HOPE CREEK GENERATING STATION

MONITORING OF LNG AND LPG SHIPPING AND CONSTRUCTION ACTIVITIES ON THE DELAWARE RIVER

Docket Nos. 50-354
50-355

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January 1983

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1. SUMMARY

On November 4, 1974, the Atomic Energy Commission issued a Construction Permit (CP) for the construction of the Hope Creek Generating Station in Salem County, New Jersey.

The Hope Creek site is located on the Delaware River estuary near the southern end of an artificial peninsula known as Artificial Island.

Amendment No. 5 to the Construction Permit requires PSE&G to monitor activities related to the shipment of liquefied natural gas (LNG) and liquefied petroleum gas (LPG) on the Delaware River. This monitoring includes shipping rates of liquefied flammable gases and various types of construction activity. The chemicals classified as liquefied flammable gases are propane, butane, butadiene, vinyl chloride and liquefied natural gas.

The results of this study show that the total conditional probability of a flammable vapor cloud reaching the Hope Creek plant is 1.5×10^{-7} for 1980 and 1.2×10^{-7} for 1981. Both values are approximately eight times lower than the 10^{-6} value established as an upper limit by the NRC, based on conservative assumptions. Therefore, the associated hazards to the health and safety of the public are negligible.

2. INTRODUCTION

The activities of interest are those which might result in an increased rate of shipping or which could cause an increased probability of accident occurrence.

An increase in the shipping rate would occur either should an existing facility increase its importation rate or because of the construction of a new storage or refining facility. PSE&G has monitored these events by keeping in touch with local authorities, contacting those refineries and import terminals on the Delaware River which are capable of receiving liquid fuels and by reviewing the "Public Notices" issued by the Department of the Army - "U.S. Corps of Engineers."

Although there is currently no LNG shipping on the river, there have been proposals to initiate such shipping. All have either been withdrawn or rejected by the Federal Energy Regulatory Commission (FERC). Consequently, there are currently no outstanding proposals for an LNG facility that could possibly affect the Hope Creek Generating Station. PSE&G is continuously monitoring the applications received by FERC relating to LNG terminals.

Other types of construction on the Delaware River could also result in increase risk to the Hope Creek Generating Station. It has been estimated (PSE&G, Dockets 50-354 and 50-355 before the NRC, exhibits 9, 10, 11) that a flammable vapor cloud which forms as a result of an accidental spill of a liquid fuel on water could travel up to 12 miles. Therefore, any spill occurring within a distance of 12 miles up or downstream of the nuclear facility has to be analyzed to determine if it presents a potential hazard to the plant. Currently, with the exception of Tower 97,* there are no rammable objects in the vicinity of shipping channel near Hope Creek. However, in the future, docks, jetties, moorings, piles, or other potential obstructions could be constructed in the river. Therefore, PSE&G is monitoring construction activity of this type.

The calculation of the probability of a flammable cloud reaching the Hope Creek plant is made from a series of conditional probabilities. These probabilities involve the expected number of accidents per mile of river transit, the probability that a spill will result given that an accident occurred, the probability that a vapor cloud will form given that there has been a spill, and the meteorological factor.

The NRC has established guidelines for the acceptable upper limit of the probability that the Hope Creek Generating Station will be affected by a flammable vapor cloud formed as a result of an accident on the river. In an estimate in which the factors are determined based on conservative approximations, the number of incidents cannot exceed 10^{-6} per year.

*Electrical Transmission Line Tower

HOPE CREEK GENERATING ST:TION

MONITORING OF LNG AND LPG SHIPPING AND CONSTRUCTION ACTIVITIES ON THE DELAWARE RIVER

3. YEARLY REPORT - 1981
(YR-3)

Docket Nos. 50-354
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3.1 Total Number of Ships Per Year

The total number of ships passing by the nuclear plant in 1980 and 1981 and carrying each of the designated chemicals was developed by Poten & Partners, Inc., a shipping consultant. The data was derived from U.S. Coast Guard Records, Import and Export Records, and the U.S. Army Corps of Engineers. The list presented in Table 1 specifies the discharge date, quantity, product, vessel, origin and, where possible, the importer. This information is summarized in Table 2, and graphically presented on Figures 1 through 5. As indicated, the total number of tankers passing by the plant was lower in 1980 and 1981 than in previous years.

Also, the shipments of vinyl chloride have ceased. This is due to the fact that the manufacturing facility, located in Puerto Rico, from which the vinyl chloride was being imported, went out of business.

3.2 Construction Activity

The construction activity along the Delaware River was monitored through the review of "Public Notices" issued by the U.S. Army Corps. of Engineers, by contacting various facilities located upstream of the plant (see Table 3 and Figure 6) and the Federal Energy Regulation Commission, which is responsible for reviewing and approving any proposals for construction of LNG terminals.

LIQUEFIELD GAS CARGOS TRANSITING THE DELAWARE RIVER - 1981
TABLE 1

DISCHARGE DATE	QUANTITY (METRIC TONS)	PRODUCT	VESSEL	ORIGIN	IMPORTER
2/8/81	11,350	Propane	Hoegh Sword	Kuwait	Elf/Sun
2/8/81	7,650	Propane	Hoegh Sword	Saudi Arabia	MSK/Sun
2/24/81	3,200	Butadiene	Garbeta	Netherlands	Exxon
2/24/81	5,700	Butadiene	Garbeta	Netherlands	Exxon
2/24/81	1,900	Butadiene	Garbeta	United Kingdom	Exxon
2/24/81	3,400	Butadiene	Garbeta	France	Exxon
3/11/81	6,125	Butane	Katrisa	Venezuela	Gulf Oil
4/18/81	10,410	Butane	Mundogas Pacific	Venezuela	Warren
6/10/81	3,970	Butadiene	Pascal	United Kingdom	
6/20/81	6,777	Butane	Clerk Maxwell	Venezuela	Warren
6/25/81	3,019	Butadiene	Nestefox	Terneuzen	
7/19/81	20,000	Propane	Monge	Saudi Arabia	Sun
7/25/81	4,039	Butadiene	Pascal	Netherlands	Paulsboro
7/25/81	1,645	Butadiene	Pascal	Netherlands	
7/25/81	1,244	Butadiene	Pascal	Netherlands	Paulsboro
7/25/81	1,256	Butadiene	Pascal	Netherlands	
7/25/81	1,244	Butadiene	Pascal	Netherlands	
9/9/81	8,245	Butane	Devonshire	Saudi Arabia	Mitsui
9/15/81	5,483	Butane	Devonshire	Saudi Arabia	Mitsui
10/25/81	11,631	Propane	Mundogas Pacific	Saudi Arabia	Mitsui
11/25/81	13,000	Butane	Mundogas Pacific	Venezuela	Warren
12/10/81	4,500	Butadiene	Sine Maersk	Netherlands	
12/12/81	1,993	Butadiene	Linge Gas	Netherlands	
12/20/81	15,000	Butane	Hoegh Skean	Saudi Arabia	Warren
12/27/81	13,100	Butane	Luigi Lagrange	Saudi Arabia	Warren

Table 2 Summary of Liquid Gas Ships

	Total Number of Ships					
Year	Propane	Butane	Butadiene	Vinyl Chloride	LNG	Total
1977	1	10	10	25	0	46
1978	5	10	1	25	0	41
1979	1	10	13	0	0	24
1980	2	9	12	0	0	23
1981	3	8	6	0	0	17
1982						
1983						
1984						
1985						
1986						
1987						
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1996						
1997						
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1999						
2000						
2001						
2002						
2003						
2004						
2005						

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Table 2 - Continued Summary of Liquid Gas Ships

		Total Number of Ships					
	Year	Propane	Butane	Butadiene	Vinyl Chloride	LNG	Total
	2001						
	2002						
	2003						
	2004						
	2005						
	2006						
	2007						
	2008						
	2009						
	2010						
	2011						
	2012						
	2013						
	2014						
	2015						
	2016						
	2017						
	2018						
	2019						
	2020						
	2021						
	2022						
	2023						
	2024						
	2025						
	2026						
	2027						
	2028						
	2029						
	2030						

The focus of our review of construction activity was on the following:

a. Have any LNG or LPG facilities been licensed on the Delaware River?

b. Have any new docking facilities been authorized which might result in an increase in transportation of propane, butane, butadiene, or vinyl chloride?

3. Has the construction of any rammable objects in or near the shipping channel in the 24 mile catchment distance near Hope Creek been proposed or authorized?

An ongoing activity, which has no impact on the nuclear power plant, is the dredging of the river in front of Artificial Island, on which the plant is located. This activity is sponsored by Public Service Electric and Gas.

3.3 Conclusions

Based on our review of "Public Notices" issued by the U.S. Army Corps of Engineers, responses to inquiry letters sent to the facilities listed in Table 3, and Federal Energy Regulatory Commission notices, we conclude that no new or proposed construction which would have an effect on the calculation of the probability of a flammable fuel vapor cloud reaching the Hope Creek Nuclear Generating Station has apparently been authorized.

Table 3

LPG Facilities located on the Delaware River

Atlantic Richfield Company
Box 7709
Philadelphia, PA 19101
(215) 339-2632

British Petroleum Oil Company
Marcus Hook, PA 19061
(215) 494-3600

British Petroleum Oil Company
Paulsboro, NJ 08066
(609) 423-4000

Cities Services Company
Box 300
Tulsa, Oklahoma 74102
(918) 586-2211

Getty Oil Company
Delaware City, Delaware 19706

Gulf Oil Company
Girard Point, Pa. 19145
(215) 389-3500

Mantua Chemicals Terminal, Inc.
Crown Point Road
Thorofare, New Jersey 08086
(609) 423-5400

Mobil Oil Company
Paulsboro, New Jersey 08066
(609) 423-1307

Table 3 - continued

Sun Oil Company
Marcus Hook, Pa. 19061
(215) 447-1244

Texaco Oil Company
Eagle Point, New Jersey 08093
(609) 845-8000

FIGURE 1
NUMBER OF SHIPS
TRANSPORTING
PROPANE

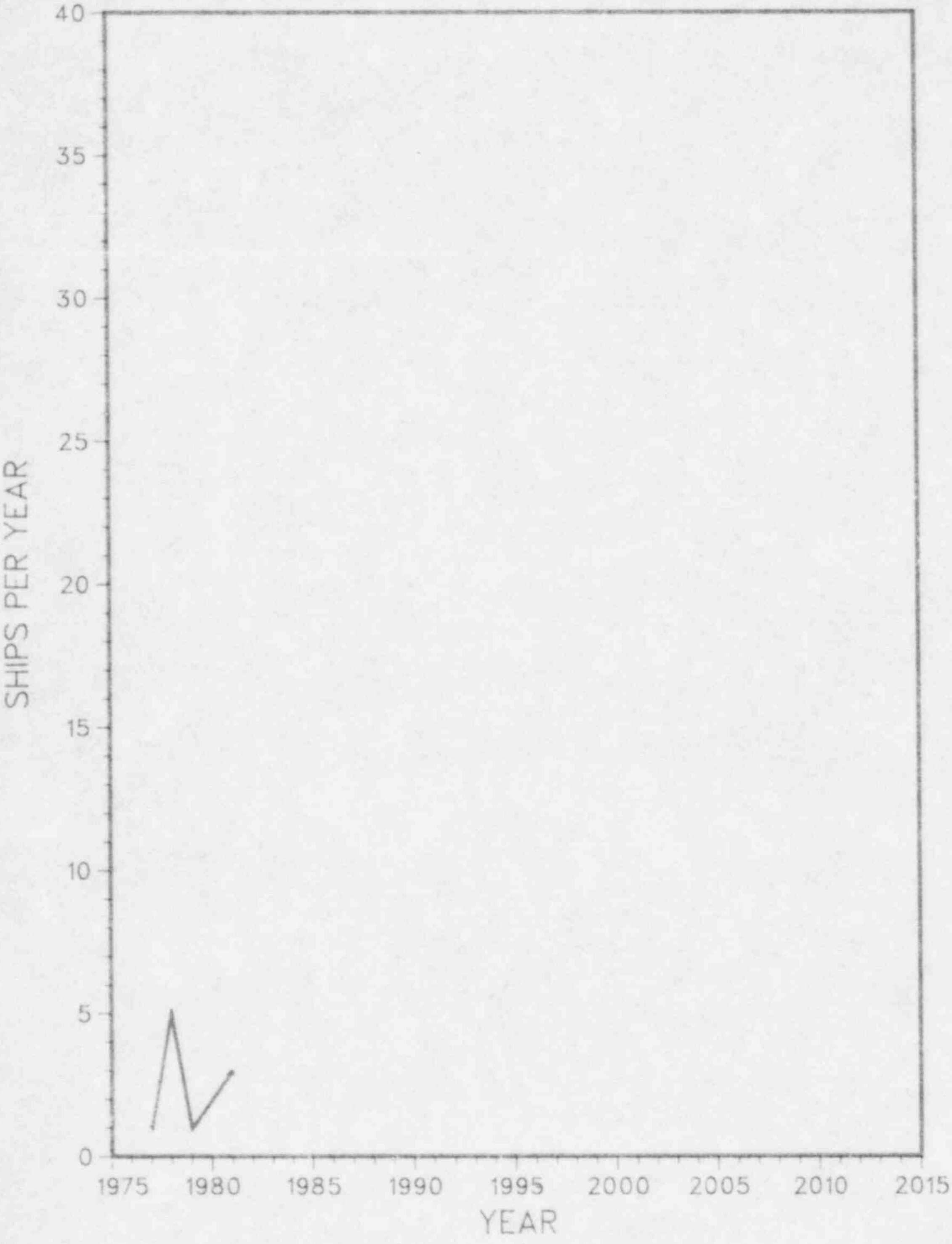


FIGURE 2
NUMBER OF SHIPS
TRANSPORTING
BUTANE

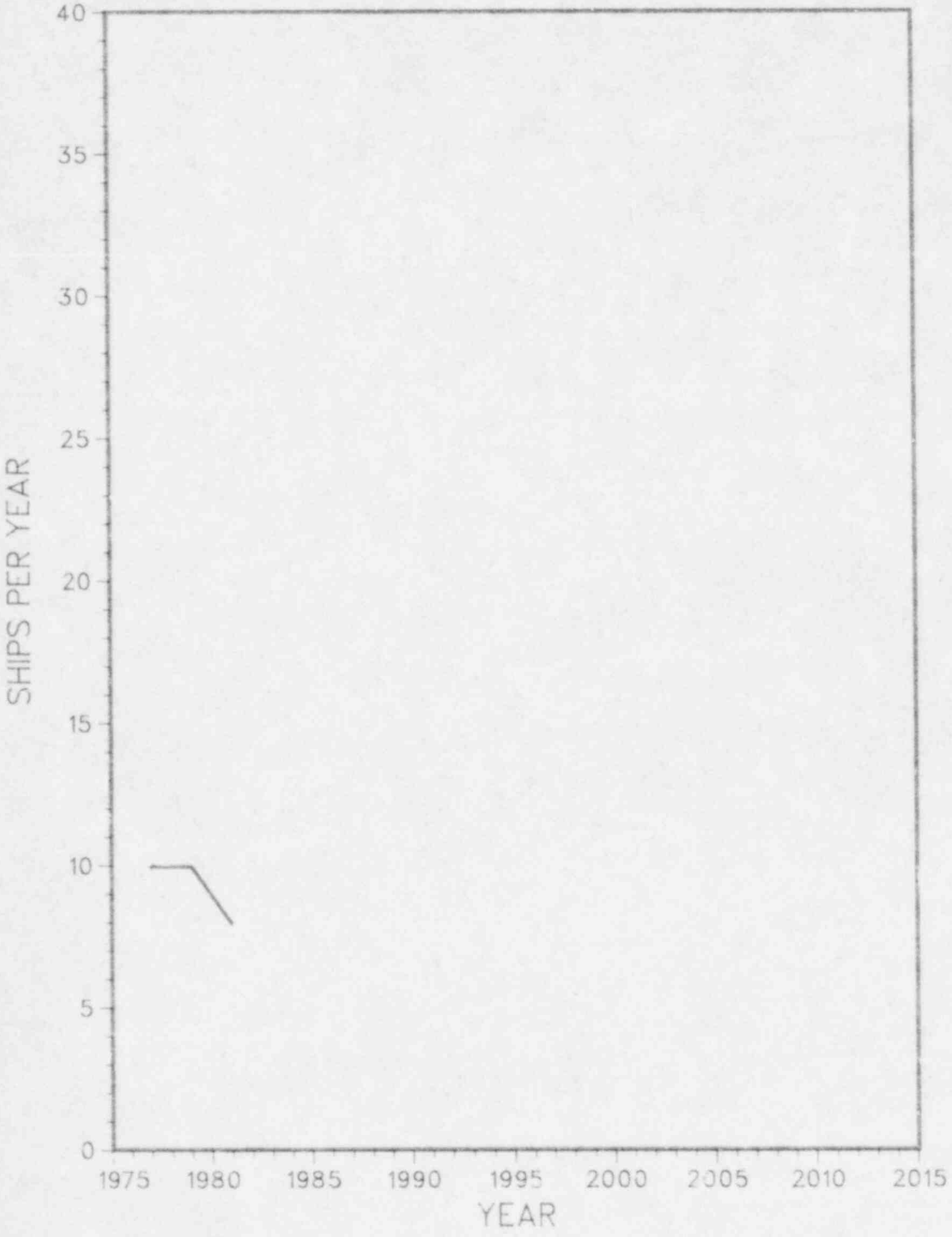


FIGURE 3
NUMBER OF SHIPS
TRANSPORTING
BUTADIENE

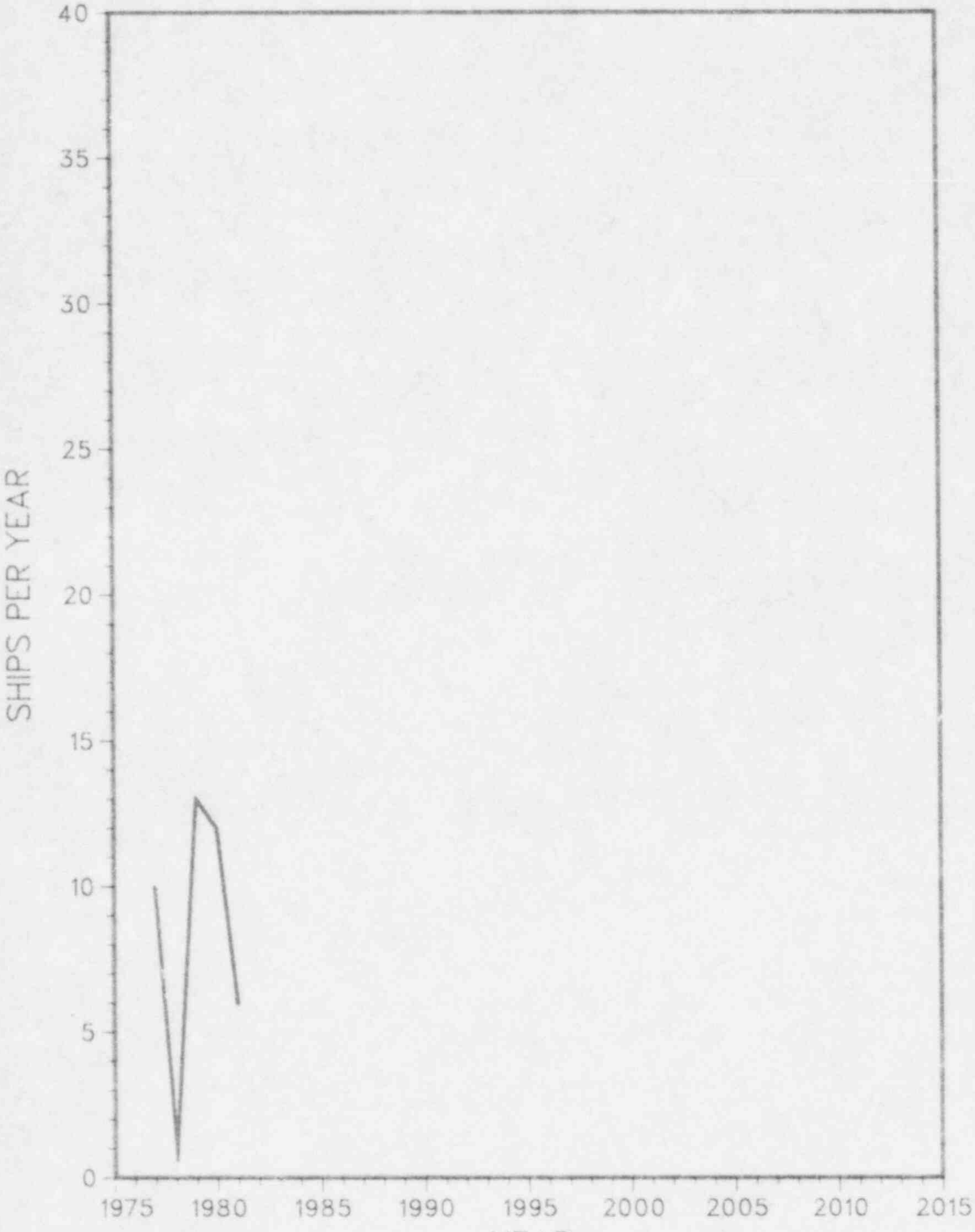


FIGURE 4
NUMBER OF SHIPS
TRANSPORTING
VINYL CHLORIDE

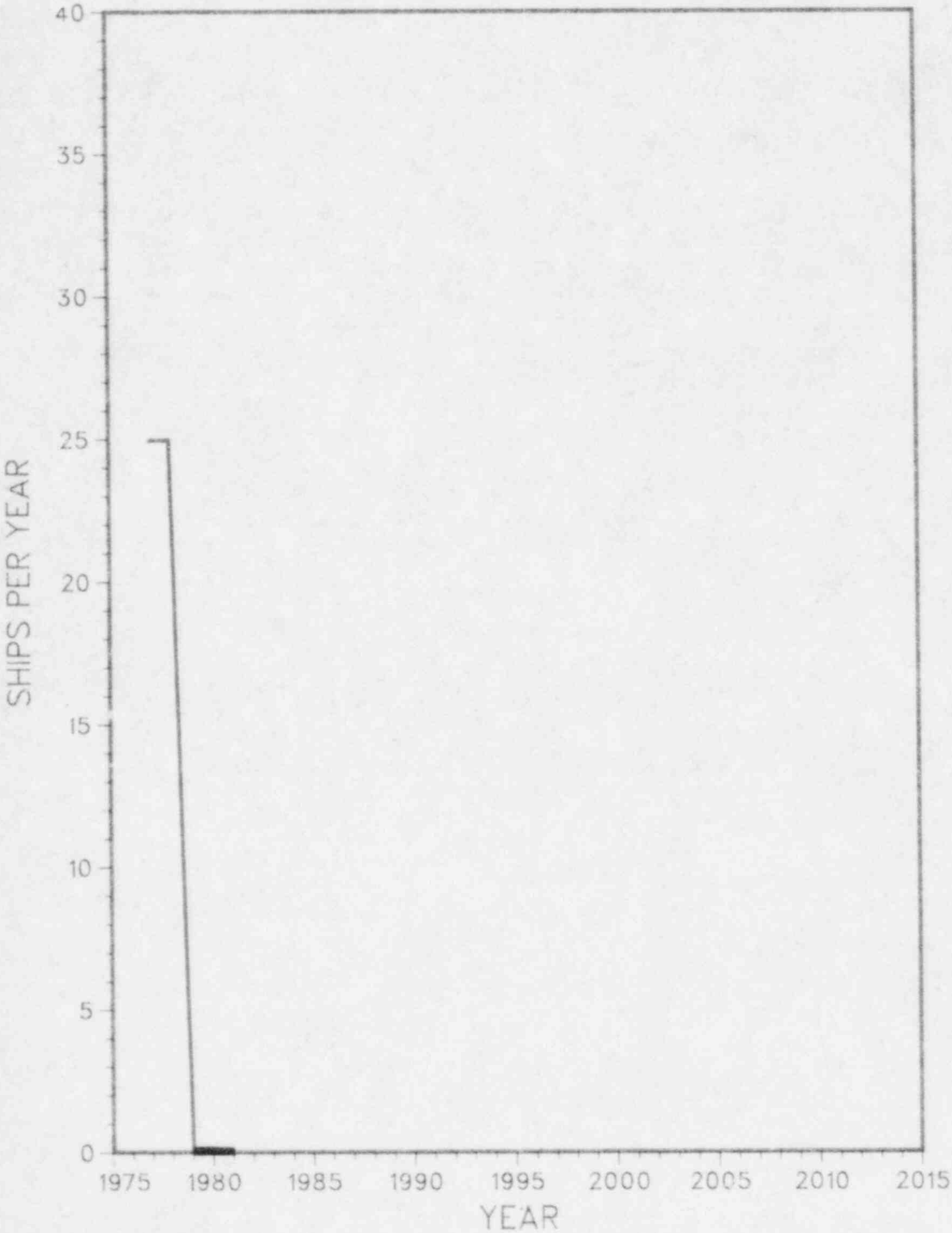


FIGURE 5
NUMBER OF SHIPS
TRANSPORTING
LNG

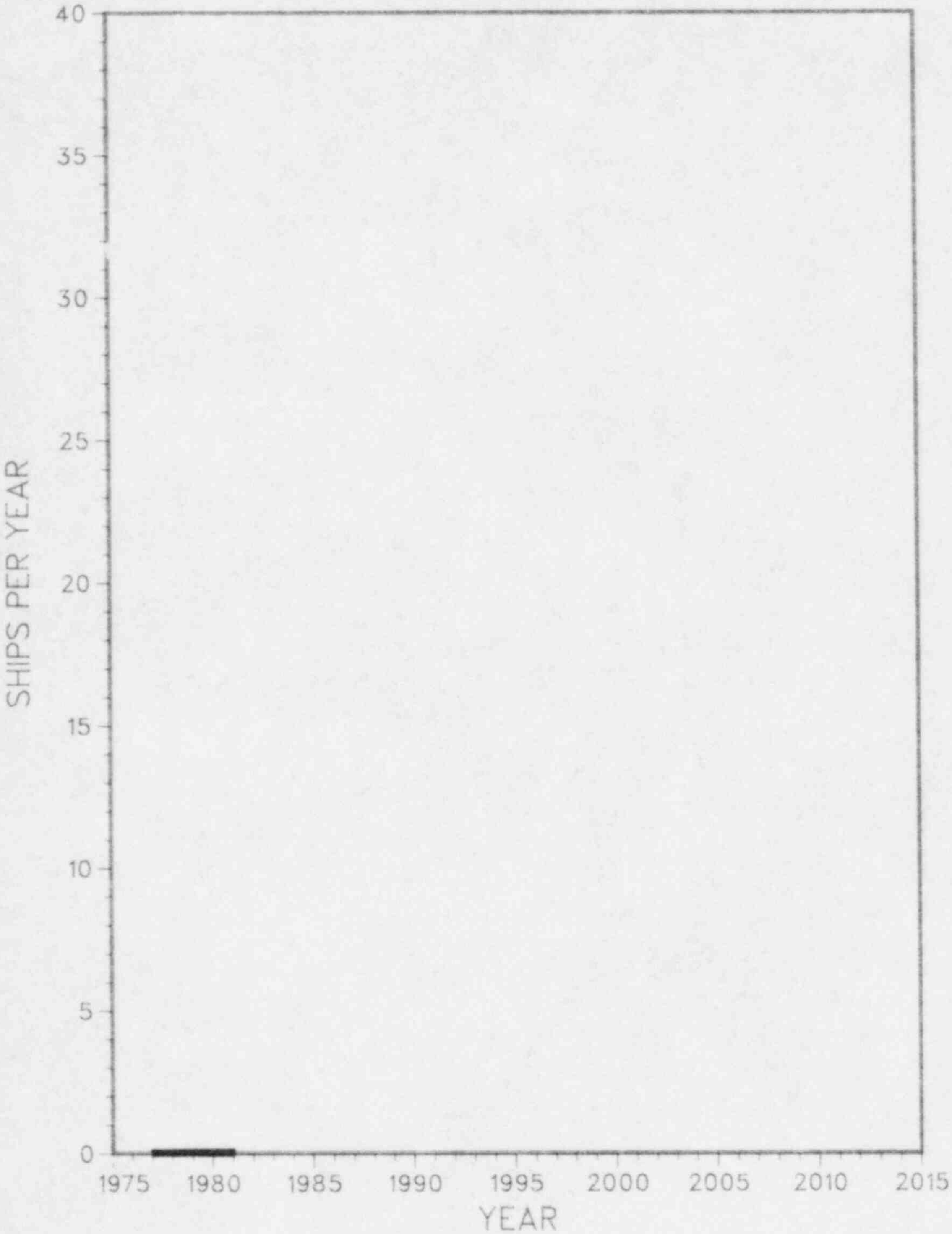
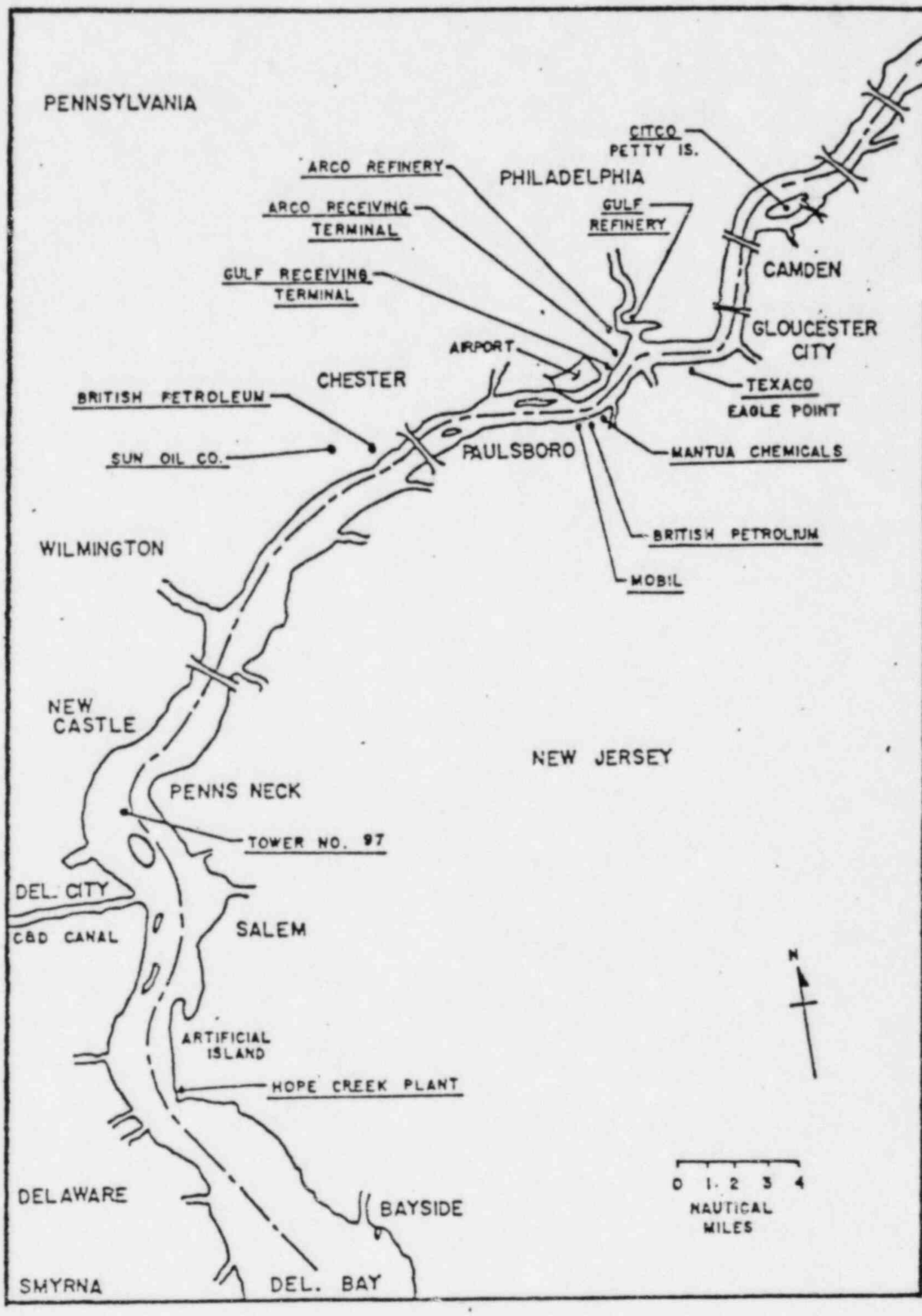


FIGURE 6



LOCATION OF MAJOR RECEIVING TERMINALS & REFINERIES & HOPE CREEK PLANT & TOWER NO. 97

HOPE CREEK GENERATING STATION

MONITORING OF LNG AND LPG SHIPPING AND CONSTRUCTION ACTIVITIES ON THE DELAWARE RIVER

4. BIYEARLY REPORT - 1981
(BYR-2)

Docket Nos. 50-354
50-355

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4.1 CALCULATION OF CONDITIONAL PROBABILITY

4.1.1 Accident Rate Per Ship Mile

The number of accidents occuring per mile traveled by liquid fuel tankers is based on information collected from the U.S. Coast Guard Marine Casualty Computer Data and the U.S. Coast Guard accident files. The total number of accidents was divided by the total exposure (average yearly one way trips on the Delaware River) as determined from the publication "Waterborne Commerce of the United States," to arrive at an accident rate per transit mile in the Delaware River. An analysis of each of these sources of data is presented in the following pages.

U.S. Coast Guard Marine Casuality Computer Data was used to identify all collision incidents on the Delaware River over the years 1979-1980 in the following seven categories:

1. a meeting situation
2. a crossing situation
3. an overtaking situation
4. an anchored or moored condition
5. fog
6. docking or undocking operation
7. not otherwise classified

Liquefied gas carriers operate in U.S. Coastal Waters under very strict supervision of the U.S. Coast Guard. In the section of river adjacent to the Hope Creek Generating Facility, the tanker will be moving in the channel at all times under Coast Guard escort. In particular, in this section of the river, the liquid gas carrier:

- will not be moored
- will not be in area of industrial docks or piers
- will not encounter any area of rock river bottom

- will not overtake or be overtaken by other ships
- will not meet other ships at bends
- will not meet oncoming ships of a relative speed of greater than 12 knots
- will not itself exceed a speed of 12 knots
- will only transit if visibility is two miles or greater
- will only transit with tug escort
- will be in continuous communications on two radio channels
- will be U.S. Coast Guard supervised

Because of the strict operating procedures involving liquefied gas carriers, those accidents which occur in the seven categories listed above were examined, and any which could not occur under the operating conditions mentioned above for liquid gas carriers were excluded. Any incidents which were questionable were included so that the estimate will be conservative, but any accident which did not involve at least one large vessel of over 18 ft. draft was discarded.

Next, the total number of one way trips in the Delaware River (either inbound or outbound) of large tankers, dry cargo, and passenger ships with a draft of more than 18 feet was obtained from the "Waterborne Commerce" publication. Each one-way trip constitutes a distance of approximately 100 miles, so that the average ship-miles/year is 100 times the total number of one-way trips.

The accident rate per ship mile was calculated by dividing the total number of accidents by the total ship miles. This calculation was carried out for the period under consideration and also for the cumulative accidents since the first estimate was made. The value calulated for a single period is for comparison purposes only; in the calculation of the overall probability, the cumulative value was used since it has more statistical validity because of the larger sample size. Tables 7 and 8 summarize these values.

4.1.2 HISTORICAL COLLISION ANALYSIS FY79-FY80

The United States Coast Guard Marine Casualty Computer Data tape was utilized to identify the occurrence of all collision incidents (the seven categories listed above) on the Delaware River in the years FY1979 and FY1980. A total of 42 collision incidents were identified and the U.S. Coast Guard serial number of each incident was recorded. This record of serial number was then utilized to obtain detailed accident reports from the U.S. Coast Guard accident files for each of the 42 incidents. These 42 detailed incident reports were examined and analyzed further.

The 42 events were initially screened with the purpose of deleting those accidents only involving relatively small vessels that are not representative of large, self-propelled, liquefied gas carriers and could not puncture the LPG gas tanks if they were the striking vessel. These are identified in Table 4 by their assigned Coast Guard case numbers. An attached Appendix summarizes our rationale for their selection, together with our rationale for all other decisions outlined below.

A second screening of the 29 remaining reports had the purpose of identifying those accidents that did not take place on or very near the 100-mile river segment of interest between the entrance of Delaware Bay and Philadelphia. The five incidents described in Table 5 were placed in this category.

The remaining 24 reports, as described in Table 6, involved collisions between ships while at least one was being intentionally moved.

Cases 91724, 92484, 92579, 93285, 94593, 94671, and 03404 involved collisions while one of the vessels was in the process of docking or undocking, or one vessel was moored or anchored. Although a liquefied gas carrier will not be moored, anchored, docked, or undocked in the 24-mile river section of interest, i.e., the catchment distance in which a cargo release might impact the nuclear generating facility, all of the above cases, with the exception of 93285 and 94671, were conservatively considered collisions while under way and worthy of inclusion in the accident data base.

This practice is consistent with previously submitted testimony before the NRC. Case 93285 involved a motor boat, which is too small to create any damage when colliding with a liquefied gas carrier, and can therefore be eliminated from the data base. Case 94671 involved a collision in fog, and can be eliminated since U.S. Coast Guard regulations do not permit movement of liquefied gas carriers in fog conditions.

The remaining cases listed on Table 6 are discussed below. Cases 02782 and 03842 involved passing situations, and were conservatively included in the data base, as was case 05160, where a barge on tow of a tug collided with a vessel while being passed and overtaken. Case 05154 was not included, since it involved a collision in a fog situation.

In conclusion, therefore, we conservatively find 8 incidents that should be included in the accident data base: 91724, 92484, 92579, 94593, 03404, 02782, 03842, and 05160. Each is considered relevant and potentially applicable to the analysis of the LNG or LPG tanker spill probability in the 24 mile river segment of interest.

The results of this analysis are summarized in Table 7.

As a reference for the methodology employed above, the following can be consulted:

Supplemental Testimony of Dr. Ashok Kalelkor in response to matters raised by the Atomic Safety and Licensing Appeals Board in ALAB-429,
11 October 1977
Docket Nos. 50-354
50-355
Pages 5-21

TABLE 4

INCIDENTS INVOLVING ONLY SMALL VESSELS

BY USCG CASE NUMBER*

91586	01140
91587	02415
91703	02920
92584	05155
92950	05161
93569	
94599	
94602	

*These incidents only involved tugs, towboats, non-self propelled barges, or other relatively small vessels.

TABLE 5

INCIDENTS WITH INCORRECT LOCATION

Case Number	Location
92584	Middle Thorofare Bridge, W·ldwood, New Jersey
92850	Middle Thorofare Bridge, Wildwood, New Jersey
93170	Christina River, Delaware
94603	Cold Springs Fish House, Cape May, New Jersey
05144	Heterford Inlet Lt., New Jersey

TABLE 6

COLLISIONS BETWEEN LARGE VESSELS

Case No.	Description
91724	Tug collided with ship, while docking.
92484	Ship collided with container crane, while docking.
92579	Ship collided with container crane, while undocking.
93285	Motor boat collided with moored fishing vessel.
94593	Ship collided with anchored ship.
94671	Ship underway lost power and collided with anchored ship, in fog.
02782	Dredge collided with ship which was passing her.
03404	Barge in tow collided with anchored ship.
03842	Barge in tow collided with ship, while being passed in an overtaking situation.
05154	Two tanker ships collided in fog, at Hog Island terminal.
05160	Barge in tow of tug collided with vessel.

TABLE 7

ACCIDENT RATE PER SHIP MILE

Year	Total Accidents	Cumulative Accidents	One-Way Trips	Cumulative One-Way Trips	Accident Rate	Cumulative Accident Rate
1969-1975	10	10	66321	66321	1.5×10^{-6}	1.5×10^{-6}
1976-1978	7	17	28344	94665	2.5×10^{-6}	1.8×10^{-6}
1979-1980	8	25	14498	109163	5.5×10^{-6}	2.3×10^{-6}
1981-1982						
1983-1984						
1985-1986						
1987-1988						
1989-1990						
1991-1992						
1993-1994						
1995-1996						
1997-1998						
1999-2000						
2001-2002						
2003-2004						
2005-2006						
2007-2008						
2009-2010						
2011-2012						
2013-2014						
2015-2016						
2017-2018						
2019-2020						
2021-2022						
2023-2024						
2025-2026						
2027-2028						
2029-2030						

TABLE 8

DELAWARE RIVER ONE-WAY TRAFFIC IN TANKERS, DRY CARGO, AND PASSENGER SHIPS OF GREATER THAN 18 FT DRAFT

(Source: "Waterborne Commerce")

Year:	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
One-Way Trips:	9744	10151	9258	9553	9858	9086	8671	9559	9300	9485	7789	6709

$$\text{Average One-Way Trips} = \frac{109163}{12} = 9100$$

Each one-way trip representing a distance of about 100 miles, the average ship-miles/year is 100 times the average number of one-way trips. Therefore, this figure is 9.1×10^5.

4.1.3 Collisions With Fixed Objects

The calculation of collision rates with fixed objects (e.g. Tower 97, which is approximately 9 miles up-river from the Hope Creek site - see Figure 6), was handled in the same manner as the accident rate. From the Coast Guard accident casualty data for the previous years, the number of occurrences of rammings of fixed objects involving a ship of over 18 feet draft was determined. As in the previous analysis, any accidents which could not have happened to a ship following U.S. Coast Guard regulations for liquefied gas carriers were eliminated from the data base. The number of one-way transits per year of ships of over 18 feet draft is the same as was used in the accident rate calculation.

The number of collisions with fixed objects is based on approximately 50 rammable objects* which large ships could have struck; Tower 97 represents one of them. Thus, to calculate the probability of a collision with Tower 97 per transit, the total number of collisions in the river is divided by 50 and then divided by the total number of one-way transits.

* As counted from NOAA Navigational Charts for the Delaware River. None of the 50 objects, except Tower 97 occur in the 24 miles of interest.

Table 9 summarizes the 13 remaining incidents that involved large ship collisions with fixed objects.

Case 92596 involved a collision with a jetty in a fog situation, and therefore is not included in the data base. Cases 93174, 94601, and 94606 involved movement and subsequent contact of a moored ship with nearby objects due to waves caused by a passing vessel. Since a liquefied gas carrier would not be moored or anchored in the 24-mile river segment of concern, this sort of accident is wholly unlikely. For similar reasons, case 02418 involving a ship that broke anchor and collided with the loading pipeline is not included in the data base.

The rest of the cases are considered applicable.

In conclusion, an examination of all 13 collisions involving vessels and fixed objects in the Delaware River (FY79-FY80) reveals that, at most, 8 of them are relevant and potentially applicable to the analysis of LNG or LPG tanker spill probability.

The results of this analysis are summarzied in Table 10.

TABLE 9

SHIP COLLISIONS WITH FIXED OBJECTS

Case Number	Object	Circumstances
91788	pier	docking pilot error
92596	jetty	in fog, trying to avoid anchored ship
93174	gangway	Moored ship surged due to wake of passing ships, and struck gangway
94601	pier	Moored ship surged due to wake of passing ship, and struck pier.
94606	pier	Moored ship surged and hit pier, due to nigh winds
02412	pier	While docking, ship struck pier
02418	pipeline	Moored ship broke anchor and damaged loading pipeline
02709	pier	Undocking
03630	pier	docking
03827	pier	docking
04975	pier	docking
05148	pier	docking
05150	pier	docking

TABLE 10

COLLISIONS WITH TOWER 97 PER TRANSIT

Year	Total Collision	Cumulative Collisions	One-Way Trips	Cumulative One-Way Trips	Collision Rate	Cumulative Collision Rate
1969-1975	8	8	66321	66321	2.4×10^{-6}	2.4×10^{-6}
1976-1978	11	19	28344	94665	7.8×10^{-6}	4×10^{-6}
1979-1980	8	27	14498	109163	1.1×10^{-5}	5×10^{-6}
1981-1982						
1983-1984						
1985-1986						
1987-1988						
1989-1990						
1991-1992						
1993-1994						
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2017-2018						
2019-2020						
2021-2022						
2023-2024						
2025-2026						
2027-2028						
2029-2030						

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4.1.4 Spills Per Accident

The probability that a spill will occur given that there has been an accident was calculated based on a complex energy conservation model developed by V. U. Minorsky.** The model estimated the depth of penetration of the hull of a ship based on the speeds of the colliding ships and the angle of collision.

Conservative estimates of the spill per accident rate are 0.1 for propane, butane, butadiene and liquefied natural gas carriers,* and 0.01 for vinyl chloride carriers. Vinyl chloride has a much smaller value because it is carried in self contained tanks near the center of the ship, at a larger distance from the hull.

Table 13 presents the probability values for spills per accident associated with each type of liquefied gas.

The probability that a storage tank on a gas carrier would be ruptured given that an accident has occurred was calculated based on a method developed by Vladimir U. Minorsky.** In order to determine if there have been any new developments in this field, PSE&G has contacted Mr. Minorsky at George S. Sharp, Inc., N. Y. Since Mr. Minorsky had retired the previous year, we discussed this item with an associate of Mr. Minorsky, Mr. Chetank Yang.

In response to our inquiry, Mr. Yang indicated that there have been no new developments in the area of ship damage models which would lead to changes in the probability figures presented in Table 11.

*These values were used in the ASLAB decision although the applicant's more rigorous estimate for LNG tankers indicates a much smaller conditional spill probability.

**V. U. Minorsky "Analysis of Ship Collisions with Reference to Protection of Nuclear Power Plants," Journal of Ship Research October 1953.

TABLE 11

SPILLS PER ACCIDENT

	Year	Propane	Butane	Butadiene	Vinyl Chloride	LNG	
	1978	0.1	0.1	0.1	0.01	0.1	
	1980	0.1	0.1	0.1	0.01	0.1	
	1982						
	1984						
	1986						
	1988						
	1990						
	1992						
	1994						
	1996						
	1998						
	2000						
	2002						
	2004						
	2006						
	2008						
	2010						
	2012						
	2014						
	2016						
	2018						
	2020						
	2022						
	2024						
	2026						
	2028						
	2030						

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4.1.5 Vapor Cloud Formation Per Spill

Given that there has been a spill of a liquefied gas cargo, a vapor cloud will form only if the fuel is not ignited at the source of the spill. In a crash situation which is large enough to release the cargo, it is expected that there will be ample sources of ignition from severed wires, frictionally heated metal, and associated sparks. Although a vapor cloud could be expected in less than one percent of all spills, a conservative value of 10 percent has been used.

Table 12 presents the probability values associated with various liquefied gases.

In order to verify if any new developments in the area of vapor cloud formation and dispersion have occurred, PSE&G has contacted the following sources involved in this type of research:

a. Gas Research Institute
   Mr. Sami Atallah - Manager, Systems Safety Research

b. Safety and Engineering Technology Section
   Arthur D. Little, Inc.
   Dr. Elizabeth M. Drake

c. Massachusetts Institute of Technology
   Professor James A. Fay

In their response to our inquiry, all three sources of information indicated that there were no new developments in this field which would lead to changes in the probability values presented in Table 12.

TABLE 12

VAPOR CLOUD FORMATION PER SPILL

	Year	Propane	Butane	Butadiene	Vinyl Chloride	LNG	
	1978	0.1	0.1	0.1	0.1	0.1	
	1980	0.1	0.1	0.1	0.1	0.1	
	1982						
	1984						
	1986						
	1988						
	1990						
	1992						
	1994						
	1996						
	1998						
	2000						
	2002						
	2004						
	2006						
	2008						
	2010						
	2012						
	2014						
	2016						
	2018						
	2020						
	2022						
	2024						
	2026						
	2028						
	2030						

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4.1.6. Meteorological Factor

The meteorological factor is based on distance between the spill and facility, and the mean wind speed and direction. It represents the probability that a vapor cloud formed at a particular location will reach the nuclear plant with a flammable mixture of fuel to air. It is not expected to change under ordinary circumstances over the lifetime of the facility and the values which were used are given in Table 13 for the entire 24 mile catchment distance and for Tower 97.

Table 13 - Meteorological Factors*

	24 Mile Catchment	Tower 97**
Propane	0.31	0.002
Butane	0.32	0.002
Butadiene	0.25	0.002
Vinyl Chloride	0.24	0.002
LNG	0.354	0.002

*For details on how the Meteorological Factor is derived, see answer to Question 3 of Exhibit 10 on Docket Nos. 50-354 and 50-355 dated January 13, 1975.

**The value of 0.002 is very conservative since it assumes a 10,000 ton spill. Such spill sizes are not considered credible for propane, butane and butadiene since individual tank sizes for such cargoes are considerably smaller.

4.1.7 Conditional Probability Calculation

The probability that a flammable vapor cloud will reach the nuclear facility was calculated for each fuel type under consideration (propane, butane, butadiene, vinyl chloride, and LNG). For each fuel type, two separate calculations were made; the first was based on the likelihood of a collision with another ship anywhere within the 24 mile catchment distance and the second was based on a ramming of Tower 97 nine miles upstream of the nuclear plant.

The overall probability of a flammable vapor cloud reaching the nuclear plant is the sum of these eight terms.*

The individual terms were calculated as the product of five other factors. These factors are:

1. Total number of ships per year
2. Accidents per mile; or accidents per passage
3. Spills per accident
4. Vapor cloud per spill
5. Meteorological factor

The first of these five factors is determined annually for each fuel type as listed in Table 1. The remaining four factors have been conservatively estimated and are described in Sections 4.1.4, 4.1.5, and 4.1.6. These factors may vary somewhat as a result of a biyearly review of shipping experience, and the method for their calculation is also described in Sections 4.1.4, 4.1.5 and 4.1.6.

The results of all these calculations are presented in Tables 14 and 15, for both ship to ship collisions and collisions with fixed objects.

4.2 Conclusions

The results provided in Tables 14 and 15 show that the total conditional probability of a flammable vapor cloud reaching the Hope Creek plant is 1.5×10^{-7} for 1980; and 1.2×10^{-7} for 1981. Both values are almost eight times less than the 10^{-6} value established as an upper limit by the NRC, based on conservative approximations.

All approximations on this study have been made in a conservative manner, the resultant probabilities of 1.5×10^{-7} and 1.2×10^{-7} being, therefore, conservative results.

*Since LNG is not shipped on the Delaware, only four cargoes (propane, butane, butadiene, and vinyl chloride) and two spill modes (ship-ship collision and collision with Tower 97) are relevant, leading to eight probability terms to be added for the total probability.

The actual LNG and LPG traffic has decreased from 1979 to 1980 and even more to 1981; no additional rammable objects, mooring or docking sites, or any other facility that might cause a significant change in the probability of a flammable vapor cloud reaching the plant have been built or are planned for construction within the 24 mile catchment distance on the Delaware River; and no proposals for construction of LNG terminals along the Delaware River have been received by FERC.

Based on the above information, we can conclude that the probability of a flammable vapor cloud reaching the nuclear facility is sufficiently small such that the associated hazards to the health and safety of the public are negligible.

TABLE 14

PROBABILITY OF FLAMMABLE VAPOR CLOUD REACHING NUCLEAR FACILITY

(Based on 1980 Data)

	No. of Ships Per Year	Accidents Per Mile	Rammings Per Passage	Spills Per Accident	Vapor Cloud Per Spill	Meteorological Factor	Probability
LNG	0	2.3x10-6		0.1	0.1	0.354	0
LPG							
Propane	2	2.3x10-6		0.1	0.1	0.31	1.4x10-8
Butane	9	$2.3x10^{-6}$		0.1	0.1	0.32	$6.62x10^{-8}$
Butadiene	12	$2.3x10^{-6}$		0.1	0.1	0.25	$6.9x10^{-8}$
Vinyl Chloride	0	2.3x10-6		0.01	0.1	0.24	0
Tower 97							
LNG	0		$5x10^{-6}$	0.1	0.1	0.002	0
LPG	23		5x10-6	0.1	0.1	0.002	$2.3x10^{-9}$
Vinyl Chloride	0		$5x10^{-6}$	0.01	0.1	0.002	0
Total							1.5x10-7

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TABLE 15

PROBABILITY OF FLAMMABLE VAPOR CLOUD REACHING NUCLEAR FACILITY

(Based on 1981 Data)

	No. of Ships Per Year	Accidents Per Mile	Rammings Per Passage	Spills Per Accident	Vapor Cloud Per Spill	Meteorological Factor	Probability
LNG	0	2.3x10-6		0.1	0.1	0.354	0
LPG							
Propane	3	2.3x10-6		0.1	0.1	0.31	2.2x10-8
Butane	8	$2.3x10^{-6}$		0.1	0.1	0.32	$6.x10^{-8}$
Butadiene	6	2.3x10-6		0.1	0.1	0.25	3.45x10-8
Vinyl Chloride	0	$2.3x10^{-6}$		0.01	0.1	0.24	0
<u>Tower 97</u>							
LNG	0		$5x10^{-6}$	0.1	0.1	0.002	0
LPG	17		5x10-6	0.1	0.1	0.002	$1.7x10^{-9}$
Vinyl Chloride	0		$5x10^{-6}$	0.01	0.1	0.002	0
Total							1.2x10-7

APPENDIX

USCG CASE REVIEWS

INTRODUCTION

The following sections, denoted by U.S. Coast Guard Case numbers, discuss our interpretation of each of the 42 reported incidents during the period FY 79-FY 80. Each begins with a transcription of notes taken during the reading of the detailed accident report files of the U.S. Coast Guard. Generally, this is followed by supplemental data obtained from a Coast Guard-supplied computerized summary of accidents, and the rationale for our decision to include or not include the incident in the accident data base.

91586

Tow tug collided with barge, due to inattention of tug operator. At C&O Oil Pier, James River, Newport News, Virginia. Should not be counted, since it involves only small vessels, and did not even occur in the Delaware River.

91587

Tow tug lost power and collided with bulkhead between Pier 11 and Pier 12 North, Delaware River. Should not be counted, since it involves only a small vessel.

91703

Coal barge collided with Pier 11 South, at Port Richmond, Philadelphia. Should not be counted, since it it involves only a small vessel.

91724

Tow tug collided with ship, while docking at Mobil Oil Co. Pier, Paulsboro, New Jersey. Although it happened while docking, this case was conservatively included in the data base.

91788

Ship collided with pier, while docking. At Pier 122, Delaware River. Although it happened while docking, this case was conservatively included in data base.

92484

Ship collided with container crane, while undocking at Berth 5, Packer Ave. Marine Terminal, Philadelphia. Conservatively included in data base.

92579

Ship collided with container crane, while undocking at Packer Ave., Marine Terminal, Philadelphia. Conservatively included in data base.

92584

Barge in tow by tug collided with anchored dredge barge, in Schuylkill River. Should not be counted, since it involves only small vessels. Also, it did not occur in the Delaware River.

92594

Fishing vessel collided with Middle Thorofare Bridge, Wildwood, New Jersey. Should not be counted, since it did not happen in the Delaware River.

92596

Passenger vessel collided with Roosvelt Inlet Jetty at Lews, Delaware. In fog, trying to avoid an anchored pleasure boat. Should not be counted, since it occurred in a fog situation, when liquefied gas carries are prohibited from traveling.

92850

Fishing vessel collided with Middle Thorofare Bridge, Wildwood, New Jersey. Should not be counted, since it did not happen in the Delaware River.

92950

Barge in tow by tug collided with dike surrounding Reedy Island Dike South Light, Delaware River. Should not be counted, since it involved only one small vessel.

93170

Ship collided with walkway at Wilmington Marine Terminal, Christina River. Should not be counted, since it did not occur in the Delaware River.

93285

Motor boat collided with moored fishing vessel, at Bowers Beach, Delaware. Should not be counted, since it involved a motor boat, which is too small to create any damage when colliding with a liquefied gas carrier.

93569

Barge in tow of tug collided with anchored motor boat, in the New Haven Harbor Entrance Channel, on the Long Island Sound. Should not be counted, since it involves only small vessels. It also occurred outside the Delaware River.

94593

Ship collided with anchored ship, at Big Stone Anchorage, Delaware Bay. Due to mechanical failure. Although it involved an anchored ship, it was conservatively included in data base.

94999

Tug boat collided with bridge and pier at Hess Oil Docks, Delair, New Jersey. Should not be counted since it involved only one small vessel.

94601

Moored ship was damaged by surging in wake of a passing ship. At Arco, Fort Mifflin Dock, Delaware River. Should not be counted, since a liquefied gas carrier will not be moored or anchored in the 24 mile river segment of concern.

94602

Barge in tow by tug collided with the Tacony Palmira Bridge, Delaware River. Should not be counted, since it involved only one small vessel.

94603

Moored fishing vessel was damaged by driftwood, at Cold Fish House in Cape May, New Jersey. Should not be counted, since it did not occur in the Delaware River.

94606

Moored ship collided with Pier 1 at Getty Oil Terminal, Delaware City. Due to high winds. Should not be counted, since liquefied gas carriers will not be moored in the river segment of interest.

94671

Ship underway lost power and collided with anchored ship, near Brandywine Light, Delaware Bay, 9 miles northwest of Cape May, New Jersey. It happened at night, in fog conditions. Should not be counted, since it happened in a fog situation.

01140

Barge broke anchor due to high winds, and collided with dredge. At Marcus Hook Anchorage area, Delaware River. Should not be counted, since it involved only small vessels.

02412

Ship, while docking, collided with Pier E, Port Richmond, Philadelphia. Conservatively included in data base.

02415

Fishing boat collided with sail boat, east of Cape May Inlet, Cape May, New Jersey. Should not be included since it involved only small vessels.

02418

Moored ship broke anchor, drifted into channel, and damaged oil loading equipment. At Mobil Oil Terminal, Paulsboro, New Jersey. Should not be counted, since a liquefied gas carrier will not be moored on the river segment of interest.

02709

While undocking, ship collided with dock at Gulf Oil Co., Hog Island, Philadelphia. Conservatively included in data base.

02782

Dredge barge collided with ship while being passed, due to suction effect of ship wake. At New Castle Range, Delaware River. Although a liquefied gas carrier will not be involved in a passing situation, this case was conservatively included in the data base.

02920

Moored barge was damaged while surging due to wake of a ship which was docking. Should not be included, since it involved only a small vessel. At Gulf Oil Terminal, Hog Island, Philadelphia.

03404

Barge in tow by tug collided with anchored ship, at Big Stone Anchorage Area of Lower Delaware Bay. Although involving an anchored ship, this case was conservatively included in the data base.

03630

Ship, while docking, collided with dock at Arco Terminal, Fort Mifflin, Delaware River. Conservatively included in data base.

03827

Ship under tow by tug collided with pier while docking, and grounded at Northern Metals Terminal, Philadelphia. Conservatively included in data base.

03842

Barge in tow by tug collided with ship, while being passed and overtaken. At Liston Range, Delaware River. Conservatively included in data base, as with case 02782.

04975

While docking, ship collided with Pier, at Pier 14, Port Richmond Terminal, Philadelphia. Conservatively included in data base.

05144

Passenger vessel collided with moored fishing vessel, near Heterford Inlet Light, New Jersey. Should not be counted, since collision occurred outside the Delaware River.

05148

Tankship in tow by tug collided with pier while docking. Conservatively included in data base.

05150

Freight vessel collided with pier, while docking. Conservatively included in data base.

05154

Two tankers collided in fog, due to pilot error. At Hog Island Terminal, Delaware River. Should not be counted, since it occurred in a fog situation.

05155

Barge suffered damage due to unknown cause. Should not be counted, since it involves only one small vessel.

05160

Barge in tow by tug collided with vessel, due to mechanical failure of vessel. Included in data base.

05161

Barge in tow by tug collided with anchored barge, in a fog condition. Should not be counted, since it involved only small vessels and occurred in a fog situation.