be low. The energy involved in changes in the ship's trim is small compared to that involved in vertical translation, so trim changes can also be ignored. The determination of frictional coefficients and effective contact areas is difficult, so this mechanism will also be neglected, providing some additional conservatism to the analysis.

Therefore, the principal energy-absorbing mechanisms during a grounding, for the purposes of this analysis, are assumed to be lateral displacement of the bottom material and vertical rise of the ship. Each of these mechanisms will be considered separately, although both would be expected to occur to some degree.

B. SHIP CHARACTERISTICS

From an examination of the dimensions of a wide variety of ships, approximate relationships can be derived that relate the ship displacement, dimensions, and general shape factors.

For bulk carriers and general cargo ships, for example, reasonable relationships are:

$$D \simeq 1.25\ H^3$$

$$B/H \simeq 3.3$$

and $$L/H \simeq 20$$

where
D = displacement (tons)
H = draft (ft)
B = beam (ft)
L = length (ft)

Transit velocities of ships in the Delaware River channels are estimated to range from 10 knots for the smaller vessels to 5 knots for the largest vessels.

From these assumptions, the draft, beam, and kinetic energy of transiting ships can be estimated as a function of displacement, as tabulated below.

Displacement (tons)	Assumed Transit Velocity (knots)	Draft (ft)	Beam (ft)	Length (ft)	Kinetic Energy (ft - lbs)
2,000	10	12	39	240	20×10^6
5,000	9	16	52	320	40×10^6
10,000	8	20	66	400	84×10^6
20,000	7	25	83	500	97×10^6
40,000	6	32	105	640	143×10^6
80,000	5	40	132	800	200×10^6

Ships smaller than 2000 tons are not considered, since their drafts are generally smaller than the water depths of interest.

C. RIVER BATHYMETRY

The rate at which the kinetic energy of the ship is absorbed by either bottom material displacement or by vertical rise will depend upon the bathymetry, or the topography of the bottom, and expecially of the slope of the bottom. Typical bottom profiles from the site of the proposed water intake structure to the channel along several rays, obtained from References 2 and 3, are plotted on Figure A-5. (Note that these curves are referenced

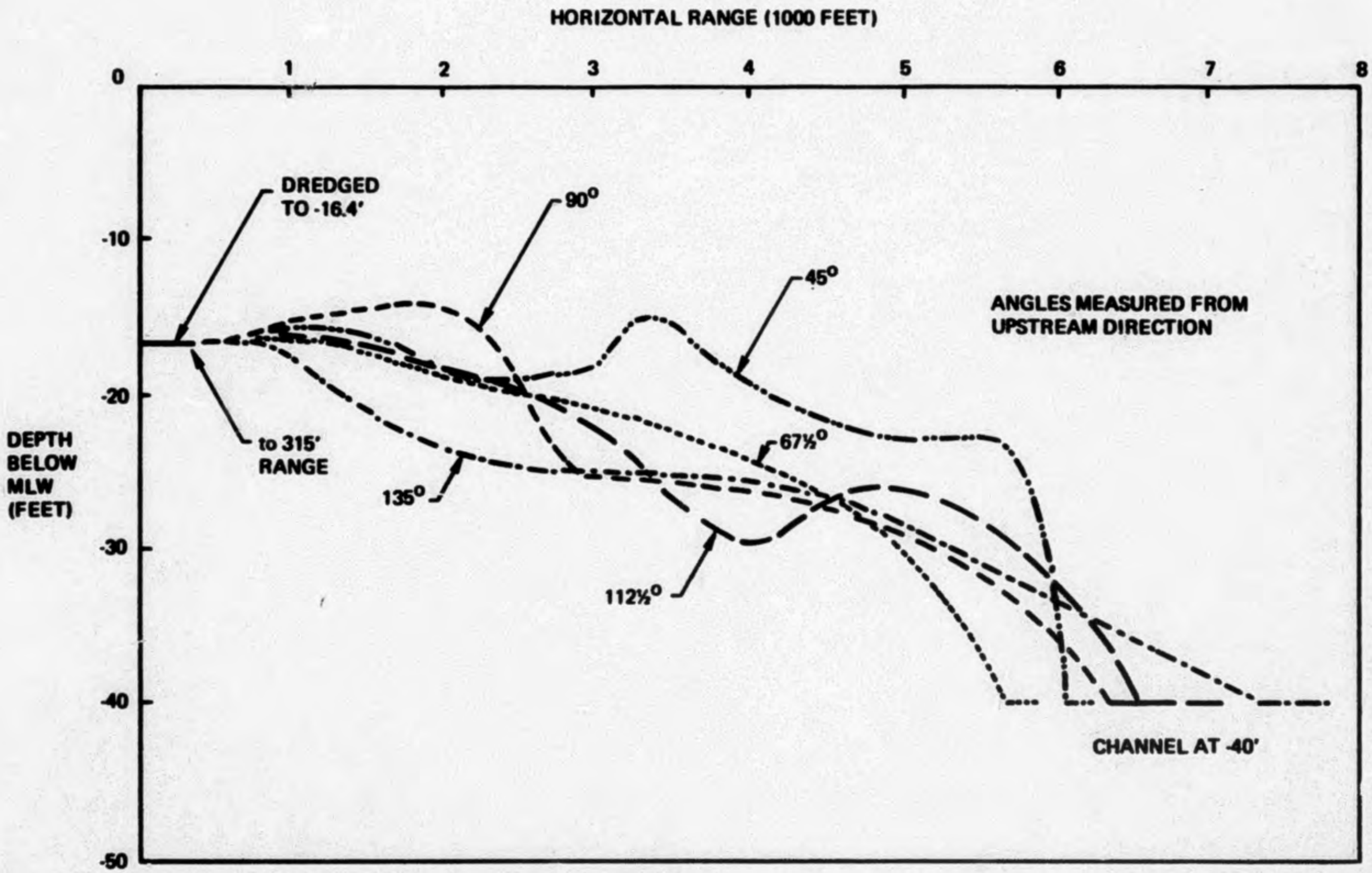

HORIZONTAL RANGE (1000 FEET)
0
1
2
3
4
5
6
7
8
-10
-20
-30
-40
-50
DEPTH
BELOW
MLW
(FEET)
DREDGED
TO -16.4'
to 315'
RANGE
90°
45°
67½°
135°
112½°
ANGLES MEASURED FROM
UPSTREAM DIRECTION
CHANNEL AT -40'

FIGURE A-5.

to the mean low water level, which is 2.6 feet below mean sea level.) The somewhat erratic slopes are not an unusual characteristic of shoaling areas.

An average constant slope may be calculated as

$$s \simeq \frac{40 - 16.4}{6000 - 315} = 0.0042 \text{ ft/ft}$$

Use of an average value of the bottom slope in grounding analyses is generally conservative, because the actual slope near the channel is considerably greater than the average slope, and most ray directions have bottom mounds which could be particularly effective in resisting on-coming ships.

D. GROUNDING BY VERTICAL TRANSLATION

Under this assumption, the kinetic energy of the on-coming ship is assumed to be converted entirely to raising the ship as a rigid body (i.e., conversion of the kinetic energy to potential energy). It is assumed that the ship, upon initial impact with the bottom, has reduced its forward power to zero, i.e., the engines have been stopped, so the total forward thrust is due to the kinetic energy available at the initial impact.

For this case, the calculation is simply: Kinetic Energy = Potential Energy.

$$\frac{1}{2} mv^2 = mgh$$

where: h = vertical rise = sd

s = bottom slope

d = transit length in grounding

Thus $d = v^2/2gs$, loading to the following results:

Displacement (tons)	d (ft)	d/L
2,000	1060	4.4
5,000	850	2.7
10,000	680	1.7
20,000	520	1.0
40,000	380	0.60
80,000	280	0.33

E. GROUNDING BY DISPLACEMENT OF BOTTOM MATERIAL

Under this assumption, the kinetic energy of the on-coming ship is dissipated by lateral displacement of the bottom material. Figure A-6 illustrates the energy balance.

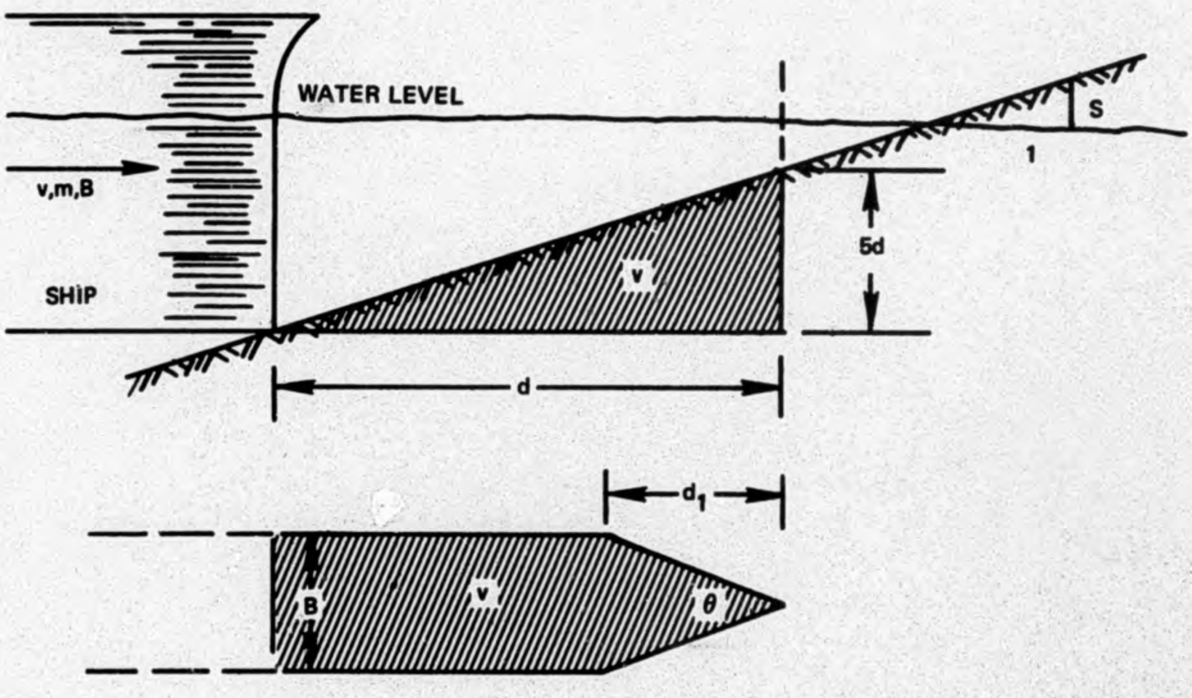


FIGURE A-6. ENERGY BALANCE: GROUNDING BY DISPLACEMENT BOTTOM MATERIAL

The energy balance for this case can be established as follows:

Let e = work required per unit volume of bottom material

= $\rho . x$

where:

ρ = weight density of bottom material

x = average distance of lateral displacement of bottom material

= $B/4$ for $d \geq d_1$

= $B/8$ for bow portion of ship

d = grounding transit length

s = bottom slope

B = beam of ship

θ = bow angle of ship

d_1 = length of bow portion of ship

= $B/2 \cot \theta/2$

V = total volume of bottom material displaced

or

$$V = \frac{sBd_1^2}{6} + \frac{sBd_1}{2} (d - d_1) + \frac{sB}{2}(d - d_1)^2$$

or the energy,

$$e.V = \rho \frac{B}{8}\left[\frac{sBd_1^2}{6} + \frac{sBd_1}{2} (d - d_1)\right] + \rho \frac{B}{4}\left[\frac{sB}{2}(d - d_1)^2\right]$$

which reduces to;

$$e.V = \frac{s\rho B^2}{8}\left[d^2 - 1.5\, d_1 d + \frac{2}{3} d_1^2\right]$$

A typical value for θ is 40 degrees. Thus, $d_1 = 1.37$ B. Letting the slope $s = .0042$, as calculated previously, and the density $\rho \simeq 100$ lb/ft^3, leads to:

$$e.V = .0525\, B^2 \left[d^2 - 2.1\, Bd + 1.25\, B^2\right]$$

This expression can be equated to the kinetic energy to obtain the grounding transit length. The values obtained in this manner are tabulated below:

Displacement	d (ft)	d/L
2,000	541	2.3
5,000	585	1.8
10,000	598	1.5
20,000	619	1.2
40,000	606	0.95
80,000	603	0.75

F. CONCLUSIONS

From these simplified and conservative analyses of grounding collisions, it can be concluded that the typical grounding transit length is a few hundred to a thousand feet, or the same order of magnitude as the length of transiting ships. This conclusion is consistent with the observation that grounding lengths are typically equal to or less then a ship length. Noting that the average distance from the Delaware River channels (Baker Range, Liston Range) to the proposed location of the water intake structure is about 6000 feet, it should be generally true that ships with drafts greater than a few feet more than the intake structure depth will ground before reaching the intake structure and therefore will not present a potential hazard to this structure by ramming.

REFERENCES FOR APPENDIX 4

(1) *Long Range Spill Disposal Study. Part 1: General Data for the Delaware River,* U.S. Corps of Engineers (no date).

(2) Nautical Chart, Delaware River, Smyrna River to Wilmington. C&GS 294 22nd Edition, November 17, 1973

(3) Hope Creek Generating Station, Site Topography. Prepared by T&A Assoc. Inc. South Plainfield, NJ (no date).

APPENDIX 5

ENERGY AVAILABLE FOR RAMMING COLLISIONS

A. INTRODUCTION

The kinetic energy available in a ramming collision of the service water intake structure by a ship will depend on the velocity and size (displacement) of the ship at the time of collision. The sizes of the ships which will present ramming hazards will depend at any given time on the tidal conditions, while the ramming velocities will, at most, be equal to the normal transiting velocities associated with ships of a given size.

B. TIDAL DATA

The tides in the Delaware River are semi-diurnal with little difference between the rises and falls. At Artificial Island, the tide height time-history is approximately sinusoidal with the duration of rise only slightly less than the duration of fall.[1] The tidal cycle is approximately 12-1/2 hours, so there are about 700 tides per year.

Tidal statistical data in terms of standard levels are given below with their referenced sources. All levels are referenced to mean sea level as zero. (The Corps of Engineers datum for the Delaware is 2.9 feet below MSL.)

Maximum credible high high water[2]	+ 33.0 ft
Flood protection level[3]	+ 25.4 ft
High high water (November 1950)[2,3]	8.5 ft
Mean high water (average height of all high waters)[2,3]	3.2 ft
Mean tide	0.3 ft
Mean sea level	0 ft
Mean low water (average height of all low water)[2,3]	- 2.6 ft
Low low water (January 1939)[3]	- 5.9 ft
Lowest projected low water[2,3]	- 8.0 ft
Design low low water[2,3]	- 10.6 ft

The normal daily tidal range at Artificial Island is 3.2 + 2.6 = 5.8 ft, while the maximum tidal range, of recorded floor and low water conditions, is 8.5 + 5.9 = 14.4 feet.

The minimum depth in the channel ranges near Artificial Island is - 42.6 ft re: MSL, and the bottom elevation of the proposed water intake structure is - 19.0 feet.

C. MAXIMUM SHIP SIZES AND IMPACT ENERGY LEVELS

At mean sea level conditions, the water depth at the intake structure is 19 feet. The largest ship which could reach the intake structure without grounding is, according to the displacement-draft relationship given in Appendix 4, equal to $1.25\ (19)^3 = 8600$ tons. With an assumed transit velocity of eight knots, the total kinetic energy at impact would be equal to 55×10^6 ft-lb. Similar calculations carried out for each of the tidal conditions given previously lead to the following tabulation:

Tidal Condition	Maximum Ship Displacement (tons)	Assumed Maximum Velocity (knots)	Kinetic Energy (ft-lb)
Maximum Credible HHW	125,000	4	200×10^6
Flood Protection Level	110,000	4	175×10^6
HHW	26,000	6	93×10^6
MHW	13,600	7	66×10^6
MT	9,000	8	57×10^6
MSL	8,600	8	55×10^6
MLW	5,500	9	44×10^6
LLW	2,800	10	28×10^6
Lowest Projected LW	1,700	10	17×10^6
Design LLW	740	12	11×10^6

Note that for more than 99 percent of the time, the tidal level will be within, say, four feet of MSL, with the corresponding kinetic energy in the 40×10^6 to 80×10^6 ft-lb range. The extreme values, leading to kinetic energy in the 200×10^6 ft-lb range, correspond to postulated hurricane conditions occurring once in 1000 years.

APPENDIX 6

BLOCKING OF WATER INTAKE STRUCTURE

A. PROBLEM STATEMENT

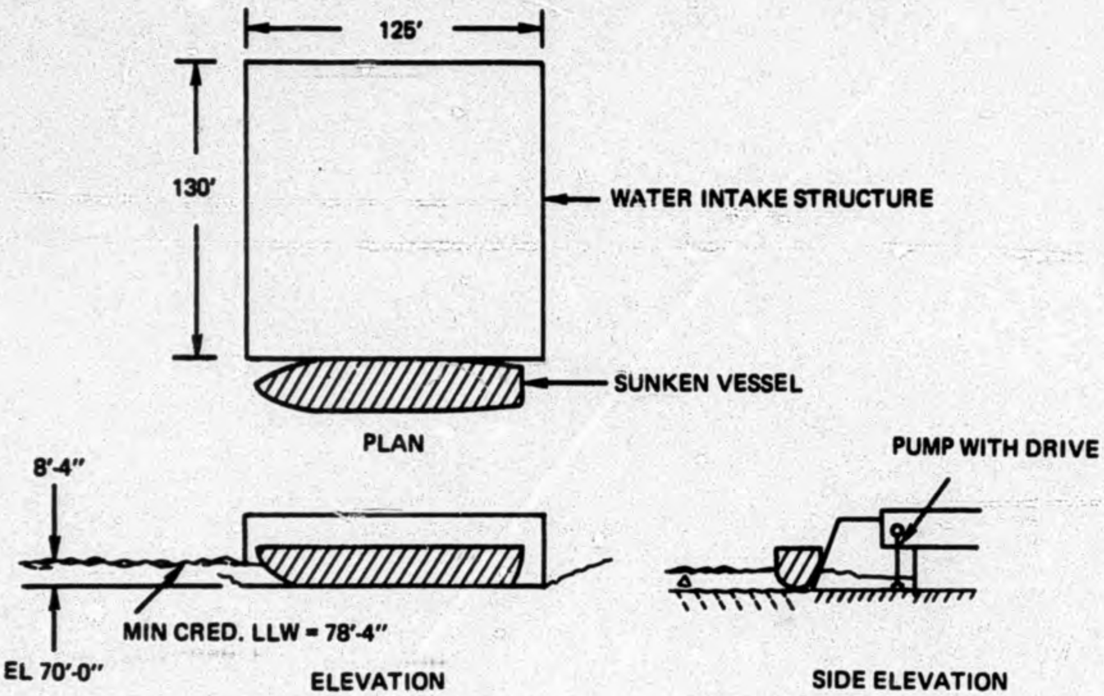
Safe operation of the power plant requires that the service water pumps deliver the required flow rate set by the specified operating mode. Blockage of the water intake structure by a sunken vessel restricts the normal access of water to the pump inlet; that is, it increases the difference between the level of the water in the river and the level of water in the sump provided for the pumps by this structure. Accordingly, the head available to the pumps is decreased by an amount that depends on the degree of blockage presented by a sunken vessel. A real hazard exists if the blockage is sufficient to reduce the head available to the service water pumps to a point below the net positive suction head (NPSH) requirements of the pumps. If the NPSH requirements of the pumps are not met, they will cavitate with a resulting immediate and sharp decrease in water rate, accompanied by pulsations in flow and possible destructive damage to the pump because of bearing failure or cavitation erosion following sometime thereafter. Therefore, a reasonable criterion for safe operation is set by the maximum tolerable blockage limit, which is that blockage of the intake structure that just reduces the head available to the pumps to their NPSH requirement when the river is at its minimum credible low low water mark.

One criterion for safe operation under blockage conditions is plant shutdown in the LOCA mode. This criterion sets the minimum tolerable safe flow rate for the plant and sets the maximum tolerable blockage. Shutdown of the plant in the LOCA operational mode specifies that two of the eight pumps deliver 15,000 GPM each for a total of 30,000 GPM.

Another criterion can be set for continuous safe operation of the plant. To meet this requirement requires that each of eight service water pumps deliver their normal design flow rate of 10,875 GPM for a total of 87,000 GPM under blockage conditions. The latter criterion sets a maximum tolerable blockage that is less than that for safe shutdown.

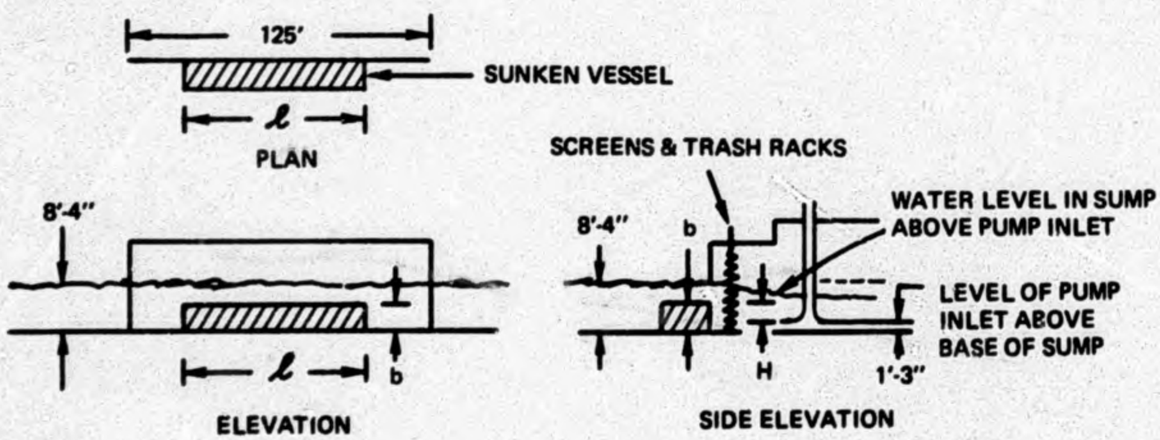
B. SYSTEM UNDER CONSIDERATION

Intake Structure with Vessel Blockage



C. MODEL SYSTEM FOR ANALYSIS

We consider the system appearing below as a simplified model of that illustrated in Section B. This simplified model is constructed to serve the purposes of fluid flow analysis which is fundamental to the solution of the problem as stated in Section A.



The cross-hatched area shown in elevation is an area assumed to be completely impervious to flow as a result of blockage.

D. ANALYSIS

Let the flow into the pump sump provided by the water intake structure be designated by Q_1. Let the minimum flow rate for safe operation of the plant be Q_2, determined by the safe operation criterion. Let the river level above the elevation of the floor of the pump sump be 8' 4", corresponding to the minimum credible low low water level. The level of the plane of the inlet bell of the pumps above the floor of the pump-sump is 1' 3". Let the water level in the sump in the vicinity of the pumps be designated by H. Let the drop in water level from that of the river to that immediately above the pumps be designated by h. Let the required net positive suction head requirement for the pumps be designated by NPSH.

Now for safe operation:

$Q_1 = Q_2$

$H + (1 \text{ atmo.}) = NPSH$

$$H + 33.9 = NPSH\,(ft - H_2O) \qquad (1)$$

By definition:

$h + H = 8.33 - 1.25 = 7.1$ (ft)

or $$H = 7.1 - h \qquad (2)$$

Combining equations 1 and 2, and criteria established in Section A, we get

$h < 41.0 - NPSH$ (ft)

$Q_1 = Q_2 = 30{,}000$ GPM (safe plant shutdown)

$Q_1 = Q_2 = 87{,}000$ GPM (safe plant operation)

An accurate evaluation of the relationship between the flow rate of water by the blockage and into the sump provided by the water intake structure depends on the difference between the water level in the river and that in the sump in the region of the pump inlet is not purely analytical means. However, useful estimates can be derived on the following bases which are believed to be reasonable:

1) Under normal plant operation, the flow restrictions produced by the screens and trash racks result in a negligible loss in head.

2) Under normal plant operation, the head loss, h, at the pump inlet is caused largely by the confinement presented by the cellular bays in which the pumps are mounted in couples. This loss is established by specification of the minimum value of H, equal to 4.75 ft. Therefore, h = 7.10 - 4.75 = 2.35 ft under normal operating conditions.

3) Because no firm data on the NPSH requirements of the service water pumps are available at this time, assume

$NPSH = 33.9 + H_{min}$

$H_{min} = 2.75$ ft

or $NPSH = 36.7$ ft

and $h_{max} = 41.0 - 36.7 = 4.30$ ft

4) In general, with blockage of the intake structure, the relationship between the flow rate to the pumps and the total head loss, h, can be expressed by equations which model the system as two flow restrictions in series. One restriction is at the face of the inlet structure caused by a sunken vessel; the other is the normal restriction whose major element is described in item 2) above. The relationship between the water flow rate and the head loss due to each of these restrictions can be expressed in the form of an orifice or weir equation, as follows:

$$Q = Q_1 = Q_2$$

$$Q = C_1 A_1 \sqrt{2 g h_1} \qquad (3)$$

$$Q = C_2 \sqrt{2 g h_2} \qquad (4)$$

$$h = h_1 + h_2 \qquad (5)$$

where:

C_1 = flow coefficient associated with flow around blockage. Assume $C_1 = 0.5$

A_1 = free flow area around blockage at intake structure.

C_2 = effective area of equivalent orifice that produces specified head loss at pumps under normal operation.

h_1 = head loss due to blockage.

h_2 = head loss due to normal restriction because of confinement of pumps within bays.

5) Inherent to the criterion for safe shutdown, it is assumed that only two pumps within two diffferent bays are operating. If all pumps were operating and the blockage of the inlet structure was the maximum tolerable based on two-pump operation, it is certain that they all would cavitate. Under these conditions they might still provide the minimum flow rate for shutdown in the LOCA mode, but operation with pump cavitation is taken to be intolerable. Moreover, the value of C_2 is assumed to be unchanged under conditions of only two of eight pumps operating.

On the basis of items 1) and 2) above, under normal operation, $h_1 \cong 0$, $h_2 = 2.35$ ft. Also Q = 87,000 FPM = 193.9 ft³ /sec. Therefore, from equation 4, $C_2 = 15.76\ ft^2$. This value of C_2 is appropriate to eight-pump normal operation.

Following the methods and assumptions outlined above, the minimum tolerable free-flow area for safe continuous plant operation is calculated as follows:

$$h_1 = h_{max} - h_2 = 4.30 - 2.35 = 1.95\ ft$$

$$A_1 = \frac{Q}{C_1\sqrt{2gh_1}} = \frac{193.9}{0.5\sqrt{64.6\,(1.95)}} = 34.6\ ft^2$$

As the total unblocked cross sectional area available for flow at the minimum credible low low water level is 125 x 8.33 = 1041 ft², the maximum tolerable blockage factor for safe continuous plant operation is

$$\frac{1041 - 34.6}{1041} = 0.967$$

The value of C_2 appropriate to two-pump operation in the LOCA mode is calculated on the basis: $h_1 \cong 0, h_2 = 2.35$ ft,* and Q = 30,000 GPM = 66.9 ft³/sec. The result is $C_2 = 5.43\ ft^2$.

The minimum tolerable free-flow area for safe shutdown in the LOCA operational mode is calculated as follows:

---

*The local head loss, h_2, is assumed to be equal to that at normal operation. In LOCA shutdown the local flows are higher because of the increase in pump flow rate from 10,875 to 15,000 GPM. This, by itself would result in a larger value of h_2. However, this increase will be offset to some degree by the fact that only two of eight pumps are operating. The assumption is that these two counter effects on head loss exactly cancel.

$$h_2 = 2.35 \text{ ft}$$

$$h_1 = 1.95 \text{ ft}$$

$$A_1 = \frac{669}{0.5\sqrt{64.4(1.95)}} = 11.9 \text{ ft}^2$$

And the maximum tolerable blockage factor is

$$\frac{1041 - 11.9}{1041} = 0.989$$

APPENDIX 7

EFFECT OF FIRE ON INTAKE STRUCTURE

The ignition of flammable liquid close to the intake structure may expose the reinforced concrete structure to an intense fire for a short period of time. In such a situation, the possibility that the reinforced concrete structure will fail in a massive sense, effectively blocking the water inflow by debris, may be considered.

The high degree of fire resistance of reinforced concrete construction has been established by extensive series of fire tests and by the results and experience of actual fires. The tests have been concerned primarily with the performance of the reinforced concrete as a load-bearing material during the fire; from such tests, it has been determined that the concrete strength is characterized primarily by the strength of the steel reinforcement, which decreases with increasing temperature. The temperature attained by the steel during fire exposure is determined by the thermal conductivity of the covering concrete and the amount of this cover. For normal weight concrete, a fire exposure of one hour will raise the steel temperature to approximately 850°F with a one-inch cover, or to approximately 500°F with a two-inch cover.(1) At these temperatures, the strength of the steel will be equal to approximately 80% and 90%, respectively, of the basic strength measured at 70°F.

These results were obtained from standard fire tests in which the test specimens are subjected to a fire controlled by a standard time-temperature curve, in accordance with NFPA No. 251 or ASTM E119. This standard curve has a rapid increase, to 1550°F, during the initial 30 minutes of the test, and a slower rate, to 1700°F, at the one hour followed by a linear increase to 2300°F at eight hours.

Since the design of reinforced concrete structures, in compliance with standard codes of the American Concrete Institute,(2,3) and according to the design specifications of waterway structures established by the Corps of Engineers,(4,5) is based on conservative factors of safety, this magnitude of loss in strength does not constitute a structural failure hazard.

It is noted that the structural design of the service water intake structure prepared for the Hope Creek Generating Station, like that of the adjacent Salem Station, is composed of relatively massive concrete slab structures, most of which are two or three feet thick, with

the reinforcement cover generally equal to two or three inches. For such structural configurations, therefore, the fire resistance would be expected to be substantially in excess of one hour. Thus, for the types and potential quantities of spilled and ignited material of interest in this study, the effect of the postulated fires would not be expected to produce any significant change in the structural integrity of the intake structure.

Another potential result of fire exposure upon reinforced concrete is spalling, in which portions of the concrete cover break off because of thermal gradients, high restraint conditions, or high levels of free moisture within the concrete. For waterways structures, the free moisture in the concrete would be expected to be relatively high, so vaporization of this water upon heating could spall the surface concrete layer, particularly if the concrete porosity and permeability are low and the time of exposure to the fire is relatively long.(6) The gross effects of such spalling, however, would not create a hazard to the structural integrity of the service water intake structure itself, nor could the spalling be extensive enough to block the intake. However, the concrete surface probably would have to be patched.

REFERENCES FOR APPENDIX 7

(1) Gibbons, A. T., "Some Aspects of Structural Fire Endurance of Concrete," presented at Second Annual Fire Protection Seminar, Montreal-Ottawa Chapter of SFPE, May 5, 1969.

(2) "Building Code Requirements for Reinforced Concrete," American Concrete Institute ACI 318-63, 1963.

(3) "Specification for Structural Concrete for Buildings," American Concrete Institute ACI 301-66, 1967.

(4) "Planning and Design of Navigation Lock Walls and Appurtenances," Corps of Engineers EM-1110-2-26-2, 30 June 1960.

(5) "Structural Design of Spillways and Outlet Works," Corps of Engineers EM-1110-2-2400, 2 November 1964.

(6) Lie, T. T., *Fire in Buildings*, Applied Science Publishers Ltd., London, 1972.

APPENDIX 8

ANALYSIS OF "WATERBORNE COMMERCE" DATA FOR DELAWARE RIVER IN 1972

In this appendix we explain the method used to determine how much of each of traffic type actually passed Artificial Island. Table A-4, which is based on the criteria for each of the categories of traffic, covers the 13 commodities which can be considered hazardous and for which volumes of over 300,000 tons were moving in the Delaware River in 1972.

A. FOREIGN IMPORTS (All less one-half of eastbound canal traffic)

Foreign imports can arrive

(1) direct from the sea, or

(2) through the Chesapeake and Delaware Canal.

It can be assumed that all the traffic coming from the sea passes Artificial Island, the exception being the crude that is discharged into lighters, which allows tankers to proceed up river with a partial cargo. The cargo traveling in the tankers is included in this category, but the cargo in the barges is apparently classified as internal traffic. Traffic moving through the canal, termed "Foreign Eastbound," either can be for Delaware River port discharge or can be through traffic going to the sea. For this reason, we take foreign import traffic passing Artificial Island to be the total less one-half of the eastbound foreign canal traffic as reported in the *Waterborne Statistics.*

B. FOREIGN EXPORTS (All less one-half of westbound canal traffic)

Foreign exports can leave

(1) direct to the sea, or

(2) through the canal.

It can be assumed that all of the traffic proceeding directly to the sea passes Artificial Island because refineries, chemical plants, etc., are generally situated north of that site. The same reasoning applies to canal traffic as to foreign imports – foreign westbound cargo, as reported in the *Waterborne Statistics*, either could be originating in the Delaware River area or could be through traffic coming from seaward. For this reason, we have taken foreign

TABLE A-4

CALCULATION OF TRAFFIC PASSING ARTIFICIAL ISLAND DURING 1972 IN MILLIONS OF SHORT TONS

CATEGORY OF TRAFFIC / HAZARDOUS COMMODITIES →	Crude Petroleum	Liquid Sulfur	Benzene and Toluene	Sulfuric Acid	Basic Chemicals & Products	Gasoline	Jet Fuel	Kerosene	Distillate Fuel Oil	Residual Fuel Oil	Lubricating Oils and Greases	Naphtha	Asphalt, Tars and Pitches	TOTAL
Foreign Imports	34.3	-	-	-	0.1	-	-	0.1	-	6.3	-	-	-	40.8
Foreign Exports	-	-	-	-	0.1	-	-	-	-	0.2	0.2	-	-	0.5
Foreign Through Upbound	0.6	-	-	-	0.1	-	-	0.2	-	1.3	-	-	-	2.2
Subtotal Foreign Traffic Upbound	34.9	-	-	-	0.2	-	-	0.3	-	7.6	-	-	-	43.0
Subtotal Foreign Traffic Downbound	-	-	-	-	0.1	-	-	-	-	0.2	0.2	-	-	0.5
Subtotal All Foreign Traffic	34.9	-	-	-	0.3	-	-	0.3	-	7.8	0.2	-	-	43.5
Domestic Coastwise Receipts	11.5	0.2	0.2	0.1	0.4	2.0	0.1	-	3.9	3.8	0.3	0.2	-	22.7
Domestic Coastwise Shipments	-	-	-	-	-	3.6	-	0.1	1.7	1.0	0.4	-	0.1	6.9
(Less One Half Westbound Canal Traffic)	-	-	-	-	-	(0.1)	-	-	-	-	-	-	(0.3)*	(0.4)
Domestic Coastwise Through Upbound	0.3	-	-	-	-	0.3	-	-	0.1	0.3	0.2	0.1	0.5	1.8
Domestic Coastwise Through Downbound	-	-	-	-	-	1.1	0.1	-	0.7	-	-	-	0.4	2.3
Subtotal Domestic Coastwise Upbound	11.8	0.2	0.2	0.1	0.4	2.3	0.1	-	4.0	4.1	0.5	0.3	0.5	24.5
Subtotal Domestic Coastwise Downbound	-	-	-	-	-	4.6	0.1	0.1	2.4	1.0	0.4	-	0.2	8.8
Subtotal All Domestic Coastwise Traffic	11.8	0.2	0.2	0.1	0.4	6.9	0.2	0.1	6.4	5.1	0.9	0.3	0.7	33.3
10% Internal Inbound Downbound	-	-	-	-	-	-	-	-	-	0.1	-	-	-	0.1
Internal Outbound Upbound All Crude & 10% Other Traffic	0.8	-	-	-	-	0.1	-	-	0.1	0.1	-	-	-	1.1
Internal Upbound All Crude & 10% Other Traffic	4.0	-	-	-	-	-	-	-	0.1	0.4	-	-	-	4.5
10% Internal Downbound	0.1	-	-	-	-	-	-	-	-	0.2	-	-	-	0.3
Subtotal Internal Upbound Traffic	4.8	-	-	-	-	0.1	-	-	0.2	0.5	-	-	-	5.6
Subtotal Internal Downbound Traffic	0.1	-	-	-	-	-	-	-	-	0.3	-	-	-	0.4
Subtotal All Internal Traffic	4.9	-	-	-	-	0.1	-	-	0.2	0.8	-	-	-	6.0
TOTAL ALL UPBOUND TRAFFIC	51.5	0.2	0.2	0.1	0.6	2.4	0.1	0.3	4.2	12.2	0.5	0.3	0.5	73.1
TOTAL ALL DOWNBOUND TRAFFIC	0.1	-	-	-	0.1	4.6	0.1	0.1	2.4	1.5	0.6	-	0.2	9.7
TOTAL ALL TRAFFIC	51.6	0.2	0.2	0.1	0.7	7.0	0.2	0.4	6.6	13.7	1.1	0.3	0.7	82.8

*Deducted from Coastwise Shipments and Domestic Coastwise Through Downbound to arrive at Downbound Traffic.

Arthur D Little Inc

export cargo passing Artificial Island to be all of that reported in the *Waterborne Statistics* less one-half of the westbound foreign canal traffic.

C. FOREIGN THROUGH TRAFFIC (All upbound and downbound)

This can be taken to mean traffic from and to the sea passing through the Chesapeake and Delaware Canal and also traffic to and from the sea destined for areas classified as non-Delaware River inland waterways. It appears that the Schuylkill River is included in this latter category. All upbound and downbound foreign through traffic has been included.

D. DOMESTIC COASTWISE RECEIPTS (All less one-half of eastbound canal traffic)

These cargos can arrive

(1) direct from the sea, or

(2) through the canal.

Some domestic receipts are probably dropped off south of the catchment area, that is, south of Artificial Island, but probably only a small amount. And only a small amount would pass the Artificial Island area if arriving through the Chesapeake and Delaware Canal. We have assumed that coastwise receipts passing the Artificial Island area consist of all traffic as reported under that heading less one half of eastbound canal traffic. This latter deduction follows the same reasoning as for foreign imports and exports – that traffic through the canal labeled coastwise could be destined either for the Delaware River system or for coastwise destinations necessitating passage through the Delaware River to proceed to sea.

E. DOMESTIC COASTWISE SHIPMENT (All less one-half of westbound domestic coastwise canal traffic)

This traffic can leave

(1) direct to sea, or

(2) through the Chesapeake and Delaware Canal.

Most of the traffic moving directly to sea would pass Artificial Island, but practically none of that passing through the canal would. We have used the same technique for calculating domestic coastwise shipments passing Artificial Island as in the three previous cases. That is, we took all of the traffic listed under this category and subtracted one-half of westbound domestic coastwise canal traffic.

F. DOMESTIC COASTWISE UPBOUND THROUGH TRAFFIC (All)

This traffic can be

(1) traffic from the sea passing westbound through the canal;

(2) traffic from the sea destined for inland waterways adjoining the Delaware River other than the Schuylkill River if this is so classified; or

(3) traffic eastbound through the canal proceeding north along the Delaware River.

Only the latter category would not pass Artificial Island and because it is not possible to identify through traffic from canal statistics, all of this category has been taken to be passing the Artificial Island area.

G. DOMESTIC COASTWISE DOWNWARD THROUGH TRAFFIC (All)

This traffic can be

(1) from the canal proceeding to sea by way of the Delaware River;

(2) from points north of the canal outside the Delaware River system and proceeding to sea;

(3) as for (2) but proceeding through the canal.

The only portion not passing Artificial Island would be the latter and using similar reasoning to that given for upbound traffic of this nature, all cargos reported as domestic coastwise downward through are taken as passing Artificial Island.

H. INTERNAL INBOUND UPBOUND (None)

This is traffic coming from another inland waterway, proceeding to a destination in the Delaware River system, and proceeding upstream. This can be arriving

(1) via the Chesapeake and Delaware Canal, or

(2) via other waterways.

There are no waterways below Artificial Island; thus no traffic of this category would pass through the catchment area.

I. INTERNAL INBOUND DOWNBOUND (10%)

This is traffic coming from another internal waterway for destinations on the Delaware River system, proceeding in a downstream direction. The traffic can be arriving

(1) from the Delaware and Chesapeake Canal, or

(2) from other waterways.

Some traffic could be expected to be passing Artificial Island but probably this is only a very small amount; most will be destined for areas north of Artificial Island. As a liberal estimate, 10% of that movement listed in this category is taken to pass Artificial Island.

J. INTERNAL OUTBOUND UPBOUND (All crude petroleum and 10% of other hazardous cargos)

This cargo originates in the Delaware River system and is proceeding to another inland waterway moving in an upstream direction. It can be proceeding

(1) to the Delaware and Chesapeake Canal, or

(2) to another inland waterway which would be north of the canal.

This category probably includes the barge traffic from the lower Delaware Bay area that is unloaded from tankers to permit those vessels to proceed up river in lighter condition, but it is unlikely to include refined products, for these commodities will be originating from refineries which are located above Artificial Island. We have taken all crude in this category but only 10% (a liberal estimate) of other hazardous commodities.

K. INTERNAL OUTBOUND DOWNBOUND (10%)

This is traffic originating in the Delaware River system destined for another inland waterway and moving in a downstream direction. None of this traffic would be passing Artificial Island.

L. INTERNAL UPBOUND (All crude petroleum and 10% of other hazardous cargos)

This is traffic originating in the Delaware River system, proceeding in an upstream direction to a destination within the system. This would include crude in barges discharged from tankers in the lower Delaware Bay area, but only a very small proportion of other traffic because there does not seem to be much industrial activity below Artificial Island or any major port facilities. We have, therefore, taken all of the crude listed in this category but only 10% of other hazardous commodities. Again this latter estimate should be considered to be rather liberal.

M. INTERNAL DOWNBOUND (10%)

This is traffic originating within the Delaware River system, proceeding downstream to a destination within the system. There is probably not much moving past Artificial Island

and what there is would mostly be products distributed to small population centers at the seaward end of the Delaware River. A very liberal estimate would be 10% of traffic in this category.

N. INTERNAL UPBOUND AND DOWNBOUND THROUGH (None)

This is traffic moving from one inland waterway to another passing through the Delaware River system, moving in both upstream and downstream directions. None of this would pass Artificial Island.

O.

Table A-4 shows for each of the 13 hazardous commodities, by category of traffic, the cargo in millions of short tons estimated to be passing Artificial Island discharged or loaded in the Delaware River area or passing through that area. Foreign, domestic, and internal traffic have been separately identified. We have also separated out upbound and downbound traffic. The justification for amounts of traffic estimated in each category were given previously in this appendix. We shall now discuss some points of detail.

Crude petroleum accounts for slightly over 62% of all estimated hazardous traffic passing Artificial Island. Direct foreign imports, that is, imports remaining within the tanker, account for almost 35 million tons. Six hundred thousand tons of these appear to be discharged on an inland waterway outside of the Delaware River system. Because westbound and eastbound crude petroleum movements through the Chesapeake and Delaware Canal total something less than 3,000 tons, it appears that these are moving to other areas, some possibly to the Schuylkill River. Three hundred and eighty-two thousand tons of crude petroleum foreign imports are reported for the Schuylkill River. "Domestic coastwise through upbound" crude petroleum, reported at 333,915 tons in the table "Trenton, New Jersey to the Sea," page 68, *Waterborne Commerce,* is also reported under Schuylkill River, page 76, *Waterborne Commerce,* under "coastwise receipts." This confirms that Schuylkill River is considered to be a separate inland waterway; the fact that the Schuylkill River does not account for all of the "foreign through upbound" crude petroleum traffic, however, indicates that other areas off the Delaware River system are also classified as inland waterways. For internal traffic, 800,000 tons are listed under "internal outbound upbound" and this also appears for the Schuylkill River under "domestic internal receipts," reinforcing our

argument that other inland waterways exist adjacent to the Delaware River system besides the Chesapeake and Delaware Canal. The internal traffic of that commodity was unloaded from tankers in the lower Delaware Bay area and barged up past Artificial Island, some of it going to refineries that are within the Delaware River system and the 800,000 tons to the Schuylkill River area. This should be considered to be barge traffic because it is the only known movement internally of crude and there is no crude oil production in that area. About 100,000 tons are indicated as being internal downbound traffic; it is not known from or to where this traffic is moving, but because of its small size it does not warrant any further investigation.

Most of the gasoline traffic is domestic coastwise, although in the section reporting "Trenton, New Jersey to the Sea," there is a substantial movement of gasoline classified as "internal;" most of this would not be passing Artificial Island, but would be distributed within the Delaware River system above Artificial Island. Owing to the apparent absence of major port facilities and large consumption centers to the south of Artificial Island, the previous comment can be considered as applying to all petroleum products. Apart from crude petroleum, the only other "internal" commodity in the hazardous category that moved in any significant quantity past Artificial Island in 1972 was residual fuel oil, in total an estimated 800,000 tons.

As explained previously in the appendix, one-half of canal traffic in some cases has been deducted from estimates in order to account for traffic that would be diverted and not passing Artificial Island, but exiting or entering the system via the Chesapeake and Delaware Canal. In the case of "asphalt, tar, and pitches" this deduction for domestic westbound canal traffic of 300,000 tons is larger than domestic coastwise shipments. The reason for this is that in the canal statistics it is not possible to separate out traffic which is destined for or originates in the Delaware River system from traffic that is passing through that system. If one adds to the domestic coastwise shipments, therefore, domestic coastwise through downbound traffic and then subtracts the estimate of one-half of the westbound canal traffic, the result will give us the domestic coastwise downbound traffic passing Artificial Island.

It can be seen that there is a noticeable imbalance between upbound total traffic of 73 million tons and downbound traffic of almost 10 million tons. Most of this is accounted for by the crude petroleum imports. The upbound traffic in residual fuel oil is also significantly greater than downbound traffic.

The calculations of traffic passing Artificial Island have been entirely deduced from the *Corps of Engineers Waterborne Commerce of the United States, 1972* and it is quite possible that further investigations will provide more information on traffic flows and clarify some of the movement for which a percentage estimate has had to be utilized. This is particularly so in the case of internal traffic. The supposition of the barge traffic, the identification of inland waterways systems apart from the Canal which are adjacent to the Delaware River system, and the possibility that some cargo is discharged in the Canal that is not considered to be Canal traffic (the tone miles estimated for the Chesapeake and Delaware Canal divided by the total tonnage indicated that all traffic reported for that inland waterway passed along its entire length) are cases in question.

"Eastbound foreign" and "westbound foreign" traffic through the Chesapeake and Delaware Canal were, for any of the commodities treated, less than 100,000 tons and so have not been deducted from "foreign imports" and "foreign exports," respectively. Similarly, "eastbound domestic coastwise" traffic was less than 100,000 tons and no deductions are made from "domestic coastwise receipts." "Foreign through downbound" traffic was less than 50,000 tons and so does not warrant consideration.

APPENDIX 9

SPILL STATISTICS FOR U.S. WATERS

1970 - 1972

The data in this appendix were furnished to A. D. Little, Inc., by the U.S. Coast Guard Headquarters in Washington, D.C. The information concerns spills of hazardous materials from vessels in U.S. waters for the period 1970-1972, in terms of the material spilled, its source, cause, volume and location. The selection of spills from the overall Coast Guard file was based on cause: collision, grounding or foundering.

TABLE A-5
TANK VESSEL ACCIDENTS
1970

MATERIAL	SOURCE	CAUSE	VOL.	STATE	WATER BODY
Crude	Tank barge	Collision	42 gal.	KY	Roadstead
	Tank ship	Collision	12,600 gal.	MS	Channel
	TOTAL	2	12,642 gal.		
DISTILLATE FUEL	Tank barge	Collision	1,500 gal.	LA	Bay
	Tank ship	Collision	16,800 gal.	CT	Dock
	Tank barge	Collision	1,000 gal.	OH	Roadstead
	Tank barge	Collision	42,000 gal.	KY	Roadstead
	Tank barge	Collision	27,500 gal.	MO	Dock
	Tank barge	Collision	84,000 gal.	FL	Port/harbor
	Tank barge	Collision	107,000 gal.	CA	Channel
	Tank barge	Collision	Unknown	CA	Bay
	Tank barge	Collision	4,000 gal.	TN	Roadstead
	TOTAL	9	283,000 gal.		

TABLE A-5 (Cont.)

Residual Fuel	Tank barge	Collision	2,100 gal.	NJ	Port/harbor
	Tank barge	Collision	134,000 gal.	NJ	Bay
	Tank barge	Collision	Unknown	MS	Channel
	Tank barge	Collision	71,000 gal.	TX	Offshore (1 mi.)
	Tank barge	Collision	Unknown	LA	Channel
	Tank barge	Collision	Unknown	LA	Coastal
	TOTAL	6	207,100 gal.		
ANY GAS OR VAPOR	Tank barge	Collision	750 gal.	TX	Channel
UNKNOWN	Tank ship	Collision	Unknown	FL	Bay
	Tank ship	Collision	Unknown	DE	Channel

TABLE A-6
TANK VESSEL ACCIDENTS
1971

MATERIAL	SOURCE	CAUSE	VOL.	STATE	WATER BODY
GRADE B FLAMMABLE (GASOLINE)	Tank barge	Collision	5,000 gal.	VT	Roadstead
	Tank barge	Collision	12,600 gal.	IL	River
	Tank barge	Collision	100 gal.	IL	River
	Tank barge	Collision	30 gal.	IL	River
	Tank barge	Grounding	100 gal.	FL	River
	Tank barge	Grounding	Unknown	NY	Channel
	Tank barge	Grounding	Unknown	CT	River
	Tank barge	Collision	10,500 gal.	KY	River
	Tank barge	Grounding	21,000 gal.	AR	River
	Tank barge	Collision	75,000 gal.	AR	Bay
	Tank ship	Grounding	5,000 gal.	AK	Bay
	Tank ship	Grounding	Unknown	NY	Port
	Tank barge	Collision	50 gal.	MO	Terminal
	Tank barge	Collision	10,000 gal.	NY	River
	Tank barge	Collision	16,000 gal.	MN	River
	TOTAL	15	155,380 gal.		

TABLE A-6 (Cont.)

MATERIAL	SOURCE	CAUSE	VOL.	STATE	WATER BODY
GRADE C FLAMMABLE	Tank barge	Grounding	1,000 gal.	WV	River
	Tank barge	Collision	420 gal.	KY	Dock
	Tank ship	Grounding	20 gal.	AK	Dock
	Tank ship	Sink/Founder	40 gal.	AR	River
	Tank ship	Sink/Founder	200 gal.	TN	Port
	Tank ship	Grounding	Unknown	CA	Bay
	Tank barge	Grounding	168 gal.	TX	River
	Tank barge	Collision	300 gal.	TX	Bay
	Tank barge	Collision	Unknown	TX	Port/harbor
	Tank barge	Collision	840 gal.	LA	River
	Tank barge	Collision	84 gal.	LA	Channel
	Tank barge	Sink/Founder	Unknown	LA	Bay
	Tank barge	Collision	Unknown	LA	Channel
	TOTAL	13	3,072 gal.		
GRADE D	Tank barge	Grounding	5,900 gal.	KY	Dock
	Tank ship	Grounding	386,000 gal.	CT	Port/harbor
	Tank barge	Sink/Founder	15 gal.	TX	Channel

TABLE A-6 (Cont.)

MATERIAL	SOURCE	CAUSE	VOL.	STATE	WATER BODY
	Tank ship	Grounding	Unknown	NY	Channel
LIGHT FLASH-POINT	Tank ship	Grounding	Unknown	NY	Channel
	Tank barge	Grounding	500 gal.	NY	River
150F 80F	TOTAL	6	392,415 gal.		
	Tank barge	Collision	2,000 gal.	TX	Port/harbor
GRADE D HEAVY	Tank ship	Collision	240,000 gal.	VI	Bay
	Tank barge	Collision	1,000 gal.	LA	Port
	TOTAL	3	243,000 gal.		
	Tank ship	Grounding	20,000 gal.	OR	Terminal (Dock)
GRADE E DIESEL	Tank barge	Grounding	15 gal.	RI	River
	Tank barge	Grounding	60,000 gal.	RI	River
	Tank barge	Collision	10 gal.	FL	Dock
	Tank barge	Grounding	Unknown	FL	Bay
	Tank barge	Capsize	75 gal.	CA	Port
	TOTAL	6	80,100 gal.		
	Tank barge	Collision	50 gal.	MO	Dock
	Tank barge	Collision	75 gal.	FL	Port
GRADE E	Tank barge	Grounding	Unknown	MN	River
	Tank barge	Collision	4,074 gal.	NY	River

TABLE A-6 (Cont.)

MATERIAL	SOURCE	CAUSE	VOL.	STATE	WATER BODY
HEAVY FUEL OILS	Tank barge	Collision	42 gal.	KY	River
	Tank ship	Collision	850,000 gal.	CA	Bay
	Tank barge	Collision	168,000 gal.	TX	Channel
	Tank ship	Collision	8,400 gal.	TX	Port
	TOTAL	8	1,030,641 gal.		
GRADE E LUB OIL	Tank ship	Grounding	5 gal.	NJ	Channel
WASTE OIL	Tank barge	Collision	Unknown	NY	River
	Tank ship	Collision	Unknown	NY	Port/harbor
	Tank barge	Grounding	10,000 gal.	NY	Beach
	TOTAL	3	10,000 gal.		
HS - LIQUID SOLUBLE/MISCIBLE IN WATER	Tank barge	Collision	Unknown	AR	River
	Tank barge	Collision	Unknown	TN	River

TABLE A-7

TANK VESSEL ACCIDENTS

1972

MATERIAL	SOURCE	CAUSE	VOL.	STATE	WATER BODY
	Tank ship	Collision	20 gal.	NJ	Dock
	Tank ship	Collision	45 gal.	NJ	Channel
	Tank barge	Collision	100 gal.	WV	River
	Tank barge	Grounding	Unknown	LA	Channel
	Tank barge	Collision	Unknown	LA	Channel
	Tank barge	Collision	17,500 gal.	IA	River
	Tank ship	Collision	50 gal.	IL	Channel
GRADE B	Tank barge	Collision	25,000 gal.	KY	River
FLAMMABLE	Tank barge	Collision	100 gal.	WV	River
	Tank barge	Collision	10 gal.	AL	River
	Tank barge	Collision	147,000 gal.	AL	Channel
	Tank barge	Collision	40,000 gal.	MO	River
	Tank barge	Collision	350,000 gal.	OH	River
	Tank barge	Collision	90,000 gal.	MO	River
	Tank barge	Collision	4,000 gal.	MO	River
	Tank barge	Collision	100 gal.	MO	River
	Tank barge	Collision	126 gal.	LA	River

TABLE A-7 (Cont.)

MATERIAL	SOURCE	CAUSE	VOL.	STATE	WATER BODY
	Tank barge	Grounding	60,000 gal.	OH	River
	Tank barge	Grounding	Unknown	NY	River
	Tank barge	Grounding	4,200 gal.	NY	Bay
	Tank barge	Collision	1,000 gal.	NY	Dock
	TOTAL	22	739,251 gal.		

TABLE A-7 (Cont.)

MATERIAL	SOURCE	CAUSE	VOL.	STATE	WATER BODY
GRADE C FLAMMABLE	Tank barge	Collision	10 gal.	KY	River
	Tank barge	Collision	4 gal.	KY	River
	Tank barge	Collision	Unknown	IL	River
	Tank barge	Grounding	10,000 gal.	NY	Channel
	Tank barge	Collision	168,000 gal.	Gulf Coast	Off shore
	Tank barge	Collision	2 gal.	CA	River
	Tank barge	Collision	42 gal.	LA	Channel
	Tank ship	Collision	1,000 gal.	CT	Dock
	Tank barge	Collision	25 gal.	LA	River
	Tank barge	Collision	1 gal.	LA	Bay
	Tank barge	Grounding	5,000 gal.	FL	River
	Tank barge	Collision	5 gal.	LA	River
	Tank barge	Sinking/Founder	2,000 gal.	LA	River
	Tank barge	Collision	420 gal.	LA	Channel
	Tank barge	Collision	21 gal.	LA	River
	Tank barge	Grounding	168 gal.	LA	Channel
	TOTAL	16	186,698 gal.		

TABLE A-7 (Cont.)

MATERIAL	SOURCE	CAUSE	VOL.	STATE	WATER BODY
	Tank barge	Collision	50 gal.	KY	River
	Tank barge	Collision	Unknown	LA	River
	Tank barge	Collision	5,200 gal.	NY	River
	Tank barge	Collision	75,000 gal.	IL	River
GRADE D	Tank barge	Collision	24,000 gal.	LA	River
LIGHT FLASH-POINT	Tank barge	Collision	Unknown	LA	River
	Tank barge	Grounding	300 gal.	NY	River
80 150	Tank ship	Grounding	Unknown	DE	Off shore
	Tank barge	Grounding	12,000 gal.	CT	Port/harbor
	Tank ship	Grounding	42,000 gal.	NJ	Channel
	Tank ship	Grounding	100 gal.	NY	River
	Tank barge	Collision	500 gal.	MN	River
	Tank ship	Grounding	Unknown	NY	River
	Tank barge	Grounding	Unknown	NY	River
	Tank barge	Collision	4,200 gal.	OH	River
	Tank ship	Grounding	Unknown	NY	Port/harbor
	TOTAL	16	163,350 gal.		

TABLE A-7 (Cont.)

MATERIAL	SOURCE	CAUSE	VOL.	STATE	WATER BODY
	Tank barge	Grounding	4,200 gal.	KY	River
GRADE D	Tank ship	Grounding	135,000 gal.	NY	River
HEAVY FLASHPOINT	Tank barge	Collision	9 gal.	KY	River
80 150	Tank barge	Grounding	150 gal.	FL	River
	Tank barge	Collision	60 gal.	OH	River
	TOTAL	5	139,419 gal.		
	Tank barge	Collision	200 gal.	WV	River
	Tank barge	Collision	500 gal.	MA	Channel
	Tank barge	Grounding	320,000 gal.	IN	River
GRADE E	Tank barge	Collision	20 gal.	MA	Dock
DIESEL OIL	Tank barge	Collision	200,000 gal.	OH	River
	Tank ship	Collision	Unknown	NY	River
	Tank barge	Grounding	Unknown	FL	Bay
	TOTAL	7	520,720 gal.		
	Tank barge	Grounding	840 gal.	WV	River
	Tank ship	Collision	100,000 gal.	ME	Port/harbor
GRADE E	Tank barge	Collision	6,000 gal.	OH	River
	Tank ship	Collision	4,200 gal.	NJ	Channel

TABLE A-7 (Cont.)

MATERIAL	SOURCE	CAUSE	VOL.	STATE	WATER BODY
HEAVY FUEL OILS	Tank barge	Grounding	500 gal.	MA	Channel
	Tank ship	Grounding	Unknown	FL	Channel
	Tank barge	Grounding	168 gal.	TX	Channel
	Tank barge	Grounding	1,000 gal.	CT	River
	Tank ship	Grounding	100,000 gal.	ME	Bay
	Tank barge	Collision	Unknown	NJ	River
	Tank barge	Sinking/Founder	3,000 gal.	NC	Bay
	Tank barge	Collision	5 gal.	NJ	Dock
	TOTAL	12	215,713 gal.		
GRADE E LUB OIL	Tank barge	Sinking/Founder	25 gal.	IL	Channel
	Tank barge	Grounding	25 gal.	FL	Bay
	TOTAL	2	50 gal.		
WASTE OIL	Tank barge	Sinking/Founder	10 gal.	PA	River
UNIDENT OIL	Tank barge	Grounding	Unknown	CT	River
HS - LIQUID LIGHTER THAN WATER	Tank barge	Collision	81,522 gal.	LA	River

TABLE A-7 (Cont.)

MATERIAL	SOURCE	CAUSE	VOL.	STATE	WATER BODY
HS - LIQUID SOLUBLE/MISCIBLE IN WATER	Tank barge	Sinking/Founder	1,680,000 gal.	LA	River
	Tank barge	Grounding	3,500 gal.	TN	River
	TOTAL	2	1,683,500 gal.		

END

DATE FILMED

11 / 26 / 74