AN ANALYSIS OF THE LIKELIHOOD OF WATERBORNE TRAFFIC AND OTHER FLOATING OBJECTS ON THE DELAWARE RIVER IMPACTING THE HOPE CREEK GENERATING STATION IN SEVERE STORMS

REPORT TO

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
NEWARK, NEW JERSEY 07101

BY

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REVISED REPORT

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1. INTRODUCTION

1.1 Introduction to Revised Report

Based on a request for clarification regarding the impact of waterborne objects on the Hope Creek Generating Station, Arthur D. Little, Inc. prepared a report dated July 1984 entitled, "An Analysis of the Likelihood of Waterborne Traffic on the Delaware River Impacting the Hope Creek Generation Station in Severe Storms." This report was formally submitted to the NRC in July and subsequently discussed with the NRC staff. In the course of that discussion the NRC requested that the report be expanded to include floating objects such as utility poles and trees in addition to waterborne traffic since such objects could compromise the leak-tightness of certain doors in the Hope Creek power block. In addition, whereas the previous report addressed the Probable Maximum Hurricane and the model hurricane, the NRC requested that an intermediate hurricane capable of flooding the grade at Hope Creek with water of depth three feet or more also be addressed.

This revised report with a slightly expanded title was prepared to address the expansions requested by the NRC. This revised report dated September 1984 replaces in its entirety the previous report of July 1984.

1.2 Background

The Public Service Electric and Gas Company (PSEG) is in the process of constructing the Hope Creek Generating Station (HCGS). The Hope Creek site is located on the Delaware River estuary near the southern end of an artificial peninsula known as Artificial Island. The site is located in Salem County, New Jersey.

As a part of the overall safety evaluation for the plant, the potential effects of waterborne traffic on the control room and water intake structure at HCGS were analyzed by Arthur D. Little, Inc. (ADL) in 1974 and described in a report (Reference 1) to PSEG. This study considered risks to the intake structure and the control room from barge and ship/tanker related spills. Significant findings of that study are contained in the Hope Creek FSAR.

In their review of certain portions of the Hope Creek FSAR, the Nuclear Regulatory Commission (NRC) raised certain new questions and requested clarification regarding the discussion of storm related high water events in the FSAR. In order to respond to those questions, PSEG asked ADL to assist them with the answers to those questions.

1.3 The NRC Request for Clarification

During their review of the FSAR, the NRC staff noted that the postulated maximum hurricane could result in a situation where there is as much as 12 feet of water on the Hope Creek site. Whereas the plant has been designed to safely withstand up to 12 feet of water above grade, such water depths could allow small draft marine vessels and other floating objects such as utility poles to enter the site should they lose power and steerage or are uprooted in a storm. The NRC requested an evaluation of this scenario from an overall plant safety perspective.

1.4 Objective of This Report

This report addresses three major objectives:

1. Although the NRC question addresses the postulated maximum hurricane, one objective of this report is to assess the probability of occurrence and the level of high water associated with these storm related events as follows:
   - o extreme wind events
   - o typical or "model" hurricanes
   - o a more severe hurricane leading to 3 ft. of water or more on grade
   - o postulated maximum hurricanes
2. The second objective is to profile the marine vessel traffic on the Delaware River and to estimate the likely population of runaway or out-of-control vessels.

3. Another objective is to develop a profile of floating objects other than marine vessels and assess their impact on the overall integrity of the plant.
4. The final objective is to utilize the information relating to storms and vessels to assess the overall probability of marine traffic on the Delaware River impacting the HCGS.

The approach taken in achieving these objectives is described below.

1.5 Approach

An evaluation of the likelihood of occurrence of the extreme wind events of concern, the model hurricane and the postulated maximum hurricane was conducted through an analysis of the site meteorology. This evaluation was performed by Meteorological Evaluation Services, Inc. for PSEG and is reported in Reference 2. The levels of high water associated with the storm situations of concern were determined using a site specific Delaware River Storm Surge Analysis model. This analysis was performed by Dames & Moore, Inc. for PSEG and is reported in Reference 3.

The profiling of traffic was based on information obtained in meetings and written communications with the U.S. Coast Guard Captain of the Port of Philadelphia (see Appendix A) and the United States Navy (see Appendix B). In addition, use was made of previous studies (Reference 1, 4, 5) and information obtained from contacts with the Philadelphia Maritime Exchange and the Pilots Association. Finally, information contained in the document "Waterborne Commerce of the United States" (Reference 6) issued annually by the Army Corps of Engineers was also analyzed to assess marine vessel distributions by draft.

The approach to assessing the likelihood of vessel impact during a storm was to utilize the characteristics of the storm events, the vessel population and marine casualty data from the U.S. Coast Guard Computerized Casualty files (Reference 7) and previous studies (Reference 1, 4, 5) to assess the overall probability of concern. Use was made of a Poisson failure rate model tied to the river/plant geometric configuration (see Appendix C) in the conduct of this evaluation.

Finally the non-marine vessels considered in this study included utility poles, houses, automobiles, fuel tanks and trees. These lighter, low kinetic energy per unit area objects were analyzed for their ability to strike metal doors in the power block with sufficient force to compromise the leak-tightness of the doors.

1.6 Assumptions in the Analysis

In performing the analysis and arriving at quantitative estimates of the probability of impact it became necessary to make certain assumptions regarding physical situations and failure rates. When such assumptions became necessary they were made in a conservative manner so as to ensure that the assumption led to an over-statement of the probability. As such, the final probability estimates reported here are deemed to be conservative over-estimates of the likelihood of occurrence of the events of concern.

A listing of the conservative estimates and assumptions utilized in this study is presented in Section 3.4.

2. DEFINITIONS OF PARAMETERS

2.1 Weather Event Scenarios

There are three meteorological events of concern to the current investigation. These include:

- o Extreme winds (no water on grade)
- o Typical (model) hurricanes (no water on grade)
- o Intermediate hurricane (3ft. of water or more on grade)
- o Probable maximum hurricanes (12 ft. of water on grade)

In each case, it was required that estimates be made of the probability that the event of concern would generate high tidal surges at the Hope Creek site. The meteorological analysis was conducted by Meteorological Evaluation Services, Inc. (MES) and is detailed in the July and August 1984 reports entitled "Hope Creek Generating Station Extreme Event Site Flooding Meteorology," (see Reference 2). Dames & Moore, Inc., was given the task to estimate peak surge water levels associated with various wind velocities and directions. Its findings are presented in detail in a report entitled "Storm Surge Calculations for Hope Creek Generating Station" (Reference 3).

Table 1 summarizes findings of MES with respect to extreme six-hour average wind speeds in the Artificial Island area as a function of a specific wind direction sector. The wind direction sectors noted thereon are those required for high water levels at the Hope Creek site. The analysis considers six-hour averages, since substantially shorter time periods would not permit the tidal surges of interest. Table 2 couples the MES findings with those of Dames & Moore to indicate the probabilities associated with various water depths above mean low water level at the Hope Creek site due to extreme wind effects. Since grade level at the site is approximately 11 feet above the National Geodetic Vertical Datum (NGVD), and since the NGVD is about three feet above the Mean Low Water (MLW) Level, it is apparent that there is negligible probability of significant flooding of the Hope Creek site due solely to extreme wind effects. However, it is also evident that water depths at

TABLE 1

HOPE CREEK GENERATING STATION ANNUAL PROBABILITIES OF EXTREME SIX-HOUR 33-FT. WIND SPEEDS BASED UPON 11 YEARS OF ARTIFICIAL ISLAND WIND DATA

Wind Direction: 79 - 170 (°AZ)

Annual Probability:	0.002	0.001
Corresponding Wind Speed (mph):	52	57

TABLE 2

INCREASED WATER DEPTHS AT HOPE CREEK WATER INTAKES DURING SELECT EXTREME WIND EVENTS

Annual Probability	Maximum 6-hr Average Wind Speed (mph)	Approximate Increased Water Depth (ft)
2×10^{-3}	52	9-12
1×10^{-3}	57	10-12

Note: 1. Data for maximum 6-hr average wind speeds as a function of annual probability were developed by Meteorological Evaluation Services, Inc. (MES)

2. Water depths presented are based upon results of Dames & Moore analyses.

3. Water depths herein are peak surge levels above mean low water. These are surge levels at the site considering the effect of open coast surge. Surge levels with 10 percent exceedance high tide are in the range of 6-7 ft for all cases.

4. An increased water depth of 12 ft over Mean Low Water at the service water intake results in a water level which is about 3 ft below plant grade.

the service water intake structure could approximate 28 feet under such conditions.

With respect to the typical (model) hurricane, MES has predicted an annual occurrence rate of 10^{-2}. Dames & Moore, in turn, has predicted a surge water level of slightly less than 14 feet above Mean Low Water. Thus, it is concluded that the model hurricane is also incapable of causing flooding at grade. It is, however, also capable of causing water depths on the order of 28-30 feet at the water intake structure.

The MES analysis predicts a 1×10^{-5} per year occurrence rate for the probable maximum hurricane. Dames & Moore predicts a surge level at the site that would produce a maximum 12 ft or so water depth over grade, with the time for initial flooding above grade to depletion of high water spanning a period of 6-8 hours. Marine vessels with less than 12 feet draft could enter the plant site under these conditions. Also the water depth at the intake structure could reach 40 feet for this unlikely, probable maximum hurricane.

2.2 Normal Vessel Traffic and Population

Appendix A describes a meeting and correspondence between Arthur D. Little, Inc. and the U.S. Coast Guard Captain of the Port, Philadelphia. These contacts permit estimates that:

- o There are about 50 large commercial vessels on the Delaware River and in port each day with drafts in the range of 18-40 ft.
- o Less than 80 tugs would be operating in the area on any given day.
- o There are about 4,500 recreational boats moored in the area.
- o There are roughly 150 barges on the Delaware River on any given day. Drafts of these range from a few feet when empty to 35 feet when loaded.

The intermediate hurricane was also analyzed by Dames & Moore as well as MES. The intermediate hurricane, one with sustained wind speeds of 80 mph or more, is capable of producing flooding on grade. Such a hurricane could result in the grade being flooded with 3 ft. of water with an estimated annual probability of 5×10^{-5}.

- o Larger vessels in the Philadelphia area generally use Marcus Hook or Mantua anchorages. There are 6-12 vessels in these locations on any given day.
- o There are contingency plans in place to increase vessel security in heavy weather.

Appendix B describes a meeting and correspondence between Arthur D. Little, Inc. and the Operations Officer of the Philadelphia Naval Shipyard. These contacts revealed that:

- o The shipyard has only one active ship (draft 25 ft). This would go out to sea or be more securely moored in the event of a hurricane.
- o There are typically 4-5 ships in the shipyard for overhaul.
- o There are 29 small craft, such as tugs or barges, in addition to camels which service overhaul efforts.
- o There are three cruisers, seven destroyers, and several submarines mothballed at the base.
- o Naval traffic on the Delaware River is relatively minimal.
- o There are no "Newport", "Anchorage", and "DeSoto" class Navy vessels at this yard.

The above data, together with information obtained from the Pilots Association and the Philadelphia Maritime Exchange, permit the following consolidated estimates with respect to the number of vessels travelling or moored in the overall area of interest on any given day.

- 60-70 self-propelled commercial vessels (excluding tugs)
- 100-150 non-self-propelled barges
- 70-80 captive (i.e., local) tugs
- 10-20 other tugs
- 6-12 large self-propelled vessels in anchorages to the south of Artificial Island
- 6-12 large self-propelled vessels in anchorages near the port of Philadelphia (north of the Hope Creek site)
- 2500-3000 recreational vessels actually in the water
- About 50 Naval vessels

2.3 Vessel Population and Traffic in Heavy Weather

U.S. Coast Guard contingency plans, as well as the desire of vessel owners/operators to safeguard their investments, indicate that vessel traffic upon the Delaware River would be greatly curtailed, if not completely halted, in the event of a severe storm. Larger vessels would have a live bridge watch and standby engine room personnel as mandated by the Coast Guard. All major vessels would be secured by additional anchors, longer anchor chains, and/or additional mooring lines. It follows that the key hazard to the Hope Creek plant would be from vessels that break mooring lines and become runaways, or in the case of larger vessels, simultaneous loss of power and steering capabilities after loss of mooring. Nevertheless, there may be a few vessels that fail to reach a safe anchorage or mooring area in time and these must also be given special attention.

It should be noted that both the model and probable maximum hurricane would be tracked from their initiation either in the Caribbean or the South Atlantic for several days prior to arrival in the vicinity of the State of New Jersey. At least twelve hours of warning would be available to Delaware River marine vessel operators of the arrival of an impending hurricane. Sufficient time is available to implement USCG plans and it is highly unlikely that there would be any vessel movement on the river.

The postulated high wind events are not as severe as the postulated scenarios for hurricanes. As such, at least six hours of persistant high winds are required to cause appreciable high water surges at Hope Creek. Once again six hours is sufficient time for marine vessel operators on the Delaware to seek shelter and secure mooring lines. Very few large ships may be underway with tug escort but it is highly unlikely that small craft or barge tows would be operating under these conditions.

Runaway Vessels

It is difficult to determine precisely the fraction of vessels in various size categories that might break loose of moorings during extreme wind or hurricane conditions. It is, however, feasible to formulate conservative estimates for the purposes of the current analysis. Such estimates are presented for the probable maximum hurricane in Table 3 for the total vessel population in the Delaware Bay to Philadelphia area.*

It is highly significant that weather conditions associated with high water levels at Hope Creek, these being the conditions of specific interest to the current analysis, require winds blowing from a generally easterly to southerly direction, and that any vessels drifting in such weather on the Delaware River will travel in a generally northerly direction. This indicates that only vessels to the south of Hope Creek are of concern as potential missiles impacting Hope Creek facilities. Since the shoreline to the south of Hope Creek is relatively devoid of highly populated or developed areas (in comparison with northern reaches of the river), it becomes necessary to account for the fact that the vast majority of runaways will occur north of the subject site and proceed in a direction away from the site.

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*These estimates for the probable maximum hurricane are conservatively assumed to apply to the less severe intermediate and model hurricanes and the extreme wind events of concern.

TABLE 3

TOTAL RUNAWAY VESSEL ESTIMATES FOR STORMS*

Vessel Type	Total Number	Assumed** Percentage Runaways	Total Number Runaways
Self-propelled	70	2%	1.4
Non-self-propelled	150	5%	7.5
Tugs	100	2%	2
Recreational boats	3000	25%	750
Navy vessels	50	1%	0.5

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*Note that most of these vessels are substantially north of the Hope Creek site. In any postulated high wind/high water scenario any runaway vessel would be pushed north. As such only vessels to the south of Hope Creek are vessels of possible concern.

**Conservative estimates based on discussions with the U.S. Coast Guard, the Pilots Association and the Philadelphia Maritime Exchange.

As noted earlier, it has been determined that there are typically 6-12 large self-propelled vessels in the Bombay Hook Point anchorage approximately 10 miles to the south of Hope Creek. For barge tows, it is relatively conservative to assume that no more than one tow of 4 barges might be forced to moor south of Hope Creek in the Bombay Hook Point anchorage due to a lack of time for reaching a safer location. In making this assumption, it is noted that there are no barge terminals or ship moorings within a 20 mile distance to the south of Hope Creek. Tow operators would not wish to be found in this area in foul weather unless forced by unavoidable circumstances. The one tow would be associated with one tug. For reasons similar to those given above, no more than three additional tugs would be expected in the area.

The Delaware Bay and River sections to the south of Hope Creek have relatively unpopulated coastlines with few roads and few facilities that might be described as marinas. Given this fact, and the fact that the vast majority of recreational boats are found in populated areas far to the north of Hope Creek, it is assumed that no more than 10 recreational boats would somehow be forced to find shelter by mooring on the Delaware River in the area immediately to the south of Hope Creek.

The U.S. Navy has indicated that it has but one active ship in Philadelphia Navy yard and that this ship goes out to sea only twice a month, unless ordered to do so to avoid being in port in a hurricane. It is therefore considered conservative to assume that this vessel would not be in the Hope Creek area during those times it would be vulnerable to the effects of a storm.

Table 4a summarizes the results of the evaluation for vessels to the south of Hope Creek with the potential for becoming runaways.

Vessels Enroute

There is always a chance that a few vessels may attempt to outrace a storm to their ultimate destination. It is therefore assumed there might be two recreational boats and one large self-propelled vessel actually moving on the river intentionally under storm conditions. These are shown in Table 4b.

TABLE 4a

EXPECTED NUMBER OF RUNAWAY VESSELS MOVING NORTH FROM THE SOUTH OF ARTIFICIAL ISLAND IN A PROBABLE MAXIMUM HURRICANE*

Vessel Type	Number To South	Assumed Percentage Runaways	Number Southern Runaways**
Self-propelled	6-12	2%	0.24
Non-self-propelled	4	50%	2.00
Tugs	4	2%	0.08
Recreational boats	10	25%	2.50
Navy vessels	0	1%	0.00

TABLE 4b

EXPECTED NUMBER OF VESSELS INADVERTENTLY MOVING UPRIVER FROM THE SOUTH OF ARTIFICIAL ISLAND IN A PROBABLE MAXIMUM HURRICANE*

Vessel Type	Number
Large self-propelled	1
Recreational	2

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*These estimates for the probable maximum hurricane are conservatively assumed to apply in the event of less severe events such as the model hurricane and the extreme wind events.

**The non-self-propelled barges and unmanned recreational boats are true runaways in that they will move as directed by the wind and surface currents. The self-propelled vessels, tugs, and Navy vessels may break mooring but could still be controlled using their own power and steerage. Should they subsequently lose both power and steerage they would be classified as runaways as well.

2.4 Resistance to Damage of Category I Structures to Recreational Boat Impacts

One of the possible results of a probable severe storm on the Delaware River could be that anchored, moored, or underway recreational boats could become unsecured or lose control under the action of the wind and waves and, as a runaway, impact the Category I structures (e.g., the service water intake structure) at the Hope Creek Generating Station. The question is whether, under such impact conditions, the Category I structures could be damaged to the extent that their ability to function is compromised. To examine this question, an evaluation is made of recreational boat impacts on Category I structures under the most severe storm postulated -- the probable maximum hurricane.

The Category I structures are designed to withstand severe design loadings based on extreme external and natural hazard conditions. These include seismic effects to the entire structure and to major components and structural elements within the structure, tornado loads, and hurricane and storm winds and flooding conditions. As a result, the Category I structures are typically of heavily-reinforced concrete construction with wall structures of thicknesses of two feet or more.

One of the structural design requirements of these structures is its ability to resist the impacts of tornado-generated missiles. Several types of missiles must be considered in this regard, including wood planks, utility poles, steel pipe, and even entire automobiles. The total kinetic energy of these design missiles range from 5000 to 1,800,000 ft-lbs. On an impact area basis, the design missiles are typically in the 150,000 to 700,000 ft-lbs per ft^2 of impact area. In one series of tests (see Reference 8) using a utility pole missile, 13.5" in diameter, 35 ft long, and weighing about 1500 lbs, was driven against a 12" thick reinforced concrete wall panel at 140 mph. The result was the splintering of the end of the pole into many small pieces and negligible structural damage to the concrete.

The kinetic energy of these utility pole missiles was about one million ft-lbs, and also was about one million ft-lbs per ft^2 of impact area. A very large recreational boat might be of the order of 10 tons. It would generate 100,000 ft-lbs of kinetic energy travelling at about 12 mph, or 10 knots. It's kinetic energy per unit area would be in the range of 1,000 ft-lbs per ft^2 of impact area. Thus, although the total energy of a boat impact could be about the same as a utility pole missile, the unit load on the wall structure would be much less. The pole, furthermore is dense and strong in axial end-loadings, while a typical boat bow-structure is not designed for major head-on impacts. On this basis, we believe that is it reasonable to conclude that the impact of large pleasure boats, wind and wave driven, against the concrete walls of Category I structures would result in severe damage to the boat and negligible damage to the concrete structure, either locally or over an extended structural area. Such events would be similar to impacts of boats or sailing vessels against sea walls or breakwaters. Impacts of boats wind and wave driven by squalls or storms against sea walls or other shoreline structures is a fairly common event. Invariably, the results in such accidents is severe damage to the boat and negligible effects to the shore structure.

There is other evidence to support this conclusion. Model studies (see Reference 9) carried out on collisions between two ships of differing impact strength have shown that the distribution of the structural damage between the two ships is quite sensitive to the relative strength or structural resistance of the two ship structures, with the weaker of the two absorbing most of the impact energy and hence being destroyed one-sidedly. On this basis, it would seem reasonable to conclude that if a boat collided with the relatively massive reinforced concrete Category I structure, most of the impact energy could be dissipated in damage to the boat. The Category I structure would not experience significant damage and would continue to meet its functional requirement.

As a result of the above considerations, recreational boats are not considered an issue of concern in this analysis and are not considered potential vessels of concern.

2.5 Total Traffic of Concern

Based on the previous discussions and the data in Tables 4a and 4b, a summary table is shown in Table 5 which identifies the total vessel population of potential concern in a storm related situation on the Delaware River. In viewing Table 5 it should be kept in mind that the non-self-propelled vessels are barges with drafts in the range of 3 feet (empty barges) to up to 40 feet (loaded ocean going tanker barge). The commercial self-propelled vessels have a draft range from 5 feet to 49 feet. The barges (non-self-propelled vessels) are considered true runaways and will move vectorially in a vector that is typically the sum of the surface current vector and three to five percent of the wind velocity vector (Reference 10). The self-propelled vessels are potential drifting objects only if they lose both power and steerage.

2.6 Resistance of Doors to Other Floating Objects

GENERAL

The safety class structures and components of a nuclear facility must be designed to remain functional following the possible exposure to floating missile impacts resulting from the extreme environmental conditions associated with storm winds and floods. Such events can generate potentially damaging missiles from a variety of objects which are in the path of the storm winds.

The characteristics of objects which define their behavior as missiles are their shape, density, surface area, and the maximum velocity they attain. The effects of impact of missles on a target structure depends on these missile characteristics and on the geometry and material of the target. In some cases, the impact process may be local, or take place so rapidly that it can be considered to have only local effects. In other cases, the duration of the load is long enough, or the impact areas is large enough relative to the structural dimensions, so that the target structure will experience a gross response over the entire structure.

The missiles considered were utility poles, automobiles, houses, fuel tanks and trees. This listing of potentially damaging missiles

TABLE 5

TOTAL TRAFFIC OF CONCERN

Vessel Type	Potential Runaway*	Runaway
Self-propelled	1.3	-
Non-self-propelled	-	2
Tugs and Navy vessels	negligible	negligible

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*A distinction is made between self-propelled and non-self-propelled vessels. A self-propelled vessel is a potential runaway since it first must lose power and steering prior to becoming a runaway vessel moving with the wind and current.

during floods and severe storms was developed in discussion with the United States Army Corps of Engineers in Washington, D.C. In particular, Mr. Henry Campbell, Operations Branch, was most helpful in developing this list.

DESIGN MISSILES

At the present time, design criteria for environmentally-damaging missiles have not been established by the NRC or by any industry agency. The missiles considered for the analysis of the door structures at HCGS included the following, based on Bechtel Design Guidelines:

- Telephone Pole 1490 lbs, 13½" round cross-section, impact velocity of 20 mph
- Automobile 4000 lbs, 20 ft^2 frontal area, impact velocity of 20 mph
- House 4000 lbs, 50 ft^2 frontal area, impact velocity of 20 mph

In addition to these missiles, the possibility exists at the HCGS for a wind- and water-driven marine vessels, such as a recreational boat*, impacting the door structures at times of extreme high tidal and wind conditions. Such a design missile was assumed to have the following characteristics:

- Boat 25,000 lbs, 10" round cross-section, impact velocity of 20 mph

It should be noted that floating objects are driven by both the wind and the surface current (or wave break effects near shorelines). The wind driven speed is between 3% and 5% of the wind speed. For the PMH this would translate to a maximum velocity of 7.5 mph. The current and/or wave effect could add up to 5.5 mph to this value for a maximum missile speed of 12 mph. A highly conservative value of 20 mph is used in this report.

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* Since recreational boats were not found to impact the plant in a manner as to compromise plant integrity, they are examined here. All other marine vessels are considered in the probability analysis in the next section.

Finally, trees and floating fuel tanks were also considered and found to be structurally weak from a "battering" point of view or having a kinetic energy per unit impact area smaller than the missiles already considered.

DOOR CONFIGURATIONS

The size of the doors considered in this analysis ranged from 3 ft by 7 ft for the smallest to 14 ft by 18 ft for the largest. Each door is fitted with double inflatable seals which control the leakage around the door periphery to a constant amount over an extension of the seal from 0" to 7/16". For some doors, the double seals are arranged in the door jamb, such that lateral deformation of the door compresses the inner seal, thereby maintaining leak tightness over a wide range of door deformations. For other doors, the double seals are outside the door opening, in the plane of the doors, with the doors larger than, and overlapping, the door opening. For this geometry, lateral deflection of the door will increase the gap at both of the seals as the door structure pivots about the edge of the door opening.

ACCEPTANCE CRITERIA

Two conditions were required for the acceptance of the door design under the postulated missile loadings:

- Structural Integrity of the door structure, based on a maximum permissible ductility ratio of 10, and
- Leak Tightness, with a maximum permissible displacement at the seals of 7/16".

ANALYSIS METHODS

- Structural Integrity: Each of the missiles was assumed to impact the door structures at the center of the door, and the entire kinetic energy of the missiles was equated to the strain energy of the door as it deformed under the impact loading. The structural behavior of the door was assumed to be elastic-perfectly plastic, and the maximum deformation at the center was limited to 10 times the elastic deflection at yield stress (i.e., ductility ratio of 10).

- o Leak Tightness: A simple geometric model was used to evaluate the increase in the gap at the seals in relation to the deformation of the center of the door. The elastic component was based on a deflection curve appropriate for a center-loaded beam, and the plastic component was based on the rotation of the door about the pivot at the door edge.

RESULTS

Based on these analysis procedures, all of the individual doors were determined to meet the above acceptance criteria.

CONCLUSIONS

The adequacy of the various door structures on the safety class structures at HCGS in resisting a variety of missiles generated under extreme environmental storms and flood conditions has been evaluated. The design missiles included such objects as wind-and-water-driven telephone poles, an automobile, a small house structure, and a pleasure boat. The door structures were evaluated for their resistance to such missiles for criteria based on the stress and deformation limits of the doors as centrally-loaded plate structures, and for the displacement limitations of the seals around the periphery of the doors which control the leak tightness.

The results of this evaluation indicated that all the door structures were acceptable as currently designed.

2.7 Site Impact Probability Assessment Model

Based on information contained in previous sections the Hope Creek site impact assessment model is based on the following:

1. All critical safety related structures at the Hope Creek site are contained in the 750 foot radius circle with the radius connecting the water intake structure and the control room.

2. The water intake structure is approximately 120 feet long and is assumed to be parallel to the shore line.

3. For the case of the probable maximum hurricane, it is assumed that all vessels of concern regardless of draft (see Table 5) can potentially strike the intake.

4. For the case of the probable maximum hurricane, the water levels over plant grade are such that only barges with drafts under 12 feet can enter the 1500 foot diameter circle and therefore be of potential concern. However, to maintain conservatism it has been assumed that all vessels, regardless of draft, shown in Table 5 can enter the site.

5. For the case of the extreme wind events and the model hurricane, regardless of draft, it is assumed that all vessels shown in Table 5 can strike the water intake.

6. Self-propelled vessels which move up towards Hope Creek from the south are tracked for purposes of this model once they are within 10 miles of Hope Creek and should they lose power and steerage they could potentially strike the intake or enter the plant site.

7. Non-self-propelled vessels (barges) moving towards Hope Creek from the south are tracked (for purposes of this model) once they are within 10 miles of the plant.

8. Runaway vessels along a river may ground, capsize, sink, or remain floating free depending upon a complex function of wind and current velocities/directions, vessel characteristics, and river characteristics.

9. Appendix C addresses the probability that a vessel enroute in severe weather would lose power and steering and become a potential missile that impacts the service water intake structure or enters the Hope Creek site

It should also be noted that the service water intake structure is approximately 120 feet in length along its single potentially vulnerable surface and is a massive structure constructed of reinforced concrete slabs, most of which are two to three feet thick, with the reinforcement cover generally equal to two or three inches. Only two of the four water intake pumps are required to be fully operational to permit safe plant shutdown.

3. PROBABILITY ESTIMATES

Based on information contained in the previous sections and Appendix C it is now possible to estimate the probability of various classes of marine vessels impacting either the Hope Creek site or the water intake structure during postulated storm situations. The two major areas of concern, the water intake structure and the 1500 ft diameter area which constitutes the power block area of the plant are discussed in turn.

3.1 Cooling Water Intake Structure

The cooling water intake structure is about 120 ft long and during any of the four postulated storm events the water depth at the structure could exceed 28 to 30 ft. The two discrete (and independent) events of concern which are evaluated here are extreme winds and hurricanes. The hurricane is a single discrete event of concern but, with some conditional probability, may occur at one of three levels of severity: model; intermediate; and probable maximum. Each discrete storm event is examined in turn for probability of impact.

3.1.1 Extreme Wind Events

Extreme wind events are more common than the model hurricane but at least six hours of high winds blowing from certain key directions is necessary to create a high water situation at the intakes. In the event of the postulated high wind event the water depth at the water intakes could be as much as 30 feet. It is assumed, however, that all vessels of concern (with drafts up to 30 or even more) can potentially strike the intake.

Self-Propelled Vessels Which are Potential Runaways

Probability of occurrence of the high wind event:	2×10^{-3}
Number of potential runaway vessels:	x 1.3
Probability of intake impact given the vessel loses power and steering:	x 2.1×10^{-6}
Annual probability of a potential runaway impacting the Hope Creek water intake structure:	5.2×10^{-9}/yr

Non-Self-Propelled Runaway Vessels (Barges)

Probability of occurrence of the high wind event:	2×10^{-3}
Number of runaway vessels:	x 2.0
Conditional probability of runaway vessel entering the vicinity of Hope Creek (i.e., within 10 miles) prior to grounding and sinking:	x 0.1
Probability of impacting the water intake structure:	x 1.2×10^{-5}
Annual probability of a runaway vessel impacting the Hope Creek water intake structure:	4.8×10^{-9}/yr

3.1.2 Hurricanes

A. Probable Maximum Hurricane

Self-Propelled Vessels Which are Potential Runaways

Probability of occurrence of PMH:	1×10^{-5}/yr
Number of potential runaways:	x 1.3
Probability of runaway impacting the Hope Creek cooling water intake structure given the vessel loses power and steering:	x 2.1×10^{-6}
Annual probability of a potential runaway impacting the Hope Creek cooling water intakes:	2.7×10^{-11}/yr

Non-Self-Propelled Runaway Vessels (Barges)

Probability of occurrence of PMH:	1×10^{-5}/yr
Number of runaway vessels:	x 2.0
Conditional probability of runaway vessel entering the vicinity of Hope Creek (i.e., within 10 miles) prior to grounding or sinking:	x 0.1
Probability of impacting the cooling water intakes once the vessel is within ten miles of Hope Creek:	x 1.2×10^{-5}
Annual probability of a runaway impacting the cooling water intakes during a probable maximum hurricane:	2.4×10^{-11}/yr

B. Intermediate Hurricane

The probability calculation for this case is similar to that for the PMH except the initial probability of occurrence for an intermediate or larger hurricane is 5×10^{-5}/yr. As such, for this integration process where the ultimate probabilities will be added, the initial term is 4×10^{-5}/yr.* The final probabilities are as follows:

Self-Propelled Vessels Which are Potential Runaways

Probability of a potential runaway impacting the cooling water intake structure:	1.1×10^{-10}/yr

Non-Self-Propelled Runaway Vessels (Barges)

Probability of a runaway impacting the cooling water intake structure	1×10^{-10}/yr

C. Model Hurricane

Once again the probability calculation is similar to that for the other hurricanes except that the initiating event probability is 10^{-2}/yr**. The probability calculations are as follows:

Self-Propelled Vessels Which are Potential Runaways

Probability of a potential runaway impacting the Hope Creek cooling water intake structure:	2.7×10^{-8}/yr

Non-Self-Propelled Runaway Vessels (Barges)

Annual probability of a runaway vessel impacting the Hope Creek cooling water intake structure:	2.4×10^{-8}/yr

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* This represents the exceedance probability of occurrence for the intermediate hurricane less the probability of occurrence of the PMH.

** This value is the exceedance probability of occurrence for the model hurricane less the probability of occurrence for the intermediate hurricane.

3.1.3 Total Cooling Water Intake Impact Probability

Adding the above estimated probabilities of impact, the annual probability of a marine vessel on the Delaware River impacting the Hope Creek cooling water intake structure is 6.1×10^{-8}/yr.

3.2 Hope Creek Site Impact

In the context of this study, the Hope Creek site is defined as the 1500 ft diameter circle with the center at the control room and the radius extending the cooling water intake structure. This circle includes the entire power block.

Based on the discussion in Section 2 of this report, the plant site can only be impacted provided there is water on grade. Of the two discrete storm events considered here, high winds and hurricanes, the high wind event does not result in any flooding of the grade at Hope Creek. The hurricane event is analyzed at three levels of severity. The model hurricane does not result in flooding of grade and a more severe hurricane is required to flood the Hope Creek site with 3 ft or more of water depth. As a result, only the intermediate hurricane and the PMH are of concern to the plant site impact analysis.

3.2.1 Probable Maximum Hurricane (PMH)

During a probable maximum hurricane, only vessels with draft of less than 12 feet can potentially enter the 1500 foot diameter plant site but most vessels on the river can potentially strike the 120 foot intake structure. For reasons of conservatism it has been assumed that all vessels can potentially enter the plant site.

Self-Propelled Vessels Which are Potential Runaways

Probability of occurrence of PMH:	1×10^{-5}/yr
Number of potential runaway vessels:	x 1.3
Probability of runaway entering the Hope Creek Site given the vessel loses power and steering:	$\times 2.5 \times 10^{-4}$
Annual probability of a potential runaway entering the Hope Creek Plant Site:	3.2×10^{-9}/yr

Non-Self-Propelled Runaway Vessels (Barges)

Probability of occurrence of PMH:	1×10^{-5}/yr
Number of runaway vessels:	x 2.0
Conditional probability of runaway vessel entering the vicinity of Hope Creek (i.e., within 10 miles) prior to grounding or sinking:	x 0.1
Probability of entering the Hope Creek site once the vessel is within ten miles of Hope Creek:	$\times 3.1 \times 10^{-3}$
Annual probability of a runaway entering the Hope Creek site during a probable maximum hurricane:	6.2×10^{-9}/yr

3.2.2 Intermediate Hurricane

The intermediate hurricane can be exceeded with an annual probability of 5×10^{-5}/yr. The probability of the more severe PMH is 1×10^{-5}/yr. As a result, for purposes of integrating all hurricane events the likelihood of a hurricane at least as severe as an intermediate hurricane but less severe than the PMH is 4×10^{-5}/yr. This hurricane, should it occur, could result in the grade at Hope Creek being flooded with water to a depth of greater than 3 ft. Clearly, most large draft marine vessels would ground prior to entering the site. For reasons of conservatism, however, it has been assumed that all vessels can potentially enter the site. With the above factors and a probability calculation similar to that for the PMH except for a larger initiation event probability, the estimates for impact probability are as follows:

Self-Propelled Vessels Which are Potential Runaways

Annual probability of a potential runaway entering the Hope Creek plant site:	1.3×10^{-8}/yr

Non-Self-Propelled Runaway Vessels (Barges)

Annual probability of a runaway entering the Hope Creek site:	2.5×10^{-8}/yr

3.2.3 Total Hope Creek Site Impact Probability

Adding the above estimated probabilities of impact, the annual probability of a marine vessel on the Delaware River impacting the Hope Creek site itself is 4.7×10^{-8}/yr.

3.3 Summation of Probabilities

Based on the above, the combined probability of the service water intake structure at Hope Creek being impacted by any vessel for any postulated storm condition is 6.1×10^{-8} occurrences/year.

Similarly, the combined probability of the Hope Creek site being impacted by any vessel for the case of a hurricane is 4.7×10^{-8} occurrences/year.

3.4 Conservative Nature of the Probability Estimates

The probability estimates presented in this report for the combined probability of a vessel impacting the service water intake as well as the combined probability of a vessel entering the Hope Creek site during storm conditions are conservative in nature. Each combined probability is composed of several initiating events and conditional events and many of these sub-elements are overestimated. The net result is that the combined probabilities of interest are also conservative, overestimates of the likelihood of occurrence. Some of the conservative estimates include the following:

1. The lines fitted to the Frechet distribution plots of the extreme wind speeds were drawn in a conservative manner. The higher observed wind speeds were given more weight in the distribution.

2. The large width of the 79-170 (°Az) sector used as a persistence criteria for the six-hour wind speed analysis.

3. For the typical or model hurricane producing very serious surge effects, the intensity, course and transport speed would all have to be synchronized with the normal tidal oscillation. Therefore the value of 10^{-2} is conservative by a significant amount, probably by half an order of magnitude.

4. The great rarity of the PMH is emphasized by the fact that between 1899 and 1982, no storm having the calculated maximum wind value of 142 mph or greater (NOAA Classes 4 or 5) has made a landfall anywhere north of Cape Hatteras. A conservative probability of occurrence of 1×10^{-5}/yr has been utilized.

5. The surge calculations are based on steady-state conditions which result in an overprediction of build-up of water at the Hope Creek site. Such ideal steady-state conditions do not occur in actual storms and such storms would not cause the degree of high water predicted and would in actuality result in lower water levels than has been used in this report.

6. The well developed United States Coast Guard plan for Delaware River traffic under severe storm conditions should preclude any large vessel from becoming a runaway. Yet it has been conservatively assumed that some runaways of significant draft would be found during the storms of concern.

7. In the event of an intermediate hurricane, the water depth on grade at Hope Creek would only be about 3 ft. In spite of this fact it has been assumed that the total population of potential marine vessel "missiles" could enter the site.

8. In the event of a PMH, the grade at Hope Creek could be covered by about 12 ft of water. Vessels with draft in excess of 12 ft would not be able to drift onto the site. Yet, in order to be conservative it has been assumed that all runaway vessels, regardless of draft, are a potential concern and could enter the site.

9. Similarly, for the extreme wind events and model hurricanes it was assumed that all vessels regardless of draft would be of concern and could potentially reach the service water intake structure. In actuality many large vessels would ground or sink prior to reaching the structure.

10. The damage potential of missiles is related to its kinetic and as such depends on the square of the velocity. Although it is highly unlikely that a floating missile would exceed a speed of 12 mph, a value of 20 mph was used in this analysis. This introduces a degree of conservatism of a factor of 3 in the damage estimates.

4. REFERENCES

1. "Analysis of Potential Effects of Waterborne Traffic on the Safety of the Control Room and Water Intakes at Hope Creek Generating Station", Arthur D. Little, Inc. Report 77289 to Public Service Electric and Gas Company, September 1974.

2. "Hope Creek Generating Station Extreme Event Site Flooding Meteorology", Meteorological Evaluation Services, Inc., to Public Service Electric and Gas Company, July 1984. Also see Supplemental Report, August 1984.

3. "Storm Surge Calculations for Hope Creek Generating Station", Dames & Moore, Inc., to Public Service Electric and Gas Company, July 1984.

4. "Monitoring LNG and LPG Shipping and Construction Activity in the Vicinity of the Hope Creek Generating Station", Arthur D. Little, Inc., Report 83202 to Public Service Electric and Gas Company, October 1979.

5. "An Update of the Analysis of Potential Effects of Waterborne Traffic on the Control Room and Water Intakes at Hope Creek Generating Station", Arthur D. Little, Inc., Report 88536 to Public Service Electric and Gas Company, March 1983.

6. "Waterborne Commerce of the United States", Part 1 - Waterways and Harbors - Atlantic Coast, 1981, Department of the Army, Corps of Engineers.

7. "Marine Casualty Computer Data", Office of Merchant Marine Safety, United States Coast Guard, Washington, D.C., 1968-1982.

8. EPRI HP-440, "Full Scale Tornado-Missile Impact Tests", Feb. 1978.

9. "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.

10. "Search and Rescue" Manual prepared and utilized by the United States Coast Guard. Revised Edition 1976.

APPENDIX A

COMMUNICATIONS WITH U.S. COAST GUARD CAPTAIN OF THE PORT, PHILADELPHIA

Acorn Park
Cambridge, Massachusetts 02140
617 864-5770 Telex 921436

Arthur D. Little, Inc.

April 12, 1984

Lt. Robert Francis
United States Coast Guard
King and Cumberland Streets
Gloucester City, New Jersey 08030

Subject: River Traffic and Contingency Plans

Dear Lt. Francis:

Many thanks to you and your colleagues for taking time to meet with me on April 10, 1984. As you recall, we are under contract to Public Service Electric and Gas Company to perform a study which requires us to further our understanding of the marine vessel traffic in the Port of Philadelphia/Delaware River and to learn about the contingency plans that have been formulated in case of hurricanes. This correspondence will confirm the details of our conversation.

Marine Vessel Traffic

- There are typically no more than 50 large vessels in port each day on commercial business. These vessels include oil tankers, container ships, etc., which have drafts of approximately 18-40 ft.
- As there are 20 tug companies in the Philadelphia area which operate an average of four tugs each, there are approximately 80 tug boats. They have a draft of 12-13 ft.
- It is difficult to estimate the exact number of barges that are typically found on the Delaware River on any given day. A rough estimate is approximately 150 on an average day. While the draft of these barges can range from 3 to 35 ft, the majority have a draft of 4-5 ft when empty and 12 ft when loaded.
- There are about 130 marinas on the Delaware River with an average of 100 moorings each. Thus, it is estimated that there are approximately 13,000 smaller recreational boats with lengths less than 45 ft and an average draft of 3-4 ft.

Brussels Houston London Los Angeles Madrid Paris Rio de Janeiro San Francisco São Paulo Tokyo Toronto Washington Wiesbaden

Arthur D. Little, Inc.

Lt. Robert Francis
United States Coast Guard

April 12, 1984

Page 2

<u>Anchorages</u>

- There are 16 anchorages on the Delaware River. The average number of ships per anchorage is variable and a function of the size and type of the ships. Selection of anchorages is made by the pilots.

<u>Hurricane Contingency Planning</u>

- Hurricanes in the Port of Philadelphia are typically "not that traumatic" as their counterclockwise winds "lose their punch" on the mandatory travel over land as they approach Philadelphia. Thus, vessels up the river are better protected than those near the mouth of the Delaware River or those out to sea. With at least one day's notice for a hurricane, there is adequate time to seek a protected berth.

- The contingency plan for the Port of Philadelphia, which includes a plan for heavy weather, is presently undergoing major revisions and updates. It will be completed during the next year.

- At present, there are emergency procedures for heavy weather that states, "Have boats removed from the water or anchor in a safe anchorage area as directed by the Commanding Officer." Furthermore, there are procedures for recommendations made on radio broadcasts. When winds are in excess of 25 knots, broadcasts are made that recommend a live bridge watch and a 30-minute standby for the main propulsion machinery. With winds in excess of [illegible]0 knots, the latter should be on immediate standby. On an event specific basis, telephone calls might be made to recommend doubling up." Similarly, the Captain of the Port might make further recommendations on the location, manning or security of vessels if the situation warranted it.

- It is fairly routine that the usual anchor length of 5 times the depth be extended to 7 times the depth in a storm situation, which is particularly important in this area where there is a soft bottom.

We would appreciate your confirming the accuracy of the information presented in this document in a letter to be sent to me.

Again, our sincere thanks for your assistance.

Yours truly,

Marian H. Long

Marian H. Long

MHL/rs
Enclosure

U.S. Department of Transportation
United States Coast Guard

Captain of the Port, Philadelphia

U.S. Coast Guard Base
Gloucester City, NJ
08030

16000

MAY 18 1984

Ms. Marian H. Long
Arthur D. Little, Inc.
Acorn Park
Cambridge, MA 02140

Dear Ms. Long:

As requested in your letter of 12 April 1984, this letter will clarify and confirm the information exchanged during our meeting on 10 April 1984.

Marine Vessel Traffic

1. Excluding the vessels that would be in the Delaware Bay and the C & D Canal, the 50 ship average is a reasonable maximum figure.

2. Of the estimated 80 tugs homeported in the Philadelphia Port, a varying percentage will be away from this port on business, and a number will be in drydock at any given date. Additionally many of these tugs are relatively small, low powered vessels that would have a very limited role in contingency planning.

3. The number of barges on the Delaware River includes oil, chemical and construction barges.

4. There are approximately 60 marinas on the Delaware River with an average of 75-100 moorings each. This would make an average of 4,500 recreational boats in the area, excluding trailered boats.

Anchorages

1. The larger vessels would generally use the Marcus Hook or Mantua anchorages. On a typical day there would be between 6 and 12 vessels utilizing the anchorages.

Hurricane Contingency Planning

1. Although the statement regarding hurricanes is generally correct, I would not count on storms losing their punch for contingency planning purposes. As I recall, the strongest winds ever recorded in the continental United States area were at Mt. Washington NH in the September 1938 storm. This storm went inland at Connecticut.

2. The statement about the heavy weather plan revisions is correct.

16000
MAY 18 1984

3. In the third statement, the sentence "have boats removed from the water or anchor in a safe anchorage area as directed by the Commanding Officer" pertains strictly to our own bases boats. The remainder of this statement which pertains to commercial vessels is correct. It should also be noted that under existing regulations, the COTP may require vessels to use two or more anchors when deemed necessary.

4. The statement regarding anchor chain length is correct.

Sincerely,

D. B. Charter
D. B. CHARTER JR.
Captain, U.S. Coast Guard
Captain of the Port,
Philadelphia

APPENDIX B

COMMUNICATION WITH PHILADELPHIA
NAVAL SHIPYARD

Acorn Park
Cambridge, Massachusetts 02140
617 864-5770 Telex 921436

Arthur D. Little, Inc.

April 12, 1984

Lt. Richard Oftedal
Attention: Code 810
Philadelphia Naval Shipyard
Philadelphia, Pennsylvania 19112

Subject: Naval Traffic and Severe Weather Contengency Plans

Dear Lt. Oftedal:

Many thanks to you for taking time to meet with me on April 10, 1984. As you recall, we are under contract to Public Service Electric and Gas Company to perform a study which requires us to further our understanding of the marine vessel traffic in the Port of Philadelphia/Delaware River and to learn about the contingency plans that have been formulated in case of hurricanes. This correspondence will confirm the details of our conversation.

- The Philadelphia Naval Shipyard has one active ship, which is the USS Patterson, a 438 ft frigate with a draft of 25 ft. It travels up and down the Delaware River twice each month.

- There are typically four or five ships in for overhaul. The length of stay ranges from approximately seven months to over two years. Frigates and cruisers that have a draft of 22-29 ft are serviced in approximately one year. It is taking two and one-half years to service the USS Forrestal, an aircraft carrier with a draft of 37 ft. In addition to entering and leaving the Port, the ships undergoing service make one trial run out to sea and back.

- There are 29 small craft, such as tugs and barges, in addition to camels which service the overhaul efforts.

- In the event of a hurricane, the USS Patterson, which is typically secured with six standard mooring lines, would possibly go out to sea. If it did stay in port, extra mooring lines would be used, an anchor would be dropped on the foot and a chain might be used to secure it to the pier. The service crafts would be moved off the windward sides of the piers and secured.

Brussels Houston London Los Angeles Madrid Paris Rio de Janeiro San Francisco São Paulo Tokyo Toronto Washington Wiesbaden

- The Philadelphia Naval Shipyard is no longer a construction yard. "Newport" class LST's (LST-1179 series) have not been built there since 1973. "Desoto County" class LST's (LST-1173 series) and "Anchorage" class LSD's (LSD-36 series) were never built there. Construction of submarines ended before 1970. These types of vessels are not present at the base nor do they come in for overhauls.

- There are three cruisers, seven destroyers, and several submarines mothballed at the base.

We would appreciate your confirming the accuracy of the information presented in this document in a letter to be sent to me.

Again, our sincere thanks for your assistance.

Yours truly,

Marian H. Long

Marian H. Long

MHL/rs

DEPARTMENT OF THE NAVY
PHILADELPHIA NAVAL SHIPYARD
PHILADELPHIA, PA 19112

IN REPLY REFER TO
Code 810:RTO:jlr
24 April 1984

Arthur D. Little, Inc.
Acorn Park
Cambridge, Massachusetts 02140
Attn: Ms. Marian H. Long

Dear Ms. Long,

I received your letter of 12 April 1984 concerning Naval Traffic and Severe Weather Contengency Plan for the Philadelphia Naval Shipyard. The information as stated in your letter is correct.

If I can be of further assistance feel free to contact me.

Richard T. Oftedal
LT, USN
Operations Officer

APPENDIX C

POISSON MODEL TO ASSESS CONDITIONAL PROBABILITY OF IMPACT GIVEN A MARINE CASUALTY

There are two basic situations in terms of marine casualty which are of concern to this analysis.

First, a manual self-propelled vessel such as a tanker, dry cargo ship or a recreational boat could be moving north on the Delaware River from the south of Hope Creek. If at some point it loses power and steering (a remote possibility) it would move under the action of wind and waves to the east bank of the Delaware. If the direction of wind and currents are just right, the vessel would strike the water intake structure (a 120 foot target) or in the event of the probable maximum hurricane, enter the plant (a 1500 foot target). The latter requires that the vessel have a draft of under 12 feet.

The second situation, which a special sub-set of the first, more general case, involves a vessel which has already lost power and steering (or has none to start with). The classes of vessels of concern to this study which fit this category are non-self-propelled barges and unmanned recreational boats. Once again, if they are coming from the south of Hope Creek and get sufficiently close to Hope Creek, the wind and surface currents can, in some cases, cause these vessels to either impact the water intake structure or in the case of the probable maximum hurricane enter the Hope Creek site.

In modeling this situation it should be noted that under the postulated storm conditions vessels moving north from the mouth of the Delaware River are quite likely to ground substantially before they reach the vicinity of Hope Creek. For purposes of this analysis, "vicinity of Hope Creek" is defined as distance up to 10 miles south of Hope Creek. Based on considerations of wind and current directions during the postulated storms and the geometry of the river the chances of a runaway, unmanned vessel approaching within 10 miles of Hope Creek without a prior grounding is less than ten percent. Should a runaway vessel or a self-propelled vessel approach the vicinity of Hope Creek, the probability of the vessel striking the water intake structure of entering the site can be estimated utilizing the model developed below.

With respect to Figure C.1, the probability that a vessel underway moves a distance x north without loss of power and steering and then loses i precisely at x is given by:

$$P = \lambda e^{-\lambda x}$$

where λ is the probability per mile of simultaneous loss of power and steering.

Should this failure occur, the vessel will strike the target of concern (either a 120 foot diameter circle or a 1500 foot diameter circle) only if it moves within the sector described by the angle 2θ. Geometric considerations indicate that

$$\theta = \tan^{-1} \frac{R}{\sqrt{(10-x)^2 + (W+R)^2 - R^2}}$$

where R = radius of the target

W = half width of the river

If all movement directions were equally likely the overall probability that a vessel will enter the vicinity of Hope Creek, lose power and steering and strike the intake is given by Q where

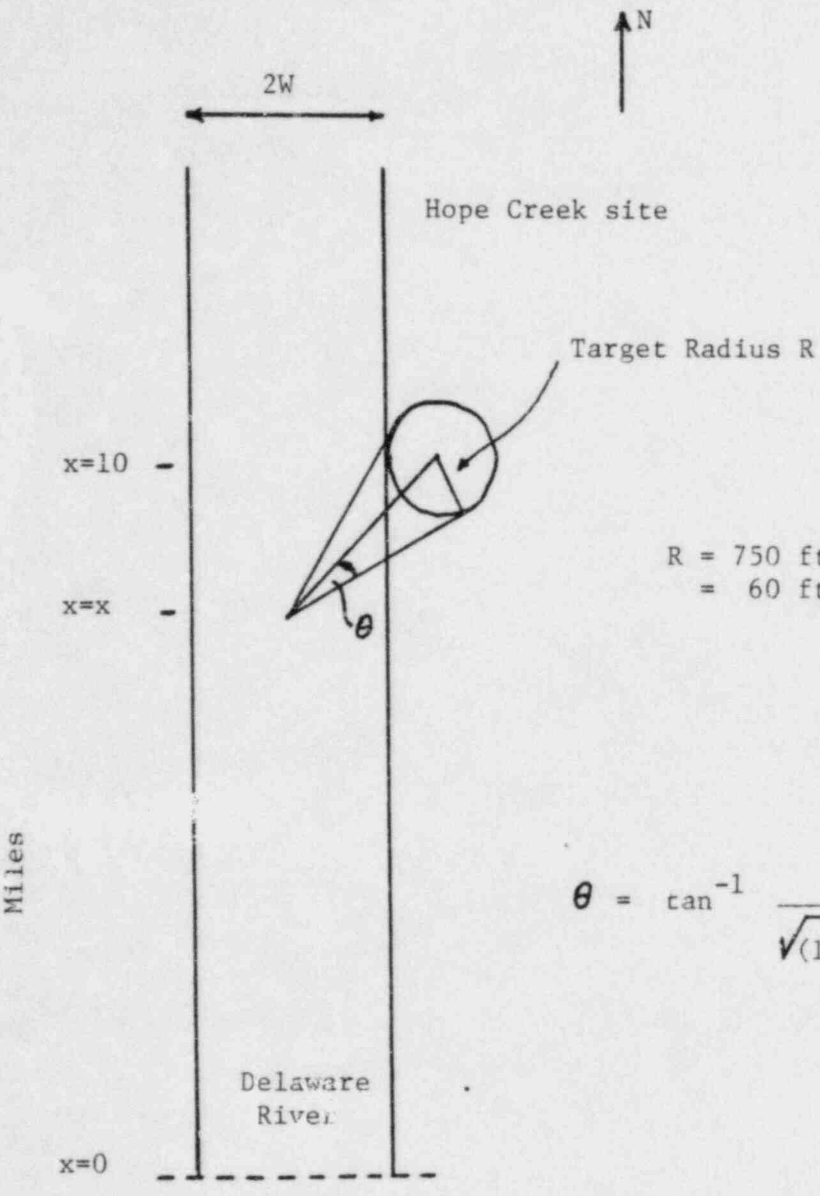
$$Q = \frac{\lambda}{\pi} \int_0^{10} e^{-\lambda x} \tan^{-1} \frac{R\,dx}{\sqrt{(10-x)^2 + (W+R)^2 - R^2}}$$

The integral Q can be evaluated for the Hope Creek situation where:

R = 60 feet and 750 feet

W = 1 mile

λ = 10^{-5}/mile



R = 750 ft for the site
= 60 ft for intake structure

$$\theta = \tan^{-1} \frac{R}{\sqrt{(10-x)^2+(R+W)^2-R^2}}$$

FIGURE C.1

IDEALIZED SCHEMATIC OF THE DELAWARE RIVER, HOPE CREEK AND THE IMPACT GEOMETRY

The failure rate λ for simultaneous loss of power and steering in a self-propelled vessel is based on historical data contained in Reference 1 and 7.

With the above parameters it can be shown that:

If a self-propelled vessel reaches a point 10 miles south of Hope Creek and is moving north, then its probability of simultaneously loosing power and steering and impacting Hope Creek is:

2.1×10^{-7} for the water intake structure

2.5×10^{-6} for entering the Hope Creek site

However, the above calculations assume that once power and steering is lost the vessel is equally likely to move in any direction. In fact, for any of the three postulated storm situations the vessel is at least 5 to 20 times more likely to head towards the targets of concern. Accounting for the relative sizes of the targets, it is conservatively assumed that corrections need to be made for the above estimates involving a factor of 10 increase in the intake impact probability and a factor of 100 in the site impact probability.

It is concluded, then, that in any of the postulated storms, the likelihood of a self-propelled vessel arriving in the vicinity of Hope Creek, simultaneously losing power and steering and striking the water intake structure is 2.1×10^{-6}/vessel. The related probability of entering the Hope Creek site is 2.5×10^{-4}/vessel under 12 foot draft.

In the special case of non-self-propelled vessels such as barges and recreational boats, based on their location of origin, size and river geometry, there is a high probability the vessel will ground and/or sink prior to entering the zone within 10 miles of the Hope Creek site. Nonetheless, if the vessel enters the vicinity of Hope Creek, it is very likely to head in a northeasterly direction under wind and current action in the postulated storms. If it enters the vicinity of Hope Creek it is far more likely to drift eastward and ground several miles to the south of Hope Creek rather than hit the targets of concern.

Utilizing this fact and the impact integral discussed earlier overall probabilities for non-self-propelled vessels were estimated.

The findings are that in the event of the postulated storms the likelihood of a non-self-propelled vessel already within ten miles of Hope Creek striking the water intake structure is 1.2×10^{-5}/vessel and the corresponding probability for entering the Hope Creek site is 3.1×10^{-3}/vessel.