Effect of Microwave Irradiation (2.45 GHz, CW) on Egg Weight Loss, Egg Hatchability, and Hatchling Growth of the Coturnix Quail

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Fertile eggs of the Coturnix quail were exposed twice a day for 30 min to 2.45-GHz continuous wave radiation at power densities of 25 or 50 mW cm\(^{-2}\) throughout the 17-day incubation period. Other eggs were exposed to 20 °C or 24 °C temperatures twice daily. Repeated exposures to 20 °C, 24 °C, or 25 mW cm\(^{-2}\) did not reduce hatchability. Irradiation at 50 mW cm\(^{-2}\) lowered hatchability, probably as a result of high egg temperatures. Hatchlings that had been irradiated by microwaves as embryos had normal growth rates and no obvious developmental abnormalities.

Key words: Coturnix quail, hatchability, growth, microwaves (2.45 GHz, CW), solar power satellite

INTRODUCTION

A satellite power system (SPS) has been proposed where geosynchronously orbiting satellites would collect solar energy and transmit that energy via microwaves to receiving antennas (rectennas) on the earth's surface. Electricity would be produced at the rectennas and transmitted by conventional high voltage lines to population centers [Glaser, 1968, 1980]. Each rectenna would have a diameter of about 10 km, and the proposed microwave power densities would range from approximately 1 mW cm\(^{-2}\) at the rectenna edge to approximately 23 mW cm\(^{-2}\) at the center. The SPS could have important negative impacts on airborne biota above the rectenna [Westerdahl and Gary, 1981]. It could theoretically have a severe environmental impact on birds since no practical method exists to prevent their access to the rectenna when landing to rest or nest.

After irradiation with 2.45-GHz continuous wave (CW) microwaves (20–40 mW cm\(^{-2}\)) for 280 to 300 min at the age of 48 h, chicken eggs showed abnormal embryogenesis [Van Ummersen, 1963]. It was concluded that factors other than thermal effects were responsible for the anomalous development. In subsequent studies involving 2.45-GHz CW microwaves, chicken eggs irradiated with 50 mW cm\(^{-2}\) for 240 s on days 1, 2, or 3, and Coturnix quail (Coturnix coturnix) eggs irradiated with 30 mW cm\(^{-2}\) for 4 h per day during the first 5 incubation days hatched.

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normally [Hills et al., 1974; McRee et al., 1975]. In the latter studies, the temperatures of the irradiated eggs did not rise above 37.5 °C, and egg hatchability and hatchling development were unaffected.

The present study was designed with regard to the uncertainty about the effects of microwave irradiation on egg weight loss and hatchability and the necessity of simulating worst case field conditions at a SPS rectenna, i.e., where the eggs in nests on the rectenna would be exposed when parents were absent from the nest. The interactive effects of microwave irradiation, ambient temperature (T_A) and ambient water vapor pressure (P_A) on egg hatchability and embryo development were studied. The Coturnix quail was chosen as the experimental animal because of the relative ease with which a large number of eggs can be incubated under laboratory conditions and the relatively short incubation period [McRee et al., 1975].

MATERIALS AND METHODS

Exposure System

A plywood exposure chamber (2.4 × 3.0 × 4.9 m) was lined with aluminum foil to which pyramidal carbon-loaded plastic foam absorber was then attached (Fig. 1). The radiating source was a Narda No. 675 standard gain horn that provided linearly polarized radiation from its position directly below the ceiling of the exposure chamber. The gain of the horn at 2.45 GHz was 14.6 dB over a region within 7° of the axis [Jasik, 1961]. Power was conveyed from a Cober S6F 2.45-GHz continuous wave generator (ripple <49%) through wave guides to the horn.

Quail eggs to be irradiated were supported large end up and 0.5 cm apart in a cardboard egg tray placed 4.2 m directly below the radiating horn. Each egg tray

![Diagram](image-url)
rested on a microwave transparent platform consisting of a plastic mesh screen supported by plastic legs 0.4 m above the pyramidal anechoic floor of the exposure chamber.

The power density within the exposure chamber was measured daily with an electromagnetic leakage monitor (Narda Microwave Corp., Model No. 81008) and probe (Narda Models No. 8121A and 8122A). Measurements were made 1 cm above the eggs in the center of the egg tray.

Dosimetry

The microwave dosimetry required calculation of the specific heat of Coturnix quail eggs under controlled environmental conditions. The specific heat for Coturnix quail eggs was calculated by calorimetry. A 1-mm diameter hole was drilled into the shell of four eggs. A thermistor was placed into the center of each egg and held in place with tape attached to the egg shell and thermistor lead. Each egg was then warmed to 43 °C in an incubator, removed, and immediately plunged into a 1 liter wide-mouth glass Dewar flask containing cold water and a second thermistor probe. The mouth of the flask was closed with a polyethylene foam lid. Temperatures of the water and egg were measured until equilibrium was reached.

A calorimeter constant (equivalent mass of water [k]) was determined for the Dewar flask by pouring water of known mass and temperature into the cool Dewar flask of known temperature, and then calculating the heat gained by the glass walls of the flask from the change in temperature. The mean of four determinations for k was 39.2 g. The specific heat of an egg was calculated as follows:

\[
S = \frac{[(k + m_2)(T_3 - T_2)]}{[m_1(T_1 - T_3)]} \tag{1}
\]

where \( m_1 \) is the mass of the egg (g), \( m_2 \) is the mass of water (g), \( T_1 \) is the initial egg temperature (°C), and \( S \) is the specific heat (cal g\(^{-1}\) °C\(^{-1}\)) [Lange 1941].

The heating rates were computed from the temperature rise of quail eggs irradiated at 92 mW cm\(^{-2}\). The eggs were implanted with probes from an RF Transparent Temperature Monitor (Narda Model 8011) interfaced with a digital voltmeter of a multi-channel recorder (Hewlett-Packard Model 34657-A). A probe was inserted into a small hole drilled into the shell, and the tip of the probe was positioned in the center of the egg. Evaporation and leakage of water and albumen from around the probes were reduced by covering the area around the probe with petroleum jelly. Each implanted egg was then placed (large end up) in the same location, the center of a styrofoam platform that was supported by a plastic net suspended 2.5 cm above the floor of a styrofoam box (0.40 × 0.28 × 0.105 m). The box had a 5-cm thick wall. The styrofoam box was placed on a styrofoam platform suspended below the microwave irradiating horn in the exposure chamber. Each egg was irradiated until its temperature rose to 45 °C. A least squares linear regression model was fitted to the linear portion of the heating curve of each egg.

The specific absorption rate (SAR) (W kg\(^{-1}\) mW cm\(^{-2}\)) for eggs was calculated as follows:

\[
SAR = \frac{[(\Delta °C \text{ min}^{-1})\text{SN}]}{(\text{mW cm}^{-2})}, \tag{2}
\]
where $N$ is a conversion factor, 69.769 mW min cal$^{-1}$ [Lange, 1941].

**Experimental Subjects**

Except during 30-min treatment periods, the experimental Coturnix quail eggs were incubated in a standard game bird incubator (G.Q.F. Manufacturing Co., Model 800) at 37.5 °C until hatching or for 19 days maximum (the Coturnix quail has a 17-day incubation period). Within the commercial incubator, the eggs were positioned on their small ends in cardboard trays and were automatically turned 60 ° back and forth every 2 h.

**Egg Weight Loss**

The conductance ($G$), the rate of movement of water through the shell of an intact quail egg maintained at constant temperature (incubator), was calculated using the following equation:

$$G = \frac{M_{H_2O}}{(P_E - P_A)}. \quad (3)$$

where $M_{H_2O}$ is the rate of decrease in egg mass due to water loss through the shell (g day$^{-1}$), $P_E$ is the saturation vapor pressure (torr) of water inside the egg at the egg temperature, and $P_A$ is the vapor pressure (torr) of water at the temperature of the air outside the egg. The fractional mass loss of an incubated egg ($F$) was computed from $M_{H_2O}$ using the following equation:

$$F = \frac{M_{H_2O}}{M_E}, \quad (4)$$

where $I$ is the length of the incubation period (days) and $M_E$ is the mass (g) of a freshly laid egg.

The $T_A$ and relative humidity in the 37.5 °C incubator and in a 24 °C incubator used in one of the treatments were measured with a motorized psychrometer (Bendix Psychron, Model 566) and in the laboratory with a wet/dry bulb sling psychrometer. Vapor pressures (torr) were computed by multiplying relative humidities by the maximum vapor pressure possible for that ambient temperature [Hodgman et al, 1961]. The ambient air temperature in the microwave and control exposure chambers were measured with the RF Transparent Temperature Monitor. It was assumed that the water vapor pressure in the two exposure chambers was the same as in the laboratory. All experimental eggs were weighed to the nearest 0.01 g every 4 days.

**Experimental Design**

Three series of experiments (Series 1-3) were conducted (Table 1). The first two contained eggs exposed to microwaves at 25 mW cm$^{-2}$, the third contained eggs exposed to 50 mW cm$^{-2}$. For each series, 120 Coturnix quail eggs were divided into four groups (Groups I to IV) and incubated at 37.5 °C. Groups I to III each consisted
TABLE 1. Treatments of Coturnix Quail Eggs in Three Series of Experiments

<table>
<thead>
<tr>
<th>Series No.</th>
<th>Group No.</th>
<th>Microwave power density (mW cm⁻²)</th>
<th>Temperature (°C) ± SD (N)ᵇ</th>
<th>Water vapor pressure (torr) ± SD (N)ᵇ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I</td>
<td>25</td>
<td>23.1 ± 1.60 (33)</td>
<td>9.30 ± 2.09 (34)</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>0</td>
<td>24.1 ± 0.61 (23)</td>
<td>5.84 ± 2.19 (14)</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>0</td>
<td>20.3 ± 1.28 (32)</td>
<td>9.30 ± 2.09 (34)</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>0</td>
<td>37.5 ± 0.09 (23)</td>
<td>19.89 ± 3.40 (23)</td>
</tr>
<tr>
<td>2</td>
<td>I</td>
<td>25</td>
<td>21.4 ± 1.35 (28)</td>
<td>7.19 ± 1.75 (35)</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>0</td>
<td>24.0 ± 0.39 (33)</td>
<td>3.53 ± 1.06 (33)</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>0</td>
<td>18.3 ± 1.39 (28)</td>
<td>7.19 ± 1.75 (35)</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>0</td>
<td>37.4 ± 0.38 (35)</td>
<td>21.35 ± 8.13 (35)</td>
</tr>
<tr>
<td>3</td>
<td>I</td>
<td>50</td>
<td>22.7 ± 3.06 (34)</td>
<td>7.87 ± 1.16 (35)</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>0</td>
<td>23.9 ± 0.37 (33)</td>
<td>4.53 ± 0.96 (33)</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>0</td>
<td>19.6 ± 1.02 (24)</td>
<td>7.87 ± 1.16 (35)</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>0</td>
<td>37.4 ± 0.37 (34)</td>
<td>24.80 ± 5.56 (34)</td>
</tr>
</tbody>
</table>

ᵃFor each series, eggs from Groups I, II, and III were removed from the incubator twice a day and subjected to the listed treatments for 30 min. Group IV eggs remained in the incubator.
ᵇN is the number of measurements.

do 30 eggs that were removed from the incubator for two 30-min periods per day. During these two periods, Group I eggs were irradiated in an exposure chamber. Group II eggs were exposed in a second incubator to an ambient temperature (Tₐ) similar to that in the exposure chamber used for Group I (24 °C), and Group III eggs were exposed to laboratory room temperature (19–20 °C). Group IV eggs were maintained in the incubator at 37.5 °C for the entire experiment and were only removed from the incubator when the eggs from each group were weighed every 4 days. At the beginning of each of the exposure periods, the eggs were removed, exposed to the treatments for 30 min and returned.

Sixty minutes before an egg tray was to be removed from the 37.5 °C incubator and exposed for 30 min, an additional fresh egg was placed in the tray. This extra egg was implanted with the probe from the RF Transparent Temperature Monitor after the egg tray was removed from the incubator and placed in the location where the eggs were to be treated. The temperature of the implanted egg was monitored throughout the exposure period. It was assumed that the temperature change in this extra egg was identical to those of the experimental eggs whose tray it shared.

Hatching Growth

All chicks that hatched from eggs involved in Series 2 and 3 were removed from the incubator within 12 h of hatching and placed in a standard commercial brooder. All birds were given food (Turkey Starter) and water ad libitum. Each chick from Series 2 was weighed to the nearest 0.1 g every 2 to 3 days for 26 to 28 days post-hatching. The chicks from Series 3 were weighed every 2 to 3 days for 15 days after hatching. Before each weighing, the chicks were visually examined for gross physical abnormalities. Detailed necropsies were not conducted.

RESULTS

Specific Absorption Rates

The SAR calculated for Coturnix quail eggs irradiated (with their large ends towards the source) to 2.45-GHz microwaves at a power density of 92 mW W⁻¹ kg⁻¹ = 0.5 W kg⁻¹ mW⁻¹ cm⁻² (Table 2).
TABLE 2. Specific Absorption Rates (SAR) for Coturnix Quail

<table>
<thead>
<tr>
<th>Species</th>
<th>Slope of heating curve</th>
<th>Specific absorption rate (SAR)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Egg mass (g) (n, SD)</td>
<td>Egg mass (g) (n, SD)</td>
</tr>
<tr>
<td>Coturnix quail</td>
<td>9.65 (16.0.53)</td>
<td>10.22 (4, 0.67)</td>
</tr>
</tbody>
</table>

*Eggs were positioned with their large ends up and were irradiated from above. See text for description of treatment.

*SAR's computed by the following equation: SAR = (N · slope · S)/92 mW cm⁻², where N = 69.769 kg cal · min⁻¹.

![Graph](image)

Fig. 2. Typical patterns of temperature change for irradiated (25 mW cm⁻²) and non-irradiated eggs during the 30-min exposure period following removal from a 37.5 °C incubator (first series).

Temperature Changes in Irradiated Eggs

Patterns of temperature change for irradiated and representative non-irradiated eggs during the 30-min exposure periods are illustrated in Figures 2–4. Each curve represents the temperature change in one egg. The temperature ($T_E$) of three representative eggs removed from the incubator and exposed to laboratory ambient temperature (19–20 °C) decreased exponentially to approximately 4 °C above that of ambient. The decline of $T_E$ in Group III in relation to exposure time (t) could be approximated by the equation:

$$T_E = 36.0 e^{-0.015t}$$  \( (5) \)

The $T_E$ of an instrumented egg that was treated with the Group II eggs that were
Fig. 3. Typical patterns of temperature change for irradiated (25 mW cm⁻²) and non-irradiated eggs during the 30-min exposure period following removal from a 37.5 °C incubator (second series).

Fig. 4. Typical patterns of temperature change for irradiated (50 mW cm⁻²) and non-irradiated eggs during the 30-min exposure period following removal from a 37.5 °C incubator (third series). Non-irradiated eggs were either exposed to 24.0 °C (Group II) or 19.6 °C (Group III).
exposed to a \( T_A \) similar to the eggs irradiated with 50 mW cm\(^{-2} \) (24 \(^\circ\)C) also decreased exponentially (\( T_E = 34.9 e^{-0.01t} \)) to 25.4 \(^\circ\)C (Fig. 4).

After removal from the incubator, two Group I eggs irradiated at 25 mW cm\(^{-2} \) cooled to 7.8 \(^\circ\)C (Fig. 2) and 8.6 \(^\circ\)C (Fig. 3) above \( T_A \) in 30 min. Results from the Group I eggs exposed at 25 mW cm\(^{-2} \) could be as closely fitted by an exponential curve as could the cooling curves for eggs exposed to room temperature (Group III) in Series 1 and 2 (Figs. 2, 3). The temperature of eggs irradiated with microwaves at 50 mW cm\(^{-2} \) decreased initially after removal from the incubator but then started to rise within the first 10 min of exposure (Fig. 4). This rise continued throughout the remainder of the exposure period. The pattern of temperature change for these eggs could not be fitted with a simple exponential curve of the type used with the control eggs or the 25-mW cm\(^{-2} \) eggs.

Linear models were produced with a natural log transformation of the \( t \) (elapsed min) values. The pattern of change in \( T_E \) of the two eggs irradiated at 25 mW cm\(^{-2} \) were not significantly different from each other (\( P > .05 \)) but were both significantly different from the \( T_E \) loss curves of the three control (Group III) eggs and of the 24 \(^\circ\)C (Group III) egg (\( P < .05 \)). The rates of temperature loss of the three Group II eggs did not differ significantly from each other or from that of the single Group II egg (\( P > .05 \)). The change in temperature of the egg irradiated with 50-mW cm\(^{-2} \) microwaves was clearly different from all of the other monitored eggs.

**Mass Losses and Hatchability of Irradiated Eggs**

The mean losses in mass of incubated quail eggs in Series 1, 2, and 3 are summarized in Table 3. The group means did not differ significantly from each other (ANOVA, \( P > .05 \)).

The daily rate of loss of mass (\( M_{H_2O} \)), estimated fractional water loss at day 17 (\( F_{17} \)), and the number of viable eggs hatched during the three series are given in Tables 4-6. Only those eggs in which development had begun were considered to be viable. With the exception of Group I in Series 3 (50 mW cm\(^{-2} \) in Table 6), Groups I, II, and III in each series did not differ in hatching success from that of the corresponding eggs in Group IV that were incubated continuously. The 30 eggs that were irradiated with 50 mW cm\(^{-2} \) (Group I of Series 3) had a significantly lower hatching success than did eggs of Group IV that remained in the incubator (\( \chi^2 = 21.32, \) d.f. = 1, \( P < .05 \)) (Table 6). Thus, hatching success was insensitive to fractional mass losses between 12% and 16%.

Water losses from the eggs that occurred during the 17th h of treatment and the water losses over the 17 days of incubation were estimated from the ambient temperature (\( T_A \), relative humidity (RH), estimated mean ambient water vapor pressure

**TABLE 3. Loss of Mass in Coturnix Quail Eggs Following Various Microwave and Control Treatments**

<table>
<thead>
<tr>
<th>Series No.</th>
<th>Group I Mean weight loss (g) ± SD*</th>
<th>Group II Mean weight loss (g) ± SD*</th>
<th>Group III Mean weight loss (g) ± SD*</th>
<th>Group IV Mean weight loss (g) ± SD*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.55 ± 0.37</td>
<td>1.66 ± 0.88</td>
<td>1.66 ± 0.88</td>
<td>1.67 ± 0.74</td>
</tr>
<tr>
<td>2</td>
<td>1.38 ± 0.37</td>
<td>1.26 ± 0.21</td>
<td>1.22 ± 0.22</td>
<td>1.33 ± 0.38</td>
</tr>
<tr>
<td>3</td>
<td>1.31 ± 0.39</td>
<td>1.40 ± 0.55</td>
<td>1.39 ± 0.55</td>
<td>1.45 ± 0.62</td>
</tr>
</tbody>
</table>

*See text for description of treatments.

*Sample size (N) was 30 eggs per group except in Series 2, Group III where it was 29.
**TABLE 4.** The Relationship Between Egg Water Loss and Hatching Success of Irradiated and Non-Irradiated Coturnix Quail Eggs Under Four Experimental Treatments (First Series)*

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>$T_{A^a}$ (°C)</th>
<th>Initial (g)</th>
<th>16 day (g)</th>
<th>$M_{H_2O}$ (g/day)</th>
<th>$F_{17^b}$ (%)</th>
<th>No. hatched</th>
<th>No. not hatched</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>30</td>
<td>23.1</td>
<td>11.38</td>
<td>9.83</td>
<td>0.10</td>
<td>14.47</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>II</td>
<td>30</td>
<td>24.1</td>
<td>10.38</td>
<td>9.20</td>
<td>0.10</td>
<td>16.24</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>III</td>
<td>30</td>
<td>20.3</td>
<td>11.23</td>
<td>9.53</td>
<td>0.11</td>
<td>16.08</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td>IV</td>
<td>30</td>
<td>37.5</td>
<td>11.02</td>
<td>9.26</td>
<td>0.11</td>
<td>16.97</td>
<td>17</td>
<td>7</td>
</tr>
</tbody>
</table>

*Eggs in Groups I and III were removed from incubator twice a day and treated to ambient temperatures below 37.5 °C for 30 min. Group IV eggs remained in incubator. See text for description of treatments.

$T_{A^a} =$ mean air temperature.

$F_{17^b} = M_{H_2O} \times 17$ days/initial mass.

*Eggs in Group I were irradiated with 25-mW cm$^{-2}$.

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**TABLE 5.** The Relationship Between Egg Water Loss and Hatching Success of Irradiated and Non-Irradiated Coturnix Quail Eggs Under Four Experimental Treatments (Second Series)*

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>$T_{A^a}$ (°C)</th>
<th>Initial (g)</th>
<th>16 day (g)</th>
<th>$M_{H_2O}$ (g/day)</th>
<th>$F_{17^b}$ (%)</th>
<th>No. hatched</th>
<th>No. not hatched</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>30</td>
<td>21.4</td>
<td>10.86</td>
<td>9.49</td>
<td>0.09</td>
<td>13.40</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>II</td>
<td>29</td>
<td>22.6</td>
<td>10.53</td>
<td>9.26</td>
<td>0.08</td>
<td>12.81</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>III</td>
<td>30</td>
<td>18.3</td>
<td>10.72</td>
<td>9.50</td>
<td>0.08</td>
<td>12.09</td>
<td>23</td>
<td>2</td>
</tr>
<tr>
<td>IV</td>
<td>30</td>
<td>37.4</td>
<td>11.06</td>
<td>9.73</td>
<td>0.08</td>
<td>12.78</td>
<td>21</td>
<td>2</td>
</tr>
</tbody>
</table>

*Eggs in Groups I to III were removed from incubator twice a day and treated to ambient temperatures below 37.5 °C for 30 min. Group IV eggs remained in incubator. See text for description of treatments.

$T_{A^a} =$ mean ambient air temperature.

$F_{17^b} = M_{H_2O} \times 17$ days/initial mass.

*Eggs in Group I were irradiated with 25-mW cm$^{-2}$.

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**TABLE 6.** The Relationship Between Egg Water Loss and Hatching Success of Irradiated and Non-Irradiated Coturnix Quail Eggs Under Four Experimental Treatments (Third Series)*

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>$T_{A^a}$ (°C)</th>
<th>Initial (g)</th>
<th>16 day (g)</th>
<th>$M_{H_2O}$ (g/day)</th>
<th>$F_{17^b}$ (%)</th>
<th>No. hatched</th>
<th>No. not hatched</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>30</td>
<td>22.7</td>
<td>11.23</td>
<td>9.92</td>
<td>0.08</td>
<td>12.39</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>II</td>
<td>30</td>
<td>23.9</td>
<td>10.08</td>
<td>9.68</td>
<td>0.09</td>
<td>13.43</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>III</td>
<td>30</td>
<td>19.6</td>
<td>10.96</td>
<td>9.57</td>
<td>0.09</td>
<td>13.48</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>IV</td>
<td>30</td>
<td>37.4</td>
<td>11.10</td>
<td>9.65</td>
<td>0.09</td>
<td>13.88</td>
<td>17</td>
<td>6</td>
</tr>
</tbody>
</table>

*Eggs from Groups I to III were removed from incubator twice a day and treated to ambient temperatures below 37.5 °C for 30 min. Group IV eggs remained in incubator. See text for description of treatments.

$T_{A^a} =$ mean ambient air temperature.

$F_{17^b} = M_{H_2O} \times 17$ days/initial mass.

*Eggs in Group I were irradiated with 50-mW cm$^{-2}$.
(P_A) and measured weight losses of experimental eggs. The ambient water vapor pressure for Groups I and III in all series was assumed to be equal to values calculated in the laboratory from measured T_A and RH. Estimates of water loss for the 17th h of actual treatment were calculated using equation 3. The maximum and minimum estimates for all treatment groups for each of the series were calculated from an assumed T_E of 37.5 °C or T_A, respectively. The "Probable" estimates of water loss for 17-h treatments were calculated from the egg temperatures of the 16th min of the temperature profiles illustrated in Figures 2–4. The computed water vapor conductances (g/day/torr) for Group IV in each of the series (0.0038 for Series 1, 0.0030 for Series 2, and 0.0039 for Series 3) were used to compute all estimated 17-h water losses for Group I to III from each series. This was necessary as only Group IV eggs were held under constant T_A. The estimated water loss for 17 days was calculated from M_{H_2O}.

Estimated differences in 17-h water losses between groups were very low in comparison to between treatment differences in 17-day water loss, and no relationship was observed between the predicted water losses for the 17 h of actual treatment (predicted from T_A and RH during the treatment) and the water loss estimates for 17 days (estimated from measured 16-day mass losses).

Relative Hatching Times of Irradiated Eggs

At the end of Series I experiments, Group IV and III eggs hatched first, followed in 6 h by Group II, and in 12 h by Group I. At the end of Series 2, Group I and II eggs hatched approximately 12 h after eggs in Group IV. Eggs in Group III followed those in Group IV by 24 h. After the third series, Group IV eggs began to hatch first, followed 6 h later by eggs from Group I. Groups II and III hatched between 12 h and 18 h after Group IV.

Growth of Hatchlings

A linear least squares regression model was fitted to the hatching growth data from Groups I to IV of Series 2 and 3. There were no significant differences of 1-day post-hatching weights between groups. The slope of the 26-day growth curve for those chicks that had been irradiated as embryos at 25 mW cm^{-2} (Series 2, Group I) was not significantly different from the slopes of the growth curves of chicks from eggs exposed to 24 °C (Series 2, Group II), 19 °C (Series 2, Group III), or kept continuously in the incubator (Series 2, Group IV) (P > .05).

Similarly, the slope of the 15-day growth curve of those chicks from eggs irradiated twice daily at 50 mW cm^{-2} (Series 3, Group I) was not significantly different from the slopes of the growth curves of chicks from 24 °C eggs (Series 3, Group II), 19 °C eggs (Series 3, Group III), or the continuous incubation eggs (P > .05).

Slopes of the growth curves from Series 2 were compared to those in Series 3. No significant differences were noted in the rates of growth of the 25 and 50 mW cm^{-2} chicks (Groups I of Series 2 and 3) or between those of Groups II (24 °C), Groups III (19 °C), or between Groups IV (continuous incubation) (P > .05).

No visibly deformed chicks were hatched from eggs that had been irradiated at 25 or 50 mW cm^{-2}.