TVA 10697 (ONE-QA-6-86) **CALCULATIONS**

Title: Frequency of Chlorine Concentration in the Control Room in Excess of the Toxicity Limit Due to a Barge Accident		Plant/Unit: BFN 1, 2, 3
Preparing Organization: NE/RAS	KEY NOUNS (Consult RIMS Descriptors List): Chlorine, Barge, Control Room, Frequency, Probability	
Branch/Project Identifiers: XD-Q0000-900003, BFNRAB2-010	Each time these calculations are issued, preparers must ensure that the original (RO) RIMS accession number is filled in.	
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Date				
USE FORM TVA 10534 IF MORE SPACE REQUIRED — List all pages added by this revision				
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Safety-related? Yes (X) No ( )

Statement of Problem

Determine the probabilistic frequency of chlorine concentration in the control room in excess of the toxicity limit due to a barge accident.

ABSTRACT [These calculations contain an unverified assumption(s) that must be verified later. Yes ( ) No (X)]

The frequency of chlorine concentration in the control room at the Browns Ferry Nuclear Plant (BFN) in excess of the toxicity limit due to a barge accident was conservatively calculated to be 8.0E-7 events/yr. This value accounts for chlorine transportation to the site from possible wind directions along a 7.1 mile segment of the Tennessee River and conservatively includes all Pasquill stability classes. This estimate is conservative in that it approximates the frequency of chlorine released due to a barge accident being transported to the BFN site. The frequency that the chlorine enters the control room and incapacitates the operators should actually be less than the estimated frequency.

NOTE: Total number of sheets in this calculation to be microfilmed including attachments 14.

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Title: Frequency of Chlorine Concentration in the Control Room in Excess of the Toxicity Limit Due to a Barge Accident

REVISION LOG

XD-Q0000-900003 (BENRAC-2-010)

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0	Initial issue	5/29/90

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CALCULATION DESIGN VERIFICATION (INDEPENDENT REVIEW) FORM

XD-Q0000-900003
BFNRA6?-010

Calculation No. ______ 0 Revision

Method of design verification (independent review) used (check method used):

1. Design Review ______ X
2. Alternate Calculation ______
3. Qualification Test ______

Justification (explain below):

Method 1: In the design review method, justify the technical adequacy of the calculation and explain how the adequacy was verified (calculation is similar to another, based on accepted handbook methods, appropriate sensitivity studies included for confidence, etc.).

Method 2: In the alternate calculation method, identify the pages where the alternate calculation has been included in the calculation package and explain why this method is adequate.

Method 3: In the qualification test method, identify the QA documented source(s) where testing adequately demonstrates the adequacy of this calculation and explain.

The purpose of this calculation is to determine the probabilistic frequency of chlorine concentration in the control room in excess of the toxicity limit due to a chlorine barge accident. This calculation is based on barge accident frequencies from generic data provided in WASH 1298. The number of chlorine barge shipments past the plant site is based on actual barge transportation data compiled for the section of the Tennessee River which passes the plant site. The atmospheric characteristics including stability classes and wind directions are based on site-specific meteorological data as reported in the BFN FSAR. The results of this calculation show that the frequency of chlorine concentration in the control room in excess of the toxicity limit due to a chlorine barge accident is 8.0e-7 events/year. In conclusion this calculation is based on credible references, uses accepted handbook methods, and [illegible] conservative and appropriate assumptions when necessary and is therefore determined to be technically adequate.

(signature)
Design Verifier
(Independent Reviewer)

5/29/90
Date

CONTENTS

Purpose:

The purpose of this analysis is to determine the probabilistic frequency of a chlorine concentration in the control room at the Browns Ferry Nuclear Plant (BFNP) in excess of the toxicity limit due to a barge accident (reference 1).

Methodology:

The frequency, F_t (events/yr), of a chlorine concentration in the control room at BFN in excess of the toxicity limit due to a barge accident is calculated using:

$$F_t = \sum F_{t_i} \qquad (1)$$

$$F_{t_i} = F_{a_i} P_r P_{t_i} \qquad (2)$$

where F_{t_i} = frequency of a chlorine concentration in the control room at BFN in excess of the toxicity limit due to a barge accident in shipping channel segment i (events/yr)

F_{a_i} = frequency of a chlorine barge accident occurring within shipping channel segment i (events/yr)

P_r = conditional probability of a chlorine release given that a chlorine barge accident has occurred

P_{t_i} = conditional probability that a chlorine release in shipping channel segment i is transported to the BFN control room air intakes.

Assumptions:

1. The failure mechanism for a chlorine release is assumed to be a barge collision or grounding. No other failure mechanisms are considered.

2. Because current barge accident data specific to the Tennessee River System is not available (reference 2), generic data based on nationwide inland waterway statistics from reference 3 is utilized. This data source is specifically referred to in reference 4. The use of generic nationwide statistics in evaluating the frequency of explosions near nuclear power plants (including barge explosions) when an adequate plant-specific data base is not available has been endorsed in reference 5 by the Nuclear Regulatory Commission. Based on this information, use of the generic nationwide accident data in reference 3 in this analysis is deemed acceptable.

3. The barge accident must occur within a 5.5 km (3.4 mile) radius of the plant to produce the postulated hazardous condition inside the control room (reference 6, page 2).

4. Atmospheric characteristics utilized for estimating the chlorine plume transportation probabilities are based on site meteorlogical data for the period January 1977 through December 1979 in reference 7.

5. Given that a 6.8 mile radius around the plant is considered per assumption 3, all points along the river length within this radius are equally likely to be the site of the postulated barge accident.

6. A chlorine barge accident is no more likely to occur within the critical exposure distance than at any other point along the Tennessee River System. This assumption is supported by data indicating that no commercial barge accidents occurred within a five mile radius of BFNP during 1984 and 1985 while 44 accidents (one with spillage) occurred on other portions of the system (reference 8).

7. Any chlorine barge accident with release is assumed to produce concentrations in the control room in excess of the toxicity limit given necessary meteorlogical conditions.

8. A sensitivity analysis to determine the effect of varying the meteorlogical conditions (e.g., Pasquill stability classes) on the chlorine concentration in the control room was not performed. In addition, it has been determined that chlorine releases are potentially hazardous to the control room operators for all Pasquill stability classes depending on the proximity of the accident to the site (reference 9). Therefore, the frequency of a chlorine concentration in the control room in excess of the toxicity limit is calculated based on chlorine plume transport probabilities that are a) conditional only on wind direction and b) conditional on wind direction and Pasquill stability class.

9. The track length of a barge traveling through the critical exposure distance is measured along the "sailing line" as indicated in reference 10.

Design Input Data:

The barge accident frequency for any given barge on the river is provided in reference 3, page 68 as

$$f_a = 1.8E\text{-}6 \text{ accidents/barge-mile traveled.}$$

This value includes all types of accidents (e.g., groundings, collisions with docks, locks, bridges, and other craft, etc.).

The number of chlorine barge shipments past BFN per year is taken from reference 11. This value is

$$n = 30 \text{ barges/yr.}$$

Reference 8 provides the basis for the calculation of the conditional probability of a chlorine release given that a chlorine barge accident has

occurred (P_r). This reference indicates that of 44 barge accidents occurring on the Tennessee River System in 1984 and 1985, only one resulted in spillage (a frequency of 0.023 per accident).

The total percentage frequencies of wind direction and Pasquill stability class on which the conditional chlorine transport probabilities P_{t_i} are based are obtained from reference 7, Tables 2.3-3 through 2.3-10. This set of data is chosen because it was measured at a level (10.0 meters) which most closely corresponds to the 79 ft. (24.1 meter) height of the control room air intakes above the Tennessee River (reference 6, calculation sheet 2).

The segmentized path lengths d_i of a barge traveling past BFN are obtained from reference 10, chart nos. 43 and 44.

Computations and Analyses:

The frequency, F_t (events/yr), of a toxic chlorine concentration in the control room at BFN due to a barge accident is calculated using:

$$F_t = \sum F_{t_i} \qquad (1)$$

$$F_{t_i} = F_{a_i} P_r P_{t_i} \qquad (2)$$

as previously defined in the Methodology section.

I. Calculation of Chlorine Barge Accident Frequencies F_{a_i} for Shipping Channel Segments

Figure 1 depicts the location of the BFN site with respect to the Tennessee River. Arcs are drawn at the two points (labeled A and B) where an imaginary circle centered at the BFN site and with a radius of 3.4 miles (assumption 3) intersects the "sailing line" of the river. The portion of the circle containing the waterway is discretized into 22.5 degree (360 degrees divided by 16 wind directions) segments labeled 1 through 8. For each shipping channel segment, the approximate distance d_i traveled by a barge along the "sailing line" is measured. The results are used in the following equation to calculate the frequency of a chlorine barge accident occuring within each segment:

$$F_{a_i} = f_a d_i n \qquad (3)$$

where f_a = the frequency of a barge accident on the river (accidents/barge-mile traveled)

n = number of chlorine barge shipments past BFN per year (barges/yr)

d_i = distance as measured in Figure 1 for segment i (miles).

As documented previously in the Design Input Data section:

f_a = 1.8E-6 accidents/barge-mile traveled

n = 30 barges/yr.

As an example, consider segment 1 through which a barge travels 3.0 miles. The chlorine barge accident frequency for this segment is

$F_{a_1} = f_a d_1 n$

F_{a_1} = (1.8E-6 accidents/barge-mile traveled)(3.0 miles)(30 barges/yr)

= 1.6E-4 accidents/yr.

The barge travel distances (d_i) and chlorine barge accident frequencies (F_{a_i}) for all of the segments (i) are tabulated below.

Table 1: Frequencies of Barge Accidents Occurring within Given Segments

Segment (i)	Barge Travel Distance within Segment d_i (mi)	Frequency of Chlorine Barge Accident within Segment (F_{a_i}) (events/yr)
1	3.0	1.6E-4
2	0.3	1.6E-5
3	0.2	1.1E-5
4	0.1	5.4E-6
5	0.1	5.4E-6
6	0.2	1.1E-5
7	0.7	3.8E-5
8	2.5	1.4E-4
Total	7.1	3.8E-4

II. Determination of the Chlorine Release Conditional Probability P_r

From the preceeding Design Input Data section:

$$P_r = \frac{1 \text{ release}}{44 \text{ accidents}} = 0.023.$$

This value is within the 0.02 to 0.05 range recommended in reference 12 (Table I on page 653) for the probability that a traffic accident involving hazardous materials will result in explosion or release Furthermore, multiplication of the 0.023 release probability by the 1.8E-6 accidents/barge-mile traveled barge accident frequency yields a total chlorine release frequency of 4.1E-8 releases/barge-mile traveled which closely corresponds to the 4.6E-8 accidents/barge-mile traveled value (4.4E-8 + 1.6E-9 + 2.3E-11) given in reference 3, Table 3 (page 70) for the moderate to extreme barge accident frequency. The calculated river-specific value is used.

III. Calculation of the Chlorine Release Transport Conditional Probabilities P_{ti}

For any given location of the postulated barge accident, only a specific range of wind direction will carry the released chlorine to the BFN site. A range of direction defines winds from within a 22.5 degree arc, the sides of which form the boundaries of one of the river segments (see Figure 1). For example, consider segment 3. Only winds from the WSW (toward the ENE) are considered to be capable of carrying chlorine toward the BFN site should the barge accident occur in this segment. The WSW range includes winds from the WSW and 11.25 degrees to either side of WSW.

For a given wind direction, there may be only a fraction of time when the wind is stable enough to carry chlorine to the site without sufficient dispersal to result in control room concentration below the toxicity limit. Therefore, the conditional probability that a chlorine release is transported to the BFN control room air intakes is calculated based on a) wind direction only and b) wind direction and Pasquill stability class (see assumption 8). Again consider segment 3 as an example. Reference 7, Tables 2.3-7 and 2.3-10 indicate that the total percentage frequencies of stability class E wind from the WSW and of a wind from the WSW irrespective of stability class are 1.43% and 4.04%, respectively. Therefore, the conditional probability of chlorine transport to the BFN site given a release in segment 3 is 0.0143 for stability class E and 0.0404 disregarding stability class. The conditional chlorine transport probabilities for each of the river segments under consideration taken from reference 7, Tables 2.3-3 through 2.3-10 are listed below:

Table 2: Conditional Probabilities of Chlorine Release Transport to the BFN Site

Segment (i)	Direction wind is from	Conditional Probability P_{ti} for Stability Class				
		A	B	C	D	E
1	WNW	0.0020	0.0053	0.0054	0.0309	0.0075
2	W	0.0012	0.0043	0.0030	0.0223	0.0189
3	WSW	0.0015	0.0030	0.0025	0.0175	0.0143
4	SW	0.0009	0.0019	0.0019	0.0065	0.0046
5	SSW	0.0010	0.0010	0.0010	0.0086	0.0083
6	S	0.0054	0.0056	0.0042	0.0260	0.0304
7	SSE	0.0068	0.0043	0.0034	0.0238	0.0286
8	SE	0.0156	0.0088	0.0056	0.0358	0.0539

Table 2 continued

Segment (i)	Direction wind is from	Conditional Probability P_{t_i} for Stability Class		
		F	G	All*
1	WNW	0.0010	0.0003	0.0523
2	W	0.0018	0.0002	0.0514
3	WSW	0.0016	0.0004	0.0404
4	SW	0.0012	0.0001	0.0176
5	SSW	0.0020	0.0011	0.0231
6	S	0.0098	0.0040	0.0857
7	SSE	0.0138	0.0102	0.0911
8	SE	0.0185	0.0067	0.1454

* Conditional probability of chlorine transport to site including all Pasquill stability classes.

IV. Calculation of the Frequencies of Chlorine Concentrations in the Control Room in Excess of the Toxicity Limit (F_{t_i})

The frequency F_{t_i} of a chlorine concentration in the control room in excess of the toxicity limit due to a chlorine barge accident in each shipping channel segment i is calculated using

$$F_{t_i} = F_{a_i} P_r P_{t_i} . \qquad (2)$$

For example, consider segment 3. From Table 1, the frequency of a chlorine barge accident in this segment is

$$F_{a_3} = 1.1E\text{-}5 \text{ events/yr.}$$

The conditional probability of a chlorine release given that a barge accident has occurred taken from calculation section II is

$$P_r = 0.023.$$

The conditional probability that a chlorine release in shipping channel segment 3 is transported to the BFN site for Pasquill stability class D is obtained from Table 2. This value is

$$P_{t_{3_D}} = 0.0175.$$

Therefore, the frequency of a chlorine concentration in the control room in excess of the toxicity limit due to a chlorine barge accident in shipping channel segment 3 is

$$F_{t_{3_D}} = (1.1E\text{-}5 \text{ events/yr})(0.023)(0.0175)$$

$$= 4.4E\text{-}9 \text{ events/yr}$$

for Pasquill stability class D.

The P_{ti} values for all shipping channel segments and stability classes are tabulated below:

Table 3: Freqencies of Chlorine Concentrations in the Control Room in Excess of the Toxicity Limit Due to Barge Accidents in Various Shipping Channel Segments

Segment	Frequency for Pasquill Stability Class (events/yr)							
	A	B	C	D	E	F	G	All
1	7.4E-9	2.0E-8	2.0E-8	1.1E-7	2.8E-8	3.7E-9	1.1E-9	1.9E-7
2	4.4E-10	1.6E-9	1.1E-9	8.2E-9	7.0E-9	6.6E-10	7.4E-11	1.9E-8
3	3.8E-10	7.6E-10	6.3E-10	4.4E-9	3.6E-9	4.0E-10	1.0E-10	1.0E-8
4	1.1E-10	2.4E-10	2.4E-10	8.1E-10	5.7E-10	1.5E-10	1.2E-11	2.2E-9
5	1.2E-10	1.[illegible]E-10	1.2E-10	1.1E-9	1.0E-9	2.5E-10	1.4E-10	2.9E-9
6	1.4E-9	1.4E-9	1.1E-9	6.6E-9	7.7E-9	2.5E-9	1.0E-9	2.2E-8
7	5.9E-9	[illegible].8E-9	3.0E-9	2.1E-8	2.5E-8	1.2E-8	8.9E-9	8.0E-8
8	5.0E-8	2.8E-8	1.8E-8	1.2E-7	1.7E-7	6.0E-8	2.2E-8	4.7E-7
Total	6.6E-8	5.6E-8	4.4E-8	2.7E-7	2.4E-7	8.0E-8	3.3E-8	8.0E-7

Summary of Results:

The probabilistic frequencies of chlorine concentrations in the BFN control room in excess of the toxicity limit due to a chlorine barge accident are listed below for each Pasquill stability class:

Table 4: Frequencies of Chlorine Concentrations in the Control Room in Excess of the Toxicity Limit due to a Barge Accident

	Pasquill Stability Class							
	A	B	C	D	E	F	G	All
Frequency (events/yr)	6.6E-8	5.6E-8	4.4E-8	2.7E-7	2.4E-7	8.0E-8	3.3E-8	8.0E-7

The frequency of a chlorine concentration in the control room in excess of the toxicity limit due to a barge accident (from all possible wind directions) is 8.0E-7 events/yr, including all Pasquill stability classes.

Conclusions:

The calculated frequency of a chlorine concentration in the control room at BFN in excess of the toxicity limit due to a barge accident (from all possible wind directions) is calculated to be 8.0E-7 events/yr, including all Pasquill stability classes. This is a very conservative estimate as it approximates only the frequency of the chlorine approaching the site. The frequency that the chlorine enters the control room and incapacitates the operators would actually be less than the estimated frequency as credit could be taken for any shift in the direction of the wind transporting the chlorine to the control room air intakes. In addition, there are barriers between the

control room air intakes and the river including the reactor building, turbine building, cooling towers, and a large hill on the south to southwest side of the site (reference 13 and reference 14, page 8). Finally, the inclusion of all Pasquill stability classes in the frequency adds conservatism in that winds of the less stable classes may disperse the chlorine to a non-hazardous level before it reaches the control room air intakes. For example, elimination of stability classes A through D as was done in reference 14 reduces the calculated frequency to 3.5E-7 events/yr. Reduction in the frequencies for segments 1, 7, and 8 would result in the greatest reduction of the total frequency since these segments compose most of the total (see Table 3).

References:

1. Patrick P. Carier's memorandum to Richard J. McMahon dated May 9, 1990 (R08 900509 825).

2. Conversations between Fredrick K. Hoyos (TVA-NE/RAS) and Don Wilkinson (U.S. Coast Guard, Nashville Tenn.), December 1989 - January 1990.

3. "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants", WASH-1238, December 1972.

4. "Assumptions For Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release", Regulatory Guide 1.78, Revision 0, June 1974.

5. "Evaluations of Explosions Postulated to Occur on Transportation Routes Near Nuclear Power Plants", Regulatory Guide 1.91 Revision 1, February 1978.

6. "Browns Ferry Nuclear Plant Toxic Barge Study", Bechtel Corp. Calculation M-2 (B22 900523 201).

7. Browns Ferry Nuclear Plant Final Safety Analysis Report (FSAR) section 2.3, amendment 6.

8. M. Ted Nelson's memorandum to L. Wang Lau dated June 26, 1987 (B81 '870630 025).

9. Conversations between William Z. Mims (TVA-NE/RAS), Fredrick K. Hoyos (TVA-NE/RAS), and Dr. Y. J. Lin (Bechtel Corp.) on May 15, 1990 and between Fredrick K. Hoyos and Dr. Y. J. Lin on May 16, 1990.

10. Tennessee River Navigation Charts Paducah, Ky. to Knoxville, Tenn., U.S. Army Engineer District, Nashville, Tenn., January 1980.

11. M. Ted Nelson's memorandum to Phillip W. Hyatt dated December 1, 1989 (B81 '90 0214 002).

12. Karl Hornyik, "Hazards to Nuclear Plants from Surface Traffic Accidents", Nuclear Technology Vol. 25, April 1975.

13. Browns Ferry Nuclear Plant, Location of Structures - Sheet 1, TVA drawing 10E201-01 R8.

14. "Probability of Chlorine Release from Barge Accident at Browns Ferry Nuclear Plant", CD-N0999-891395 R0 (BFNRAG2-001 R0) (B81 '870720 050).

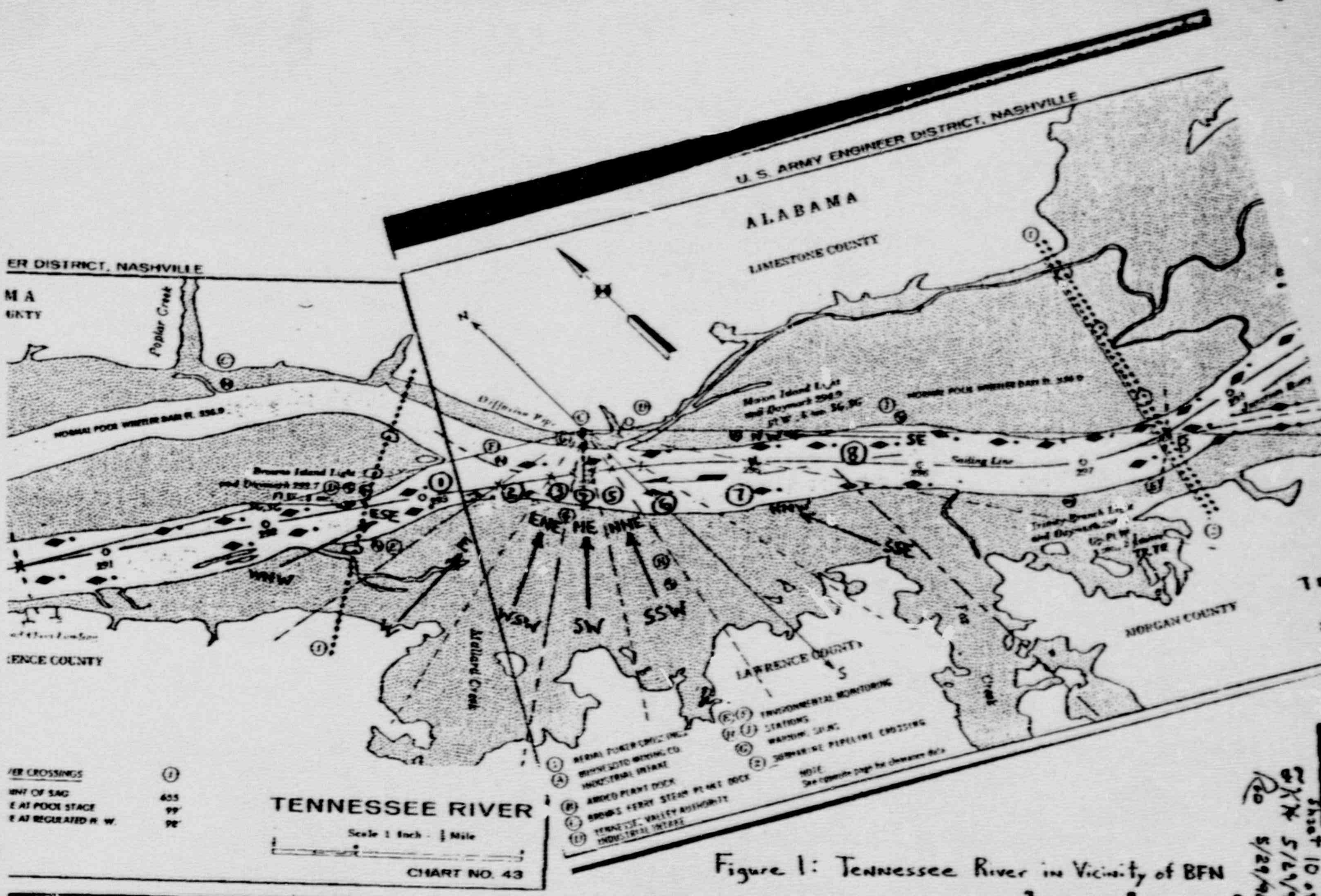

Figure 1: Tennessee River in Vicinity of BFN

Sheet 10 of
5/29/90
5/29/90