THERMOREGULATION AND TEMPERATURE RELATIONS OF
ALLIGATORS AND OTHER LARGE ECTOTHERMS
INHABITING THERMALLY STRESSED
HABITATS

Annual Progress Report
for Period 1 July 1976-30 September 1977

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June, 1977

Prepared for the U.S. Energy Research and Development Administration
Under Contract EY-76-7-02-2502.*000

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Abstract

Heat exchange between the alligator and its environment is primarily by radiation and conduction with metabolism and evaporation being much less important. The energy budget model is an accurate and precise tool for prediction of equilibrium body temperatures. The transient model tracks heating and cooling curves very closely and is a good predictor of time dependent temperature change.

Predictions of turtle behavior made from climate space diagrams are supported by our observational data. Convection coefficients are similar to those reported for ground squirrels and lizards. The effect of wind speed on evaporative water loss has been measured and related to changes in boundary layer thicknesses by the use of Schlieren photographs.

Steady state energy budgets and heat transfer coefficients have been finalized for largemouth bass. A first approximation model has been formulated to predict time dependent heat exchange in this fish. Experiments are underway to test this model.

Turtles in PAR pond on the Savannah River Plant appear to use thermal effluents as a source of heat for thermoregulation. Thermal effluents have little effect in the near shore microclimates of this reservoir.

Theoretical computations indicate that body size and skin color have important effects on the body temperatures of large ectotherms.

The CTM test of temperature tolerance is a good indicator of stress in aquatic organisms.

Since June 1976 four articles have been published, three are in press, two are in review, and six are in preparation.

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The purpose of this project has been to analyse the biophysical and thermal relationships between large ectotherms and their aquatic environment. During the first 2½ years (October 1974-May 1977) significant progress has been made in laboratory and field studies on alligators, turtles and fish. In addition, our mathematical modeling efforts have been quite successful and we have begun to investigate the effect of body size and physical characteristics on temperature regulation of ectotherms. Finally we have attempted to develop model systems for the study of stress in aquatic organisms. This report will discuss our progress since 1 July 1976. A summary report for the entire project period (1 October 1974-30 September 1977) accompanies this report and is more inclusive.

Overall objectives to be accomplished in the third year of this project were to 1.) Continue to construct and refine climate space diagrams for alligators, large turtles and large fish, 2.) Test these steady state and time dependent energy budget computations in the laboratory, and 3.) Carry out field studies on the physiological and behavioral adjustments of turtles in response to changes in water temperature produced by reactor effluents in PAR pond at the Savannah River Ecology Laboratory (SREL).

Significant progress has been made on all three objectives. The first two can best be discussed in terms of progress made with regard to each experimental animal.

Alligator Studies

By October 1977 laboratory studies on alligators will be complete. During

the second year of this project we completed most of our steady state heat exchange studies for this animal. The last year has been spent analyzing these results, preparing manuscripts for publication and conducting experiments to test the transient energy budget model.

Heat exchange between the alligator and its environment is primarily by radiation and conduction with metabolism and evaporative water loss being much less important (Fig. 1). These results have been presented by Terpin (1976) and will be discussed at three meetings this summer (list of scientific presentations attached). Our analysis indicates that the steady state energy budget model (Spotila et al. 1972) is an accurate and precise tool for the prediction of equilibrium body temperatures of alligators (Fig. 2).

Over the past two years we have carried out a series of experiments to test the transient energy budget model proposed by Spotila et al. (1973). Heating and cooling experiments have been completed. Data analysis and computer simulation indicate that the transient model is also a good predictor. For examples see Figures 3 and 4. The transient model tracks the actual heating and cooling curves very closely.

During the past year we have modified the climate space simulation chamber (C.S.S.C.) so that we can now control floor temperature independent of air temperature. At this time we are installing and testing a new temperature control, cam programmer that allows us to simulate fluctuating thermal regimes. Soon we will begin additional experiments to complete our tests of the transient energy budget model for alligators. These experiments will include the effect of diurnal changes in air temperature as well as variations in floor temperature to determine the effect of conduction on heat transfer. These experiments will be completed by October 1977.

Our final alligator experiments are designed to determine the rates of evaporative water loss from alligators. These experiments will be completed this summer. We will test alligators at several temperatures and wind speeds in the C.S.S.C. and wind tunnel.

The quality of our alligator related research is indicated by the publication of our results on mouth gaping in the journal Nature (Spotila et al. 1977) and by acceptance of our paper on alligator thermoregulation for presentation at the XXVIIth International Congress of Physiological Sciences, July 1977, in Paris, France. We are in the last stages of preparation of our manuscript on the effect of radiation and convection on the body temperature of the alligator, It will be submitted for publication by October 1977.

Turtle Studies

Climate space diagrams have been formulated for the turtle Chysemys scripta. This group of climate spaces, for different sized turtles, was almost identical in size and shape. A typical climate space is presented in Figure 5. This represents the interaction between the physical and physiological properties of the turtle and the physical factors of its environment. It indicates the climatic limits of the turtle and suggests that terrestrial activity would be limited to spring and fall. In water, this turtle could be active throughout the year. Turtles may bask under conditions that are found outside of their climate space, however, they must return to a less adverse environment within the climate space to prevent overheating. Duration of excursions beyond the climate space are limited by the heat storage capacity of these turtles. During spring and fall, turtles could bask for long periods of time because

they would have a lower body temperature at initiation of basking and solar radiation would be at relatively low intensities. When temperatures and radiation levels are higher in summer, the time spent basking by turtles would be reduced. These predictions are supported by our field observations (Foley and Spotila, unpublished data).

Convection coefficients (Fig. 6) determined for turtles are similar to those reported for ground squirrels (Eutamias) by Heller (1972) and lizards (Dipsosaurus dorsalis) by Porter et al. (1973). It appears that most terrestrial animals act as cylinders in terms of convective heat transfer. Our paper on convection coefficients and climate spaces for C. scripta has not yet been sent for publication. Our data analysis over the past year has suggested a few additional experiments that we plan to complete this summer. At this time we have determined convection coefficients for turtles perpendicular and parallel to wind flow in air. Now we will obtain the same information for a turtle in water. Methodology will be similar to that described by Erskine (1976). Once these tests are completed we will finalize our manuscript (Foley and Spotila 1977a) and submit it for publication. Results obtained to date have been initially summarized by Foley (1976).

During the past year Robert Foley has completed analysis of the turtle evaporative water loss data and submitted a paper for publication. That paper has been accepted by COPEIA and is now in revision (Foley and Spotila 1977b). Rates of water loss increased as wind speed and air temperature increased but were inversely proportional to body size (Fig. 7). An increase in wind speed caused a large decrease in boundary layer thickness and a large increase in evaporative water loss. This was visualized with Schlieren photographs (Fig. 8).

Tests of the turtle climate space are being conducted using the C.S.S.C. Although definitive findings are not available at this time, preliminary results are encouraging. These tests will continue into the next project year.

Some effort has been expended in attempting to formulate a transient energy budget model for the turtle. This aspect of the project was deemphasized in order to concentrate on the transient budget for fish and on analysis of field data on the thermoregulation of turtles in PAR pond at SREL. These studies will be discussed below. We plan to resume efforts aimed at formulation of transient energy budgets for turtles during the next project year.

Largemouth Bass Studies

We set three goals for our bass research that were to be accomplished during the third year of this project. These were 1.) Finalize the theoretical work on the steady state energy budget and heat transfer coefficients for a largemouth bass, 2.) Formulate a time dependent mathematical model to predict the body temperatures of largemouth bass, and 3.) Conduct heating and cooling experiments on live largemouth bass exposed to moving water.

Development of the steady state energy budget and measurement of the heat transfer coefficients for bass have been completed and are contained in an article which will be published in the July 1977 issue of Physiological Zoology (Erskine and Spotila 1977). During the past year Richard Kubb has been studying the problem of transient modeling of fish temperatures. Despite his heavy course schedule as a new graduate student he has spent a great deal of time on this problem and has put together a transient model that we believe

will be workable as a first approximation of time dependent temperature change of a fish in a heterothermal environment. Kubb combined the heat transfer equations for fish developed by Erskine (1976) with the time dependent model published by Spotila et al. (1973) to produce a time dependent model for a fish.

Time Dependent Model

A steady-state energy budget, as described by Gates (1962), Birkebak (1966), and Porter and Gates (1969), for terrestrial animals, is generally described as:

$$Q_{abs} + M = \epsilon \sigma (T_r + 273)^4 + h_c (T_r - T_a) + E_t + C \quad (1)$$

where,

Q_{abs}	=	total absorbed radiation
M	=	metabolic heat production
ϵ	=	surface emmissivity
σ	=	Stefan-Boltzman constant
T_r	=	radiant surface temperature
T_a	=	ambient temperature
h_c	=	convection coefficient
E_t	=	total evaporative heat loss
C	=	heat loss through conduction

Erskine (1976) adapted this terrestrial steady-state energy budget equation to account for the physical conditions experienced by fish. Several

avenues of heat transfer for terrestrial organisms, such as solar radiation, thermal radiation, and evaporation are not available in water. Thus, Equation (1) is reduced to yield the steady-state energy budget equation for a fish in water:

$$M = h_t(T_r - T_w) \quad (2)$$

where, T_w = water temperature

h_t = heat transfer coefficient (conduction-convection)

Equation (2) shows that heat flow is bi-directional. When T_r is greater than T_w heat is liberated to the environment. If T_r is less than T_w heat flows into the fish. In essence, at any point in time and space, the fish is locked into its thermal environment and unlike terrestrial ectotherms has inadequate physiological means of counteracting heat inputs or outputs. The only modes available for a fish to maintain an energy balance during thermal stress are:

1. Migrations in response to ambient temperature changes
2. Storage of heat in the body tissues

Both of these mechanisms play an important role in the ability of fish to maintain optimal body temperatures.

Time dependent modeling of heat transfer in biological organisms presents several analytical problems, such as changing environmental and physiological parameters through time, and creating a time-lag as a result of the organism's ability to store heat. This type of problem is often solved by a series of difference equations. Spotila et al. (1973) developed a time dependent model for heat transfer in terrestrial poikilotherms using such a series of difference equations.

Within this model, the animal is considered to be a cylinder consisting of a given thickness of insulation surrounding a body core. For mathematical convenience in treating heat flow through the insulation, the cylinder is divided into several layers. The effect of heating and cooling is considered equally distributed about the animal surface and heat transfer between the animal core and the surface occurs radially and symmetrically in order to reduce the problem to one dimension.

For all layers and the core, heat flux can be defined according to the first law of thermodynamics as:

$$\text{Heat in} - \text{Heat out} = \text{Heat stored} \quad (3)$$

In terrestrial organisms, for the first layer, heat flux at the surface is defined by:

$$Q_{\text{net}} = Q_{\text{abs}} - \epsilon \sigma (T_s + 273)^4 - h_c (T_s - T_a) \quad (4)$$

where,

$$Q_{\text{net}} = \text{net heat flow}$$

$$T_s = \text{surface temperature}$$

From Equation (2) we see that for a fish in water, this reduces to:

$$Q_{\text{net}} = M - h_t (T_s - T_w) \quad (5)$$

Therefore, heat exchange in layers 1-6 and the core can be described by the following three equations:

$$\text{Heat in} = (Q_{\text{net}}) (A_i) \Delta t \quad (6)$$

$$\text{Heat out} = K \frac{dt}{dr} (A_i + 1) \Delta t \quad (7)$$

$$\text{Heat stored} = (C_i) (\rho_i) (\text{Vol}_i) (T_i' - T_i) \quad (8)$$

where,

- A_i = area of outer surface of layer i
 Δt = specified time interval between calculation
 $K \frac{dt}{dr}$ = temperature gradient
 ρ_i = density of layer i
 T_i = temperature ($^{\circ}\text{C}$), of layer i at time i
 T_i = temperature ($^{\circ}\text{C}$), of layer i at the end of a time interval Δt
 C_i = specific gravity of layer i
 Vol_i = volume of layer i

By substituting Equations (6), (7), and (8) into Equation (3), body temperatures of each layer can be computed. Development of these equations is described in detail by Spotila et al. (1973).

An IBM model 370/158 computer system is used to solve a series of difference equations describing heat transfer through the body wall of a fish in an iterative fashion using Newton's method. This approach does not allow for an analytical solution but rather is restricted to an approximation to the true value. Approximations of body temperature to within 0.0001°C are possible with this method and are sufficient since this is more precise than available instruments for the measurement of body temperature.

Heating and Cooling Experiments

Experiments on live fish are scheduled for this summer. 38 gauge thermocouples will be surgically implanted into the dorsal epaxial muscle, body surface, and cloaca of live and dead largemouth blackbass in order to measure

changes in body temperature during heating or cooling. Fish will be anesthetized with MS 222, placed in wire cages and equilibrated to a water temperature of 25°C. Then, the fish will be immediately subject to a change in water temperature (e.g., ±5°C) by lowering the cage into a ring-shaped tank located at the environmental physiology laboratory, State University of New York at Buffalo. A description of the laboratory facility was given by Morin and Lanphier (1972). Changes in white muscle, surface and core temperatures will be monitored through time using a Kaye multichannel recorder (Model 6000) until equilibrium temperatures are reached. Heating and cooling curves will be drawn from the data and time constants determined by graphical analysis. These experimentally derived time constants will be compared to time constants predicted from the model in order to determine accuracy and precision of the model. Heating and cooling experiments will be conducted in still and moving water with laminar flow.

Similar heating and cooling studies will be conducted on live and dead largemouth bass inhabiting a heated reservoir located at the Savannah River Ecology Laboratory, Aiken, South Carolina. Fish (in cages) will be immersed into the boil in PAR pond (thermal effluent discharge area) and body temperatures monitored with a Bailey thermocouple thermometer until equilibrium is reached. Time constants will be determined as described above. This experiment will allow us to compare the effect of turbulent water flow on heating rates under field conditions with laminar flow effects under laboratory conditions.

By October, 1977, we will have sufficient data to test the Kubb model for transient heat flow. Next project year we will concentrate on data analysis and systems identification to determine the accuracy and precision of this

the reservoir. A minimum level of visible and near infrared radiation is needed before they will emerge to bask ($0.8 \text{ cal. cm.}^{-2} \text{ min.}^{-1}$ at $0.3 - 3.0 \mu\text{m}$) -see Figs. 10 and 11. High winds inhibited basking. When wind speed increased to $300 \text{ cm. sec.}^{-1}$ or more, turtles submerged (Fig. 11). Basking appeared to be a form of thermoregulation. A turtle lying at the surface of the water exposed to the sun had a body temperature $1-2^{\circ}\text{C}$ above ambient water temperature (Fig. 12).

Turtles have not been seen to bask in the Hot Arm near the boil (site of release of thermal effluent into the Hot Arm). Turtles have been observed swimming in this area and have been trapped there. We have hypothesized that they were using the effluent as a substitute for solar radiation and were shuttling between the thermal area and other cooler areas in a form of behavioral thermoregulation. We plan to present a paper at the November symposium entitled, "The Response of Turtles to Heated Effluents from a Nuclear Production Reactor." This will be a joint paper with Dr. Gibbons of SREL.

At this time research is continuing on the response of turtles to heated effluents in PAR pond. Joseph Schubauer is conducting his masters thesis research on this subject. He is supported by a SREL graduate research participation grant and is under the direction of Dr. Spotila and Dr. Gibbons. From a review of our data base to date, Schubauer has formed two hypotheses concerning the seasonal activity of turtles in the Hot Arm:

1. Turtles inhabit the Hot Arm during part of the year and move out when temperatures of the water exceed their preferred temperatures. (As was noted by Murphy and Brisbin (1974) for PAR pond alligators and for largemouth bass by Gibbons et al. (1972) and Gibbons and Bennett (1973).

2. Turtles are active in the Hot Arm during cooler parts of the year and estivate when water temperatures exceed their preferred temperatures.

His thesis research is designed to test these hypotheses and will continue during the next project year. He will test these two hypotheses by quantitatively measuring home ranges and movements of turtles exposed to heated effluents in the Hot Arm and those in a selected control area in the West Arm. This will be accomplished by systematic trapping, biotelemetry and observations of turtle activity from May, 1977 to January, 1978.

Effect of Body Size and Physical Characteristics on
Temperature Regulation of Ectotherms

Environmental heat load, the size of an animal and its insulative properties place specific demands on an animal's metabolism and evaporative water loss rates. Small animals must compensate for their lack of bulk and insulation by large adjustments in metabolism and evaporative water loss under high and low energy flux conditions. If such adjustments are not possible, then these animals must behaviorally thermoregulate and/or avoid such conditions. Large size allows an animal to maintain a relatively constant rate of metabolism and water loss when exposed to widely varying heat loads (Spotila and Gates 1975).

The effect of size and physical characteristics of an animal have been overlooked in the rush to find new physiological mechanisms of thermoregulation among ectothermic vertebrates. Our alligator experiments have shown that size is very important in the thermoregulation of ectotherms. Large alligators

(14-20 cm. in body diameter) maintain equilibrium body temperatures $6-8^{\circ}\text{C}$ above ambient when exposed to intense visible radiation while alligators less than 10 cm. in body diameter have temperatures $2-3.5^{\circ}\text{C}$ above ambient (Fig. 13). These findings agree with the computations of Spotila et al. (1972) and Spotila et al. (1973). Thus it is appropriate to continue the use of mathematical modeling to delineate important parameters in the thermoregulation of large ectotherms.

During the past year we have used the time dependent mathematical model for the body temperatures of large reptiles to consider the effect of body size, skin color and metabolism on the body temperature of large animals. An animal with a 1 meter body diameter has a stable internal temperature. A 20cm. diameter animal with no fur would experience daily fluctuations in body temperature if exposed to warm temperate climate conditions. However, a 2 meter diameter ectotherm would have a body temperature like that of the 1 meter animal. Thus there appears to be a point of diminishing returns in terms of body size. High (mammal level) metabolic rates would be disadvantageous for a large animal in a warm temperate climate (Fig. 14). Such an animal would overheat and be in danger of death.

Skin color can change body temperature of a large ectotherm by as much as $8-9^{\circ}\text{C}$. A large white alligator (1m. diameter) exposed to a summer day in Florida would have a body temperature of $30.6-31.3^{\circ}\text{C}$ while a black alligator of the same size would have a body temperature of $39.2-39.7^{\circ}\text{C}$.

This type of analysis helps us to focus on critical factors affecting the thermoregulatory mechanisms employed by large ectotherms. We plan to continue this theoretical approach in order to develop new hypotheses that can then be tested in laboratory and field experiments.

Model Systems for the Study of Stress
in Aquatic Organisms

Stress plays an important role in the ability of organisms to withstand extreme temperatures. Synergistic effects of heavy metals, other toxicants and temperature may harm organisms that would otherwise be able to tolerate one of these stresses alone. This problem has been discussed by Cairns et al. (1975a, b) and increases in toxicity of arsenic and mercury to fish with an increase in water temperature have been reported by MacLeod and Pessah (1973) and Sorensen (1976).

Throughout this project several ancillary studies have been conducted on the effect of temperature and arsenic on small fish, including fish larvae. These experiments have been supported in part by this ERDA contract because they were related to the ability of ectotherms to thermoregulate in response to thermal effluents. During the past year we have prepared the results of three of these studies for publication. One is in press (Bonin and Spotila 1977), one is in revision (Paladino and Spotila 1977), and one is in review (Kowalski et al. 1977).

As a result of these studies we have found that the Critical Thermal Maximum (CTM) test for temperature tolerance (Hutchison 1961) is a model system that is useful as an indicator of stress. The CTM is a measure of an organism's ability to adjust to changes in environmental temperature. An increase in acclimation temperature usually causes an increase in CTM. This has been demonstrated for fish (Hassan and Spotila 1976), salamanders (Zweifel 1957, Hutchison 1961, Brattstrom and Regal 1965, Scalander and West 1969, Spotila 1972), and frogs (Brattstrom and Lawrence 1962, Brattstrom 1968,

Mahoney and Hutchison 1969). CTM is also an indicator of processes that are occurring at the cell, tissue and organ levels. The relationship between such changes and temperature tolerance have been reviewed at length by Hochachka and Somero (1973), Prosser (1973) and Langerspetz (1974). Changes at the cellular level due to aging, disease, starvation, or dehydration, are often manifested as alterations in the temperature tolerance of the whole organism (Hutchison 1961, Pough and Wilson 1970, Pough 1974, unpublished data from our laboratory). The application of a stress, such as a toxic material, or the presence of a disease will often result in a reduction in the temperature tolerance of affected fish (Burton, et al. 1972, Paladino 1976, Kowalski and Spotila, unpublished data). Muskellunge fry undergoing swimup (changing from a sessile non feeding larvae to an active, swimming, predatory individual) exhibited a decrease in CTM (Hassan and Spotila 1976). Apparently this was a critical stage in the development of these fish and signalled changes at the cell, tissue and organ levels. In the same study, fish that were starved also showed a drop in CTM. These results were confirmed by Bonin and Spotila (1977) for fish reared under hatchery conditions.

We plan to report our findings on this and other model systems for the study of stress at the Environmental Stress Symposium to be sponsored by SREL in November, 1977.

Concluding Comments

During the past year, three articles and one note have been published (Hassan and Spotila 1976, Spotila and Berman 1976, Spotila et al. 1977 and Spotila 1976), three articles are in press (Erskine and Spotila 1977, Bonin

and Spotila 1977, and Terpin et al. 1977), two articles have been accepted and are in revision, two articles are in review, and six articles are in preparation. Five papers are scheduled to be presented at meetings this summer including one at the International Physiological Congress in Paris. We anticipate presenting four papers at the Stress Symposium being held by SREL in November, 1977.

The project director, James R. Spotila, spent 100% of his time on this investigation in August, 1976 and June, 1977. He spent 50% of his time in the project during the academic year 1976-1977.

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Figure 1. Pie diagrams of physical and physiological avenues of heat energy exchange between a 20 cm diameter alligator and its environment. Each pie shows the steady state energy exchange expressed as percent relative contribution of each form of heat transfer. Cond=conduction, Evap=evaporation, Rerad=radiation of heat from animal to environment, Conv=convection, Q_{abs} =heat radiation absorbed by animal, and Metab=metabolic rate of animal. A. Energy exchange under black body conditions. $Q_{\text{abs}} = 0.61 \text{ cal cm}^{-2} \text{ min}^{-1}$. Substrate, air, dorsal surface and core temperatures are temperatures obtained under equilibrium conditions between the animal and its environment. B. Energy exchange under simulated daylight conditions. $Q_{\text{abs}} = 0.75 \text{ cal cm}^{-2} \text{ min}^{-1}$. Temperatures are for equilibrium conditions. Data taken from Terpin (1976)

Figure 2. Predicted versus measured equilibrium body temperature of alligators tested under different environmental conditions. Solid line is line expected if measured body temperature equals predicted body temperature. Dashed line is a regression line for the data points computed by the method of least squares ($r=0.97$). Closed circles represent blackbody conditions, X's represent low light intensities and open circles represent high light intensities.

Figure 3. Predicted versus measured body core temperatures through time of a 14 cm diameter alligator exposed to high light intensity under controlled environmental conditions. Solid line with circles represents measured body temperatures and dashed line represents predicted body temperatures. Radiation absorbed (Q_{abs}) = $0.75 \text{ cal cm}^{-2} \text{ min}^{-1}$, environmental temperature = 25.6°C ($\bar{X}$), and wind speed equals 157 cm sec^{-1} .

Figure 4. Predicted and measured temperature differences (ΔT) between alligator body temperature and environmental temperature for the experiment graphed in figure 3. Solid line represents measured ΔT and dashed line represents predicted ΔT . Environmental conditions are given in caption for figure 3.

Figure 5. A climate space diagram for an average size *C. scripta* (1000 g) showing the effects of radiation, air temperature and wind speed under steady state conditions. The solid, dashed and dot-dashed lines in each set were calculated for wind speeds of 10, 100 and 400 cm sec⁻¹ respectively. Upper limits were calculated for a body temperature of 40°C using corresponding values of metabolism = 0.0899 ml O₂ g⁻¹ hr⁻¹ and evaporative water loss = 0.028 cal cm⁻² min⁻¹. Lower limits were drawn according to the same procedures at a body temperature of 1°C; metabolism = 0.0012 ml O₂ g⁻¹ hr⁻¹ and evaporative water loss = 0.021 cal cm⁻² min⁻¹.

Figure 6. Effect of wind velocity on convection coefficients (h_c) for three animals oriented perpendicular to wind flow. Convection coefficients for *Dipsosaurus dorsalis* (solid triangles) were taken from Porter et al. (1973), for *Chrysemys scripta* (open squares) from Foley (1976) and for *Eutamias amoenus* (solid hexagons) from Heller (1972). Regression lines are similar and differ very little from the values of h_c available for cylinders.

Figure 7. Three dimensional plot of evaporative water loss of *Chrysemys scripta* as a function of body weight, air temperature, and wind speed. Plane outlined by dotted lines is for water loss in still air (10 cm sec^{-1}), plane outlined with dashed lines is for water loss at 100 cm sec^{-1} , and plane outlined with solid lines is for water loss at 400 cm sec^{-1} .

Figure 8. Schlieren photographs of a hot box turtle shell, with laminar and turbulent boundary layers shown in the accompanying diagrams.

Figure 9. Par pond, a reservoir on the Savannah River Plant, Aiken, South Carolina, receiving heated water effluent from a nuclear reactor. Reservoir is approximately 1200 ha. Arrow indicates point of hot-water entry. Upon entry, waste heat is rapidly dispersed in the hot arm. Dashed line indicates extent of thermal influence.

Figure 10. Effect of visible solar radiation ($0.3-3.0\mu\text{m}$) and wind speed on basking behavior of turtles. In upper half of figure, solid line with squares represents solar radiation. Solid line with circles represents wind speed. Arrows indicate start and end of a given basking period. Each arrow represents a single turtle.

Figure 11. Effect of solar radiation and wind speed on basking behavior of turtles. In upper half of figure, total radiation (all wavelengths) is represented by a solid line with squares and visible radiation (0.3-3.0 μm) by a solid line with circles. A solid line with triangles represents wind speed. In lower half of figure, arrows indicate duration of basking. Each arrow represents a single turtle.

Figure 12. Effect of visible solar radiation ($0.3-3.0\mu$) and water temperature on body temperature of a turtle. Solid line with squares represents visible radiation. Deep water temperature is indicated by a dashed line with circles and shallow water temperature by a dotted line with circles. Solid line with circles represents body temperature. Solid bar indicates periods when turtle was at the surface of the water exposed to direct sunlight.

Figure 13. Difference between body and air temperatures for large (13.3 to 20.3 cm diameter, squares) and small (4.0 to 8.9 cm in diameter, circles) alligators tested at different air temperatures under high light intensities. Wind speed was constant ($157.0 \text{ cm sec}^{-1}$). Regression line was computed by the method of least squares ($r=0.92$).

Figure 14. Effect of metabolic rate on predicted body temperatures of large reptiles under warm temperature climate conditions. A. Effect of low reptilian metabolic rates. B. Effect of high mammalian metabolic rates. Body diameters of 1 and 2 meters were used in these calculations. Diurnal fluctuations in environmental temperature and radiation absorbed of 25° to 35° C and 0.8 to $1.2 \text{ cal cm}^{-2}\text{min}^{-1}$ respectively were simulated. Mathematical methods are described in Spotila *et al.* (1973).