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POWER PLANT ENTRAINMENT SIMULATION UTILIZING A CONDENSER TUBE SIMULATOR

Annual Report
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Prepared for
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NOTICE

ABSTRACT

Striped bass, *Gammarus* and *Neomysis* from the Hudson River estuary were subjected to passage through a condenser tube simulator at various combinations of temperatures, flow rate and biocide concentration. Striped bass yolk sac stages were more susceptible to all stressors than older larval fish. The youngest larvae exhibited 50% mortality immediately after 10 minute exposures to temperatures above 31°C; for older larvae this was observed at temperatures above 33°C. Flow rates above 2 meters per second (mps) through the condenser tube resulted in an initial 30% mortality of yolk sac larvae, while 16 day old larvae displayed no initial mortality at flow rates as high as 3.0 mps. At biocide concentrations greater than 1.0 parts per million (ppm) of residual chlorine, more than half the yolk sac larvae died immediately after a 10 minute exposure. At chlorine doses as high as 2.7 ppm, 31 day old fish survived at a rate of at least 70%; among certain groups, 100% survival was observed. However, latent (24 h) survival of these fish was reduced to 0% at a dose of 1.57 ppm. For mixed populations of G. *tigrinus* and G. *daiberi*, thermal doses above 39°C for both 10 and 30 minute exposures were lethal. When *Neomysis americana* was subjected for 10 and 30 minutes to temperatures above 34°C, 24 h mortalities were greater than 50%. Flow rates of 1.0, 2.0 and 3.0 mps had no detectable effect upon either *Gammarus* or *Neomysis*. Ten minute exposures to residual chlorine concentrations above 1.4 ppm resulted in greater than 50% latent mortality for the amphipod. *Neomysis americana* displayed latent mortality as high as 90% after a 10 minute exposure to residual chlorine doses as low as 0.75 ppm. Larval fish and macroinvertebrates exposed to condenser tube passage had lower survival than those which were only plume entrained. In experiments where flow rate and biocide concentrations varied, the simultaneous addition of a sublethal thermal exposure usually increased the mortality.

SUMMARY

Studies with the Power Plant Condenser Tube Simulator were initiated in December, 1977, to determine the effects of thermal, chemical and pressure stresses on entrained zooplankton. The New York State Energy Research and Development Authority's Condenser Tube Simulator is a one-to-one simulation of a "typical" power plant condenser. It consists of paired, 50' stainless-steel tubes, each of which may be programmed, independently, to simulate varying flow conditions, temperature change (ΔT) and chlorination procedures. Specialized systems permit the injection and collection of organisms in the test system without the adverse effects of net-induced mortality.

Research carried out in 1977-78 concentrated upon estuarine organisms. Three species common in many east coast estuaries were selected for study: larval stages of the striped bass, *Morone saxatilis*; the estuarine amphipod *Gammarus* spp. (a composite of *G. tigrinus* and *G. daiberi*); and the common estuarine mysid shrimp, *Neomysis americana*. All three species are subject to potentially heavy entrainment losses in a number of estuarine systems, including the James River, Patuxent River, Chesapeake Bay, Chesapeake/Delaware Canal, Delaware River, and the Hudson River estuary.

The test organisms used in the research reported here were obtained from culture (striped bass, *Gammarus* spp., *Neomysis*). Known quantities were injected into the simulator, and exposed to the stresses of ΔT, chlorination, and changes in hydrostatic pressure alone, and in combination. All three stress parameters were varied, at different times in the test program, to cover the range of variation expected to occur in various nuclear-powered and fossil-fueled steam electric stations. ΔT varied from 0 to 59°C, chlorine concentration varied from 0 to 5.0 mg ℓ^{-1} residual chlorine, and minimum hydrostatic pressure (as a function of flow rate) was varied from approximately atmospheric (14.7 psia) to a partial vacuum of ∿ 7.0 psia.

The mechanical effects of condenser tube passage alone had little or no effect upon survival of striped bass yolk-sac larvae and larvae, *Gammarus*, or *Neomysis*.

Thermal mortality data derived during 1978 were in agreement with data currently available in the literature. For all three test organisms the effects of thermal shock imposed during condenser tube passage were greater than the effects of thermal shock alone.

The combined effects of increased temperature, condenser tube passage and biocide (chlorine) application were essentially additive for striped bass; the same combination of effects caused some degree of synergy among *Gammarus* and *Neomysis*.

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Gammarus appears to be sensitized to the effects of temperature and chlorine by passage through the condenser tube environment. Although no direct impact of the condenser tube was apparent in experiments with *Gammarus*, the degree of synergy expressed indicates the occurrence of a subtle, sublethal sensitization to other stresses associated with passage through the condenser tube.

Neomysis is sensitized to the effects of chlorine and temperature by condenser tube passage; however, the resultant synergy is not so strongly expressed as in *Gammarus*.

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1. Introduction

Entrainment mortality at steam-electric generating stations is considered the most important, direct impact that power plants may have on aquatic biota. Nonetheless, accurate estimates of entrainment mortality from field and laboratory studies have been difficult to obtain. In the case of field studies, mortality due to sampling gear, handling and recent thermal history frequently confounds the data, rendering many conclusions suspect. Laboratory studies of entrainment mortality have necessarily focussed on single variables (temperature, biocide application) without regard to synergistic responses or additional stresses such as shear, hydrostatic pressure, turbulence and the time-history of stress application.

Several workers have attempted to estimate the effects of power plant entrainment using devices which simulated one or more of the factors known to operate on entrained organisms during the process of plant passage. Coutant and Kedl (1974), Kedl and Coutant (1976), Schubel (1974) constructed and tested devices designed to expose organisms to stresses such as turbulence, shear, temperature, and hydrostatic pressure change simultaneously. For the most part, these authors found little or no effect on the various species of fish eggs, yolk-sac larvae and larvae which they tested. A major drawback to these earlier studies of simulated power plant conditions, however, was that in no case were the test devices able to simulate accurately the time-history of stress application for more than a single test variable. In addition, no results are available which describe the effects of passage through a circulating water pump upon ichthyoplankton.

The necessity to have a better understanding of the entrainment process and the precise effects that entrainment causes has led to the development of several devices, each important in deriving an improved estimate of mortality of fishes and invertebrates which pass through power plant cooling systems. These are: 1) the power plant pump simulator, located at the Oak Ridge National Laboratory; 2) the LMS "larval table" low stress sampling device (McGroddy and Wyman, 1977); and 3) the New York State ERDA condenser tube simulator, located on the Hudson River at Verplanck, N.Y. Each of these devices answers the need for specialized treatments to be applied to test organisms. In the case of the simulators, the specialized treatment may be the imposition of a stress. In the case of the larval table, the requirement is for collection of organisms from an environmental sample with a minimum of stress due to net impact.

This report deals exclusively with studies conducted during 1978 with the New York State ERDA power plant condenser tube simulator. The simulator was designed specifically to impose upon organisms the precise thermal, mechanical, hydraulic and chemical stresses which occur in an operating steam electric station. Operation of the simulator provides an accurate time-history of condenser-related events. The simulator is controllable, such that individual loops of the dual system can be operated independently at the same time, thereby providing for strict experimental control over test variables. Complete details of the simulator, its mechanical features, and its operating ranges may be found in previous publications (NYU, 1977; Poje et al., 1978).

The condenser tube simulator (CTS) was constructed and first tested in 1976. Original studies performed on the amphipod Gammarus tigrinus and the phantom midge Chaoborus punctipennis showed that: 1) the CTS could be used to test the responses of organisms to simultaneous, multiple stresses; and 2) the interaction of temperature stress and chlorine stress on entrained test animals was synergistic in nature. Furthermore, predicted effects on entrainment due to fluid-induced stresses (e.g., hydrostatic pressure) were observed (see Beck et al., 1975; NYU, 1976; Poje, unpublished data), making multiple stress evaluation possible.

Tests with estuarine organisms were initiated in 1977, when the CTS was moved to Verplanck, N.Y. When the condenser was installed at the Verplanck site, a wet-lab and flowing water system was also installed in order to optimize production and maintenance of test organisms. The Verplanck site is immediately adjacent to the Consolidated Edison striped bass hatchery, operated by Texas Instruments' Ecological

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Services Division. The work performed in 1977 concentrated on striped bass (Morone saxatilis), carp (Cyprinus carpio), and amphipods (Gammarus spp.). Results of the 1977 program (NYU, 1978; O'Connor and Poje, in preparation) demonstrated the sensitivity of striped bass to combined thermal, chemical and fluid-induced stresses, as well as damage to test organisms caused by collection gear. Carp larvae were found to be far more tolerant of condenser-imposed stresses than striped bass. Experiments with Gammarus were inconclusive, in that the operation of the simulator at the relatively low flows used in 1977 did not permit quantitative recovery of Gammarus from the instrument.

Experience gained in 1977 clearly demonstrated that conical plankton net sampling induced an appreciable fraction of the mortality attributed to condenser tube passage. In order to achieve the goal of assessing the impact of only those factors involved in entrainment stress (temperature, biocide and fluid/pressure variables), an alternative method for collecting organisms from the simulator was devised. Prior to the 1978 season, therefore, scaled-down models of the LMS larval table were constructed and installed replacing the collection nets used in earlier studies.

The results presented in this report deal with studies conducted in 1978 at Verplanck, N.Y. All experiments were performed using organisms collected from the Hudson River estuary, or derived from Hudson River organisms through culture techniques (Bayless, 1972; Ginn, 1976; Poje, 1977). The objective of the condenser tube simulator research program is to determine the lethal and sublethal effects of condenser tube passage on entrainable estuarine organisms under conditions the organisms would be exposed to at a typical, operating power plant. The 1978 study represents the completion of one year's effort, part of a two-year research program. During this first year, lethal and sublethal effects of condenser passage on striped bass, *Gammarus*, and the opossum shrimp (*Neomysis americana*) were determined. Studies planned for the second year include the use of carp, white perch (*Morone americana*) water fleas (*Daphnia* spp.) and phantom midge larvae in a design similar to that presented in this report.

2. Materials and Methods

The power plant condenser tube simulator (NYU, 1976, 1977; Ginn et al., 1978; Poje et al., 1978) consists of a source tank, a circulation pump, biota injection system, hypochlorite pumping station, dual condenser tubes and collection tables. Heat is applied to the water as it passes through the condenser tubes by chromalox heaters which surround most of the 50 ft (15.25 m) long condenser tubes (Figure 2-1). The details of simulator operation have been described previously (NYU, 1976, 1977).

The newly installed biota collection system consists of larval collection (LCT) tables (particle separation devices), originally applied to power entrainment studies by McGroddy and Wyman (1977) (Figure 2-2). These devices were incorporated into the 1978 CTS studies, since net collection of organisms entrained in power plant flows can result in excessive mortalities, and true estimates of entrainment mortality may not be observed (O'Connor and Schaffer, 1977). Original collection design for the simulator consisted of conical plankton nets suspended in cylindrical barrels for the recovery of organisms passed through the simulator (NYU, 1977). No excessive mortalities due to collection were observed for those invertebrates with rigid exoskeletons (*Chaoborus* sp. or *Gammarus tigrinus*) or for larger carp larvae (7.6-9.5 mm) passed through the simulator at condenser tube flow rates below those at existing power plants.

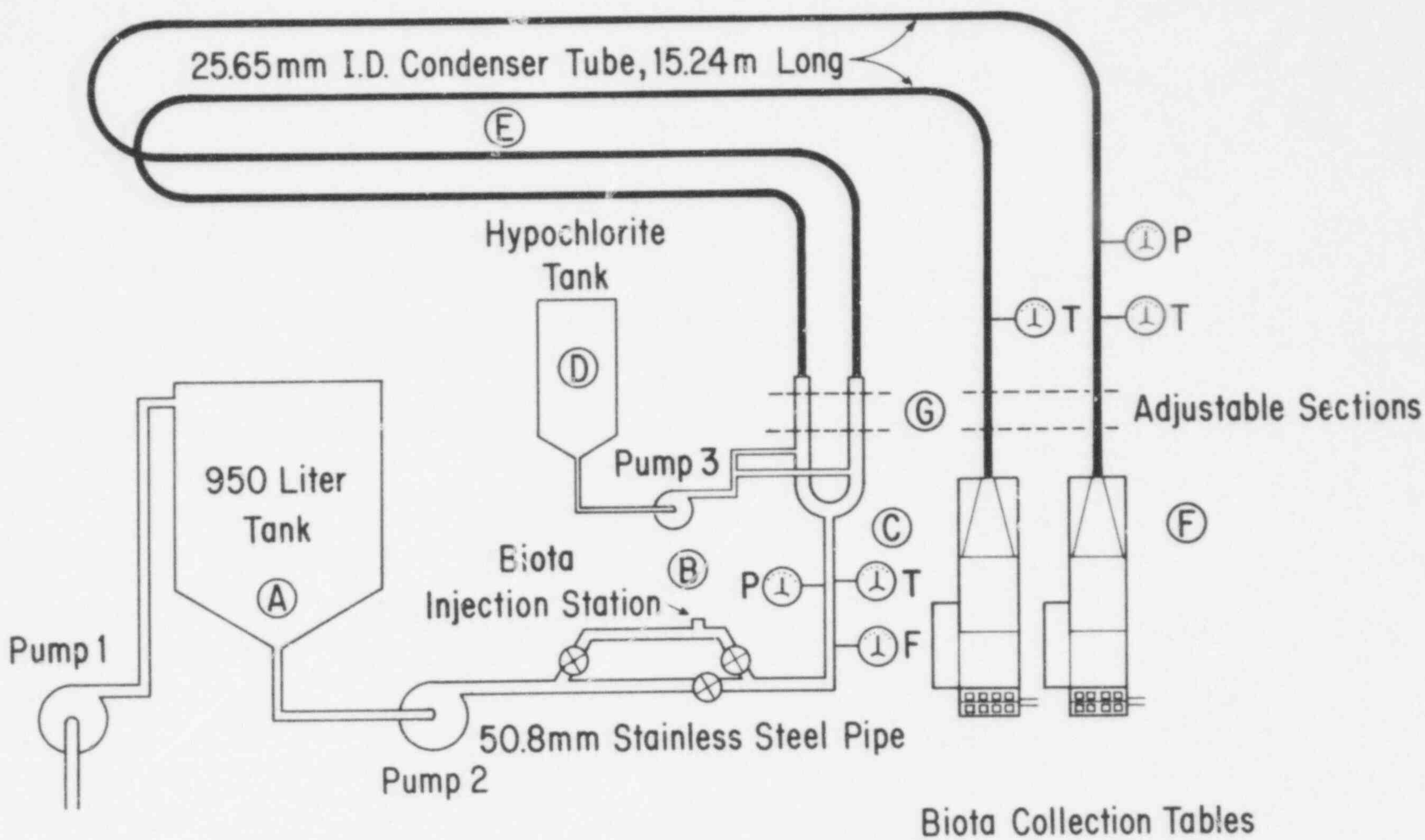


Figure 2-1 Schematic diagram of the power plant condenser tube simulator: A-source tank; B-biota injection system; C-flow splitting unit; D-biocide injection system; E-condenser tubes; F-larval collection tables; G-area of the simulator where height adjustments are made; various gauge positions are noted.

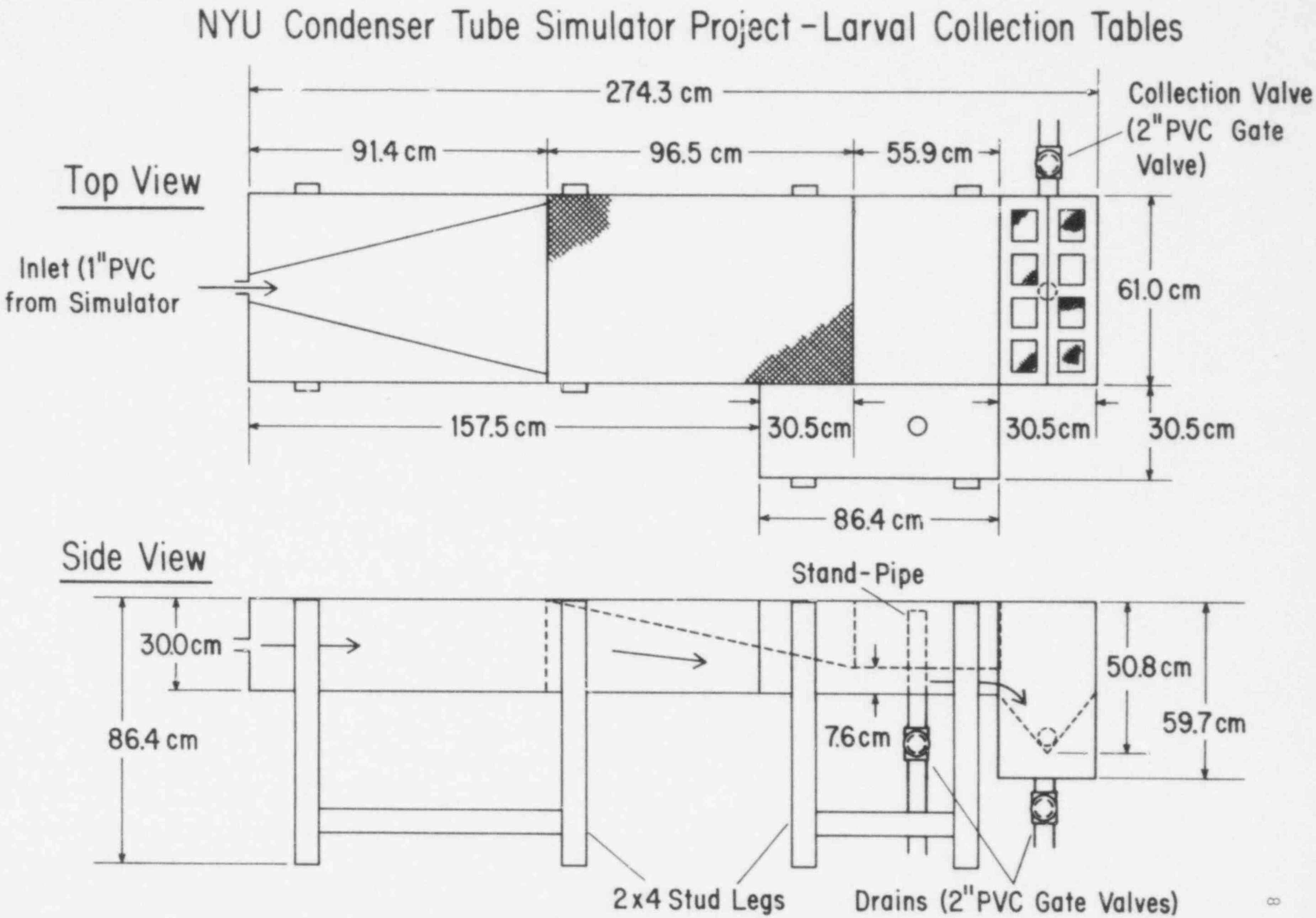


Figure 2-2 Schematic diagram of the larval collection tables utilized for organism concentration and retrieved.

However, striped bass (Morone saxatilis) larvae exhibited excessive collection-induced mortality even at low flow rates (Poje et al., 1978).

Each simulator loop is equipped with its own LCT (refer to Figure 2-2). These tables are designed such that the entrained organisms are expelled from the simulator into a large, slowly moving body of water. Their initial velocity is reduced rapidly in the larval table; net impaction at high velocities is avoided and organisms are collected with a minimum of collection-induced mortality (McGroddy and Wyman, 1977).

Each LCT is 274 cm long, 61 cm wide, 30 cm deep in the table portion and 60 cm deep in the collection end. They were constructed of 3/4-inch plywood coated with epoxy resin and fiberglass. Each table is functionally divided into three sections. The intake expansion section receives the flow from the simulator and widens from a diameter of 2.5 cm to 61.0 cm over a distance of 90.0 cm. This expands the area of the flow, thereby reducing velocity. The volume reduction and flow diversion section consists of an angled screen (400 μm mesh; 97 cm × 61 cm) which allows a large portion of the flow, but none of the entrained organisms, to pass into a weir. The terminal collection section filters the remaining volume of water by means of eight symmetrically displayed screens (400 μm mesh; approximately 10 cm × 10 cm). The experimental organisms are retained in a shallow trough which can be drained by operating a manual ball valve.

For an experiment, each LCT is filled to capacity. The level is maintained by means of a standpipe (5 cm diameter) in the weir. After a time sufficient for test organisms to have passed through the condenser system and into the tables, the flow to the tables is diverted through a by-pass. The weir standpipe is removed and the LCT volume is reduced. The collection drain is then opened; the test organisms are concentrated into the troughs and removed through the trough drainage valves.

2.1 Experimental Design

All experiments conducted with the condenser tube simulator in 1978 were designed to compare survival of condenser tube-entrained and "plume-entrained" animals. The condenser tube-passed organisms were injected into the simulator flow and received temperature and/or chlorine dosage at a variable flow rate (Carter et al., 1977; NYU, 1978). The split flow divided the organisms to each condenser loop. Although the ratio of collected test organisms was not exactly 1:1, observed frequency distributions did not vary from a normal approximation to the binomial distribution with $P = 0.5$ and $\alpha = 0.05$.

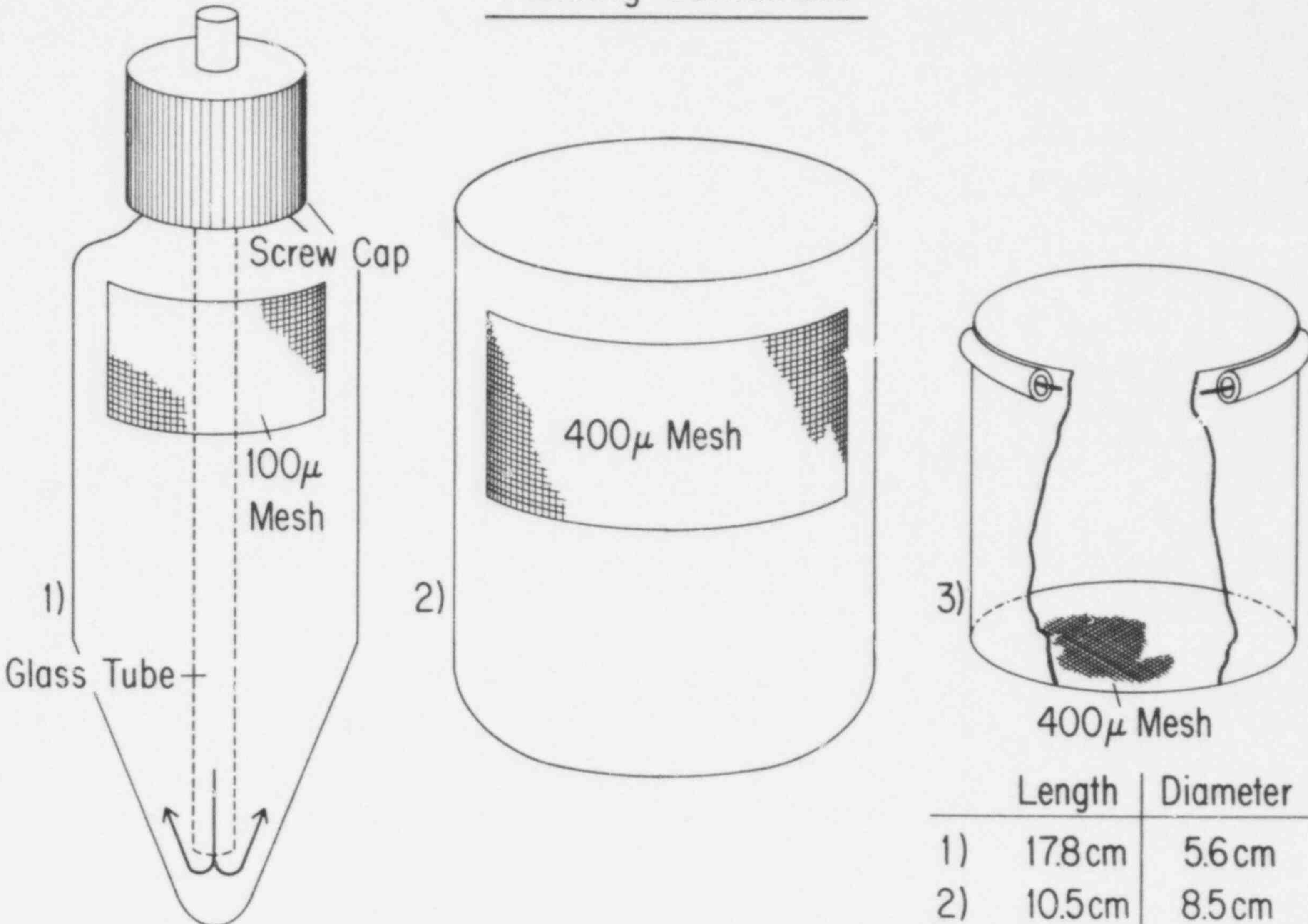
"Plume entrained" organisms referred to in these studies are, in fact, static control organisms which do not experience exposure to the condenser loop. Insofar as static controls represent a condition similar to organisms which may become entrained in the discharge effluent in the natural situation, they represent an important mechanism for estimating effluent plume impact. In future studies, plume entrainment will be more realistically approximated by manipulation of thermal and chemical stresses to simulate the decay constants observed in discharge plume studies (Ginn and O'Connor, 1978).

Plume-entrained groups were held in flow-through exposure chambers (Figure 2-3) which were suspended for the same exposure period in the larval collection tables. These organisms experienced thermal stress and/or biocide stress applied to their respective condenser loop. Plume-entrained organisms experienced neither the fluid-induced stresses of condenser tube passage nor any collection-induced stress which may occur in the larval tables. Three experimental variables were examined for each species: temperature elevation (ΔT); chlorine concentration; and flow rate.

The effect of recovery in larval collection tables was also assessed in experiments where flow rate varied. In flow-rate experiments, a third group of control organisms (flow control) was poured into the intake end of the larval collection tables, exposed to collection stresses, and recovered in the same manner as the condenser tube-passed animals. They encountered the stresses of thermal change, biocide application, and damage due to larval table collections, but not the fluid-induced damage of condenser passage.

Duplicate sets of organisms were subjected in each experiment to the isolation and enumeration stresses and

Holding Containers



	Length	Diameter
1)	17.8 cm	5.6 cm
2)	10.5 cm	8.5 cm
3)	8.5 cm	6.5 cm

Figure 2-3 Containers utilized for organism exposure and maintenance: 1. holding vessel for striped bass eggs and yolk sac larvae; 2. holding vessel for post yolk sac larval fish and macroinvertebrates; 3. plume entrainment exposure vessel.

placed into flow-through containers. These laboratory controls were counted at all observation periods and served as indicators of overall population mortality and handling stress.

All test and control organisms were rinsed and returned to ambient conditions immediately after exposure. The numbers of living and dead larvae in each test group were counted immediately after exposure; latent effects were observed at 24 hours (h), and in some instances at 48 h. All test groups were held at ambient temperature in flow-through containers (Figure 2-3) which were equipped with individual water supply. Dissolved oxygen was monitored in the source tank (intake) water and collection tank (discharge) water with a Y.S.I. dissolved oxygen meter. At no time did saturation fall below 90%. Temperature was monitored by a Y.S.I. telethermometer.

2.1.1 Striped Bass

Striped bass (Morone saxatilis) early life history stages were the only fish species investigated during 1978. Although Texas Instrument hatchery operations spawned white perch (Morone americana), and goldfish young were produced from river stock in our own facility, the numbers available were insufficient for adequate testing procedures.

All experiments with striped bass utilized Verplanck quarry water for simulator operations and for subsequent observation periods in the holding facilities. This was the same water system in which striped bass were spawned and maintained by the Texas Instrument hatchery. The physical and chemical quality of the Verplanck quarry water supply has been described (Texas Instruments, 1974).

Four experiments tested the effects of temperature on striped bass survival at various stages of larval development, at three flow rates with simulator passage and with plume entrainment (Table 2-1). For larvae 10 days post hatch, 100 animals were utilized for each replicate. In those experiments using older larvae (> 10 days post hatch) holding container stresses were minimized by using 50 larvae per replicate. Larvae were exposed to temperature changes of 0.0, 8.0, 10.0, 12.0, 14.0, 16.0 and 18.0°C above ambient in each experiment. Final temperatures were not the same for all experiments, since ambient temperature varied from 15.0 to 18.0°C. The objectives of these experiments were to determine the lethal limits of temperature change for each flow rate through the simulator and to examine any age specific temperature tolerance patterns.

It can be assumed that the interactions of fluid-induced stresses of condenser tube passage and ΔT would be most apparent at exposures sublethal for either individual stress. Consequently, the effect of flow velocity on survival of larvae was examined at ambient temperature and at a sublethal 7.0°C ΔT (Table 2-1). The flow velocities in each experiment were 1.0, 2.0, and 3.0 meters per second (mps),

Table 2-1. *Morone saxatilis* experimental temperature and flow regimes tested during 1978. All exposures were for 10 minute durations.

Variable examined	Larval stage (days post hatch)	Range of exposures (number of variations)	Flow, mps	Temperature, °C
Temperature (°C)	Larvae (24)	0.0-18.0 ΔT (7)	3.0	Ambient = 17.2
Temperature (°C)	Larvae (29)	0.0-18.0 ΔT (7)	1.0	Ambient = 18.0
Temperature (°C)	Larvae (10)	0.0-18.0 ΔT (7)	2.0	Ambient = 15.0
Temperature (°C)	Larvae (18)	0.0-18.0 ΔT (7)	2.0	Ambient = 16.2
Flow, meters per second, mps	Yolk sac (3)	1.0-3.0 mps (3)	Varied	Ambient = 15.0
Flow, mps	Yolk sac (3)	1.0-3.0 mps (3)	Varied	ΔT = 7.0 (22.0 actual)
Flow, mps	Larvae (16)	1.0-3.0 mps (3)	Varied	Ambient = 16.0
Flow, mps	Larvae (16)	1.0-3.0 mps (3)	Varied	ΔT = 7.0 (23.0 actual)

covering the range of average flows at existing power plants (Schubel, 1974). Two different life history stages were utilized. For yolk-sac larvae, 100 animals were utilized per replicate. The older post-yolk-sac larvae were tested in groups of 50 per replicate.

The effect of chlorination upon survival of early yolk-sac larvae and older larvae were examined at ambient temperature and at an elevated sublethal temperature (Table 2-2). Exposures consisted of plume entrainment and condenser tube passage at 2.0 mps flow rate. For the yolk-sac larvae, 100 organisms per replicate were utilized, while the older larval stages were run with 50 animals per replicate sample. Biocide (as 5.25% sodium hypochlorite) was administered to the condenser tube simulator via the biocide injection system (NYU, 1977). Chlorine concentrations were assayed as total residual chlorine using a Wallace and Tiernan amperometric titrator with a lower detection limit of 0.05 ppm. No fluctuations in free chlorine concentrations were detected during the exposure period. The chlorine demand of the quarry water was not measurable. Chlorine doses for yolk sac larvae were 0.0, 0.20, 0.37, 0.69, 1.46 and 2.78 parts per million (ppm) total residual chlorine. For 31-day-old post-yolk-sac larvae the chlorine concentrations were 0.0, 0.14, 0.29, 0.68, 1.57 and 2.73 ppm total residual chlorine.

Table 2-2. *Morone saxatilis* experimental chlorine regimes tested during 1978. All exposures were for 10 minute durations. Chlorine measured as parts per million total residual chlorine.

Variable examined	Larval stage (days post hatch)	Range of exposures (number of variations)	Flow, mps	Temperature, °C
Chlorine plume entrained	Yolk sac (1)	0.0-2.78 (6)	plume	Ambient = 15.0
Chlorine plume entrained	Yolk sac (1)	0.0-2.78 (6)	plume	ΔT = 5.8 (20.8 actual)
Chlorine condenser tube passed	Yolk sac (1)	0.0-2.78 (6)	2.0	Ambient = 15.0
Chlorine condenser tube entrained	Yolk sac (1)	0.0-2.78 (6)	2.0	ΔT = 5.8 (20.8 actual)
Chlorine plume entrained	larvae (31)	0.0-2.73 (6)	plume	Ambient = 19.0
Chlorine plume entrained	larvae (31)	0.0-2.73 (6)	plume	ΔT = 5.0 (24.0 actual)
Chlorine condenser tube entrained	larvae (31)	0.0-2.73 (6)	2.0	Ambient = 19.0
Chlorine condenser tube entrained	larvae (31)	0.0-2.73 (6)	2.0	ΔT = 5.0 (24.0 actual)

2.1.2 Invertebrates

The experimental regime used in 1978 included two crustacean invertebrates, the gamaridean amphipod, Gammarus spp. and the mysid shrimp, Neomysis americana. The ecology of each of these species renders them potentially subject to power plant entrainment (NYU, 1976, 1977) while also being of major importance in the estuarine food chain (McFadden, 1977; Ginn, 1976).

The experimental regimes to which Gammarus spp. were subjected included temperature, flow rate and additions of chlorine as stress factors (Table 2-3). Exposures of Gammarus were carried out for 10 minutes at elevated temperatures (ΔT's) ranging from $0^{\circ}C$ to $19.0^{\circ}C$ above Hudson River ambient. Ambient ranged from $21.0^{\circ}C$-$22.0^{\circ}C$. Exposures of 30 minutes duration were run covering a range of ΔT from 0-$14.0^{\circ}C$ above an ambient temperature of $26.75^{\circ}C$.

Variable flow rate experiments with Gammarus spp. included exposure to flow rates of 1.0, 2.0 and 3.0 meters per second (mps) for 10 minutes. Response to flow rate under conditions of both ambient temperature ($23.5^{\circ}C$) and a $10.0^{\circ}C$ ΔT were studied.

Chlorination experiments with Gammarus were broken into four sub-groups. Plume-entrained and condenser tube-entrained Gammarus each received chlorine doses at ambient temperatures ranging from $18.0^{\circ}C$ to $25.0^{\circ}C$ and at a sublethal elevated temperature of $31.0^{\circ}C$.

Table 2-3. Gammarus spp. experimental regimes tested during 1978.

Variable examined	Exposure time	Range of Exposures (number of variations)		Flow, mps	Temperature, °C
Temperature, (°C)	10 min	0-19.0 ΔT	(5)	2.0	Ambient = 21.0-22.0
Temperature, (°C)	30 min	0-14.0 ΔT	(6)	2.0	Ambient = 26.75
Flow, meters per second, mps	10 min	1.0-3.0 mps	(3)	Varied	Ambient = 23.5
Flow, mps	10 min	1.0-3.0 mps	(3)	Varied	ΔT = 10.0
Chlorine plume entrained	10 min	0-2.95 ppm*	(8)	-	Ambient = 18.0-25.0
Chlorine plume entrained	10 min	0-2.10 ppm*	(8)	-	ΔT = 6-13 (31.0 actual)
Chlorine condenser tube entrained	10 min	0-2.63 ppm*	(8)	2.0	Ambient = 18.0-25.0
Chlorine condenser tube entrained	10 min	0-3.40 ppm*	(8)	2.0	ΔT = 6-13 (31.0 actual)

*parts per million measured as total residual chlorine

Neomysis americana experienced the same array of experimental regimes as did *Gammarus* spp. with only minor differences in the ranges of exposures to which they were subjected and the ambient temperature during exposure (Table 2-4).

Table 2-4. Neomysis americana experimental regimes tested during 1978.

Variable examined	Exposure	Range of Exposures (number of variations)	Flow, mps	Temperature, °C
Temperature, (°C)	10 min	0.0-10.0 ΔT (6)	2.0	Ambient = 26.75
Temperature, (°C)	30 min	0.0-10.0 ΔT (6)	2.0	Ambient = 26.75
Flow, meters per second, mps	10 min	1.0-3.0 mps (3)	Varied	Ambient = 24.0
Flow, mps	10 min	1.0-3.0 mps (3)	Varied	ΔT = 6.0 (30.0 actual)
Chlorine plume entrained	10 min	0.0-2.48* (9)	-	Ambient = 21.0 - 24.0
Chlorine plume entrained	10 min	0.0-2.00* (8)	-	ΔT = 6.0 - 8.5 (30.0)
Chlorine condenser tube entrained	10 min	0.0-2.83* (8)	2.0	Ambient = 21.0 - 24.0
Chlorine condenser tube entrained	10 min	0.0-2.71* (8)	2.0	ΔT = 6.0 - 8.5 (30.0)

*parts per million measured as total residual chlorine

3. Results

3.1 Striped Bass Results

3.1.1 Temperature Experiments

Striped bass larvae (10 and 16 days old) were subjected to simulator passage (2.0 mps) and plume entrainment simultaneously, with a ΔT ranging from 0.0 to 18.0°C above ambient temperature. The percent survival and percent stunned (larvae exhibiting abnormal locomotory behavior but maintaining vital signs, such as heartbeat) were assessed at the immediate observation (Tables 3-1, 3-2). For younger larvae the immediate mortality pattern disclosed greater sensitivities at 31.0°C and 33.0°C, while the percentage stunned remained high ($\bar{x} > 60\%$) throughout the thermal exposure regimes (Figure 3-1).

For 16 day old larvae immediate mortality was minimal ($< 15\%$) even at a final temperature of 34.2°C (Figure 3-2). The percent stunned for these larvae was more indicative of the temperature stress (Figure 3-3). Above 28°C, an average of 50% of the plume-entrained animals were stunned. In contrast, the percent stunned was 50% above 26°C and 90% of the organisms at 34.0°C for fish passed through the simulator. For both larval age groups laboratory control replicate survival was less than 50% at 24 h, the point at which the observations were terminated.

No significant differences in survival existed between simulator passed versus plume-entrained exposure regimes

Table 3-1. Percent survival and percent stunned of plume exposed and condenser tube passed <u>Morone saxatilis</u> (10 day old larvae) immediately after a 10 minute exposure to elevated temperatures. Ambient temperature was 15°C. Flow velocity was 2.0 mps.

Temperature, °C	(ΔT)	CTP Survival	(*)	CTP Stunned	Plume exposed Survival	(*)	Plume exposed Stunned
15.0	(0.0)	97.2	(71)	-	100.0	(101)	-
		95.5	(89)	97.8	95.9	(98)	-
23.0	(8.0)	90.9	(77)	44.2	92.9	(99)	51.2
		75.3	(89(	61.8	97.9	(97)	41.2
25.0	(10.0)	76.8	(82)	58.5	98.9	(92)	10.9
		93.4	(76)	27.6	96.8	(93)	18.3
27.0	(12.0)	84.9	(86)	59.3	84.9	(106)	51.0
		72.6	(95)	74.7	86.3	(51)	68.6
29.0	(14.0)	94.0	(84)	35.7	92.1	(101)	37.6
		46.7	(90)	83.3	98.0	(98)	30.6
31.0	(16.0)	72.6	(84)	-	78.4	(97)	69.1
		49.5	(101)	51.5	67.6	(102)	88.2
33.0	(18.0)	17.5	(103)	-	74.7	(99)	-
		14.6	(96)	99.0	25.0	(104)	100.0

*Number exposed

775 26

Table 3-2. Percent survival and percent stunned of plume exposed and condenser tube passed Morone saxatilis (16 day old larvae) immediately after a 10 minute exposure to elevated temperatures. Flow velocity was 2.0 mps. Ambient temperature was 16.2°C.

Temperature, °C	(ΔT)	Plume Exposed Survival	(*)	Plume Exposed Stunned	Condenser Tube Passed Survival	(*)	Condenser Tube Passed Stunned
16.2	(0.0)	96.2	(26)	4.0	85.4	(41)	41.5
		94.0	(50)	28.0	100.0	(41)	14.6
24.2	(8.0)	100.0	(51)	13.7	100.0	(52)	21.2
		100.0	(50)	26.0	96.2	(53)	15.1
26.2	(10.0)	100.0	(51)	15.7	95.3	(43)	41.9
		100.0	(52)	9.6	100.0	(51)	33.3
28.2	(12.0)	100.0	(51)	21.6	94.6	(56)	35.7
		100.0	(50)	10.0	95.8	(48)	64.6
30.2	(14.0)	92.2	(51)	68.6	98.1	(53)	47.2
		100.0	(50)	64.6	95.7	(47)	70.2
32.2	(16.0)	94.2	(52)	28.8	96.1	(51)	70.6
		100.0	(50)	52.0	91.1	(56)	83.9
34.2	(18.0)	94.1	(51)	17.6	83.7	(43)	83.7
		90.4	(52)	88.5	90.5	(42)	100.0

* = number exposed

775 263

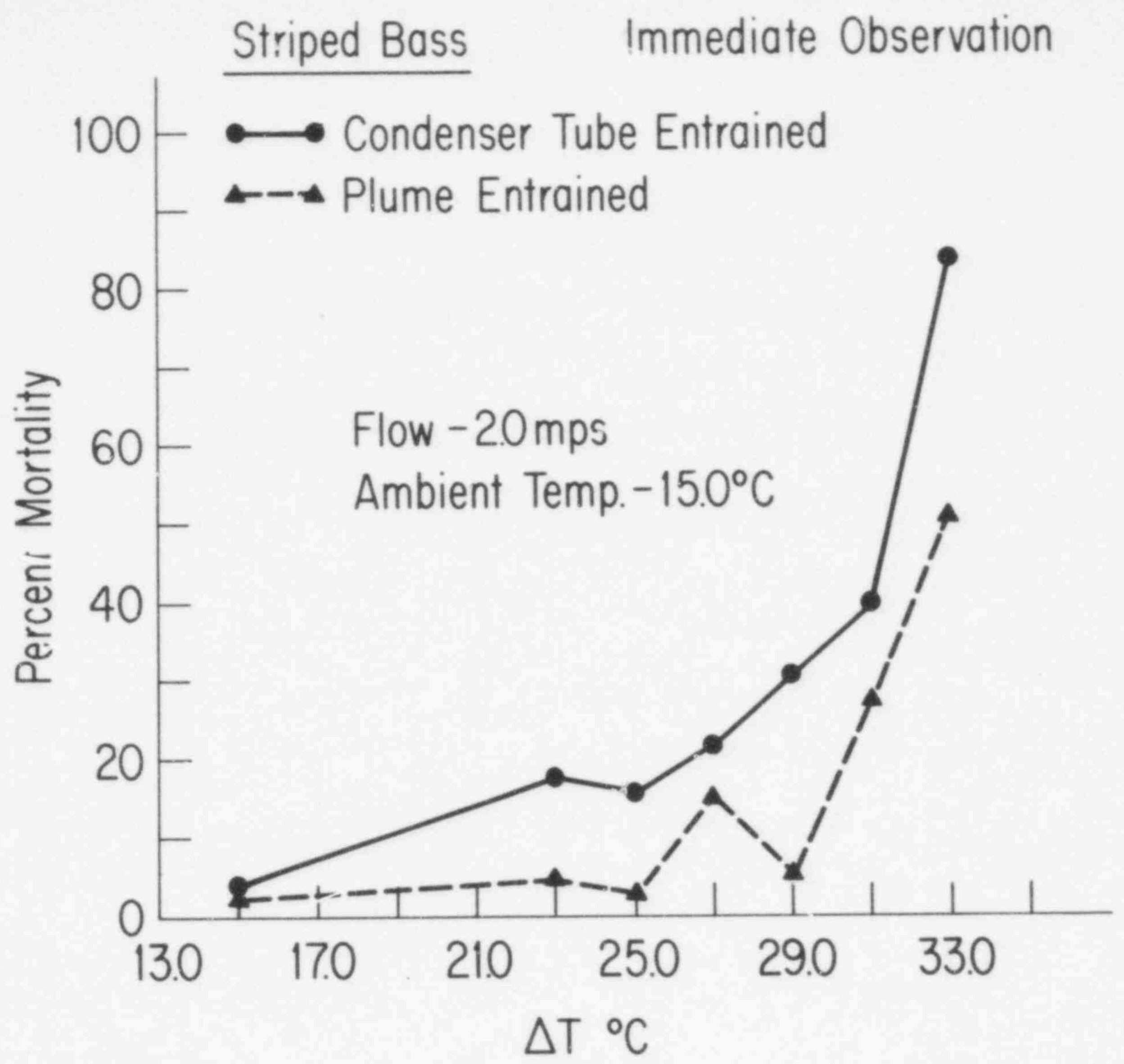


Figure 3-1 Percent mortality of plume entrained and condenser tube passed *Morone saxatilis* larvae 10 days post hatch immediately after a 10 minute exposure to elevated temperatures.

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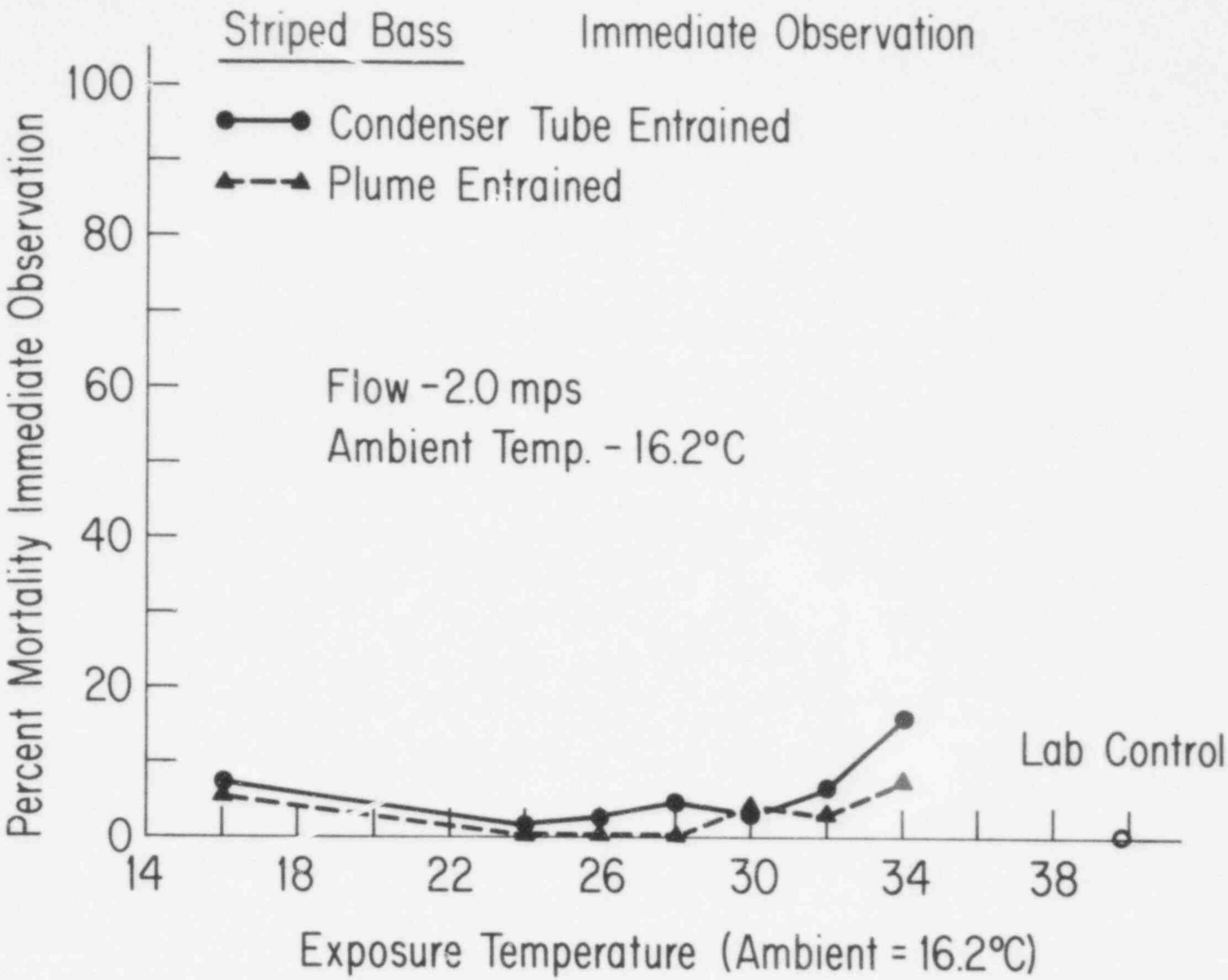

Figure 3-2 Percent mortality of plume entrained and condenser tube passed *Morone saxatilis* larvae 18 days post hatch immediately after a 10 minute exposure to elevated temperatures.

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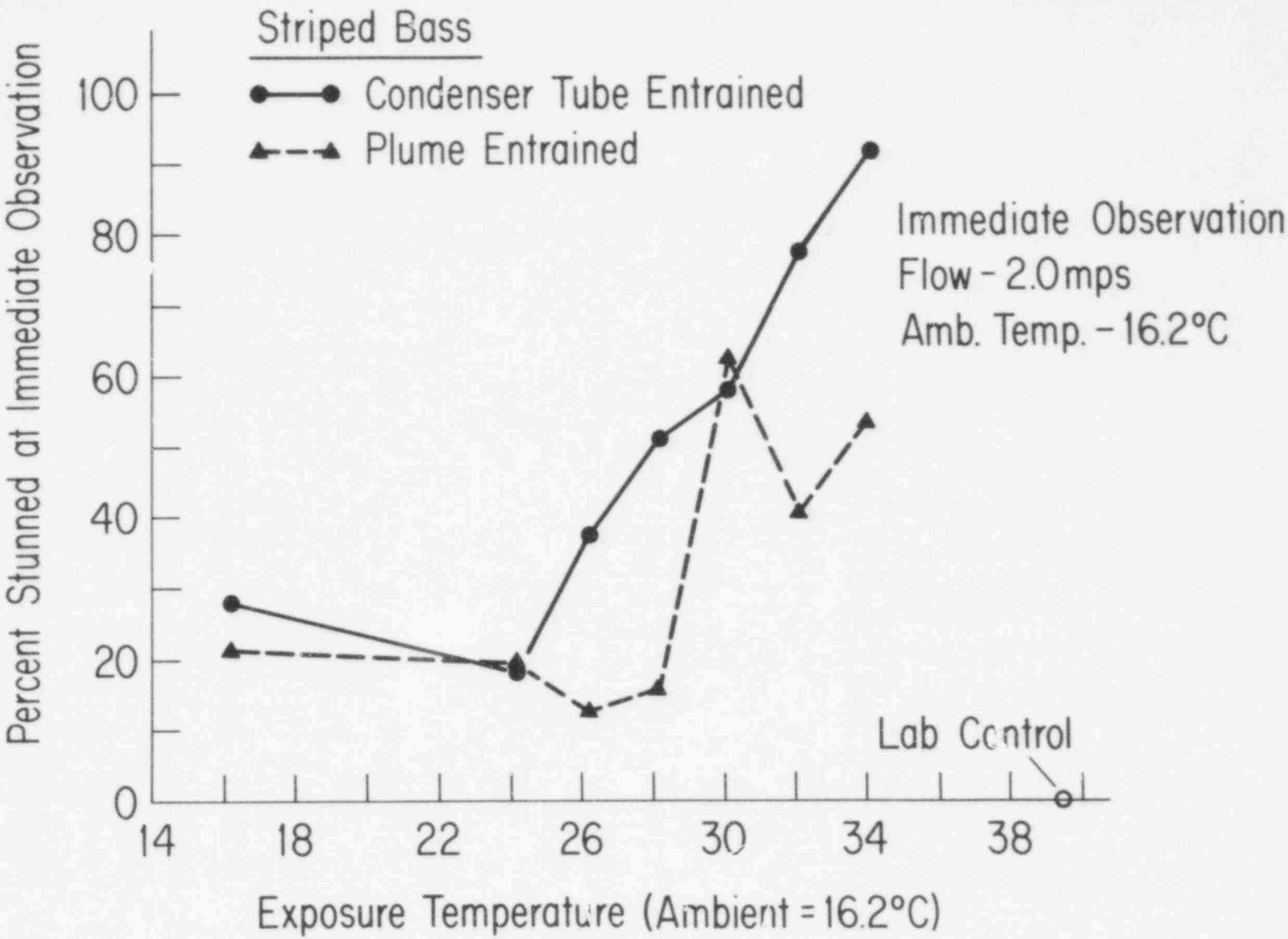

Figure 3-3 Percent stunned of plume entrained and condenser tube passed *Morone saxatilis* larvae 18 days post hatch immediately after a 10 minute exposure to elevated temperatures.

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(Table 3-3). The 16-day old larvae had a higher percent survival than those 10 days old ($P < 0.05$).

Larvae greater than 23 days post-hatch tolerated handling stress and temperature better than the younger larvae. Immediate survival of 24-day old larvae exposed at 3.0 mps was > 95% at all temperatures for plume entrainment and the majority of simulator passed animals (Table 3-4). Simulator passed animals exhibited mortality of approximately 20% at 35°C. At 24 h post exposure mortalities increased beyond laboratory control mortality (21.6%) (Figure 3-4). Condenser passed animals in each temperature grouping had higher mean mortalities than their respective plume entrained groups. An analysis of variance disclosed no significant differences attributable to exposure temperature for plume vs. condenser exposures (Table 3-5b).

Striped bass 29 days post hatch had immediate survival greater than 85% at both exposure regimes and at all temperatures (Table 3-6). At the 24 h observation, larvae exposed to plume conditions exhibited lower mortalities than those passed through the condenser tube at all temperatures greater than ambient (18.0°C) (Figure 3-5). Analysis of variance indicated significant differences attributable to condenser tube passage, and to the various ΔT groupings (Table 3-5a). Data were grouped into homogeneous subsets by a Student-Newman-Keuls procedure. Plume entrained larvae exposed at temperatures as high as 34.0°C showed no differences from

775 267

Table 3-3. Analysis of variance of the effects of exposure regime, temperature and larval age on survival of *Morone saxatilis* immediately after a 10 minute exposure.

A. 10-day old larvae

Source of variation	d.f	Mean Square	F	P
Among exposure groups	1	968.2	1.852	N.S.
Among temperature groups	6	987.8	1.889	N.S
Within groups	14	522.8	-	-

B. 18-day old larvae

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	1319.9	1.778	N.S.
Among temperature groups	6	881.8	1.188	N.S.
Within groups	14	742.2	-	-

C. Combined

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	1018.8	1.466	N.S.
Among temperature groups	6	795.9	1.145	N.S.
Among age groups	1	3810.4	5.483	*
Within groups	28	694.9	-	-

*=0.05>P>0.01

N.S.=not significant at α=0.05

775 268

Table 3-4. Survival of plume entrained and condenser tube passed <u>Morone saxatilis</u> (post yolk sac larvae) after a 10 minute exposure to elevated temperatures. Ambient temperature was 17.2°C. Flow rate was at 3.0 mps.

Temperature, °C	(ΔT)	% Survival Plume entrained Immediate	(*)	24 hr.	48 hr.	Condenser Tube Passed Immediate	(*)	24 hr.	48 hr.
17.2	(0.0)	100.0	(52)	38.5	36.5	85.1	(47)	31.9	27.7
		100.0	(49)	67.3	59.2	100.0	(51)	60.8	51.0
25.2	(8.0)	100.0	(52)	82.7	76.9	100.0	(48)	31.3	25.0
		100.0	(53)	39.6	26.4	100.0	(54)	44.4	44.4
27.2	(10.0)	100.0	(51)	74.5	66.7	100.0	(52)	21.2	19.2
		100.0	(50)	98.0	82.0	100.0	(54)	75.9	70.4
29.2	(12.0)	100.0	(51)	49.0	45.1	100.0	(53)	18.9	13.2
		100.0	(50)	74.0	66.0	100.0	(57)	10.5	10.5
31.2	(14.0)	100.0	(52)	63.5	61.5	97.9	(47)	23.4	23.4
		100.0	(52)	61.5	57.7	94.0	(50)	30.0	30.0
32.2	(16.0)	96.1	(51)	21.6	13.7	92.5	(53)	5.7	3.8
		100.0	(52)	25.0	23.1	97.7	(43)	14.0	9.3
35.2	(18.0)	98.0	(50)	10.0	4.0	80.8	(26)	0.0	-
		98.1	(52)	5.8	3.8	90.2	(41)	0.0	-

775 269

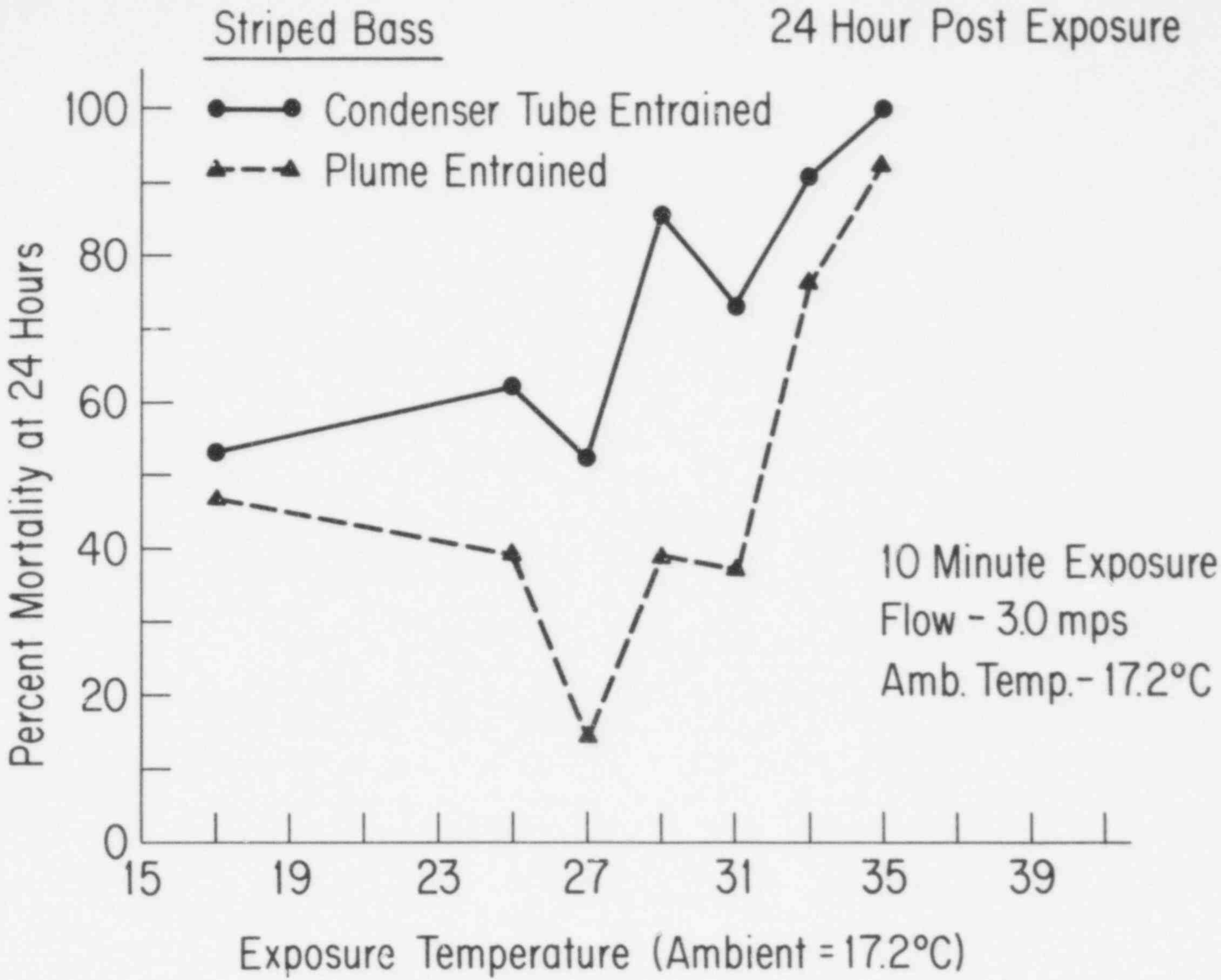

Figure 3-4 Percent mortality of plume entrained and condenser tube passed *Morone saxatilis* larvae 24 days post hatch at 24 h after a 10 minute exposure to elevated temperatures.

Table 3-5. Analysis of variance of the effects of exposure regime and temperature on *Morone saxatilis* larvae at 24 hours after a 10 minute exposure.

A. Flow rate=1.0 mps; larvae 29 days post hatch

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	4169.4	25.444	***
Among temperature groups	6	1232.6	7.522	***
Within groups	14	163.9	-	-

B. Flow rate=3.0 mps; larvae 24 days post hatch

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	2156.1	3.931	N.S.
Among temperature groups	6	1055.9	1.925	N.S.
Within groups	14	548.5	-	-

N.S.=not significant at α=0.05

***= P<0.001

775 271

Table 3-6. Survival of plume entrained and condenser tube passed <u>Morone saxatilis</u> (post yolk sac larvae) after a 10 minute exposure to elevated temperatures. Ambient temperature was 18.0°C. Flow rate was 1.0 mps.

Temperature, °C (ΔT)		% Survival							
		Plume entrained				Condenser tube passed			
		Immediate	(*)	24 hr.	48 hr.	Immediate	(*)	24 hr.	48 hr.
18.0	(0.0)	100.0	(49)	77.8	65.3	100.0	(51)	90.2	82.4
		100.0	(50)	88.0	78.0	100.0	(50)	64.0	58.0
26.0	(8.0)	100.0	(50)	88.0	80.0	100.0	(50)	48.0	40.0
		100.0	(50)	84.0	76.0	97.6	(41)	65.9	63.4
28.0	(10.0)	100.0	(50)	82.0	70.0	96.1	(51)	39.2	31.4
		100.0	(50)	88.0	80.0	94.9	(59)	35.6	28.8
30.0	(12.0)	100.0	(51)	78.4	72.5	98.3	(60)	13.3	11.7
		100.0	(50)	74.0	68.0	100.0	(40)	45.0	37.5
32.0	(14.0)	100.0	(53)	64.2	52.8	100.0	(46)	15.2	15.2
		100.0	(52)	53.8	47.0	100.0	(42)	11.9	11.9
34.0	(16.0)	100.0	(52)	86.5	80.8	91.7	(60)	10.0	10.0
		100.0	(50)	60.0	54.0	96.5	(57)	15.8	10.5
36.0	(18.0)	100.0	(51)	4.1	4.1	92.5	(40)	0.0	-
		98.0	(50)	30.0	28.0	87.2	(47)	0.0	-

*Number exposed

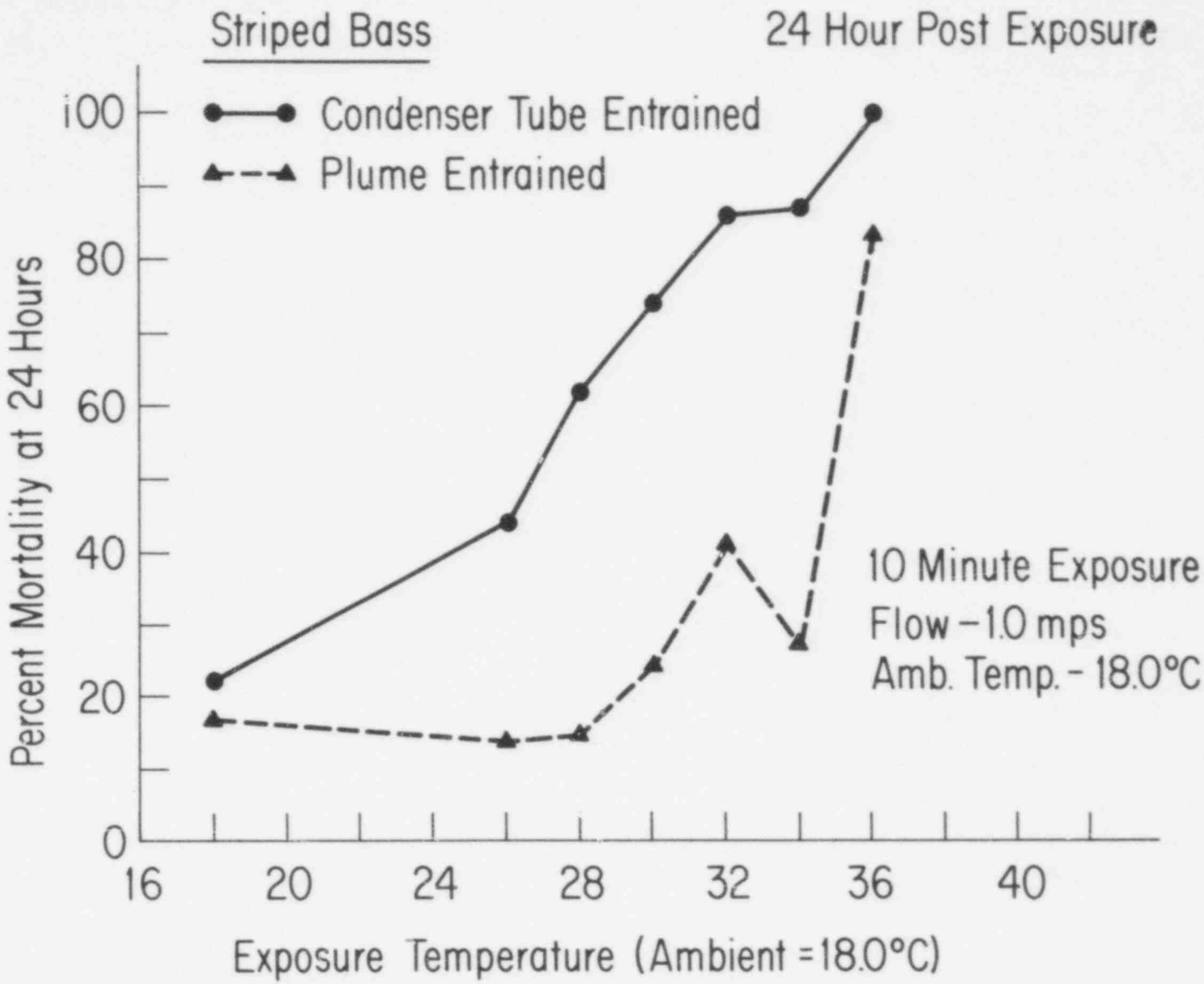

Figure 3-5 Percent mortality of plume entrained and other condenser tube passed *Morone saxatilis* larvae 29 days post hatch at 24 h after a 10 minute exposure to elevated temperatures.

laboratory control groups (82.8% survival). Only at 36.0°C did a significant portion of the larvae die (86.2% mean mortality; $P < 0.001$). Mortality for condenser tube passed larvae exposed at temperatures above 26.0°C were in excess of laboratory control mortality at 24 h. Animals exposed at 18.0°C and 26.0°C had 24 h mortalities constituting a homogeneous subset with a mean survival of 67%. Those exposed to 26.0, 28.0 and 30.0°C were recognized as a homogeneous subset with mean survival of 39%. Larvae passed through the simulator at 28.0°C and above were grouped into a survival subset with a mean of 18%.

3.1.2 Flow Experiments

The immediate and 24 h survival of striped bass yolk-sac larvae 3 days post hatch was assessed at three flow rates at ambient temperature (15.0°C) and at an elevated temperature (ΔT = 7.0°C) (Table 3-7). Immediate survival among all exposure groups showed a mean greater than 70%. Within group variability was sufficiently high to eliminate any statistically significant differences between temperature exposures, between flow exposed and simulator passed, or among the three flow rate groups (Table 3-8a). The mean survival data indicate a trend of increasing mortality for simulator passage with increasing flow rate at ambient temperature and at elevated temperatures. Flow control animals were more erratic in response to flow rates and temperature regimes (Figure 3-6).

Table 3-7. Survival of flow exposed and condenser tube passed (CTP) <u>Morone saxatilis</u> (yolk sac larvae) after a 10 minute exposure to varied flow velocities at ambient temperature (15.0°C) and at an elevated temperature (ΔT=7.0°C; 22.0 actual temperature). Plume exposed were subjected only to temperature variation.

		% Survival					
Flow Rate	Temperature	CTP			Flow exposed		
		Immediate	(*)	24 hr.	Immediate	(*)	24 hr.
1.0 mps	Ambient	100.0	(93)	4.3	91.8	(98)	17.3
		70.4	(71)	21.1	51.3	(117)	43.6
1.0 mps	ΔT	82.6	(86)	4.7	86.7	(98)	11.2
		55.7	(97)	49.5	42.9	(98)	22.4
2.0 mps	Ambient	83.3	(66)	24.2	41.9	(117)	18.8
		84.0	(81)	13.6	84.5	(97)	58.8
2.0 mps	ΔT	88.2	(93)	77.4	88.2	(110)	0.0
		40.4	(99)	1.0	85.1	(87)	0.0
3.0 mps	Ambient	67.8	(87)	35.6	73.2	(97)	44.3
		67.1	(85)	22.4	49.5	(95)	24.2
3.0 mps	ΔT	41.2	(97)	32.0	81.6	(98)	63.3
		57.0	(100)	12.0	73.5	(98)	59.2
Plume exposed	Ambient	98.0	(98)	4.1			
		99.0	(101)	1.0			
		61.3	(93)	50.5			
		80.0	(100)	71 0			
Plume exposed	ΔT	78.6	(98)	9.2			
		90.7	(97)	80.4			
		83.8	(99)	45.5			
		58.7	(92)	0.0			

*Number exposed

Table 3-8. Analysis of variance of the effects of exposure regime, temperature, flow rate and larval age on survival of *Morone saxatilis* immediately after a 10 minute exposure.

A. 3-day old larvae

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	23.2	0.018	N.S.
Among temperature groups	1	6.1	0.005	N.S.
Among flow rate groups	2	251.6	0.197	N.S.
Within groups	12	1278.7	-	-

B. 16-day old larvae

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	<0.1	<0.001	N.S.
Among temperature groups	1	2.5	0.011	N.S.
Among flow rate groups	2	53.8	0.235	N.S.
Within groups	12	229.1	-	-

C. Combined

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	11.1	0.007	N.S.
Among temperature groups	1	8.2	0.006	N.S.
Among flow rate groups	2	57.6	0.095	N.S.
Among age groups	1	8221.4	5.453	*
Within groups	24	1507.7	-	-

N.S.=not significant at $\alpha=0.05$
*=$0.05>P>0.01$

775 276

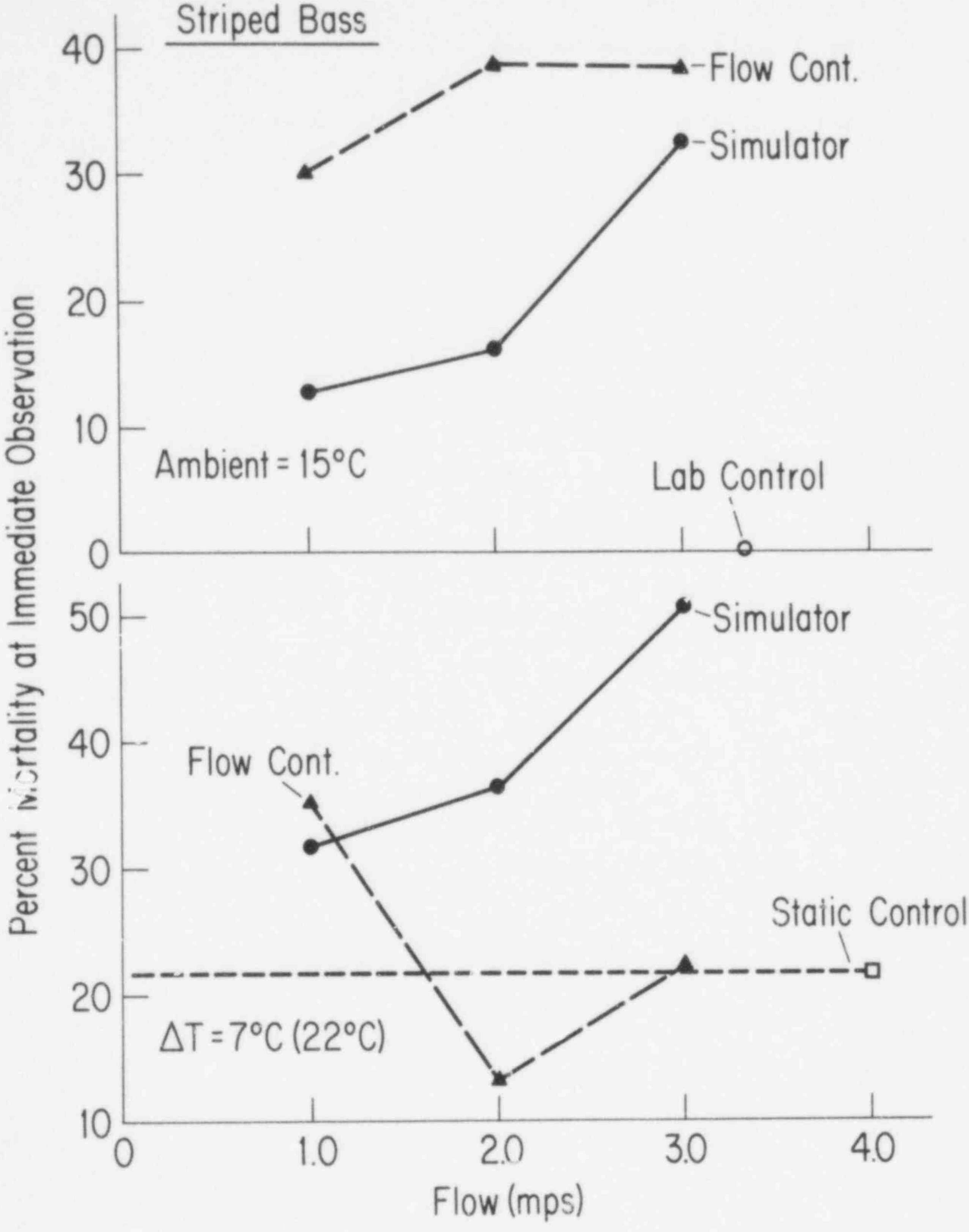

Figure 3-6 Percent mortality of flow control and condenser tube passed Morone saxatilis yolk sac larvae 3 days post hatch immediately after a 10 minute exposure at three flow rates.

775 277

Sixteen-day old larvae exhibited immediate survival greater than 95% for all exposures at ambient and at elevated temperatures (Table 3-9). By 24 h, survival for plume-entrained larvae had decreased below 50% and analyses were discontinued. Analysis of variance at the immediate observation disclosed no significant differences attributable to temperature or to exposure regime, to simulator passage versus flow control exposure regime, or to any of the three flow rates (Table 3-8b). There were no obvious trends in the mortality patterns at the immediate observation (Figure 3-7). The percentage overall survival for 16-day old larvae was significantly higher ($P < 0.05$) than that of the yolk-sac larvae exposed to similar conditions (Table 3-8c).

3.1.3. Chlorine Experiments

Striped bass yolk sac larvae (1 day post hatch) exhibited an erratic survival pattern after exposure to various chlorine doses either during plume exposure or condenser tube passage (Table 3-10). At total residual chlorine concentrations up to 0.2 ppm, survival was greater than 95% in all cases. Survival varied from 0.0% to 90% at the highest exposure dose (2.78 ppm). The mean % mortality indicated a trend of reduced survival with increasing chlorine dosage at an elevated temperature; condenser tube passed organisms showed higher mortalities than plume entrained organisms (Figure 3-8). Simulator passage was associated with higher mean

Tables 3-9. Survival of flow exposed and condenser tube passed (CTP) Morone saxatilis (post yolk sac larvae) after a 10 minute exposure to varied flow velocities at ambient temperature (16.0°C) and at an elevated temperature (ΔT=7.0°C; 23.0 actual temperature). Plume exposed were subjected only to temperature variation.

		% Survival					
Flow Rate	Temperature	CTP			Flow exposed		
		Immediate	(*)	24 hr.	Immediate	([illegible])	24 hr.
1.0 mps	Ambient	96.9	(64)	20.3	97.9	(47)	14.9
		100.0	(49)	8.2	97.9	(47)	29.8
1.0 mps	ΔT	100.0	(29)	10.3	95.7	(47)	8.5
		97.7	(43)	37.2	96.2	(52)	42.3
2.0 mps	Ambient	100.0	(35)	57.1	100.0	(49)	49.0
		100.0	(40)	17.5	95.1	(41)	39.0
2.0 mps	ΔT	95.3	(43)	65.1	100.0	(46)	21.7
		100.0	(52)	59.6	100.0	(39)	61.5
3.0 mps	Ambient	97.6	(41)	34.1	100.0	(49)	32.7
		100.0	(46)	50.0	100.0	(42)	76.2
3.0 mps	ΔT	100.0	(40)	10.0	100.0	(51)	41.2
		95.8	(48)	27.1	100.0	(50)	34.0
Plume exposed	Ambient	100.0	(49)	49.0			
		100.0	(48)	75.0			
		100.0	(50)	50.0			
Plume exposed	ΔT	100.0	(50)	32.0			
		100.0	([illegible]3)	62.5			
		100.0	(50)	54.0			

*Number exposed

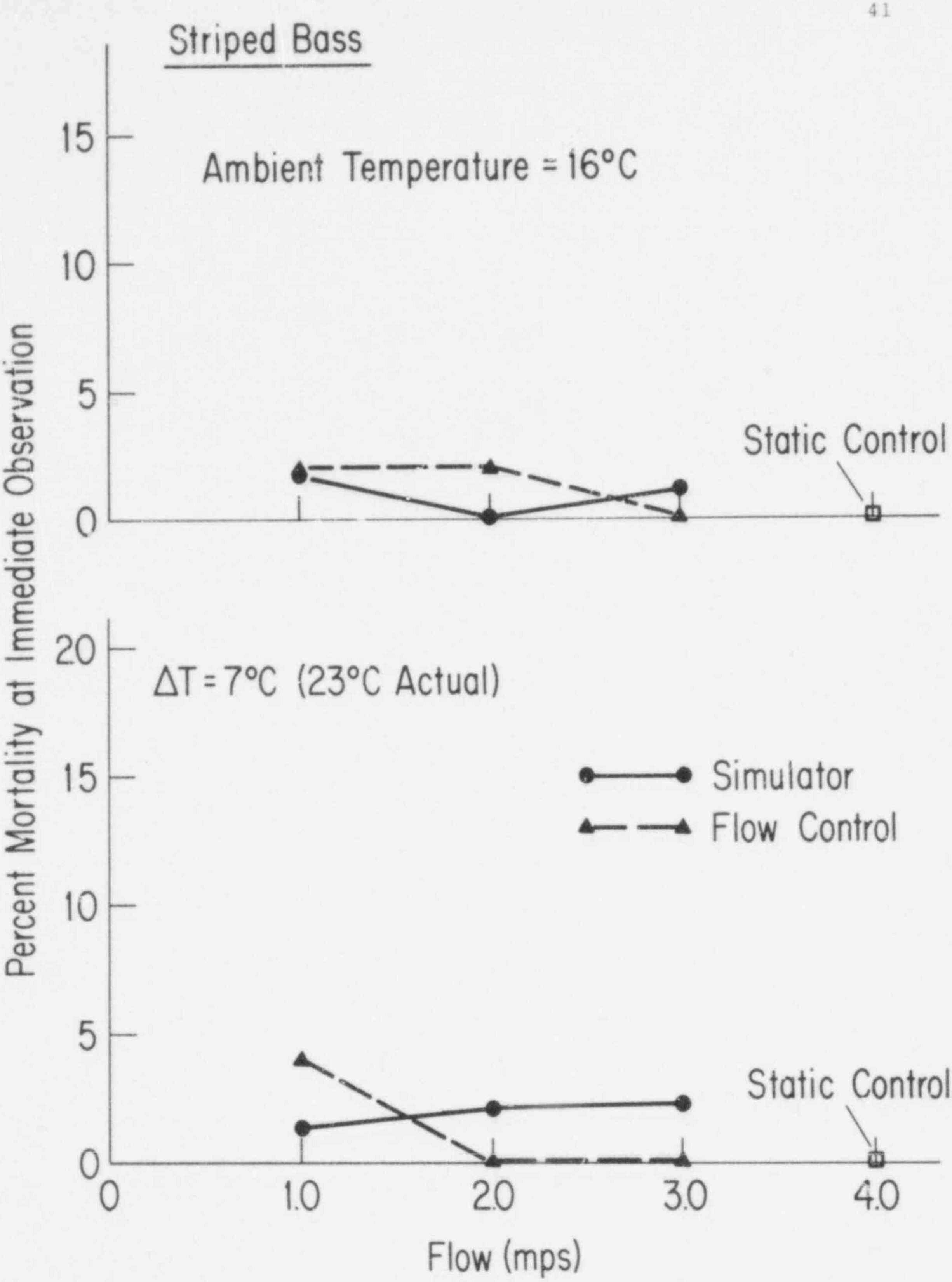

Figure 3-7 Percent mortality of flow control and condenser tube passed *Morone saxatilis* larvae 16 days post hatch immediately after a 10 minute exposure at three flow rates.

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Table 3-10. Survival of plume exposed and condenser tube passed Morone saxatilis eggs and yolk sac larvae immediately after a 10 minute exposure to varied concentrations of total residual chlorine (TRC). Bass were exposed at ambient temperature (15.0^{o}C) and at a 5.8^{o}C ΔT. Flow velocity was 2.0 mps.

TRC (ppm)	Temperature	% Survival Plume exposed		Condenser tube passed	
0.0	Ambient	100.0	(100)	100.0	(89)
		100.0	(90)	100.0	(101)
0.0	ΔT	100.0	(99)	100.0	(105)
		100.0	(94)	98.8	(83)
0.20	Ambient	99.0	(98)	98.7	(87)
		99.0	(101)	99.0	(102)
0.20	ΔT	100.0	(100)	97.9	(97)
		98.0	(100)	96.0	(99)
0.37	Ambient	96.0	(100)	81.5	(92)
		90.8	(98)	86.5	(85)
0.37	ΔT	96.8	(94)	96.7	(91)
		95.1	(103)	56.6	(66)
0.69	Ambient	91.0	(100)	56.4	(101)
		93.3	(105)	53.2	(94)
0.69	ΔT	93.7	(95)	38.7	(62)
		74.2	(93)	50.6	(85)
1.46	Ambient	79.8	(94)	55.6	(72)
		34.0	(100)	40.2	(97)
1.46	ΔT	45.8	(96)	22.5	(71)
		14.6	(96)	2.2	(90)
2.78	Ambient	74.2	(97)	45.1	(91)
		90.1	(91)	78.2	(78)
2.78	ΔT	50.0	(100)	11.1	(90)
		0.0	(72)	10.2	(98)

*Number exposed

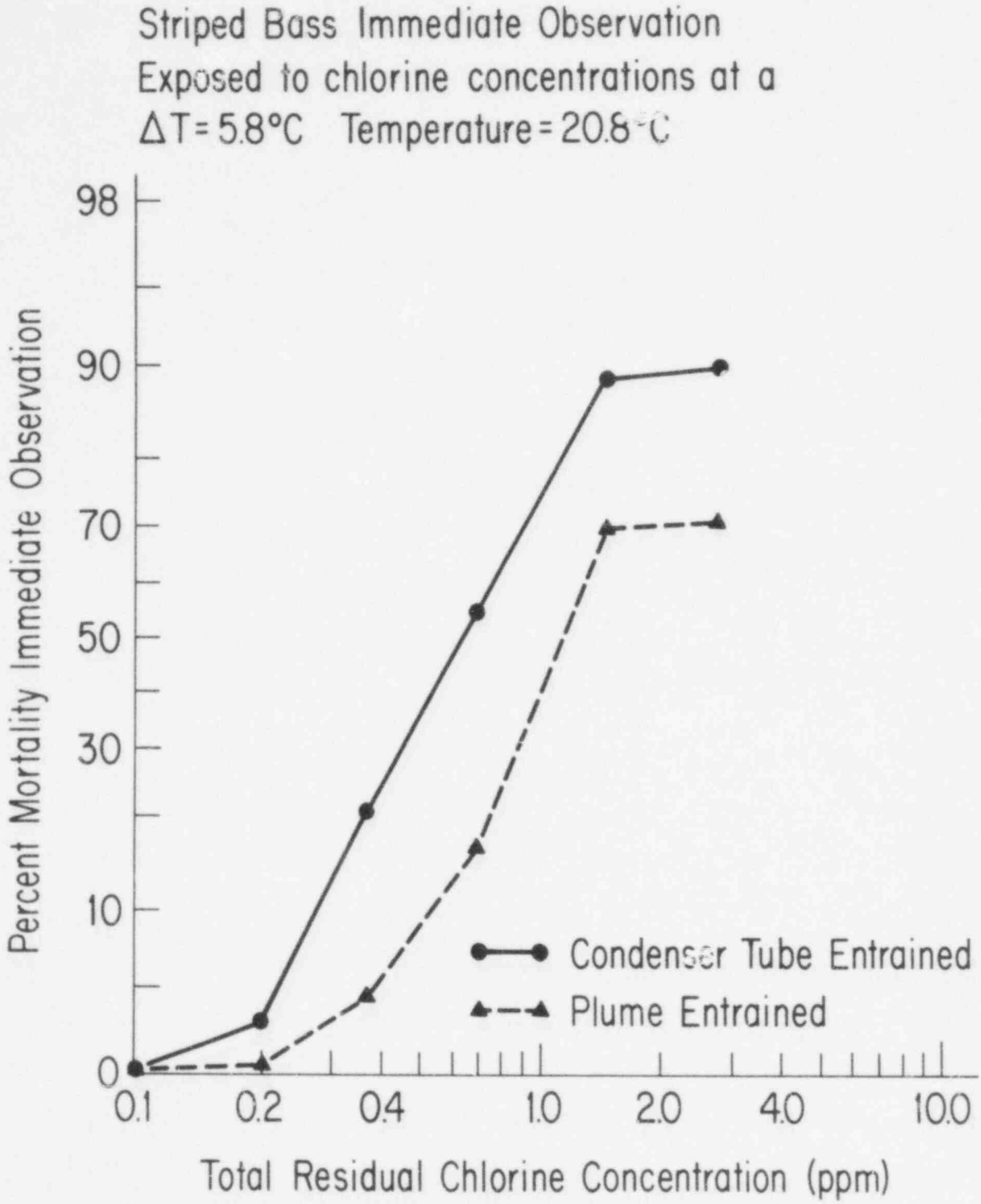

Figure 3-8 Percent mortality of plume entrained and condenser tube passed *Morone saxatilis* yolk sac larvae 1 day post hatch immediately after a 10 minute exposure to various chlorine concentrations at an elevated temperature (20.8°C).

775 282

mortalities for larvae subjected to the same doses of chlorine at ambient temperature. The highest chlorine concentration (2.78 ppm) caused an apparent increase in survival (Figure 3-9).

There were no significant differences in survival attributable to either exposure regime or to exposure temperature (Table 3-11). However, the various chlorine concentrations did have a significant effect upon survival ($P < 0.05$). All exposure data were grouped into single chlorine concentration groupings and subjected to a multiple range test by the Student-Newman-Keuls procedure. Larvae exposed to 1.46 ppm and 2.78 ppm chlorine residual had similar mean percent survivals, both less than 45%. Those exposed to the lower chlorine doses of 0.37 ppm and 0.69 ppm comprised a homogeneous subset, with a group survival of approximately 80%. At chlorine doses from 0.0 ppm to 0.37 ppm, mean survival was greater than 88%.

Striped bass larvae (31 days post hatch) were also exposed to various chlorine doses at ambient temperature (19.0°C) and at an elevated temperature (24.0°C). Immediate survival was greater than 90% for all exposures at all chlorine concentrations as high as 1.57 ppm (Table 3-12). Mean survival for all exposures at a chlorine dose of 2.78 ppm was 88%. Survival was sufficiently high among all groups to mask any differences in survival due to exposure regime, exposure temperature, or chlorine concentration (Table 3-13a).

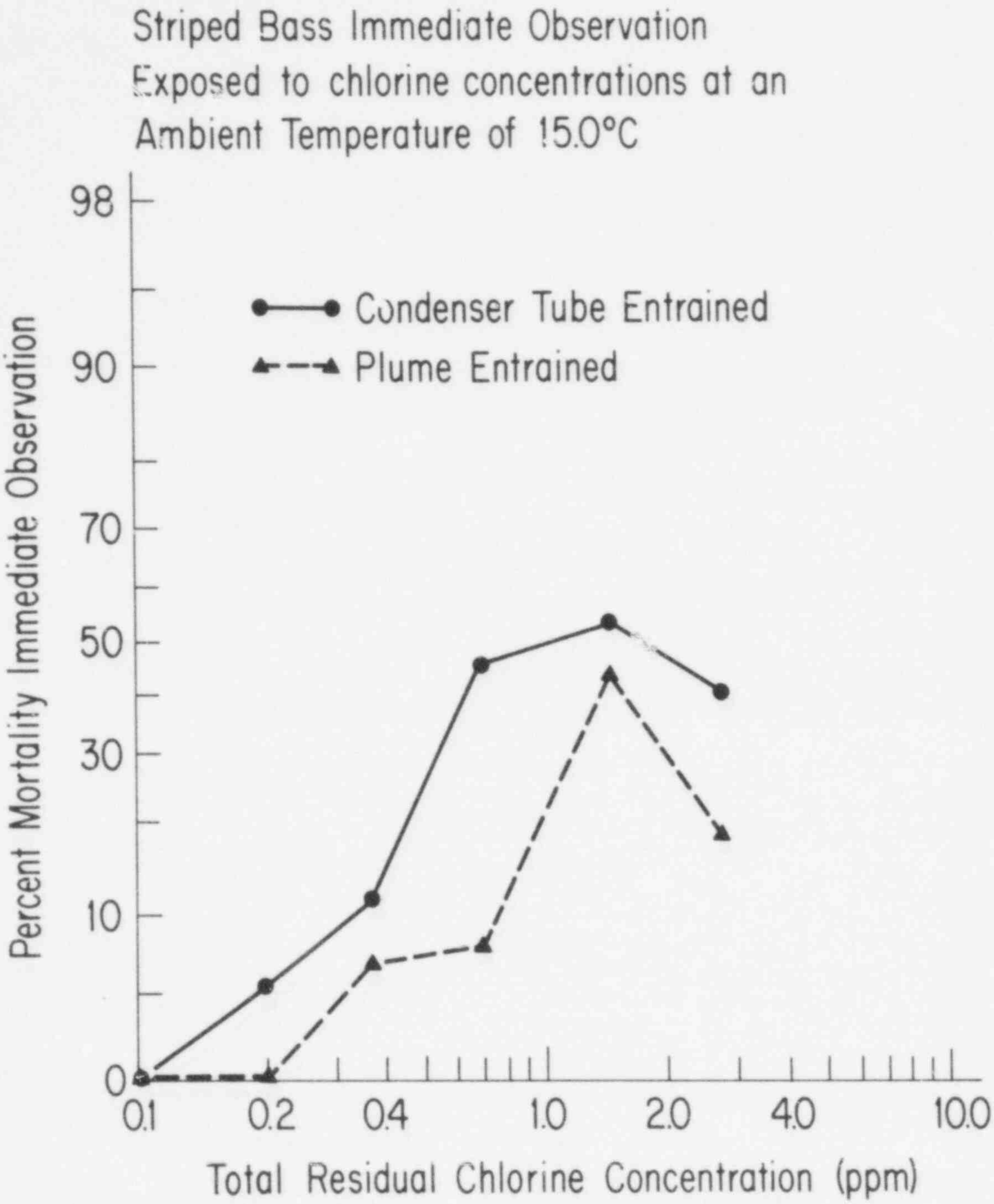

Figure 3-9 Percent mortality of plume entrained and condenser tube passed *Morone saxatilis* yolk sac larvae 1 day post hatch immediately after a 10 minute exposure to various chlorine concentrations at ambient temperature (15.0°C).

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Table 3-11. Analysis of variance of the effects of exposure regime temperature and chlorine exposure on survival of *Morone saxatilis* yolk sac larvae immediately after a 10 minute exposure.

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	1271.3	0.856	N.S.
Among temperature groups	1	1551.8	1.045	N.S.
Among chlorine groups	5	3917.2	2.639	*
Within groups	24	14[illegible]4.4	-	-

N.S.=not significant at α=0.05

*=0.05>P>0.01

Table 3-12. Survival of plume exposed and condenser tube passed (CTP) Morone saxatilis post yolk sac larvae after a 10 minute exposure to varied concentrations of total residual chlorine (TRC). Bass were exposed at ambient temperature (19.0°) and at a 5.0°C ΔT. Flow velocity was 2.0 mps.

TRC(ppm	Temperature	% Survival									
		Plume exposed				CTP					
		Immed.	(*)	24 hr.	48 hr.	Immed.	(*)	24 hr.	48 hr.		
0.0	Ambient	100.0	(50)	96.0	94.0	100.0	(47)	89.4	87.2		
		100.0	(51)	90.2	76.5	100.0	(39)	82.1	79.5		
0.0	ΔT	100.0	(49)	79.6	71.4	100.0	(51)	72.5	64.7		
		100.0	(49)	81.6	71.4	100.0	(54)	59.3	51.9		
0.14	Ambient	100.0	(51)	94.1	86.3	93.5	(46)	65.2	63.0		
		100.0	(51)	86.3	82.4	100.0	(51)	84.3	74.5		
0.14	ΔT	100.0	(52)	82.7	75.0	100.0	(50)	42.0	38.0		
		100.0	(50)	88.0	74.0	98.0	(50)	62.0	34.0		
0.29	Ambient	100.0	(52)	84.6	71.2	100.0	(55)	52.7	43.6		
		98.0	(51)	98.0	96.0	100.0	(49)	40.8	38.8		
0.29	ΔT	100.0	(51)	80.4	74.5	97.9	(47)	38.3	34.0		
		100.0	(48)	66.7	56.3	100.0	(44)	15.9	13.6		
0.68	Ambient	100.0	(50)	86.0	78.0	98.2	(56)	30.4	28.6		
		100.0	(50)	78.0	70.0	100.0	(49)	40.8	40.8		
0.68	ΔT	98.0	(51)	41.2	35.3	97.9	(47)	10.6	10.6		
		100.0	(51)	90.2	84.3	100.0	(55)	16.4	16.4		
1.57	Ambient	100.0	(53)	28.3	20.8	100.0	(40)	0.0	0.0		
		100.0	(47)	12.8	12.8	100.0	(39)	0.0	0.0		
1.57	ΔT	100.0	(50)	0.0	0.0	100.0	(51)	0.0	0.0		
		100.0	(50)	0.0	0.0	100.0	(53)	0.0	0.0		
2.73	Ambient	94.1	(51)	2.0	2.0	97.9	(47)	0.0	0.0		
		83.7	(49)	0.0	0.0	83.3	(48)	0.0	0.0		
2.73	ΔT	94.5	(55)	0.0	0.0	100.0	(52)	0.0	0.0		
		75.5	(49)	0.0	0.0	72.5	(51)	0.0	0.0		

*Number exposed

Table 3-13. Analysis of variance of the effects of exposure regime, temperature and chlorine dosage on survival of *Morone saxatilis* larvae after a 10 minute exposure.

A. Immediate observation

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	4.1	0.014	N.S.
Among temperature groups	1	1.0	0.003	N.S.
Among chlorine groups	5	379.9	1.329	N.S.
Within groups	24	285.0	-	-

B. 24 hour observation

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	3433.8	10.104	**
Among temperature groups	1	1318.9	3.881	N.S.
Among chlorine groups	5	6222.3	18.310	***
Within groups	24	339.8	-	-

C. 48 hour observation

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	2665.1	9.077	**
Among temperature groups	1	1385.7	4.719	*
Among chlorine groups	5	5198.7	17.705	***
Within groups	24	293.6	-	-

N.S.=not significant at $\alpha=0.05$
*=0.05>P>.01
**=.01>P>.001
***=P<.001

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Survival was reduced at 24 h after exposure due to handling and holding, and due to latent effects of the imposed stresses (Table 3-12). Total mortality occurred among condenser tube passed organisms at 1.57 ppm at both ambient and ΔT exposures. Plume entrained animals at the same chlorine dose had low (< 30%) survival at ambient temperature. Mortality at ambient temperature shows a trend of mortality increasing with chlorine dose and with simulator condenser tube passage (Figure 3-10). Mean mortality at an elevated ΔT increased with chlorine concentration and with condenser tube passage (Figure 3-11). The differential survival was attributable to exposure regime ($P < 0.01$) and chlorine concentration ($P < 0.001$) (Table 3-13b).

Data were grouped by exposure regime and chlorine concentration and subjected to a multiple range test by a Student-Newman-Keuls procedure. For plume entrained larvae, homogeneous survival subsets were formed by exposures to 1.57 ppm and 2.75 ppm with mean survivals of 10% and 1%; all exposures at 0.68 and less had 24 h group survival of greater than 70%. In contrast, condenser tube passed animals formed three homogeneous subsets: 1.57 ppm and 2.75 ppm exposures with 0% group mean survival; 0.29 ppm and 0.68 ppm exposures with 37% and 25% group mean survival; and 0.0 ppm and 0.14 ppm exposure with 76% and 63% group mean survival.

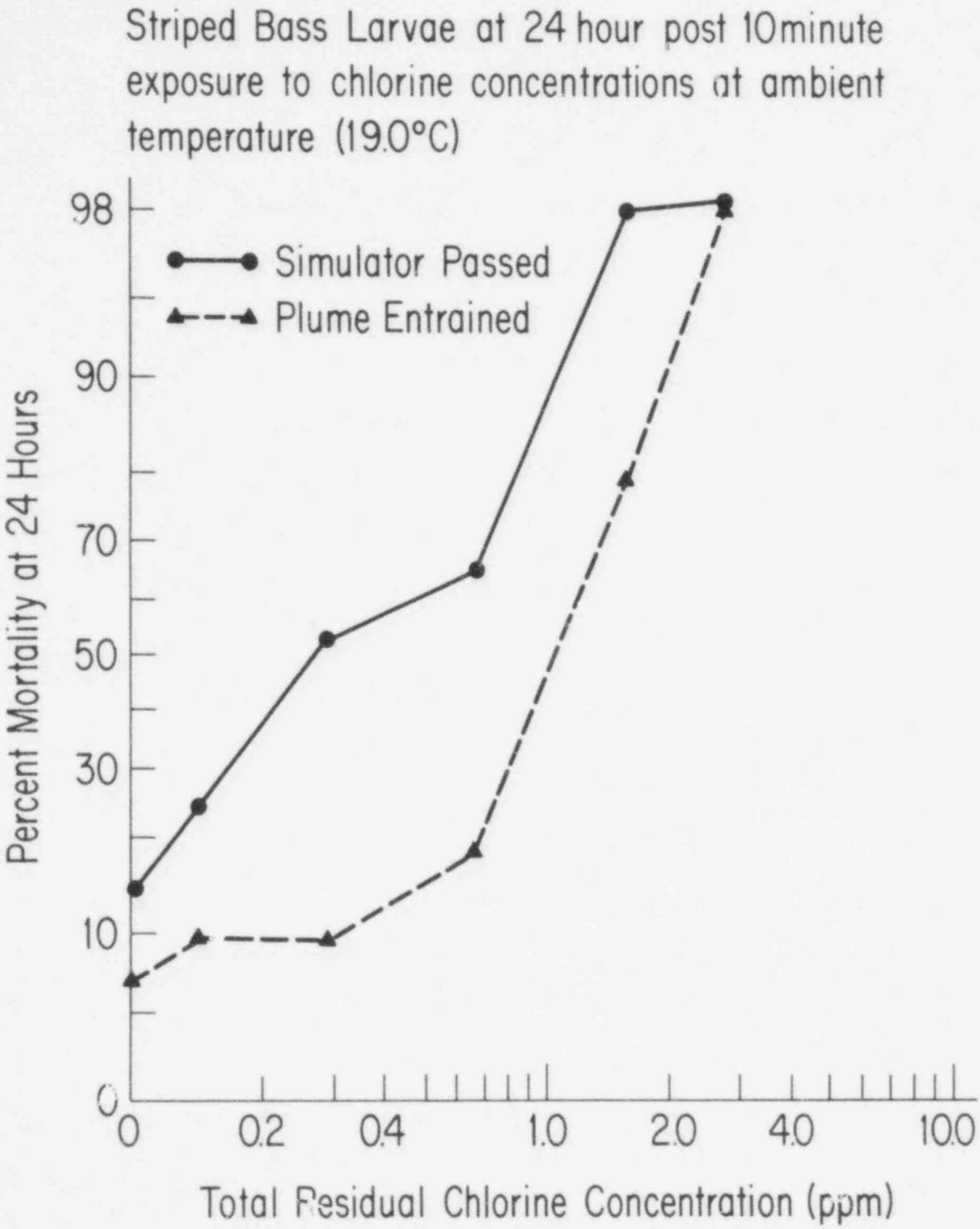

Figure 3-10 Percent mortality of plume entrained and condenser tube passed Morone saxatilis larvae 31 days post hatch at 24 h after a 10 minute exposure to various chlorine concentrations at ambient temperature ($19.0^{o}C$).

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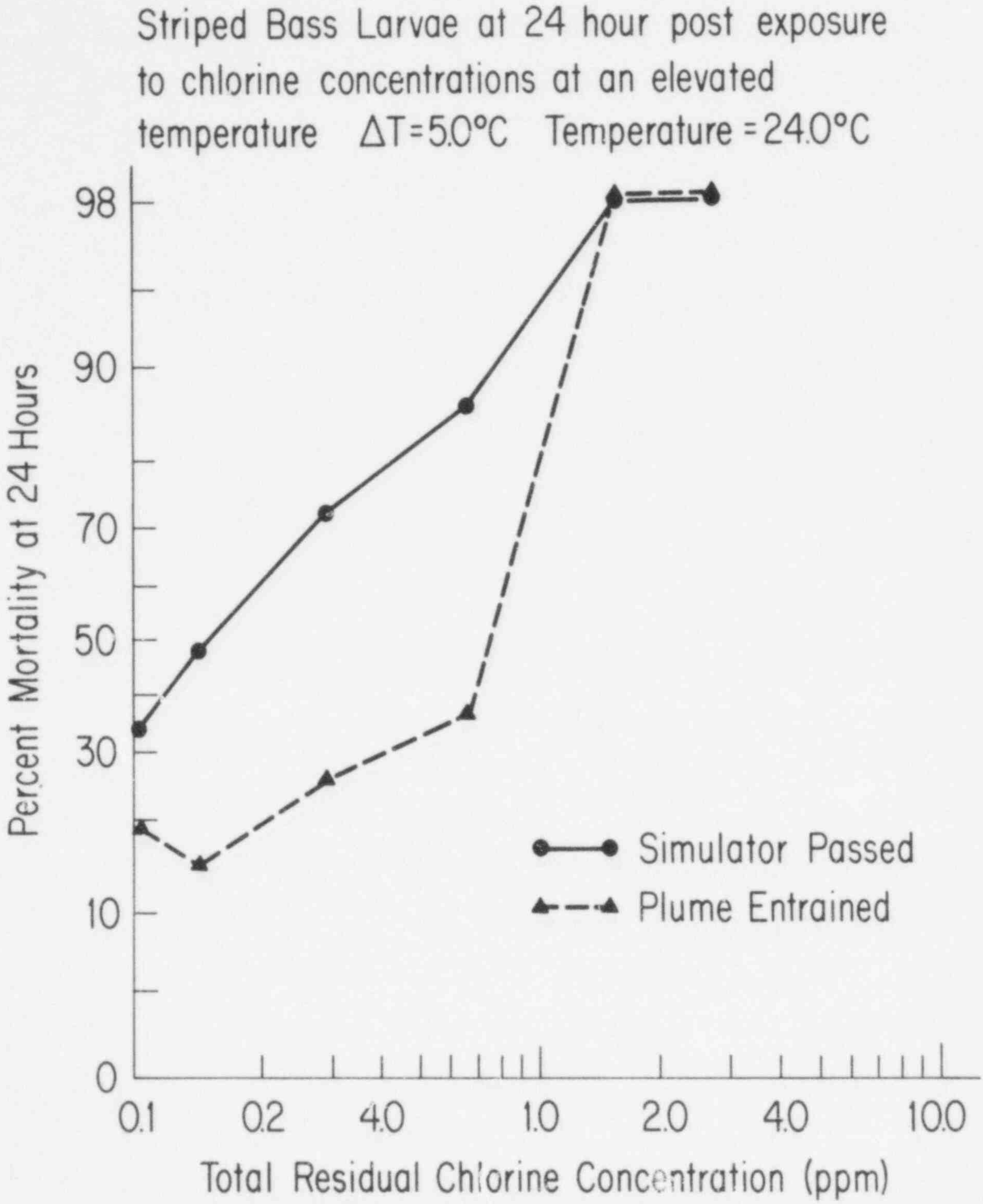

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Figure 3-11 Percent mortality of plume entrained and condenser tube passed Morone saxatilis larvae 31 days post hatch at 24 h after a 10 minute exposure to various chlorine concentrations at an elevated temperature (24.0°C).

Percent survival 48 h after exposure showed statistically significant differences in survival due to exposure groups ($P < 0.01$), temperature of exposure ($P < 0.05$) and residual chlorine concentration ($P < 0.001$) (Table 3-13c). Data were grouped and analyzed according to thermal exposure, plume entrained or condenser tube passed, and chlorine concentration. Two homogeneous subsets were formed for plume-entrained larvae by exposure to high concentration, 1.57 ppm and 2.73 ppm residual chlorine, and by exposure at 0.68 ppm and lower residual chlorine doses. The high dosage group had mean survival of 9% at ambient temperature and 0% at an elevated temperature. The lower dosage group had mean survival of 82% at ambient temperature and 68% at an elevated temperature.

Forty-eight hour post exposure mean survival at ambient temperature was grouped into four subsets: chlorine survival was 0% at 1.57 ppm and 2.73 ppm and 35% and 41% at 0.68 ppm and 0.29 ppm chlorine. At 0.14 ppm, survival was 69%, increasing to 83% at 0.0 ppm chlorine. When condenser tube passage occurred at an elevated temperature, three homogeneous subsets were formed at the 48 h observation. Group mean survival was 9% at 0.29 ppm and all higher doses. Group mean survival was 29% at 0.29 ppm and 0.14 ppm, and 58% at 0.0 ppm.

3.2 Gammarus spp. Results

3.2.1 Temperature Experiments

Survival of Gammarus spp. exposed for 10 minutes to a series of elevated temperatures was higher immediately after exposure than after 24 h (Table 3-14). At final temperatures approaching the upper lethal limit of Gammarus, this is particularly apparent. Only the observations at 24 h were used in statistical analysis.

Factorial analysis of variance incorporating the 24 h survival data (Table 3-15a) showed a significant effect of exposure regime ($P < .05$) and elevated temperature ($P < .001$) on the survival of Gammarus spp. The pattern of increasing mortality with increasing temperature was enhanced in condenser tube passed animals as compared to those subjected to plume entrainment (Figure 3-12).

Identification of homogeneous subsets by multiple range tests employing the Student-Newman-Keuls procedure ($P < .05$) showed that survival of plume entrained Gammarus exposed for 10 minutes to temperatures up to 39.0°C was not significantly lower than that at ambient temperature. Similar exposure at 40.5°C, however, resulted in 100% mortality after 24 h (Table 3-14). In contrast, Gammarus survival after condenser tube exposure to 40.5°C and to 39.0°C was significantly lower than survival at all other test temperatures with a combined survival of 14%. Even survival at 38.0°C

Table 3-14. Survival of plume entrained and condenser tube passed <u>Gammarus</u> spp. after a 10 minute exposure to elevated temperatures. Ambient temperature was 22.0°C.

Temperature (°C)	(ΔT) (°C)	% Survival: Plume entrained, Immediate	(*)	24 hr.	% Survival: Condenser tube passed, Immediate	(*)	24 hr.
22.0	(0.0)	100.0	(40)	97.5	100.0	(37)	100.0
		100.0	(38)	100.0	100.0	(30)	96.7
36.0	(15.0)	95.1	(41)	92.7	90.6	(32)	78.1
		97.8	(45)	95.6	89.1	(46)	87.0
38.0	(17.0)	100.0	(40)	95.0	89.5	(38)	65.8
		100.0	(40)	77.5	93.2	(45)	66.7
39.0	(17.0)	79.5	(39)	71.8	61.5	(39)	17.9
		90.5	(42)	84.2	58.3	(36)	44.4
40.5	(19.0)	11.9	(42)	0.0	0.0	(41)	0.0
		12.5	(40)	0.0	5.8	(52)	0.0

*Number exposed

Table 3-15. Analysis of variance of the effects of exposure regime and temperature on the survival of <u>Gammarus</u> spp. at 24 hours after exposure.

A. 10 Minute Exposure

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	606.2	4.969	*
Among temperature groups	4	4263.1	34.948	***
Within groups	10	122.0	-	-

B. 30 Minute Exposure

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	1009.4	4.890	*
Among temperature groups	5	2922.5	14.157	***
Within groups	12	206.4	-	-

*=0.05>P>0.01

***=P<0.001

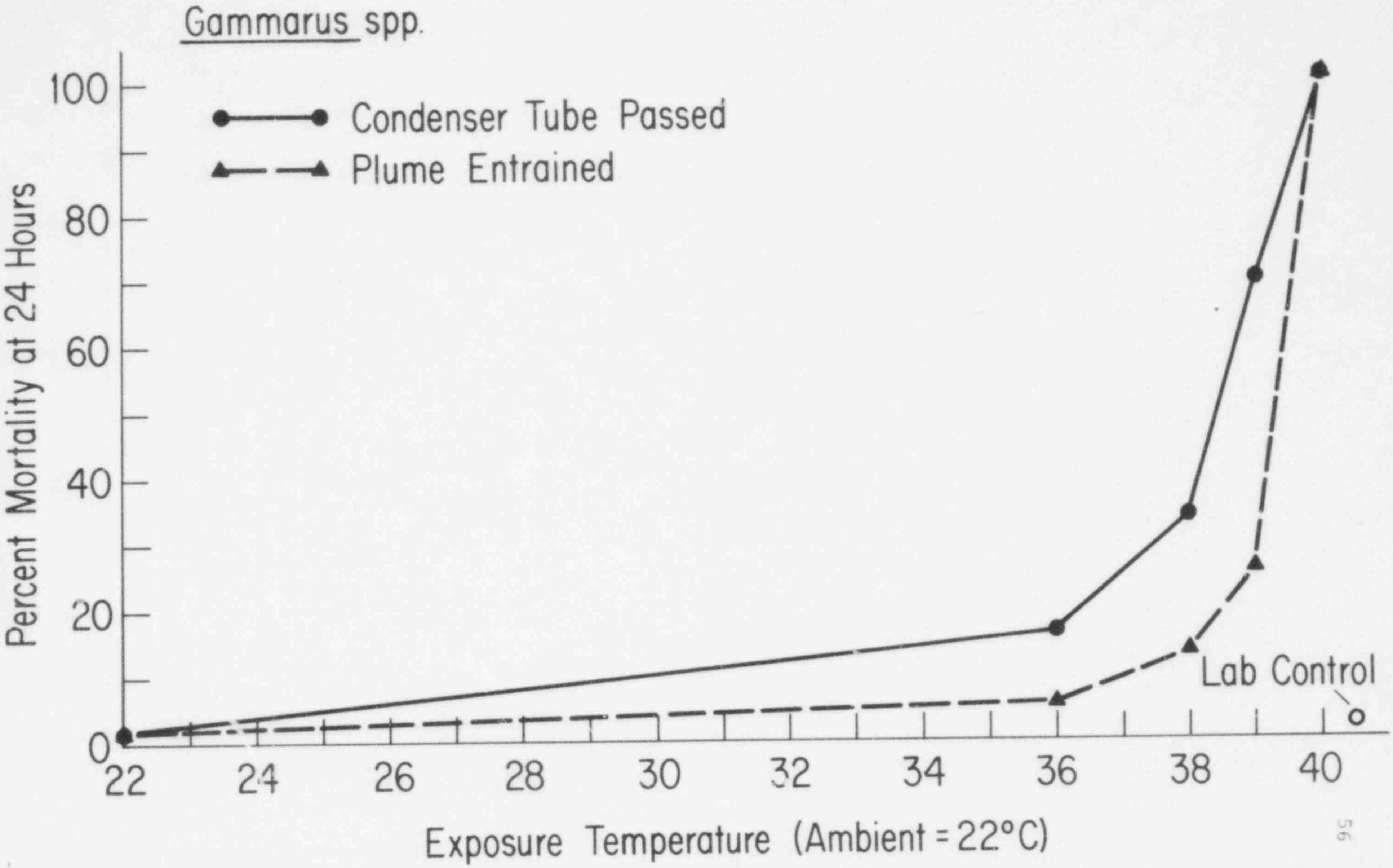

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Figure 3-12 Percent mortality of plume entrained and condenser tube passed Gammarus spp. at 24 h after a 10 minute exposure to elevated temperatures.

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and 36.0°C combined (74%) was significantly less than at 36.0°C and ambient combined (90% mean survival).

Survival patterns of <u>Gammarus</u> exposed for 30 minutes to a series of elevated temperatures above an ambient of 26.75°C was best demonstrated at observations 24 h after exposure (Table 3-16; Figure 3-13). Analysis of variance of 30 minute exposure data separates exposure regime ($P < .05$) and temperature increments ($P < .001$) as factors responsible for altered survival (Table 3-15b). The effect of temperature increase in decreasing survival was more pronounced in condenser tube entrained animals than in plume entrained animals.

Latent (24 h) survival data arranged into homogeneous subsets indicated that test temperatures up to 38.75°C resulted in no significant survival reduction in 30 minute plume entrained <u>Gammarus</u> as compared to ambient controls. Similar exposure to 40.75°C, however, reduced survival to less than 30%. In contrast, for condenser tube passed gammarids, a test temperature of 40.75°C resulted in total mortality, while exposure to 38.75°C reduced survival to a mean of approximately 50%. Only at test temperatures of 32.75, 34.75 and 36.75°C did these condenser tube passed amphipods exhibit survival comparable to ambient (26.75°C) exposed controls.

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Table 3-16. Survival of plume entrained and condenser tube passed *Gammarus* spp. after a 30 minute exposure to elevated temperatures. Ambient temperature was 26.75°C.

Temperature (°C)	(ΔT)	% Survival: Plume entrained Immediate	(*)	24 hr.	Condenser tube passed Immediate	(*)	24 hr.
26.75	(0.0)	97.4	(38)	94.7	100.0	(15)	100.0
		100.0	(42)	100.0	95.0	(20)	95.0
32.75	(6.0)	100.0	(41)	97.6	100.0	(51)	96.1
		100.0	(40)	100.0	100.0	(31)	100.0
34.75	(8.0)	100.0	(37)	100.0	93.5	(31)	80.6
		100.0	(41)	97.6	100.0	(48)	100.0
36.75	(10.0)	100.0	(40)	97.5	92.3	(39)	76.9
		92.5	(40)	92.5	95.8	(24)	87.5
38.75	(12.0)	100.0	(37)	89.2	91.7	(12)	66.7
		100.0	(37)	97.3	63.2	(19)	42.1
40.75	(14.0)	51.4	(35)	28.6	0.0	(47)	0.0
		31.6	(38)	15.8	0.0	(43)	0.0

*Number exposed

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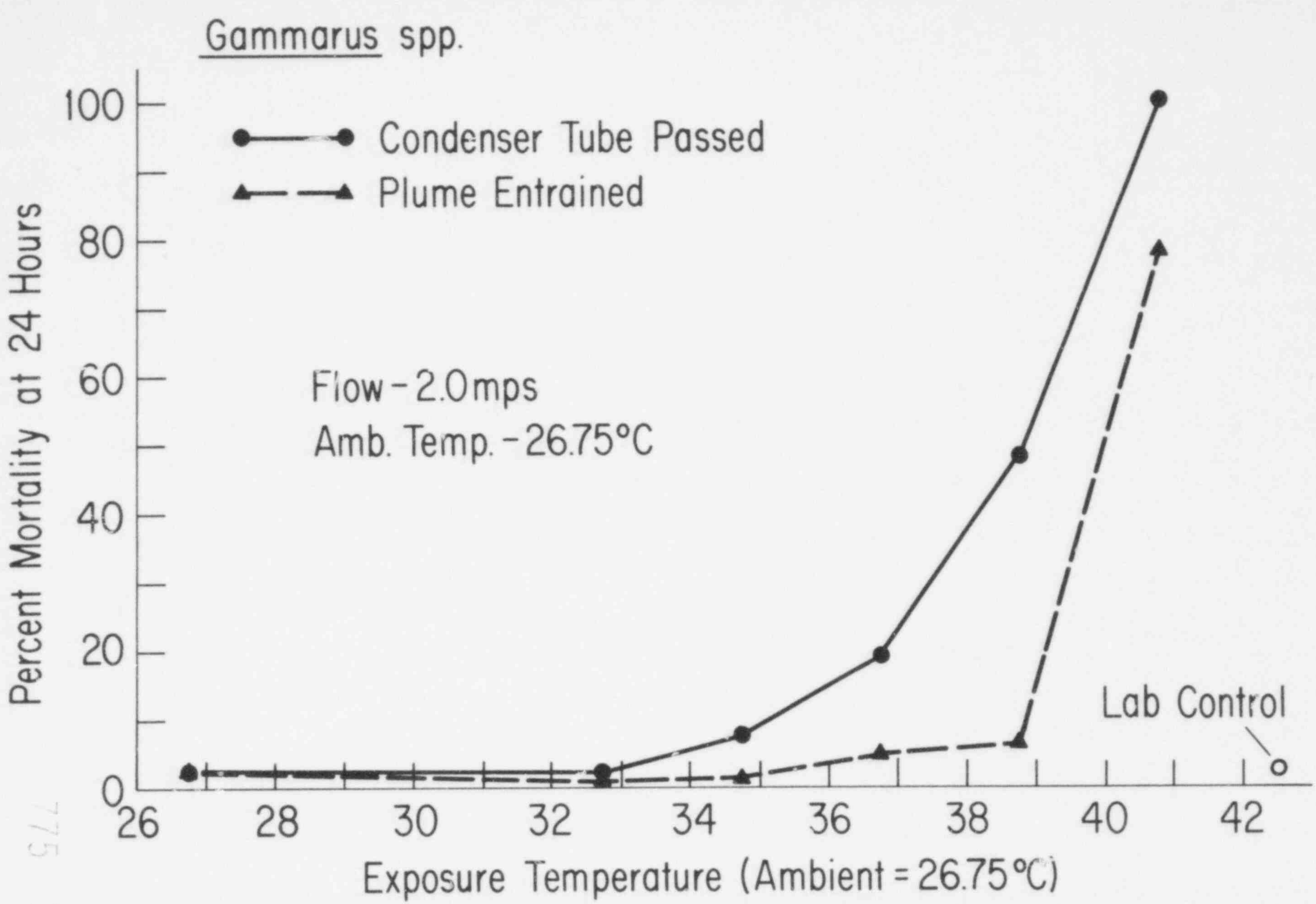

Figure 3-13 Percent mortality of plume entrained and condenser tube passed *Gammarus* spp. at 24 h after a 30 minute exposure to elevated temperatures.

3.2.2 Flow Experiments

Exposure of Gammarus spp. to flow rates of 1.0, 2.0 and 3.0 meters per second had no detectable effect on immediate or 24 h mortality (Figure 3-14). Results of factorial ANOVA showed that no significant differences in survival existed among the three exposure groups (condenser tube entrained, plume entrained, flow), between two temperature groups, (ambient and sublethal ΔT) or among the three flow rate groups (Table 3-17b).

3.2.3 Chlorine Experiments

Immediate observation of high Gammarus survival after exposure to a series of total residual chlorine doses at ambient temperature gave misleadingly low estimates of chlorination impact (Table 3-18). Observations 24 h after exposure indicate, more closely, the magnitude of impact of chlorination on the species.

Mean survival at 24 h after exposure to a range of chlorine residuals from 0.13 ppm to 0.59 ppm was greater than 90%. At 1.37 ppm and 2.95 ppm residual chlorine, survival of plume entrained Gammarus was reduced to 59.7% and 6.3% respectively (Table 3-18).

Condenser tube passed Gammarus spp. showed no reduction in survival after 24 h to chlorine concentrations of from 0.14 ppm to 0.49 ppm. Gammarus exposed to condenser tube passage and 0.55 ppm chlorine showed 24 h survival reduced to approximately 79%, while mean survival percentages of

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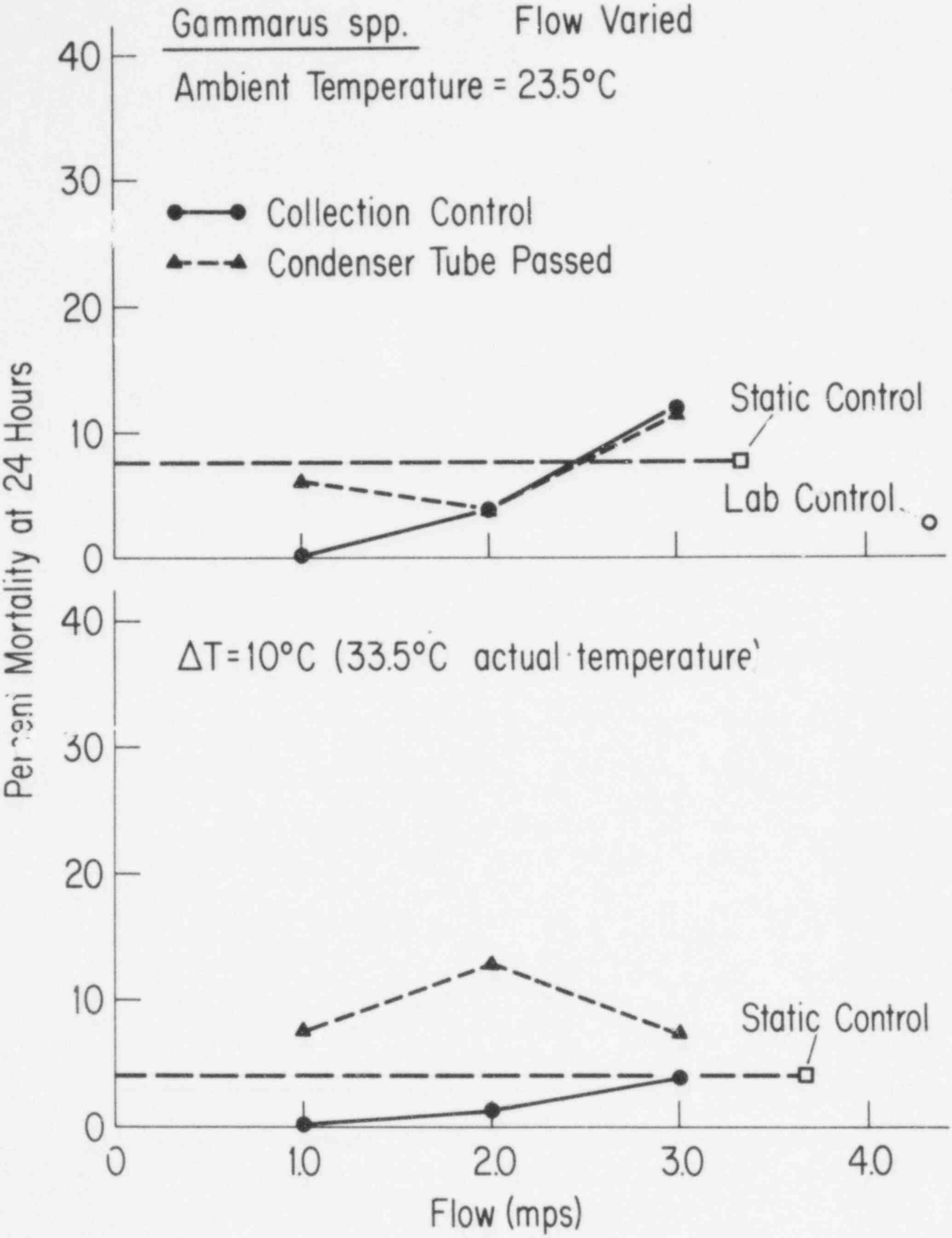

Figure 3-14 Percent mortality of flow control and condenser tube passed *Gammarus* spp. at 24 h after a 10 minute exposure to three flow rates.

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Table 3-17. Analysis of variance of the effects of exposure regime, temperature, and flow rate on the survival of *Neomysis americana* (A) and *Gammarus* spp. (B) at 24 hours after a 10 minute exposure.

A. *Neomysis americana*

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	34.2	0.109	N.S.
Among temperature groups	1	101.4	0.323	N.S.
Among flow rate groups	2	101.8	0.325	N.S.
Within groups	12	313.7	-	-

B. *Gammarus* spp.

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	2	171.4	0.383	N.S.
Among temperature groups	1	1.0	0.002	N.S.
Among flow rate groups	2	136.8	0.305	N.S.
Within groups	18	447.9	-	-

N.S.=not significant at α=0.05

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Table 3-18. Survival of plume entrained (PE) and condenser tube passed (CT) *Gammarus* spp. after a 10 minute exposure to various doses of chlorine measured as parts per million total residual chlorine (TRC). Ambient temperatures ranged from 18.0°C to 25.0°C.

TRC(ppm)	% Survival Plume entrained Immediate	(*)	24 hr.	TRC	Condenser tube passed Immediate	(*)	24 hr.
0.0	100.0	(38)	100.0	0.0	97.3	(37)	94.6
	100.0	(42)	90.5		100.0	(43)	9[illegible].7
0.13	100.0	(43)	88.4	0.14	100.0	(32)	96.9
	100.0	(40)	95.0		100.0	(52)	86.5
0.21	100.0	(33)	97.0	0.20	100.0	(40)	97.5
	100.0	(32)	81.3		100.0	(35)	91.4
0.49	100.0	(41)	97.6	0.49	100.0	(31)	100.0
	100.0	(38)	89.5		100.0	(39)	100.0
0.53	100.0	(28)	89.3	0.55	100.0	(23)	100.0
	100.0	(34)	100.0		97.4	(38)	65.8
0.59	100.0	(38)	94.7	0.66	86.1	(36)	66.7
	100.0	(44)	97.7		80.8	(26)	76.9
1.37	78.9	(38)	21.7	1.37	84.2	(38)	18.4
	100.0	(39)	97.4		88.6	(44)	84.1
2.95	69.2	(39)	7.7	2.63	80.0	(35)	40.0
	65.9	(41)	4.9		88.4	(43)	41.9

*Number exposed

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71.0, 53.7 and 41.0 resulted from chlorine concentrations of 0.66 ppm, 1.37 ppm and 2.63 ppm respectively.

The chlorine residual concentration at which 50% mortality had occurred at 24 h (LC-50) vary only slightly between plume entrained (LC-50; 1.5 ppm) and condenser tube passed Gammarus (LC-50; 1.6 ppm) (Figure 3-15).

For exposures at elevated temperatures (31.0°C) the latent survival at 24 h provides a stronger indication of chlorination stress than the immediate observation. At 24 h survival was greater than 90% for plume entrained Gammarus exposed to the residual chlorine range from 0.12 ppm to 0.74 ppm with the exception of reduced survival of Gammarus exposed at 0.40 ppm chlorine (74.5% at 24 h) (Table 3-19; Figure 3-16). Reductions in survival to 46.7% and to 6.4% occurred at 1.37 ppm and 2.10 ppm chlorine respectively.

Gammarus exposed to condenser tube passage and 31.0°C with chlorination showed no apparent survival reduction over the range of 0.15 ppm to 0.49 ppm chlorine concentration (Table 3-19; Figure 3-16). Twenty-four hour survival of Gammarus over this range of chlorination was greater than 85%. Survival was reduced to 75.0% at 0.80 ppm residual chlorine, to 23.2% at 1.36 ppm and to 13.8% at 3.40 ppm.

Condenser tube passage at 31.0°C reduced survival to 50% with a dose of approximately 1.02 ppm residual chlorine. Plume entrainment at 31.0°C required approximately 1.35 ppm chlorine to reduce survival to 50%.

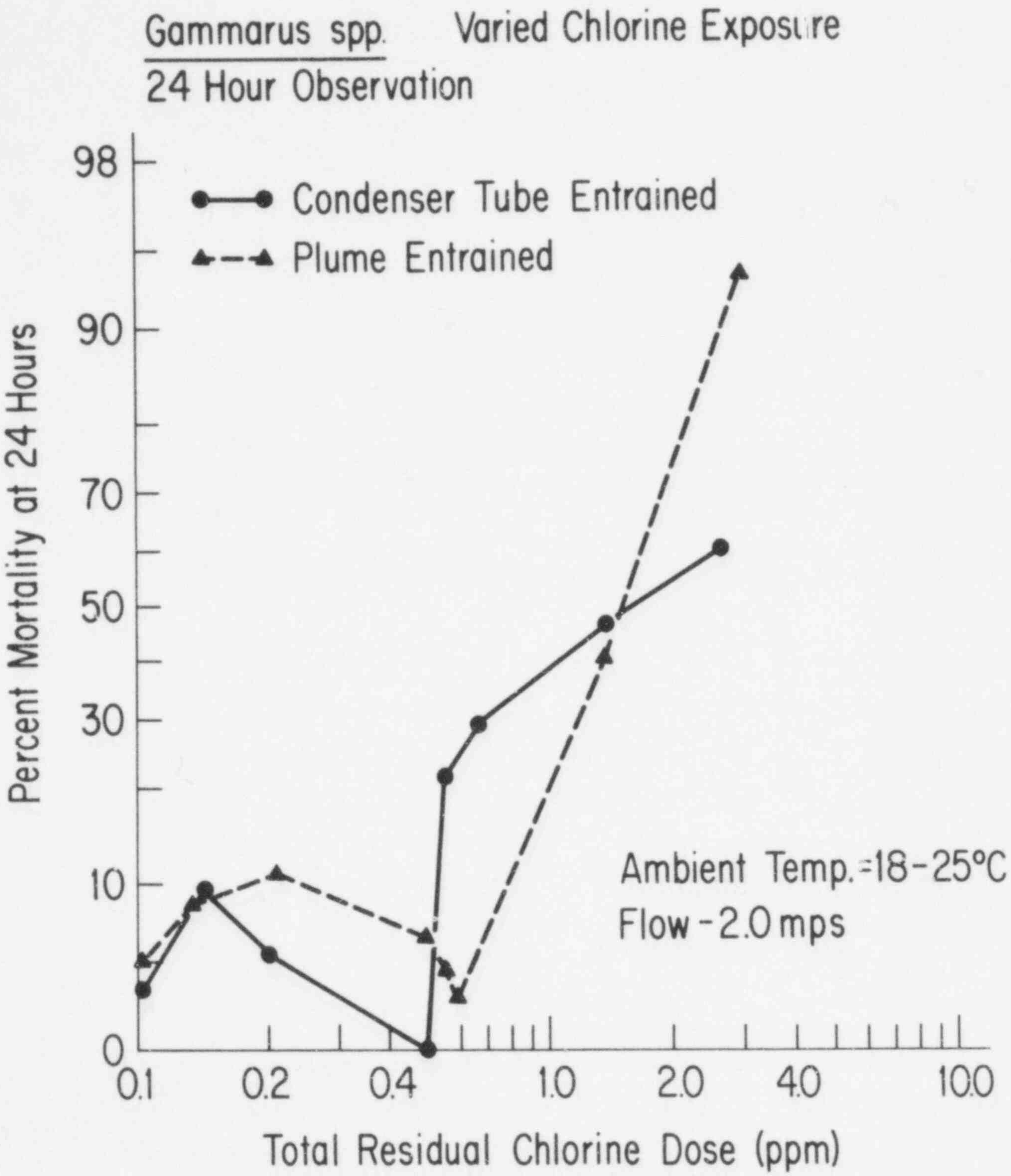

Figure 3-15 Percent mortality of plume entrained and condenser tube passed Gammarus spp. at 24 h after a 10 minute exposure to various chlorine concentrations at ambient temperature.

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Table 3-19. Survival of plume entrained (PE) and condenser tube passed (CT) Gammarus spp. after a 10 minute exposure to various doses of chlorine measured as parts per million total residual chlorine (TRC) and an elevated temperature. Final temperature of 31.0°C with ambient temperatures ranging from 18-25°C.

	% Survival						
TRC(ppm)	Plume entrained			TRC	Condenser tube passed		
	Immediate	(*)	24 hr.		Immediate	(*)	24 hr.
0	100.0	(33)	97.0	0	94.9	(39)	82.1
	100.0	(40)	95.0		100.0	(40)	92.5
0.12	100.0	(38)	92.1	0.15	100.0	(48)	100.0
	92.7	(41)	92.7		100.0	(43)	93.0
0.18	100.0	(42)	97.6	0.20	100.0	(43)	93.0
	100.0	(35)	97.1		100.0	(45)	73.3
0.40	100.0	(30)	83.3	0.47	96.6	(29)	89.7
	100.0	(25)	64.0		96.7	(30)	83.3
0.49	100.0	(36)	91.7	0.49	100.0	(56)	91.1
	100.0	(38)	100.0		100.0	(44)	95.5
0.74	100.0	(41)	100.0	0.80	82.4	(34)	76.5
	100.0	(38)	97.4		91.2	(34)	73.5
1.36	75.0	(36)	0.0	1.36	70.5	(44)	0.0
	100.0	(39)	89.7		80.4	(51)	43.1
2.10	80.0	(45)	11.1	3.40	78.0	(50)	14.0
	63.6	(33)	0.0		76.3	(59)	13.6

*Number exposed

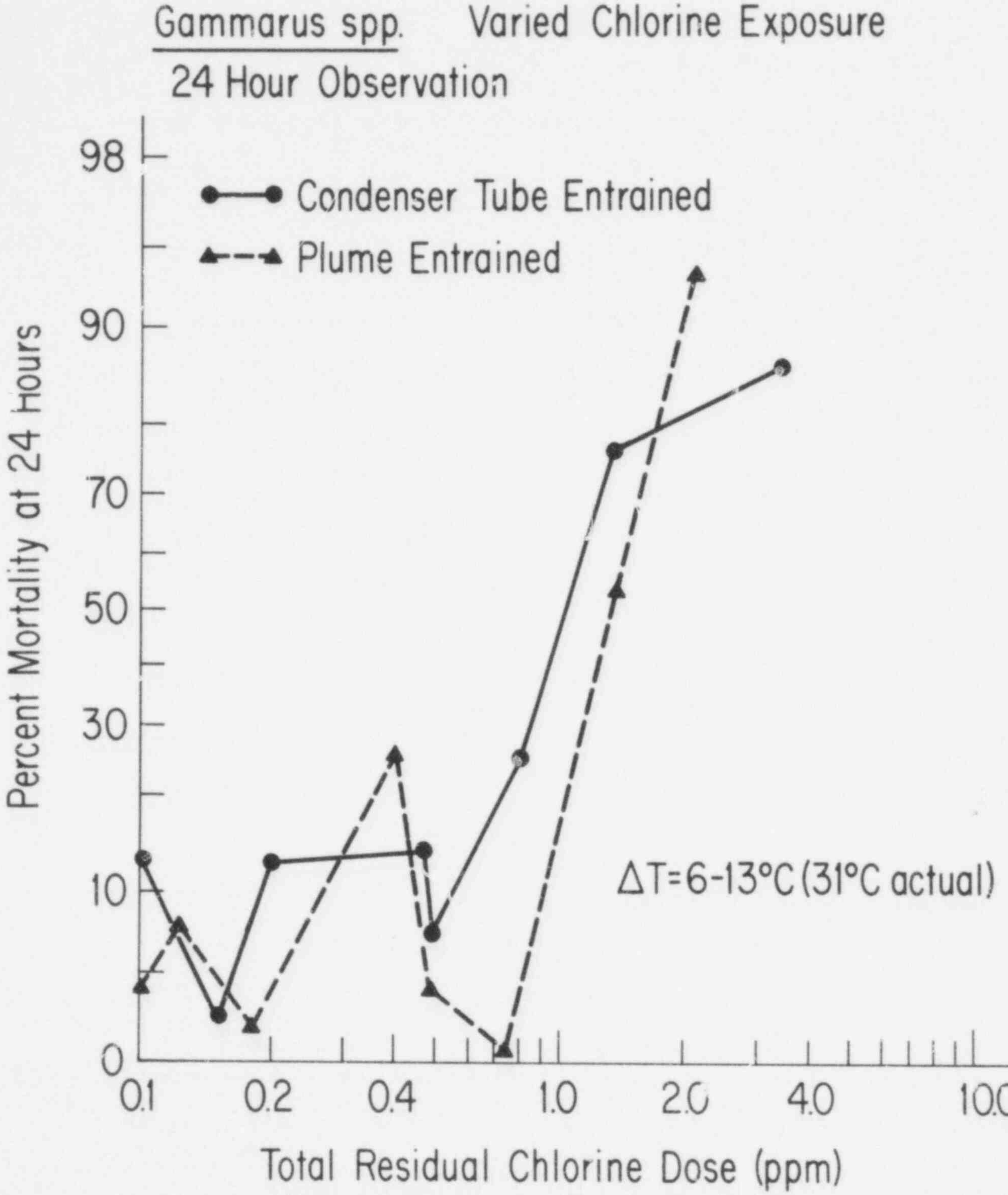

Figure 3-16 Percent mortality of plume entrained and condenser tube passed *Gammarus* spp. at 24 h after a 10 minute exposure to various chlorine concentrations at an ambient temperature (31.0°C).

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3.3 Neomysis americana Results

3.3.1 Temperature Experiments

Neomysis americana was exposed to an array of elevated temperatures during condenser tube passage and during plume entrainment for 10 minute and 30 minute exposure periods.

Mysids survived 10 minute exposures at temperatures up to 34.75°C regardless of the mode of exposure (i.e., condenser tube passage or plume entrainment) based upon immediate observations (Table 3-20). Significant decreases in percent survival following a 10 minute ΔT of 10.0°C (36.75°C) were observed immediately in both exposure regimes. Only 1.2% of the plume entrained and none of the condenser tube passed organisms were able to withstand this exposure. Latent mortalities at 24 hours post exposure rose sharply within a span of 4.0°C (32.75-36.75°C) in the condenser tube passed group, whereas a similar increase in mortality occurred over a span of 2.0°C (34.75-36.75°C) within the plume entrained group (Figure 3-17).

After 24 hours neither group displayed survival following exposure to 36.75°C. The 24 hour post exposure data were subjected to analysis of variance to identify the effects of exposure mode and temperature and their interactions upon the survival patterns of Neomysis americana. Statistically significant differences in percent survival can be attributed to the effects of exposure groups ($P < 0.01$) and to effects of temperature ($P < .001$) (Table 3-21a). Greater mortality

Table 3-20. Survival of plume entrained and condenser tube passed Neomysis americana after a 10 minute exposure to elevated temperatures. Ambient temperature was 26.75°C.

Temperature, °C	(ΔT)	% Survival: Plume Entrained: Immediate	(*)	Plume Entrained: 24 hr.	Condenser Tube Passed: Immediate	(*)	Condenser Tube Passed: 24 hr.
26.75	(0.0)	100.0	(38)	81.6	100.0	(60)	80.0
		100.0	(40)	80.0	100.0	(47)	87.2
28.75	(2.0)	100.0	(40)	92.5	97.9	(48)	81.3
		100.0	(43)	93.0	100.0	(58)	82.8
30.75	(4.0)	100.0	(39)	87.2	100.0	(53)	84.9
		100.0	(41)	90.2	100.0	(49)	83.7
32.75	(6.0)	100.0	(45)	77.8	96.7	(61)	77.0
		100.0	(39)	82.1	100.0	(55)	83.6
34.75	(8.0)	92.3	(39)	71.8	75.9	(54)	44.4
		97.7	(44)	75.0	68.5	(54)	37.0
36.75	(10.0)	2.5	(40)	0.0	0.0	(37)	0.0
		0.0	(42)	0.0	0.0	(62)	0.0

*Number exposed

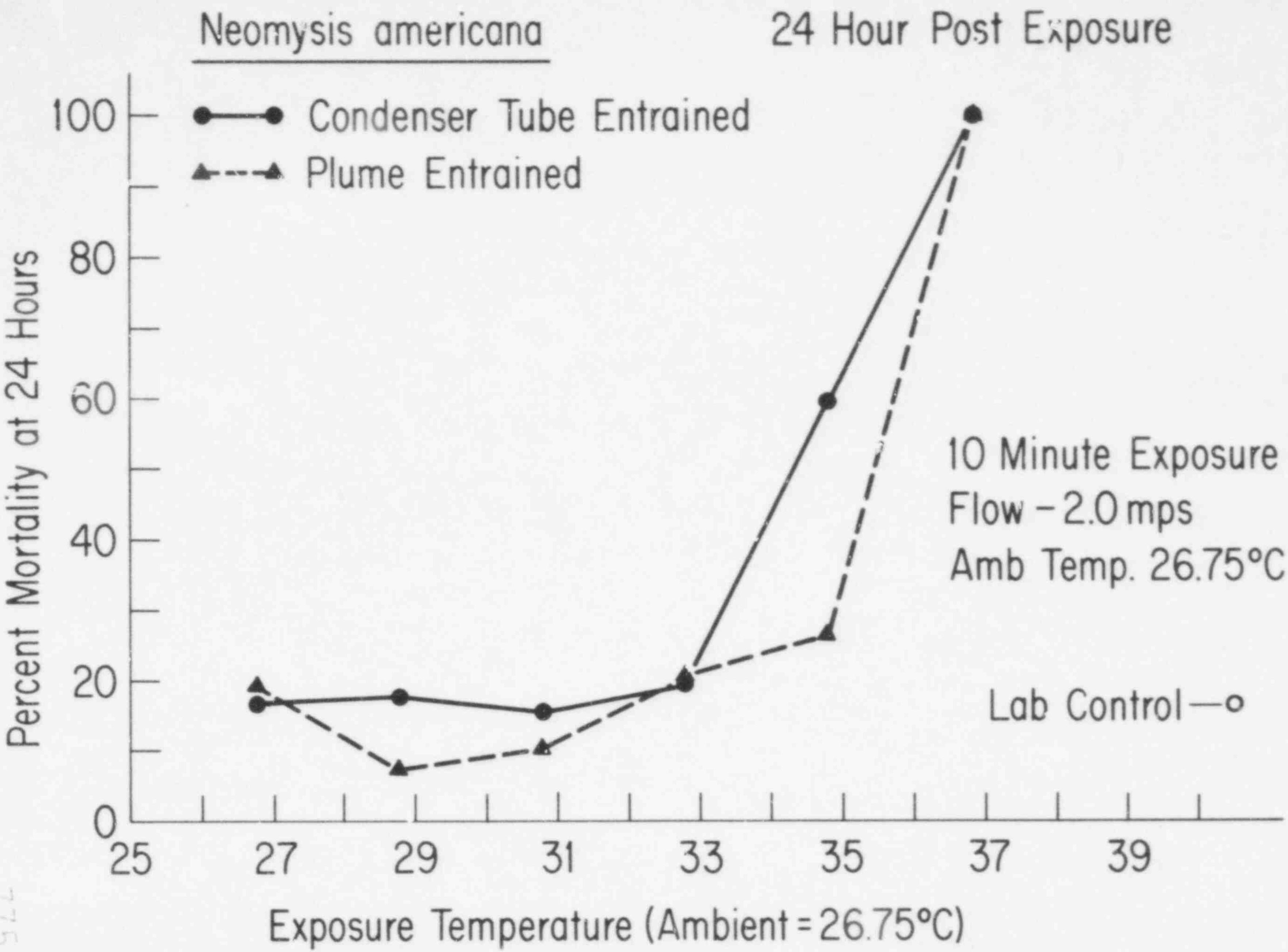

Figure 3-17 Percent mortality of plume entrained and condenser tube passed Neomysis americana at 24 h after a 10 minute exposure to elevated temperatures.

Table 3-21. Analysis of variance of the effects of exposure regime and temperature on the survival of *Neomysis americana* 24 hours after exposure.

A. 10 minute exposure

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	150.0	9.447	**
Among temperature groups	5	2879.9	181.335	***
Within groups	12	15.9	-	-

B. 30 minute exposure

Source of variation	d.f.	Mean Square	F	P
Among exposure groups	1	130.0	1.137	N.S.
Among temperature groups	5	4312.3	37.716	***
Within groups	12	114.3	-	-

N.S.=not significant α=0.05

**=0.01>P>0.001

***=P<0.001

was due to condenser tube passage than to plume entrainment. A final temperature of 34.75° to 36.75°C caused significantly reduced survival, while temperatures of 26.75 to 32.75°C were sublethal.

The 30 minute exposure groups subjected to 35.25°C exhibited decreased survival compared to organisms exposed to 33.25°C (Table 3-22). Within this 2.0°C range (33.25-35.25°C), the mean survival for the plume entrained mysids decreased from 100.0% to 50.8% and for the condenser tube passed organisms from 92.6% to 3.2%. At 36.25°C, there was no survival in either exposure regime at the immediate observation.

The mean percent mortality of the condenser tube passed organisms at the 24 hour observation increased by 24.5% between 31.25°C and 33.25°C, and by 66.3% between 33.25°C and 35.25°C (Figure 3-18). Temperatures up to 33.25°C did not significantly decrease the survival of plume entrained animals during a 30-minute exposure (Table 3-22). Latent decreases in percent survival analyzed by factorial analysis of variance methods showed significant differences due to the effects of temperature but indicated no significant effect due to exposure regime (Table 3-21b). A Student-Newman-Keuls procedure indicated that exposure to 35.25 and 36.25°C produced homogeneous subsets characterized by very high mortality (greater than 95%). Exposure at 33.25°C and less was characterized by mortality indistinguishable from ambient controls.

Table 3-22. Survival of plume entrained and condenser tube passed Neomysis americana after a 30 minute exposure to elevated temperature. Ambient temperature was 26.25°C.

Temperature, °C	(ΔT)	% Survival: Plume Entrained, Immediate	(*)	24 hr.	% Survival: Condenser Tube Passed, Immediate	(*)	24 hr.
26.25	(0.0)	100.0	(41)	90.2	100.0	(52)	94.2
		100.0	(45)	75.6	100.0	(44)	84.1
29.25	(3.0)	100.0	(46)	91.3	95.9	(49)	89.8
		97.6	(42)	85.7	97.9	(47)	97.9
31.25	(5.0)	100.0	(40)	95.0	97.7	(43)	93.0
		100.0	(41)	95.1	97.5	(40)	95.0
33.25	(7.0)	100.0	(37)	97.3	93.6	(47)	70.2
		100.0	(46)	93.5	91.7	(48)	68.8
35.25	(9.0)	59.1	(44)	27.3	2.4	(42)	2.4
		41.9	(43)	14.0	3.8	(53)	3.8
36.25	(10.0)	0.0	(41)	0.0	0.0	(45)	0.0
		0.0	(36)	0.0	0.0	(45)	0.0

*Number exposed

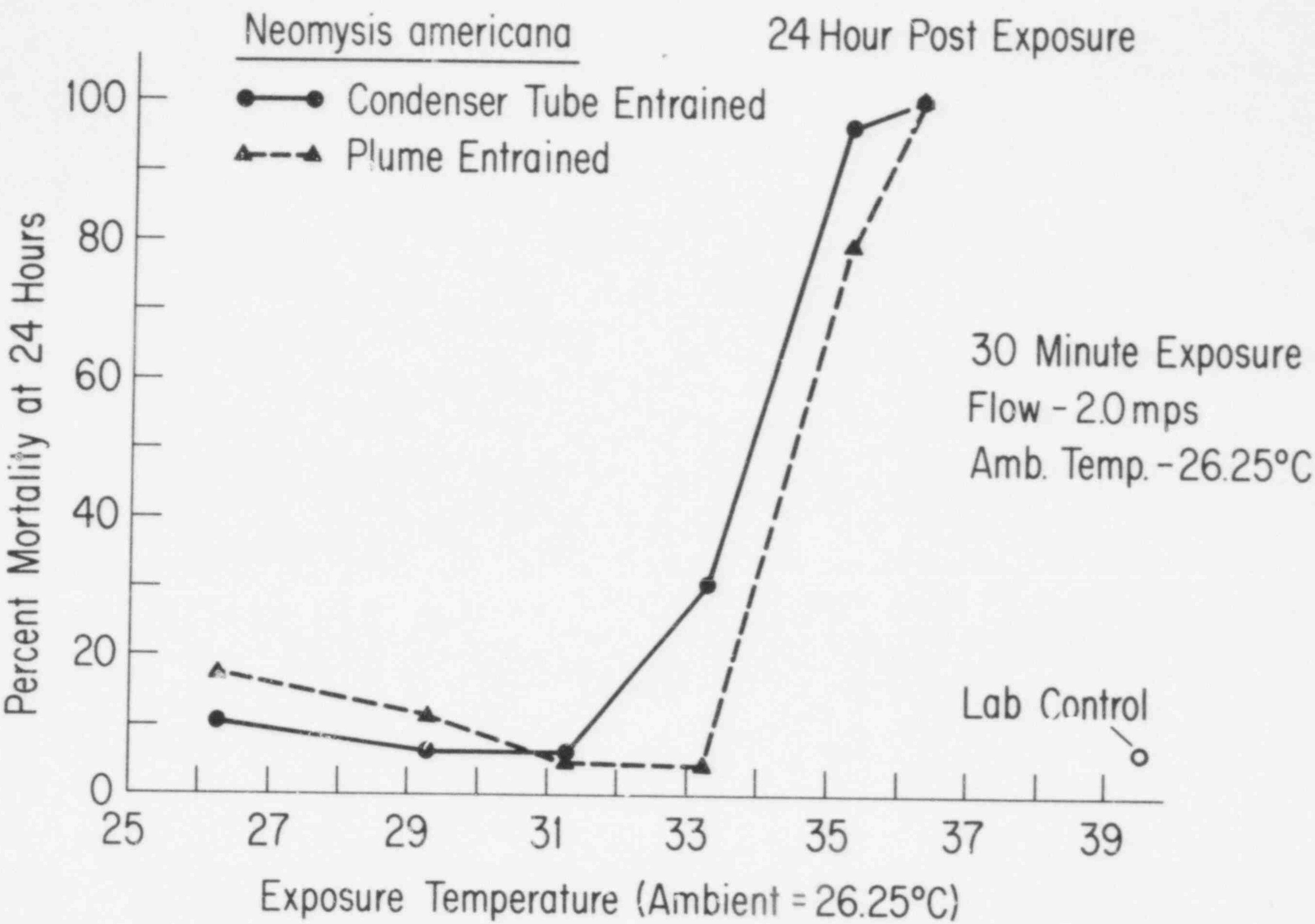

Figure 3-18 Percent mortality of plume entrained and condenser tube passed *Neomysis americana* at 24 h after a 30 minute exposure to elevated temperatures.

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3.3.2 Flow Experiments

Ten minute exposures to either 1.0. 2.0, or 3.0 meter per second condenser tube flow velocities were imposed upon two groups of N. americana. One group was subjected to ambient temperatures of 22.5-24.0°C and the other to a sublethal ΔT producing a final temperature of 30.0°C. Sublethal temperatures superimposed upon increasing flow velocities did not cause increased mortality; neither did exposure at ambient temperatures, regardless of the time of observation (Table 3-23). In all immediate observations, the percent survival approached 100.0%; identical to the values of plume entrained organisms that had served as controls. After 24 hours, only two exposures revealed mean mortality in excess of 10 percent (Figure 3-19); 1.0 mps condenser tube passage at ambient temperature (10.8%) and 1.0 mps flow controls at 30.0°C (15.2%).

The 24 hour percent survival data were employed in an analysis of variance test to identify possible effects or interactions among exposure regimes, temperatures, and flow rates. All results proved non-significant at $P < 0.05$ (Table 3-17A).

3.3.3 Chlorine Experiments

Ten minute exposure of N. americana to a variety of total residual chlorine concentrations was conducted at ambient temperatures (21.5°C-24.0°C) and at a ΔT of 6.0°C to 8.5°C resulting in a final temperature of 30.0°C.

Table 3-23. Survival of condenser tube passed and flow exposed *Neomysis americana* after a 10 minute exposure to various flow rates at ambient temperature (24.0°C) and at an elevated temperature (ΔT=6, 30.0°C actual temperature). Plume exposed animals were exposed only to temperature.

		% Survival					
		CTP			Flow exposed		
Flow Rate	Temperature	Immediate	(*)	24 hr.	Immediate	(*)	24 hr.
1.0	Ambient	97.9	(47)	87.2	100.0	(41)	97.6
		100.0	(45)	91.1	100.0	(34)	94.1
1.0	ΔT	100.0	(40)	87.5	100.0	(38)	89.5
		100.0	(44)	93.2	97.8	(45)	80.0
2.0	Ambient	95.3	(43)	95.3	100.0	(36)	91.7
		100.0	(50)	100.0	100.0	(44)	97.7
2.0	ΔT	97.6	(41)	90.2	97.4	(38)	94.7
		100.0	(50)	100.0	94.3	(35)	91.4
3.0	Ambient	100.0	(29)	100.0	95.0	(40)	92.5
		100.0	(29)	93.1	100.0	(44)	97.7
3.0	ΔT	100.0	(37)	94.6	100.0	(41)	95.1
		100.0	(40)	92.5	100.0	(43)	90.7
Plume entrained	Ambient	100.0	(35)	85.7			
		100.0	(43)	100.0			
		100.0	(41)	100.0			
Plume entrained	ΔT	100.0	(34)	88.2			
		100.0	(43)	95.3			
		100.0	(41)	92.7			

*Number exposed

775 315

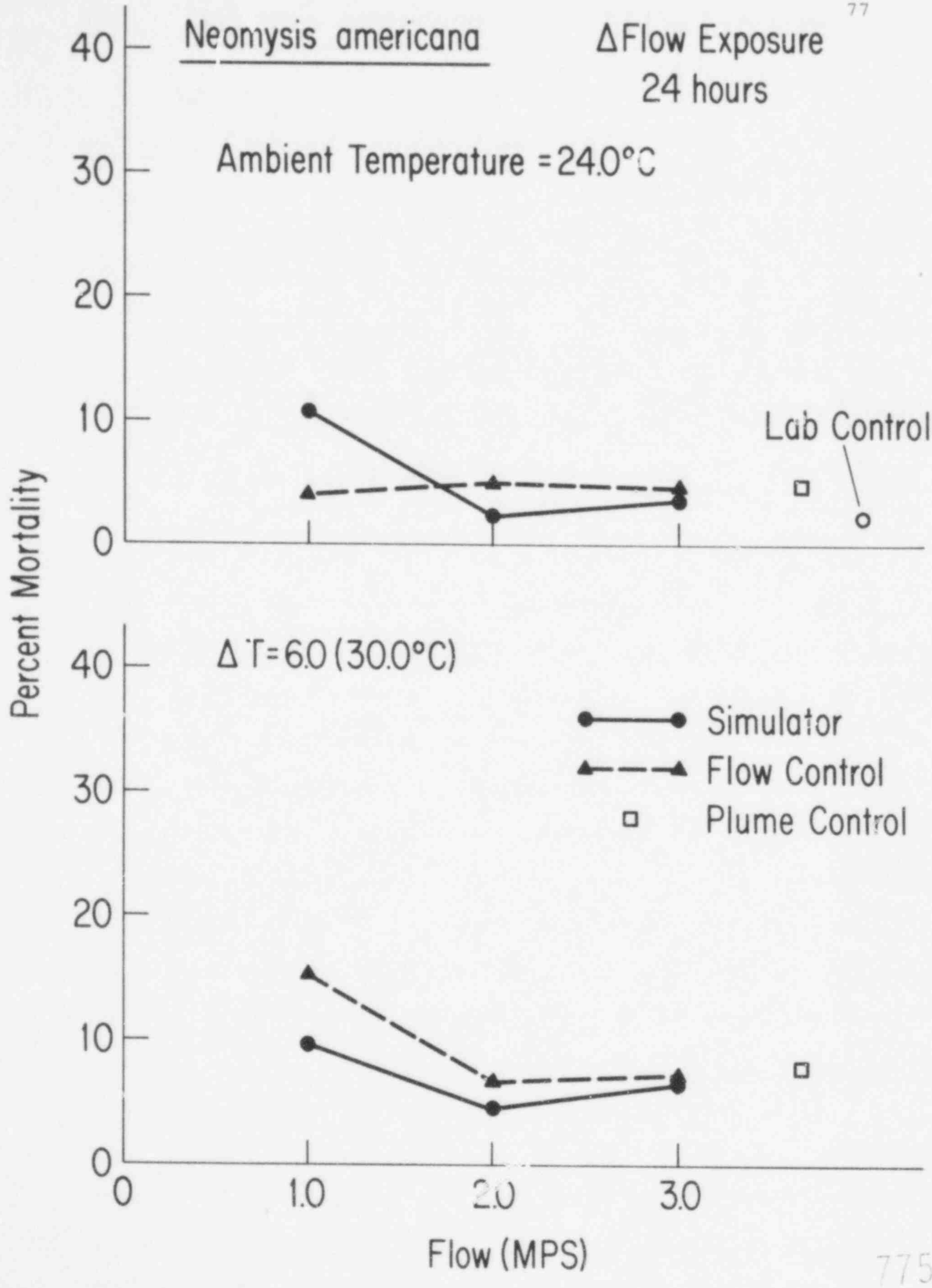

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Figure 3-19 Percent mortality of flow control and condenser tube passed Neomysis americana at 24 h after a 10 minute exposure to three flow rates.

At ambient temperatures, both immediate and 24 hour post exposure percent survival varied with chlorine concentration and exposure regime (Table 3-24). A mean percent mortality exceeding 50% for plume entrained organisms did occur within the chlorine exposure range of 1.33 to 1.80 ppm (Figure 3-20). At a concentration of 2.4[illegible] ppm, the mean percent survival of plume entrained mysids was reduced sharply (1% survival) at immediate observations, and none were surviving 24 hours after exposure (Table 3-24).

Observations both immediately and at 24 h showed that condenser tube passage was more stressful than plume entrainment for similar temperature and biocide exposures. At 1.33 ppm chlorine, 97% of the plume entrained mysids were alive immediately following exposure and 66.0% were survivng 24 h later. However, after condenser tube passage at 1.30 ppm chlorine, 70% of the animals were alive immediately after exposure and only 30% survived up to the 24 h observation (Table 3-24).

Concentrations of chlorine between 0.92 and 1.30 ppm bracketed the 50% mortality dose for the 24 hour observation of organisms exposed via condenser tube passage (Figure 3-20). Immediately following exposures between 1.30 and 1.71 ppm, a similar level of mortality occurred. A residual chlorine concentration of 2.83 ppm resulted in 100% mortality after 24 h for condenser tube passed mysids at ambient temperatures (Figure 3-20).

Table 3-24. Survival of plume entrained (PE) and condenser tube passed (CTP) Neomysis americana after a 10 minute exposure to various total residual chlorine (TRC) concentrations at ambient temperatures (21.5°C-24°C).

TRC (ppm)	Plume entrained Immediate	(*)	24 hr.	TRC	Condenser tube passed Immediate	(*)	24 hr.
			% Survival				
0.0	100.0	(44)	95.5	0	100.0	(54)	96.3
	100.0	(38)	94.7		100.0	(51)	88.2
0.11	100.0	(42)	97.6	0.12	100.0	(44)	90.9
	100.0	(44)	90.9		98.1	(52)	88.5
0.17	100.0	(41)	90.2	0.22	100.0	(34)	94.1
	100.0	(44)	95.5		100.0	(61)	95.1
0.25	100.0	(39)	97.4	0.53	97.6	(42)	76.2
	100.0	(39)	92.3		100.0	(42)	92.9
0.51	100.0	(44)	77.3	0.92	100.0	(38)	55.3
	100.0	(39)	76.9		87.2	(47)	38.3
0.71	90.2	(41)	68.3	1.3	63.4	(41)	24.4
	97.4	(39)	76.9		76.8	(56)	35.7
1.33	100.0	(46)	82.6	1.71	34.1	(41)	4.9
	93.9	(49)	49.0		40.0	(40)	2.5
1.80	60.0	(45)	20.0	2.83	2.2	(46)	0.0
	53.7	(41)	7.3		2.6	(38)	0.0
2.48	0.0	(40)	0.0				
	2.5	(40)	0.0				

*Number exposed

775 318

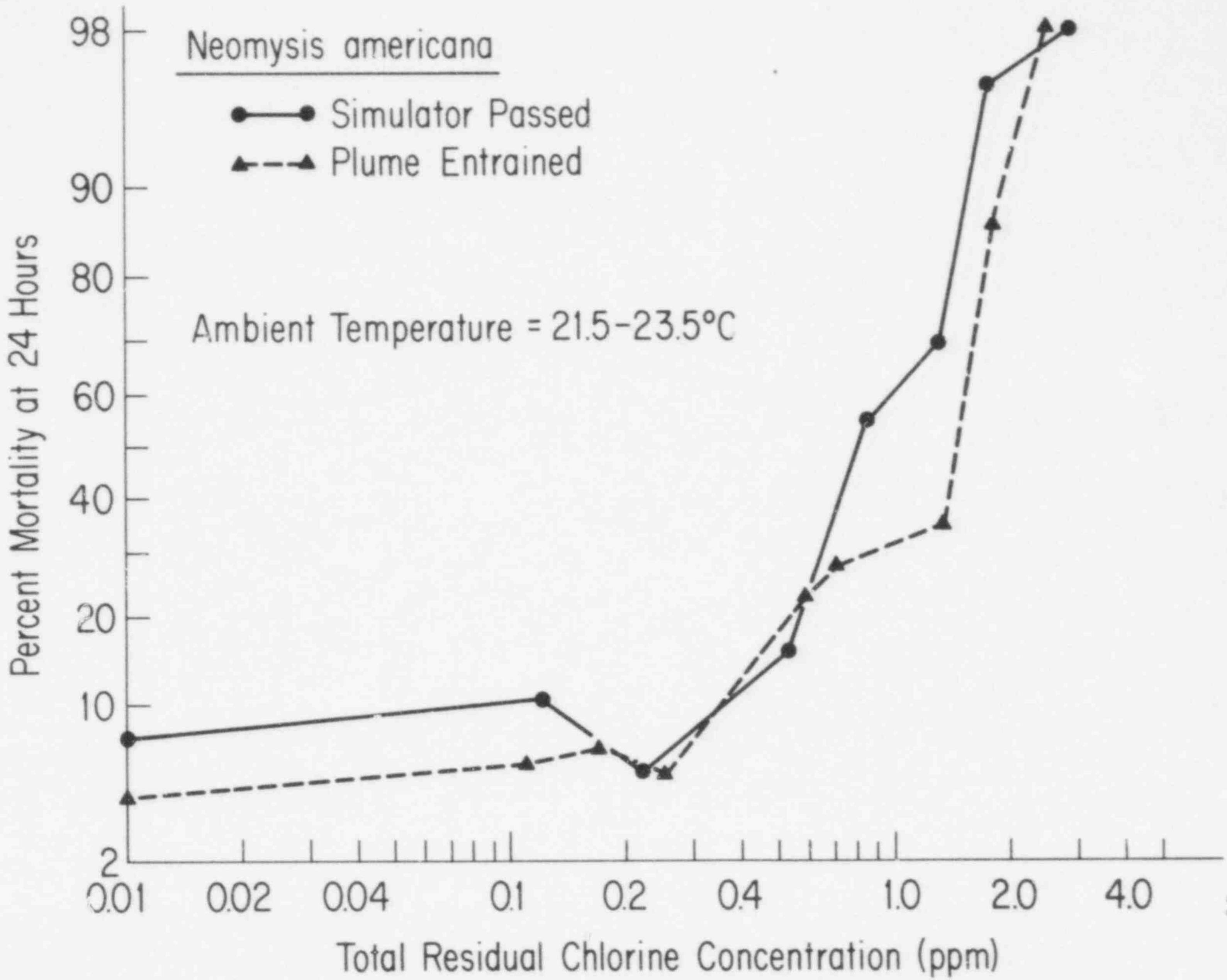

Figure 3-20 Percent mortality of plume entrained and condenser tube passed Neomysis americana at 24 h after a 10 minute exposure to various chlorine concentrations at ambient temperature.

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Reduced survival was observed at more dilute chlorine concentrations when a ΔT of 6.0°C to 8.5°C (30.0°C final temperature) was applied (Table 3-25; Figure 3-21). For plume entrained animals, latent 24 h survival was unchanged from immediate survival at chlorine doses as high as 0.73 ppm. However, at 24 h mortality increased for the plume entrained group exposed to 1.22 ppm chlorine at 30.0°C, and a dose of 2.0 ppm resulted in immediate and 24 h survival of less than 10%.

For condenser tube exposure, the first significant decline in survival appeared 24 h after exposure to 0.75 ppm chlorine. Only 14% of the mysids survived. Immediate survival decreased suddenly following exposures to 1.21 ppm chlorine (mean percent survival $<$ 12%). Although some mysids were still alive immediately following condenser tube passage at 1.75 ppm, it is apparent that the resistance to mortality at this biocide exposure is minimal and short-lived. At concentrations of 2.71 ppm an absolute lethal dose was generated. The minimum dose required to result in 0% survival 24 h post exposure in a system operating at 30.0°C is approached at 1.21 ppm chlorine (Figure 3-21).

Table 3-25. Survival of plume entrained (PE) and condenser tube passed (CTP) <u>Neomysis americana</u> after a 10 minute exposure to various total residual chlorine (TRC) concentrations at an elevated temperature (30.0°C; ΔT=6 or 8.5°C).

TRC(ppm)	% Survival Plume entrained Immediate	(*)	24 hr.	TRC	Condenser tube passed Immediate	(*)	24 hr.
0.0	100.0	(41)	97.6	0.0	100.0	(39)	97.4
	100.0	(36)	91.7		100.0	(42)	100.0
0.11	100.0	(43)	97.7	0.12	100.0	(48)	97.9
	100.0	(41)	100.0		97.6	(41)	90.2
0.19	100.0	(42)	95.2	0.23	95.7	(46)	89.1
	92.3	(39)	92.3		92.3	(26)	88.5
0.26	100.0	(36)	97.3	0.46	96.1	(51)	92.2
	97.4	(39)	92.3		100.0	(39)	94.9
0.55	100.0	(34)	88.2	0.75	81.4	(43)	20.9
	100.0	(38)	60.5		52.3	(44)	6.8
0.73	97.6	(41)	68.3	1.21	14.0	(43)	0
	100.0	(43)	79.1		9.5	(42)	2.4
1.22	81.3	(48)	16.7	1.75	3.7	(54)	0.0
	80.0	(40)	10.0		6.1	(33)	0.0
2.0	5.0	(40)	2.5	2.71	0.0	(49)	0.0
	7.0	(43)	0.0		0.0	(47)	0.0

*Number exposed

775 321

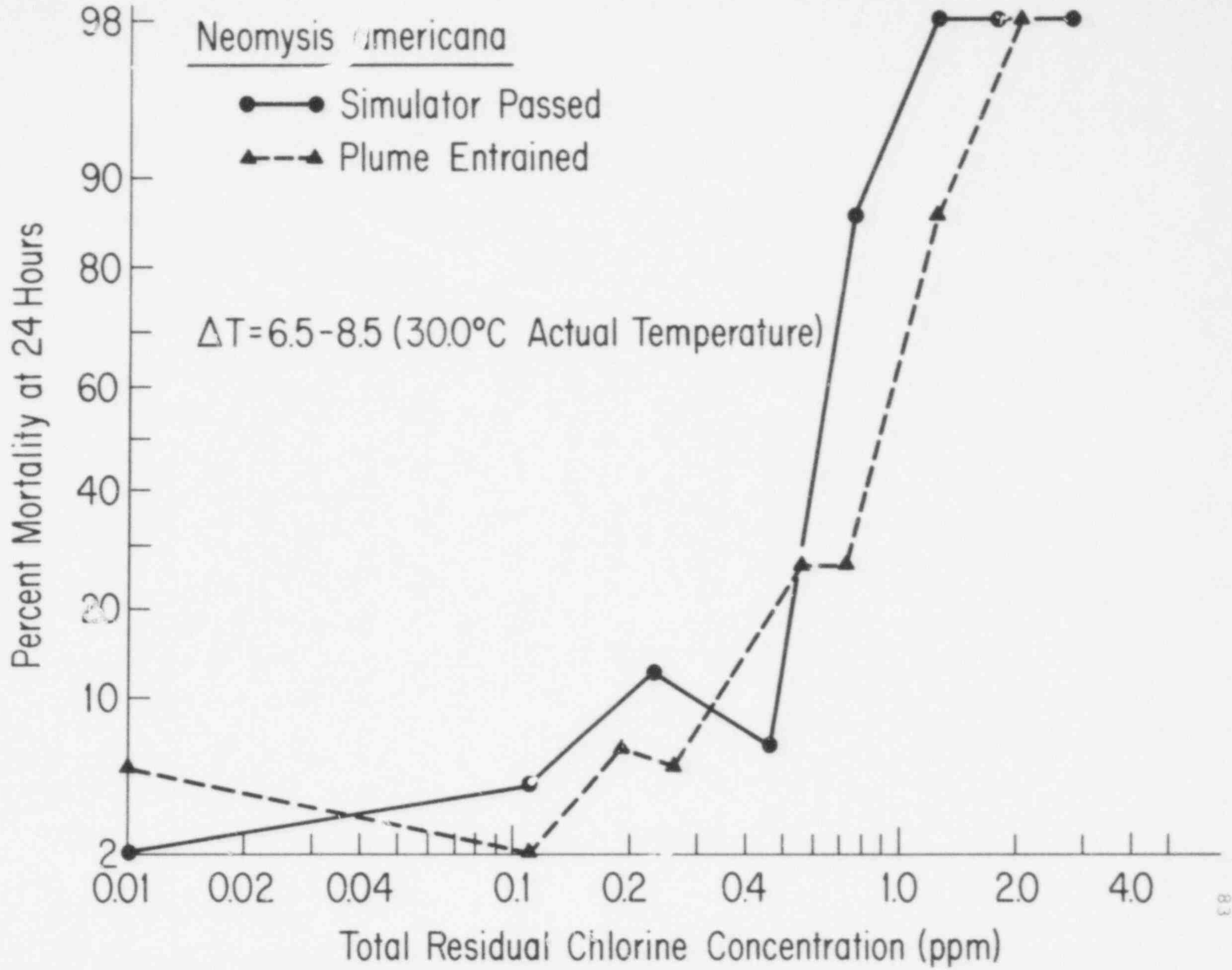

Figure 3-21 Percent mortality of plume entrained and condenser tube passed *Neomysis americana* at 24 h after a 10 minute exposure to various chlorine concentrations at an elevated temperature (30.0°C).

4. Discussion

Mortality among entrained striped bass larvae is due to the effects of thermal, mechanical and chemical stresses acting either alone, or in combination with one another during condenser tube passage. It has not been determined as to whether these stress factors act synergistically, or in a simple, additive fashion; however, in the case of chlorine, observed mortalities are greater at a sublethal ΔT than would be expected based upon the effects of chlorine exposure alone.

Throughout the experimental series it was found that the effect of condenser tube passage, in and of itself, was not a major factor in the mortality of striped bass, particularly at the immediate observation. In two instances it was found that condenser tube passage did affect survival, but only at the 24 h observation. These results conflict with field studies and theoretical assessments of entrainment mortality resulting from various "fluid-induced" stresses, including the physical and mechanical effects of shear and abrasion (Schubel and Marcy, eds., 1978).

Several studies (Marcy, 1971, 1973; Marcy et al, 1978; Austin et al., 1973; Nawrocki, 1977; Copeland et al., 1975) have reported that mortality of entrained ichyoplankton was due to physical damage caused during plant passage. Striped bass may be more resistant to physical stress than the organisms observed in these previous studies. This has been verified in numerous studies with striped bass at Hudson River power plants, where the incidence of mutilated or macerated fish in discharge samples is quite small, despite collection at relatively high velocities (O'Connor and Schaffer, 1977; New York University, 1977). If the maceration or mutilation observed for other species cannot usually be accounted for by collection gear (Marcy, personal communication), then the physical damage done to entrained organisms may be due either to condenser tube passage or to the pumping system. Marcy et al. (1978) have analyzed experimental data on shear stress (Morgan et al., 1976) and determined that stresses imposed upon striped bass eggs and larvae in power plant condenser tubes are unlikely to cause mortality. Therefore, the physical damage done to entrained ichthyoplankton must occur either in the pump, the intake water box, or in the discharge water box. Studies have recently begun at the Oak Ridge National Laboratory (Suffern, 1977) which will evaluate the circulating water pump as a source of mortality for entrained ichtyoplankton, especially striped bass.

The combined effects of condenser tube passage and increased temperature had a profound effect on striped bass life history stages which was not manifest immediately, but was readily apparent 24 h after the stress was imposed. The rate of flow caused a difference in response to the same stress between larvae of approximately the same age. Larvae tested at 1.0 mps showed slightly greater mortality after

24 h than larvae tested at 3.0 mps. Except for the flow rate, conditions were the same in both experiments. In theory, both groups of animals had received the same time/excess temperature treatment, since the full duration of thermal exposure was 10 min. This factor, the time/excess temperature factor, is, according to Carter et al. (1977), a critical component in determining thermal mortalities (see also Schubel et al., 1978; Kennedy et al., 1974; Schubel, 1974).

One potential difference between the two treatments may have been the longer period of time the organisms were exposed to the thermal environment of the condenser tube. At 1.0 mps larvae are exposed to a rapidly increasing thermal gradient (varying with ΔT) for a period of 15.24 sec. Larvae passing the condenser tube at 3.0 mps are exposed for only 5.08 sec., but to the same thermal gradients. In addition, during condenser tube passage the animals exposed at 1.0 mps were subjected to lower hydrostatic pressures than those passed at 3.0 mps.

Overall survival between the 1.0 and 3.0 mps test groups was statistically similar for plume-entrained organisms, although fish tested at 3.0 mps survived, on the average, less well than those exposed at 1.0 mps. Significant differences in mortality appeared between 10 and 12 C ΔT at 1.0 mps. Variance within the 3.0 mps group was sufficiently high as to mask statistically significant differences.

Since the rates of temperature increase were approximately the same for plume-entrained animals in both groups, and for the animals tested at 3.0 mps (full ΔT attained in 3-5 sec.) and less for animals tested at 1.0 mps (full ΔT attained in $\sim$ 15 sec.) temperature alone can be discounted as the most likely factor for causing mortality.

The duration of time in the condenser tube while undergoing a thermal stress could have caused the observed differences in mortality. The literature contains no reference to experiments specific to this question, however. Further studies should be conducted which will assist in determining whether, at low flow and moderate-to-high ΔT, mortality may increase as a function of the stress of condenser tube passage. Such data will be critical in evaluating proposed power plant operating regimes aimed at mitigating entrainment mortality (Committee on Entrainment, 1978).

Few conclusions can be drawn with regard to the combined effects of temperature, flow rate, and sampling gear. Studies aimed at defining the rates of mortality induced by the collection gear under specific test conditions suffered from unusually high 24 h mortalities among control (plume-exposed) groups. Most experiments conducted during 1978, however, showed that plume-exposed animals had essentially the same mortality as organisms which had been exposed to the condenser tube and to the larval table collection device at ambient chemical and thermal conditions. More experiments will be conducted in 1979 to complete our evaluation of the larval table as an effective collection mechanism in power plant ichthyoplankton studies.

The combined effects of condenser tube passage, ΔT (5.8C) and chlorine exposure on striped bass yolk-sac larvae showed a significant effect when chlorine concentrations reached approximately 4 ppm. At higher chlorine concentrations the imposition of a moderate ΔT in the range of power plant operations (Schubel, 1974; Lauer et al., 1974) along with condenser passage resulted in mortalities greater than those observed among plume-entrained groups exposed only to chlorine and temperature stress. Post yolk-sac larvae showed a similar response, but only at the 24 h observation. The effects of temperature, chlorination and entrainment, therefore, are more severe on yolk-sac larvae.

Eichorn (1977) studied the responses of striped bass life history stages to chlorine and determined an LC_{50} value far in excess of the concentrations found to cause mortality in the present study (LC_{50} = 1.30 ppm total residual chlorine (Eichorn, 1977) vs. $\ll$ 1.0 ppm). While the results of the present study with striped bass are more consistent with chlorine bioassays published elsewhere (e.g., Roberts et al., 1974; Arthur and Eaton, 1971; Mattice, 1976), the reduced LC_{50} value compared to that of Eichorn (1977) may be due as much to differences in test conditions as to real differences in chlorine LC_{50} for fish from the same population.

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Natural Hudson River water normally carries a heavy load of detritus and dissolved organic matter (Schaffer, 1978) which results in a high chlorine demand (Ginn and O'Connor, 1978). Eichorn's bioassay data (1977) were based on initial chlorine concentrations which declined rapidly during the experiment. Bioassay data from the present study were obtained using water with low dissolved organic matter and essentially no suspended solids. The differences in the LC_{50} values presented here, and by Eichorn, could be explained by the tremendous differences in chlorine demand of the test systems.

Our research indicates a strong interactive effect among chlorine, temperature, and condenser tube passage. Whether the interactive effect is additive or synergistic remains open to question. Among yolk-sac larvae, which showed a high degree of variability in response at the initial observation, the effect seems synergistic; i.e., at chlorine concentrations of 0.69 ppm and above, the mortality of thermally-stressed, condenser tube-passed organisms (∿ 90%) differed from the summation of condenser tube effect in the same experiment (∿ 0%) and the effect on thermally-exposed, chlorine-treated controls (mortality ∿ 70-75%).

Striped bass post yolk-sac larvae show a slightly different pattern, however, when one considers the mortality at the 24 h observation as well as the mortality at the immediate observation. Chlorine concentrations of up to 2.73 ppm failed to cause any substantial decrease in surviv ı

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among post yolk-sac larvae at the immediate observation. After 24 h, however, survival patterns were substantially different: 1) more than half the plume-exposed organisms had died after exposure to 1.57 ppm chlorine; 2) all condenser tube-passed organisms exposed to more than 0.68 ppm chlorine had died; 3) the mortality of all organisms exposed to chlorine (> 0.14 ppm) and temperature (ΔT 5.0C) was greater than groups exposed to chlorine alone; 4) mortality was greater among all condenser tube-passed organisms than among plume-exposed organisms. The differences between mortality due to all three factors, and that due to temperature and chlorine alone is, in most cases, approximately equal to the mortality induced by passage through the condenser tube/sampling gear complex. The total response, therefore, cannot be considered as evidence of a synergistic effect among the mechanical, thermal, and chemical stresses applied.

The combined effects of ΔT, chlorination and condenser tube passage were found to act synergistically on Gammarus. A strong synergy (excess mortality > 20%) was observed due to the combined effects of temperature and condenser tube passage. Chlorination, in and of itself, caused relatively little mortality until concentrations exceeded 0.5 ppm. Temperature increases combined with chlorination stress, however, induced a greater mortality in the test population than among controls.

Data from plume-entrained (control) organisms exposed to temperature alone gave an LC_{50} value between 38.5C and 40C. This was slightly higher than, but consistent with, previous bioassay data obtained in static tests (Ginn et al., 1974). The acclimation temperatures of the organisms used in these experiments was slightly higher than that used by Ginn et al. (1974), which may account for the slightly elevated LC_{50} value.

Gammarus which had passed through the condenser system were less tolerant of thermal shock than control groups, whether exposed to the test condition for 10 min or 30 min. Plume-entrained and condenser tube-passed organisms showed substantial decreases in survival at lower temperatures during the 30 min exposure. A ΔT of 10C for 30 min caused mortality of $\sim$ 20% for condenser-passed organisms, whereas similar mortalities for the 10 min exposure did not occur until a 15C ΔT was attained. Ginn et al. (1974) demonstrated a change in temperature response with duration of exposure to ΔT; however, the full range of exposures (5-60 min) did not yield as significant a change as is observed among condenser tube-passed organisms.

The combined effects of temperature and condenser passage on Gammarus are synergistic. Furthermore, for the 10 min exposure, the synergy appears to increase; the differential (excess) mortality among the condenser tube-passed organisms increases from 12% to 47% as ΔT increased from 15C to 17C. One may propose, in explanation of this phenomenon, that Gammarus became more susceptible to physical stresses as temperature increased, even though sublethal thermal doses were applied. It is possible to discount certain physical effects as possible sources of mortality based upon work in this, and other, laboratories.

Poje (unpublished data) has examined the lethal responses of Gammarus to positive and negative hydrostatic pressures. He determined that the degree of decompression induced by operating steam stations (including the simulator) causes no mortality. Other species of zooplankton, however, particularly those which possess hydrostatic organs (e.g., Chaoborus punctipennis), may suffer latent mortality due to bursting of air bladders.

Other physical factors which may affect survival through the condenser tube are turbulence and shear. Although not a direct simulation of condenser tube turbulence, flow control studies conducted in 1978 demonstrated that the turbulence associated with the larval collection tables caused no excess mortality among Gammarus; nor did special studies conducted in 1977 (Poje et al., 1978) in which Gammarus were exposed to turbulent mixing which occurred when the condenser tube simulator discharged into conical plankton nets.

Ulanowicz (1975) has discussed shear as an important factor in mortality of planktonic organisms. In a recent review (Marcy et al., 1978) shear was considered as a potential source of mortality in steam electric station condenser tubes. However, based on experimental data derived from tests with striped bass (Morgan et al., 1976), it is unlikely that shear forces associated with power plants could cause measurable effects. None of these studies was conducted in conjunction with thermal shock. In the present report, since condenser tube passage with no ΔT or chlorine caused little impact on striped bass ichthyoplankton under most circumstances, we concur with Marcy et al. (1978) that shear is not an important factor in ichthyoplankton mortality.

The responses of crustaceans may differ from those of ichthyoplankton, however. Since the crustacea, such as *Gammarus*, have a rigid exoskeleton, they might suffer more from shear effects during condenser passage than the resilient, vertebrate forms. The synergy between ΔT and condenser passage is of sufficient magnitude as to warrant further, intensive study.

The results of chlorination at ambient water temperatures on *Gammarus* spp. survival show that threshold concentrations of residual chlorine lie between 0.5 and 0.6 ppm. Given the variability of the data, there appears to be no identifiable interaction of chlorination with exposure mode at ambient temperatures. The added stress of elevated temperatures on *Gammarus* spp. during condenser tube chlorination gave some indication of stress interaction. Comparison of ambient and ΔT chlorination of plume-entrained *Gammarus* indicates that mortality may be independent of sublethal temperature. However, condenser tube passage with ΔT results in a 30% higher mortality at 1.36 ppm residual chlorine than does ambient water condenser tube chlorination at 1.37 ppm.

Although both ambient temperature and ΔT chlorination of Gammarus show greater mortality rates with increasing TRC values for plume-entrained organisms, it must be noted that conditions such as these are not likely to be encountered in normal power plant operation. Ginn and O'Connor (1978), in effluent avoidance experiments, showed that G. daiberi displayed significant avoidance behavior to full strength and dilute chlorinated effluents where TRC levels were at or below detectable limits. Gammarus, therefore, would be expected to actively avoid a chlorinated effluent plume and thereby escape exposure. Chlorine residual concentrations of approximately 1.0 ppm at the condensers are not unrealistic. Concentrations in effluents are generally much lower due to factors of dilution, tubulent mixing, and the chlorine demand of the source water.

Neomysis americana showed a response to the combined effects of condenser tube passage which was quite different from that shown by Gammarus, but similar to that of striped bass. While Neomysis was quite sensitive to thermal shock, the combined effects of ΔT and condenser tube passage were additive rather than synergistic. On the other hand, the combined effects of chlorine and condenser tube passage demonstrate a strong synergy which is compounded by the effects of temperature.

The effects of temperature, alone, on Neomysis are in close agreement with Lauer et al. (1974), who demonstrated a LD_{50} of 34C for Neomysis exposed to a series of ΔT's for 5 min. When the same ΔT series was applied to condenser-passed organisms the LD_{50} was reduced to between 32 and 34C. By comparison to Lauer et al. (1974), the combined effect of a 10 min. ΔT and condenser passage gave a mortality similar to that induced by a 30 min. static exposure temperature bioassay.

Longer exposure to ΔT reduced the LD_{50} level somewhat; more importantly, for plume-entrained and condenser-passed organisms alike, the slope of the response curve became much steeper, indicating a narrow threshold at which a high proportion of mortalities may occur.

Exposure of Neomysis to various flow rates at a sublethal ΔT (6.0C) proved, based upon 24 h survival data, that neither exposure to the ΔT, exposure to the condenser, nor to the stresses of collection had any substantial effect on survival. This is of considerable interest, since Neomysis has been shown in a number of studies to be among the most sensitive of estuarine organisms to handling and mechanical stress. Studies of macrozooplankton survival at the Indian Point power plant demonstrated that Neomysis survived less well than either Gammarus (Ginn, 1976) or Monoculodes (N.Y.U., 1976).

Neomysis' ability to tolerate the stress of condenser tube passage and the stress of the collection table at a sublethal ΔT shows that this species, which is substantially less tolerant of thermal shock than Gammarus (LC_{50} ∿ 32-34C vs LC_{50} ∿ 38-40C for Gammarus) can be entrained, without risk to the population, if the short-term exposure maximum is below 33°C. In the parlance of the Committee on Entrainment (1978), the strategy of maximizing cooling water flow in order to minimize temperature change is, for Neomysis, a satisfactory measure to mitigate entrainment losses. For many species (Marcy et al., 1978) mechanical damage is quite extensive, and eliminates low ΔT pumping as a viable alternative in entrainment impact mitigation.

The combined effects of condenser passage, sublethal ΔT and chlorination cause substantial mortality among populations of Neomysis which, according to present and previous studies, should not have been severely affected. The effects of chlorination became apparent, under all test regimes of condenser passage, sublethal ΔT and chlorine application, at concentrations slightly greater than 0.5 ppm. When any additional stress was combined with the chlorine, mortalities increased much more rapidly than in the control (chlorine-exposed) group.

The stress of condenser tube passage with chlorine was less severe a stress than a ΔT of 6C added to the chlorine stress. Organisms which had been exposed to chlorine (1.3

ppm and condenser tube passage had survival of $\sim$ 30%, whereas Neomysis exposed to 1.2 ppm chlorine residual and ΔT 6C had survival of $\sim$ 13%. The combination of all three stress factors led to essentially complete mortality at 1.2 ppm chlorine. Chlorine concentrations of 0.75 ppm, which alone, or in combination with either ΔT or condenser passage, led to survival rates of approximately 70%, resulted in only 14% survival in combination with ΔT and condenser passage.

5. Summary and Conclusions

1. The NYSERDA power plant condenser tube simulator has been applied successfully in studies of the responses of striped bass (Morone saxatilis), amphipods (Gammarus spp.) and opposum shrimp (Neomysis americana) to thermal, mechanical, and chemical stresses associated with entrainment.
2. The mechanical effects of condenser tube passage alone had little or no effect upon survival of striped bass yolk-sac larvae and larvae, Gammarus, or Neomysis.
3. Thermal mortality data derived during 1978 were in agreement with data currently available in the literature. For all three test organisms the effects of thermal shock imposed during condenser t[illegible] passage were greater than the effects of thermal shock alone.
4. The combined effects of increased temperature, condenser tube passage and biocide (chlorine) application were essentially additive for striped bass; the same combination of effects caused some degree of synergy among Gammarus and Neomysis.
5. Gammarus appears to be sensitized to the effects of temperature and chlorine by passage through the condenser tube environment. Although no direct impact of the condenser tube was apparent in

experiments with *Gammarus*, the degree of synergy expressed indicates the occurrence of a subtle, sublethal sensitization to other stresses associated with passage through the condenser tube.

6. *Neomysis* is sensitized to the effects of chlorine and temperature by condenser tube passage; however, the resultant synergy is not so strongly expressed as in *Gammarus*.

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Striped bass, Gammarus and Neomysis from the Hudson River estuary were subjected to passage through a condenser tube simulator at various combinations of temperatures, flow rate and biocide concentration. Test conditions and procedures are described and results are presented.

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