BIOLOGICAL EVALUATION OF AIR CURTAIN AT ARKANSAS NUCLEAR ONE – UNIT 1

ARKANSAS POWER & LIGHT COMPANY
P.O. Box 551
Little Rock, Arkansas 72203

February 1976

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTD)

APPENDIX

TABULATED DATA

ILLUSTRATIONS

ILLUSTRATIONS (CONTD)

ILLUSTRATIONS (CONTD)

ILLUSTRATIONS (CONTD)

TABLES

TABLES (CONTD)

SUMMARY

The Ecological Services branch of Texas Instruments Incorporated (TI) was retained by Arkansas Power & Light Company (AP&L) to determine the efficiency of an air curtain in reducing fish impingement at Arkansas Nuclear One — Unit 1, on Dardanelle Reservoir, Arkansas.

TI has characterized the species composition and abundance, biomass, and length-frequency distribution of fishes impinged during the four seasonal air curtain test periods and has related these data to selected physicochemical water and meteorological parameters measured during air curtain testing. This report has evaluated the efficiency of the air curtain in deterring fish, while suggesting causal relationships, conclusions, and recommendations aimed at mitigating impingement losses at Arkansas Nuclear One.

Arkansas Nuclear One, Units 1 and 2, are located in Pope County, Arkansas, 2 mi southwest of the town of London on a peninsula formed by Dardanelle Reservoir. Units 1 and 2 are pressurized water reactors (PWR) with capacities of 836 Mw and 912 Mw respectively. Unit 1, designed for once-through cooling, began commercial operation in 1974. A hyperbolic natural-draft cooling tower is being constructed for Unit 2, which is scheduled to be on line in 1977. A 0.75-mi-long intake canal carries cooling water to the plant intake forebays. Traveling screens of 3/8-in. mesh protect these forebays from trash, fish, and other fouling materials.

The air curtain structure is located across the mouth of the intake canal in approximately 15 ft of water. The canal is approximately 400 ft wide at its juncture with Dardanelle Reservoir. Four glass-fiber pipes lying side by side on the canal bottom extend for distances of 400, 300, 180, and 80 ft respectively. Airholes have been drilled in each pipe at 1-in. intervals starting at the far end and progressing toward shore far enough to reach the end of the next longest pipe. The effect is a row of airholes extending 400 ft and all

emitting air at approximately equal pressure. Dardanelle Reservoir is part of the McClellan-Kerr Arkansas River navigation system extending from the confluence of the Arkansas and Mississippi Rivers to Catoosa, Oklanoma, on the Verdigris River. The reservoir exhibits seasonal patterns of water temperatures, dissolved-oxygen levels, and other physicochemical parameters typical of a southern (temperate) reservoir. Water temperatures range from near freezing in winter to approximately 90°F (32.2°C) in summer. Dissolved oxygen levels follow a seasonal pattern inversely related to water temperature. The reservoir currently supports a relatively diverse warm-water fish community consisting of 53 species and supports a small commercial fishery and a growing sport fishery.

Historically, small-meshed wire gratings had been utilized as barrier-guides to divert fish to bypasses at weirs, dam spillways, and streams. The first air curtain devices were used during the 1940's as barrier-guidance systems at these fish passes. These initial units were only partially successful in diverting fish.

Behavioral studies during the 1950's showed that fish deterrence with respect to air bubbles was a species-specific phenomenon, with certain species 100% deterred and others virtually unaffected.

Experimenters during the late 1960's observed that perception of the air-bubble curtain was entirely visual. Later researchers, however, discovered that a number of senses, including vision, were involved in response to the air curtain, as well as species-specific behavioral characteristics, swimming abilities, and environmental conditions.

Only a few field applications were found, probably owing to the erratic nature and inconclusive findings of air curtain testing under controlled laboratory conditions. At best, however, extant laboratory and field data are erratic and inconclusive. Results appear to be site- and species-specific and are subject to a multitude of interrelated and not completely understood variables.

The air curtain at Arkansas Nuclear One was tested during fall and winter 1974 and spring and summer 1975. Testing procedures during each season consisted of six consecutive weekly runs of 3 days "on" and 3 days "off" operation over six consecutive days, with a day between runs. Air and water temperature, percent cloud cover, wind direction and intensity, and rainfall were recorded daily during all four seasonal tests. Water-turbidity measurements were less frequent. All reported problems, mechanical failures, and operational variances were recorded and considered during data analysis. Statistical analyses were performed to test for differences between impingement rates during air curtain ON and OFF status and for possible relationships between impingement and water temperature.

Thirty-eight species of fish representing 14 families were collected from intake screens during seasonal air curtain testing from October 1974 through August 1975.

Numbers of species impinged declined from a high of 29 during the fall to 20 during the winter and rose to 26 species during spring and summer. No discernible differences were observed in the number of species impinged during ON/OFF testing.

Threadfin shad, gizzard shad, blue catfish, channel catfish, white bass, and freshwater drum were the species appearing in the greatest number of seasonal test runs. White crappie, white bass, and bluegill sunfish were taken in the majority of fall, spring, and summer tests but only infrequently during the winter. Occurrences of the aforementioned species were evenly distributed over ON and OFF tests. No overall seasonal trends could be discerned.

A total of 9,571,922 fish weighing 173,641 pounds was impinged over the entire four-season test period. Of this, 4,930,127 fish weighing 90,870 pounds were collected during air curtain operation. This compares with 4,641,795 fish weighing 82,770 pounds impinged when the air curtain was not operating. Impingement rates for all species combined rose during the fall and winter to levels of >200,000 fish and 1000 pounds per 3-day period. Impingement declined through the spring and summer. Highest impingement counts occurred while Dardanelle Reservoir water temperatures remained below 60°F (18.3°C). A comparison of ON/OFF test data revealed no statistically significant differences in numbers or biomass impinged during the fall, winter, or summer. Significantly ($\alpha = 0.05$)* higher impingement numbers were observed during air curtain operation in the spring. Significantly ($\alpha = 0.05$) higher biomass was impinged when the air curtain was on in five of six spring tests.

Threadfin shad, gizzard shad, blue catfish, channel catfish, freshwater drum, white crappie, and white bass accounted for the greatest numbers and biomass impinged throughout the study. Threadfin and gizzard shad combined contributed the greatest proportion (>95%) of numbers and biomass impinged during fall and winter tests. During these seasons, threadfin shad clearly dominated both numbers (>91%) and biomass (>88%). No distinct differences in species composition between ON and OFF tests were observed during fall or winter. Gizzard shad and freshwater drum dominated spring and summer tests respectively. Some differences in species composition between ON and OFF testing were observed during these two seasons, but these differences did not appear to be significant.

Since threadfin shad contributed the greatest number and biomass impinged over the four-season test period, their overall impingement rates were of major importance. A total of 8,850,744 threadfin shad weighing 159,649 pounds were impinged over the four-season test period. Overall, more threadfin shad were impinged during air curtain operation (4,560,419 fish; (83,732

*Observations were considered to be significantly different when the probability of the observed difference occurring by random chance was less than the established alpha (α) level. For example, a difference considered significant at the $\alpha = 0.05$ level would be expected to occur by chance less than one time in 20 if no true difference existed. Thus, the probability that a statement of significant differences is incorrect is less than the fraction expressed in the alpha (α) level.

pounds) than when the air curtain was inoperative (4,290,325 fish; 75,917 pounds). However, these differences were found to be not significant at the $\alpha = 0.10$ level.

Threadfin shad impingement rates rose during late fall and winter and declined through spring and summer. Highest impingement rates (>100,000 fish and >1,000 pounds per 3-day period) were observed when Dardanelle Reservoir water temperatures ranged between 60°F (15.5°C) and 42°F (5.6°C).

During the fall significantly ($\alpha = 0.05$) greater numbers and biomass of threadfin shad were impinged when the air curtain was not in operation. No differences were observed during the winter or summer; however, a greater number of threadfin shad were impinged during air curtain operation in the spring.

The majority of differences between air curtain ON/OFF impingement rates of the other six major species during the four-season test period were indicative of higher catches during air curtain operation.

The majority of the fish impinged over the four-season test period were in the 61-90 mm or 91-120 mm size classes, presumably young-of-the-year or yearlings. Air curtain status did not alter the length frequency of the fish impinged during any test period.

There appeared to be a positive relationship between high impingement and increased turbidity, but the paucity of turbidity data makes this finding inconclusive. Although vision is related to avoidance of the air curtain, other sensory mechanisms are probably involved.

Impingement rates for all species combined and for six of the seven most heavily impinged species were found to be significantly correlated with water temperatures in Dardanelle Reservoir during fall 1974 and spring 1975. In the majority of cases these significant correlations were negative; i.e., higher impingement was associated with lower temperatures and lower impingement with higher temperatures. Based on current-velocity measurements at the air curtain, and temperature-related fish-behavior data, it was concluded that regardless of air curtain status, even the relatively low water velocities observed at the air curtain overwhelmed the swimming abilities of smaller members of most fish species during late fall and winter. Therefore, the high impingement rates observed during late fall and winter may have represented impingement of passive, moribund, smaller or weaker fish thermally stressed by water temperatures below 60°F (15.3°C).

No other parameters monitored, i.e. cloud cover, rainfall, wind direction and velocity, were directly related to impingement patterns during seasonal ON/OFF testing.

The assumption that there was no significant lag time between a fish passing through the air curtain and being collected on the screens appeared to be true since no significant differences occurred comparing respective days (e.g., third day on test vs third day off test). The inefficiency of the air curtain may have masked lag-time effect.

It is recommended that, until industry-wide testing proves the reliability of one or more behavioral screening systems, no further funds or time be expended in testing or installing these behavioral devices at Arkansas Nuclear One.

TI recommended that Arkansas Power & Light Company continue to evaluate the impact of impingement on the fishery resources of Dardanelle Reservoir through impingement monitoring and related biological reservoir studies. Only if this evaluation indicates significant biological impact should mechanical screens or alternative mitigation measure be implemented.

SECTION I
INTRODUCTION

To meet present and projected energy needs, Arkansas Power & Light Company (AP & L) contracted with Bechtel Corporation (San Francisco) to construct two nuclear-fueled electric-power generating stations (pressurized water reactors) at Russellville, Arkansas (Figure I-1).

Unit 1 is designed for once-through cooling; a hyperbolic, natural-draft cooling tower is being constructed for Unit 2.

A major utility-related environmental concern involved with the withdrawal of once-through cooling water has been the impingement of aquatic organisms, especially fish, on the plant intake screens. In a move to avoid or mitigate this impingement problem, which has plagued numerous utilities across the United States and abroad, AP&L contracted with Bechtel Corporation to construct an air-bubble curtain at the confluence of the intake canal and the reservoir before Arkansas Nuclear One - Unit 1, went online. Texas Instruments Incorporated (TI), Dallas, Texas, was retained by AP&L on 12 February 1974 to design and implement a statistically valid biological testing program to determine the efficiency of this air curtain in reducing fish impingement.

In accomplishing this major objective, TI has characterized the species composition and abundance, biomass, and length frequency distribution of fishes impinged during the four seasonal air curtain test periods. To aid in the understanding and explanation of test findings, these impingement data have been related to various selected physicochemical water and meteorological parameters measured during air curtain testing.

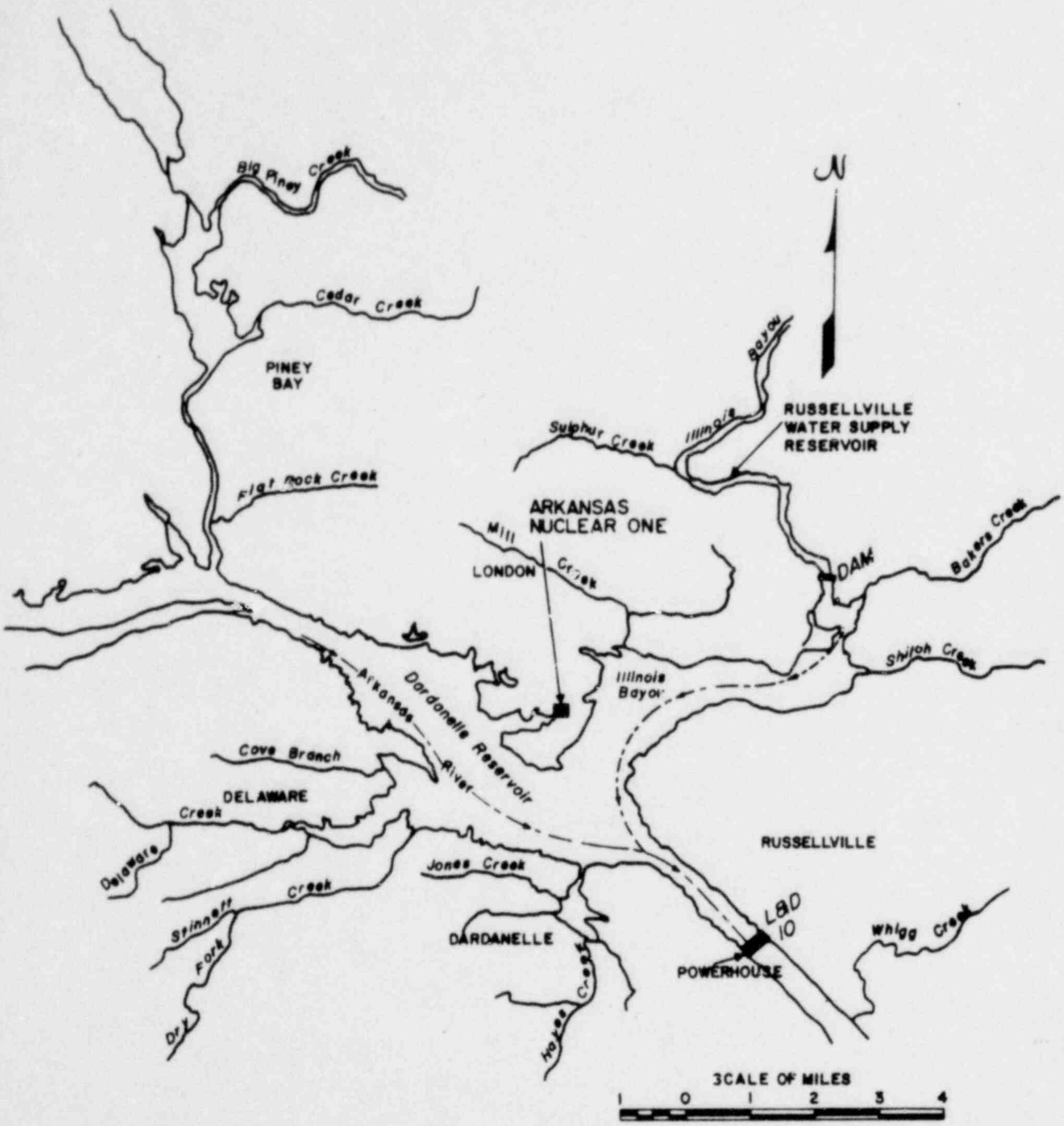

Figure I-1. Location of Arkansas Nuclear One, Units 1 and 2 on Dardanelle Reservoir, Arkansas

TI has compared Arkansas Nuclear One air curtain test data with information collected during a comprehensive review of available air curtain literature, a survey of life history information on the fish species most heavily impinged at Arkansas Nuclear One-Unit 1, and studies performed by AP&L, Arkansas Polytechnic College, and the Arkansas Game & Fish Commission on Dardanelle Reservoir.

This annual report principally addresses the efficiency of the air curtain in deterring fish, while also suggesting causal relationships and conclusions.

SECTION II

DESCRIPTION OF ARKANSAS NUCLEAR ONE, UNITS AND 2

Arkansas Nuclear One, Units 1 and 2, are located in Pope County, Arkansas, 2 mi (3.2 km) southwest of the city of London on a peninsula formed by Dardanelle Reservoir (Figure II-1). The site encompasses approximately 1164 acres (471.4 hectares).

Both Units 1 and 2 are pressurized water reactors (PWRs) with capacities of 836 Mw and 912 Mw, respectively. Unit 1, which is designed for once-through cooling, began commercial operation in December 1974. A hyperbolic, natural-draft cooling tower is being constructed for Unit 2 which is scheduled to be on line in 1977.

Cooling water is taken from Dardanelle Reservoir through a 0.75-mi (1.2-km) long intake canal to eight forebays at Unit 1. In 1977, this canal will also carry makeup water to Unit 2, which is supplied by two separate forebays (Figures II-2 and II-3).

Water velocity profiles were mapped along prescribed transects and at pre-determined depths at distances of 20 ft and 50 ft in front of the Dardanelle Reservoir intake canal juncture on 11 December 1974 by the U.S. Geological Survey, and are presented in Figure II-4.

At the confluence of the intake canal and the reservoir, the approach velocity of the intake water is $\leq$ 0.3 fps (0.09 m/sec). Water velocity increases to 3.0 fps (0.9 m/sec) at one point within the canal due to reduced canal depth and width. Velocities then reduce to approximately 1.5 fps (0.46 m/sec) along the remainder of the canal up to the Unit-1 intake screens. The average velocity across the Unit-2 traveling screens (operational in 1977) will be 0.34 fps (0.1 m/sec) (Arkansas Power & Light Co., 1974).

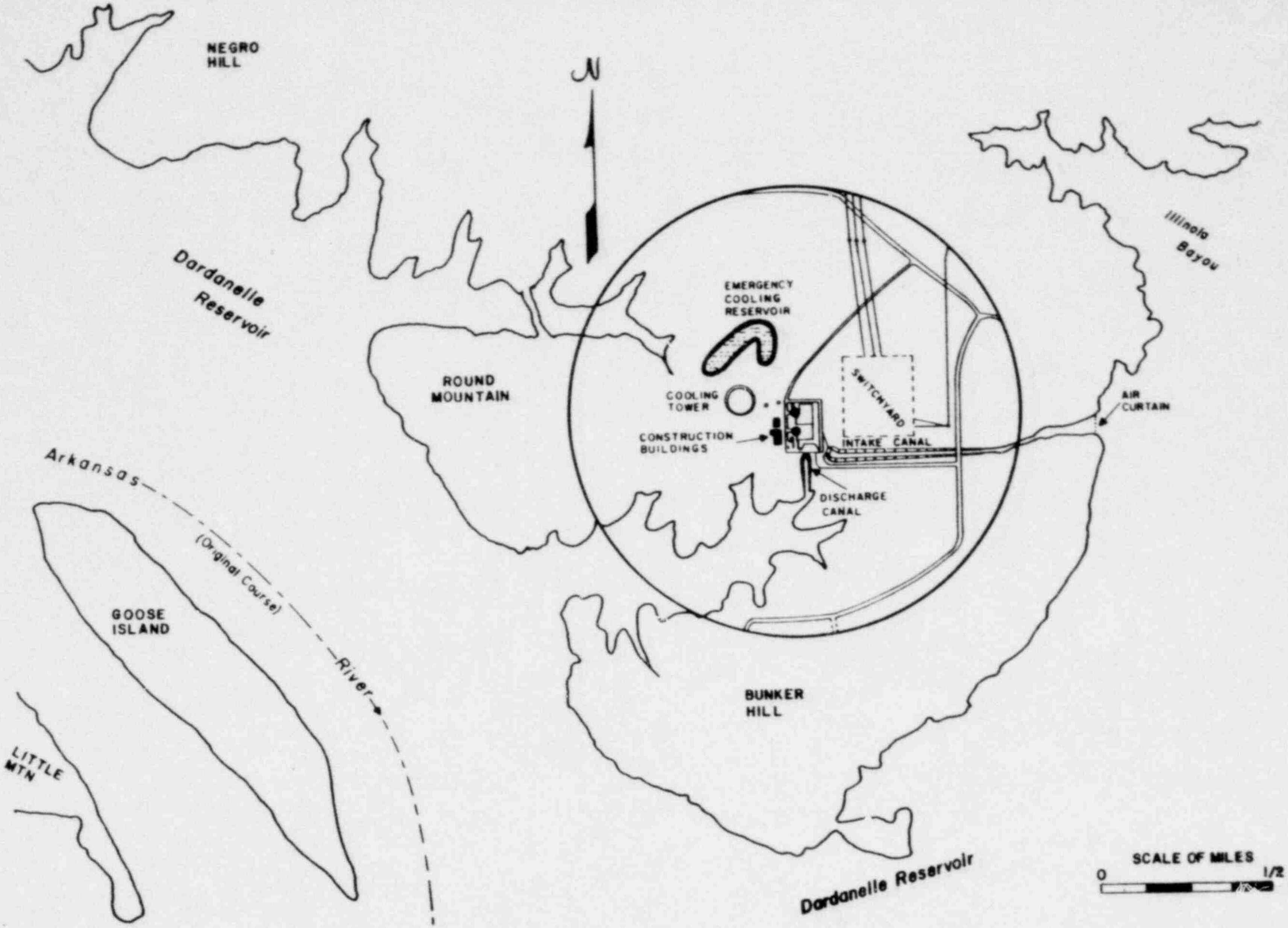

Figure II-1. Plant Arrangement for Arkansas Nuclear One, Units 1 and 2, on Dardanelle Reservoir, Arkansas

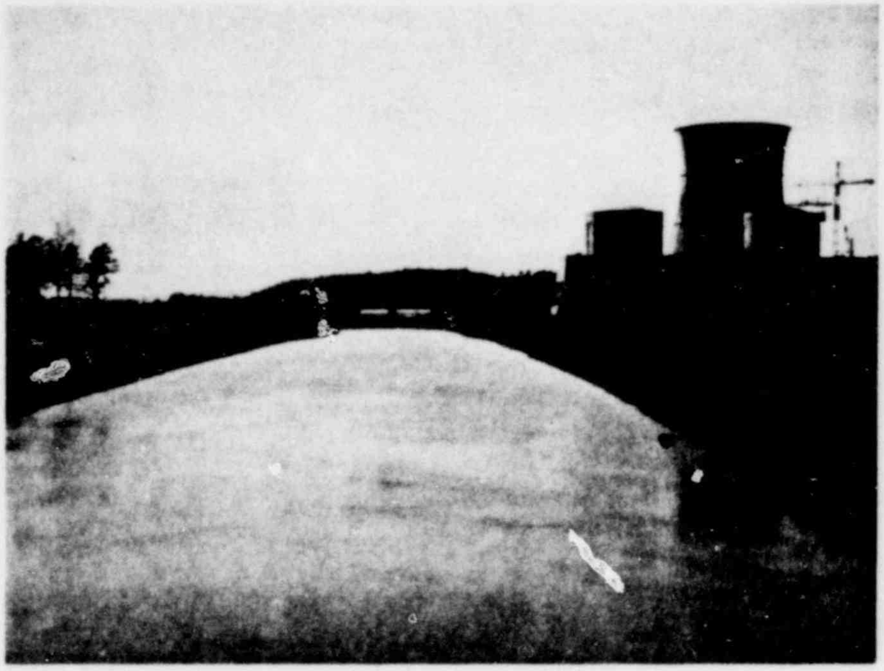

Figure II-2. Photograph Showing Portion of Intake Canal toward Arkansas Nuclear One

Figure II-3. Photograph Showing Portion of Intake Canal toward Lake Dardanelle

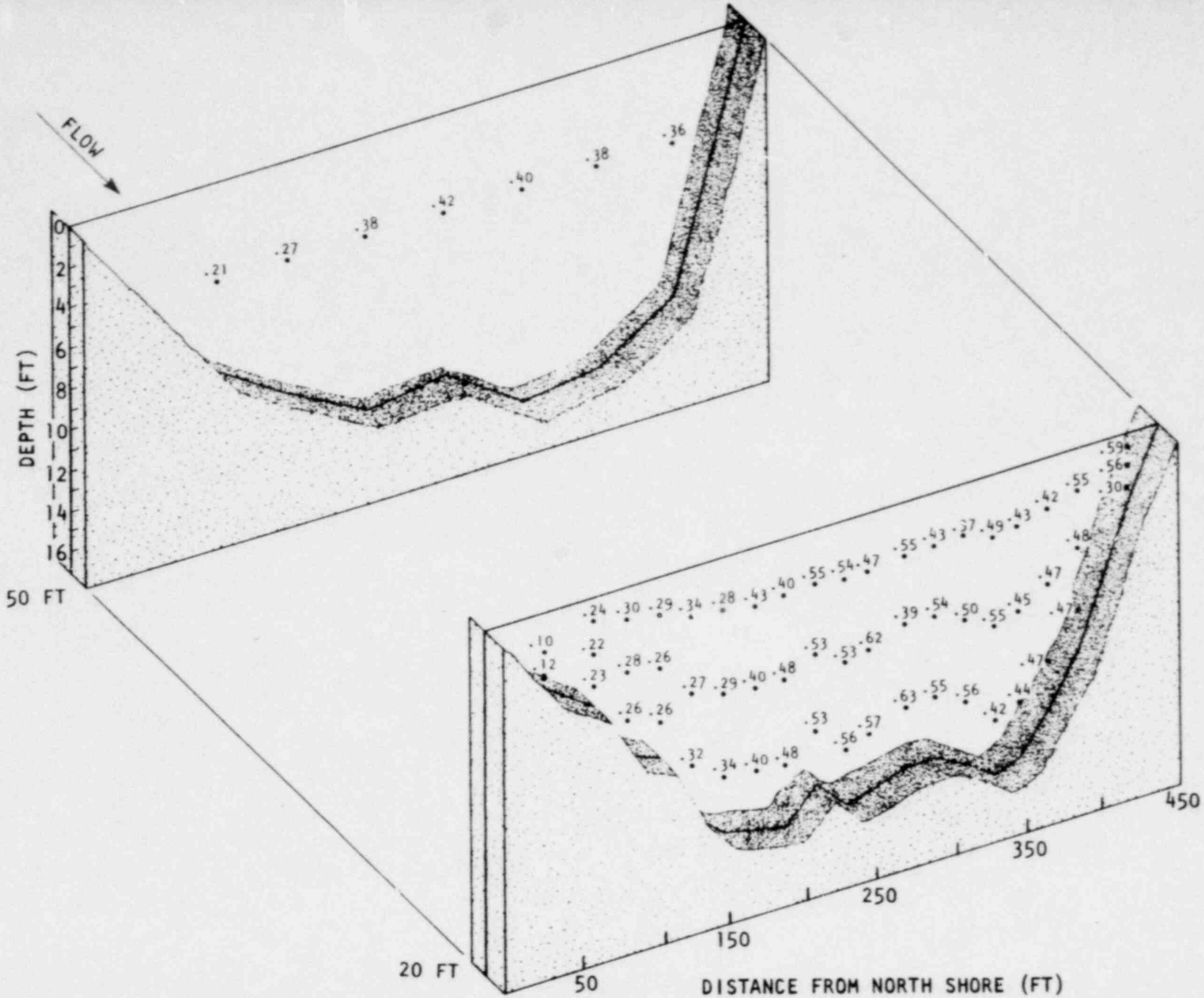

Figure II-4. Water Current Velocity Profile at 20 Ft and 50 Ft in Front of Air Curtain, 11 December 1974

Each of the 10 forebays (eight for Unit 1, two for Unit 2) is protected from trash, fish, and other fouling materials by means of a 10-ft (3.1-m) wide vertical traveling screen constructed of 3/8-in. (0.9-cm) wire mesh. There are no fixed screens in front of the traveling screens, only the usual bar racks. The rate of speed of the traveling screens is fixed; however, the pressure on the wash system can be adjusted. The traveling screens are automatically cleaned by wash pumps which discharge into high-velocity spray nozzles, washing away debris as the screens travel past the nozzles. Collected trash is sluiced through a trough into one of two trash grinders located in front of screens 4 and 5; the ground material, plus water, is then discharged in front of screen 2 where it then passes through the screen, through Unit-1 condenser, and out the discharge canal.

Unit 1's four circulating water pumps are designed with a total capacity of 762,960 gal./min (2,887,040.6 ℓ/min) [1700 ft^3/sec (48.1 m^3/sec)]. Cooling water passes through Unit-1 condensers and is returned to Dardanelle Reservoir via an effluent canal and 80-acre (32.4 hectares) discharge bay. (Figure II-1). Blowdown discharge from the Unit-2 cooling tower will add 3600 gal./min (13,622.4 ℓ/min) of warmer water to the discharge of Unit 1, adding approximately 0.5% to the thermal discharge of Unit 1 (Arkansas Power & Light Co., 1974).

Bechtel Corporation (San Francisco) under contract to AP&L constructed an air curtain at the confluence of the Arkansas Nuclear One intake canal and Dardanelle Reservoir, the purpose of which was to deter fish from entering the intake canal proper.

The air curtain structure is located in approximately 15 ft of water, across the mouth of the intake canal, which is approximately 400 ft wide at the juncture with Dardanelle Reservoir (Figure II-5). Four fiberglass pipes (4-in. in diameter) lie side by side (10 in. apart, center to center) on the canal bottom for distances of 400 ft (completely across), 300, 180, and 80 ft respectively (Figure II-6). Each pipe is drilled along the upper surface with 3/32-in. air holes, spaced 1 in., center-to-center, apart. These air holes are located only in the last section of each pipe. A series of control valves provide approximately equal amounts of air pressure at each hole, thus forming one uniform 400-ft-long air curtain across the mouth of the intake canal.

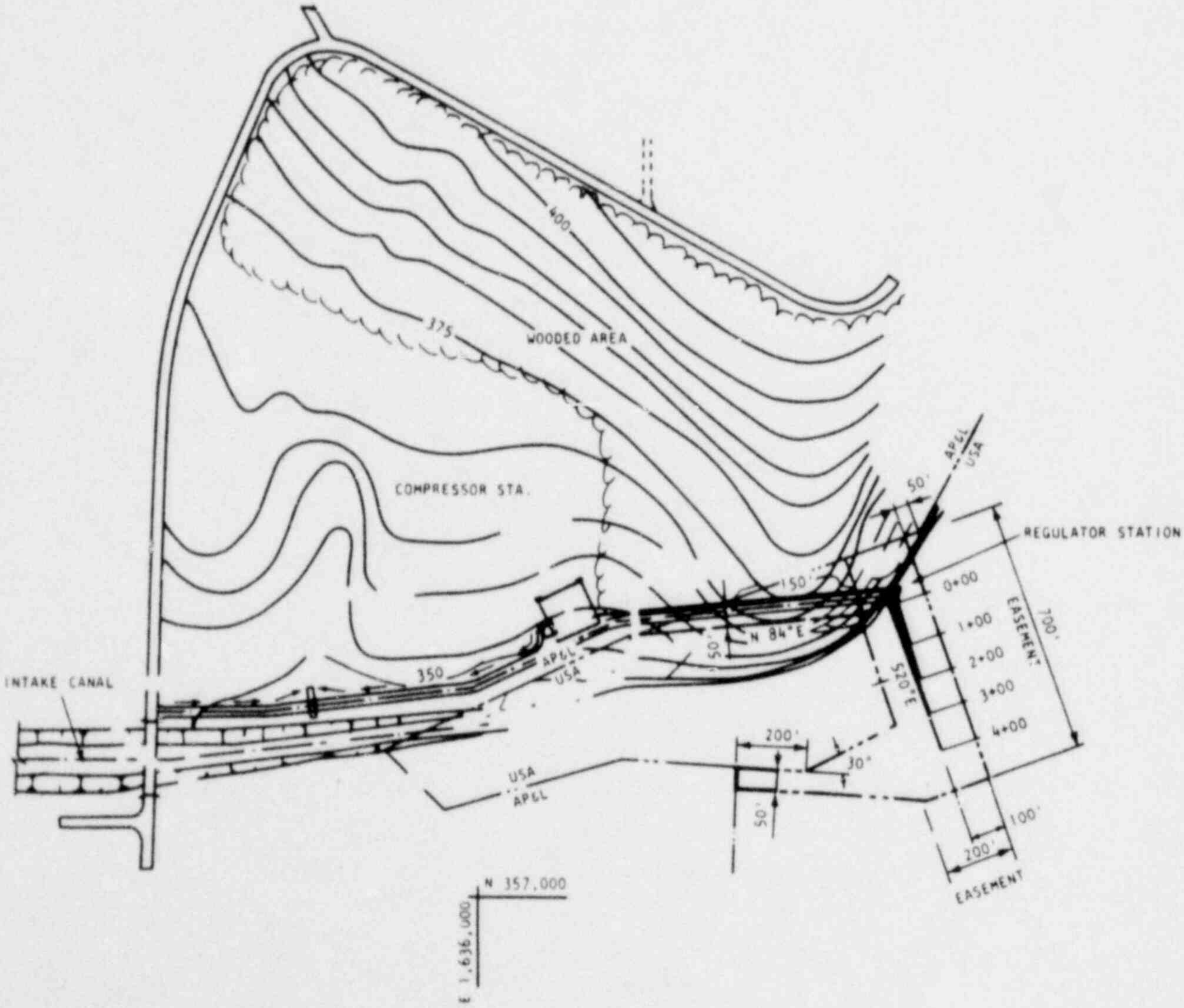

Figure II-5. Plan of Air Curtain at Mouth of Arkansas Nuclear One Intake Canal, Dardanelle Reservoir (Arkansas Power & Light Co., 1974)

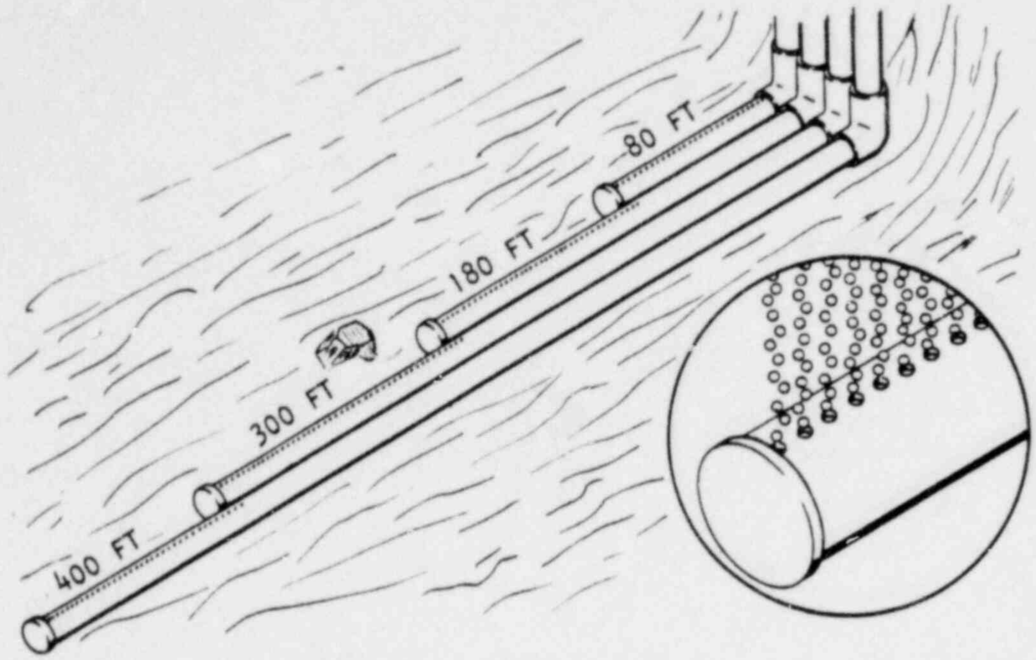

Figure II-6. Schematic of Air Curtain in Intake Canal to Arkansas Nuclear One

Compressed air for the curtain is provided by six air compressors, each with a capacity of 650 cfm at 100 psig. Located onshore, these compressors are connected by a system of manifolds and pipe to the four pipes making up the air curtain (Figure II-7). The pipeline from the compressors to the air curtain is insulated to reduce noise.

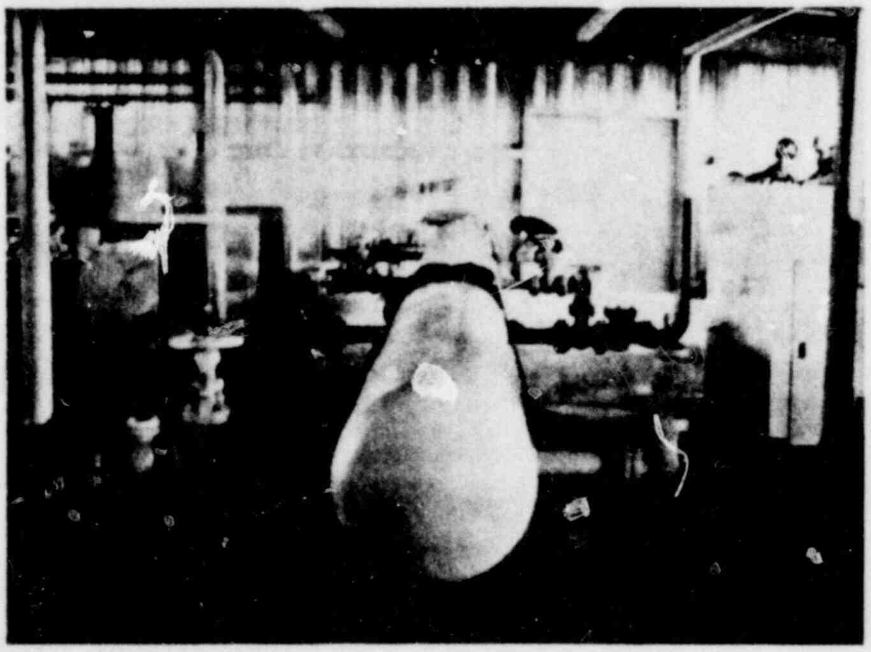

Figure II-7. Six Air Compressors Providing Air by Way of Manifolds to One Pipe Leading to Air Curtain

During the normal operationa' mode, five compressors were utilized, with one unit serving as a back-up. During operation of the air curtain, the water surface is actually raised a few inches (Figure II-8).

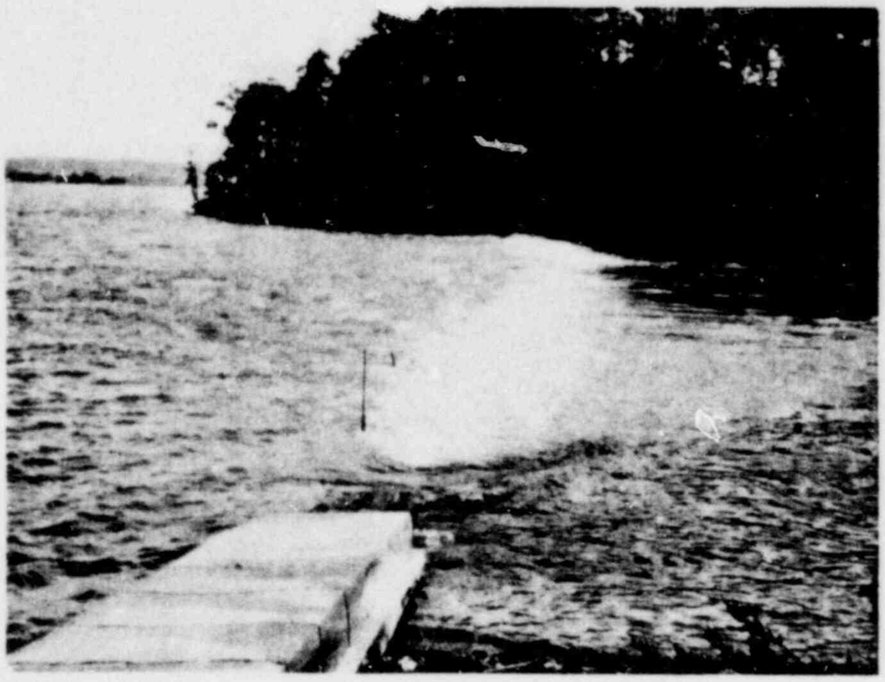

Figure II-8. Photograph of Air Curtain at Head of Intake Canal (Note water turbulence due to air curtain)

SECTION III
DESCRIPTION OF DARDANELLE RESERVOIR

Dardanelle Reservoir (Figure III-1) is part of the McClellan-Kerr Arkansas River navigation system which extends from the confluence of the Arkansas and Mississippi rivers to Catoosa, Oklahoma, on the Verdigris River. The reservoir surface coverage varies between 34,000 and 36,000 surface acres (13,891.5 and 14,013.0 hectares) with a shoreline length of 315 mi (506.8 km) at a pool elevation of 338 ft (103.0 m) (Arkansas Power & Light Co., 1974).

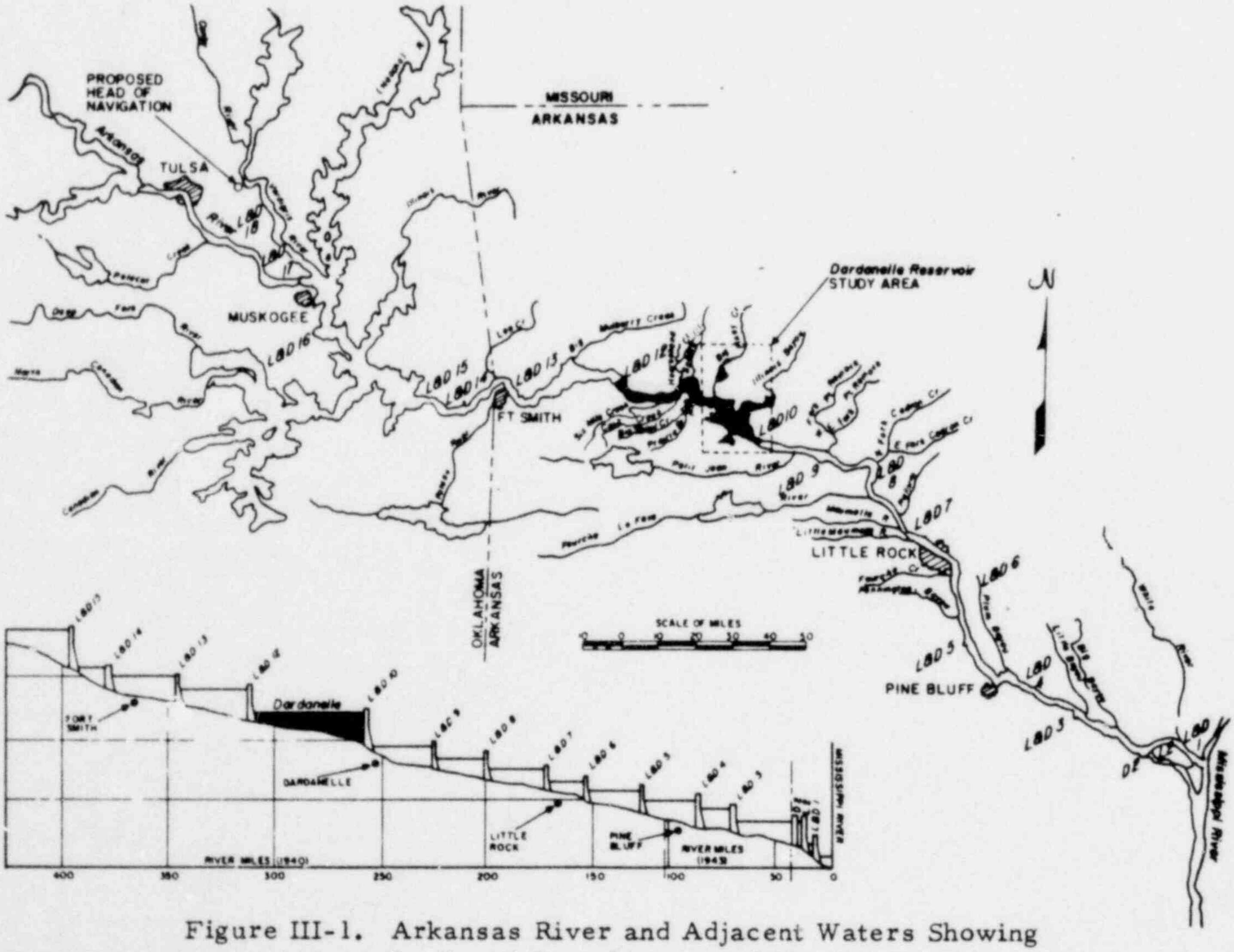

Figure III-1. Arkansas River and Adjacent Waters Showing Lock and Dam System and Dardanelle Reservoir

The reservoir's maximum volume since being filled was 502,000 acre-ft on 5 June 1974 at a pool elevation of 338.45 ft (103.16 m) above mean sea level; minimum volume since being filled to the bottom of the power pool was 415,000 acre-ft on 13 October 1969 at a pool elevation of 335.8 ft (102.4 m).

The Arkansas River at Dardanelle Reservoir, over the 34-yr period extending from 1923 to 1957 (Army Corps of Engineers), produced an average daily discharge of 34,260 ft^3/sec (969.56 m^3/sec) or 24,820,000 acre-ft/year (maximum, 52,206,000; minimum, 5,354,000). During that period, the maximum daily discharge was 683,000 ft^3/sec (19,328.9 m^3/sec) on 13-14 May 1943 and the minimum daily discharge was recorded at 400 ft^3/sec (11.3 m^3/sec). The lowest flow on record was 43 ft^3/sec (1.2 m^3/sec) in December 1970.

Major tributaries (Figure III-1) contributing to Dardanelle Reservoir include Six Mile Creek, Horsehead Creek, Spadra Creek, Cane Creek, Big Shoal Creek, Big Piney Creek, and the Illinois Bayou.

Dardanelle Dam (Lock and Dam 10) is 259 mi (416.7 km) upstream from the mouth of the Arkansas River and is the first of four dams with lift capabilities to 54 ft (16.5 m), including storage for hydropower; construction of this dam was initiated in 1957 and commercial generation began in 1965. The minimum and maximum pool elevations behind Dardanelle Dam are 336 ft (102.4 m) and 338 ft (103.0 m), with a normal power generation storage capacity of 2 ft (0.6 m). Power generation is based on the mean daily inflow equaling mean daily outflow within the 336- to 338-ft limits. The four hydroelectric generating units at Dardanelle Dam produce a total power output of 124,000 kw (124 Mw).

Dardanelle Reservoir exhibits seasonal patterns of water temperatures, dissolved-oxygen levels, and other physicochemical parameters, typical of a southern (temperate) storage reservoir. Water temperatures range from near freezing in winter to about 90°F in summer. Dissolved oxygen levels follow a seasonal pattern inversely related to water temperature (Arkansas Power & Light Co., 1974). The reservoir currently possesses a relatively diverse warm-water fish community consisting of 53 species, representing 18 families of fish, and supports both a small commercial fishery and growing sport fishery.

For a more detailed characterization of the physicochemical makeup of Dardanelle Reservoir, see the AP&L Environmental Report for Arkansas Nuclear One — Unit 2, Vol. 1, 1974.

SECTION IV
AIR CURTAIN LITERATURE SURVEY

A. GENERAL

Behavioral experiments involving the reaction of fishes to various response-evoking stimuli such as cold and warm temperatures, dissolved oxygen, light, forage, predators, etc., are quite numerous in the literature. The great majority of these studies, however, were not designed specifically for solving the fish impingement problem which has been plaguing the power industry.

Section 316(b) of the 1972 Federal Water Pollution Control Act requires that:

> "... the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact."

In response to this requirement, utility companies have closely examined those few studies involving fish reactions to stimuli that appeared to act as deterrents and/or guiding mechanisms. Further, numerous utilities have initiated "in-house" or funded fish behavioral studies in the hope of discovering ways to minimize the chances for serious damage to the local and/or migrant fish community through entrapment and/or impingement at plant intake structures.

Fish responses to solid physical barriers (traveling screens, fixed screens, perforated screens, drum and disc screens) and reactions to behavioral barriers (sound, illumination, electricity, louvers, chains, jets of water, and curtains of bubbled air) have been evaluated at a number of test facilities and plant sites (USEPA, 1973).

In consonance with the major objective of evaluating the efficiency of an air curtain for deterring fish at Arkansas Nuclear One, Texas Instruments has conducted a case history review of this device's past performance under both laboratory and actual operational conditions. To this end, our survey has been directed specifically to air curtain test results. Mention of other behavioral screening methods are included only when pertinent to the discussion of these experimental data.

The results of this survey are presented in the following subsections:

- The basic hypothesis behind the air curtain device
- Chronology of air curtain experimentation, involving both laboratory testing and plant-related operational experience

B. HYPOTHESIS

Fish behavior can be described simply as taxa, directed reaction or directed movement in response to a stimulus. Such behavior is induced by either extrinsic physical and/or chemical stimuli or by intrinsic biological factors. An air curtain is one of a series of essentially behavioral screen-like devices, which, by giving off both visual and tactile stimuli, makes use of a fish's behavioral response, i.e., avoidance of an apparent physical barrier to deter or guide the fish from a potentially unsuitable area.

Basically, an air curtain consists of a length of tubing or pipe perforated by a series of air jets or air holes supplied with forced air from electrically powered compressors and arranged to provide a continuous curtain of air bubbles over an entire water body cross section (USEPA, 1973). Its effectiveness depends upon a fish reacting voluntarily or involuntarily to the air bubbles released by the bubbler device. This response, in turn, is acted upon by a succession of internal and external factors such as species specific distribution patterns and abundance levels, behavioral differences, ambient natural and/or man-made environmental conditions, and competing or overriding stimuli.

C. CHRONOLOGY

1. Introduction

Historically, small meshed wire gratings had been utilized as barrier-guides to divert fish to fish passes (Bramsnaes, Mogens and Otterstrom, no date) at weirs, streams and hydroelectric dam spillways. On large streams and at hydroelectric dam spillways, however, the need for constant maintenance and the reduction of water flow due to clogging by waterborne debris proved these devices to be both costly and inefficient. What was needed was a barrier and guidance system which would regulate the passage of fish, yet not diminish power generating efficiency.

2. Laboratory Experimentation

Successful diversion or deterrence of a fish species has been shown to depend primarily upon the ability of that particular species to respond to the stimulus employed. This response is in part linked to the fish's sense of sight and touch together with its lateral line, which all interact to determine the orientation of the fish (Bibko, Wirtenan, and Kueser, 1974).

The first air curtain devices were designed to act as barrier-guidance systems to assist fish in locating the mouths of these fish passes (Bramsnaes, Mogens and Otterstrom, no date). Engineers and biologists at the laboratories of the Royal Technical College of Copenhagen, Denmark, collaborated on the testing of a barrier made by "veils of air" formed by small bubbles rising from a perforated tube placed on the test chamber bottom.

In laboratory tests on four species of fish [6- to 35-cm rainbow trout *(Salmo gairdneri)* , 35- to 40-cm carp *(Cyprinus carpio)*, 10- to 50-cm pike *(Esox* sp.) and 70- to 80- cm eels *(Arguilla arguilla)*], it was found that at water current velocities from 5 to 15 cm/sec, the barrier effectively diverted carp and pike. Trout, however, passed through apparently unaffected. It was concluded that the veil of air was partially successful in diverting fish. Further, it was suggested that the effects of the veil of air would be greater in stagnant than in running water, where the veil (to some extent) would be affected by the water current.

Behavioral studies conducted by Brett and Mackinnon (1953) using chinook salmon *(Oncorhynchus tshawytscha)*, indicated that sudden flashes of bright light were successful in diverting them, while air bubbles had no effect at all. Other studies cited by Brett and Mackinnon (1953), however, showed that fish deterrence with respect to air bubbles was a species-specific phenomenon, with certain species 100% deterred and others virtually unaffected.

Studies performed by Bates and VanDerWalker (1969) were aimed at designing an effective low-cost method of guiding and collecting juvenile salmonids from irrigation and power plant intakes as well as streams and rivers. It was felt that the methods employed in sound, light, and electricity deterrence technologies were not successful enough to warrant field application. They therefore explored the areas of water and air guidance systems during 1963-64 in a specially designed test flume at the Carson National Fish Hatchery, Carson, Washington. Test results indicated that at temperatures between 7.8 -11.1 C (46-52 F), maximum deflection (90%) occurred during daylight hours at a screen approach velocity of 1.9 fps; night tests, however, produced little (10-30%) or no guiding effects. It was concluded that the effectiveness of the air-bubble curtain in deflecting downstream migrants was a function of the fishes' ability to see it. This ability would be obviously decreased during the night or in areas of high turbidity. Preliminary experiments using artificial lights as an illumination source at the location of the air curtain failed to improve its nighttime efficiency. These last two findings precluded the curtain's use as a functional barrier to downstream migrant salmonids.

Also linked to apparent sensory response limitations are those conditions fostered by ambient environmental factors such as water temperature, which can alter or completely change existing response efficiencies with respect to any particular fish species (Bibko, Wirtenan and Kueser, 1974). Behavioral screening systems rely on the swimming ability of the various species to avoid the artificial stimulus. Swimming ability, in turn, is related to species and size within species differences. This swimming ability is also known to be significantly affected by temperature, with markedly reduced swimming ability demonstrated in the colder winter months (USEPA, 1973).

Research conducted at the Edenton National Fish Hatchery, Edenton, North Carolina, during December 1973, sought to assess the influence of water velocity, direction and temperature on swimming behavior of 3- to 8-in. striped bass *(Morone saxatilis)* and 10- to 14-in. gizzard shad *(Dorosoma cepedianum)*, and to determine the efficiency of an air curtain and intense illumination as deterrents to fish impingement.

Findings with regard to current velocity preferences showed that fish repeatedly chose a swim path through sectors of low current velocity unless presented with a deterrent. Temperature levels did indeed influence both the physiological state of the test fish and subsequent efficiency of the air curtain. Young striped bass swimming against a current of 0.7 fps would not cross an air bubble screen with free space between bubble holes of 1 in. (center-to-center) at 4.5°C (40°F) or 11.1 C (52°F), but became lethargic and drifted passively through the air screen (with the current) at a temperature of 0.8°C (33.5°F). Gizzard shad did not cross the air curtain at 11.1°C (52°F) against the current, but continually drifted through with the current at ambient temperatures of 0.8°C (33.5°F) and 4.5°C (40°F). It was noted that young striped bass were not deterred at any water temperature if a gap of 5.1 cm (2 in.) or more was allowed in the air curtain screen.

Tests on physical placement of the air curtain showed that it was necessary to place the air curtain no more than 5 cm (2 in.) from the test tank floor. When placed any farther from the bottom, it was discovered that the test fish would pass unimpeded under the curtain pipe.

The air curtain appeared to be equally effective in deterring striped bass when little ambient light was present. This finding tends to cloud the results of Bates and VanDerWalker (1969) that these systems are ineffective under nighttime conditions. It also suggests that other than entirely visual sense mechanisms are involved in the avoidance reaction.

In summary, it was concluded that properly designed fish deterrent devices such as the air curtain tested by Bibko, Wirtenan and Kaesner (1973) may substantially reduce fish impingement at operating power plants, and may represent a cost-effective alternative to closed system cooling. However, limitations placed upon a fish's physiological condition and subsequent screen efficiency by ambient environmental conditions such as water temperature, turbidity, current velocity would be shared with all systems which relied on swimming ability of fish to escape an intake (USEPA, 1973).

3. Operational Experience

Due to the erratic nature and inconclusive findings of air curtain testing under controlled laboratory conditions, only a limited number of actual "in the field" applications of this device can be found in the available literature.

Smith (1961) applied air curtain theory toward guiding fish, in an effort to increase fishing efficiency of the sardine fishery. He found that herring, because of their skittish and easily frightened nature, were effectively guided by an air curtain from deeper waters into bays and shoals and eventually into capture weirs. The guidance mechanism was effective as long as the curtain was moved slowly enough to prevent fright, if predators were not in the immediate vicinity, and if crowding was minimized.

A small but growing number of utilities are considering operating or experimenting with air-bubble curtains along with other behavior-oriented screening devices to assess their efficiency in deterring or guiding fish from plant intake structures. Among these utilities are Consolidated Edison of New York on the Hudson River, Toledo Edison Company on Lake Erie, Wisconsin Public Service Company on the south shore of Lake Erie, Pennsylvania Electric Company, Florida Power and Light Co., Commonwealth Edison in Chicago, and Arkansas Power & Light Co. on the Dardanelle Reservoir (USEPA, 1973). However, many of these results have not been published.

An apparently successful application of air-bubble curtain technology was reported to Florida Power and Light Co. by Maxwell (1973) in his state-of-the-art report on fish diversion (USEPA, 1973). The system was installed at a power plant on Lake Michigan in Wisconsin, where the principal fish species involved was the alewife *(Alosa pseudoharengus)*, a schooling fish which averages 15-20 cm (6-8 in.) in length as an adult. Prior to air curtain installation, major shutdowns caused by high impingement of alewives on the intake screens and eventual serious intake flow reduction had occurred on several occasions. This air curtain's purpose, therefore, was to repel large schools of fish rather than to stop all individuals. Test results showed that the curtain was equally effective in repelling fish during day or night. Further, since installation of the air-bubble curtain, only one or two shutdowns due to heavy alewife impingement have occurred during more than four years of operation.

Perhaps the longest documented record of air-bubble curtain testing exists at Consolidated Edison's Indian Point Power Plants located on the Hudson River, approximately 42 mi north of New York City. Since Indian Point Unit 1 went on line in 1962, impingement of fishes on the cooling water intake screens has been a major recurring problem (Alevras, 1974).

During the years immediately following the startup of Indian Point Unit 1, several attempts were made to repel fish from the intakes using sound, altered light regimes, and an air bubbler. These efforts were all reported as unsuccessful (Alevras, 1974).

The Indian Point nuclear generating plant (Figure I-1) located on the east bank of the Hudson River [RM 42.5 (68 km)] near Peekskill, New York, consists of three nuclear reactors (Units 1, 2, and 3) and associated power-generating and water-circulating apparatus. Licensed capacities for Units 1 and 2 are 890 MW(t) [net, 265 MW(e)] and 2758 MW(t) [net, 873 MW(e)] respectively; license-requested capacity for Unit 3, which is still under construction, is 3025 MW(t) [net, 1033 MW9e)].

The total water-pumping capacity of all three units is 2,058,000 gpm (7791 m^3/min). Unit 1 has two 140,000-gpm (530-m^3/min) condenser circulating water pumps which draw water through four intake bays located behind several pilings supporting a dock. In addition, Unit 1 has six service water pumps with a combined capacity of 38,000 gpm (144 m^3/min); service water is drawn through all four intake bays. Units 2 and 3 have six 140,000-gpm (530-m^3/min) condenser circulating water pumps each but, unlike Unit 1, their circulating pumps draw water through only one intake bay. Units 2 and 3 have service water pumps with total capacities of 30,000 gpm (114 m^3/min) each. The service water for these two units, however, is drawn through service-water bays located in the middle of the unit intake structure rather than through the main intake bays as at Unit 1.

Units 1 and 2 have fixed fine screens [0.375-in. (0.95-cm) mesh] at the entrance of the intake bays and vertical traveling screens [also 0.375-in. (0.95-cm) mesh] behind the fixed screens. Unit 3 intakes have vertical traveling screens [0.375-in. (0.95-cm) mesh] rather than fixed screens, located at the intake openings (Texas Instruments, 1974a).

The bubbler array utilized at Unit 1 was composed of two vertical rows of horizontal bubblers, with bubblers spaced 4 ft apart in each row. The lower bubbler was in contact with the river bottom. Additionally, a flexible hose was used to fill any bubble-free gaps below the rigid pipe. The inner row of bubblers was 18 in. from the fixed screen; the outer row was 36 in. from the screen. Air was released from each bubbler through 1/32-in. holes spaced on 1/2-in. centers along the pipe. Each bubbler spanned the width of the fixed screen and turned inward at a 90 angle toward the fixed screen to produce an air curtain on the sides of the array. A system of valves permitted control of air flow to the bubblers. A total of 900 scfm of pressurized air was released during initial testing. Subsequent testing was conducted at 400 scfm (Alevras, 1974).

A preliminary testing of this air curtain's potential as a fish-protection device at Indian Point occurred during a 10-day period between February 17 and 29, 1972. This array of bubbler pipes was placed in front of a single intake forebay at Indian Point Unit 1, and the system tested. Results indicated that with the air curtain in operation, this single forebay (No. 12) impinged the fewest fish of the four intake forebays (Nos. 11 through 14) present at Unit 1. However, counts on adjacent forebays (Nos. 13 and 14) increased commensurately with the reduction at forebay No. 12. By examination of pre- and post-test data for all four forebays, it was determined that air bubbler operation at forebay No. 12 produced a significant change in the distribution of fish collected at Unit 1 forebays (Alevras, 1974). The apparent effect of the air bubbler was to reduce the number of fish entering the bay equipped with the air system and divert these fish to the remaining three bays where they were subsequently impinged (Quirk, Lawler and Matusky, 1973). It was concluded that the air bubbler was influencing the behavior of fish in front of the intake screens, but that a test using an air bubble system across the entire intake was needed to determine if the system was capable of reducing the total number of fish collected.

While this new system was under construction additional testing of the air bubbler and fixed screen system was conducted at the four intake forebays of Indian Point Unit 1 from 16 June 1972 through 16 August 1972. During this experimentation cycle, the fixed screens in front of the travelling screens at forebays Nos. 11 and 12 were raised; fixed screens at forebays Nos. 13 and 14 remained in place. The air curtain test unit was placed in front of forebay No. 12. The following test results were reported by Alevras (1974):

- Without a fixed screen present, the air bubblers at bay 12 did not repel fish.
- With the bubbler operating, fish impingement counts increased significantly during hours of darkness at forebay 12, while during daylight, bay 12 collected as many fish with the bubbler operating as without.
- The air curtain did not appear to repel fish, and may attract fish during hours of darkness.

It was suggested that there was a possible confounding effect of removing fixed screens 11 and 12, while keeping fixed screens 13 and 14 in place. Fixed screens at bays 13 and 14 may have diverted fish into bays 11 and 12, causing a higher impingement rate in these bays (Texas Instruments, 1974a). Texas Instruments (1974a) also proposed that the effectiveness of the Unit-1 air curtain may have been severely hampered at night by the high turbidities at Indian Point. Bates and VanDerWalker (1969) concluded that an air curtain would be a poor fish deflector in highly turbid water. This conclusion was based on their test results conducted in clear water which showed lessened diversion rates during hours of darkness. Bibko, Wirtenan and Kueser (1974) however, found an air curtain equally effective during daylight and darkness in clear water flume tests; operational testing at a plant on Lake Michigan showed identical findings (Maxwell, 1973). It may be, therefore, that there are other than optic-related variables involved in the explanation of these increased nighttime impingement rates.

Subsequent tests were conducted when the fixed screen was reinstalled at forebay 12. It was found that the turbulent action of the air curtain rolled fish off the fixed screen, keeping the screen free of fish and debris. These dead or moribund fish were repeatedly rotated from the screen to the Hudson River and back to the same or adjacent screen (Texas Instruments, 1972).

A complete but temporary bubble system was installed at all four intake forebays of Indian Point Unit 1 during December 1972. Testing of this system, however, was not conducted during this month. Standard impingement data showed that with the bubblers operating continuously during this month, daily impingement rates were below the numbers expected based upon past experience.

A complete and permanent air bubbler system was installed at Indian Point Units 1 and 2 in the winter of 1972-1973. Unit 1 was taken off line since the system was installed and no testing has been conducted to date. Tests at Unit 2, however, were conducted from 16 February through 2 April 1973. The Unit 2 air curtain consisted of eight frames, each frame composed of a 4-in. (10.2-cm) vertical header, with seven parallel 2-in. (5.1-cm) lateral connections located at 4-ft (1.2-m) intervals along the length of the vertical header. Each lateral connection supplied two parallel 1.5-in. (3.8-cm) horizontal headers. Vent holes of 0.03-in. (0.8-mm) diameter were drilled in the upper quadrants of the headers at intervals of 1 in. (2.54 cm). Air-pressure indicators were mounted in the bottom of each frame. To prevent excessive circulator vibration, airflow was limited to a maximum of 400 scfm (11.3 m^3/min)/main intake bay. The results of this testing showed that fewer fish were collected on traveling screens at Unit 2 intake forebays when the air curtain was on for more than 10 hours. However, it should be noted that these analyses were based on numbers of fish actually collected from the traveling screens. An unknown number of impinged fish were observed floating away from the fixed screens when the air curtain was on. These fish may have been removed from the screens by the air curtain and consequently were not collected. Therefore, the counts recorded may have been an underestimate of the impingement at these screens (Texas Instruments, 1974a).

Based upon test data from Units 1 and 2, Texas Instruments concluded the following:

- Indian Point air curtains appear to be located at points where approach velocities exceeded the swimming abilities of the fishes, especially during times of low water temperatures (based on data from Unit 2 winter testing).

- Subjective observations indicated that the air curtains reduced the amount of trash that would have been impinged and collected on the traveling screens, and kept large floating debris (ice and logs) away from the intake structures.

- The bubble barrier was apparently effective in controlling ice in front of the intake

It was suggested that should there be a positive correlation between impingement and trash loads (causing head loss and increased intake velocities), the air curtain might indirectly reduce impingement by reducing the head loss caused by trash loads. Further, the air curtain might be used as a possible replacement for the warm water recirculation systems which are currently being used to control ice at many existing installations.

Results of constant air curtain operation at Indian Point Unit 2 from June through October 1973 indicated reduced impingement rates for this time period when compared to data for previous years. Actual air curtain testing however, was not conducted during this time period. Therefore, it is impossible to determine if the low counts were the result of the air bubblers or were caused by other factors.

4. Summary

The Environmental Protection Agency (1973) has stated that the mechanism of bubble screening was not sufficiently well understood to recommend this device's adoption generally. It was suggested that these types of systems might be experimented with in an attempt to solve localized problems at existing intakes since the costs involved in installing these systems are relatively small. Bibko, Wirtenan and Kueser (1974) agreed that while the costs involved in installing and operating fish deterrent systems are definitely small in comparison with alternative measures, such as cooling towers, the potential benefits may be equal to or greater than those which would be realized with alternative methods to once-through cooling.

At best, however, extant lab and field test data concerning the efficiency of air curtains in deterring or guiding fish are erratic and inconclusive. Results appear to be both site and species specific, and are subject to a multitude of interrelated and as yet not completely understood variables.

SECTION V

TEST DESIGN AND ANALYSIS METHODOLOGY

A. AIR CURTAIN TESTING PROGRAM

Seasonal testing of the air curtain consisted of six consecutive weekly runs* of 3 days "on" and 3 days "off" operation over six consecutive days, with 1 day between runs. The seventh day impingement results were not used in the analysis (Figure V-1). This program constituted a complete block design with the air curtain at two levels of operation (Level 1, air curtain on; level 2, air curtain off), each week constituting a block. Six such blocks (tests) per season were considered to be the minimum information required for testing purposes.

Arkansas Power & Light personnel were responsible for acquiring test data at the plant site. These data were submitted to TI periodically, with fall, winter, spring, and summer tests scheduled as shown in Figure V-1. The months were grouped into seasons as follows:

Fall:	September, October, November
Winter:	December, January, February
Spring:	March, April, May
Summer:	June, July, August

Testing was not scheduled during the first month of each season.

During the fall and winter test periods, all intake screens were washed and all fish collected once per day on Monday, Wednesday, Thursday, and Saturday and twice per day on Tuesday and Friday.** All daily washings

---

*A run is defined as six consecutive "test" days, with the air curtain "on" for 3 days ("on" test) and "off" for 3 days ("off" test).

**The two washings each Tuesday and Friday were for the Nuclear Regulatory Commission (NRC) monitoring program. The second washing was 8 hours after the first.

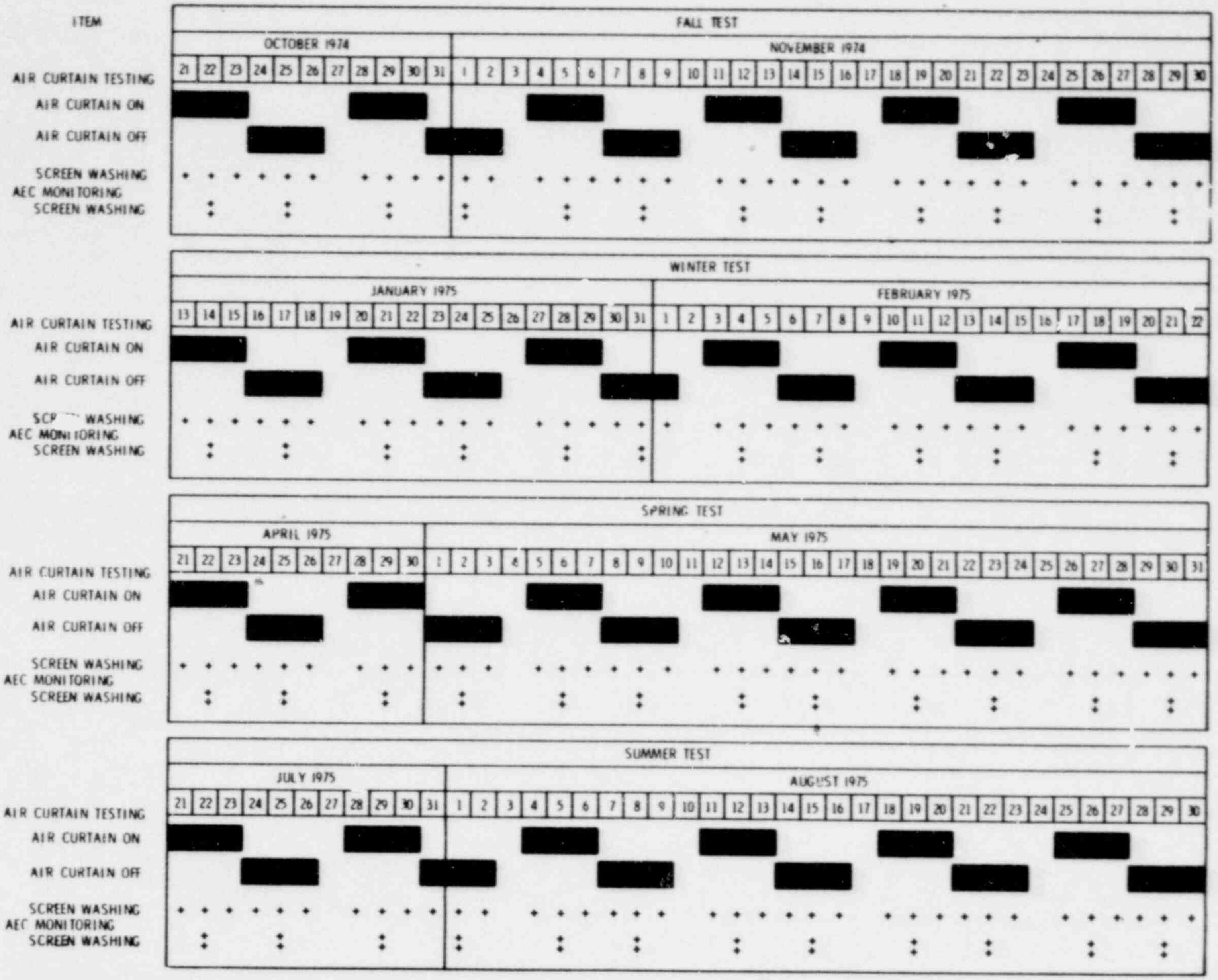

Figure V-1. Air Curtain Testing Program Schedule at Arkansas Nuclear One - Unit 1 for 1974-1975 were performed at 0800, with the second washings on Tuesday and Friday at 1600. Catches from the second washings each Tuesday and Friday were added to the next day's 0800 catch, since these fish would have been collected then had they not been collected at 1600 the previous day.

On days of extremely high impingement during the winter testing period, 16-hr collections were processed instead of the usual 24-hr collections because of manpower limitations. These data were extrapolated to 24-hr rates for purposes of analysis and comparison.

The practice of performing two screen washings on Tuesdays and Fridays was discontinued during spring and summer air curtain tests; rather, all fish were collected once per day, Mondays through Saturdays, at 0800.

B. AIR CURTAIN TESTING PROCEDURAL DESIGN

All screens were washed and all fish removed at 0800 on the first day of the 6-week seasonal test period and disregarded; shortly thereafter, the air curtain was put in operation. At 0800 on the two succeeding consecutive days (first and second day of "on" test), the screens were washed and the fish processed. At 0800 on the third consecutive day (end of third day of "on" test), the fish were processed, the air curtain shut down and three consecutive days of "off" testing performed, with fishes removed and processed at 0800 on each of the three days. This process of turning the air curtain on or off (depending on the test) shortly after the 0800 washing on the third day continued throughout the six runs. Fish collected at 0800 following each seventh day (the day between runs) were not processed. This overall procedure provided clean screens at the beginning of each "on" or "off" test and each run.

It was proposed that fish passing through the air curtain when it was in operation might have remained in the 0.75-mi-long intake canal and not impinged until the air curtain "off" test period, and vice versa. The actual lag time between a fish's entering the intake canal and its subsequent impingement on the plant intake screens at Arkansas Nuclear One — Unit 1 is presently unknown. No doubt this time period depends on the species involved; the size, behavior patterns, and physical condition of the fish; water temperature and other physicochemical factors; and intake velocity. We assumed that:

1) once a fish is past the air curtain and canal entrance, the lag time is independent of air curtain status (ON-OFF); and short in relation to the sampling period

2) once a fish is within the canal, only the strongest and/or largest individuals can surpass the 3.0-fps velocity,

Therefore, all fish collected at 0800 at the end of a test day were recorded as having passed through the air curta during the previous 24 hours.

C. SAMPLE COLLECTION AND PROCESSING

For the 24-hr impingement determination, the 3/8-in. wire mesh vertical traveling screens (Figure V-2) on each forebay were rotated until all fish were removed. The fish were then washed by a high-pressure water wash system from the traveling screen into a sluiceway, where they were collected in a wire basket. These fish were separated by species, weighed to the nearest one-tenth pound, and enumerated. If the total catch (before species segregation) was too great to make counting or processing the entire sample feasible, the entire sample was weighed, and a representative subsample was taken. Then this subsample was processed as if it were a total sample. Based on total weight of the catch (W), the total weight of the subsample (W'), and number and weight per species in the subsample, the number and weight per species in the total collection were calculated as

1) Total weight per species = subsample weight per species x $\frac{W}{W'}$

2) Total number per species = subsample number per species x $\frac{W}{W'}$

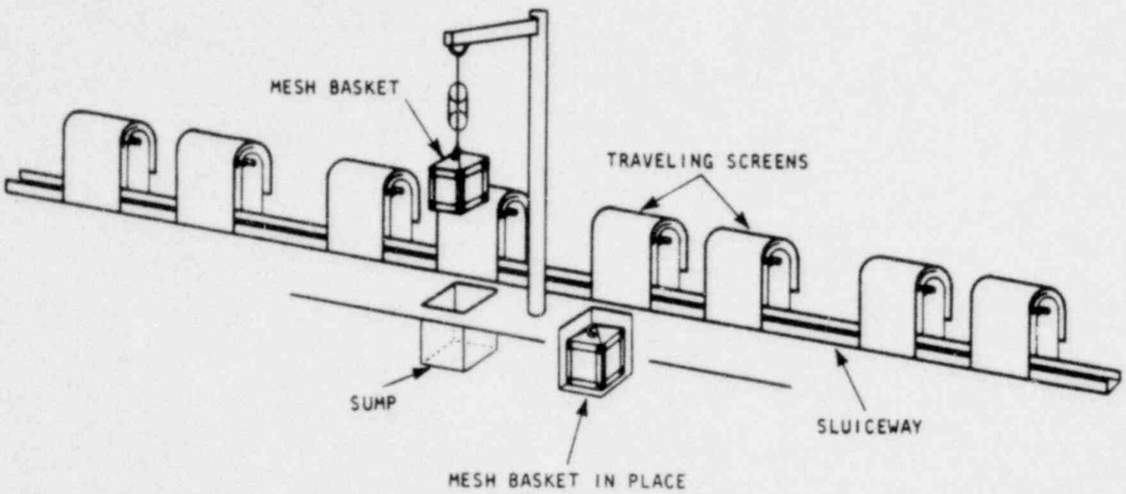

Figure V-2. Schematic Showing Traveling Screen System and Fish Collection Hardware at Arkansas Nuclear One - Unit 1

Following the species enumeration and weight determination, each species was separated into size groups to determine the length-frequency and biomass composition of the impinged fish; total length (cm) and weight (to the nearest tenth of a pound) were recorded for individual fish. When the number in a species group was low (< 25 fish), each individual in that group was weighed and measured. If the total number (N) in a particular species was ≥ 25 but ≤ 100, 25% of that group was processed. If the group numbered ≥ 101, 25 fish + 1% of N - 100 fish were processed. In certain instances, the upper size ranges of a number of fish species were represented by only a few large individuals. To avoid selecting against size classes with few individuals in the subsample, all large individuals in the group were measured before a subsample was taken. Percent length-frequency distribution was calculated as the percent contribution made by a particular size group to the entire species.

D. PHYSICOCHEMICAL PARAMETERS

Air and water temperature, percent cloud cover, wind direction and intensity and rainfall were recorded daily during all four seasonal air curtain test periods; water turbidity measurements were irregular and less frequent. All environmental data collected during seasonal air curtain testing are presented in Appendix Tables A-12 through A-15.

E. OPERATIONAL VARIANCES

The operational mode of the air curtain, circulating pumps, and air compressors was to remain constant over the 4-season test cycle, as well as during all six runs within any one seasonal test period. Technical difficulties and manpower limitations did occur, however, over the span of each 6-week test. These variations in operational mode or related problems might, in some cases, be expected to influence sample and therefore test validity. As such, all reported problems, mechanical failures, and operational variances are presented in Table V-1 and have been considered during data analysis.

F. STATISTICAL ANALYSIS

The air curtain test analysis design comprised a two-way layout with two treatments (on/off) in six blocks for each seasonal period (five blocks for the spring test).*

---

*The 6th run during spring testing was invalidated due to irreconcilable variance from normal testing procedures.

Table V-1

Variance in Mode of Operation during Air-Curtain Testing at Arkansas Nuclear One, October 21, 1974-August 30, 1975

Date	Test Status	Normal Mode of Operation	Actual Mode of Operation and Associated Malfunction
FALL TEST			
Oct 21, 1974	Run I, ON test	Five compressors operating, 0800 Oct 20 to 0800 Oct 21	Only four compressors operating from 1330 Oct 20 to 0800 Oct 21
22	Run I, ON test	Five compressors operating, 0800 Oct 21 to 0800 Oct 22	Only four compressors operating from 0800 Oct 21 to 0800 Oct 22
24	Run I, OFF test	Air curtain off, 0800 Oct 23 to 0800 Oct 24	Air curtain left on from 0800 Oct 23 until 1000 Oct 23
30	Run II, ON test	Four circulator pumps operating, 0800 Oct 29 to 0800 Oct 30	All circulator pumps turned off at 1330 Oct 29, two circulator pumps turned on at 1930 Oct 29
31	Run II, OFF test	Four circulator pumps operating, 0800 Oct 30 to 0800 Oct 31	All circulators turned off at 0820 Oct 30. Two pumps turned on at 1900 Oct 30. Air curtain turned off at 0815 Oct 30.
Nov 1, 1974	Run II, OFF test	Four circulator pumps operating, 0800 Oct 31 to 0800 Nov 1	All pumps turned off at 0830 Oct 31. Four pumps turned back on at 1515 Oct 31.
7	Run III, OFF test	Air curtain off 0800 Nov 6 to 0800 Nov 7	Air curtain turned off at 0900 Nov 6
11	Run IV, On test	Sample period 0800 Nov 10 to 0800 Nov 11. Air curtain operating 0800 Nov 10 to 0800 Nov 11.	Sample period 0800 Nov 10 to 1100 Nov 11; sample not processed. Air curtain not operational until 1100 Nov 10.
12	Run IV, ON test	Sample period 0800 Nov 11 to 0800 Nov 12	Actual sample period from 1100 Nov 11 to 0800 Nov 12.
13	Run IV, ON test	All screens washed at 0800 Nov 13	Screen B not washed until 1300 Nov 13
14	Run IV OFF test	Four circulator pumps operating, 0800 Nov 13 to 0800 Nov 14. All screens washed at 0800 Nov 14.	Circulator pump A turned off 0240 Nov 14 and turned on at 1000 Nov 14. Screens A and B washed at 0130 Nov 14; screens C and D washed at 0620 Nov 14. All fish discarded.
18	Run V, ON test	Air curtain operating, 0800 Nov 17 to 0800 Nov 18	Air curtain not operating until 1000 Nov 17.
21	Run V, OFF test	Air curtain off, 0800 Nov 20 until 0800 Nov 21	Air curtain not turned off until 0900 Nov 20.
25	Run VI, ON test	Air curtain operating, 0800 Nov 24 until 0800 Nov 25	Air curtain not operating until 0930 Nov 24.
28	Run VI, OFF test	All fish collected at 0800 Nov 28 weighed and measured	All fish collected at 0800 Nov 28 and disposed of through trash grinder.
WINTER TEST			
Jan 13, 1975 14	Run I, ON test	Four circulator pumps operating	One circulator pump turned off at 0600 and turned on at 1500 Jan 13.
Feb 3, 1975 4 5	Run IV, ON test	Five air compressors on	Three air compressors on from 0800 Feb 2 to 0800 Feb 5.
10	Run V, ON test	Five air compressors on	No air compressors on from 0800 Feb 9

Table V-1 (Contd)

Date	Test Status	Normal Mode of Operation	Actual Mode of Operation and Associated Malfunction
SPRING TEST			
Apr 21, 1975	Run I, ON test	Air curtain operating, 0800 Apr 20 to 0800 Apr 21	Sample period, 1230 Apr 20 to 0800 Apr 21; data extrapolated to approximate 24-hr test period.
May 26, 1975	Run II, ON test	24-hr test period, ON mode	No data; test not run.
29	Run VI, ON test	First OFF test period for Run VI	Air curtain remained on.
30	Run VI, ON test	Second OFF test period for Run VI	Air bubble curtain remained on.
	Run VI, ON test	Third OFF test period for Run VI	Air bubble curtain turned off 1500 May 30; test invalidated.
SUMMER TEST			
Jul 21 22	Run I, ON test	Air curtain operating across entire width of intake canal	End cap detached from third section of air-curtain pipe; only three-fourths of bubble curtain operational.
23	Run I, ON test	0800 Jul 22 to 0800 Jul 23 sample period, ON mode	Screens not washed until 1030 Jul 23; data extrapolated to approximate 24-hr test period.
24	Run I, OFF test	Four circulator pumps operational	One circulator pump turned off at 1158 Jul 23.
24	Run I, OFF test	0800 Jul 23 to 0800 Jul 24 sample period, OFF mode	Screens washed at 1030 Jul 23 and at 0800 Jul 24. Data for Jul 24 extrapolated to approximate 24-hr test period.
25	Run I, OFF test	Four circulator pumps operating	Only three circulator pumps operational until 0100 Jul 25; four circulator pumps operational from 0100 to 0800 Jul 25.

Several statistical tests were available to test for a difference between the two treatments. The three tests utilized were the paired t-test (exactly equivalent to a randomized complete block analysis of variance F-test with two treatments), the Wilcoxon signed-ranks test, and the Sign test.

To test for a possible relationship between impingement during air curtain testing with physical parameters (i.e., water temperature), three measures of association (Pearson's r, Spearman's rho and Kendall's tau) were applied.

The nonparametric test procedures utilized in the analysis of air curtain test data followed Conover (1971). The parametric analysis methods are described in Snedecor and Cochran (1967).

SECTION VI
RESULTS AND DISCUSSION

A. GENERAL

Thirty-eight species of fish representing 14 families were identified from intake screen samples taken at Arkansas Nuclear One-Unit 1 during seasonal air curtain testing from October 1974 through August 1975 (Table VI-1). These numbers compare with a combined total of 53 species representing 18 families collected in Dardanelle Reservoir by all previous investigators between 1968 and 1974. Of the species previously reported over that period but not impinged during this study, the majority were either taken only rarely by the other researchers or they were taken in small quantities; it is also possible that some of those species previously reported and not represented in our samples were present but not of an impingeable size at the time of our sampling (Texas Instruments, 1975).

Seasonal numbers of species impinged during air curtain testing declined from a high of 29 during the fall test period to 20 species during the winter, and rose to 26 species during both spring and summer tests. Species numbers impinged with the air curtain on and off displayed no distinct or consistent differences over the four seasonal test periods (Table VI-1).

The principal species which occurred during the greatest number of seasonal air curtain test runs were: threadfin shad, gizzard shad, blue catfish, channel catfish, white bass, and freshwater drum. Occurrences of the principal species were evenly distributed between ON and OFF tests, and no overall seasonal trends could be discerned (Table VI-1). White crappie, white bass, and bluegill sunfish were collected in the great majority of test runs during fall, spring, and summer testing, but were infrequently impinged during the winter tests.

Table VI-1

Taxonomic List and Percent Frequency of Occurrence of Fish Species Impinged during Air-Curtain Testing at Arkansas Nuclear One-Unit 1, 1974-1975

Scientific Classification	Common Name	Fall 1974 Air Curtain On	Fall 1974 Air Curtain Off	Winter 1974 Air Curtain On	Winter 1974 Air Curtain Off	Spring 1975 Air Curtain On	Spring 1975 Air Curtain Off	Summer 1975 Air Curtain On	Summer 1975 Air Curtain Off
Lampreys-Petromyzontidae									
Ichthyomyzon castaneus (Girard)	Chestnut lamprey			0	5	47	47		
Paddlefishes-Polyodontidae									
Polyodon spathula (Walbaum)	Paddlefish			5	0				
Gars-Lepisosteidae									
Lepisosteus osseus (Linnaeus)	Longnose gar			5	0			0	6
Lepisosteus platostomus (Rafinesque)	Shortnose gar							0	6
Herrings-Clupeidae									
Dorosoma cepedianum (Lesueur)	Gizzard shad	100	100	100	100	100	100	83	100
Dorosoma petenense (Gunther)	Threadfin shad	100	100	100	100	100	100	100	100
Alosa chrysochloris (Rafinesque)	Skipjack herring	33	11	5	11			17	22
Mooneyes-Hiodontidae									
Hiodon alosoides (Rafinesque)	Goldeye					7	7		
Minnows and Shiners-Cyprinidae									
Cyprinus carpio (Linnaeus)	European carp	22	11	5	0	73	73		
Carassius auratus (Linnaeus)	Goldfish	5	0						
Notemigonus crysoleucas (Mitchill)	Golden shiner	17	33	5	5	67	67	28	56
Pimephales notatus (Rafinesque)	Bluntnose minnow	0	11						
Notropis girardi (Hubbs & Ortenburger)	Arkansas river shiner					20	7	6	6
Notropis cornutus (Mitchill)	Common shiner	0	5						
Notropis simus (Cope)	Bluntnose shiner	17	5						
Suckers-Catostomidae									
Carpiodes carpio (Rafinesque)	River carpsucker	33	5			53	27	17	0
Ictiobus cyprinellus (Valenciennes)	Largemouth buffalofish					7	0		
Ictiobus bubalus (Rafinesque)	Smallmouth buffalofish	33	28			60	40	11	0
Freshwater Catfish-Ictaluridae									
Ictalurus furcatus (Lesueur)	Blue catfish	100	100	83	67	100	100	100	100
Ictalurus punctatus (Rafinesque)	Channel catfish	100	94	89	78	100	100	100	100
Pylodictis olivaris (Rafinesque)	Flathead catfish					27	40	39	33
Ictalurus melas (Rafinesque)	Black bullhead	22	0	0	11	53	40		
Silversides-Atherinidae									
Labidesthes sicculus (Cope)	Brook silverside	0	11						
Menidia audens (Hay)	Mississippi silverside	83	89	67	61	33	7	28	17
Temperate Waterbasses-Percichthyidae									
Morone chrysops (Rafinesque)	White bass	94	100	5	17	87	80	89	78
Morone saxatilis (Walbaum)	Striped bass	0	5			0	7	28	22
Sunfishes-Centrarchidae									
Micropterus salmoides (Lacepede)	Largemouth bass	0	5			13	7	33	11
Pomoxis nigromaculatus (Lesueur)	Black crappie	11	17	5	0			11	6
Pomoxis annularis (Rafinesque)	White crappie	94	100	33	22	100	100	100	100
Chaenobryttus gulosus (Cuvier)	Warmouth	11	17			33	27	6	22
Lepomis cyanellus (Rafinesque)	Green sunfish	50	28	5	5	40	20	11	28
Lepomis megalotis (Rafinesque)	Longear sunfish	28	28	5	5	47	47	56	39
Lepomis macrochirus (Rafinesque)	Bluegill sunfish	72	61	0	0	93	100	100	94
Lepomis humilis (Girard)	Orange spotted sunfish	22	5	5	0	20	20	22	0
Lepomis microlophus (Gunther)	Redear sunfish	0	5					6	0
Percidae-Perches									
Percina caprodes (Rafinesque)	Logperch					7	7	6	0
Drums-Sciaenidae									
Aplodinotus grunniens (Rafinesque)	Freshwater drum	100	100	50	67	100	100	100	100
Cichlids-Cichlidae									
Tilapia sp.	Tilapia	33	5						

*Percentage determined by dividing the number of 24-hr samples in which a species occurred by the total number of 24-hr on/off tests run during a given season.

B. TOTAL NUMBERS AND BIOMASS IMPINGED

A total of 9,571,922 fish comprising a biomass of 173,641 pounds was impinged over the entire 4-season (24-week) air curtain test cycle (October 1974-August 1975). Of these totals, 4,930,127 fish weighing 90,870 pounds were collected during air curtain operation. The number and biomass of fish impinged when the air curtain was off totalled 4,641,795 fish weighing 82,770 pounds. A complete tabulation by individual species, test run, and season is presented in Appendix Tables A-1 through A-4.

Impingement rates during air curtain testing rose during late October 1974, when testing began, through the end of the fall test period (November 30, 1974) (Figure VI-1). An increase in impingement rates occurred during week three of fall testing, raising numerical and biomass impingement levels from less than 10,000 fish and 100 pounds per 3-day period to more than 20,000 fish and 150 pounds per 3-day period, when during this week, water temperatures in Dardanelle Reservoir declined below 65°F (18.33°C). High impingement levels (> 200,000 fish and 1000 pounds per 3-day period) persisted through the remainder of the fall and winter test periods. As water temperatures in Dardanelle Reservoir rose from winter lows, both numerical and biomass impingement levels decreased through the spring and summer 1975 test periods to levels of generally < 1000 fish and 50 pounds impinged per 3-day test period.

A comparison of air curtain ON and OFF test data for fall 1974, winter 1974-75, and summer 1975 revealed no statistically significant differences in the levels of fish impinged. Both the Wilcoxon test ($\alpha = 0.10$) and Sign test ($\alpha = 0.05$), however, revealed a significant difference in the numbers impinged between ON and OFF tests during the spring season (Table VI-2). Figure VI-1 shows slight but consistently greater numbers of fish impinged during air curtain operation during this period.

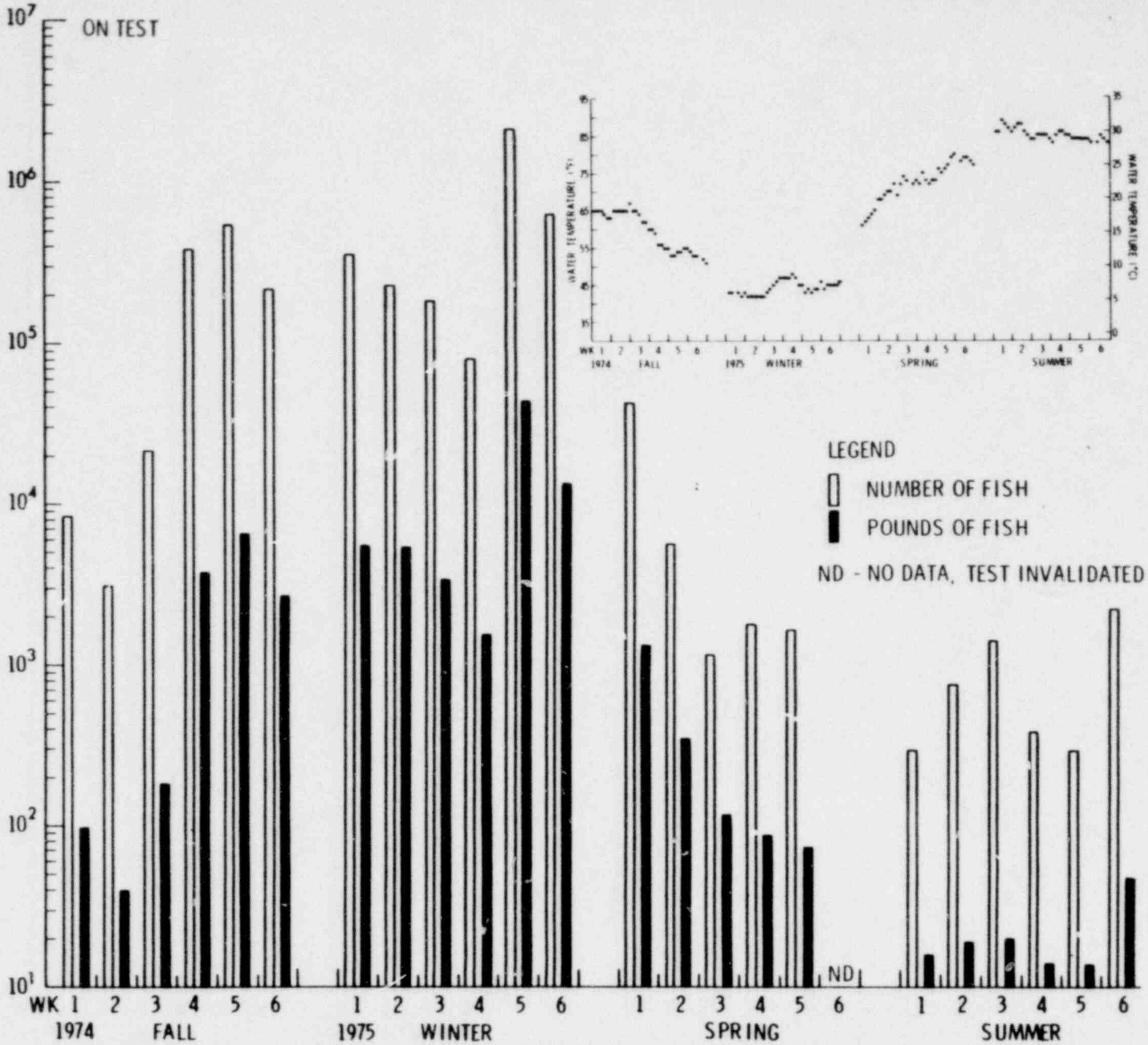

Figure VI-1. Total Numbers and Biomass (lbs) of All Fish Species Impinged per 3-Day Test Period during Seasonal Air-Curtain Testing at Arkansas Nuclear One, October 1974-August 1975 (Page 1 of 2)

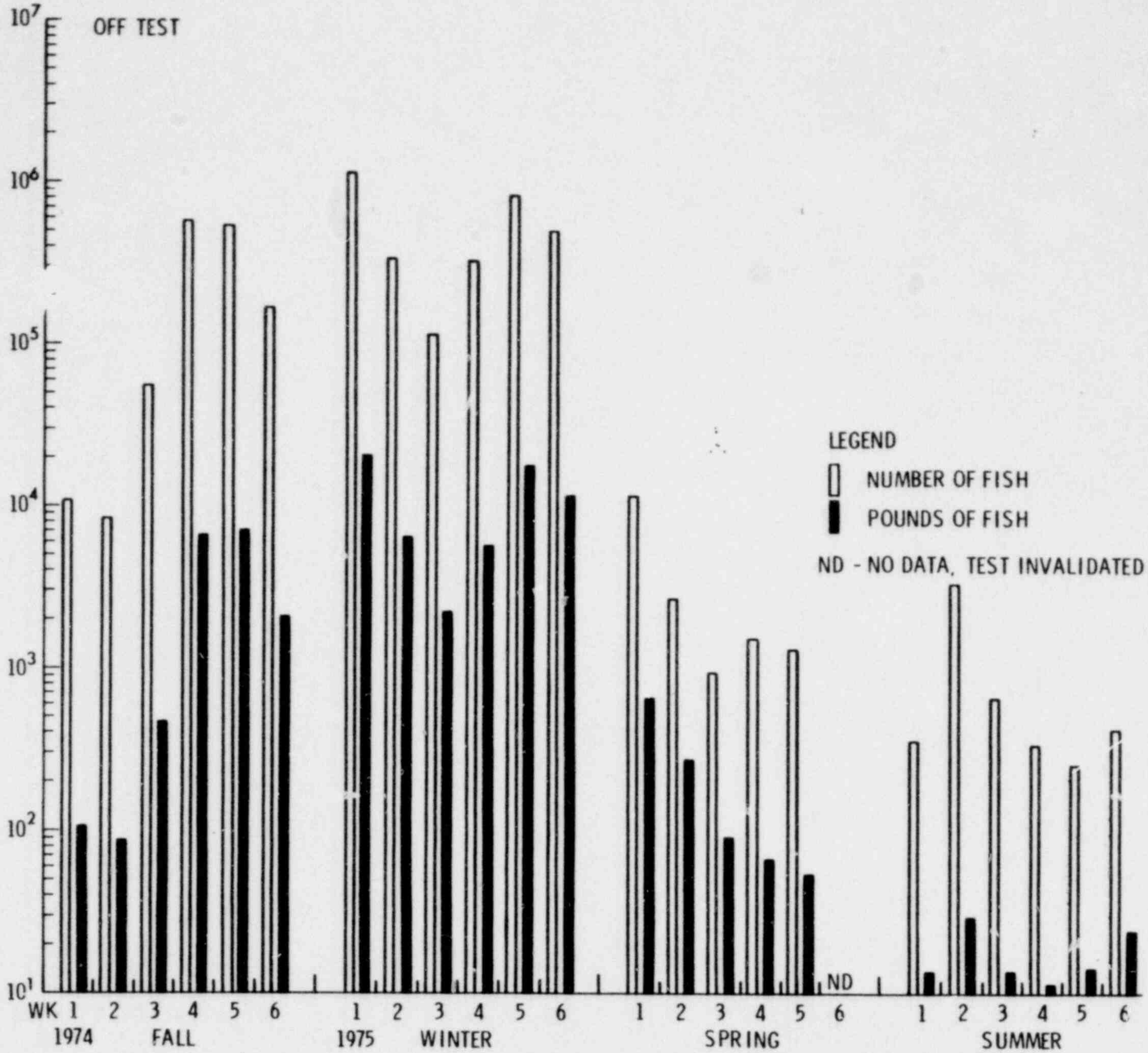

Figure VI-1. (Page 2 of 2)

Table VI-2

Statistical Tests for Difference in Fish Numbers Impinged during On and Off Air-Curtain Testing at Arkansas Nuclear One-Unit 1

	Fall			Winter			Spring			Summer		
Species	P	W	S	P	W	S	P	W	S	P	W	S
All species	-0.803	8	4	0.254	10	3	1.151	0†	5*	-0.016	9	4
Threadfin shad	-0.975	5	5*	0.258	10	3	1.019	1.5	4†	0.581	10	3
Gizzard shad	-0.248	10	3	0.091	10	3	1.694	2	4†	-1.163	3	4
Blue catfish	0.879	10	3	-1.020	6	3	1.682	0†	5*	-0.803	6.5	4
Channel catfish	1.653	3	5*	1.020	6	4	1.555	0†	5*	0.845	6	3
Freshwater drum	0.139	8	4	-0.970	6	3	1.105	3	3	-0.261	9	4
White crappie	-1.264	8	3	-0.550	4	3	0.970	4	4†	-1.745	1.5	4
White bass	0.759	9.5	3	-1.442	IC	2	1.262	2.5	4†	0.497	7	4

P = Paired t test
W = Wilcoxon test
S = Sign test

*Significant at $\alpha = 0.05$ level
†Significant at $\alpha = 0.10$ level

IC = Insufficient nonzero catches to detect any difference between on and off tests

Examination of fall, winter, and summer air curtain test data revealed no significant difference in the biomass of fish impinged with the air curtain on or off. Spring test data, however, revealed a significant difference in biomass levels between ON and OFF status (Sign test, $\alpha = 0.05$) (Table VI-3). As shown in Figure VI-1, a greater biomass was impinged with the air curtain on in 5 of 6 test runs during spring.

C. SPECIES COMPOSITION

Threadfin shad, gizzard shad, blue catfish, channel catfish, freshwater drum, white crappie, and white bass accounted for the greatest numbers and biomass impinged throughout the study (Figure VI-2). Threadfin and gizzard shads contributed the greatest proportion (> 95%) of impinged numbers and biomass during the fall and winter test periods. Of these two

Table VI-3

Statistical Tests for Difference in Fish Biomass Impinged during On and Off Air-Curtain Testing at Arkansas Nuclear One - Unit 1

Species	Fall			Winter			Spring			Summer		
	P	W	S	P	W	S	P	W	S	P	W	S
All species	-0.990	5	5	0.285	10	3	1.268	0†	5*	0.887	6	4
Threadfin shad	-1.323	4	5*	0.307	10	3	1.024	3	3	0.718	9	4
Gizzard shad	-0.010	10	3	-0.504	10	3	1.848	0*	5*	-0.115	10	3
Blue catfish	0.703	10	4	0.070	9	4	0.529	5	4†	1.022	8	3
Channel catfish	0.068	10	3	-0.276	10	3	1.720	1	4†	-0.057	10	3
Freshwater drum	0.246	9	3	-1.286	6	3	1.199	3	3	0.026	9	4
White crappie	1.517	5	4	-1.038	1	3	-0.389	5	4†	-0.802	8	3
White bass	0.376	10	3	-1.277	IC	2	0.141	7	3	-0.914	7	4

P = Paired t test
W = Wilcoxon test
S = Sign test

*Significant at $\alpha = 0.05$ level
†Significant at $\alpha = 0.10$ level

IC = Insufficient nonzero catches to detect any difference between on and off tests

species, the threadfin shad clearly dominated both numbers (> 91%) and biomass (> 88%) impinged during these seasons. No distinct differences in species composition were discerned between ON and OFF air curtain status during the fall or winter tests.

A shift in species compositional patterns was observed in both spring and summer 1975 air curtain test findings, reflecting a noticeable decline in the numbers and biomass of threadfin shad, as well as increased impingement of gizzard shad during the spring and freshwater drum in the spring and summer. A comparison of ON and OFF spring test results shows that a greater percentage of threadfin shad and freshwater drum were impinged with the air curtain on. More gizzard shad, however, were impinged during the spring with the air curtain off (Figure VI-2).

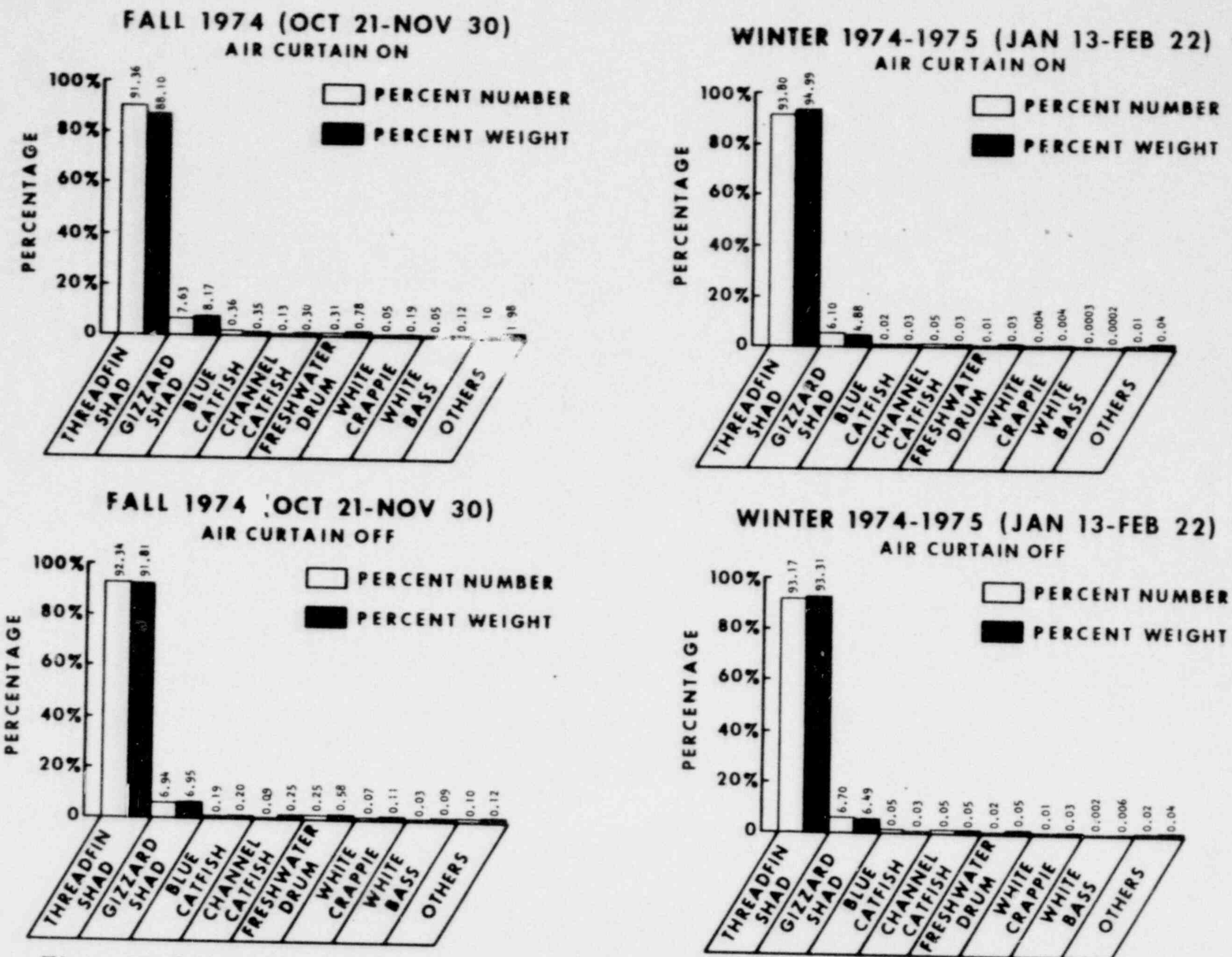

Figure VI-2. Percent Composition of Fish Species Impinged during ON/OFF Air-Curtain Testing at Arkansas Nuclear One, October 1974-August 1975 (Page 1 of 2)

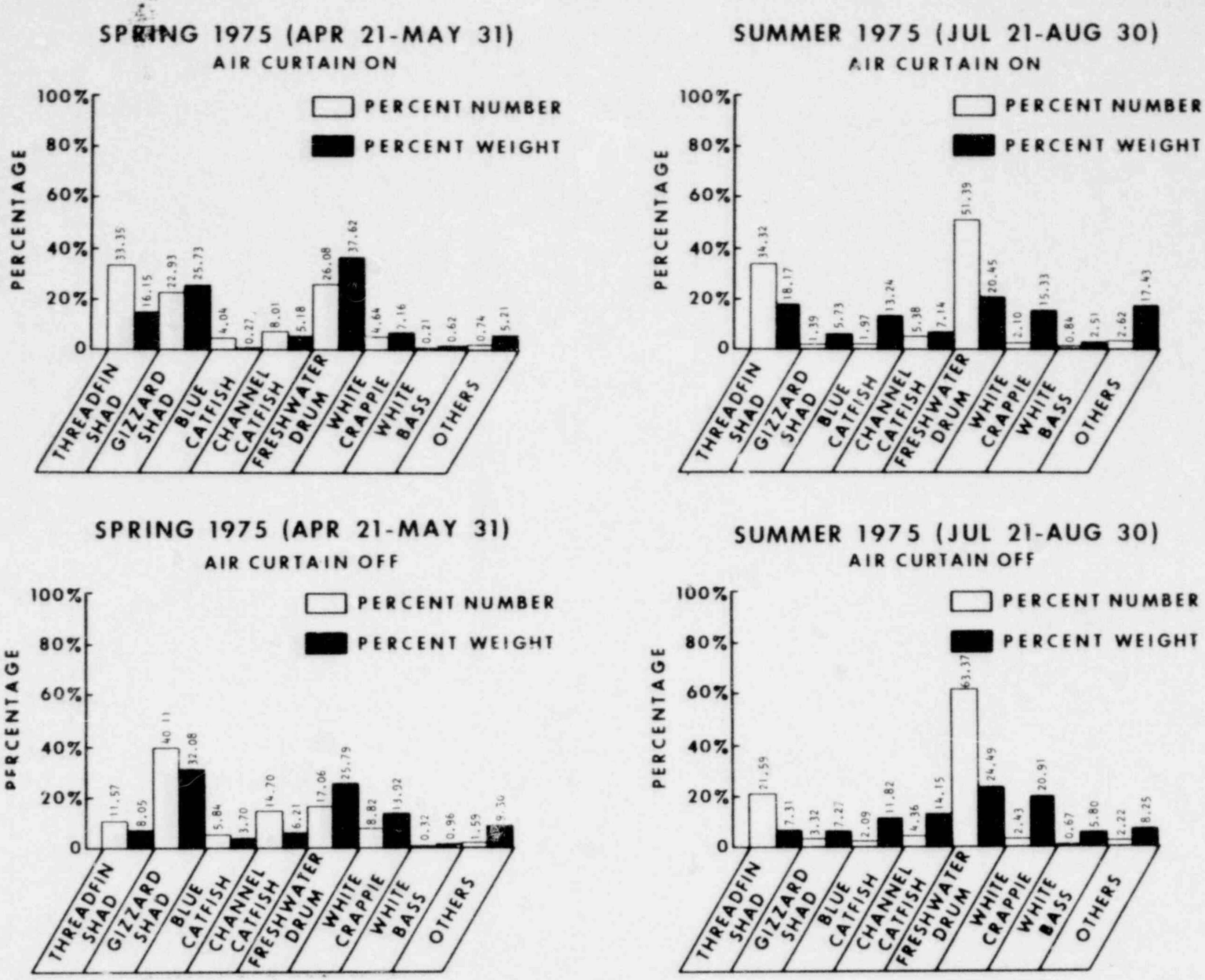

Figure VI-2. (Page 2 of 2)

Freshwater drum accounted for a considerable proportion of the reduced impingement levels observed during summer 1975 air curtain testing, with threadfin shad and white crappie ranking second and third respectively. A comparison of summer 1975 impingement levels for air curtain operation versus no air curtain revealed somewhat higher percentage of threadfin shad impinged during air curtain operation, but a greater percentage of freshwater drum and white crappie impinged with the air curtain off (Figure VI-2).

D. INDIVIDUAL SPECIES

1. Threadfin Shad

A total of 8,850,744 fish comprising a biomass of 159,649 pounds was impinged over the entire 4-season air curtain test period (October 1974 through August 1975). Overall, more threadfin shad were impinged during air curtain operation (4,560,419 fish; 83,732 pounds) than when the air curtain was off (4,290,325 fish; 75,917 pounds). However, the differences in impinged numbers and biomass when collapsed over the 4-season test cycle were found to be nonsignificant at the $\alpha = 0.10$ level (Paired t-test, Wilcoxon test, Sign test).

Since threadfin shad accounted for more than 90% of the total number and 88% of the total biomass impinged during the fall and winter seasons, impingement patterns for this species resemble closely the variations described for all species combined. Threadfin shad impingement rates increased from October 21, 1974, when fall testing began, through the end of the winter test period (Figure VI-3). The dramatic rise in impingement levels observed for all species combined during week three of fall air curtain testing can be attributed to the greatly increased numbers of threadfin shad impinged during this period. As previously noted, this rise in impingement occurred during a time when water temperatures were declining from 65°F (18.3°C) in Dardanelle Reservoir (Figure VI-3). More than 100,000 threadfin shad >1,000 pounds impinged per 3-day period were recorded for both ON and OFF tests over the last two weeks of the fall test period and the entire 6-week winter test.

As water temperatures rose above 65°F (18.3°C) during week two of spring testing, threadfin shad impingement rates declined sharply to less than 300 fish and 5 pounds per 3-day test period. Summer test results showed an increasing trend in impingement rates approaching fall 1974 levels by the end of the 6-week summer test period (Figure VI-3).

A comparison of total numbers and biomass of threadfin shad impinged during and without air curtain operation indicated a statistically significant difference in the fall test period (Sign test, α = 0.05 level) (Tables VI-2 and VI-3). Figure VI-3 shows that during the fall, consistently greater numbers and biomass of threadfin shad were impinged when the air curtain was not in operation.

No significant differences were observed in threadfin shad impingement rates during the winter 1974-1975 and summer 1975 air curtain tests. Spring test results, however, indicated that more threadfin shad were impinged during air curtain operation (Sign test, α = 0.05 level) (Table VI-2).

Length-frequency distribution comparisons of threadfin shad impinged during the four seasonal air curtain ON/OFF test periods revealed no discernible differences in the size ranges of fish impinged with or without air curtain operation (Figure VI-4).

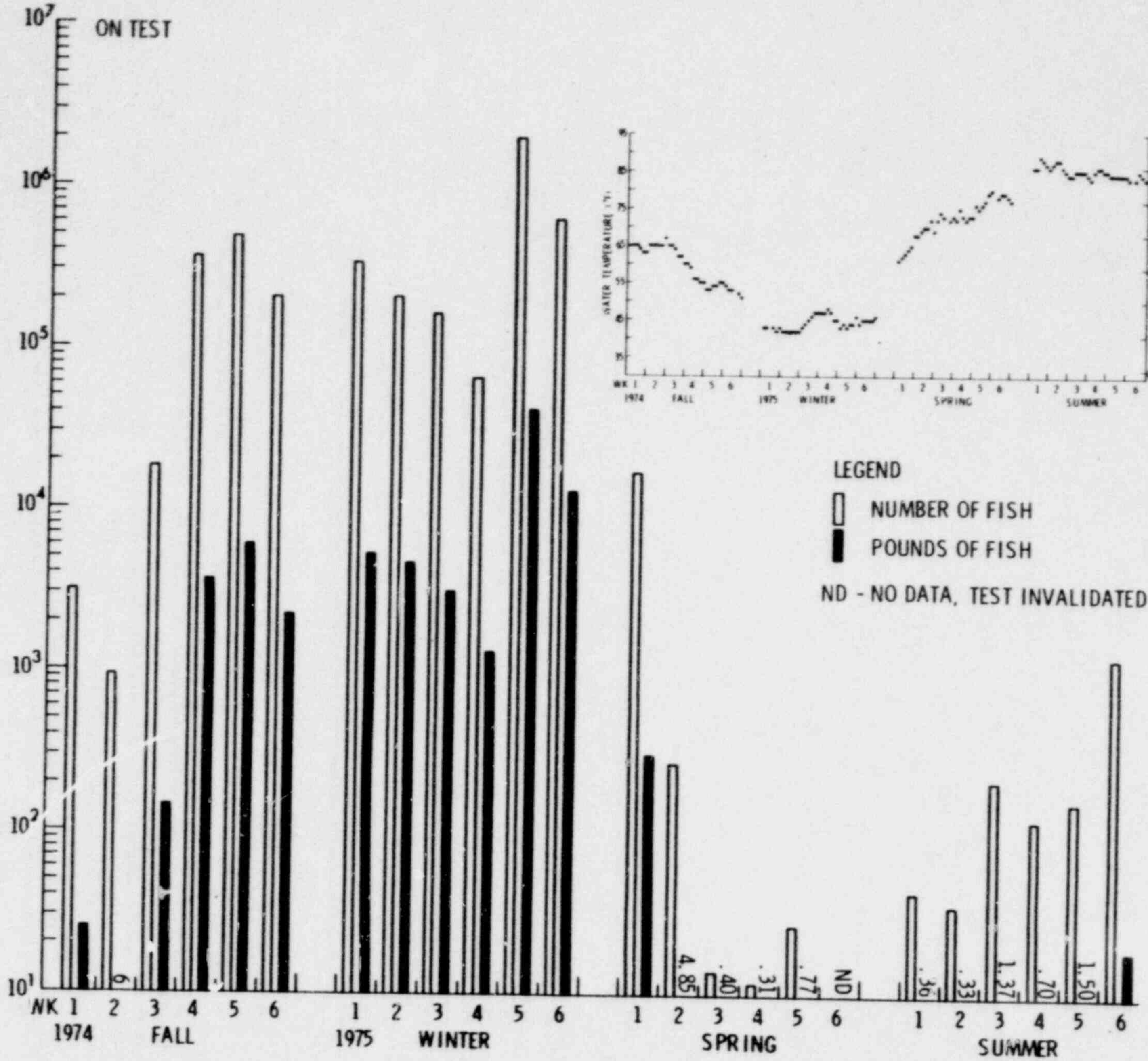

Figure VI-3. Total Numbers and Biomass (lbs) of Threadfin Shad Impinged per 3-Day Test Period during Seasonal Air-Curtain Testing at Arkansas Nuclear One, October 1974-August 1975 (Page 1 of 2)

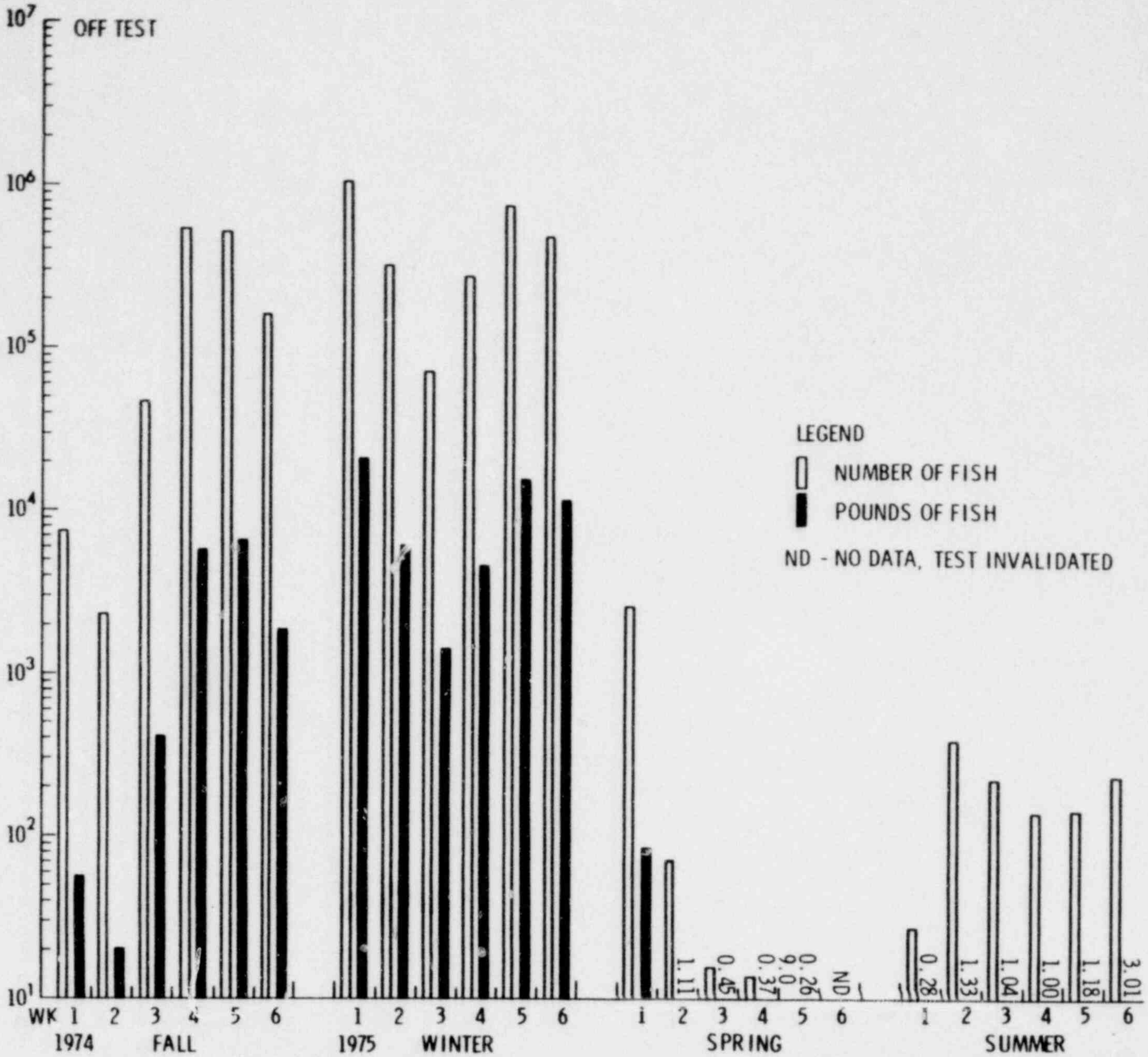

Figure VI-3. (Page 2 of 2)

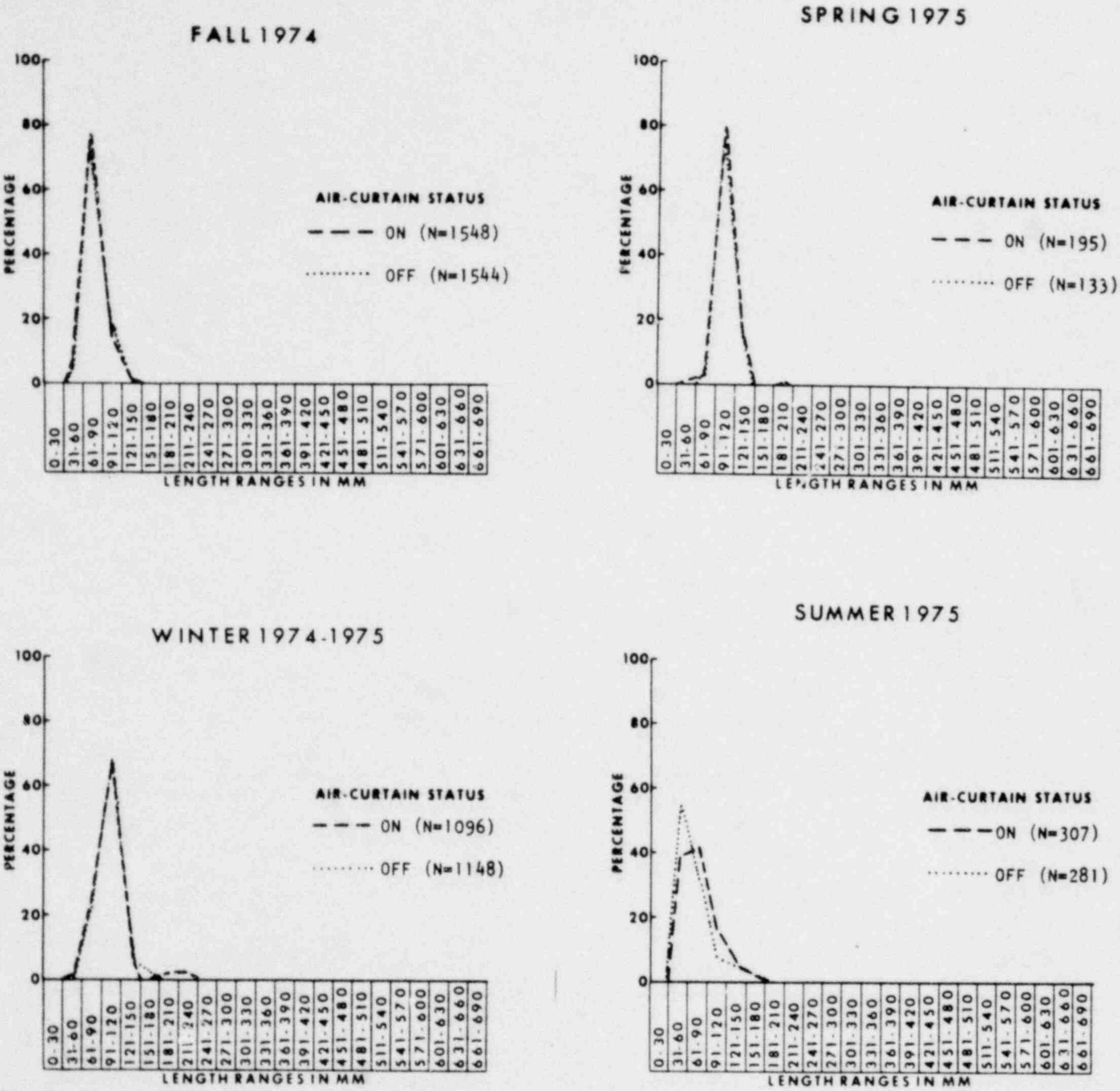

Figure VI-4. Seasonal Length-Frequency Distribution of Threadfin Shad Impinged during Air-Curtain Testing at Arkansas Nuclear One

The predominant threadfin shad size class impinged during the fall 1974 test period was the 60-90 mm length group. These young-of-the-year fish were recruited into 90-120 mm size range as yearlings* by January and February 1975 where they appeared as the dominant size class in winter tests (Figure VI-4). A relatively low number of 121-150 mm threadfin shad, possibly a mixture of yearling and older fish (based on the data of McConnell and Gerdes, 1964) were also impinged during the winter test period (Figure VI-4).

Reduced growth during the winter and spring months was evidenced by the continued predominance of 91-120 mm yearling threadfin shad impinged during spring 1975 tests. A somewhat larger proportion of 121-150 mm fish occurred during spring testing; however, this percentage remained relatively small compared to the numbers of 91-120 mm shad impinged. Young-of-the-year (1975 year class) threadfin shad, recruited into an impingeable size range (minimum ≥ 30 mm), appeared in summer air curtain test samples. These 0+ year fish were represented in both the 30-60 mm and 60-90 mm size ranges, which comprised the majority of the threadfin shad impinged during summer testing (Figure VI-4). Yearling and older threadfin contributed only a small percentage of impinged numbers during this season.

2. Gizzard Shad

Arkansas Nuclear One - Unit 1 traveling screens impinged 649,182 gizzard shad weighing 11,016 pounds over the four seasons of air curtain testing from October 1974 through August 1975. More gizzard shad were impinged during air curtain operation (327,320) than when the air curtain was not functioning (321,862). Greater biomass (5721 pounds) was impinged, however, during off tests than during on tests in this same time period (Appendix Tables A-1 through A-4).

---

*Presuming January 1 as a fish's birth date, 1-year old (1+) fish, which are in their second year of life.

Numbers and biomass of impinged gizzard shad increased from the beginning of air curtain testing (October 21) through the end of the fall test period. Catches of gizzard shad increased on the traveling screens to > 1,000 fish per 3-day period as temperatures fell below 65°F (18.3°C) in Dardanelle Reservoir during week three of the fall test (Figure VI-5). Gizzard shad impingement rates of approximately 10,000 fish and > 100 pounds per 3-day period were maintained through the remainder of the fall and the entire winter test period.

As Dardanelle Reservoir water temperatures rose above 65°F during spring 1975 testing, gizzard shad impingement rates declined to < 1,000 fish and < 50 pounds per 3-day test. This declining trend continued through the remainder of the spring and summer test periods (Figure VI-5).

The only statistically significant difference in the numbers of gizzard shad impinged over the 4-season test cycle occurred during the spring 1975 test period, when consistently more gizzard shad were impinged during air curtain operation than with the air curtain not functioning during 4 of 5 test runs (Table VI-2, Figure VI-5). A comparison of gizzard shad biomass impinged during these same weeks consistently indicated statistically greater biomass levels during air curtain ON than during air curtain OFF tests (Table VI-3, Figure VI-5).

Most of the gizzard shad impinged during the fall 1974 test runs were young-of-the-year fish, primarily in the 61-90 mm size class (Figure VI-6). Gizzard shad impinged during winter tests were mainly yearlings (91-120 mm size class). Spring 1975 data reveals the presence of two distinct year classes of gizzard shad; 1+ shad of the 1974 year class (predominantly 121-150 mm length) and 2+ fish ranging between 181 and 240 mm (based on growth data for Elephant Butte Lake of Jester and Jensen, 1972). This assumes, however, similar growth rates for Dardanelle Reservoir and Elephant Butte gizzard shad. The stronger bimodal distribution seen in summer 1975 data apparently indicates the recruitment of 1975 young-of-the-year gizzard shad into an impingeable size range (> 30 mm) as well as the presence of a mixutre of 1+ and 2+ fish ranging from 151 to 240 mm (Figure VI-6).

No differences between ON/OFF modes could be discerned for the length-frequency distribution during the fall, winter, and spring seasons. Summer test data, however, indicated that a greater percentage of young-of-the-year gizzard shad (30-90 mm) were impinged with the air curtain off, while a greater number of larger shad (151-240 mm) were impinged during air curtain operation (Figure VI-6).

3. Freshwater Drum

A total of 31,958 freshwater drum weighing 1,377 pounds was impinged during the four seasons of air curtain testing, October 1974 through August 1975. Overall, impingement levels for both biomass and numbers of freshwater drum were higher during air curtain operation (20,576 individuals and 886 pounds) than when the air curtain was not operating (11,382 individuals and 451 pounds) (Appendix Tables A-1 through A-4).

A general rise in freshwater drum impingement levels from < 100 fish per 3-day test to more than 400 individuals per 3-day test was observed during the fall season as water temperatures declined below 60°F (15.5°C) in Dardanelle Reservoir (Figure VI-7). Winter test impingement rates, however, were generally low (< 100 individuals per 3-day test) and displayed no distinct trend over the 6-week test period. Considerable variations in impingement rates occurred during both spring and summer tests. Highest impingement levels for freshwater drum occurred during the first week of spring testing as reservoir temperatures rose from 60° to 65°F (15° to 18°C). A total of 15,299 individuals comprising a biomass of 830 pounds was collected during this week. Subsequent impingement rates declined below 1,000 fish per 3-day test and continued at or near this level through the remainder of the spring and summer tests.

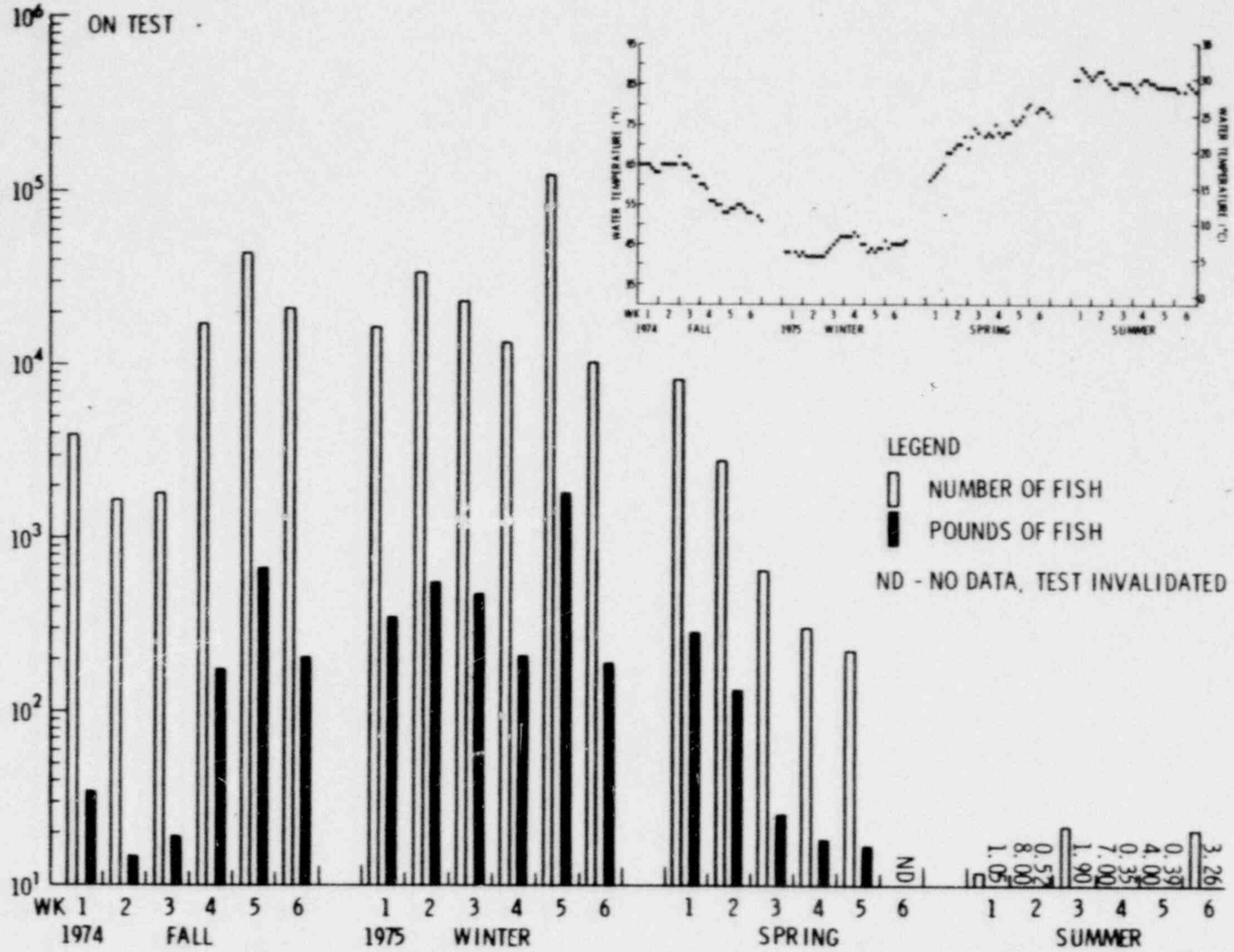

Figure VI-5. Total Numbers and Biomass (lbs) of Gizzard Shad Impinged per 3-Day Test Period during Seasonal Air-Curtain Testing at Arkansas Nuclear One, October 1974-August 1975 (Page 1 of 2)

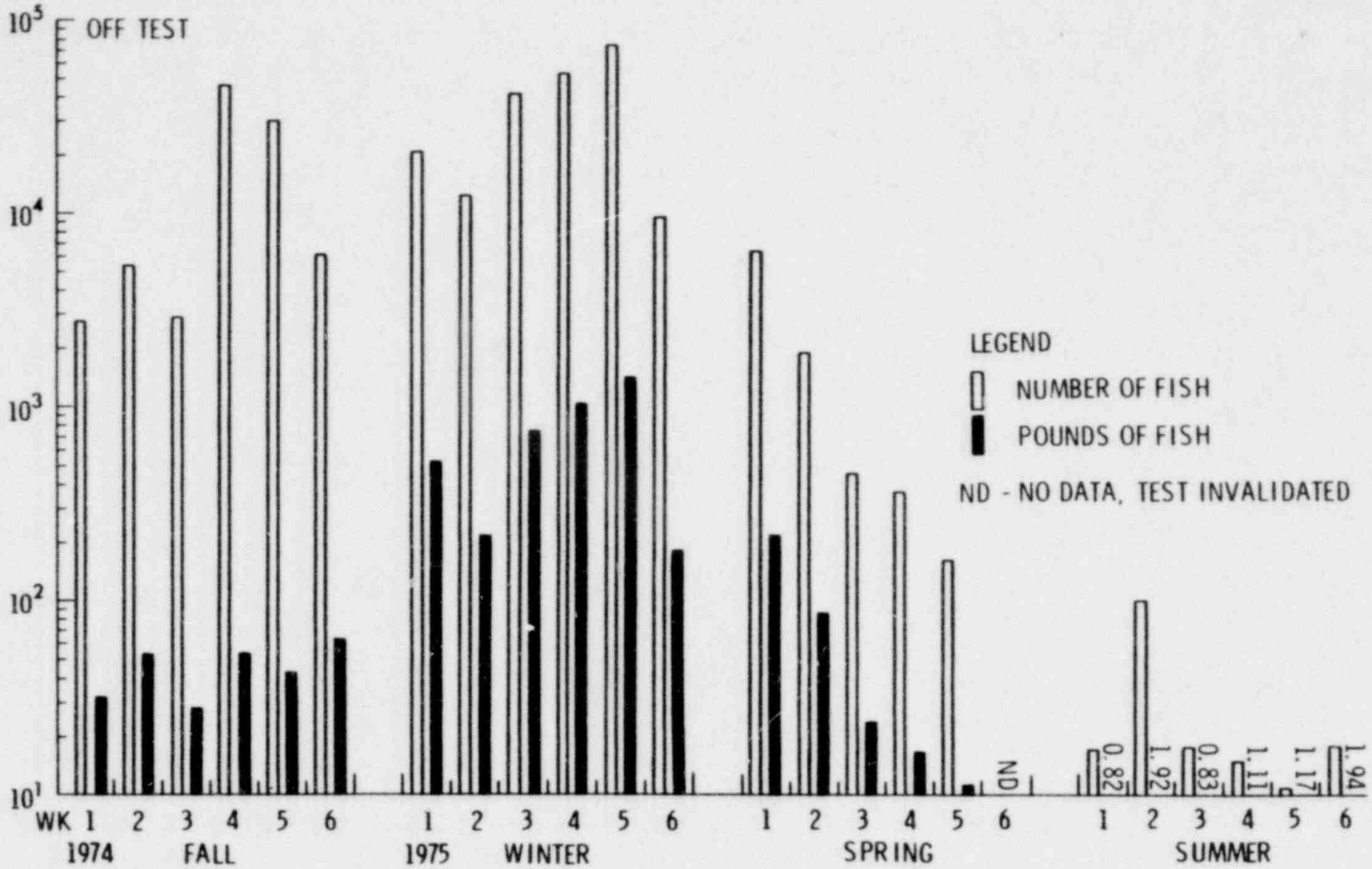

Figure VI-5. (Page 2 of 2)

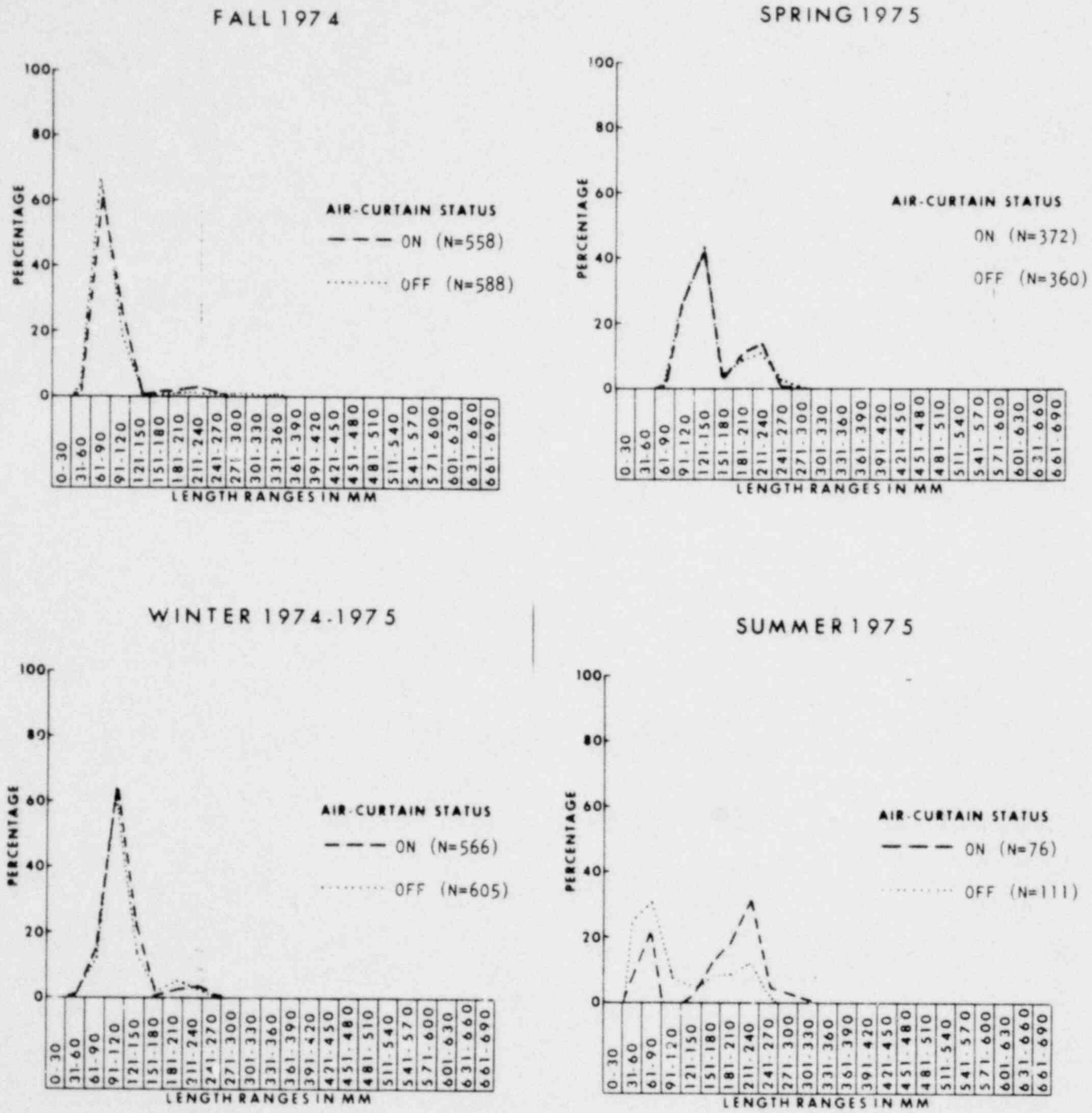

Figure VI-6. Seasonal Length-Frequency Distribution of Gizzard Shad Impinged during Air-Curtain Testing at Arkansas Nuclear One

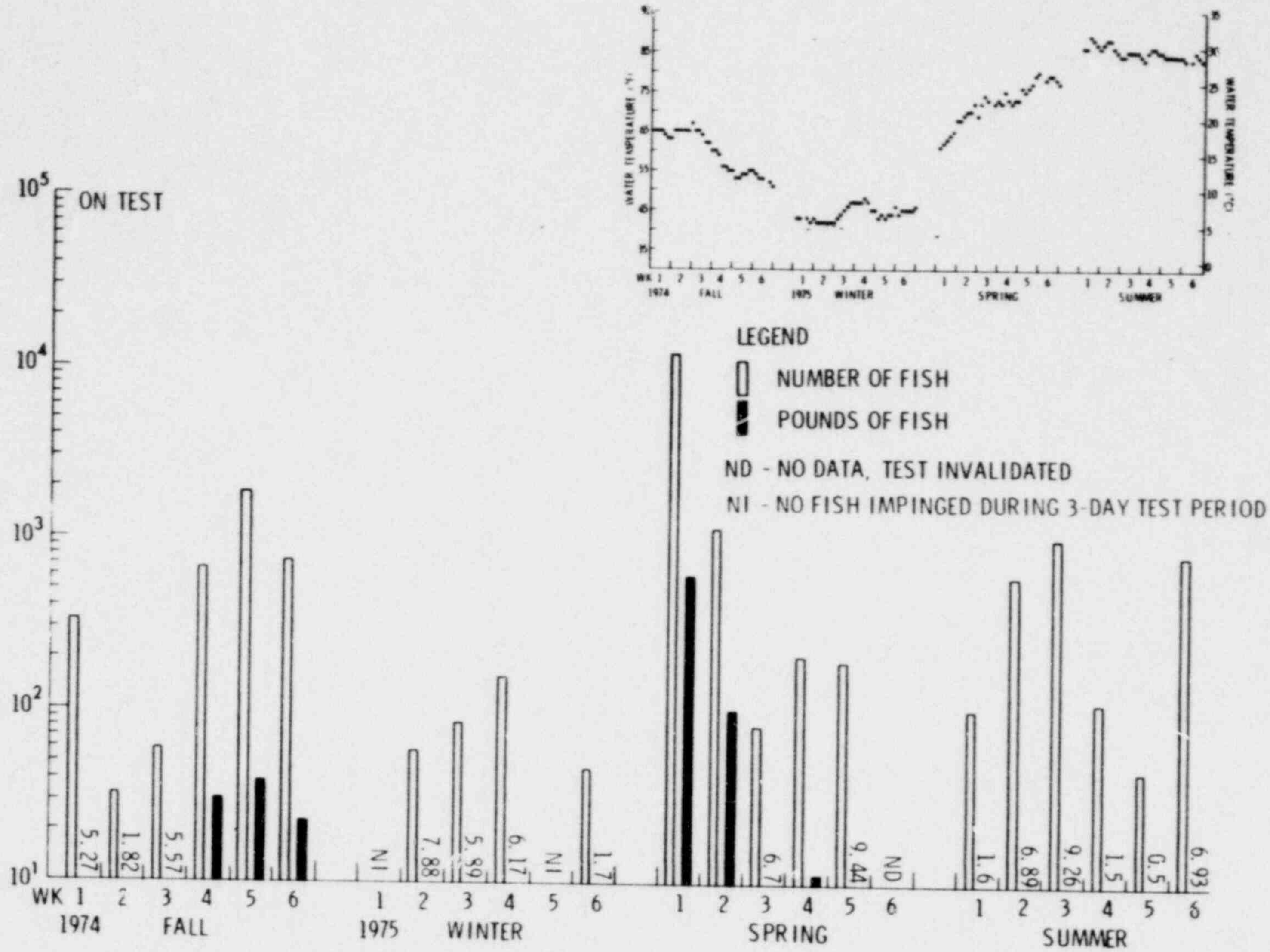

Figure VI-7. Total Numbers and Biomass (lbs) of Freshwater Drum Impinged per 3-Day Test Period during Seasonal Air-Curtain Testing at Arkansas Nuclear One, October 1974-August 1975 (Page 1 of 2)

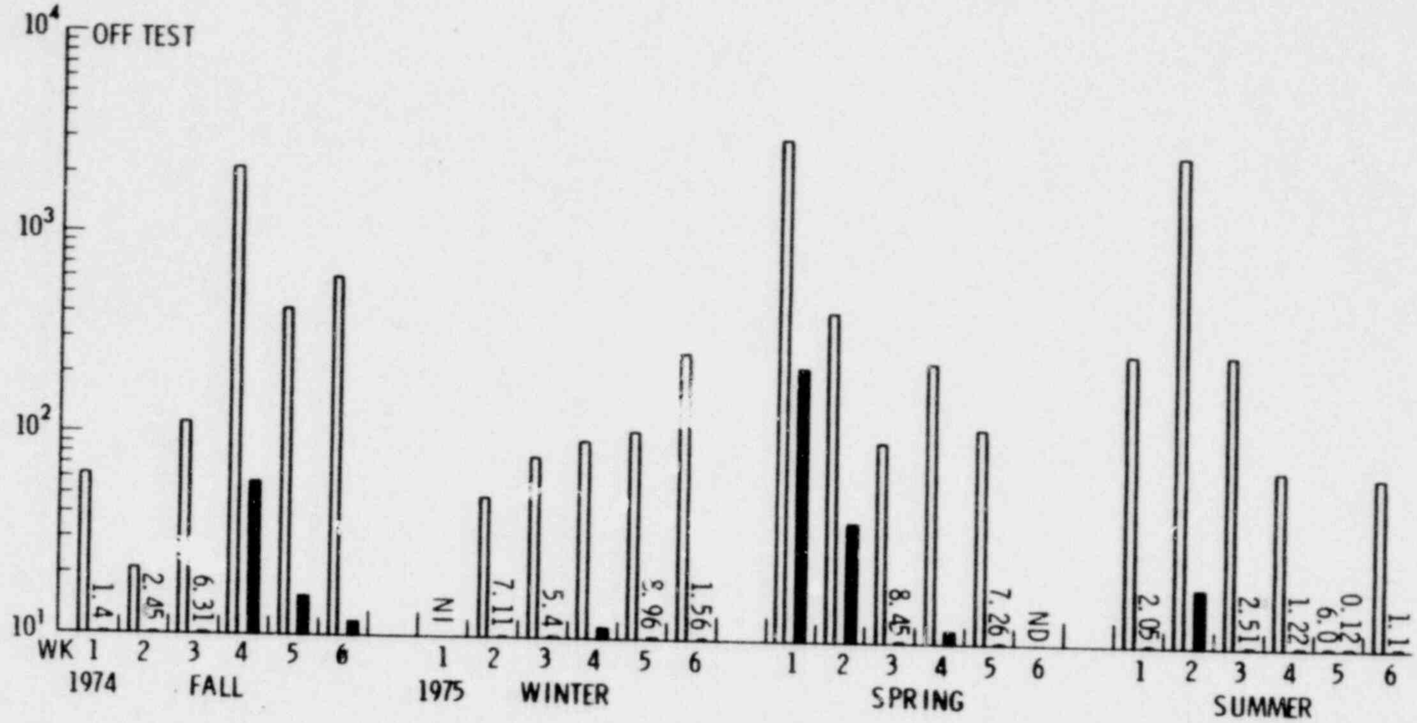

Figure VI-7. (Page 2 of 2)

There were no statistically significant differences between ON and OFF modes for numbers or biomass of freshwater drum impinged (Tables VI-2 and VI-3).

The greatest percentage of freshwater drum impinged during the fall test period was the 61-90 mm size group (Figure VI-8). These were presumably young-of-the-year fish. Smaller percentages of 2+ through 5+ yr old drum (based on data from Tatum, 1975b) were also impinged during this season. Yearling fish (1+) of the 1974 year class, predominantly in the 61-90 mm size range, constituted the largest percentage of drum impinged during the winter season, with increased percentages of 2+ to 5+ drum also occurring. Spring test data also show a continued dominance of yearling freshwater drum (1974 year class) as 91-150 mm individuals. These yearlings were essentially absent from summer 1975 test runs. Young-of-the-year drum (60-90 mm) constituted the largest percentage of this species taken during this period.

No differences in ON and OFF modes were discerned for length-frequency distribution of freshwater drum (Figure VI-8).

4. Channel Catfish

Total channel catfish impinged during air curtain testing (October 1974 through August 1975) were 14,611 fish weighing 334 pounds. Of this catch, 8,109 individuals comprising a biomass of 177 pounds were impinged during air curtain operation, while 6,502 fish accounting for 157 pounds were impinged during air curtain Off tests (Appendix Tables A-1 through A-4).

The numbers of channel catfish impinged remained almost consistently above 100 individuals per 3-day ON and OFF tests during both

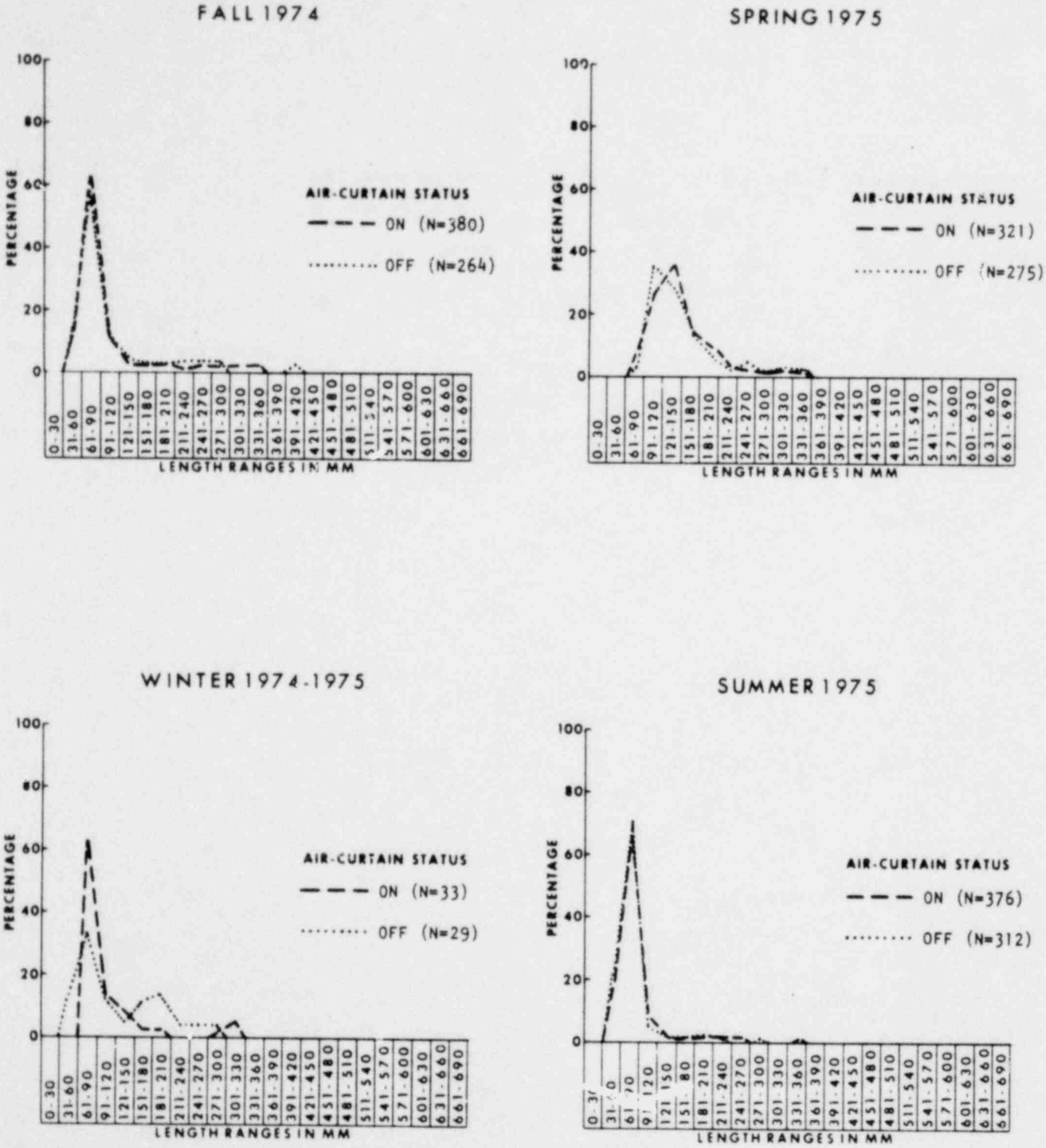

Figure VI-8. Seasonal Length-Frequency Distribution of Freshwater Drum Impinged during Air-Curtain Testing at Arkansas Nuclear One fall and winter test periods; however, no seasonal trends were apparent (Figure VI-9). Biomass levels during these two periods generally remained below 10 pounds per 3-day test. Both numbers and biomass of channel catfish impinged declined steadily from approximately 3,000 individuals and 50 pounds per 3-day test during week one of the spring test to approximately 40 fish and <5 pounds at the end of the summer test period.

Although there were no apparent differences between air curtain ON and OFF test impingement rates of channel catfish during either the winter or summer test seasons, statistically significantly greater numbers (Sign test $\alpha = 0.05$) were impinged during air curtain operation in both the fall and spring test periods (Table VI-2 and Figure VI-9).

No distinct or consistent differences were observed in the length-frequencies of channel catfish impinged during the 4-season testing period (Figure VI-10). The bimodal length-frequency distribution displayed for fall 1974 indicates the probable presence of two distinct year classes of channel catfish, young-of-the-year (61-90 mm) and yearling fish (121-150 mm). Year class 1974 fish as yearlings, clearly dominated winter test catches as 61-90 mm individuals. Although this same size class continued to account for the majority of the channel catfish impinged during spring 1975, the 121-150 mm size class representing 2+ fish (based on data from Tatum, 1975b) constituted >20% of both ON/OFF test catches during this period. Majority of channel catfish impinged during summer were spread over a relatively wide size range, from 60 mm to 180 mm. This range probably encompassed young-of-the-year 1+ and 2+ individuals with individuals in the 421-450 mm size range also represented.

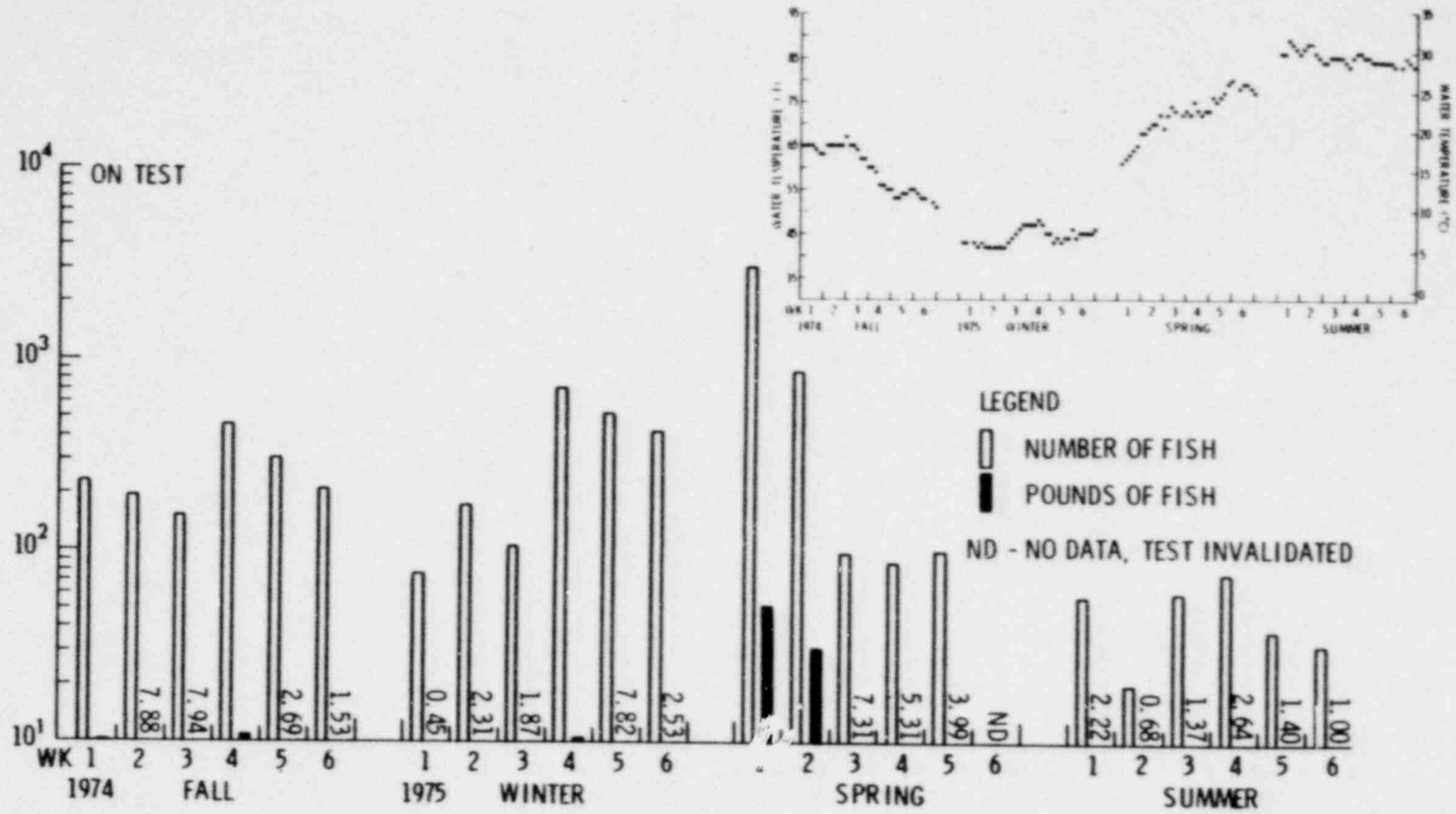

Figure VI-9. Total Numbers and Biomass (lbs) of Channel Catfish Impinged per 3-Day Test Period during Seasonal Air-Curtain Testing at Arkansas Nuclear One, October 1974-August 1975 (Page 1 of 2)

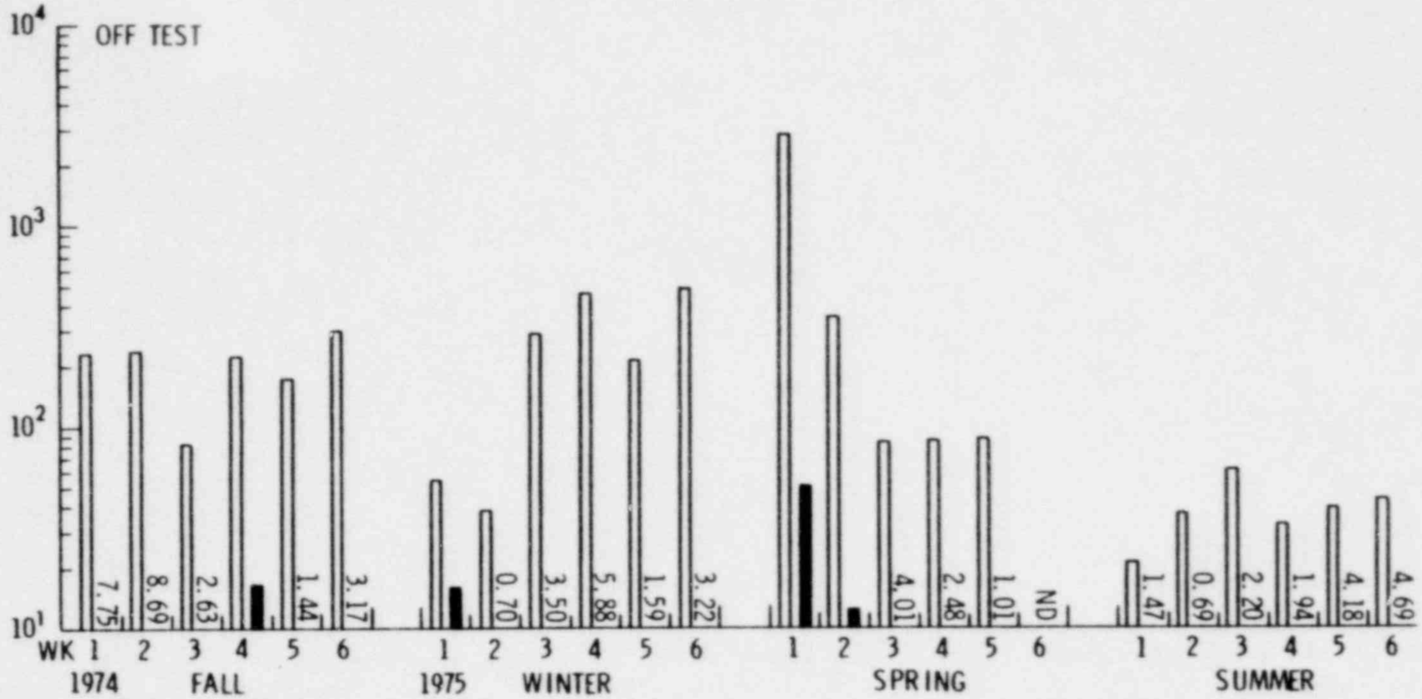

Figure VI-9. (Page 2 of 2)

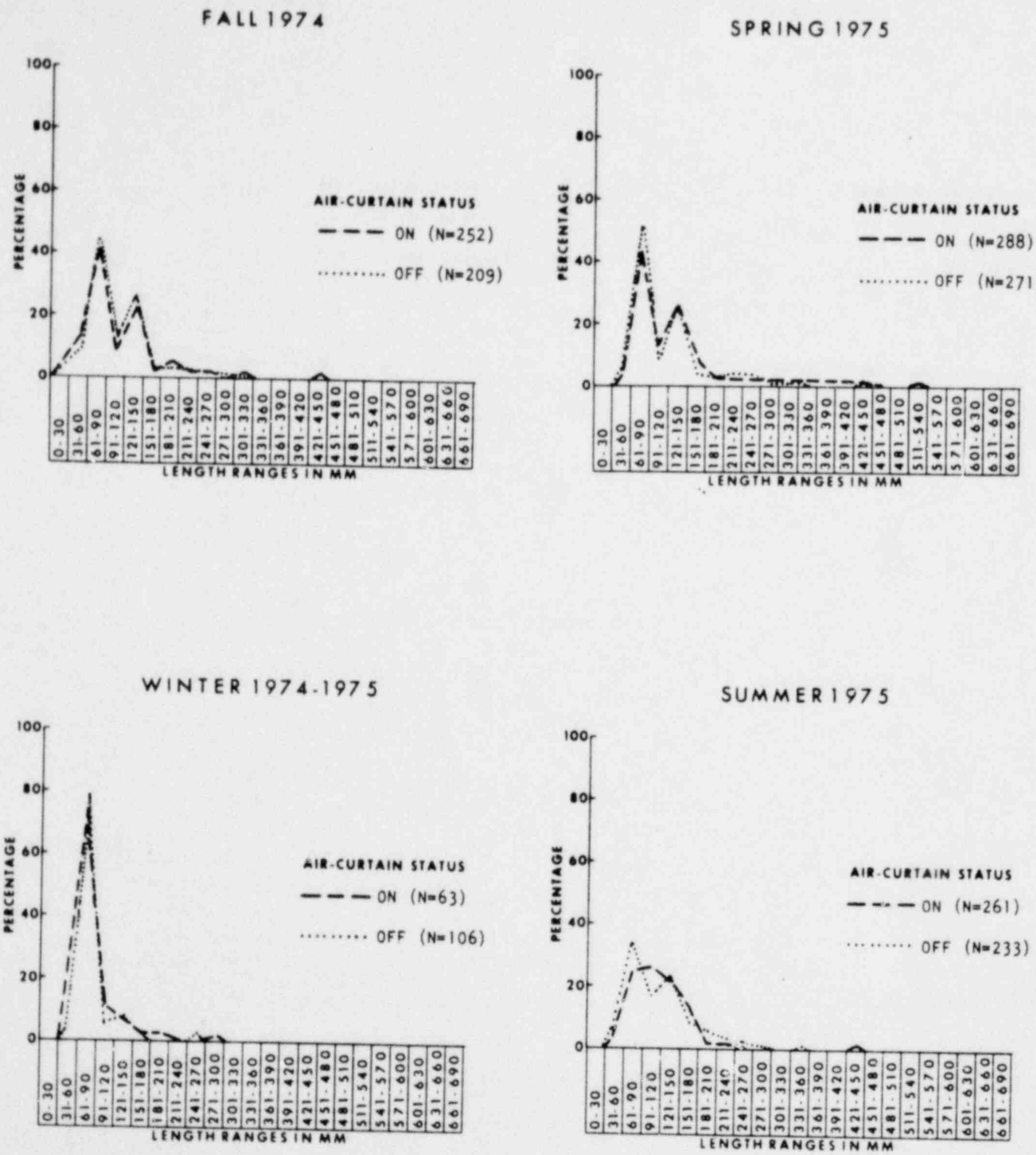

Figure VI-10. Seasonal Length-Frequency Distribution of Channel Catfish Impinged by Air-Curtain Testing at Arkansas Nuclear One

5. Blue Catfish

A total of 12,946 blue catfish comprising 241 pounds biomass was impinged during the four seasons. Both greater numbers (7,380) and biomass (133 pounds) of blue catfish were collected during air curtain operation than during those periods when the air curtain was off (5,566 individuals weighing 108 pounds) (Appendix Tables A-1 through A-4).

Numbers of blue catfish impinged during both ON and OFF air curtain testing increased during the fall as temperatures fell below 65°F (18.3°C) and fluctuated at relatively high levels of > 1,000 fish per 3-day test during the winter test period (Figure VI-11). Warming temperatures during spring coincided with a declining trend in numerical impingement. Summer test reflected low levels of impingement (< 30 fish per 3-day test) and no distinct trend over the 6-week test period. Blue catfish biomass levels throughout the 4-season test period remained relatively low and indicated no distinct seasonal pattern.

Spring test alone revealed a statistically significant difference between air curtain ON/OFF impingement rates (Table VI-2, Figure VI-11). Both the Wilcoxon test ($\alpha = 0.10$) and the Sign test ($\alpha = 0.05$) indicated that consistently greater numbers of blue catfish were being impinged when the air curtain was on than when it was off. Greater biomass was impinged during air curtain operation, although the differences between ON and OFF testing were not significant (Sign test, $\alpha = 0.05$).

Young-of-the-year individuals (61-90 mm) accounted for the majority of the blue catfish impinged during fall 1974 (Figure VI-12). This year class (1974) appeared again as the dominant size group in both winter and spring tests (91-120 mm) as yearlings. The bimodal distribution

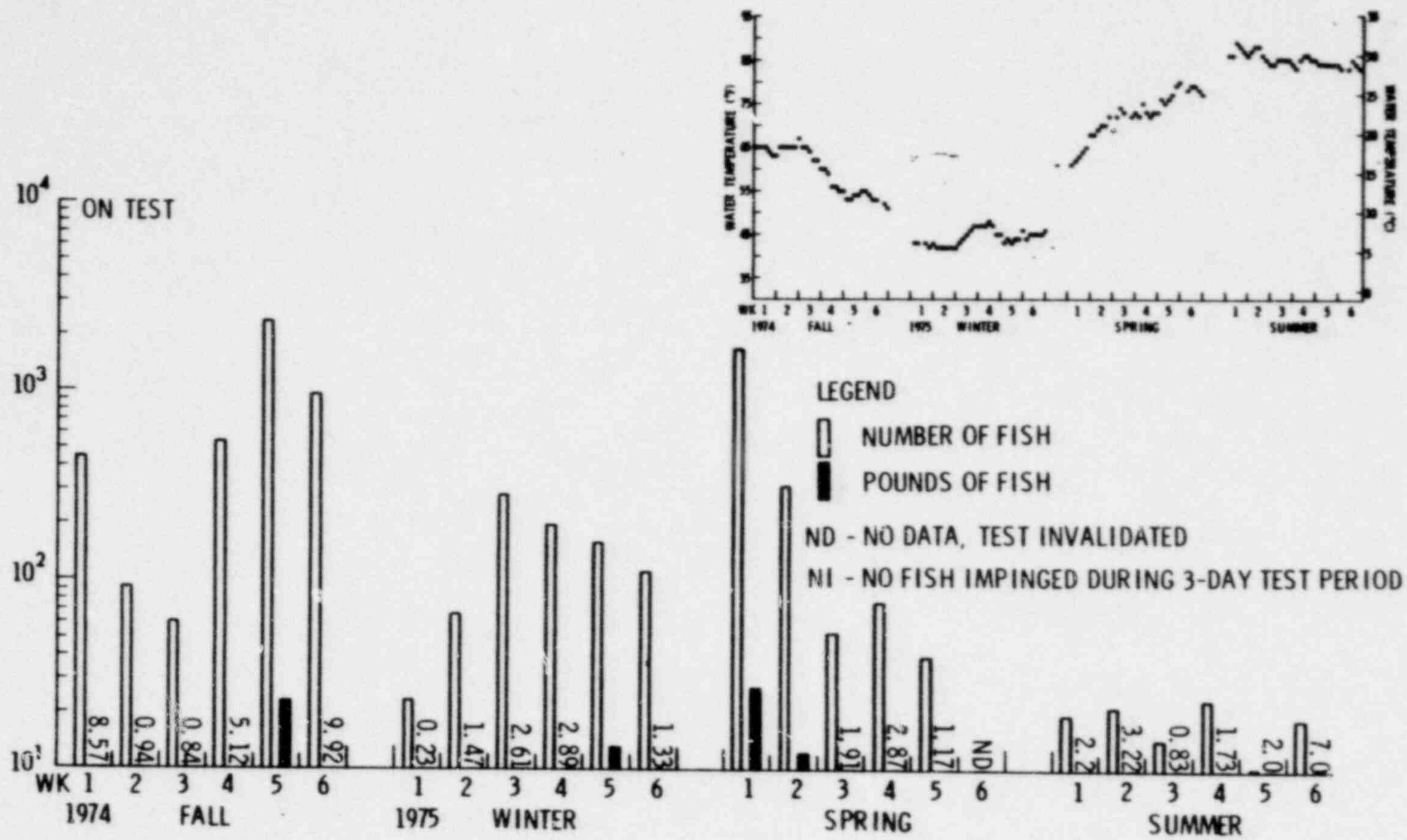

Figure VI-11. Total Numbers and Biomass (lbs) of Blue Catfish Impinged per 3-Day Test Period during Seasonal Air-Curtain Testing at Arkansas Nuclear One, October 1974-August 1975 (Page 1 of 2)

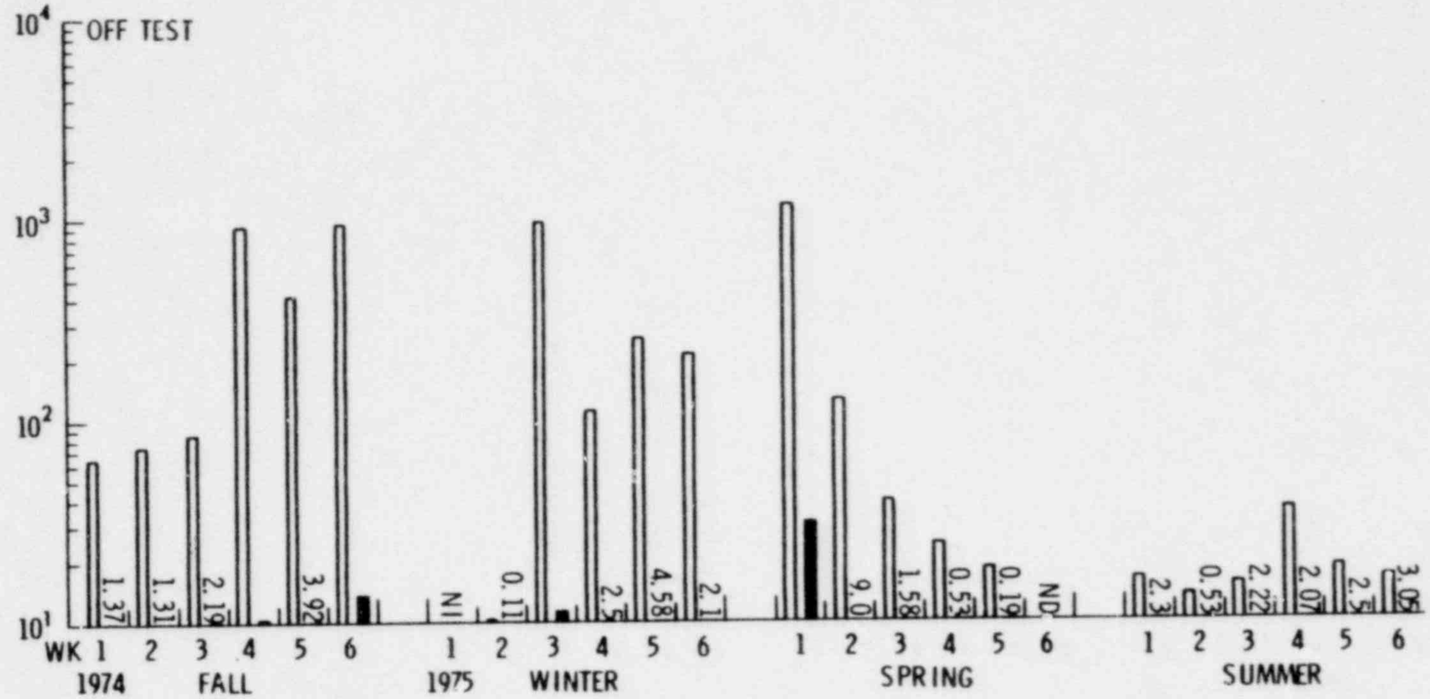

Figure VI-11. (Page 2 of 2)

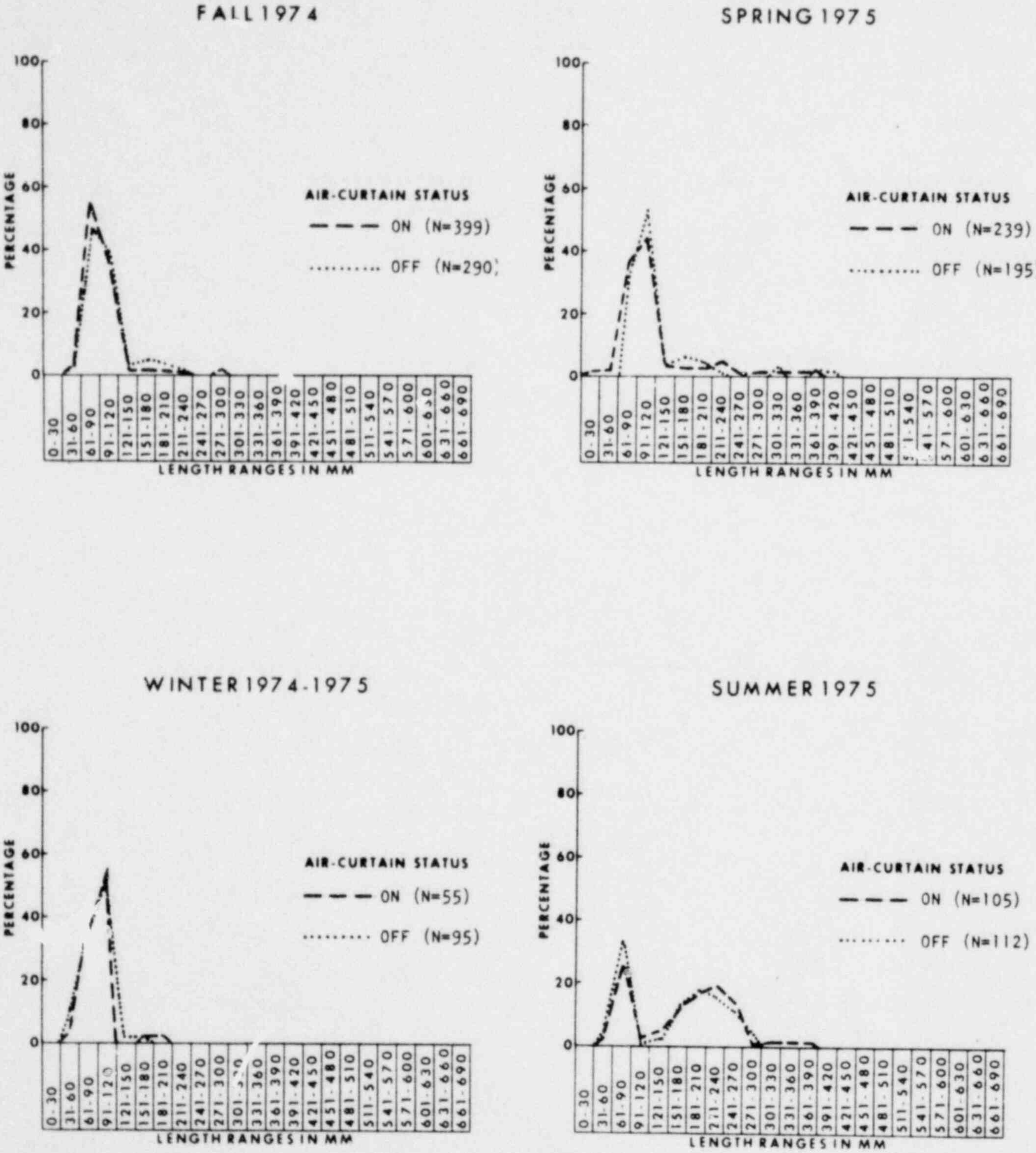

Figure VI-12. Seasonal Length-Frequency Distribution of Blue Catfish Impinged during Air-Curtain Testing at Arkansas Nuclear One pattern during summer shows the recruitment of impingeable size 1975 young-of-the-year blue catfish (61-90 mm) as well as the presence of both yearling (1974 year class) and possibly older fish (211-240 mm size class; based on data from Tatum, 1975b).

6. White Crappie

A total of 6,639 white crappie accounting for 407 pounds biomass was impinged during the four seasonal test periods. Overall, more white crappie (3,361) were impinged during air curtain ON tests than during OFF tests (3,298). Greater white crappie biomass, however, was impinged with the air curtain off (218 pounds) than during air curtain operation (189 pounds) (Appendix Tables A-1 to A-4).

The majority of the white crappie impinged were collected during the fall 1974 and spring 1975 test seasons (Figure VI-13). Impingement levels during the third week of fall testing rose from previous values of <70 fish to >100 individuals per 3-day test as water temperatures in Dardanelle Reservoir fell below 60°F (15.5°C). Winter test impingement rates stabilized at levels of <100 fish per 3-day test, but increased to >100 fish as water temperatures rose in Dardanelle Reservoir during spring testing. Impingement levels for the entire 6-week summer test period displayed no discernible trends and were consistently <30 fish impinged per 3-day period during both ON and OFF tests.

The only statistically significant difference in numbers and biomass of white crappie impinged during ON/OFF air curtain testing occurred during the spring season. Over this 6-week period, greater numbers and biomass of white crappie were impinged during air curtain operation than when the air curtain was not functioning (Sign test, $\alpha = 0.05$) in the majority of test runs.

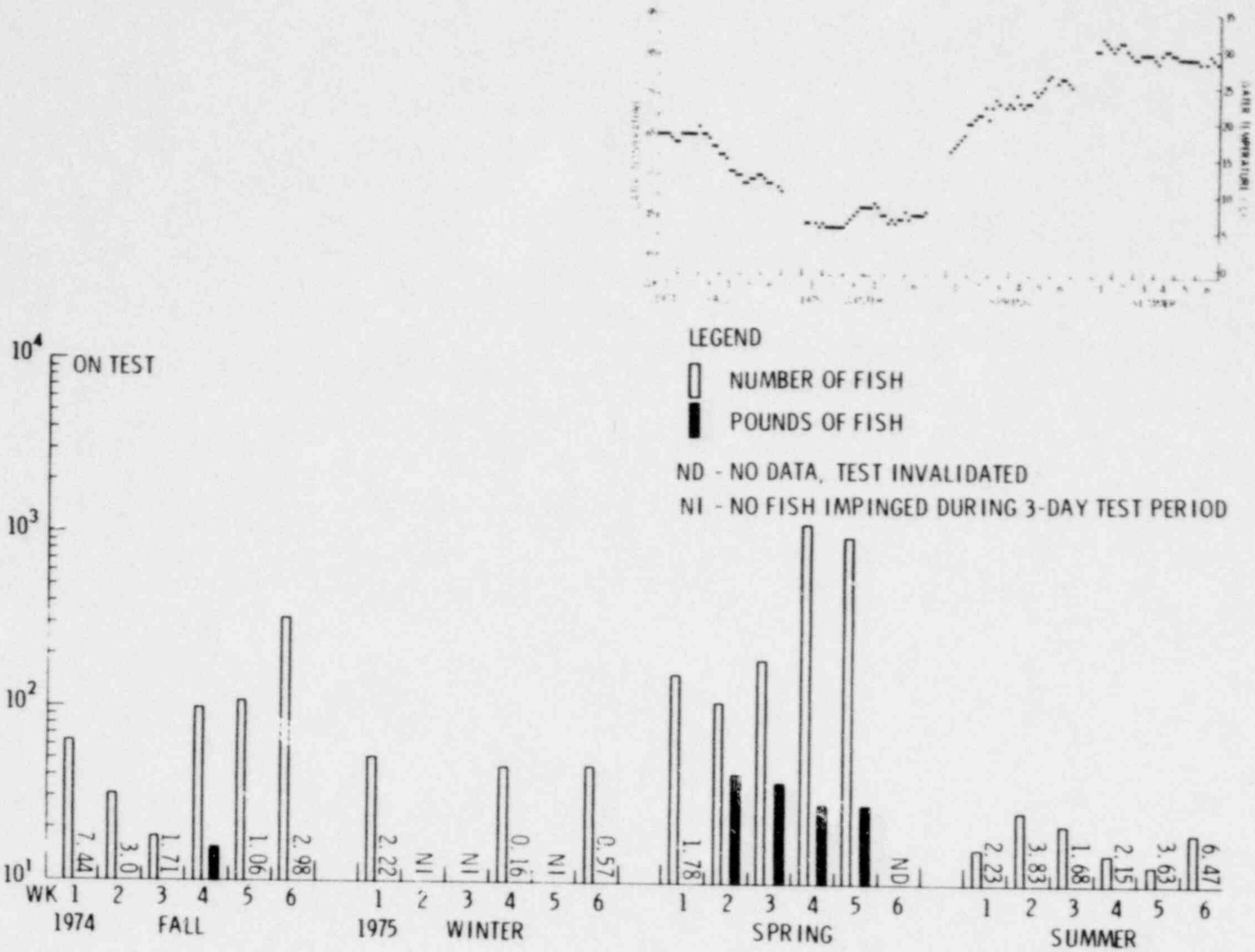

Figure VI-13. Total Numbers and Biomass (lbs) of White Crappie Impinged per 3-Day Test Period during Seasonal Air-Curtain Testing at Arkansas Nuclear One, October 1974-August 1975 (Page 1 of 2)

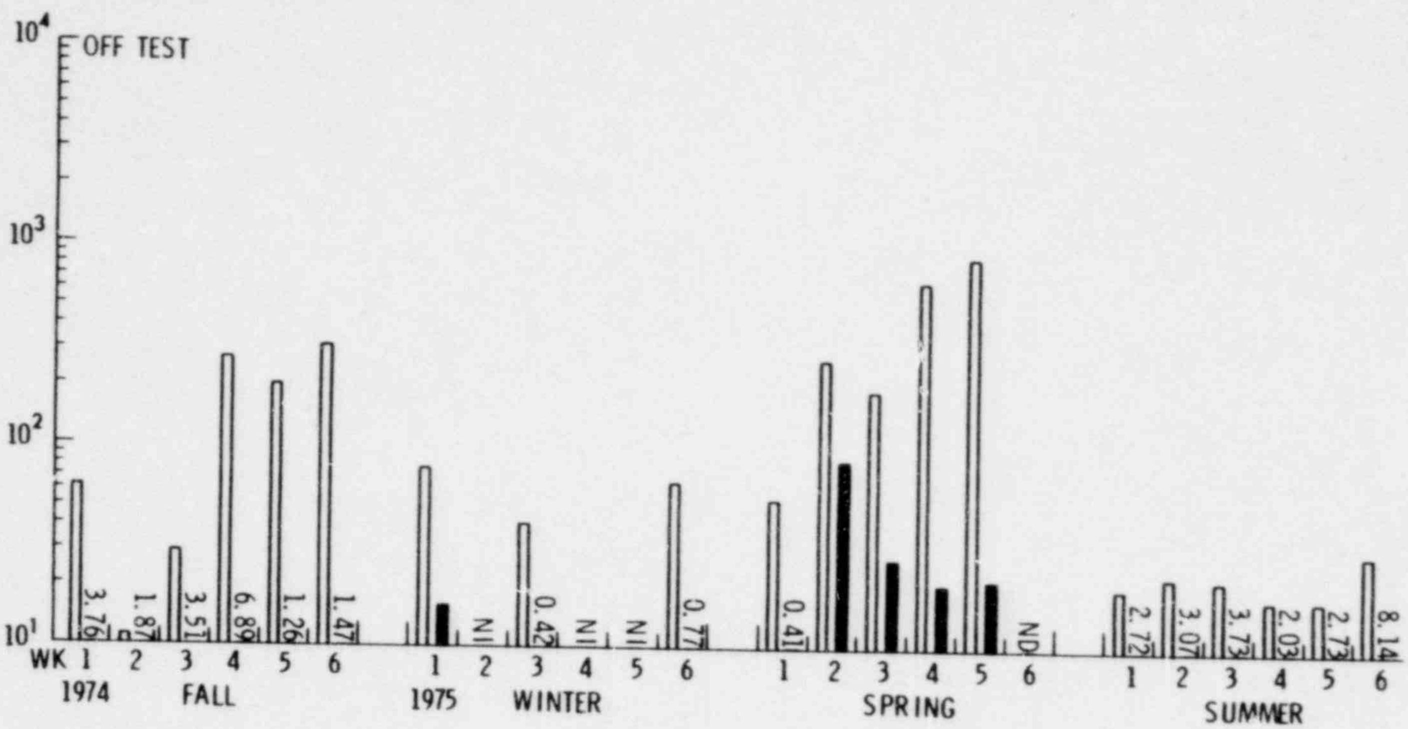

Figure VI-13. (Page 2 of 2)

White crappie measuring 61-90 mm contributed the greatest percentage of this species impinged during fall 1974 and winter 1974-75 air curtain tests (Figure VI-14). A considerably smaller percentage of 1973 year class white crappie (based on growth data from Tatum, 1975b) appeared at 151-180 mm as 1+ fish during fall testing and in low numbers as 2+ fish (181-210 mm) during the winter. One plus (1+) white crappie (61-90 mm) constituted the largest size class impinged during spring 1975 testing. Relatively low percentages of 2+ through 4+ white crappie (based on growth data from Tatum, 1975b) were also impinged during both ON and OFF air curtain tests. Summer tests results show the presence of young-of-the-year white crappie as 31-60 mm individuals, as well as a relatively even length-frequency distribution over all size groups from 31 mm to 240 mm. These size ranges encompassed white crappie from young-of-the-year through 3+ fish. Smaller percentages of 4+ through 6+ white crappie (from growth data of Tatum, 1975b) were also impinged during both ON and OFF testing.

A comparison of the length-frequency distribution of white crappie impinged during air curtain testing revealed that more fish in the 90- to 240-mm size range were impinged with the air curtain off during both the fall and summer test periods. No differences were observed during winter testing, however, possibly because of the small sample size, or during spring testing (Figure VI-14).

7. White Bass

Of the seven fish species most regularly and heavily impinged during seasonal testing, the white bass accounted for the smallest percentage of both numbers and biomass collected on plant intake screens. A total of 1,270 white bass comprising a biomass of 68 pounds was impinged

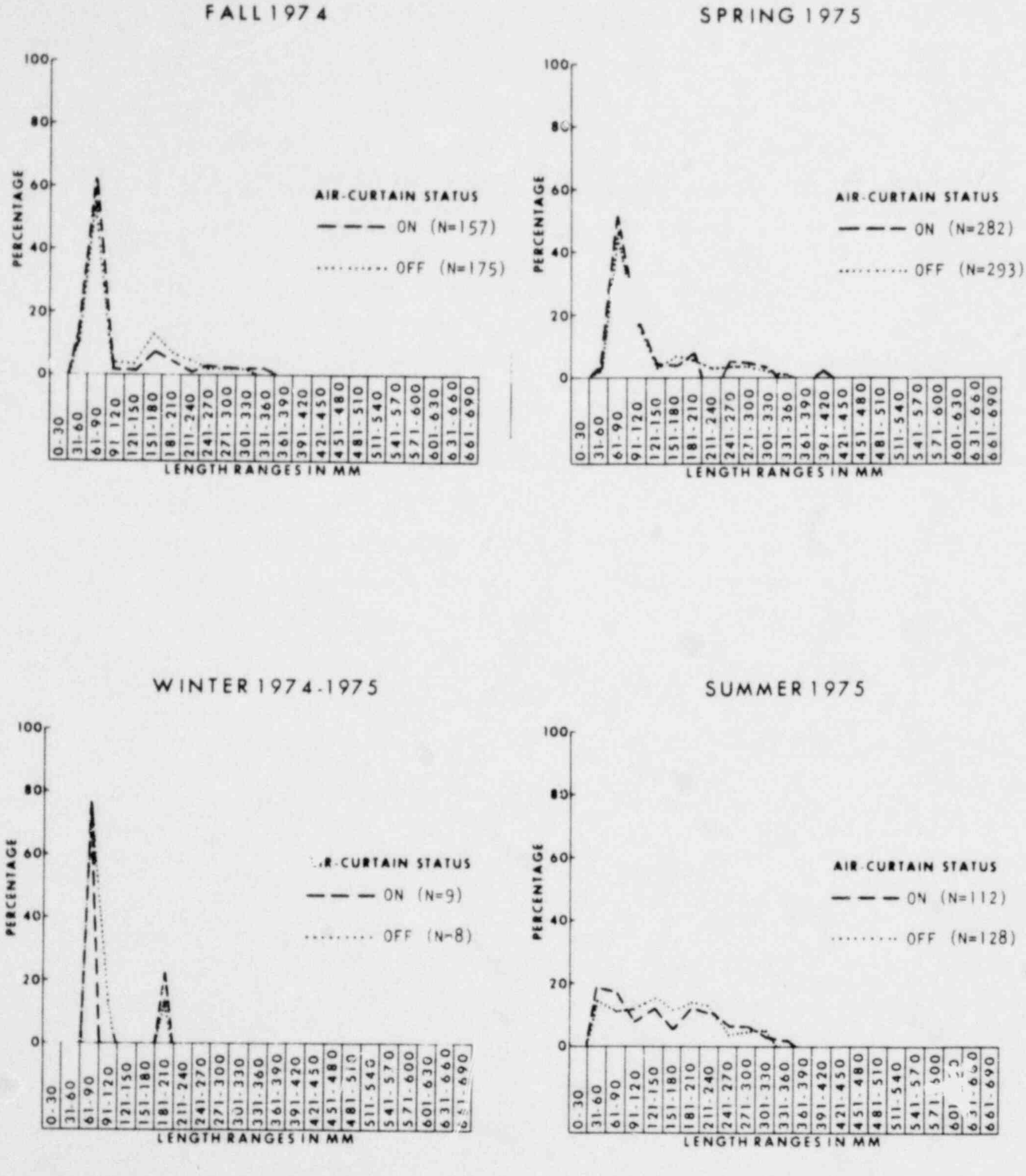

Figure VI-14. Seasonal Length-Frequency Distribution of White Crappie Impinged during Air-Curtain Testing at Arkansas Nuclear One over the 24 weeks of testing. Although a greater number of white bass was impinged during air curtain operation than when the air curtain was off (all seasons combined), the only statistically significant difference between white bass impingement rates during ON/OFF testing occurred during the spring 1975 test. In 4 of the 5 ON/OFF test runs compared for this season, more white bass were impinged during air curtain operation than during air curtain off tests (Tables VI-2 and VI-3). More white bass were impinged during the fall test period than during the three subsequent test seasons combined (Figure VI-15). Impingement rates were highest (> 70 fish per 3-day test) during the last three weeks of fall testing (November 11 through November 30) when water temperatures fell from 15.5°C to 10°C (60°F to 50°F) in Dardanelle Reservoir. The numbers and biomass of white bass impinged over the remaining three seasonal test periods were generally below 10 fish per 3-day test during both ON and OFF test periods.

A comparison of the length-frequency distribution of white bass impinged during air curtain ON/OFF testing indicates a somewhat greater percentage of larger fish impinged when the air curtain was off during fall and spring tests (Figure VI-16). Summer results show impingement of white bass in the 301- to 390-mm size range when air curtain was off, a size range not represented during on tests. The bimodal length-frequency distribution observed during winter tests was probably the result of low sample number; however, larger white bass were still impinged when the air curtain was off.

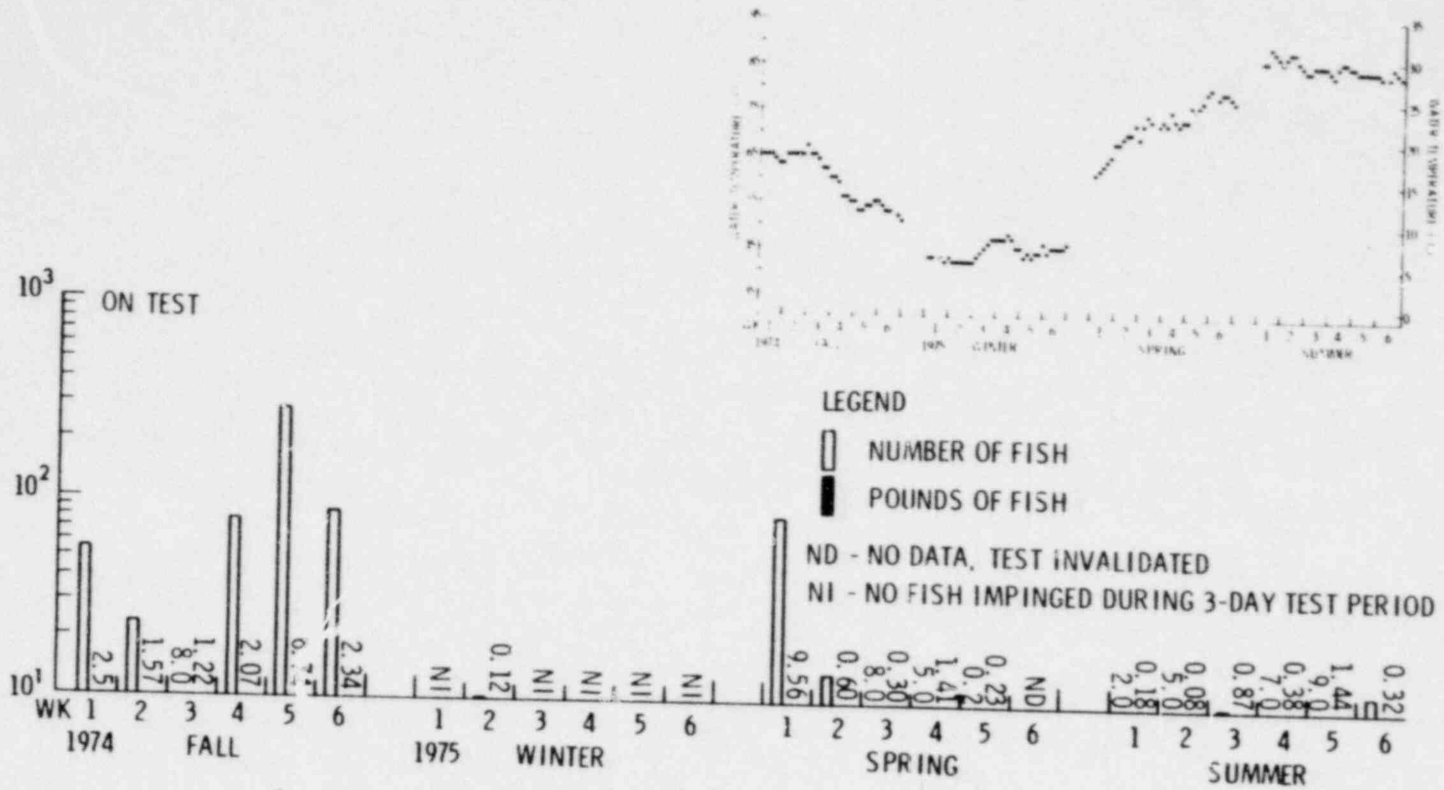

Figure VI-15. Total Numbers and Biomass (lbs) of White Bass Impinged per 3-Day Test Period during Seasonal Air-Curtain Testing at Arkansas Nuclear One, October 1974-August 1975 (Page 1 of 2)

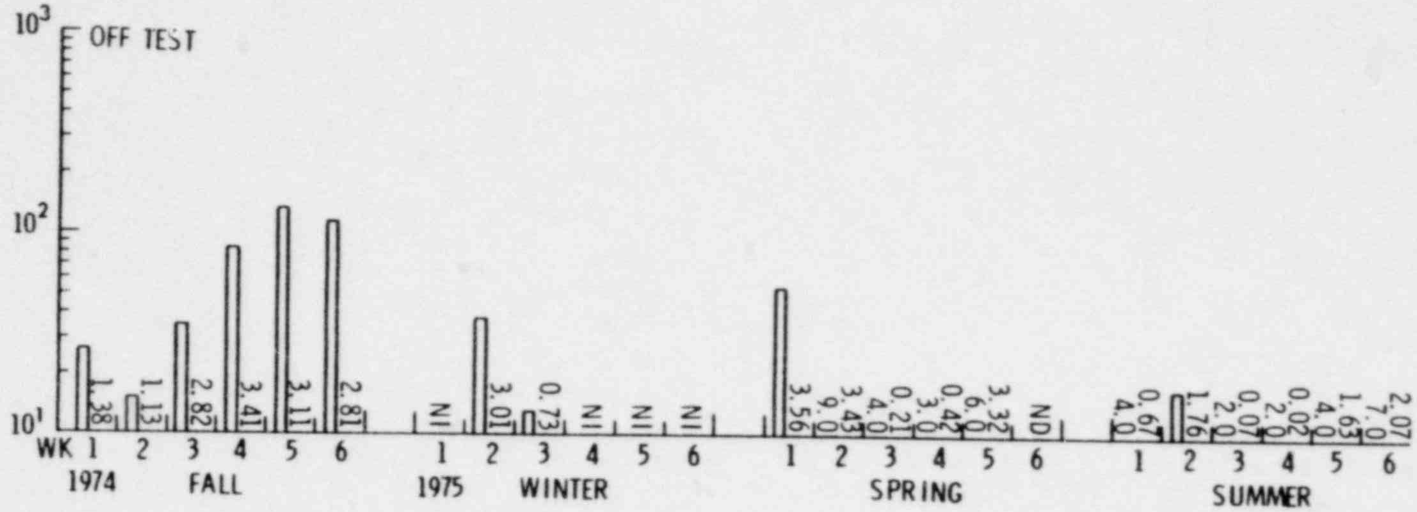

Figure VI-15. (Page 2 of 2)

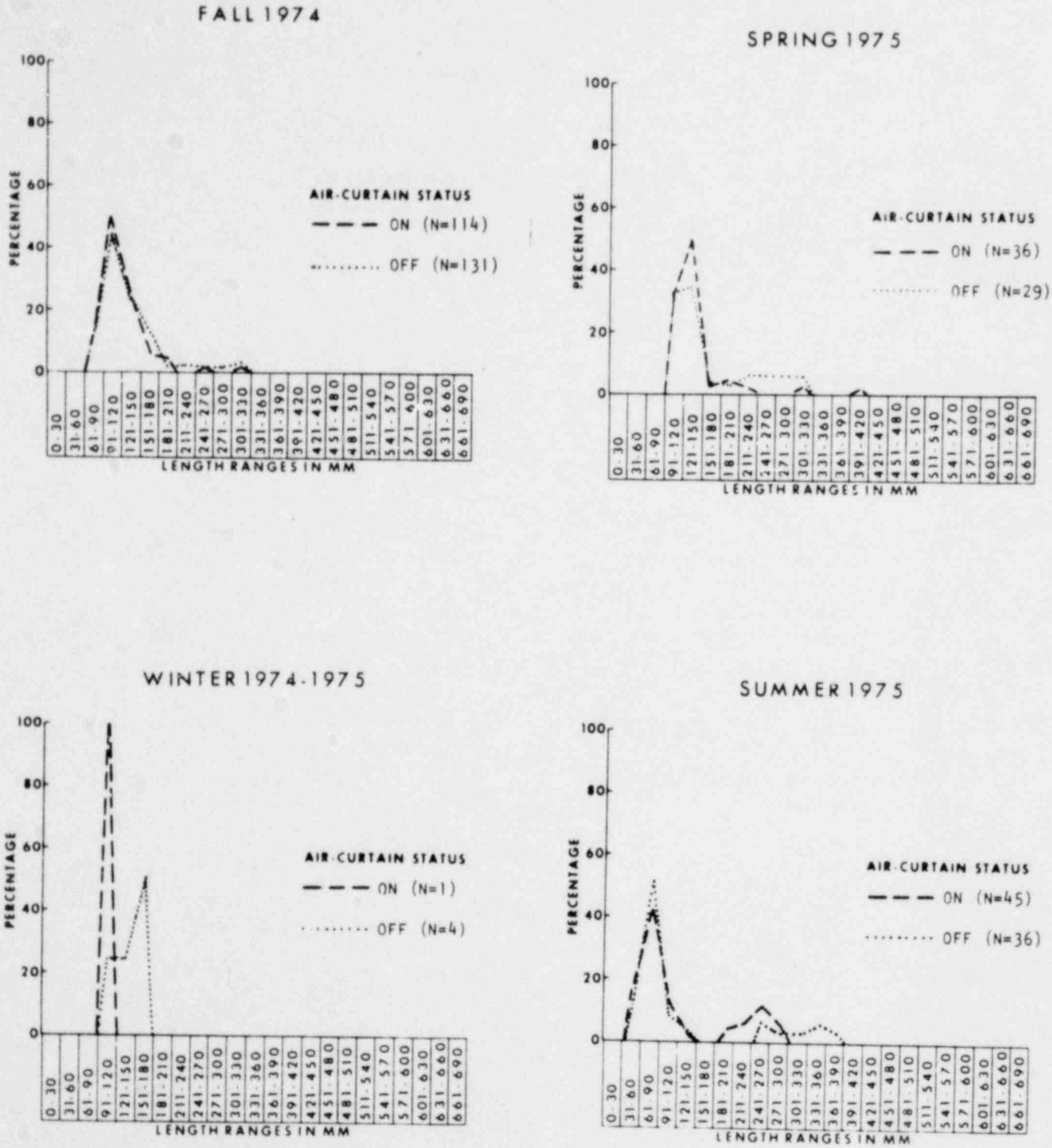

Figure VI-16. Seasonal Length-Frequency Distribution of White Bass Impinged during Air-Curtain Testing at Arkansas Nuclear One

8. Other Species

Excluding the seven major species, a total of 4,572 individuals weighing 587 pounds was impinged during the four seasonal tests. A complete tabulation of impingement data for these species is presented in Appendix Tables A-1 through A-4.

Impingement rates increased to > 200 fish per 3-day test during week 3 of fall 1974 testing as water temperatures in Dardanelle Reservoir fell below 15.5°C (60°F) (Figure VI-17). Impingement subsequently declined during winter testing and stabilized at levels of 60 to 90 individuals impinged per 3-day period during the spring. Summer displayed the lowest impingement rates for the 4-season test period, with levels of < 40 fish impinged per 3-day test throughout the 6-week season. Biomass of other species impinged over the 4-season test period displayed no seasonal patterns or consistent differences and depended mainly on the species composition of the fish impinged.

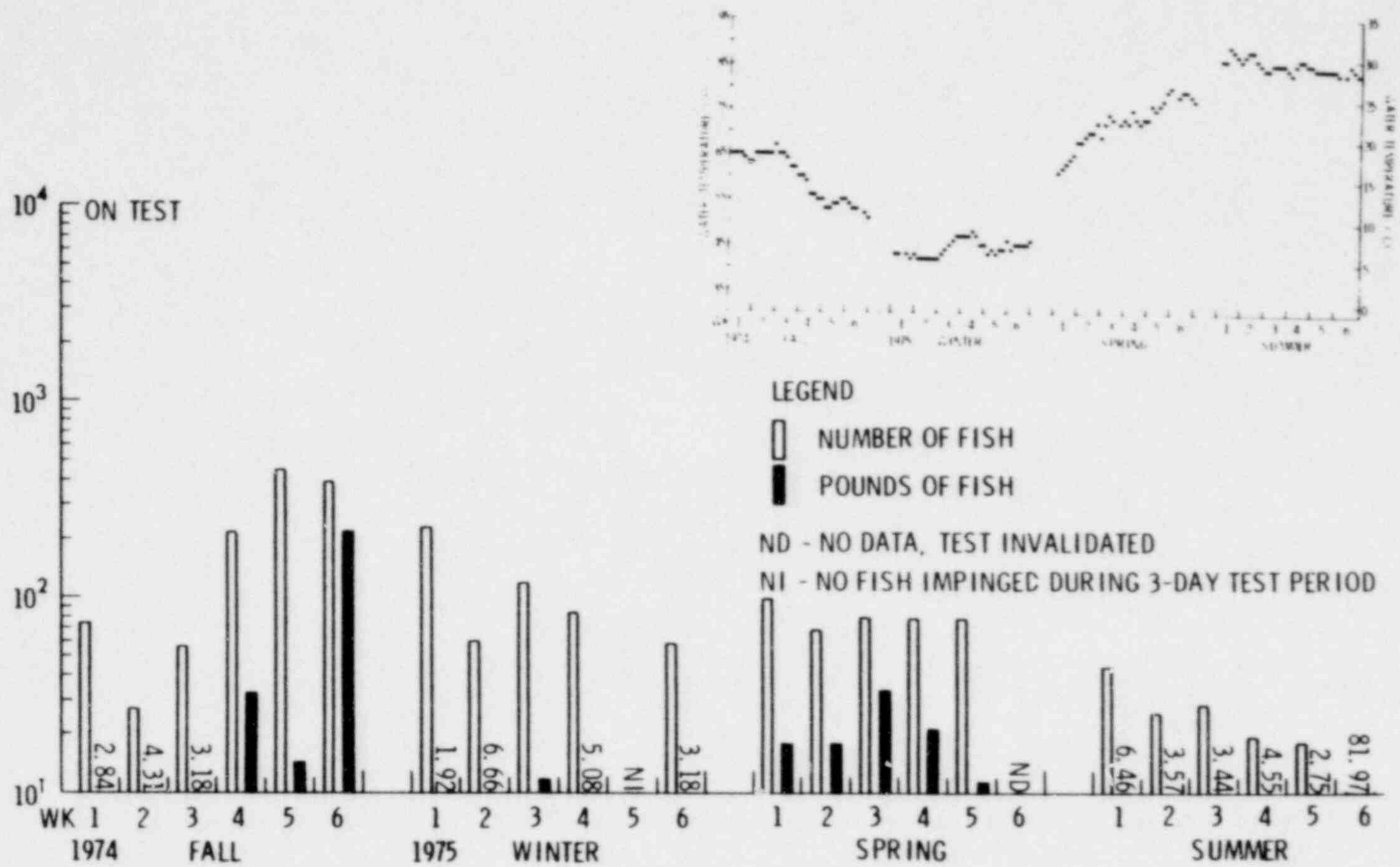

Figure VI-17. Total Numbers and Biomass (lbs) of Other Fish Species Impinged per 3-Day Test Period during Seasonal Air-Curtain Testing at Arkansas Nuclear One, October 1974-August 1975 (Page 1 of 2)

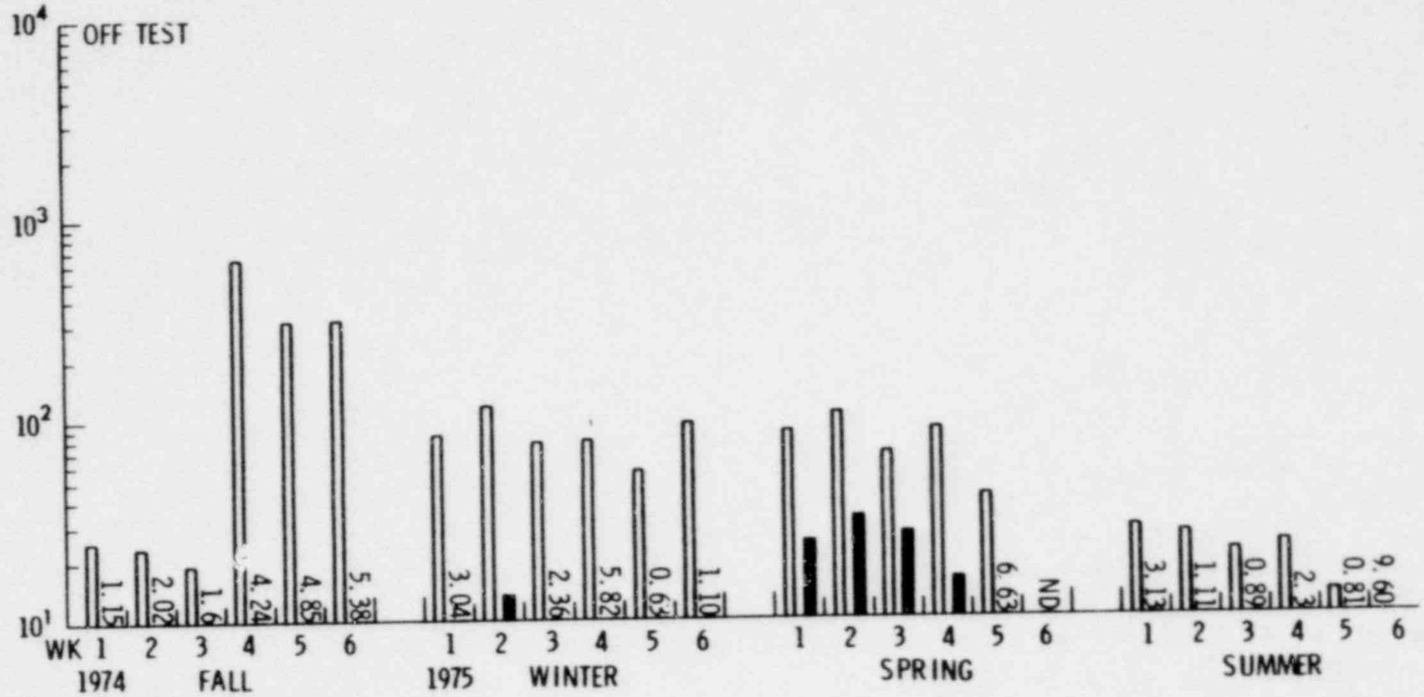

Figure VI-17. (Page 2 of 2)

SECTION VII

IMPINGEMENT DURING AIR CURTAIN TESTING IN RELATION TO ABIOTIC FACTORS

The effectiveness of a behavioral screening system such as the air curtain constructed at the mouth of the Arkansas Nuclear One intake canal depends on the following variables:

- The ability of the fish to sense by tactile, visual, or olfactory means the presence of the barrier
- Species-specific behavioral response to stimuli produced by the screening device
- Various species' swimming ability

These variables, in turn, are related to and affected by a number of interacting natural and man-induced physical and chemical parameters.

Concurrent environmental data and impingement figures obtained during air curtain testing are compared on a seasonal basis in the following paragraphs to help explain the results obtained during ON/OFF air curtain operation.

A. TURBIDITY

Measurements taken during seasonal air curtain testing indicate moderate to high turbidities in Dardanelle Reservoir throughout the year with highest levels occurring during late fall and winter (Appendix Tables A-12 through A-15). The relatively small amount of turbidity data does not lend itself to detailed statistical comparisons with air curtain test information, but a visual comparison reveals an apparently positive relationship between high impingement and increased turbidity.

There were no day/night comparisons of fish impingement levels, so there is no clarifying evidence of the curtain's efficiency during hours of lessened visibility. Turbidity was measured at the beginning of each air curtain test run. Because these readings were taken only during ON test periods, however, no comparisons of turbidity levels between ON/OFF tests are available. It might be suggested that air curtain operation, with its accompanying vibration and turbulence patterns, may have affected normal turbidity patterns during ON testing at the mouth of the intake canal. However, a seasonal comparison with monthly turbidity measurements collected by Sinclair (1968-1975) over an 8-year period at a station adjacent to the plant intake canal indicates turbidity levels comparable to those observed during air curtain testing.

As noted above, the success of the air curtain in deterring fish depends, in part, on a fish's ability to sense its presence. Therefore, lowered visibility resulting from turbidity levels might be expected to affect this sensing ability. Early air curtain test studies by Bates and Van DerWalker indicated lower impingement rates during daylight and greater impingements at night. Consequently, it was assumed that the sensory response mechanism involved in avoiding the bubble screen was entirely visual (Bates and VanDerWalker, 1969). These and subsequent researchers postulated, therefore, that air bubble screens would probably not be effective in waters with high turbidities. Texas Instruments (1974a) observed higher nighttime impingement rates during air curtain testing at the Indian Point power plant on the Hudson River; at the time, it was suggested that these high night impingements were the result of high turbidities further diminishing the already lessened night vision of fish approaching the bubble curtain. It should be noted, however, that these day/night differences may simply have been the result of diel abundance and distribution patterns of the fish populations in the vicinity of the Indian Point site. Studies in North Carolina with gizzard shad and striped bass (Bibko, Kueser, and Wirtenan, 1973) and in Lake Michigan with alewives (as reported in a review article by Maxwell, 1973) showed air curtain efficiency to be as high in complete darkness as in daylight.

Fishes' sense of touch, in concert with their lateral-line system, is known to interact in determining their orientation (Bibko, Kueser, and Wirtenan, 1973). This tactile response was implicated by Bates and VanDer Walker (1969) as the mechanism by which juvenile salmonids avoided water-jet deflectors; although these deflectors provided limited visual contrast with main canal flow, nighttime and daylight deflection efficiencies were comparable. It would seem logical, therefore, that an air bubble screen, though providing limited visual contrast during the night or in waters of moderate to high turbidity, would generate sufficient tactile stimuli (pressure waves, turbulence) to be sensed by an approaching fish.

Although air curtain test data at Arkansas Nuclear One do appear to indicate a rising trend in impingement with increased turbidities, the paucity of data from this and other studies renders this finding inconclusive. It is suggested that while vision is related to avoidance of the air curtain system, other sensory mechanisms are probably involved.

B. WATER TEMPERATURE

Impingement rates for all species combined and six of the seven most heavily impinged species were found to be significantly correlated statistically with water temperatures in Dardanelle Reservoir during fall 1974 and spring 1975 air curtain test periods. In the great majority of cases, these significant correlations were negative; i.e., higher impingement was associated with lower temperatures and lower impingement with higher temperatures. However, a small number of positive correlations were observed for blue catfish, channel catfish, and freshwater drum during the winter and white crappie during the spring (Tables VII-1 and VII-2).

Table VII-1

Statistical Tests for Correlation between Numbers of Fish Impinged and Water Temperature during On/Off Air-Curtain Testing at Arkansas Nuclear One

Species	Air-Curtain Status	Fall			Winter			Spring			Summer		
		P	S	K	P	S	K	P	S	K	P	S	K
All species	On	-0.854*	-0.883*	-0.733*	-0.253	-0.314	-0.200	-0.929*	-0.700	-0.600†	-0.5[illegible]3	-0.294	-0.200
	Off	-0.681	-0.771†	-0.600†	-0.507	-0.657	-0.600†	-0.694	-0.700	-0.600†	-[illegible].009	-0.203	-0.133
Threadfin shad	On	-0.846*	-0.883†	-0.733*	-0.248	-0.314	-0.200	-0.899*	-0.700	-0.600†	-0.687	-0.899*	-0.800*
	Off	-0.691	-0.771†	-0.600†	-0.542	-0.657	-0.600†	-0.758	-1.000*	-1.000*	-0.508	-0.551	-0.533
Gizzard shad	On	-0.896*	-0.883*	-0.733*	-0.325	-0.657	-0.467	-0.982*	-1.000*	-1.000*	-0.333	-0.029	-0.000
	Off	-0.502	-0.657	-0.467	0.454	0.314	0.200	-0.848†	-1.000*	-1.000*	0.021	0.456	0.333
Blue catfish	On	-0.788†	-0.795†	-0.600†	0.484	0.657	0.467	-0.948*	-0.900*	-0.800*	0.427	0.551	0.400
	Off	-0.884*	-0.886*	-0.733*	0.740 ⊕	0.714*	0.467	-0.783	-1.000*	-1.000*	0.089	0.015	-0.067
Channel catfish	On	-0.642	-0.618	-0.333	0.750 ⊕	0.600	0.600 ⊕	-0.968*	-0.700	-0.600†	-0.153	-0.058	0.000
	Off	-0.318	-0.029	0.067	0.803 ⊕	0.771 ⊕	0.600 ⊕	-0.782	-0.600	-0.400	-0.663	-0.812†	-0.667†
Freshwater drum	On	-0.829*	-0.883*	-0.733*	0.774 ⊕	0.522	0.400	-0.924*	-0.700	-0.600†	-0.184	-0.058	0.000
	Off	-0.548	-0.829*	-0.7[illegible]3*	0.477	0.429	0.200	-0.790	-0.700	-0.600†	0.072	[illegible].696	0.533
White crappie	On	-0.767†	-0.795†	-0.600†	0.513	0.213	0.133	0.669	0.800 ⊕	0.600 ⊕	0.399	0.464	0.400
	Off	-0.951*	-0.886*	-0.733*	-0.011	0.030	0.000	0.869 ⊕	0.900 ⊕	0.800 ⊕	-0.369	-0.279	-0.200
White bass	On	-0.745†	-0.795†	-0.600†	IC	IC	IC	-0.944*	-1.000*	1.000*	-0.884*	-0.841*	-0.567†
	Off	-0.953*	-0.943*	-0.867*				-0.654	-0.700	-0.600†	-0.095	-0.[illegible]24	-0.133

* Significant at α = 0.05 level
† Significant at α = 0.10 level

P = Pearson's r test
S = Spearman's ρ (rho) test
K = Kendall's τ (tau) test

IC = Insufficient nonzero catches to detect any correlation with water temperature.
⊕ = Circled significant correlations are positive; all other significant correlations are negative.

Table VII-2

Statistical Tests for Correlation between Biomass of Fish Impinged and Water Temperature during On/Off Air-Curtain Testing at Arkansas Nuclear One

Species	Air Curtain Status	Fall			Winter			Spring			Summer		
		P	S	K	P	S	K	P	S	K	P	S	K
All species	On	-0.864*	-0.883*	-0.733*	-0.243	-0.314	-0.200	-0.963*	-1.000*	-1.00 *	-0.506	-0.116	0.0
	Off	-0.253	-0.829*	-0.733*	-0.462	-0.657	-0.600†	-0.8631	-1.000*	-1.000*	-0.306	-0.579	-0.400
Threadfin shad	On	-0.849*	-0.383*	-0.733*	-0.237	-0.314	-0.200	-0.899*	-0.700	-0.600†	-0.683	-0.899*	-0.800*
	Off	-0.692	-0.829*	-0.867*	-0.492	-0.657	-0.600†	-0.752	-1.000*	-1.000*	-0.081	-0.203	-0.133
Gizzard shad	On	-.0792†	-0.8827*	-0.7333*	-0.365	-0.657	-0.467	-0.985*	-1.00 *	-1.00 *	-0.525	-0.261	-0.267
	Off	-0.525	-0.543	-0.200	0.412	0.314	0.200	-0.861*	-1.00 *	-1.00 *	-0.489	-0.667	-0.533
Blue catfish	On	-0.737†	-0.647	-0.467	-0.069	-0.314	-0.200	-0.987*	-0.900*	-0.800*	-0.360	-0.058	0.0
	Off	-0.854*	-0.943	-0.867*	0.779 ⊕	0.771 ⊕	0.600 ⊕	-0.842†	-1.00 *	-1.00 *	-0.212	-0.579	-0.333
Channel catfish	On	0.745 ⊕	0.529	0.333	0.687	0.600	0.467	-0.978*	-1.00 *	-1.00 *	-0.005	-0.058	0.0
	Off	0.127	0.429	0.333	-0.269	0.371	0.333	-0.837*	-1.00 *	-1.00 *	-0.688	-0.812†	-0.667†
Freshwater drum	On	-0.906*	-0.883*	-0.733*	0.206	0.058	0.133	-0.944*	-0.700	-0.600†	-0.020	-0.029	-0.133
	Off	-0.499	-0.714	-0.467	0.257	0.200	0.200	-0.802	-0.900*	-0.800*	0.061	0.522	0.400
White crappie	On	0.159	0.471	0.333	-0.179	0.213	0.133	0.663	0.0	-0.20	-0.414	-0.232	-0.133
	Off	0.032	0.429	0.200	-0.472	0.030	0.0	0.058	0.100	0.0	-0.479	-0.696	-0.533
White bass	On	-0.641	-0.412	-0.333	IC	IC	IC	-0.897*	-0.700	-0.600†	-0.532	-0.638	-0.533
	Off	-0.818*	-0.600	-.0467				-0.168	-0.600	-0.400	-0.475	-0.551	-0.533

*Significant at α = 0.05 level
†Significant at α = 0.10 level

P = Pearson's r test
S = Spearman's ρ (rho) test
K = Kendall's τ (tau) test

IC = Insufficient nonzero catches to detect any correlation with water temperature.

⊕ Circled significant correlations are positive, all other significant correlations are negative correlations.

In most instances, correlations with temperature were observed during both ON and OFF tests, but it should be noted that this was not always the case (Tables VII-1 and VII-2). A lack of significant correlation with water temperature during either ON or OFF testing should not be construed as reflecting a significant difference in impingement levels between the tests. ON and OFF air curtain test data were compared against water temperatures independent of each other; as such, the findings indicate the degree of variation between the trends displayed for ON or OFF air curtain test impingement levels and Dardanelle Reservoir water temperatures during a given season rather than differences in impingement rates between tests.

Water temperature has proved to be a major factor influencing fishes' physiological state and behavioral responses, especially those involving swimming performance. These responses, in turn, play a significant role in the ability to avoid or be guided by a behavioral screening mechanism such as the air curtain.

Fishes are cold-blooded organisms, which means that their internal body temperatures and the speed and coordination with which bodily functions occur (metabolic rates) are directly related to the ambient temperatures of their surroundings. Within certain limits, these two factors exhibit a positive correlation; i.e., the higher the water temperature, the more active the fish, and vice versa. Ambient temperatures approaching either high or low extremes, however, have been shown to result in loss of equilibrium, muscular incoordination, and feeding cessation, leading to extensive damage or death. Endpoints or lethal limits have been established by extensive laboratory and field testing for a number of fish species inhabiting Dardanelle Reservoir (Texas Instruments, 1974b and 1975). It is worthy of note that in Dardanelle Reservoir a number of these species are living close to their lower lethal limit, as established in laboratory tests, during late fall, winter, and early spring.

A number of studies have evaluated the effects of low water temperatures on fish species. King (1970) found that swimming speeds for white perch decreased with decreasing temperature. Hocutt (1973) observed similar results for juvenile largemouth bass, spotfin shiner, and channel catfish exposed to rapid temperature changes. Bibko, Wirtenan, and Kueser (1973) noted considerable differences between the cruising speeds of young striped bass at 4.5°C (40°F) and 11.1°C (52°F). Chittenden (1972), studying American shad, observed slower and wobbly swimming, extremely sluggish movements below 6°C (42.8°F), cessation of feeding, frequent temporary equilibrium loss, no response to hand movements below 4.4°C (39.4°F), and frequent collisions with objects shortly before death. Colby (1971), experimenting with alewives, reported reduced swimming speed, little or no response to external stimuli, disorientation, frequent collisions, cessation of feeding, and diminished tendency to school between 4.5° and 2.2°C (40° and 36°F). In air bubbler tests, Bibko, Wirtenan, and Kueser (1973) observed that gizzard shad became lethargic swimmers at 4.4°C (40°F) and drifted repeatedly through the air screen; at 0.8°C (33.5°F), striped bass became lethargic swimmers and were pushed backwards through the air screen repeatedly. Hubbs (1951) found that threadfin shad in the Colorado River displayed a minimum tolerance of 54° to 56.6°F (12.2° to 14.2°C). Coward (1963) observed that threadfin shad acclimated at 20°C (68°F) showed resistance times of 16.4 to 125 min. for temperatures of 5° to 7°C (41.0° to 44.6°F); he suggested that cold-stressed shad may enter a semicomatose state in which they are incapable of movement and possess only limited sensory perception although they are still alive.

Low temperatures have been considered as one of the major factors affecting impingement levels during winter at Consolidated Edison's Indian Point plant on the Hudson River because the greatest amount of impingement and entrapment has been related with periods of coldest water temperatures (U.S. AEC, 1973; Texas Instruments, 1974a). We suggest that the significant correlations between impingement and water temperatures observed during fall and spring at Arkansas Nuclear One are the result of the seasonal onset and subsequent cessation of the adverse effects induced by decreasing water temperatures in Dardanelle Reservoir. Intake approach velocities observed in the vicinity of the Arkansas Nuclear One air curtain show that the largest magnitudes occur within the first one-half of the right (north) zone nearest the center of the transect. However, except for the nearshore zones, the observed currents are almost uniform across the transect (Figure II-4). The low-level current velocities observed in the vicinity of the air curtain (generally <0.6 fps) are within the range (0.5-1.0 fps) recommended for most power plants (U.S. EPA, 1973; Bibko, Wirtenan, and Kueser, 1973). These current velocity levels would appear to be within the swimming capabilities of all except the smaller or weaker fish of impingeable size at water-temperature conditions approximating late spring, summer, and early fall in Dardanelle Reservoir (Texas Instruments, 1972; U.S. EPA, 1973; Bibko, Wirtenan, and Kuesner, 1973). Length-frequency data for the seven most heavily impinged fish species over the four seasonal test periods show the heaviest impingement pressure to be on young-of-the-year fish (Figures VI-11 through VI-17).

Based on the aforementioned data, it is quite likely that regardless of air curtain status even the relatively low velocity levels observed in front of the air curtain may be much beyond the swimming abilities of smaller members of most fish species during the late fall and winter. Therefore, the high impingement rates observed during late fall and winter may have represented impingement of passive moribund, smaller or weaker fish thermally stressed by decreasing water temperatures.

C. OTHER PARAMETERS

A number of additional environmental parameters monitored during seasonal air curtain testing are presented in Appendix Tables A-12 through A-15. None of these additional parameters were correlated with impingement patterns during seasonal ON/OFF testing.

SECTION VIII
CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The following conclusions are based on the results of a year's seasonal testing, 6 wk per season, of the air curtain at Arkansas Nuclear One.

Under present operating conditions the air curtain does not effectively deter fish from entering the intake canal. Consequently, it does not substantially reduce the impingement of fish on the Arkansas Nuclear One-Unit I intake screens. On the contrary, impingement was higher during air-curtain operation in 13 of 16 tests where statistically significant differences in impingement rates were observed.

Although seasonal variations in species composition of impinged fish were observed, these variations were independent of air-curtain operational status.

Growth and subsequent recruitment into an impingeable size were observed for the seven major species considered over the course of the study period. Air-curtain operation, however, did not alter the length-frequency distribution of the species impinged.

Impingement was negatively correlated with water temperature. Increasing impingement rates were associated with declining temperatures in the fall, while decreasing impingements were associated with rising temperatures in the spring.

It is our opinion that under present operating conditions highest impingement rates will continue to occur during the late fall, winter, and early spring, regardless of air-curtain status. Catches during these periods will continue to be predominantly young-of-the-year fish, especially threadfin shad, thermally stressed when Dardanelle Reservoir water temperatures fall below 60°F (15.5°C).

B. RECOMMENDATIONS

Thorough evaluation of the air curtain at Arkansas Nuclear One has demonstrated that this device is not effective in deterring fish from entering the plant intake canal. These findings, as well as the impingements observed during fall and winter, suggest two courses of further study in solving the impingement problem.

- Evaluate the biological impact of present impingement rates on the fishery resources of Dardanelle Reservoir
- Evaluate alternatives in plant intake structure design to reduce impingement only if biologically significant impact is determined.

1. Biological Study

TI is currently performing a comprehensive evaluation of the potential impact of impingement on the fishery resources of Dardanelle Reservoir. This soon-to-be-concluded study is addressing the past and present fishery resources of Dardanelle Reservoir, considering not only existing physicochemical and biological studies of the reservoir, but also life history information in the literature on the species most heavily impinged. This information, in conjunction with screen impingement data from Arkansas Nuclear One, will determine seasonal abundance patterns and community structure as well as estimated current impingement losses.

This information is being weighed against the socioeconomic value of the fish species most heavily impinged, based on sport and commercial fishery statistics compiled for Dardanelle Reservoir, so as to determine the direct or indirect impact of impingement on existing sport and/or commerical fisheries. This form of study could continue on an ongoing basis, utilizing data obtained by involved research institutions and state agencies to provide a continuous update of fish population levels and associated impingement impact.

2. Alternative Structural Design

TI has reviewed the proposed best technology available for minimizing adverse environmental impact of cooling water structures, as presented by a number of researchers, notably the U.S. Environmental Protection Agency (1973), Sharma (1974), Texas Instruments (1974), and Reisbol (1975). After reviewing the findings of these and other studies, we have reached the following general conclusions concerning the two major categories of screening devices as related specifically to the situation at Arkansas Nuclear One.

a. Behavioral Screening Devices

These devices vary considerably in effectiveness, depending on fish size, species, and ambient environmental conditions. No one behavioral system has been wholly successful in significantly reducing fish impingement. Consequently, no individual device is recommended for use at existing and proposed plants by any regulatory agency. Furthermore, any of these behavioral systems would be essentially ineffective when applied to a number of thermally stressed fish species, especially threadfin and gizzard shads, which are reduced to a moribund or semicomatose state by low water temperatures in Dardanelle Reservoir during late fall and winter.

b. Mechanical Screening Systems

Pressures brought to bear on utilities by Section 316(b) of the 1972 Federal Water Pollution Control Act, however, have spawned a multitude of mechanical fish protective devices designed to be installed at cooling-water intake structures. Through trial and error at a number of plant sites and through biological investigations, a number of mechanical screening devices have been shown to have some merit. For a thorough review of these systems, see the USEPA (1973) document "Development Document For Proposed Best Technology Available For Minimizing Adverse Environmental Impact of Cooling Water Intake Structures," Proceedings of the Second Workshop on Entrainment and Intake Screening held at Johns Hopkins University, 1974 (L. D. Jensen Ed.), Sharma (1974), and Reisbol (1975).

We recommend that until subsequent industry-wide testing proves the efficiency of one or more of these behavioral systems in deterring or guiding fish under environmental conditions applicable to Arkansas Nuclear One, no further time or funds should be expended in testing or installing such devices at Arkansas Nuclear One-Unit I.

SECTION IX

CITED LITERATURE

Alevras, R.A. 1974. Status of air bubble fish protection systems at Indian Point stations on the Hudson River. Proc. 2nd Entrainment and Intake Screening Workshop, Johns Hopkins Univ. Baltimore, Feb 5-9, 1973, p. 289-292.

Anon. 1974. A new fish screen: will it work? Electr. World. 181(2):93.

Arkansas Power & Light Co. 1974. Environmental report for Arkansas Nuclear One - Unit 2, Arkansas Power & Light Co., AEC Docket 50-368, Mar 1974.

Bates, D.W. and J.G. VanDerWalker. 1969. Exploratory experiments on the deflection of juvenile salmon by means of water and air jets. U.S. Dept. Int., Bur. Comm. Fish. Seattle, Wash., 11 p.

Bibko, P.N., L. Wirtenan, and P.E. Kueser. 1974. Preliminary studies on the effects of air bubbles and intense illumination on the swimming behavior of the striped bass (*Morone saxatilis*) and the gizzard shad (*Dorosoma cepedianum*). Proc. 2nd Entrainment and Intake Screening Workshop, Johns Hopkins Univ., Feb 5-9, 1973, p. 293-304.

Bramsnaes, F., J. Mogens, and C.V. Otterstrom. No date. Barriers against fish by means of electricity or veils of air.

Brett, J.R. and D. MacKinnon. 1953. Preliminary experiments using lights and bubbles to deflect young spring salmon. J. Fish. Res. Bd. Can. 10(8): 548-559.

Chittenden, M.E. Jr. 1972. Responses of young American shad, *Alosa sapidissima*, to low temperatures. Trans. Am. Fish. Soc. 101(4):680-685.

Colby, P.J. 1971. Alewife dieoffs: why do they occur? Limnos 4(2): 18-27.

Conover, W.J. 1971. Practical nonparametric statistics. John Wiley and Sons, New York, N.Y., 462 p.

Coward, J.E. 1963. Effect of dissolved salts and temperature on the survival of threadfin shad. M.S. Thesis, Univ. Arkansas, Fayetteville, 30 p.

Hocutt, C.H. 1973. Swimming performance of three warmwater fishes exposed to a rapid temperatur change. Chesapeake Sci. 14(1): 11-16.

Hubbs, C. 1951. Minimum temperature tolerances for fishes of the genera *Signalosa* and *Herichthys* in Texas. Copeia 1951(4): 297.

Jester, D.B. and B.L. Jensen. 1972. Life history and ecology of the gizzard shad, *Dorosoma cepedianum* (Lesueur) with reference to Elephant Butte Lake. New Mexico State Univ. Agr. Exp. Sta. Res. Rep. 218, 56 p.

King, L.R. 1970. Results of swimming speed and endurance studies on white perch as determined by the Beamish respirometer. Ichthyological Associates Rpt. to Consolidated Edison Company of New York, Inc.

Maxwell, W.A. 1973. Fish diversion for electrical generating station cooling systems. A state-of-the-art report for Florida Power & Light Co., Mar.

McConnell, W.J. and J.H. Gerdes. 1964. Threadfin shad, *Dorosoma petenense*, as food of yearling centrarchids. Calif. Fish Game 50(3):170-175.

Quirk, Lawler, and Matusky. 1973. Statistical analysis of fish impingement data, Indian Point generating station. Rpt. to Consolidated Edison Company of New York, Inc.

Riesbol, H.S. 1975. Fish screens: the state of the art - 1. Electr. World 183(6):155-156.

Sharma, R.K. 1974. Siting and designing of water intake structures to minimize fish kills. Draft of paper presented at 10th Water Resources Conf., Las Croabas, Puerto Rico, Nov 18-22, 1974. Avail. from author, Argonne National Lab., Argonne, Ill.

Sinclair, C.B. 1968-1975. Dardanelle Reservoir - Illinois Bayou embayment background survey. Prog. Rpts. for the years 1968 through 1975. Little Rock Univ. Prepared for Arkansas Power and Light Co., Little Rock.

Smith, K.A. 1961. Air curtain fishing for Maine sardines. Comm. Fish. Rev. 23(3): 1-14.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical methods. Iowa St. Univ. Press, Ames,

Tatum, B. 1975a. Dardanelle Reservoir fish survey. Proj. 873, Prog. Rpt. 3. Prepared for Arkansas Power & Light Co., Little Rock.

Tatum, B. 1975b. Dardanelle Reservoir fish survey. Proj. 873, Prog. Rpt. 4. Prepared for Arkansas Power & Light Co., Little Rock.

Texas Instruments Incorporated. 1972. Literature survey of fish behavior to screening and guiding devices at water intakes and a recommended future testing program. Flume study. Prepared for Consolidated Edison Company of New York, Inc.

Texas Instruments Incorporated. 1974a. Indian Point impingement study report for the period 15 June 1972 through 31 December 1973. Prepared for Consolidated Edison Company of New York, Inc.

Texas Instruments Incorporated. 1974b. Report covering proposed fish monitoring, air curtain testing, and thermal shock survey at Arkansas Nuclear One - Unit 1. Prepared for Arkansas Power & Light Co., Little Rock.

Texas Instruments Incorporated. 1975. Evaluation of potential impact of impingement on fishery resources and dissolved oxygen, Dardanelle Reservoir. Semiannual Rpt.

U.S. Atomic Energy Commission. 1973. Proposed Appendix B to facility operating license DPR-26. For Consolidated Edison Company of New York, Inc., Indian Point Nuclear Generating Units Numbers 1 and 2, Docket Numbers 50-3 and 50-247, Environmental Tech. Spec. Requirements for Once-Through Cooling, Aug 7, 1973.

U.S. Environmental Protection Agency. 1973. Development document for proposed best technology available for minimizing adverse environmental impact of cooling water intake structures. EPA 440/1-74-015.

APPENDIX A
TABULATED DATA

Table A-1

Numbers and Biomass* of Fish Species Impinged during Fall Air-Bubble Curtain Testing at Arkans s Nuclear One - Unit 1, October 21-November 30, 1974

		Air Curtain On								Air Curtain Off							
		Oct 21		Oct 22		Oct 23		Total		Oct 24		Oct 25		Oct 26		Total	
	Species	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
Test I	White bass	20	1.00	14	0.69	19	0.81	53	2.50	14	0.88	7	0.31	5	0.19	26	1.38
	Threadfin shad	1,418	8.25	722	7.38	974	9.88	3,114	25.51	1,887	14.50	2,374	19.94	3,234	23.00	7,495	57.44
	Gizzard shad	1,099	0.8[illegible]	1,068	15.06	1,208	10.88	3,975	34.75	1,029	11.31	1,021	12.00	730	9.63	2,780	32.94
	Blue catfish	185	5.44	181	2.00	78	1.13	444	8.57	18	0.50	34	0.56	16	0.31	68	1.37
	Channel catfish	5[illegible]	2.00	103	4.81	74	3.38	232	10.19	84	2.25	62	2.25	85	3.25	231	7.75
	Freshwater drum	120	1.25	141	2.25	70	1.77	331	5.27	27	0.75	27	0.25	8	0.40	62	1.40
	White crappie	15	1.94	20	3.50	28	2.00	63	7.44	23	2.25	24	1.44	14	0.07	61	3.76
	Mississippi silverside	4	0.01	4	0.01	2	<0.01	10	0.02	3	0.02	1	<0.01	1	0.01	5	0.03
	Golden shiner	8	0.06	3	0.02			11	0.08	3	0.02	3	0.03	2	0.01	8	0.06
	Bluegill sunfish	17	0.38	4	0.02	7	0.13	28	0.53			3	0.06	3	0.05	6	0.11
	Green sunfish	4	0.01	1	<0.01	3	0.06	8	0.07								
	Longear sunfish	2	.05	2	0.01			4	0.06			1	0.01			1	0.01
	Warmouth	2	0.02					2	0.02	1	0.02					1	0.02
	Redear sunfish									1	<0.01					1	0.00
	Orangespotted sunfish	1	<0.01**					1	0.00								
	Black crappie			6	0.59			6	0.59					1	0.22	1	0.22
	Skipjack herring	1	0.09					1	0.09								
	European carp					1	1.38	1	1.38			1	0.69			1	0.69
	Common shiner											1	0.01			1	0.01
	Total							8,284	97.07							10,748	107.19

		Oct 28		Oct 29		Oct 30		Total		Oct 31		Nov 1		Nov 2		Total	
	Species	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
Test II	White bass	13	0.69	7	0.63	3	0.25	23	1.57	3	0.56	7	0.19	5	0.38	15	1.13
	Threadfin shad	321	2.25	597	3.56	27	0.19	945	6.00	12	0.13	1,021	8.63	1,573	11.50	2,606	20.26
	Gizzard shad	171	1.75	1,323	11.31	174	1.50	1,668	14.56	278	2.31	3,842	37.00	1,188	11.63	5,308	50.94
	Blue catfish	21	0.25	55	0.56	15	0.13	91	0.94	6	0.25	36	0.75	31	0.31	73	1.31
	Channel catfish	56	1.19	69	2.50	70	4.19	195	7.88	79	2.88	97	3.06	56	2.75	232	8.69
	Freshwater drum	5	0.38	24	0.38	5	1.06	34	1.82	3	0.38	8	1.94	10	0.13	21	2.45
	White crappie	12	0.75	14	1.94	6	0.31	32	3.00	2	1.00	5	0.31	4	0.56	11	1.87
	Mississippi silverside			1	0.01			1	0.01			[illegible]	0.03	1	0.01	4	0.04
	Golden shiner					2	0.01	2	0.01	1	0.01	[illegible]	0.01	1	0.01	4	0.03
	Bluegill sunfish	2	0.31	6	0.38	5	0.03	13	0.72	4	0.03	4	0.02	1	0.13	9	0.18
	Green sunfish			1	<0.01			1	0.00			1	<0.01			1	0.00
	Longear sunfish			2	0.01			2	0.01			1	<0.01	1	<0.01	2	0.00
	Warmouth											1	0.01			1	0.01
	Skipjack herring	1	0.25	1	0.15			2	0.40					1	0.13	1	0.13
	European carp			1	1.44			1	1.44								
	River carpsucker			1	0.01			1	0.01								
	Blu tnose shiner			3	0.02			3	0.02								
	Smallmouth buffalo					1	1.69	1	1.69			1	1.63			1	1.63
	Total							3,015	40.08							8,289	88.67

*Biomass is presented in pounds.

**Biomass values <0.01 are not included in the totals.

Table A-1 (Contd)

		Air Curtain On								Air Curtain Off							
		Nov 4		Nov 5		Nov 6		Total		Nov 7		Nov 8		Nov 9		Total	
	Species	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
Test III	White bass			5	0.25	3	0.97	8	1.22	6	0.38	6	0.44	23	2.00	35	2.82
	Threadfin shad	2,456	23.75	8,100	60.25	8,429	64.88	18,985	148.88	15,199	127.69	16,091	140.00	17,465	148.50	48,755	416.19
	Gizzard shad	1,323	14.44	315	2.32	186	2.81	1,824	19.57	970	8.19	1,196	9.44	798	11.25	2,964	28.88
	Blue catfish	26	0.56	3	0.03	31	0.25	60	0.84	19	0.38	18	0.25	49	1.56	86	2.19
	Channel catfish	88	4.00	29	3.13	35	0.81	152	7.94	26	0.94	10	0.25	46	1.44	82	2.63
	Freshwater	16	1.00	12	0.81	31	3.76	59	5.57	28	2.31	16	1.44	68	2.56	112	6.31
	White crappie	1	0.13	6	0.75	11	0.83	18	1.71	5	0.25	7	0.88	16	2.38	29	3.51
	Mississippi silverside	3	0.02	1	0.01	3	0.02	7	0.05			2	0.01	6	0.04	8	0.05
	Bluegill sunfish	31	0.13	5	0.25	1	<0.01	37	0.38	1	<0.01			1	<0.01	2	0.00
	Green sunfish			1	<0.01			1	0.00					1	<0.01	1	0.00
	Longear sunfish	2	0.01					2	0.01								
	Orangespotted sunfish	1	<0.01	1	<0.01			2	0.00	1	0.04					1	0.04
	Skipjack herring	1	0.06					1	0.06					1	0.05	1	0.05
	European carp			1	0.44			1	0.44	1	1.06					1	1.06
	River carpsucker			1	2.19			1	2.19								
	Bluntnose shiner	1	0.01					1	0.01	1	0.01					1	0.01
	Smallmouth buffalo			1	0.01	1	0.01	2	0.02	1	<0.01			1	0.01	2	0.01
	Black bullhead					1	0.02	1	0.02								
	Brook silverside									1	<0.01					1	0.00
	Largemouth bass													1	0.38	1	0.38
	Total							21,162	188.91							52,082	464.13

		Nov 11**		Nov 12		Nov 13		Total		Nov 14**		Nov 15		Nov 16		Total	
	Species	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
Test IV	White bass	26	0.69	43	1.13	9	0.25	78	2.07	28	[illegible]	54	0.97	1	1.30	83	3.41
	Threadfin shad	119,027	1,233.94	84,556	860.07	153,498	1,607.81	357,051	3,701.82	175,876	1,994.7	254,516	2,924.91	97,235	1,064.50	527,627	5,984.11
	Gizzard shad	5,711	57.39	6,376	59.19	5,045	55.58	17,123	172.16	15,698	173.98	22,135	254.63	9,260	93.12	47,093	521.63
	Blue catfish	174	1.71	169	1.69	178	1.72	521	5.12	306	3.41	216	1.61	396	5.21	918	10.23
	Channel catfish	152	3.67	215	5.65	88	1.69	455	11.01	75	5.64	108	9.98	42	1.30	225	16.92
	Freshwater drum	221	10.08	153	5.65	289	14.51	663	30.24	711	19.42	1,025	21.89	396	16.94	2,132	58.25
	White crappie	33	3.55	23	1.88	43	5.22	99	10.65	91	2.30	108	2.58	73	2.01	272	6.89
	Mississippi silverside	26	0.28	19	0.19	33	0.36	78	0.83	156	0.99	270	1.61	42	0.36	468	2.96
	Bluegill sunfish					2	0.01		0.01	19	<0.01	27	<0.01	10	<0.01	56	<0.00
	Green sunfish					27	0.15	27	0.15								
	Longear sunfish					1	<0.01	1	0.00								
	Warmouth					19	0.19	19	0.19								
	European carp					1	1.06	1	1.06								
	River carpsucker	11	7.12	9	6.21	13	9.63	33	23.16								
	Bluntnose shiner					13	0.15	13	0.15								
	Smallmouth buffalo											54	0.64			54	0.64
	Black bullhead					1	0.01	1	0.01								
	Brook silverside											27	0.32			27	0.32
	Tilapia	11	2.26	9	0.7[illegible]	13	3.76	33	6.77								
	Bluntnose minnow											27	0.32			27	0.32
	Total							376,237	3,965.4							578,982	6,605.68

*Biomass is presented in pounds

**Average of succeeding two test days

Table A-1 (Contd)

Test V

Species	Air Curtain On								Air Curtain Off							
	Nov 18		Nov 19		Nov 20		Total		Nov 21		Nov 22		Nov 23		Total	
	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
White bass	184	4.86	76	1.12	26	0.76	286	6.74	35	0.84	77	1.80	23	0.47	135	3.11
Threadfin shad	207,070	2,434.91	160,691	2,114.13	129,921	1,461.47	497,682	6,010.51	307,579	4,045.98	146,296	2,031.59	52,468	663.31	506,343	6,740.88
Gizzard shad	36,545	572.21	4,977	65.59	2,654	45.09	44,176	682.89	9,506	125.74	14,471	201.19	6,155	107.97	30,132	434.90
Blue catfish	1,259	11.54	858	8.48	206	3.18	2,323	23.20	35	0.84	211	1.13	170	1.95	416	3.92
Channel catfish	79	0.30	172	1.78	64	0.61	315	2.69			133	1.13	39	0.31	172	1.44
Freshwater drum	761	11.54	1,030	27.44	64	0.76	1,855	39.74	106	1.25	192	12.15	123	2.41	421	15.81
White crappie	52	0.61	57	0.45			109	1.06	35	0.42	96	0.45	69	0.39	200	1.26
Mississippi silverside	105	1.21	248	2.45			353	3.66	70	0.84	77	0.68	31	0.23	178	1.75
Green sunfish					13	<0.01	13	0.00	35	<0.01					35	0.00
Longear sunfish													8	0.08	8	0.08
Warmouth													8	<0.01	8	0.00
Orangespotted sunfish					13	0.15	13	0.15								
Black crappie									35	0.84					35	0.84
Skipjack herring					13	0.76	13	0.76								
Smallmouth buffalo					13	0.15	13	0.15			19	<0.01			19	<0.00
Tilapia			38	9.59			38	9.59					8	1.95	8	1.95
Bluntnose minnow											19	0.23			19	0.23
Total							547,189	6,781.14							538,129	7,206.17

Test VI

Species	Nov 25		Nov 26		Nov 27		Total		Nov 28**		Nov 29		Nov 30		Total	
	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
White bass	31	0.87	18	0.58	36	0.89	85	2.34	38	0.94	25	0.52	51	1.35	114	2.81
Threadfin shad	140,062	1,605.79	29,713	327.47	32,617	324.38	202,392	2,257.64	53,923	653.94	45,930	540.16	61,915	767.72	16,768	1,961.82
Gizzard shad	14,009	102.35	2,946	[illegible]	4,475	51.19	21,430	203.24	2,001	20.98	2,418	28.63	1,583	13.32	6,002	62.93
Blue catfish	398	5.89	269	2.02	205	2.01	872	9.92	323	4.57	360	4.70	286	4.44	969	13.71
Channel catfish	92	0.87	68	0.31	50	0.35	210	1.53	102	1.06	112	0.76	92	1.35	306	3.17
Freshwater drum	367	13.51	247	4.47	115	5.84	729	23.82	203	3.94	211	4.70	194	3.17	608	11.81
White crappie	153	0.69	115	1.59	57	0.70	325	2.98	104	0.49	74	0.35	133	0.63	311	1.47
Mississippi silverside	153	0.87	39	0.31	43	0.23	235	1.41	78	0.72	74	0.64	82	0.79	234	2.15
Bluegill sunfish	15	<0.01	7	0.04	4	<0.01	26	0.04					20	<0.01	20	0.00
Green sunfish			11	0.08	7	<0.01	18	0.08					10	<0.01	10	0.00
Black crappie			7	0.89			7	0.89			12	0.12			12	0.12
Skipjack herring					4	0.46	4	0.46								
River carpsucker											37	0.23			37	0.23
Smallmouth buffalo	31	0.17	7	0.04			38	0.21								
Black bullhead	31	0.52	4	0.04			35	0.56								
Tilapia			4	1.05	4	0.89	8	1.94								
Goldfish	15	0.52					15	0.52								
Striped bass													1	2.88	1	2.88
Total							226,429	2,717.58							170,392	2,063.1

*Biomass is presented in pounds

**Average of succeeding two test days

Table A-2

Numbers and Biomass* of Fish Species Impinged during Winter Air-Bubble Curtain Testing at Arkansas Nuclear One – Unit 1, January 13–February 22, 1974

Test	Species	Air Curtain On								Air Curtain Off							
		Jan 13		Jan 14		Jan 15		Total		Jan 16		Jan 17		Jan 18		Total	
		No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
Test I	Threadfin shad	49,437	706.4	179,461	2,833.10	114,449	1,769.73	343,347	5,309.25	287,927	5,537.85	332,408	6,500.07	473,829	9,053.45	1,094,164	21,091.37
	Gizzard shad	1,563	26.91	9,437	213.01	5,500	119.96	16,500	359.88	2,633	73.10	13,862	272.96	4,825	166.24	21,318	512.30
	Blue catfish	15	0.15			8	0.08	23	0.23								
	Channel catfish			51	0.30	26	0.15	77	0.45			57	16.30			57	16.30
	White crappie	8	1.18	26	0.30	17	0.74	51	2.22					78	16.62	78	16.62
	Miss. silverside	45	0.37	103	0.91	74	0.64	222	1.92	23	0.23	57	0.68			80	0.91
	Spoonbill catfish									1	2.13					1	2.13
	Total							360,220	5,673.95							1,115,698	21,639.63

Test	Species	Jan 20		Jan 21		Jan 22		Total		Jan 23		Jan 24		Jan 25		Total	
		No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
Test II	White bass					10	0.12	10	0.12	10	0.33			28	2.68	38	3.01
	Threadfin shad	72,556	1,668.79	85,841	2,044.55	45,920	1,064.49	204,317	4,777.83	46,114	1,052.57	111,573	1,863.02	174,817	3,201.55	332,504	6,117.14
	Gizzard shad	24,305	369.53	4,541	76.21	5,680	99.54	34,526	545.28	2,435	51.97	2,302	35.90	7,391	126.12	12,128	213.99
	Blue catfish	17	0.20	18	0.21	30	1.06	65	1.47	10	0.11					10	0.11
	Channel catfish	102	0.82	71	1.49			173	2.31	10	0.03			28	0.67	38	0.70
	Freshwater drum			18	0.21	40	7.67	58	7.88	19	5.44	28	1.67			47	7.11
	Miss. silverside			18	0.21	30	0.24	48	0.45	10	0.11	49	0.57	28	0.33	87	1.01
	Black crappie					10	6.25	10	6.25								
	Skipjack herring													28	12.38	28	12.38
	Total							239,207	5,341.55							344,880	6,355.45

Test	Species	Jan 27		Jan 28		Jan 29		Total		Jan 30		Jan 31		Feb 1		Total	
		No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
Test III	White bass									13	0.73					13	0.73
	Threadfin shad	113,987	2,209.57	30,704	556.13	18,348	359.14	163,039	3,124.84	19,529	312.70	26,680	575.06	24,300	547.54	70,509	1,435.30
	Gizzard shad	18,490	417.20	3,041	37.35	2,402	42.68	23,933	497.23	9,537	164.92	24,727	469.96	8,161	137.32	42,425	772.20
	Blue catfish	111	1.05	42	0.43	123	1.13	276	2.61	396	4.55	347	4.43	221	2.49	964	11.47
	Channel catfish	22	0.26	42	1.16	44	0.45	108	1.87	79	1.21	33	0.21	182	2.08	294	3.50
	Freshwater drum	22	0.26	34	4.30	26	1.13	82	5.89	7	0.24	22	2.74	47	2.42	76	5.40
	White crappie													40	0.42	40	0.42
	Miss. silverside	45	0.53	17	0.18	35	0.37	97	1.08			11	0.11	24	0.35	35	0.46
	Orangespotted sunfish					9	0.08	9	0.08								
	European carp			8	8.64			8	8.64								
	Green sunfish													8	0.07	8	0.07
	Longear sunfish											11	0.42			11	0.42
	Black bullhead													8	0.14	8	0.14
	Shortnose gar	1	2.00					1	2.00								
	Chestnut lamprey											11	1.27			11	1.27
	Total							187,553	3,644.24							114,394	2,231.38

*Biomass is presented in pounds

**Mean of two preceding test days

Table A-2 (Contd)

Test IV

Species	Air Curtain On: Feb 3 No.	Feb 3 Wt	Feb 4 No.	Feb 4 Wt	Feb 5 No.	Feb 5 Wt	Total No.	Total Wt	Air Curtain Off: Feb 6 No.	Feb 6 Wt	Feb 7 No.	Feb 7 Wt	Feb 8 No.	Feb 8 Wt	Total No.	Total Wt
Threadfin shad	17,990	411.29	23,943	457.10	24,202	460.09	66,135	1,328.48	14,852	274.93	41,834	875.88	225,045	3,568.10	281,731	4,718.91
Gizzard shad	4,260	67.10	6,015	92.93	3,650	52.25	13,925	212.28	8,046	172.13	26,841	408.25	19,782	476.17	54,669	1,056.55
Blue catfish	30	1.02	104	1.29	58	0.58	192	2.89	9	0.09	66	2.07	34	0.34	109	2.50
Channel catfish	90	4.60	299	3.35	320	2.89	709	10.84	282	4.12	142	1.42	34	0.34	458	5.88
Freshwater drum	30	0.10	46	1.51	80	4.56	156	6.17	38	6.04	22	0.13	34	5.05	94	11.22
White crappie			23	0.11	22	0.05	45	0.16								
Miss. silverside	10	0.10	23	0.22	7	0.05	40	0.37			44	0.39			44	0.39
Golden shiner											11	0.13			11	0.13
Skipjack herring					7	4.09	7	4.09			11	5.04			11	5.04
Green sunfish			23	0.33			23	0.33								
Longear sunfish	10	0.29					10	0.29								
Black bullhead											11	0.26			11	0.26
Total							81,247	1,565.90							337,138	5,800.88

Test V

Species	Air Curtain On: Feb 10 No.	Feb 10 Wt	Feb 11 No.	Feb 11 Wt	Feb 12 No.	Feb 12 Wt	Total No.	Total Wt	Air Curtain Off: Feb 13 No.	Feb 13 Wt	Feb 14 No.	Feb 14 Wt	Feb 15 No.	Feb 15 Wt	Total No.	Total Wt
Threadfin shad	685,912	14,311.91	930,743	18,162.35	441,081	10,461.47	2,057,736	42,935.73	322,479	6,583.02	243,829	6,001.05	143,106	3,044.82	759,414	15,628.89
Gizzard shad	41,842	617.80	39,833	647.38	43,850	588.02	125,525	1,853.20	52,565	1,078.02	18,765	250.82	6,090	147.05	77,420	1,475.89
Blue catfish			158	13.19			158	13.19	65	0.77	105	1.25	80	2.56	250	4.58
Channel catfish	172	2.61	158	1.89	185	3.32	515	7.82			105	0.63	107	0.96	212	1.59
Freshwater drum											53	0.63	53	8.33	106	8.96
Miss. silverside											53	0.63			53	0.63
Total							2,183,934	44,809.94							837,455	17,120.54

Test VI

Species	Air Curtain On: Feb 17 No.	Feb 17 Wt	Feb 18 No.	Feb 18 Wt	Feb 19 No.	Feb 19 Wt	Total No.	Total Wt	Air Curtain Off: Feb 20 No.	Feb 20 Wt	Feb 21 No.	Feb 21 Wt	Feb 22 No.	Feb 22 Wt	Total No.	Total Wt
Threadfin shad	163,817	3,278.30	232,509	4,878.26	229,822	5,611.24	626,148	13,767.80	188,603	4,056.95	142,400	3,236.81	162,514	4,351.64	493,517	11,645.40
Gizzard shad	3,376	70.34	4,739	64.27	2,364	57.29	10,479	191.90	1,913	40.59	3,016	80.33	5,052	63.64	9,981	184.56
Blue catfish	28	0.34	82	0.99			110	1.33			28	0.33	184	1.77	212	2.10
Channel catfish	28	0.34	124	0.49	284	1.70	436	2.53	68	1.23	166	0.66	258	1.33	492	3.22
Freshwater drum					47	1.70	47	1.70	205	1.23	55	0.33			260	1.56
White crappie					47	0.57	47	0.57			28	0.33	37	0.44	65	0.77
Miss. silverside	28	0.34					28	0.34			55	0.66	37	0.44	92	1.10
Golden shiner	28	0.34					28	0.34								
Longnose gar					1	2.50	1	2.50								
Total							637,324	13,969.01							504,619	11,838.71

*Biomass is presented in pounds

**Mean of two preceding test days

Table A-3

Numbers and Biomass* of Fish Species Impinged during Spring Air-Bubble Curtain Testing at Arkansas Nuclear One - Unit 1, April 21-May 31, 1975

Test I

Species	Air Curtain On								Air Curtain Off							
	Apr 21		Apr 22		Apr 23		Total		Apr 24		Apr 25		Apr 26		Total	
	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
White bass	34	0.80	9	0.61	40	8.15	83	9.56	23	0.87	17	2.35	13	0.34	53	3.56
Threadfin shad	13,061	230.44	2,685	49.80	1,597	27.57	17,343	307.81	1,015	55.10	986	17.00	617	17.69	2,618	89.79
Gizzard shad	5,594	194.60	1,264	54.13	1,256	50.96	8,114	299.69	2,153	50.51	1,870	85.00	2,459	88.37	6,482	223.88
Blue catfish	1,057	13.67	368	8.40	244	5.01	1,669	27.08	505	19.79	384	6.60	287	4.54	1,176	30.93
Channel catfish	1,723	24.47	736	13.55	625	12.13	3,084	50.15	781	19.79	853	19.99	1,225	10.97	2,859	50.75
Freshwater drum	8,719	396.31	2,295	129.90	1,150	76.86	12,164	603.07	1,497	106.76	884	57.80	754	63.18	3,135	227.74
White crappie	80	0.46	48	0.69	30	0.63	158	1.78	23	0.14	17	0.14	13	0.13	53	0.41
Golden shiner			4	0.04			4	0.04			10	0.27	13	0.04	23	0.31
Bluegill sunfish	23	0.11	4	0.09	7	0.43	34	0.63	5	0.05	3	0.03	4	0.04	12	0.12
Smallmouth buffalo											3	0.44			3	0.44
Black bullhead	11	0.34			7	0.17	18	0.51			7	0.14	4	0.04	11	0.18
River carpsucker					3	0.30	3	0.30					4	7.50	4	7.50
European carpsucker	11	11.48			3	4.38	14	15.86	5	4.59			4	10.45	9	15.04
Largemouth bass									5	0.14					5	0.14
Flathead catfish	11	0.11	9	0.09	3	0.03	23	0.23	5	0.14	7	0.14	4	0.13	16	0.41
Total							42,711	1,316.71							16,459	651.20

Test II

Species	Apr 28		Apr 29		Apr 30		Total		May 1		May 2		May 3		Total	
	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
White bass	5	0.15	2	0.09	7	0.36	14	0.60			3	3.10	6	0.33	9	3.43
Threadfin shad	81	1.56	170	2.86	25	0.43	276	4.85	51	0.74	16	0.25	6	0.12	73	1.11
Gizzard shad	1,523	82.88	742	32.22	585	23.01	2,850	138.11	851	34.79	660	30.79	470	24.19	1,981	89.77
Blue catfish	151	6.00	117	3.44	38	2.69	306	12.13	40	7.43	63	1.39	18	0.18	121	9.00
Channel catfish	474	14.17	227	10.31	174	7.48	875	31.96	193	7.83	95	2.18	68	2.62	356	12.63
Freshwater drum	524	54.20	383	27.80	269	18.77	1,176	100.77	272	19.86	88	7.90	74	11.54	434	39.30
White crappie	35	14.87	27	12.03	47	15.94	109	42.84	96	32.97	95	28.05	71	25.67	262	86.69
Golden shiner	20	0.15	9	0.21			29	0.36	11	0.06					11	0.06
Bluegill sunfish			7	0.44	5	0.18	12	0.62	11	1.99	9	1.11	12	0.39	32	3.49
Green sunfish									6	0.17					6	0.17
Longear sunfish					2	0.09	2	0.09	17	0.57			6	0.39	23	0.96
Black crappie	5	1.06			2	0.59	7	1.65			3	3.35			3	3.35
Smallmouth buffalo	5	3.78			5	7.90	10	11.68			3	4.93			3	4.93
European carp			2	2.06			2	2.06	6	7.09	3	3.76	9	9.85	18	20.70
Largemouth bass					5	1.29	5	1.29								
Arkansas River shiner											3	0.03			3	0.03
Flathead catfish													3	0.03	3	0.03
Total							5,673	349.01							3,338	275.65

*Biomass is presented in pounds

Table A-3 (Contd)

Test III — Species	Air Curtain On: May 5 No.	May 5 Wt	May 6 No.	May 6 Wt	May 7 No.	May 7 Wt	Total No.	Total Wt	Air Curtain Off: May 8 No.	May 8 Wt	May 9 No.	May 9 Wt	May 10 No.	May 10 Wt	Total No.	Total Wt
White bass			6	0.23	2	0.07	8	0.30	2	0.11	1	0.03	1	0.07	4	0.21
Threadfin shad	3	0.05	3	0.09	8	0.26	14	0.40	8	0.19	4	0.13	4	0.13	16	0.45
Gizzard shad	229	10.25	250	9.31	177	7.38	656	26.94	161	7.38	137	7.63	168	9.00	466	24.01
Blue catfish	16	1.13	18	0.19	18	0.59	52	1.91	20	0.44	13	1.06	6	0.08	39	1.58
Channel catfish	25	3.44	32	2.56	42	3.31	99	9.31	30	1.75	29	1.13	23	1.13	82	4.01
Freshwater drum	23	2.63	17	1.44	31	2.63	71	6.70	20	1.69	30	2.38	48	4.38	98	8.45
White crappie	50	12.25	67	14.63	73	11.69	190	38.57	50	13.63	41	6.19	92	7.50	183	27.32
Mississippi silverside									1	0.01	1	0.02	2	0.01	4	0.04
Golden shiner			1	0.01	4	0.04	5	0.05	2	0.01			2	0.04	4	0.05
Bluegill sunfish	4	0.13	9	0.54	20	0.92	33	1.59	4	0.33	8	0.98	5	1.04	17	2.35
Green sunfish					3	0.03	3	0.03			1	0.03	1	0.01	2	0.04
Longear sunfish			4	0.26	5	0.14	9	0.04	2	0.09	1	0.06	2	0.16	5	0.31
Warmouth					1	0.04	1	0.04								
Orangespotted sunfish					2	0.01	2	0.01			3	0.04			3	0.04
Smallmouth buffalo	2	2.75	2	3.75	1	1.38	5	7.88	5	9.13			3	5.38	8	14.51
Black bullhead	1	0.01	1	0.03			2	0.04			2	0.06			2	0.06
River carpsucker	1	2.00	1	2.00	1	1.69	3	5.69			1	1.50	2	1.63	3	3.13
European carp	2	3.44	2	2.20	4	8.50	8	14.14			2	2.94	1	1.25	3	4.19
Chestnut lamprey	2	0.20			3	0.27	5	0.47	4	0.44	8	0.88	2	0.22	14	1.54
Largemouth bass			1	0.10	1	0.10										
Bigmouth buffalo					2	2.81	2	2.81								
Total							1,168	116.92							953	92.29

Test IV — Species	Air Curtain On: May 12 No.	May 12 Wt	May 13 No.	May 13 Wt	May 14 No.	May 14 Wt	Total No.	Total Wt	Air Curtain Off: May 15 No.	May 15 Wt	May 16 No.	May 16 Wt	May 17 No.	May 17 Wt	Total No.	Total Wt
White bass	2	0.29	2	1.09	1	0.03	5	1.41	2	0.38	1	0.04			3	0.42
Threadfin shad	7	0.15	2	0.07	3	0.09	12	0.31	4	0.13	4	0.09	6	0.15	14	0.37
Gizzard shad	99	5.13	132	8.06	76	5.25	307	18.44	95	5.00	125	5.44	152	6.56	372	17.00
Blue catfish	36	1.75	33	0.94	5	0.18	74	2.87	9	0.39	8	0.01	7	0.04	24	0.53
Channel catfish	41	3.25	25	0.81	21	1.25	87	5.31	19	1.00	25	0.48	41	1.00	85	2.48
Freshwater drum	92	5.69	64	3.69	55	2.38	211	11.76	43	2.50	103	4.56	96	4.75	242	11.81
White crappie	226	12.25	495	9.44	293	6.44	1,014	28.13	203	4.69	279	6.75	202	10.25	684	21.69
Mississippi silverside	1	0.02					1	0.02					1	0.01	1	0.01
Golden shiner	7	0.06	5	0.05			12	0.11	4	0.04	2	0.02	6	0.06	12	0.12
Bluegill sunfish	13	1.28	6	0.49	2	0.11	21	1.88	9	0.69	11	0.19	7	0.11	27	0.99
Green sunfish			2	0.01			2	0.01	2	0.01	3	0.03			5	0.04
Longear sunfish			1	0.09	1	0.01	2	0.10			1	0.01	2	0.13	3	0.14
Warmouth			1	0.01	1	0.05	2	0.06			1	0.05	2	0.04	3	0.09
Orangespotted sunfish											1	0.01			1	0.01
Black crappie			2	2.20	2	2.20	6	0.21	4	0.16					10	0.37
Smallmouth buffalo	2	3.31	2	2.75			4	6.06	4	6.38					4	6.38
Black bullhead	1	0.18			1	0.38	2	0.56	1	0.01	1	0.01			2	0.02
River carpsucker	1	0.61	1	1.38	1	0.01	3	2.00			1	0.25			1	0.25
European carp	2	1.69	2	2.56	1	2.50	5	[illegible]			2	4.75	1	1.19	3	5.94
Chestnut lamprey	5	0.54	7	0.79	4	0.41	16	1.74	1	0.12	4	0.44	5	[illegible]	10	1.04
Arkansas River shiner	2	0.03			1	0.01	3	0.04								
Flathead catfish									1	0.01			2	[illegible]	3	[illegible]
Logperch					1	0.01	1	0.01	1	0.01					1	[illegible]
Total							[illegible]	[illegible].77							1,510	[illegible]

*Biomass is presented in pounds

Table A-3 (Contd)

Test	Species	Air Curtain On								Air Curtain Off							
		May 19		May 20		May 21		Total		May 22		May 23		May 24		Total	
		No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
Test V	White bass	1	0.20			1	0.03	2	0.23			2	0.63	4	2.69	6	3.32
	Threadfin shad	4	0.10	5	0.14	18	0.53	27	0.77	1	0.03	4	0.09	4	0.14	9	0.26
	Gizzard shad	78	5.88	51	4.25	97	7.06	226	17.19	73	5.25	49	3.44	40	3.00	162	11.69
	Blue catfish	13	0.52	10	0.46	16	0.19	39	1.17	12	0.13	4	0.04	2	0.02	18	0.19
	Channel catfish	17	0.73	35	1.63	48	1.63	100	3.99	37	0.38	23	0.25	26	0.38	86	1.01
	Freshwater drum	67	2.94	62	3.25	68	3.25	197	9.44	42	2.13	46	3.50	27	1.63	115	7.26
	White crappie	279	9.00	334	9.63	376	9.38	989	28.01	388	9.88	289	7.38	221	5.63	898	22.89
	Mississippi silverside													1	0.01	1	0.01
	Golden shiner	4	0.04	4	0.04	9	0.13	17	0.21	4	0.04	3	0.05			7	0.07
	Bluegill sunfish	7	0.36	7	0.29	12	0.30	26	0.95	9	0.31	4	0.11	2	0.08	15	0.50
	Green sunfish	1	0.13					1	0.13	1	0.01					1	0.01
	Longear sunfish	1	0.13			2	0.11	3	0.24								
	Warmouth	2	0.01			2	0.05	4	0.06	3	0.03			2	0.04	5	0.07
	Orangespotted sunfish			1	0.01	2	0.02	3	0.03			1	0.01			1	0.01
	Black crappie			3	0.39	3	0.06	6	0.45			1	0.11			1	0.11
	Smallmouth buffalo	1	1.50			1	1.75	2	3.25			1	0.34			1	0.34
	Black bullhead	1	0.01	1	0.02			2	0.03					1	0.03	1	0.03
	River carpsucker			1	1.19			1	1.19								
	European carp	1	1.25	2	3.00			3	4.25	2	2.06	2	2.00			4	4.06
	Chestnut lamprey	3	0.38	1	0.11			4	0.49			1	0.17			1	0.17
	Striped bass									1	0.19					1	0.19
	Arkansas River shiner			1	0.01			1	0.01								
	Flathead catfish					1	0.01	1	0.01								
	Goldeye									1	1.06					1	1.06
	Total							1,654	72.10							1,334	53.25
Test VI		May 26		May 27		May 28		Total		May 29		May 30		May 31		Total	
		No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
		← No Data →															

*Biomass is presented in pounds

Table A-4

Numbers and Biomass* of Fish Species Impinged during Summer Air-Bubble Curtain Testing at Arkansas Nuclear One - Unit 1, July 21-August 30, 1975

Test I

Species	Air Curtain On								Air Curtain Off							
	Jul 21		Jul 22		Jul 23		Total		Jul 24		Jul 25		Jul 26		Total	
	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
White bass	1	0.17			1	0.01	2	0.18			2	0.66	2	0.01	4	0.67
Threadfin shad	13	0.13	21	0.19	9	0.04	43	0.67	12	0.10	9	0.14	7	0.04	28	0.28
Gizzard shad	8	0.79	2	0.08	2	0.19	12	1.06	6	0.64	4	0.05	7	0.13	17	0.82
Blue catfish	6	0.28	7	0.98	6	0.94	19	2.20	8	0.97	2	0.24	6	1.09	16	2.30
Channel catfish	23	0.74	22	0.88	13	0.60	58	2.22	4	0.18	9	1.06	8	0.23	21	1.47
Freshwater drum	52	0.75	37	0.25	13	0.60	102	1.70	52	0.36	36	0.38	190	1.31	278	2.05
White crappie	8	1.09	3	0.73	5	0.41	16	2.23	4	0.31	5	0.41	6	2.00	20	2.72
Golden shiner	3	0.01					3	0.01	1	0.01	1	0.01	1	0.01	3	0.03
Bluegill sunfish	13	1.69	6	0.69	6	0.89	25	3.27	2	0.26	4	0.31	7	0.66	13	1.23
Green sunfish	1	0.08			1	0.05	2	0.13	1	0.14			1	0.08	2	0.22
Longear sunfish			1	0.10			1	0.10	2	0.10					2	0.10
Warmouth	1	0.11					1	0.11					1	0.08	1	0.08
Orangespotted sunfish	1	0.01					1	0.01								
Black crappie			1	0.04			1	0.04								
Skipjack herring											1	0.01			1	0.01
River carpsucker					1	0.98	1	0.98								
Smallmouth buffalo			1	1.19			1	1.19								
Largemouth bass					1	0.05	1	0.05	1	0.30	1	0.01			2	0.31
Striped bass			1	0.01			1	0.01								
Shortnose gar											1	1.13			1	1.13
Longnose gar									1	0.01					1	0.01
Arkansas River shiner			1	0.02			1	0.02								
Flathead catfish			3	0.53			3	0.53			2	0.01			2	0.01
Logperch	1	0.01					1	0.01								
Total							295	16.31							412	13.44

Test II

Species	Jul 28		Jul 29		Jul 30		Total		Jul 31		Aug 1		Aug 2		Total	
	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No	Wt	No.	Wt
White bass	2	0.05	3	0.03			5	0.08	2	0.02	7	0.05	8	1.69	17	1.76
Threadfin shad	21	0.16	9	0.04	6	0.13	36	0.33	16	0.14	114	0.38	263	0.81	393	1.33
Gizzard shad	6	0.51	2	0.01			8	0.52	15	0.39	45	0.47	40	1.06	100	1.92
Blue catfish	7	1.40	10	1.13	4	0.69	21	3.22	2	0.08	8	0.24	3	0.21	13	0.53
Channel catfish	3	0.13	8	0.34	9	0.21	20	0.68	5	0.20	14	0.18	18	0.31	37	0.69
Freshwater drum	345	4.38	189	1.38	76	1.13	610	6.89	231	1.75	1,586	11.19	905	6.31	2,722	19.25
White crappie	12	1.54	8	0.63	6	1.66	26	3.83	5	0.94	9	1.00	9	1.13	23	3.07
Mississippi silverside	1	0.01			1	0.01	2	0.02			2	0.01	1	0.01	3	0.02
Golden shiner	3	0.02					3	0.02	1	0.01			1	0.01	2	0.02
Bluegill sunfish	3	0.38	5	0.41	3	0.28	11	1.07	3	0.31	5	0.16	3	0.17	11	0.64
Longear sunfish	1	0.13	1	0.09			2	0.22	1	0.08	1	0.08			2	0.16
Warmouth											1	0.05			1	0.05
Orangespotted sunfish	2	0.03					2	0.03								
Skipjack herring					1	0.03	1	0.03								
Smallmouth buffalo	1	2.13					1	2.13								
Striped bass													1	0.01	1	0.01
Flathead catfish			2	0.04	1	0.01	3	0.05	2	0.19	3	0.01	1	0.01	6	0.21
Total							751	19.12							3,331	29.66

*Biomass is presented in pounds

Table A-4 (Contd)

		Air Curtain On								Air Curtain Off							
		Aug 4		Aug 5		Aug 6		Total		Aug 7		Aug 8		Aug 9		Total	
	Species	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
Test III	White bass	7	0.45	1	0.01	2	0.41	10	0.87			1	0.06	1	0.01	2	0.07
	Threadfin shad	106	0.75	48	0.31	62	0.31	216	1.37	56	0.16	60	0.38	108	0.50	224	1.04
	Gizzard shad	10	0.58	6	0.38	6	0.94	22	1.90	4	0.22	3	0.23	11	0.38	18	0.83
	Blue catfish	6	0.53	5	0.28	3	0.02	14	0.83	7	1.19	7	0.88	1	0.15	15	2.22
	Channel catfish	26	0.56	17	0.30	17	0.51	60	1.37	19	0.63	18	0.63	24	0.94	61	2.20
	Freshwater drum	561	4.25	301	2.63	173	2.38	1,035	9.26	99	0.88	87	0.94	85	0.69	271	2.51
	White crappie	8	0.55	8	0.50	6	0.63	22	1.68	8	1.69	9	1.94	5	0.10	22	3.73
	Mississippi silverside	2	0.01			1	0.01	3	0.02								
	Golden shiner									1	0.01					1	0.01
	Bluegill sunfish	5	0.08	4	0.16	4	0.40	13	0.64	1	0.13	8	0.42	3	0.17	12	0.72
	Green sunfish											1	0.02			1	0.02
	Longear sunfish	1	0.04	1	0.10			2	0.14								
	Warmouth													1	0.05	1	0.05
	Redear sunfish	1	0.13					1	0.13								
	River carpsucker			1	1.94			1	1.94								
	Largemouth bass			1	0.47			1	0.47								
	Striped bass	2	0.01	1	0.01			3	0.02	2	0.04	1	0.01	1	0.01	4	0.06
	Flathead catfish	1	0.06	1	0.01	1	0.01	3	0.08			2	0.03			2	0.03
	Total							1,406	20.72							634	13.49
		Aug 11		Aug 12		Aug 13		Total		Aug 14		Aug 15		Aug 16		Total	
	Species	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
Test IV	White bass	2	0.01	2	0.18	3	0.19	7	0.38	1	0.01	1	0.01			2	0.02
	Threadfin shad	33	0.24	16	0.08	73	0.38	122	0.70	48	0.31	53	0.25	39	0.44	140	1.00
	Gizzard shad	5	0.12			2	0.23	7	0.35	3	0.33	6	0.49	6	0.29	15	1.11
	Blue catfish	5	0.39	7	0.75	11	0.59	23	1.73	11	0.94	18	0.88	6	0.25	[illegible]	2.07
	Channel catfish	22	0.78	19	0.55	36	1.31	77	2.64	7	0.69	14	0.50	13	0.75	34	1.94
	Freshwater drum	58	0.42	26	0.39	33	0.69	117	1.50	34	0.28	21	0.31	18	0.63	73	1.22
	White crappie	4	0.02	5	0.69	6	1.44	15	2.15	8	0.69	4	0.75	6	0.59	18	2.03
	Mississippi silverside					1	0.02	1	0.02								
	Golden shiner	1	0.01					1	0.01	1	0.01	1	0.01			2	0.02
	Bluegill sunfish			7	0.75	7	0.59	14	1.34	6	0.69	4	0.02	1	0.51	11	1.22
	Longear sunfish	1	0.08					1	0.08	1	0.10	2	0.14	2	0.13	5	0.37
	Black crappie													2	0.39	2	0.39
	Largemouth bass			1	2.88			1	2.88								
	Arkansas River shiner									1	0.01					1	0.01
	Flathead catfish					1	0.22	1	0.22					2	0.29	2	0.29
	Total							387	14.00							340	11.69

* Biomass is presented in pounds

Table A-4 (Contd)

Test	Species	Air Curtain On								Air Curtain Off							
		Aug 18		Aug 19		Aug 20		Total		Aug 21		Aug 22		Aug 23		Total	
		No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
Test V	White bass	3	0.35	2	1.00	4	0.09	9	1.44	1	0.01	1	0.50	2	1.12	4	1.63
	Threadfin shad	45	0.44	45	0.44	64	0;62	154	1.50	47	0.44	53	0.37	43	0.37	143	1.18
	Gizzard shad	3	0.22			1	0.17	4	0.39	5	0.43	3	0.34	3	0.40	11	1.17
	Blue catfish	3	0.49	5	0.58	2	1.00	10	2.07	5	0.56	4	0.69	9	1.25	18	2.50
	Channel catfish	16	0.50	13	0.40	10	0.50	39	1.40	10	0.56	10	0.37	19	3.25	39	4.18
	Freshwater drum	24	0.26	18	0.17	6	0.07	48	0.50	1	0.08	2	0.02	3	0.02	6	0.12
	White crappie	4	0.75	6	0.94	3	1.94	13	3.63	5	0.88	2	0.29	11	1.56	18	2.73
	Golden shiner			1	0.01			1	0.01	1	0.01					1	0.01
	Bluegill sunfish	4	0.69	2	0.01	2	0.08	8	0.78	3	0.01	3	0.16	2	0.37	8	0.54
	Green sunfish													1	0.02	1	0.02
	Longear sunfish			2	0.18			2	0.18			1	0.12			1	0.12
	Warmouth											1	0.03			1	0.03
	Orangespotted sunfish			1	0.01	1	0.01	2	0.02								
	Black crappie					1	0.12	1	0.12								
	Skipjack herring											1	0.09			1	0.09
	River carpsucker					1	1.50	1	1.5								
	Largemouth bass			1	0.06	1	0.07	2	0.13								
	Striped bass			1	0.01			1	0.01								
	Total							295	13.68							252	14.32

Test	Species	Aug 25		Aug 26		Aug 27		Total		Aug 28		Aug 29		Aug 30		Total	
		No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt	No.	Wt
Test VI	White bass	6	0.09	3	0.19	3	0.04	12	0.32			3	0.38	4	1.69	7	2.07
	Threadfin shad	253	3.75	528	8.19	480	7.50	1,261	19.44	114	1.50	60	0.63	60	0.88	234	3.01
	Gizzard shad	4	0.88	6	0.69	11	1.69	21	3.26	4	0.39	7	0.97	7	0.58	18	1.94
	Blue catfish	10	6.31	3	0.19	5	0.72	18	7.22	7	1.44	3	0.51	6	1.10	16	3.05
	Channel catfish	10	0.27	10	0.23	13	0.50	33	1.00	15	0.75	12	3.50	16	0.44	43	4.69
	Freshwater drum	335	2.56	385	3.31	111	1.06	831	6.93	40	0.44	17	0.53	12	0.13	69	1.10
	White crappie	6	1.75	7	1.59	7	3.13	20	6.47	9	3.53	8	1.39	13	3.22	30	8.14
	Mississippi silverside											1	0.01			1	0.01
	Golden shiner					1	0.01	1	0.01					1	0.01	1	0.01
	Bluegill sunfish	2	0.01	4	0.21	2	0.01	8	0.23			3	0.33	1	0.06	4	0.39
	Green sunfish											1	0.04			1	0.04
	Longear sunfish	1	0.09	2	0.21	1	0.04	4	0.34								
	Skipjack herring			1	0.10	1	0.11	2	0.21	1	0.11	1	0.04			2	0.15
	Largemouth bass			1	0.65			1	0.65								
	Striped bass	2	0.53					2	0.53								
	Total							2,204	46.61							426	24.60

*Biomass is presented in pounds

Table A-5

Length-Frequency Distribution of Threadfin Shad Impinged during Air-Bubble Curtain Testing at Arkansas Nuclear One – Unit 1, October 21, 1974-August 25, 1975

Season	Length (mm)	Air Curtain On – Run/Date I	II	III	IV	V	VI	No. Measured Each Length	Air Curtain Off – Run/Date I	II	III	IV	V	VI	No. Measured Each Length
Fall		10/21	10/28	11/4	11/11	11/18	11/25		10/21	10/28	11/4	11/11	11/18	11/25	
	0-30														
	31-60	20	16	24	29	14	9	112	33	12	34	14	2	10	105
	61-90	69	49	228	344	246	260	1,196	159	70	378	261	189	104	1,161
	91-120	5		4	88	79	62	238	10	4	34	77	109	36	270
	121-150		1			1		2	1	1			3		5
	No. of Fish Measured	94	66	256	461	340	331	1,548	203	87	446	352	303	150	1,544
Winter		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17	
	0-30														
	31-60	2						2			1	1		1	3
	61-90	115	28	51	23	3	36	256	50	71	29	45	40	26	261
	91-120	113	144	146	120	35	191	749	224	65	11	139	185	175	799
	121-150	1	37	15	9	12	10	84	14	13	17	8	9	23	84
	151-180										1				1
	181-210				3			3							
	211-240				2			2							
	No. of Fish Measured	229	211	212	157	50	237	1,096	288	149	59	193	234	225	1,148
Spring		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26	
	0-30						Insufficient Data							Insufficient Data	
	31-60		1					1							
	61-90	4	2			1		7	6	1					7
	91-120	78	38	10	10	21		157	63	14	13	12	4		106
	121-150	14	5	3	2	5		29	11	1	1	2	5		20
	151-180														
	181-210			1				1							
	No. of Fish Measured	96	46	14	12	27		195	80	16	14	14	9		133
Summer		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25	
	0-30														
	31-60	20	19	36	27	15	3	120	15	55	38	19	15	10	152
	61-90	18	13	15	13	17	51	157	9	9	15	12	19	27	91
	91-120	4	1	1	3	6	31	46		1		3	4	16	24
	121-150	3	3	2		2	3	13	3	2	2	2	1	3	13
	151-180				1			1							
	No. of Fish Measured	45	36	54	44	40	88	307	27	68	55	36	39	56	281

Table A-6

Length-Frequency Distribution of Gizzard Shad Impinged during Air-Bubble Curtain Testing at Arkansas Nuclear One – Unit 1, October 21, 1974-August 25, 1975

	Length (mm)	Air Curtain On – Run/Date I	II	III	IV	V	VI	No. Measured Each Length	Air Curtain Off – Run/Date I	II	III	IV	V	VI	No. Measured Each Length
Fall		10/21	10/28	11/4	11/11	11/18	11/25		10/21	10/28	11/4	11/11	11/18	11/25	
	0-30														
	31-60	4	7	2				13	5	4	1	13			23
	61-90	80	73	79	44	31	42	349	110	105	75	40	36	33	299
	91-120	8	9	11	15	59	54	156	20	7	10	41	49	19	116
	121-150			2		1	5	8	2		1	1	1		5
	151-180		1				2	3			2				2
	181-210	1	4	2			4	11	4	1	2				7
	211-240	5	4	3			4	16	1	1	1				3
	241-270			1			1	2			1				1
	271-300										1				1
	301-330										1				1
	331-360														
	No. of Fish Measured	98	98	100	59	91	112	558	142	118	95	95	86	52	588
Winter		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17	
	0-30														
	31-60			1	1		1	3			1	1			2
	61-90	18	22	17	7	16	10	90	2	16	29	11	8	16	82
	91-120	69	57	49	82	64	47	368	32	58	84	92	72	45	383
	121-150	4	17	21	3	5	8	58	46	6	9	8	8	5	82
	151-180			1		1		2				2	2		4
	181-210	2	1	4	3	8	1	19	1	2	13	10	2	1	29
	211-240	2	6	6	4	5	1	24	1	3	6	7	2	3	22
	241-270		1					1				1			1
	271-300														
	301-330														
	331-360														
	361-390														
	391-420		1					1							
	No. of Fish Measured	95	105	99	100	99	68	566	82	85	142	132	94	70	605
Spring		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26	
	0-30						Insufficient Data							Insufficient Data	
	31-60														
	61-90	1	1			1		3		1					1
	91-120	37	24	15	11	13		100	37	16	18	20	4		95
	121-150	33	35	42	32	18		160	37	38	39	34	16		164
	151-180	1	4	4	1	4		14	2	4	1	4	3		14
	181-210	3	11	9	10	6		39	6	9	6	7	7		35
	211-240	8	6	8	16	13		51	7	10	9	10	10		46
	241-270	1		1		1		3			1	1	2		4
	271-300		1			1		2			1				1
	No. of Fish Measured	84	82	79	70	57		372	89	78	75	76	42		360
Summer		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25	
	0-30														
	31-60			2	3		1	6	5	13	5	3	1		27
	61-90	3	3	8	1	1		16	4	17	6	5	1	1	34
	91-120								2	2	1		2	2	9
	121-150		1	1				2	1		1			2	4
	151-180	3	1	2	1	1	1	9		3	1	3	2	1	10
	181-210	1	1	3			9	14	2		2		2	4	10
	211-240	5	2	4	2	2	9	24			2	4	2	4	12
	241-270	2		1			1	4		2			1	2	5
	271-300			1				1							
	No. of Fish Measured	14	8	22	7	4	21	76	14	37	18	15	11	16	111

Table A-7

Length-Frequency Distribution of Blue Catfish Impinged during Air-Bubble Curtain Testing at Arkansas Nuclear One - Unit 1, October 21, 1974-August 25, 1975

		Air Curtain On							Air Curtain Off						
		Run/Date							Run/Date						
	Length (mm)	I 10/21	II 10/28	III 11/4	IV 11/11	V 11/18	VI 11/25	No. Measured Each Length	I 10/21	II 10/28	III 11/4	IV 11/11	V 11/18	VI 11/25	No. Measured Each Length
Fall	0-30														
	31-60	4	1	1	2	2	2	12			2	6	1	1	8
	61-90	24	28	9	30	37	95	223	20	12	28	39	19	20	138
	91-120	28	15	7	9	33	59	151	18	8	11	26	14	34	111
	121-150		1	1	1			3			4	1			5
	151-180	1	3			1	1	6	4	3	1	1	1	1	11
	181-210	1					1	2	1	2	3	1		1	8
	211-240	1						1							
	241-270														
	271-300								1			1			2
	301-330														
	331-360														
	361-390														
	391-420														
	421-450														
	451-480														
	481-510														
	511-540														
	541-570	1						1							
	No. of Fish Measured	60	48	18	42	73	158	399	44	25	49	75	35	57	283
Winter		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17	
	0-30														
	31-60				1			1			3	4			7
	61-90	1	1	10	7	1	1	21		1	28	2	2	2	35
	91-120	1	3	14	11		2	31			43	1	3	4	51
	121-150										1				1
	151-180				1			1					1		1
	181-210		1					1							
	No. of Fish Measured	2	5	24	20	1	3	55		1	75	7	6	6	95
Spring		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26	
	0-30		1				Insufficient Data	1						Insufficient Data	
	31-60	1	1					2							
	61-90	25	28	11	9	17		90	24	11	8	13	6		62
	91-120	31	17	30	10	18		106	35	18	25	4	22		104
	121-150	1	3	4		1		9	2			4			6
	151-180	2	3	2				7	2	1	4	2			9
	181-210	1	1	2	1	1		6	3	2	1	1			7
	211-240		3	2	2	3		10			1				1
	241-270				1			1							
	271-300		1		1			2							
	301-330	1	1					2	2		1				3
	331-360			1				1							
	361-390	1	1					2	2						2
	391-420									1					1
	No. of Fish Measured	63	60	52	24	40		239	70	33	40	24	28		195
Summer		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25	
	0-30														
	31-60	1			1			2		2				1	3
	61-90		4	[illegible]	12		2	27	1	7	2	23	4		37
	91-120	1			1			2				1			1
	121-150	4			1		1	6	1			1			2
	151-180	5	3	2		2	1	13	3	2	4	2	2	1	14
	181-210	1	6	1	2	3	4	17	2	1	4	4	3	5	19
	211-240	3	3	1	3	4	6	20	5	1	4	1	5	4	20
	241-270	4	4	1	3		1	13	3			2	4	3	12
	271-300		1					1			1	1		2	4
	301-330						1	1							
	331-360					1		1							
	361-390														
	391-420						1	1							
	421-450														
	451-480														
	481-510														
	511-540														
	541-570														
	571-600						1	1							
	No. of Fish Measured	19	21	14	23	10	18	105	15	13	15	35	18	16	112

Table A-8

Length-Frequency Distribution of Channel Catfish Impinged during Air-Bubble Curtain Testing at Arkansas Nuclear One - Unit 1, October 21, 1974-August 25, 1975

Season	Length (mm)	Air Curtain On, Run/Date I	II	III	IV	V	VI	No. Measured Each Length	Air Curtain Off, Run/Date I	II	III	IV	V	VI	No. Measured Each Length
Fall		10/21	10/28	11/4	11/11	11/18	11/25		10/21	10/28	11/4	11/11	11/18	11/25	
	0-30														
	31-60	2	4	7	14		4	31	4	7	6	1	1		19
	61-90	7	20	18	15	15	12	107	26	25	14	6	10	16	97
	91-120	10	6	6	2			24	9	9	4	1			23
	121-150	27	12	13	1	2	3	58	23	16	8	2	1	1	51
	151-180	1	2	2	2			7	3	2	1			1	7
	181-210	4	3	2	3			12	2	1	4				7
	211-240	2		2	1			5	1	1	1				3
	241-270	2		1	1			4		1					1
	271-300								1			2			3
	301-330	1	1		1			3	1						1
	331-360														
	361-390														
	391-420														
	421-450			1				1							
	No. of Fish Measured	56	48	52	40	17	39	252	70	63	38	12	12	18	212
Winter		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17	
	0-30														
	31-60											1	1	1	3
	61-90	2	7	7	20	2	10	48		1	31	34	5	13	84
	91-120		1	2	4			7			3	4			7
	121-150		2	1	1	1		5	1	1	3	3		1	9
	151-180				1			1			1	1			2
	181-210			1				1							
	211-240														
	241-270											1			1
	271-300				1			1							
	No. of Fish Measured	2	10	11	27	3	10	63	1	2	38	44	6	15	106
Spring		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26	
	0-30						Insufficient Data							Insufficient Data	
	31-60	5	1		1	1		8	4	1	1	2			8
	61-90	31	31	11	21	29		123	33	11	9	36	51		140
	91-120	20	4	7	6	1		38	12	6	4		3		25
	121-150	14	22	20	14	3		73	26	17	16	8	2		69
	151-180	3	4	3	3	1		20		2	5	3			10
	181-210		1	2	1	1		5	1			1	1		3
	211-240		3		1			4	1	1		3	2		7
	241-270	1			3	1		5	1	1	2	2			6
	271-300		1			1		2			1				1
	301-330	2			1			3			1				1
	331-360		1			2		3							
	361-390			2				2							
	391-420		1					1							
	421-450			1				1	1						1
	451-480														
	481-510														
	511-540			1				1							
	No. of Fish Measured	76	68	47	57	40		288	77	39	39	55	59		271
Summer		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25	
	0-30														
	31-60	1	1	5	3		3	13		7	2	2		2	13
	61-90	5	6	18	16	13	11	69	7	16	23	7	11	14	78
	91-120	27	4	16	7	10	5	69	6	4	14	7	5	6	42
	121-150	13	4	15	11	7	8	58	4	8	9	13	9	12	55
	151-180	7	4	6	8	7	3	35	2	2	7	1	6	5	23
	181-210	3	1		1	1	3	9	1		4	1	3	3	12
	211-240	3			2			5			1	3	1		5
	241-270				1	1		2					1		1
	271-300										1				1
	301-330														
	331-360								1						1
	361-390														
	391-420														
	421-450				1			1							
	451-480														
	481-510														
	511-540												1		1
	541-570														
	571-600													1	1
	No. of Fish Measured	59	20	60	50	39	33	261	21	37	61	34	37	43	233

Table A-9

Length-Frequency Distribution of Freshwater Drum Impinged during Air-Bubble Curtain Testing at Arkansas Nuclear One - Unit 1, October 21, 1974-August 25, 1975

Season	Length (mm)	Air Curtain On – Run/Date I	II	III	IV	V	VI	No. Measured Each Length	Air Curtain Off – Run/Date I	II	III	IV	V	VI	No. Measured Each Length
Fall		10/21	10/28	11/4	11/11	11/18	11/25		10/21	10/28	11/4	11/11	11/18	11/25	
	0-30														
	31-60	7	7	5	13	4	7	43	7	1	6	17	1	3	35
	61-90	36	17	18	24	63	83	241	24	8	18	59	21	26	156
	91-120	8	4	4	1	14	22	53	1	8	7	16	3	4	39
	121-150	1	2	2	1	2		8	2		3	4			9
	151-180	1			1	1	5	9		2	2			2	6
	181-210	1		2	1	1	1	6	1			1	1		3
	211-240		1	1				2	2	1	2			1	6
	241-270		1	1	3		2	7	1		3	2	3		9
	271-300		2	1	3		2	[illegible]	1		2	1			4
	301-330						1	1							
	331-360	1		1				2							
	361-390														
	391-420									1					1
	No. of Fish Measured	55	34	36	47	85	123	380	39	21	43	100	29	36	268
Winter		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17	
	0-30														
	31-60														
	61-90		2	3	15	1		21				1		2	3
	91-120		2	2				4			3	2	1	5	10
	121-150			1	1		1	3			2	1		1	4
	151-180				1			1			2				2
	181-210			1				1		2		1			3
	211-240											2	2		4
	241-270										1				1
	271-300			1				1			1				1
	301-330		1		1			2		1					1
	No. of Fish Measured		5	8	18	1	1	33		3	8	7	3	8	29
Spring		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26	
	0-30						Insufficient Data							Insufficient Data	
	31-60														
	61-90	18	3	3	2			26	5		1	3			9
	91-120	21	12	8	23	23		87	21	10	9	30	31		101
	121-150	30	40	18	13	15		116	34	12	11	14	9		80
	151-180	11	13	5	7	4		40	10	5	10	6	4		35
	181-210	7	8	8	3	3		29	6	10	3	4	1		24
	211-240	1		3	2	4		10	2	2	2		1		7
	241-270	1		2	2	1		6	2	4	2	2	1		11
	271-300	1		1				2				1			1
	301-330		2	2				4	1		2		1		4
	331-360				1			1		1			1		2
	361-390														
	391-420														
	421-450														
	451-480											1			1
	No. of Fish Measured	90	78	50	53	50		321	81	44	40	61	49		275
Summer		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25	
	0-30														
	31-60	8	15	13	11	11	12	70	7	21	12	17		8	65
	61-90	24	53	62	29	32	55	255	37	77	52	26	4	23	219
	91-120	1		5	8	6	13	34	1	1	3	3	1	7	16
	121-150	1					1	2		1					1
	151-180		1	1			1	3	2				1		3
	181-210		1		2			3			1			3	4
	211-240	2						2		1	1	1			3
	241-270	1	1	2	1			5							
	271-300											1			1
	301-330														
	331-360		1	1				2							
	No. of Fish Measured	37	73	84	51	49	83	376	47	101	69	48	6	41	312

Table A-10

Length-Frequency Distribution of White Crappie Impinged during Air-Bubble Curtain Testing at Arkansas Nuclear One - Unit 1, October 21, 1974-August 25, 1975

		Air Curtain On							Air Curtain Off						
		Run/Date							Run/Date						
	Length (mm)	I 10/21	II 10/28	III 11/4	IV 11/11	V 11/18	VI 11/25	No. Measured Each Length	I 10/21	II 10/28	III 11/4	IV 11/11	V 11/18	VI 11/25	No. Measured Each Length
Fall	0-30														
	31-60	7		1			13	21	9			2	1	7	19
	61-90	21	20	8	6	6	39	100	29	5	17	10	14	12	87
	91-120		1	1				2	4						4
	121-150	1	1				1	3	3		1				4
	151-180	3	4	3	1		2	13	4	1	5	2			12
	181-210	1	1	2	2		1	7	7	4	1	1			13
	211-240		1					1	2						2
	241-270	3	1	1	1			6	2		1				3
	271-300	1	1					2	1		2				3
	301-330	1						1		1	1				2
	331-360	1						1							
	No. of Fish Measured	39	30	16	10	6	56	157	61	11	28	15	15	19	149
		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17	
Winter	0-30														
	31-60														
	61-90	1			5		1	7			5			1	6
	91-120													1	1
	121-150														
	151-180														
	181-210	2						2	1						1
	No. of Fish Measured	3			5		1	9	1		5			2	8
		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26	
Spring	0-30						Insufficient Data							Insufficient Data	
	31-60	2	3	1				6		3					3
	61-90	21	14	15	47	47		144	12	31	15	48	40		146
	91-120	1	1	5	22	26		55	1	5	3	19	32		60
	121-150	1	2	5	4			12		1	4	2	1		8
	151-180	1	2	5	1	3		12		5	5	6	3		19
	181-210	1	4	5	5	4		19		5	11	1	1		18
	211-240			2				2		3	2	1	2		8
	241-270		1	5	4	2		12		5	1	2	1		9
	271-300		9	3				12		9	4	1			14
	301-330		4	3		1		8		4		1	2		7
	331-360										1				1
	361-390					1		1							
	No. of Fish Measured	27	40	49	83	84		283	13	71	46	81	82		293
		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25	
Summer	0-30														
	31-60	4	6	4	5	1	1	21	4	9	5	1	1		20
	61-90	2	4	5	3	1	4	19	3	4	3	2		2	14
	91-120	1	1	4		2	1	9	2	2	1	3	3	3	14
	121-150	5	3	3	1	1		13	2	1	1	3	6	6	19
	151-180		4	1			1	6	2	1	2	4	1	3	13
	181-210	1	3	2	3	2	2	13	4		3	4	3	2	16
	211-240	1	1	3	1	2	4	12		3	4		2	6	15
	241-270		3			1	3	7		1	1		1	3	6
	271-300	2			1	2	2	7	1		1	1	1	3	7
	301-330		1			1	2	4	1	2	1			2	6
	331-360				1			1							
	No. of Fish Measured	16	26	22	15	13	20	112	19	23	22	18	18	30	128

Table A-11

Length-Frequency Distribution of White Bass Impinged during Air-Bubble Curtain Testing at Arkansas Nuclear One - Unit 1, October 21, 1974-August 25, 1975

Season	Length (mm)	Air Curtain On							Air Curtain Off						
		Run/Date							Run/Date						
		I 10/21	II 10/28	III 11/4	IV 11/11	V 11/18	VI 11/25	No. Measured Each Length	I 10/21	II 10/28	III 11/4	IV 11/11	V 11/18	VI 11/25	No. Measured Each Length
Fall	0-30														
	31-60														
	61-90	6			5	4		15	1	1	4	4			10
	91-120	24	12	3	8	5	8	60	9	5	17	7	8	6	52
	121-150	15	7	3	1	4	4	34	11	4	5	1		1	22
	151-180	5	2					7	4	4	7				15
	181-210	1	1	1				3	1						1
	211-240								1						1
	241-270		1					1		1					1
	271-300										1				1
	301-330			1				1			1				1
	No. of Fish Measured	51	23	8	14	13	12	123	27	15	35	12	8	7	104

Season	Length (mm)	I 1/13	II 1/20	III 1/2	IV 2/3	V 2/10	VI 2/17		I 1/13	II 1/20	III 1/27	IV 2/3	V 2/10	VI 2/17	
Winter	0-30														
	31-60														
	61-90														
	91-120		1					1			1				1
	121-150							1		1					1
	151-180									1	1				2
	No. of Fish Measured		1					1		2	2				4

Season	Length (mm)	I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26		I 4/21	II 4/28	III 5/5	IV 5/12	V 5/19	VI 5/26	
Spring	0-30														
	31-60														
	61-90														
	91-120	6		4		1		11							
	121-150	10	3	4	1			18	7		1	1			9
	151-180				1			1	5	2	2	1	0		10
	181-210				1	1		2			1				1
	211-240				1		Insufficient Data	1					1	Insufficient Data	1
	241-270											1	1		2
	271-300												2		2
	301-330				1			1	1				1		2
	331-360									1			1		2
	361-390														
	391-420	1						1							
	421-450														
	451-480														
	481-510														
	511-540														
	541-570														
	571-600		1					1							
	No. of Fish Measured	17	4	8	5	2		36	13	3	4	3	6		29

Season	Length (mm)	I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25		I 7/21	II 7/28	III 8/4	IV 8/11	V 8/18	VI 8/25	
Summer	0-30														
	31-60		1	1	3	1	2	8		4			1		5
	61-90	1	3	6	1	2	6	19	3	10	1	2		3	19
	91-120		1		1		3	5		2				1	3
	121-150			1				1			1				1
	151-180														
	181-210	1			1			2							
	211-240					3		3							
	241-270			2		2	1	5					2	1	3
	271-300				1	1		2						1	1
	301-330								1						1
	331-360												1	1	2
	361-390									1					1
	No. of Fish Measured	2	5	10	7	9	12	45	4	17	2	2	4	7	36

Table A-12

Environmental Parameters Recorded at Arkansas Nuclear One Intake Canal during Fall Air-Bubble Curtain Testing, October 21-November 30, 1974

Run	Test Date	Air-Bubble Curtain Status	Water Temperature (°F)	Air Temperature (°F)	Turbidity (JTU)	Wind Direction	Wind Velocity (mph)	% Cloud Cover	Rainfall (in.)
I	Oct 21	On	65	49	10	S	slight	10	0
	22	On	65	53	-	-	-	0	0
	23	On	65	47	-	-	calm	0	0
	24	Off	64	50	-	W-NW	slight	15	0
	25	Off	63	67	-	-	calm	100	0
	26	Off	63	57	-	S	0-12	85	0.03
II	Oct 28	On	65	59	45	W	slight	100	0.05
	29	On	65	65	-	S	slight	80	1.35
	30	On	65	71	-	SE	moderate	100	0
	31	Off	65	71	-	W	moderate	100	0
	Nov 1	Off	65	63	-	SE	moderate	100	1.84
	2	Off	67	63	-	-	moderate	65	0
III	Nov 4	On	65	60	25	W	strong	100	1.75
	5	On	65	44	-	S	slight	0	0
	6	On	64	42	-	NE	moderate	0	0
	7	Off	62	39	-	E	slight	100	0
	8	Off	62	44	-	E	slight	15	0
	9	Off	60	47	-	E	slight	100	0
IV	Nov 11	On	60	59	-	SW	moderate	5	1.5
	12	On	59	45	68	W	15	0	0
	13	On	56	36	-	W	12	15	0
	14	Off	56	37	-	N	0-12	15	0
	15	Off	55	26	-	W	0-8	0	0
	16	Off	55	43	-	NE	0-3	100	0.01
V	Nov 18	On	53	48	85	W	4	100	1.5
	19	On	53	54	-	W	<2	100	0.01
	20	On	54	45	-	NW	0-14	0	0
	21	Off	54	32	-	SW	12	0	0
	22	Off	55	37	-	S	8	0	0
	23	Off	55	64	-	SE	4	100	0.05
VI	Nov 25	On	54	35	110	NE	2-5	0	0
	26	On	53	33	-	S	8	0	0
	27	On	53	41	-	W	5	0	0
	28	Off, No data							
	29	Off	52	42	-	NW	5-8	100	<1
	30	Off	51	29	-	NW	15	100	0.91

Table A-13

Environmental Parameters Recorded at Arkansas Nuclear One Intake Canal during Winter Air-Bubble Curtain Testing, January 13-February 22, 1975

Run	Test Date	Air Bubble Curtain Status	Water Temperature (°F)	Air Temperature (°F)	Turbidity (JTU)	Wind Direction	Wind Velocity (mph)	% Cloud Cover	Rainfall (in.)
I	Jan 13	On	43	13	28	N-NW	0-12	15	0
	14	On	43	22	-	W-SW	0-12	5	0
	15	On	No data						
	16	Off	43	34	-	-	-	0	0
	17	Off	42	33	-	E	8-12	100	0
	18	Off	43	39	-	-	calm	100	<0.1
II	Jan 20	On	42	24	40	NE	8	10	0
	21	On	42	26	-	E	10-20	5	0
	22	On	42	35	-	S	8	0	0
	23	Off	42	20	-	S	12	15	0
	24	Off	42	30	-	SW	12	60	0
	25	Off	42	41	-	W	20	90	0.16
III	Jan 27	On	43	47	-	W	10	100	0
	28	On	44	49	-	S	12	10	0
	29	On	45	68	-	S-SW	10-20	95	0
	Jan 30	Off	46	50	-	E-NE	12	100	0
	31	Off	47	54	-	N-NE	12	100	0.86
	Feb 1	Off	47	45	-	NE	12	100	1.03
IV	Feb 3	On	47	42	-	NE	12	100	0.34
	4	On	47	44	-	SE	12	100	0.50
	5	On	48	47	-	N	10-15	100	0.49
	6	Off	47	22	-	W	15	100	0.13
	7	Off	45	16	-	W	12-15	15	0
	8	Off	45	24	-	NE	12	20	0
V	Feb 10	On	43	22	48	S	15	40	0
	11	On	44	45	-	NW	8	100	0
	12	On	43	40	-	NW	15	100	0
	13	Off	44	26	-	SE	10	100	0
	14	Off	44	38	-	S-SE	12	15	0
	15	Off	46	53	-	N	14	10	0
VI	Feb 17	On	44	32	-	SW	12	95	0.15
	18	On	45	40	-	N	14	100	0
	19	On	45	29	-	NW	10	0	0
	20	Off	45	27	-	N-NE	8	0	0
	21	Off	45	44	-	S	12	100	0
	22	Off	46	54	-	S	10	100	0

Table A-14

Environmental Parameters Recorded at Arkansas Nuclear One Intake Canal during Spring Air-Bubble Curtain Testing, April 21-May 31, 1975

Run	Test Date	Air-Bubble Curtain Status	Water Temperature (°F)	Air Temperature (°F)	Turbidity (JTU)	Wind Direction	Wind Velocity (mph)	% Cloud Cover	Rainfall (in.)
I	Apr 21	On	61	42	10	E-SE	12	0	0
	22	On	62	49	-	NE	8	5	0
	23	On	63	68	-	S	10	100	0.08
	24	Off	64	70	-	S-SW	8	80	0
	25	Off	65	68	-	S-SW	0-4	90	1.4
	26	Off	68	70	-	NE	5-8	70	0
II	Apr 28	On	68	62	18	S	8	100	0.42
	29	On	69	58	-	E	10	100	0
	30	On	70	60	-	S	5-8	10	0.03
	May 1	Off	70	60	-	NE	4	10	0
	2	Off	72	58	-	E	12	100	0
	3	Off	69	60	-	SW	8-10	100	1.7
III	May 5	On	72	60	15	NE	0-5	25	0
	6	On	74	68	-	S-SE	0-10	30	0
	7	On	73	68	-	S	10	100	1.5
	8	Off	No data						
	9	Off	72	65	-	S	4	90	1.25
	10	Off	73	59	-	E	5-10	15	1.5
IV	May 12	On	72	62	-	NW	8	0	0
	13	On	75	57	32	SW	12	60	0
	14	On	73	63	-	E	12	100	0
	15	Off	72	63	-	NW	8	85	0.71
	16	Off	73	53	-	NE	5-8	30	0
	17	Off	73	54	-	W	5-10	0	0
V	May 19	On	76	66	-	W	8	50	0
	20	On	75	75	-	S	10-15	80	0
	21	On	76	64	-	S	5-10	100	0.75
	22	Off	77	68	-	S	8-12	0	0
	23	Off	79	71	-	S	5-10	25	0
	24	Off	80	70	-	SW	3-5	95	0
VI	May 26	No data							
	27	On	78	65	25	NE	3-5	80	0.09
	28	On	79	67	-	SE	10	100	0.27
	29	On	79	66	-	E	10-12	80	0.44
	30	On	78	68	-	NE	3-5	5	0
	31	Off	77	-	-	-	-	-	-

Table A-15

Environmental Parameters Recorded at Arkansas Nuclear One Intake Canal during Summer Air-Bubble Curtain Testing, July 21-August 30, 1975

Run	Test Date	Air-Bubble Curtain Status	Water Temperature (°F)	Air Temperature (°F)	Turbidity (JTU)	Wind Direction	Wind Velocity (mph)	% Cloud Cover	Rainfall (in.)
I	Jul 21	On	86	77	-	SW	2	35	0.03
	22	On	86	75	-	W	4	20	0.05
	23	On	89	76	-	S	10	10	0
	24	Off	88	76	-	SW	10	80	0
	25	Off	87	78	-	E	0	90	0
	26	Off	86	74	-	E	10	95	0.1
II	Jul 28	On	87	74	18	SE	5	100	0
	29	On	88	70	-	SE	5-10	0	0
	30	On	88	79	-	E	15	75	0
	Jul 31	Off	86	72	-	E	10	80	0
	Aug 1	Off	85	72	-	NW	3	100	0.02
	2	Off	84	74	-	W	10	100	0.15
III	Aug 4	On	84	66	17	NE	3	0	0.72
	5	On	85	66	-	NE	9	0	0
	6	On	85	69	-	NW	2	0	0
	7	Off	85	69	-	E	12	5	0
	8	Off	85	64	-	E-SE	10	5	0
	9	Off	84	66	-	E	10	0	0
IV	Aug 11	On	83	68	11	SE	8	0	[illegible]
	12	On	85	70	-	E	5	0	[illegible]
	13	On	86	74	-	E	8	0	0
	14	Off	86	76	-	SW	5	40	0
	15	Off	85	71	-	SW	8	85	0.75
	16	Off	85	71	-	W	12	100	1.23
V	Aug 18	On	84	74	14	W	3-5	50	0.20
	19	On	84	71	-	SW	5	100	0.02
	20	On	84	69	-	NW	5	5	0
	21	Off	84	75	-	NE	2	0	0
	22	Off	84	72	-	NW	3	0	0
	23	Off	84	77	-	NE	3	0	0
VI	Aug 25	On	83	75	16	SE	5	40	0
	26	On	-	71	-	S	5	100	0.05
	27	On	83	72	-	S	5	20	0
	28	Off	85	75	-	NE	5-8	0	0
	29	Off	84	72	-	S	10	90	0
	30	Off	83	70	-	S	12	100	0.5