THE EFFECTS OF PROLONGED TRAINING ON THE RESISTANCE TO RADIATION-INDUCED CHANGES IN MALE ALBINO RATS

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ABSTRACT

THE EFFECTS OF PROLONGED TRAINING ON THE RESISTANCE TO RADIATION-INDUCED CHANGES IN MALE ALBINO RATS

by Robert Kertzer

The purpose of this investigation was to study the effects of various levels of preirradiation physical activity, from weanling age to adulthood, upon the radiation resistance of mature rats.

Two-hundred and fifty 26-day old male albino rats (Sprague-Dawley strain) were randomly assigned to one of five treatments. Group 1 (sedentary control) received no special treatment, other than radiation, and was confined to individual sedentary cages both prior to and after being irradiated. Group 2 (spontaneous control) received no special treatment, other than radiation, and was housed in individual spontaneous exercise cages until irradiated and then confined to individual sedentary cages. Group 3 (sedentary forced) was housed in individual sedentary cages both prior to and after being irradiated. During the training period prior to irradiation, these animals were forced to swim daily for one-half hour with two per cent body weight attached to the

base of the tail. Group 4 (spontaneous forced) was housed in individual spontaneous exercise cages until irradiated and then confined to individual sedentary cages. Prior to being irradiated these animals also were forced to swim daily for one-half hour with two per cent body weight attached to the base of the tail. Group 5 (spontaneous effect) was housed in individual spontaneous exercise cages both prior to and after being irradiated. These animals were not subjected to the preirradiation forced training regimen.

The preirradiation treatments were begun at 27 days of age and were carried on throughout puberty and early adulthood. On the 83rd day of the preirradiation treatments, 20 per cent of the animals, randomly selected with stratification by groups were placed in sedentary cages for an approximate 64-hour rest period prior to irradiation. The forced swimming regimen was terminated for these animals at this time. On the 84th, 85th and 86th days, a similar procedure was followed with 20, 30 and 30 percent of the animals respectively. Following the 64-hour rest period, each animal was exposed to 650 r while confined in a three-inch by nine-inch lucite chamber.

Nine days before and five days following irradiation, a blood sample was drawn from the orbital sinus of each animal to determine the WBC and eosinophil count. During the 30 days immediately following irradiation, mortality and survival time in hours were recorded for all groups of animals. At the end of the 30-day period, the surviving animals in all groups were sacrificed. Upon death or sacrifice, body weight as well as the weights of the spleen and adrenals were determined.

Statistical analysis of the experimental data has prompted the following conclusions:

1. Forced swimming for one-half hour daily with two per cent body weight attached significantly increases spontaneous activity.

2. Forced swimming and/or spontaneous activity for a prolonged period reduce body weight.

3. Illumination of animal quarters 24 hours daily significantly reduces volitional activity as compared to 12-hour per day illumination.

4. Irradiation decreases spontaneous activity.

5. Prolonged training does not alter WBC or eosinophil levels either prior to or following irradiation.

6. Prolonged training has no effect on either adrenal weight per body weight or gross splenic weight following irradiation.

7. Level of preirradiation physical activity has no effect on postirradiation mortality and survival time.

8. Body weight appears to be the most significant factor influencing survival time following irradiation with the heavier animals in all treatment groups having significantly increased survival times.

THE EFFECTS OF PROLONGED TRAINING ON THE

RESISTANCE TO RADIATION-INDUCED

CHANGES IN MALE ALBINO RATS

By

Robert Kertzer

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To my wife Joyce, for maintaining an intact family unit.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure		Page

CHAPTER I
THE PROBLEM

Introduction

In recent years, the rapid development of nuclear armaments, combined with conflicting international ideologies, has contributed to the constant possibility of a world catastrophe. Furthermore, automation has reduced the amount of physical activity necessary to carry on the tasks of daily living. It would be well to know the interrelationships and possible physiological consequences of these socially superimposed phenomena.

Statement of the Problem

The purpose of this investigation was to study the effects of various levels of preirradiation physical activity, from weanling age to adulthood, upon the radiation resistance of mature rats. The information gained should aid in evaluating the influence of physical conditioning upon the mortality and selected physiological and anatomical parameters of animals exposed to lethal doses of radiation.

Importance of the Problem

Considerable work has been done already on (a) the effects upon mortality of fatigue produced by exhaustive exercise immediately prior to and/or immediately following irradiation

(7, 8, 36, 38); (b) the effects upon mortality of daily postirradiation exercise combined with various radiation doses (19, 20); and (c) the effects of radiation upon recovery from fatigue (8), the ability to perform an exhaustive exercise test (6, 21, 35, 40) and volitional activity (18, 22). Data are incomplete in regard to the effects of radiation upon animals subjected to physical training over a long period of time prior to being irradiated.

There is substantial evidence to indicate that extended programs of relatively vigorous daily activity result in significant alterations in a number of physiological and anatomical parameters which are also affected by irradiation (5, 9, 10, 11, 12, 16, 25, 26, 28, 29, 32, 33, 44). Some of these changes are similar to those produced by irradiation, whereas others are distinctly opposite (2, 4, 7, 8, 19, 20, 30, 31, 35, 36, 37, 40, 41). This raises the question as to whether or not various types of prolonged physical training will influence resistance to damage caused by lethal doses of radiation.

Limitations of the Study

1. Small laboratory animals may be investigated in numbers sufficient for generalization within the chosen population; however, the physiological results of

animal studies cannot be translated directly to human subjects.

2. The strong psychosomatic response which may be expected in man when he is aware of the fact that he has been exposed to a lethal dose of radiation limits extrapolation from the rat to the human.

3. No attempt was made either to measure or control food intake.

4. The physiological changes produced by 650 roentgens of radiation may be vastly different than those produced by other doses.

5. Exercise regimens, other than those employed in the present investigation, might produce dissimilar results.

Definition of Terms

1. Roentgen. - One roentgen is that quantity of X-or gamma radiation such that the associated corpuscular emission (electrons and ions) per 0.001293 gm. of air produces, in air, ions carrying 1 electrostatic unit of charge of either sign (2).

2. Mode of Irradiation. - 250 k v p x-rays; 15 M.A.; .5 mm. Cu (HVL 1.5 mm Cu) 78 inches TSD; 3.6 r/minute (air dose).

3. <u>LD 50/30</u>. - That dosage of radiation estimated to eliminate 50% of the population within a 30-day period.

CHAPTER II
REVIEW OF RELATED LITERATURE

In making a study of the effects of prolonged training on the resistance to radiation-induced changes it seems wise to have some knowledge of the effects of pre- and post-irradiation exercise and the associated changes in both mortality and related physiological and anatomical parameters.

American Investigations

Postirradiation Exercise

Smith and Smith (35) forced mice to exercise in a revolving cage following irradiation. Animals receiving 325 r tolerated 12 hours of continuous activity immediately after or at any time up to 13 days postirradiation. Animals receiving 400 r tolerated eight hours of continuous activity on three consecutive days beginning immediately after or at any time up to 13 days postirradiation with little, if any, effect upon survival time. All animals receiving 600 r and then forced to exercise for eight continuous hours on three consecutive days died. When the radiation effects in exercised animals were compared with those observed in nonexercised irradiated control animals, it was concluded that there were no marked consequences either of irradiation upon exercise tolerance or of post-irradiation exercise upon mortality.

Smith and Smith (36) subjected mice to various levels and durations of exercise following whole-body irradiation. Three days of moderate exercise of eight consecutive hours a day in equally spaced sessions of three hours, decreased slightly, if any, the tolerance of mice to prior irradiation. Following a radiation dose which was 100 per cent lethal, seven of 30 mice could not tolerate three successive days of exercise for eight hours a day. No differences in survival time were noted between those mice surviving the exercise period and irradiated controls. The radiation tolerance of mice was not increased by phenobarbital sedation following irradiation. It was concluded that radiation lethality doses not parallel the rate of O_2 utilization under the experimental conditions employed.

Kimeldorf and Jones (20) studied the relationship of radiation dose to lethality in exercised animals exposed to x-rays. Male Sprague-Dawley rats were forced to swim until fatigued daily for four weeks following irradiation. As a result, these animals showed a greater mortality, with increased deaths at lower doses, than similar animals receiving only radiation. The nonexercised rats displayed a calculated median lethal dose which was 28 per cent higher than that computed for exercised animals. It was concluded that exercise increases the level of mortality when performed postirradiation.

Kimeldorf, Jones and Castanara (21) studied the effect of irradiation upon the performance of daily exhaustive exercise by the rat. For periods as long as nine weeks post-irradiation, rats were forced to perform a standardized exhaustive swimming test five times weekly. The ability to perform this test was decreased by exposure to x-rays in the 300-1000 r range. The extent of the decrease in performance was dependent upon dosage. Those rats surviving the test period recovered sufficiently to attain their preirradiation exercise levels by the ninth week. However, these animals were not able to perform as well as non-irradiated exercised control animals. The rats dying within a short period following irradiation were almost normal in performance, whereas those animals dying later displayed a lower level of performance which varied with the duration of the survival period.

Kimeldorf et al. (22) studied the effect of repeated exposures to x-rays on the volitional activity of adult male rats. Under controlled conditions of light, sound and temperature, the daily volitional activity of each animal was recorded for 15 consecutive weeks. Dose increment effects were investigated by subjecting animals to 50 r, 100 r and 150 r at weekly intervals. The resulting cumulative doses were 600 r, 1200 r and 1350 r, respectively. By spacing 150 r doses at seven, 14 and 28 day intervals, the effect of changing the interval between exposures was studied. Irrespective of increment size or interval between exposures, a decrease in activity was noted after each irradiation. Statistically significant differences were observed between experimental and nonirradiated control groups immediately following each 150 r exposure, after six of 12 exposures to 100 r and following three of 12 exposures to 50 r. The decrease in activity was a function of the increment size rather than the cumulative dose. With the exception of weekly 150 r exposures, recovery occurred within a week following each exposure. After six weekly exposures to 150 r, recovery in activity was less than normal. The responses to each 150 r dose were comparable regardless of the intervals between exposures.

Jones et al. (18) also studied the effect of irradiation on voluntary activity of the adult male rats utilizing single doses of x-rays, ranging from 200-1000 r. A prompt significant reduction was noted at all doses. A period of increased activity immediately followed the initial decrease. Within five days postirradiation, all animals exposed to 200 r and 300 r were completely recovered. No further detectable effects of irradiation upon voluntary activity at these levels were noted. When animals were exposed to x-rays of 400 r or more, some animals died. In the animals which survived, there was an initial period of depressed activity, followed by a recovery period, and then a second depression. This subsequent reduction in activity reached a low value during the third week postirradiation. The amount of time required for surviving animals to completely recover from the second depression in activity seemed to be proportional to the x-ray dose. Those rats which died within the first nine days postirradiation displayed voluntary activity levels which continuously decreased from the day of irradiation until death. In animals dying after nine days postirradiation, the first depression was followed by some recovery. However, there was a second decrease in activity which persisted until death.

Kimeldorf and Baum (19) investigated the changes in organ and body growth following exhaustive exercise, x-irradiation and postirradiation exercise. Eight hundred and sixty-four male Sprague-Dawley rats were used in the investigation. Animals were subjected to no stress, to repeated swims to exhaustion, to various single doses of irradiation, or to irradiation plus various numbers of bouts of postirradiation exhaustive swimming. The animals were 55 days old when the experimental treatments were begun, and sacrifices were conducted 3, 9, 18 and 30 days following. Body weight was reduced in the experimental animals by both exhaustive exercise and exposure to irradiation. Relative to body weight: (a) either exercise or irradiation produced a decrease in thymus weight, an increase in adrenal weight, and no change in kidney weight; (b) exercise produced an increase and irradiation a decrease in the weights of the gluteus maximus, heart, spleen and testes; (c) exercise had no effect upon the pituitary weight whereas irradiation reduced the weight of this gland; and (d) exercise increased thyroid weight while irradiation failed to alter it. In general, changes following irradiation were found to be immediate and to be related to dosage, whereas exercise-induced changes were accumulative and related to the number of repetitions. When animals were subjected to

irradiation plus exhaustive fatigue, the responses were predominately those of irradiation and were not markedly increased by exercise. Postirradiation exercise did tend to prevent recovery from radiation damage.

Smith and Smith (39) studied the effects of thyroid and radiation on sensitivity to hypoxia, basal rate of O_2 consumption and tolerance to exercise. Mice treated with thyroid were found to have increased basal O_2 consumption, increased sensitivity to hypoxia and a depressed ability to tolerate exercise. These three parameters followed the same course of development with time. Within the limits imposed by the experiment, animals exposed to 325 r exhibited no decrease in exercise tolerance and no observable changes in basal O_2 consumption. These irradiated mice did show a decrease in sensitivity to progressive hypoxia. In mice receiving both thyroid and irradiation there were no increases in basal O_2 consumption or decreases in tolerance to exercise beyond those caused by thyroid alone. However, the doubly treated animals had a greater resistance to hypoxia than animals receiving only thyroid. It was concluded that early failures in an exercise test and deaths of thyroid-administered animals during exercise were indicative of impaired functional capacity

of the heart rather than of general muscular fatigue.

Preirradiation Exercise

Brown and White (7) studied preirradiation fatigue as a factor in the prevention of irradiation deaths in rats. Ten female Sprague-Dawley rats were swum to exhaustion on ten successive days. Five of these animals were irradiated on the eleventh day with 1200 r of cobalt^{60} immediately after an exhaustive swim. The other five animals received the same dose of radiation but without immediately prior exercise. All animals which swam before being irradiated were alive one month after irradiation, whereas all of the other animals died within ten days following the radiation exposure. It was concluded that fatigue-induced anoxia serves as a protective mechanism against lethal doses of radiation.

Preirradiation Training

Kimeldorf and Jones (20) demonstrated that a short training program prior to irradiation (for a period of ten days) has no significant effect upon mortality.

Pre- and Postirradiation Exercise

Brown and White (8) forced sixteen adult Sprague-Dawley rats to swim to exhaustion on ten successive days. The animals then were matched on mean swimming time and assigned

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Pre- and Postirradiation Exercise

Brown and White (8) forced sixteen adult Sprague-Dawley rats to swim to exhaustion on ten successive days. The animals then were matched on mean swimming time and assigned

to two treatments. On the eleventh day, the animals in Group I were swum to exhaustion, immediately irradiated with 1200 r of cobalt^{60}, and two hours later again swum to exhaustion. Group II was irradiated first, immediately swum to exhaustion, and two hours later again fatigued by a swim to exhaustion. The groups had similar swimming times during the first swim on the day of irradiation, but Group II swam significantly longer during the second session. It was concluded that irradiation immediately following exhaustive fatigue retards the biological processes involved in recovery from fatigue more than irradiation immediately prior to fatigue. Subsequently, both groups were forced to swim to exhaustion once a day until death or for a period of seven days after irradiation. The animals in Group II were able to do significantly more work, as measured by total swimming time, during this postirradiation period but died significantly earlier. All animals in Group II died within six days after irradiation; only two animals in Group I died within six days and two lived more than 30 days. Statistical analysis revealed that the difference in postirradiation work was not responsible for the difference observed in mortality rate. Both differences were shown to be the result of the relative states of fatigue of the two

groups at the time of irradiation. It was concluded that (a) anoxia associated with fatigue protected the animals in Group I from radiation injury, (b) preirradiation anoxia could not explain the lack of recovery from postirradiation fatigue in Group I, and (c) a condition which increased radiation injury in Group II also increased their relative ability to do work postirradiation.

Kimeldorf, Jones and Fishler (23) studied male Sprague-Dawley rats in an effort to ascertain the role of metabolic level in determining radiosensitivity. The experimental animals performed a standardized exhaustive exercise, consisting of swimming in individual tanks. These animals were exercised once a day for ten days prior to irradiation. Following irradiation they were exercised daily, five times per week. After irradiation with 600 r, 50% of the exercised rats died and all nonexercised irradiated controls survived. At a dose (700 r) that was lethal to 44% of the nonexercised animals, mortality was 92% among exercised rats. At a highly lethal dose (860 r), exercised animals displayed symptoms of roughened coat, diarrhea and crusted nares much sooner following irradiation than did the nonexercised controls. The exercised rats had a much shorter post-irradiation survival time in addition to a higher mortality

rate. The authors conclude that the results provide evidence of the relation between radiosensitivity and metabolic level.

Russian Investigations

Zimkin and Korobkov, two Russian investigators, have reviewed the studies of their co-workers in the area of exercise and radiation (50).

Postirradiation Exercise

Sergeyev, working with rabbits, demonstrated a rise in mortality in animals exercised following a radiation dose of 1000 r. Intensity of radiation sickness was increased in the exercised animals. In the investigations of Popov, all dogs died who were forced to execute daily hourly runs on a treadmill at a speed of 6 km./hr. following irradiation. Markelov also demonstrated that following an intravenous injection of 1 millicure/kg. of radioactive Sr_{89}, physical exercise intensified radiation sickness in rats.

On the other hand, Trifonov showed that daily moderate exercise following irradiation both reduces and postpones the onset of mortality. Mortality of 24 control rats subjected to irradiation of 1150 r was 54 per cent after 25 days with the average length of life of those dying being 3.77 days. Animals which were swum without weights for 15 minutes daily over a ten-day period following irradiation

with the same dose had a 35 per cent mortality with the average life span being 6.57 days. More severe exercise after irradiation (1 hour and 20 minutes daily for ten days) produced no further decrease in mortality but did prolong the life of those who eventually perished. Pinchook and Scherban irradiated mice with either 800 or 1200 r before forcing them to swim for 30 minutes in water at 25-30° C. After a dose of 1200 r all mice died. However, mice who were only irradiated lived, on the average, less (4-12 days) than those irradiated and swum (4-75 days). Of 80 mice exposed only to irradiation with 800 r 15 (18.7 per cent) survived, but 20 (25 per cent) of those irradiated and swum survived. For the mice who died after being subjected only to irradiation the average length of life was less (8.87 days) than for those subjected to irradiation and subsequent swimming (10.35 days).

Preirradiation Exercise

Oogodskaya and Yondin forced rats to swim for 8-10 minutes with a ten-gram weight on their tails at 15-20 minutes before or immediately before irradiation. Mortality for 40 control rats was 35 per cent, while mortality for 40 exercised rats was only 22 per cent. In one experiment of Trifonov, 25 rats were swum to exhaustion

immediately prior to irradiation with 1150 r. Mortality in the experimental group was approximately the same (56 per cent) as in a group of nonexercised control rats (54 per cent). However, average length of life in the exercised rats was greater (7.36 days) than in the controls (3.77 days).

Preirradiation Training

The experiments of Sergeyev demonstrated that preliminary physical training decreases the mortality of irradiated animals. Using rabbits, he showed that systematic physical exertion for 10-25 days prior to irradiation with 1000 r reduces radiation sickness. In this study, radiation sickness was slight in the trained rabbits, even when they were subjected to daily physical exertion following irradiation. Tovbin, using three groups of 12 mice each, found that after a dose of 726-800 r control group mortality was 75 per cent; in one group trained for 50 days in dynamic work, mortality was 42 per cent; and, in a group trained during the same time in static efforts (hanging on a slender pole), mortality was 25 per cent. Trifonov also investigated the effects of pretraining on mortality following irradiation. Rats, which were trained by swimming and hanging from a pole for 1 1/2 months (35-38 training periods), died from radiation sickness in a

smaller percentage and on later dates than control animals. Trifonov emphasizes the importance of the exercise intensity. Longer sessions of training in swimming (up to 3 1/2 hours per day) showed a smaller prophylactic effect than shorter periods (30-60 minutes). Zimkin conducted experiments on 44 male rats of which 22 were subjected to training. Seven rats were exercised by running in a wheel which revolved at a rate of 13 revolutions per minute, and 14 rats were trained by hanging from a vertically suspended rope. The duration of exercise was increased by two minutes daily for 15 days. In subsequent exercise bouts for 30 days (with interruptions for vacations) the duration was held to 30 minutes. Animals were irradiated with 600 r. All rats surviving on the 28th day after irradiation were sacrificed. Four control and four experimental animals were sacrificed immediately following irradiation in order to study histological changes in various tissues. Therefore, the analyses of mortality, body weight changes, food consumption for one hour, number of leucocytes and hemoglobin content were carried out on data obtained from 18 control and 18 experimental animals. The results indicate that the experimental rats were more resistant to radiation than the

controls. In the group of trained animals 15 survived (81.1%) while only 10 (55.5%) of the untrained controls lived. Six of the control animals died in the period from the 6th to the 10th day following irradiation. One control animal died on the 13th day and one on the 19th day after irradiation. The average length of life for the control rats who died postirradiation was 10 days while the experimental animals lived, on the average, 15 days. Food consumption and body weight were decreased in all rats, but more so in the control group. Histological changes in the heart muscle of trained and untrained animals indicated a marked protein "dystrophy"; however, Zimkin and Korobkov report it was less widespread in the trained animals.

CHAPTER III
EXPERIMENTAL METHOD

Design of Experiment

Sample

Two hundred and fifty weanling (26-day-old) male Sprague-Dawley rats were randomly assigned to one of five treatment groups. A sample size of 50 for each group was chosen because previous experience with animal training studies in this laboratory (15, 25, 27) indicated that the variability of the parameters studied is such that it would be desirable to be able to detect, as significant, differences at least as small as two-thirds of one standard deviation, while holding the probability of making a type I statistical error to the .05 level and that of making a type II error to the .20 level. According to these specifications a sample size of 36 in each group was calculated as sufficient to distinguish between the effects of the various training programs which were used. Assuming, however, that concurrent irradiation would increase the within group variances to some unknown extent and that a few animals might be lost by drowning in the forced training period, by confinement during the radiation procedure or by the anesthetic during blood sampling, a sample size of 50 animals in each group was chosen arbitrarily.

In fact, three animals in one of the forced activity groups and two in the other did drown in training. One animal in one of the other groups died while under anesthesia during preirradiation blood sampling. Consequently, animals were eliminated randomly, and 47 rats in each group were irradiated. No animals were lost as a result of confinement during irradiation. Postirradiation blood sampling resulted in the death of one additional animal. Once again, equal groups were maintained by random elimination. Therefore, 46 animals per group comprised the final sample. This yielded a minimum statistical power of .90 for the several analysis of variance calculations made.

Treatment Groups

The following five treatment groups of animals were utilized in this investigation:

Group 1: A sedentary control group which received no special treatment, other than radiation. These animals were confined to individual sedentary cages both prior to and after being irradiated. (Each sedentary cage is 24 cm. long by 18 cm. wide by 18 cm. tall.)

Group 2: A spontaneous control group which received no special treatment, other than radiation. They were housed in individual spontaneous exercise cages until irradiated

and then confined to individual sedentary cages. (Each spontaneous exercise cage consists of an individual sedentary cage plus a freely revolving drum of 35 cm. diameter and 13 cm. width. These cages permit the animals to rest or exercise at will.)

Group 3: A sedentary forced exercise group which was housed in individual sedentary cages both prior to and after being irradiated. During the training period prior to irradiation, these animals were forced to swim daily for one-half hour with two per cent body weight attached to the base of the tail.

Group 4: A spontaneous forced exercise group which was housed in individual spontaneous exercise cages until irradiated and then confined to individual sedentary cages. Prior to being irradiated these animals also were forced to swim daily for one-half hour with two per cent body weight attached to the base of the tail.

Group 5: A spontaneous effect group which was housed in individual spontaneous exercise cages both prior to and after being irradiated. These animals were not subjected to the preirradiation forced training regimen.

From the five treatment groups, the following were determined:

1. The effects of sedentary cage existence upon resistance to radiation-induced changes.

2. The effects of spontaneous activity upon resistance to radiation-induced changes.

3. The effects of prolonged forced exercise upon resistance to radiation-induced changes.

4. The interaction between the effects produced by spontaneous and forced exercise.

5. The effects of radiation upon spontaneous activity.

Preirradiation Forced Training Procedures

Those animals which were subjected to the swimming regimen (Groups 3 and 4) were swum in individual cylindrical tanks measuring 11 inches in diameter and 30 inches in depth. Animals were always swum between 8:00 A.M. and 11:30 A.M. Beginning on the 50th day of the preirradiation treatments, a few animals were unable to complete the required one-half hour swim with two per cent body weight attached to the base of the tail. On the 53rd day two rats died while swimming. On the 56th day another died. Swimming was omitted on the 61st day as a one-day rest period seemed advisable. A fourth animal died on the 68th day. Consequently, a second rest period was inserted on the 69th and 70th days. Beginning with the 71st day, whenever an

animal was unable to complete the one-half hour swim with weight attached, he was pulled from the tank, the weight was removed, the animal was given a one-minute rest, and he was replaced in the tank without the weight attached for the remainder of the one-half hour swim. Approximately five animals required this procedure daily with only one additional rat drowning during the remainder of the preirradiation period. Water temperature was maintained between 36° and 38° C. during swimming. After each swim period the animals were dried with a towel and replaced in their respective cages.

Duration of Preirradiation Treatments

The preirradiation treatments were begun at 27 days of age and were carried on throughout puberty and early adulthood. On the 83rd day of the preirradiation treatments, 20 per cent of the animals, randomly selected with stratification by groups were placed in sedentary cages for an approximate 64-hour rest period prior to irradiation. The forced swimming regimen was terminated for these animals at this time. On the 84th, 85th, and 86th days, a similar procedure was followed with 20, 30 and 30 per cent of the animals respectively. This practice was employed since Brown and White (7) found that irradiation with 1200 r of $cobalt^{60}$

immediately following exhaustive fatigue produced no deaths within one month while all animals not exhausted by swimming died within ten days. It was assumed that exhaustive fatigue functioned as a protective mechanism. The present investigation was concerned with the long-term effects of physical training upon resistance to radiation rather than the immediate effects of fatigue. Therefore, the 64-hour rest period between the end of training and irradiation was incorporated into the experimental design.

Radiation

Following the 64-hour rest period, each animal was exposed to 650 r while confined in a three-inch by nine-inch lucite chamber. Twenty-four animals were irradiated simultaneously. The total time required for irradiation was 180.5 minutes. Animal positions were rotated every 36.1 minutes to provide equal exposures for all. The radiation dose was set at 650 r because Andrews (2) has reported that the LD 50/30 for the rat is between 600 and 700 r.

Blood Measures

Nine days before and five days following irradiation a blood sample was drawn from the orbital sinus of each animal to determine the WBC and eosinophil count. A 24-hour period of confinement in sedentary cages was provided for

all animals, regularly in spontaneous cages, prior to the drawing of each blood sample.

Postirradiation Period

During the 30 days immediately following irradiation, a laboratory technician was with the animals twenty-four hours a day. Mortality and survival time in hours for all groups of animals were recorded during this period. At the end of the thirty-day period, the surviving animals in all groups were sacrificed.

Upon death or sacrifice, body weight as well as the weights of the spleen and adrenals were determined. The thymus was observed subjectively, but not weighed, since its postirradiation condition prohibited proper extraction and trimming. These organs were selected for study since Andrews (2) has reported that lymphoid tissue is highly sensitive to irradiation with sufficient consistency to warrant the use of such tissues as biological radiation dosimeters.

General Procedures

Throughout the entire investigation, all animals received water and a commercial ground animal diet, ad libitum. The temperature in the housing quarters was maintained between 70° and 78° F. Body weight for each animal was determined once a week throughout the preirradiation period,

and the weight to be attached to the base of the tail during swimming was changed on the following day. Daily voluntary exercise data for each animal housed in a spontaneous exercise cage was recorded at 7:45 A.M. daily.

For the first 71 days of the preirradiation period, an automatic timer illuminated the animal quarters 12 hours each day. Since it was necessary for the technician to observe each animal hourly following irradiation, lights were kept on 24 hours a day beginning on the 72nd day. The 24-hour illumination was started 12 days prior to irradiation in order to provide an adjustment period for the animals.

Statistical Methods

The differences in mortality between the five treatment groups were analyzed using the chi-square test for multiple independent samples (34).

A Pearson product-moment coefficient of correlation was calculated between the pre- and postirradiation spontaneous activity values for the spontaneous effect group to determine the consistency of the effect of radiation on voluntary activity of rats. The difference between the pre- and postirradiation spontaneous activity levels in group 5 was evaluated by the standard one-way analysis of variance technique (14).

Standard one- and two-way fixed effects analysis of variance techniques were employed where appropriate to analyze the data on preirradiation spontaneous activity levels, body weights, eosinophil and white blood cell counts, organ weights and survival times (14). The Tukey method for multiple comparisons between means was used whenever significant F-values were obtained (14).

CHAPTER IV

RESULTS AND DISCUSSION

Results

Daily spontaneous activity was evaluated in order to determine the effects of (a) forced swimming on voluntary exercise (b) voluntary activity on resistance to mortality following irradiation and (c) irradiation on level of spontaneous activity.

Preirradiation Spontaneous Activity

Figure 1 compares the daily voluntary activity of the spontaneous control animals (Group 2) with the spontaneous forced (Group 4) for the 84-day preirradiation training period. A one-way fixed effects analysis of variance was calculated where Groups 2 and 4 were factor A and the criterion variable was 84-day spontaneous activity. This analysis enabled one to determine the effects of forced swimming on spontaneous activity. Table 1 shows the results. Figure 2 indicates mean spontaneous activity values preirradiation.

Table 1

Analysis of Variance for Preirradiation Spontaneous Activity

Source of Variance	SS	DF	MS	F
Among Groups	9342244	1	9342244	3.89
Within Groups	216031102	90	2400345	
Total	225373346	91		

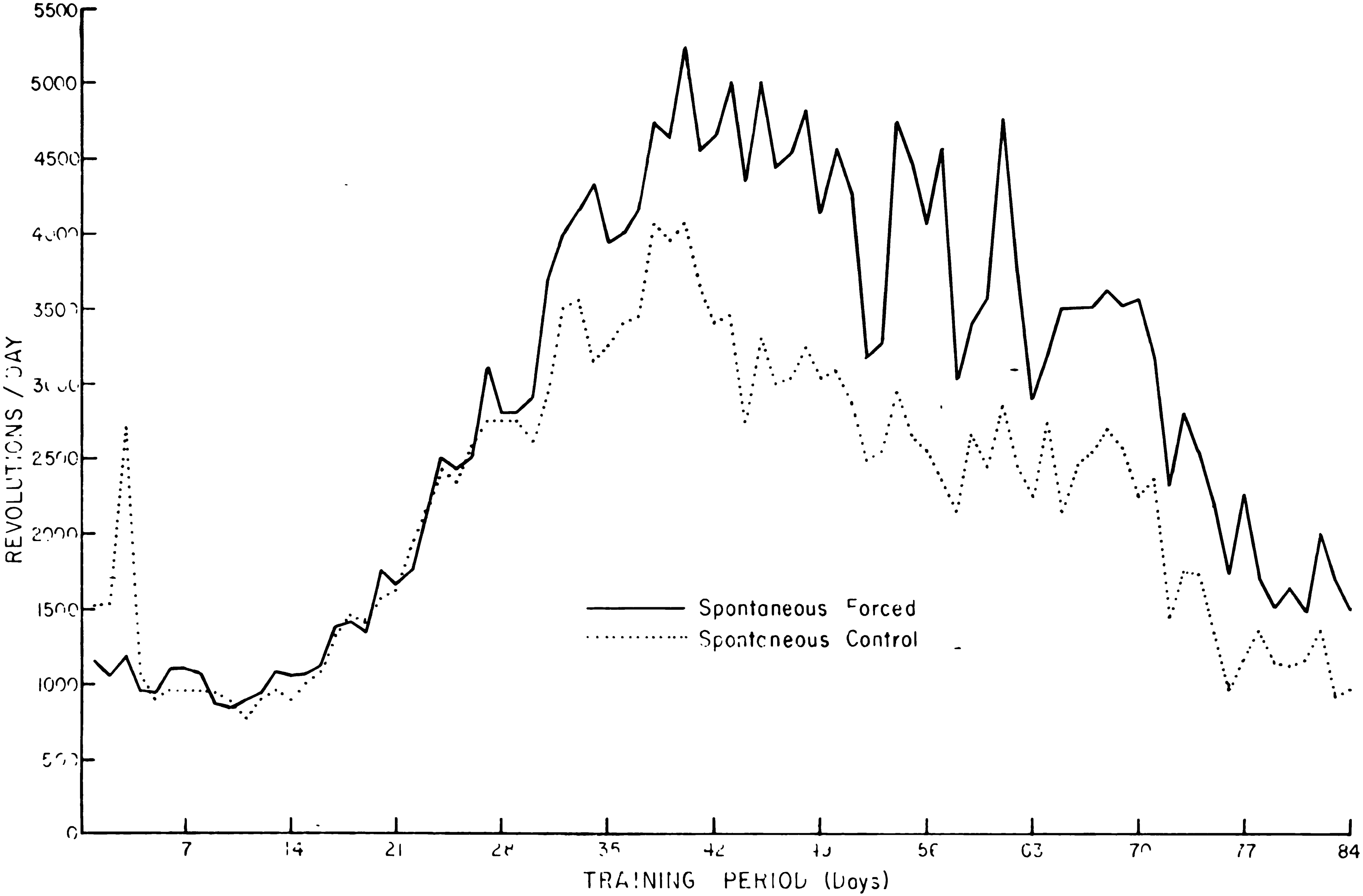

Figure 1 Daily Preirradiation Spontaneous Activity

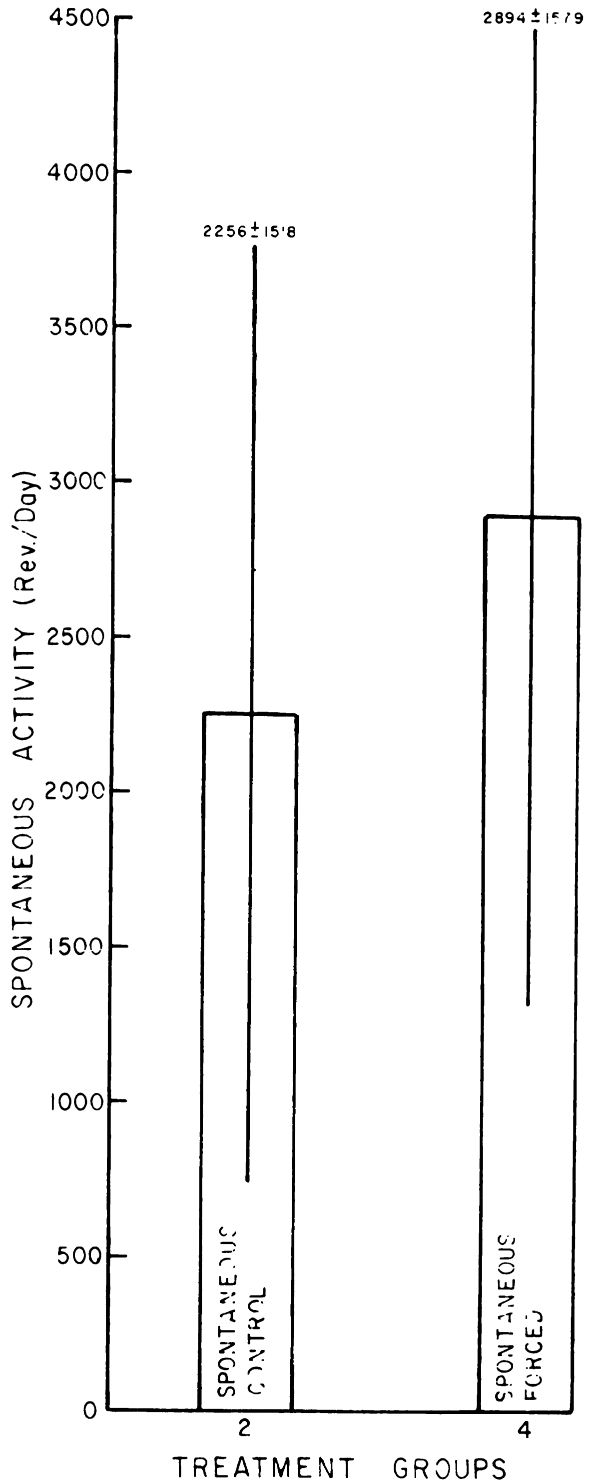

Figure 2: Mean Daily Spontaneous Activity Preirradiation

The computed F value was not significant indicating that, at the 5% level of confidence, there was no difference in preirradiation spontaneous activity between the two groups. The power of the test was .90. It should be noted, however, that the analysis of variance is not a completely satisfactory technique in interpreting longitudinal data of the sort that we are dealing with here. Consequently, a sign test was employed utilizing the same data. The sign test showed that, at the 5 per cent level, the spontaneous forced animals (Group 4) were significantly more active than the spontaneous controls (Group 2) for the preirradiation training period.

A two-way fixed effects analysis of variance was calculated where the spontaneous control (Group 2), spontaneous forced (Group 4) and spontaneous effect (Group 5) treatments were factor A; the upper and lower halves of the 84-day preirradiation spontaneous activity relative to groups was factor B; and the criterion variable was survival time in hours. This analysis permits consideration of both treatment and level of preirradiation spontaneous activity as factors in determining survival time following irradiation. Figure 3 shows the mean values for the three groups evaluated. Table 2 shows the results of the analysis of variance test.

Table 2

Analysis of Variance for Level of Preirradiation Activity and Survival Time

Source of Variance	SS	DF	MS	F
Treatment	16168	2	8084	
Level	18342	1	18342	.595
Interaction	82299	2	41149	1.334
Error	4070745	132	30838	
Total	4187555	137		

The computed F values indicate that, at the specified level of confidence, there were no significant differences between upper and lower halves of preirradiation spontaneous activity relative to groups and survival time. For this test the probability of making a Type II statistical error was .10.

Lighting, Irradiation and Spontaneous Activity

For the first 71 days of the treatment period the lights in the animal room were kept on 12 hours per day. For the remainder of the experiment lights were kept on 24 hours a day in order to facilitate hourly checks on animals following irradiation. Three 11-day periods were selected: (a) the last 11 days prior to 24-hour lighting, (b) the 11-day period between the first day of 24-hour lighting and the first day of irradiation and, (c) the first 11 days following irradiation with 24-hour lighting. A two-way mixed

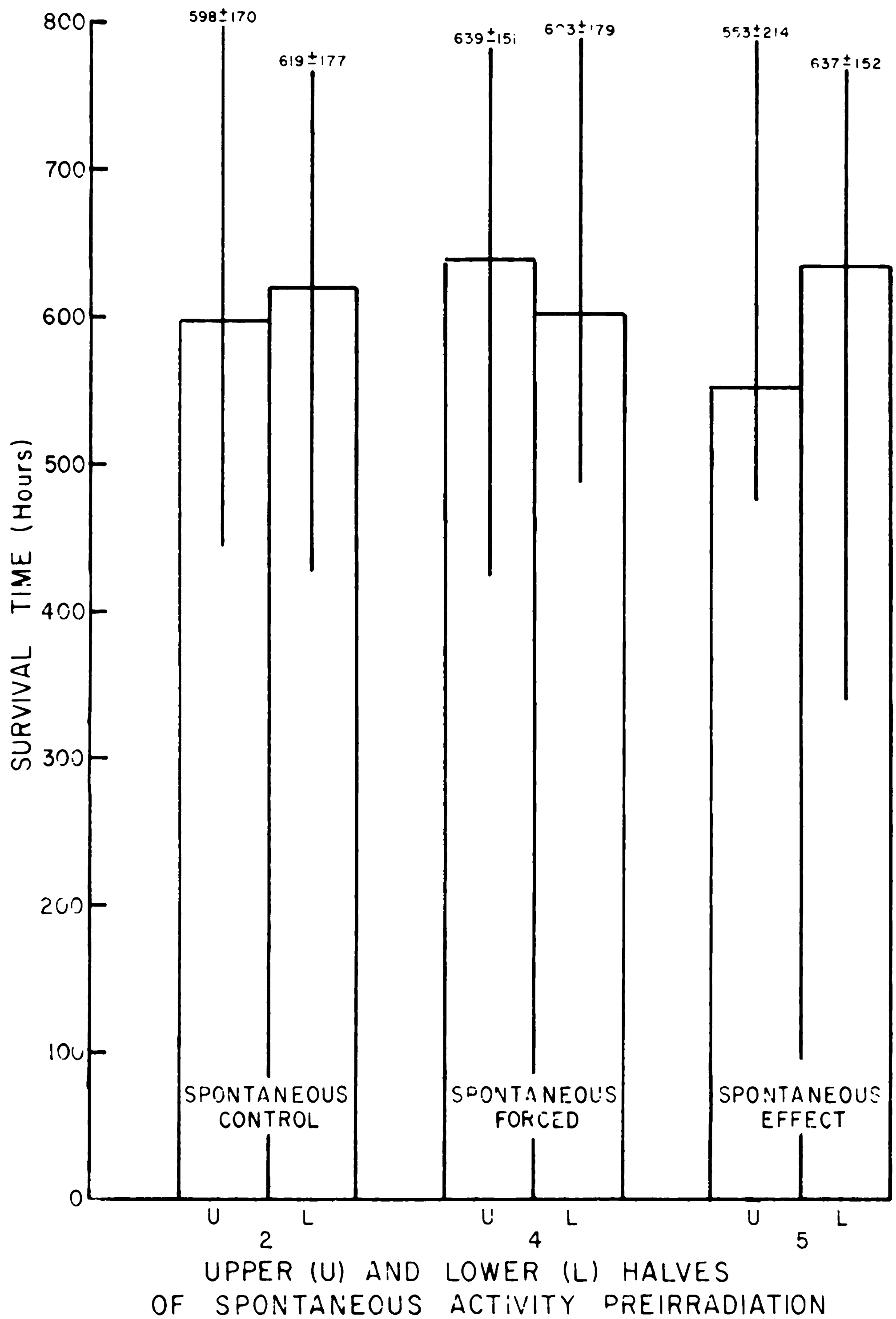

Figure 3: Upper and Lower Halves of Spontaneous Activity and Survival Time

model analysis of variance was calculated where the three 11-day periods were fixed factor A, the 46 spontaneous effect (Group 5) animals were random factor B, and the criterion variable was mean 11-day spontaneous activity. This analysis permits one to determine the effects of both 24-hour illumination and irradiation on spontaneous activity. Figure 4 shows the effects of 24-hour lighting and irradiation on spontaneous activity from the 60th day of training until sacrifice. Table 3 indicates the results of the analysis of variance test. Figure 5 shows mean activity levels for the three periods.

Table 3

Analysis of Variance for Effects of Lighting and Radiation on Activity

Source of Variance	SS	DF	MS	F
Periods	246284790	2	123142395	55.35*
Animals	211791112	45	4706469	
Interaction	200228515	90	2224761	
Total	658304418	137		

* indicates that F value is significant at 5% level.

Since the computed F value was significant at the specified level of confidence a Tukey test for multiple comparisons between means was calculated. Table 4 shows the results.

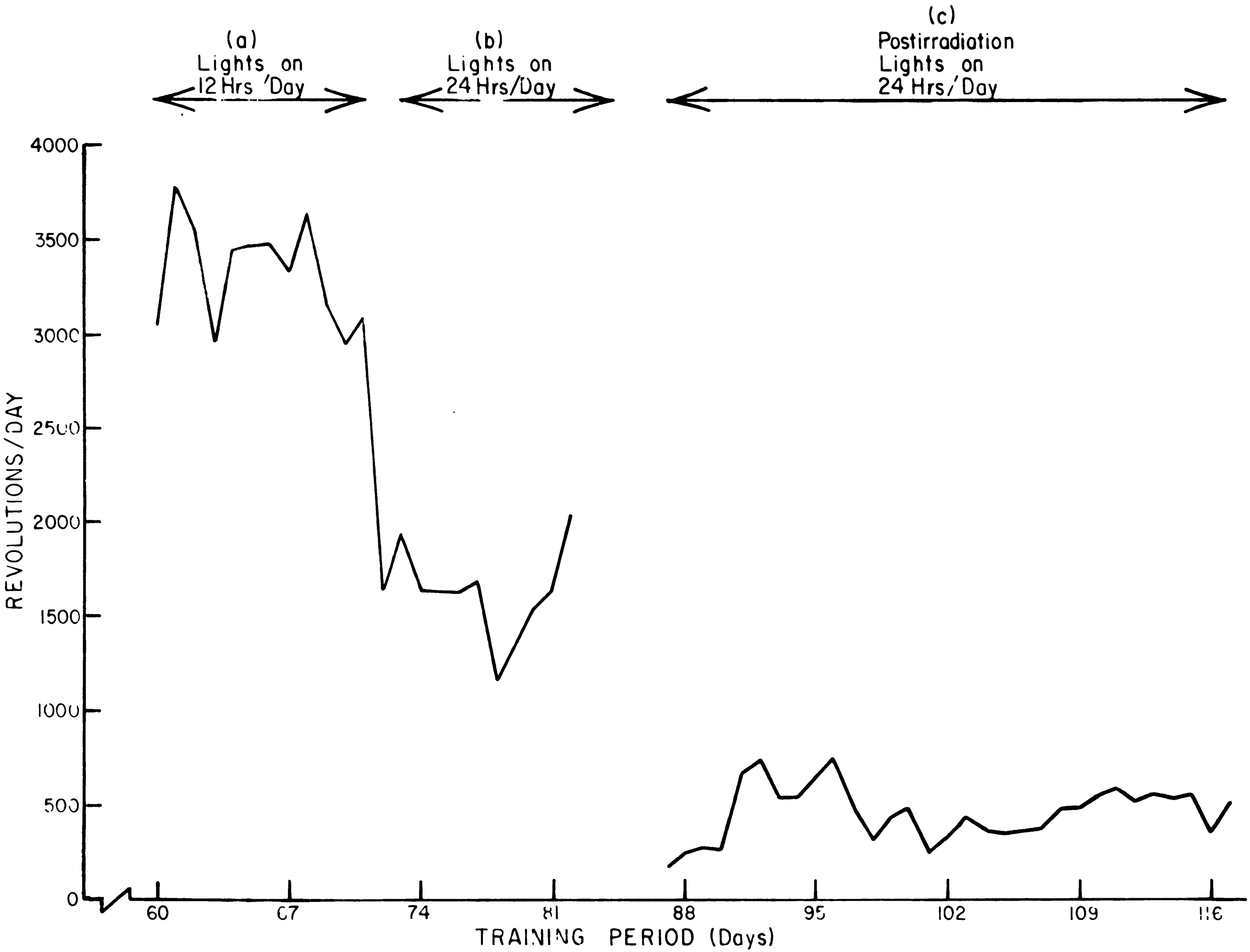

Figure 4: Lighting and Radiation Effects on Activity

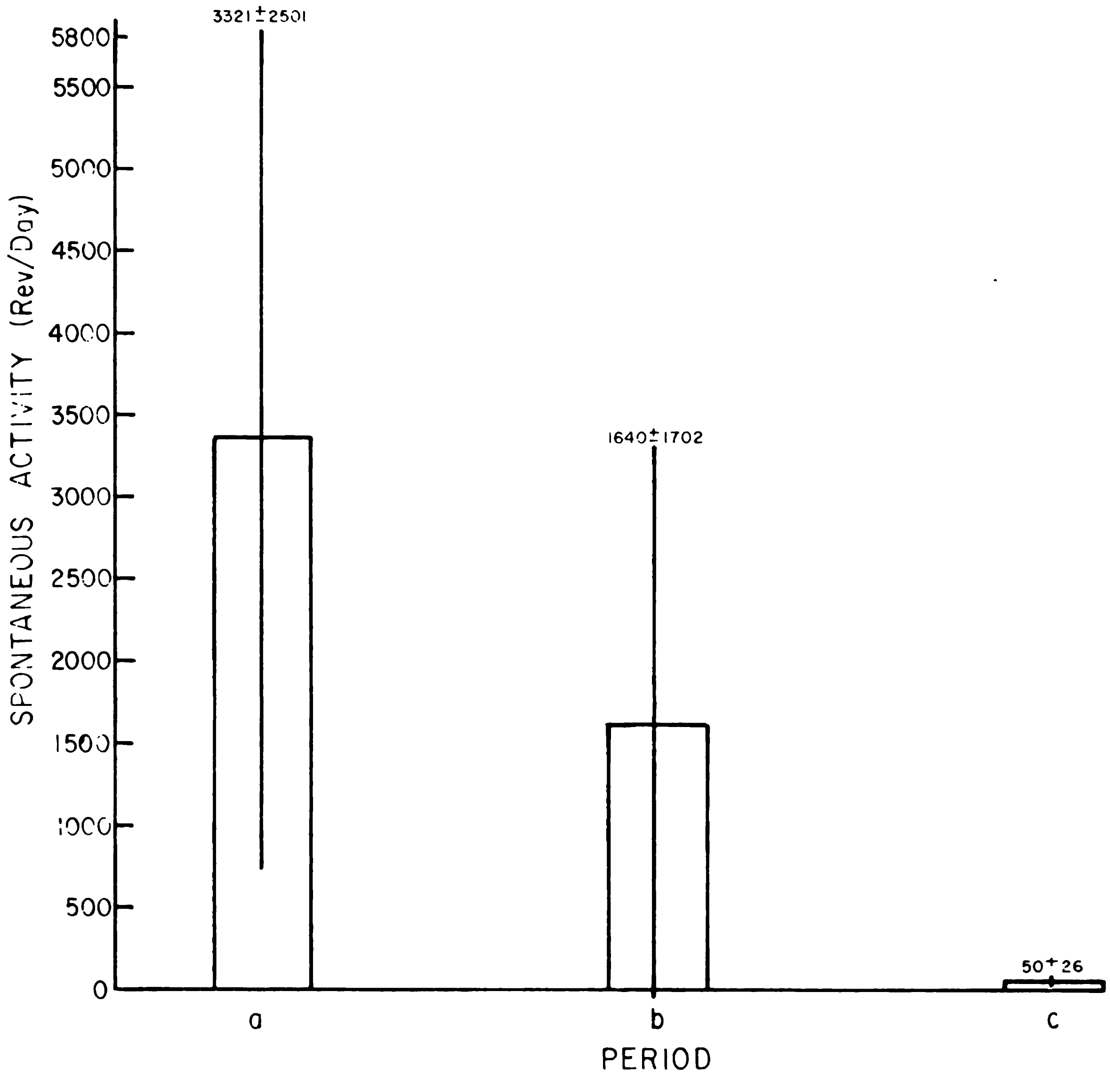

Figure 5: Lighting and Radiation Effects on Activity (Mean values)

Table 4

Tukey Test for Effects of Lighting and Radiation on Activity

Mean Comparisons	Significance at 5%
Period 1 > Period 2	Significant
Period 1 > Period 3	Significant
Period 2 > Period 3	Significant

The results of the Tukey test indicate that mean activity was significantly higher during 12-hour lighting than during both 24-hour lighting preirradiation and 24-hour lighting post-irradiation. Furthermore, mean activity level for the 24-hour lights on period preirradiation was significantly higher than the 24-hour lights on period postirradiation.

Postirradiation Spontaneous Activity

A one-way fixed effects analysis of variance was calculated where the upper and lower halves of 3-day postirradiation spontaneous activity for the spontaneous effect (Group 5) treatment was factor A and the criterion variable was survival time in hours. This type of analysis permits one to determine the effects of level of postirradiation activity on survival time. Figure 6 shows mean survival times for the upper and lower levels of activity. Table 5 indicates the results of the analysis of variance test. The computed F value indicates that there was no difference, at the specified level of confidence, between upper and lower halves of

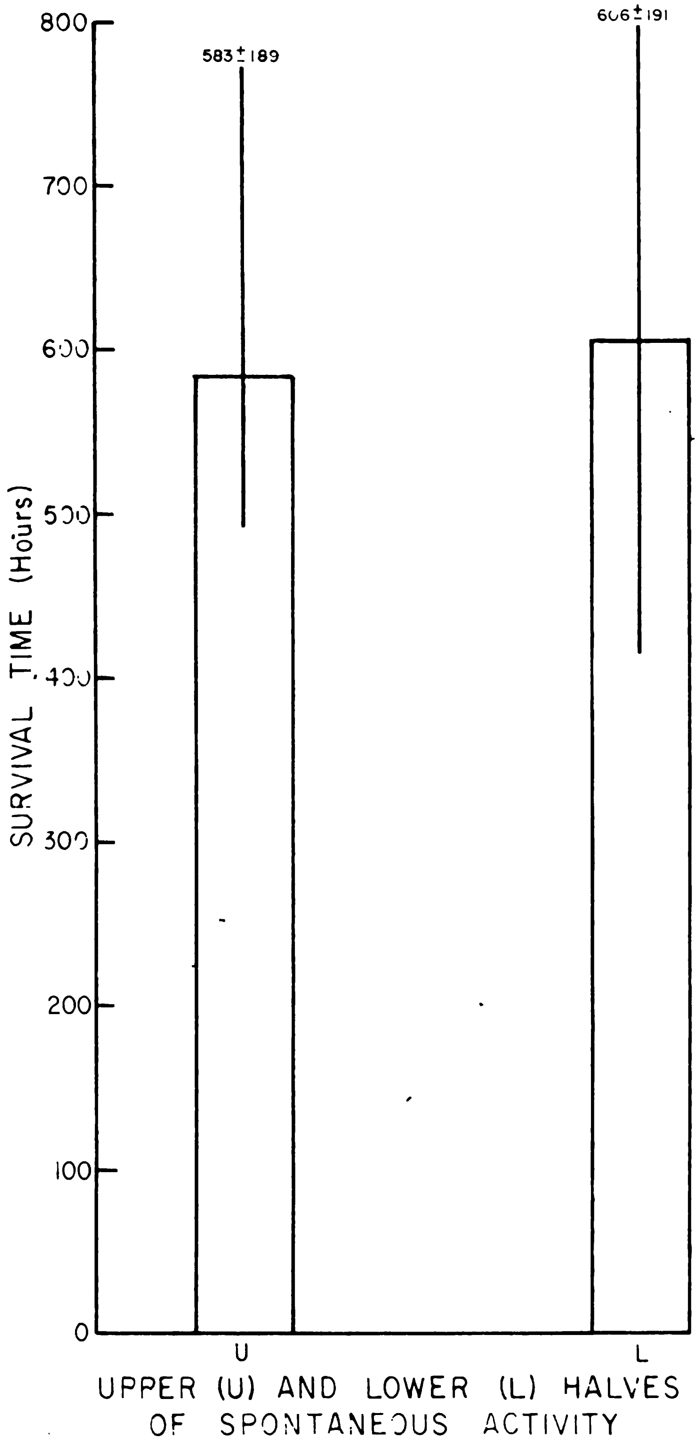

Figure [illegible]: Upper and Lower Halves of 5-Day Postirradiation Spontaneous Activity and Survival Time

Table 5

Analysis of Variance for Postirradiation Activity Level and Survival Time

Source of Variance	SS	DF	MS	F
Among Levels	6362	1	6362	.175
Within Levels	1596980	44	36295	
Total	1603343	45		

postirradiation spontaneous activity and survival time. The power of the test was .90.

A Pearson product-moment correlation coefficient was calculated between 11-day preirradiation spontaneous activity and 3-day postirradiation spontaneous activity for the spontaneous effect (Group 5) treatment. The resulting r value (.344), which was significantly different from zero at the 5 per cent level, indicated that both high and low level activity animals were affected in the same way by radiation.

Body Weight

Figure 7 shows weekly body weight changes for the five treatment groups. Final body weights prior to irradiation are shown in Figure 8. A one-way analysis of variance was calculated where Groups 1, 2, 3 and 4 were factor A and the criterion variable was body weight during the last week prior to irradiation. This procedure enables one to determine the effects of the four treatments on body weight prior to

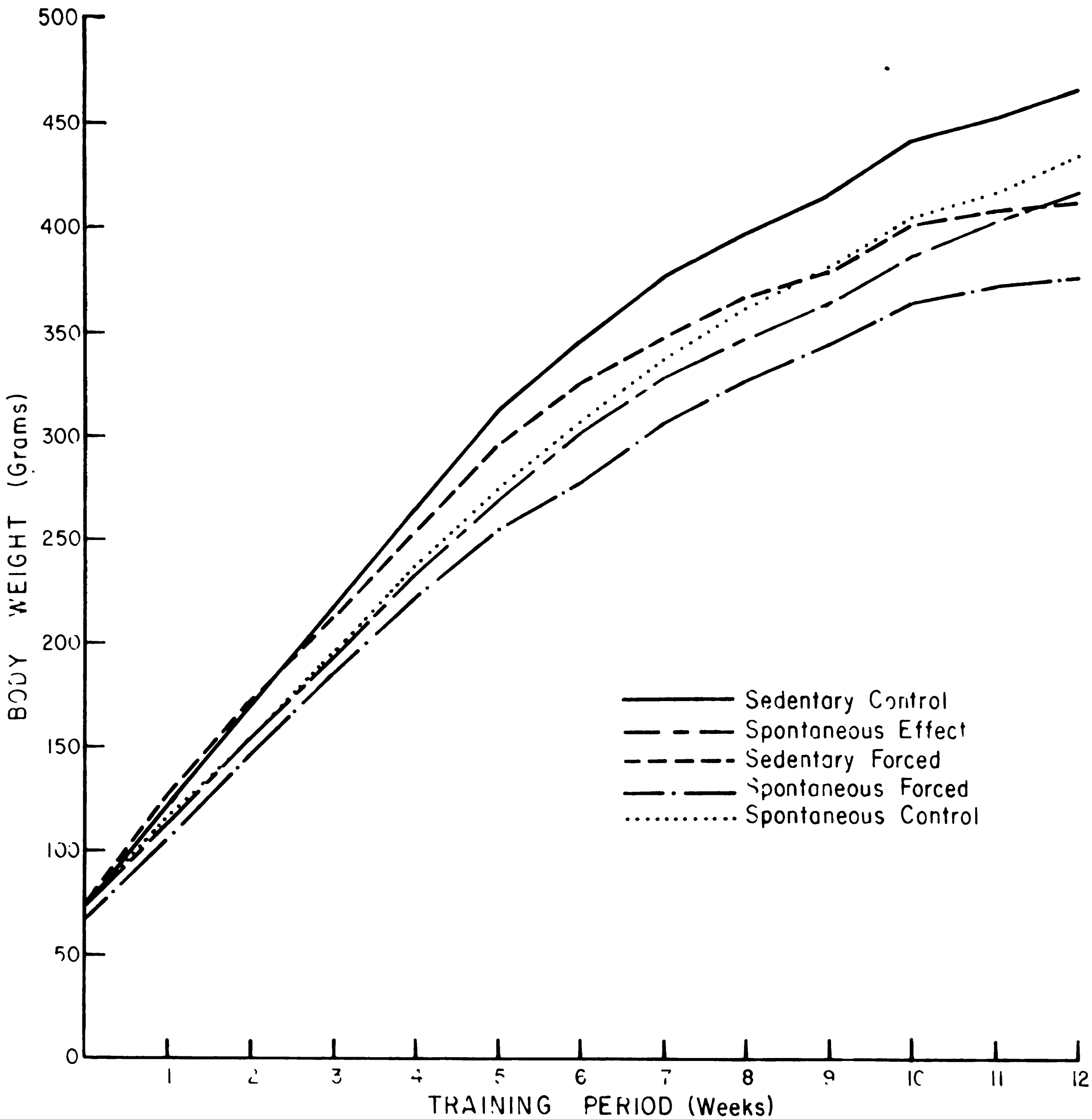

Figure 7. Treatment Effects on Body Weight

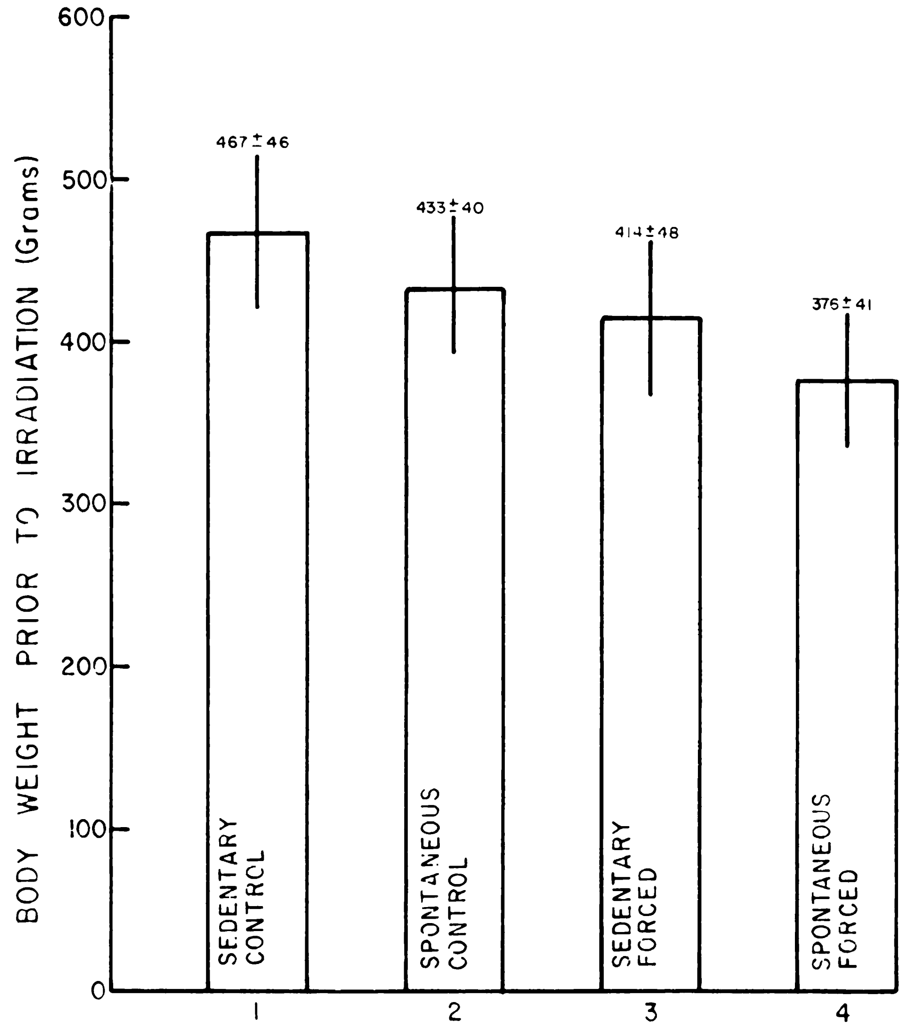

Figure 8: Mean Body Weight Prior to Irradiation

irradiation. The results of the analysis of variance are shown in Table 6.

Table 6

Analysis of Variance for Body Weights Prior to Irradiation

Source of Variance	SS	DF	MS	F
Among Groups	195872	3	65290	32.843*
Within Groups	357836	180	1987	
Total	553709	183		

* indicates that the F value is significant at the 5% level.

Since the computed F value was significant at the specified level of confidence the Tukey test for multiple comparisons between means was employed. Table 7 indicates the results.

Table 7

Tukey Test for Body Weights Prior to Irradiation

Mean Comparison	Significance at 5%
Group 1 > Group 2	Significant
Group 1 > Group 3	Significant
Group 1 > Group 4	Significant
Group 2 > Group 3	Significant
Group 2 > Group 4	Significant
Group 3 > Group 4	Significant

The results of the Tukey test show that the sedentary controls (Group 1) were significantly heavier than the spontaneous controls (Group 2), the sedentary forced (Group 3) and the spontaneous forced (Group 4) during the final week prior to irradiation. Furthermore, Group 2 was significantly heavier than either Group 3 or Group 4 and Group 3 was significantly heavier than Group 4.

A two-way fixed effects analysis of variance was calculated where the five treatments were factor A; the upper and lower halves of body weight relative to groups during the last week prior to irradiation were factor B; and the criterion variable was survival time in hours. This analysis permits consideration of both treatment and level of pre-irradiation body weight as factors in determining survival time following irradiation. Figure 9 shows the upper and lower halves of body weight relative to groups with respect to survival time. The results of the analysis of variance are shown in Table 8.

Table 8

Analysis of Variance for Level of Body Weight and Survival Time

Source of Variance	SS	DF	MS	F
Treatment	54857	4	13714	
Level	196925	1	196925	6.566*
Interaction	244238	4	61059	2.036
Error	6597728	220	29989	
Total	7093749	229		

* indicates that the F value is significant at the 5% level.

The results of Table 8 indicate that the level effects are significant. The mean survival time of all animals who were in the upper half of their group was 636 hours. This was

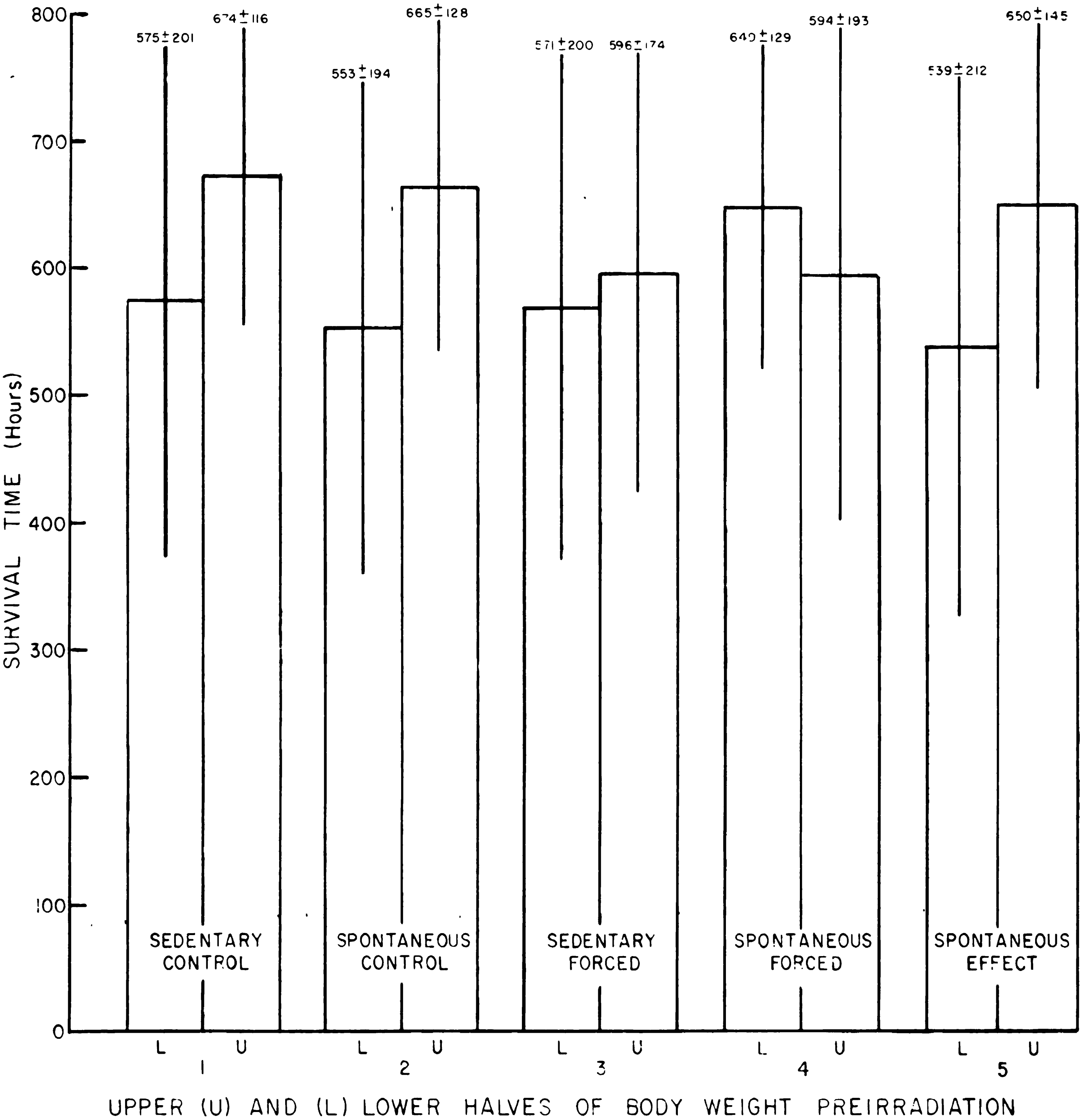

Figure 9: Upper and Lower Halves of Body Weight Preirradiation and Survival Time

significantly greater than the mean survival time of all the animals in the lower half of their group, which was 578 hours.

White Blood Cells

Figure 10 shows mean WBC values 9 days prior to irradiation. A one-way analysis of variance was calculated where Groups 1, 2, 3 and 4 were factor A and the criterion variable was WBC 9 days prior to irradiation. This procedure enables one to determine the effects of the four treatments on WBC count prior to irradiation. The results are shown in Table 9.

Table 9

Analysis of Variance for WBC Preirradiation

Source of Variance	SS	DF	MS	F
Among Groups	36375149	3	12125049	1.919
Within Groups	1137549185	180	6319717	
Total	1173924335	183		

The computed F value shows that, at the specified level of confidence, there were no significant differences between groups with regard to WBC 9 days prior to irradiation. The power of the test was .90.

A two-way fixed effects analysis of variance was calculated where the five treatments were factor A; the upper

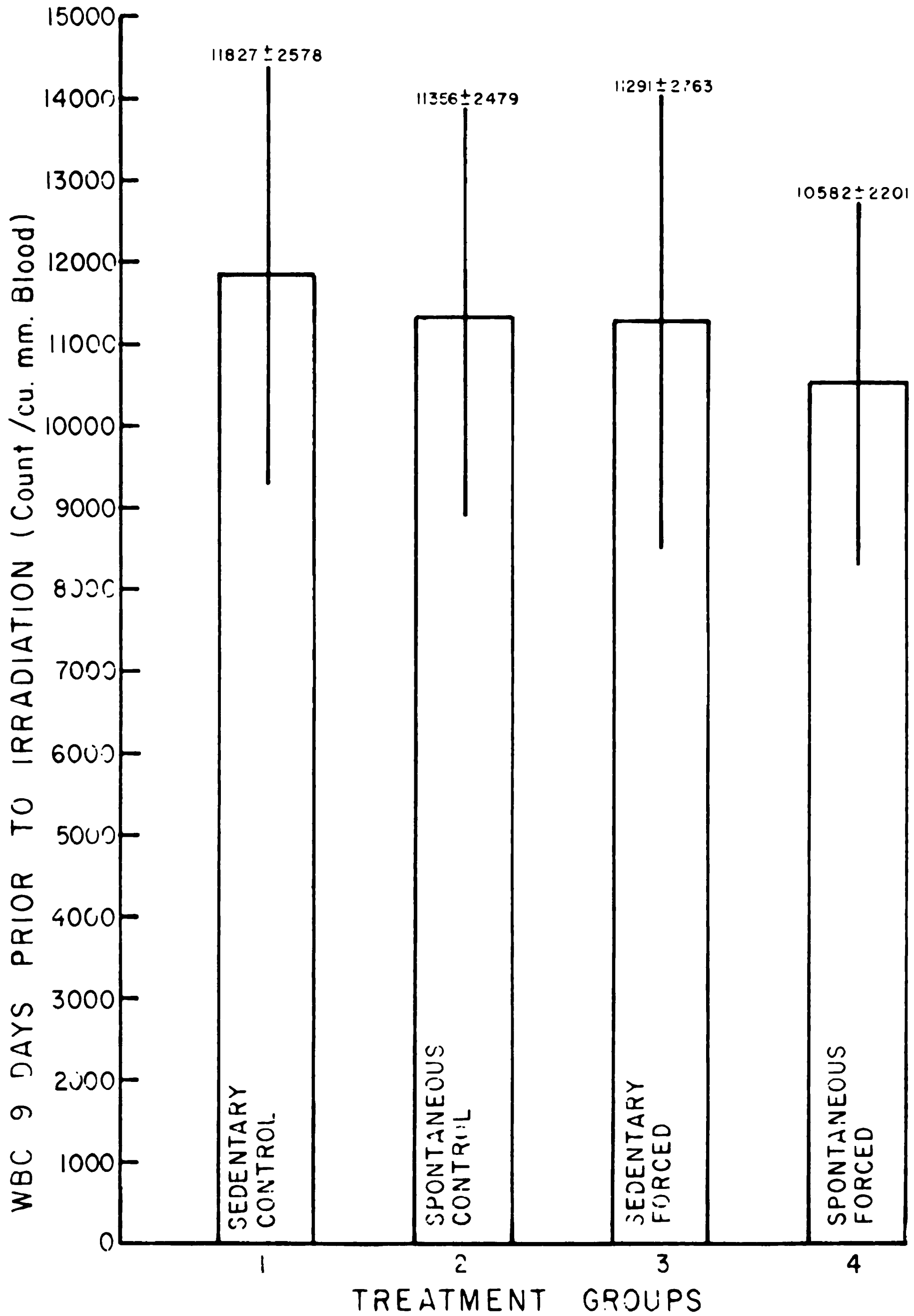

Figure 10: WBC 9 Days Prior to Irradiation

and lower halves of WBC relative to groups 9 days prior to irradiation were factor B; and the criterion variable was survival time in hours. This analysis permits consideration of both treatment and level of WBC preirradiation as factors in determining survival time after irradiation. Figure 11 shows the relationship between the upper and lower halves of WBC preirradiation and survival time. The results of the analysis of variance are shown in Table 10.

Table 10

Analysis of Variance for Levels of WBC Preirradiation and Survival Time

Source of Variance	SS	DF	MS	F
Treatment	54857	4	13714	
Level	60166	1	60166	2.065
Interaction	569954	4	142488	4.891*
Error	6408771	220	29130	
Total	7093749	229		

* indicates that F value is significant at 5% level.

The results of Table 10 indicate that the interaction effects were significant. The Tukey test for multiple comparisons between means was employed. Those comparisons which were significant at 5% level are shown in Table 11.

Figure 12 shows mean WBC level five days postirradiation for the five treatment groups. A one-way fixed effects analysis of variance was calculated where the five treatments

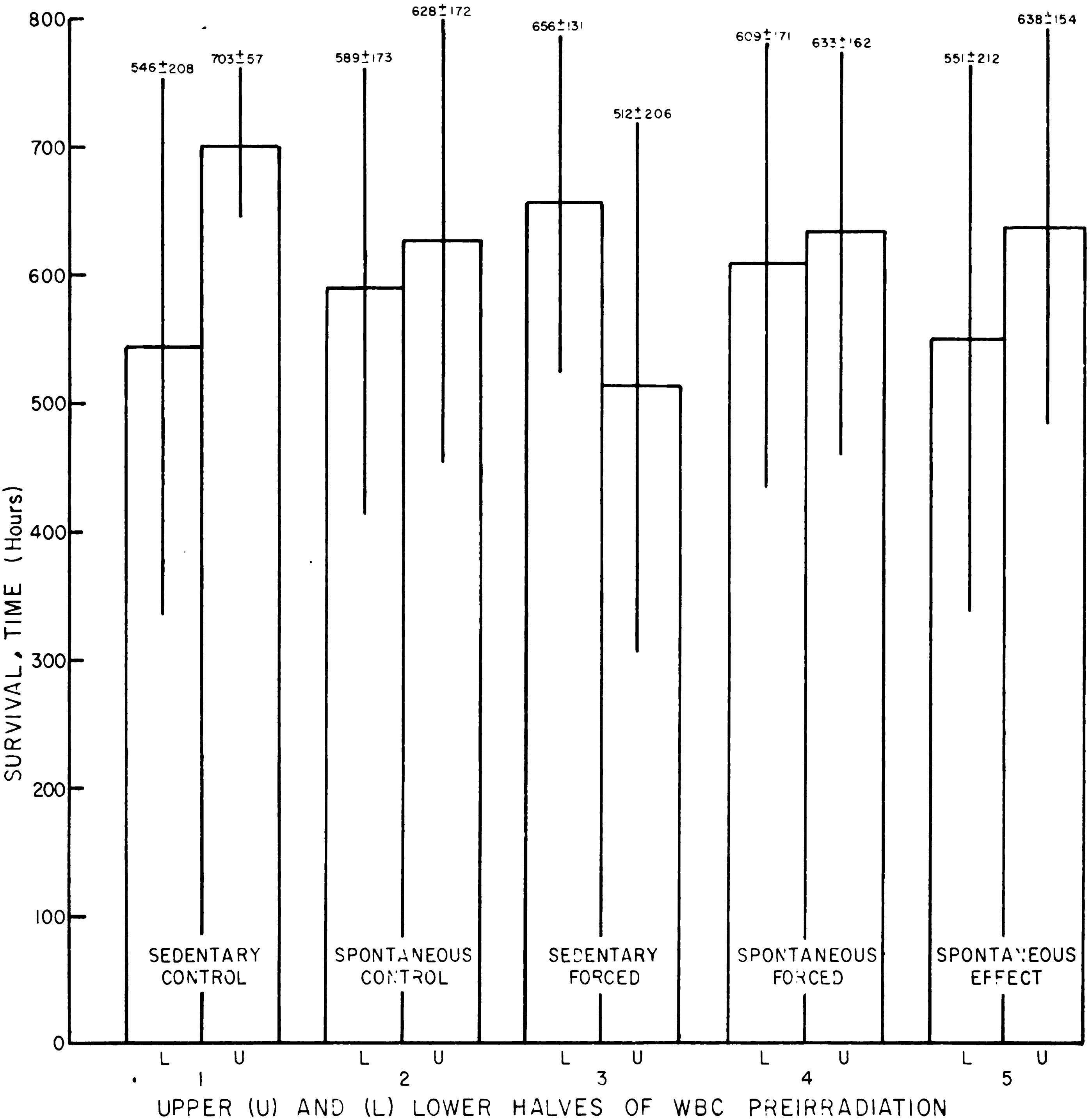

Figure 11: Upper and Lower Halves of WBC Preirradiation and Survival Time

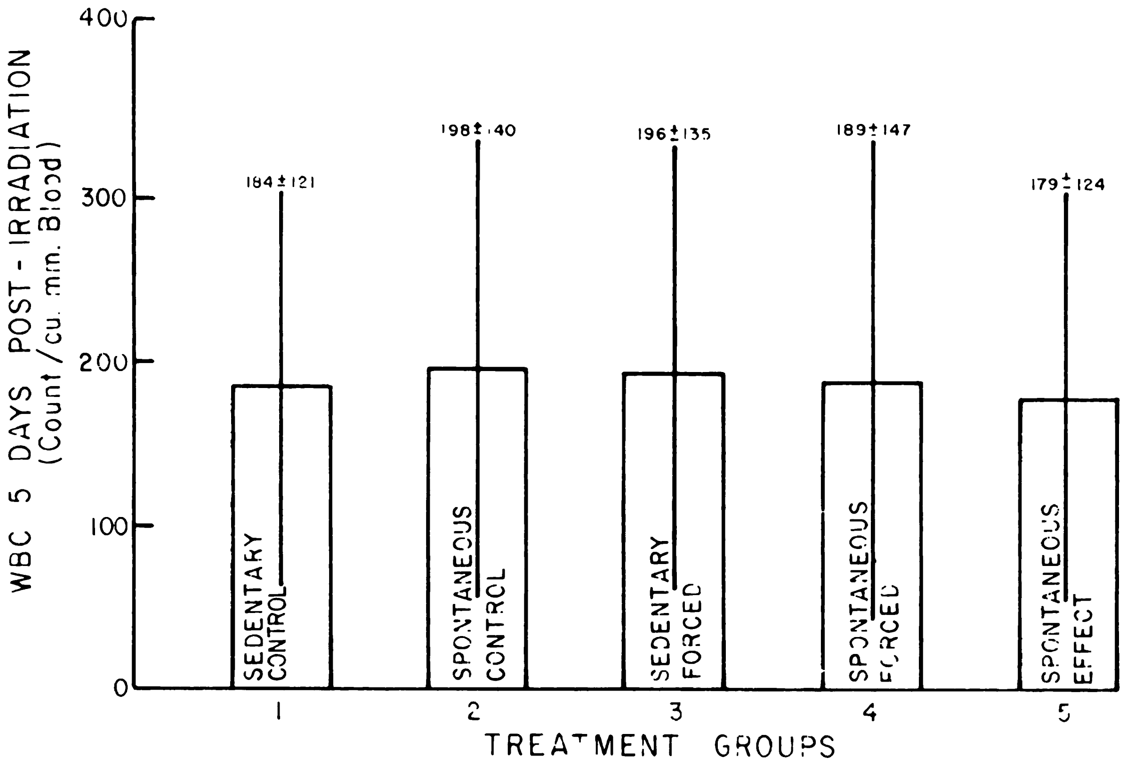

Figure 14: WBC 5 Days Postirradiation

Table 11

Tukey Test for Levels of WBC and Survival Time

1 upper > 2 lower, 5 lower, 1 lower, 3 upper
3 lower > 5 lower, 1 lower, 3 upper
5 upper > 3 upper
4 upper > 3 upper
2 upper > 3 upper

were factor A and the criterion variable was WBC five days postirradiation. This analysis permits one to evaluate the effects of the treatments on WBC postirradiation. The results are shown in Table 12.

Table 12

Analysis of Variance for WBC Five Days Postirradiation

Source of Variance	SS	DF	MS	F
Among Groups	12239	4	3059	.170
Within Groups	4061250	225	18049	
Total	4073489	229		

The results, as indicated in Table 12, show that there were no significant differences in WBC postirradiation between groups. The probability of making a Type II statistical error was .10.

A two-way fixed effects analysis of variance was calculated where the five treatments were factor A; the upper and lower halves of WBC five days postirradiation relative to groups were factor B; and the criterion variable was survival time in hours. The above procedure permits consideration of both treatment and level of WBC postirradiation as factors in determining survival time following irradiation. Figure 13 shows the relationship between upper and lower halves of WBC postirradiation and survival time. The analysis of variance is shown in Table 13.

Table 13

Analysis of Variance for WBC Level Postirradiation and Survival Time

Source of Variance	SS	DF	MS	F
Treatment	54857	4	13714	
Level	7123	1	7123	.227
Interaction	140011	4	35002	1.117
Error	6891757	220	31326	
Total	7093749	229		

The F values, as indicated in Table 13, show that there were no differences between level of WBC postirradiation relative to groups and survival time.

Eosinophils

Figure 14 shows mean eosinophil levels nine days prior to irradiation for Groups 1, 2, 3 and 4. A one-way fixed effects analysis of variance was calculated where Groups 1, 2, 3 and 4 were factor A and the criterion variable was eosinophil count nine days prior to irradiation. The

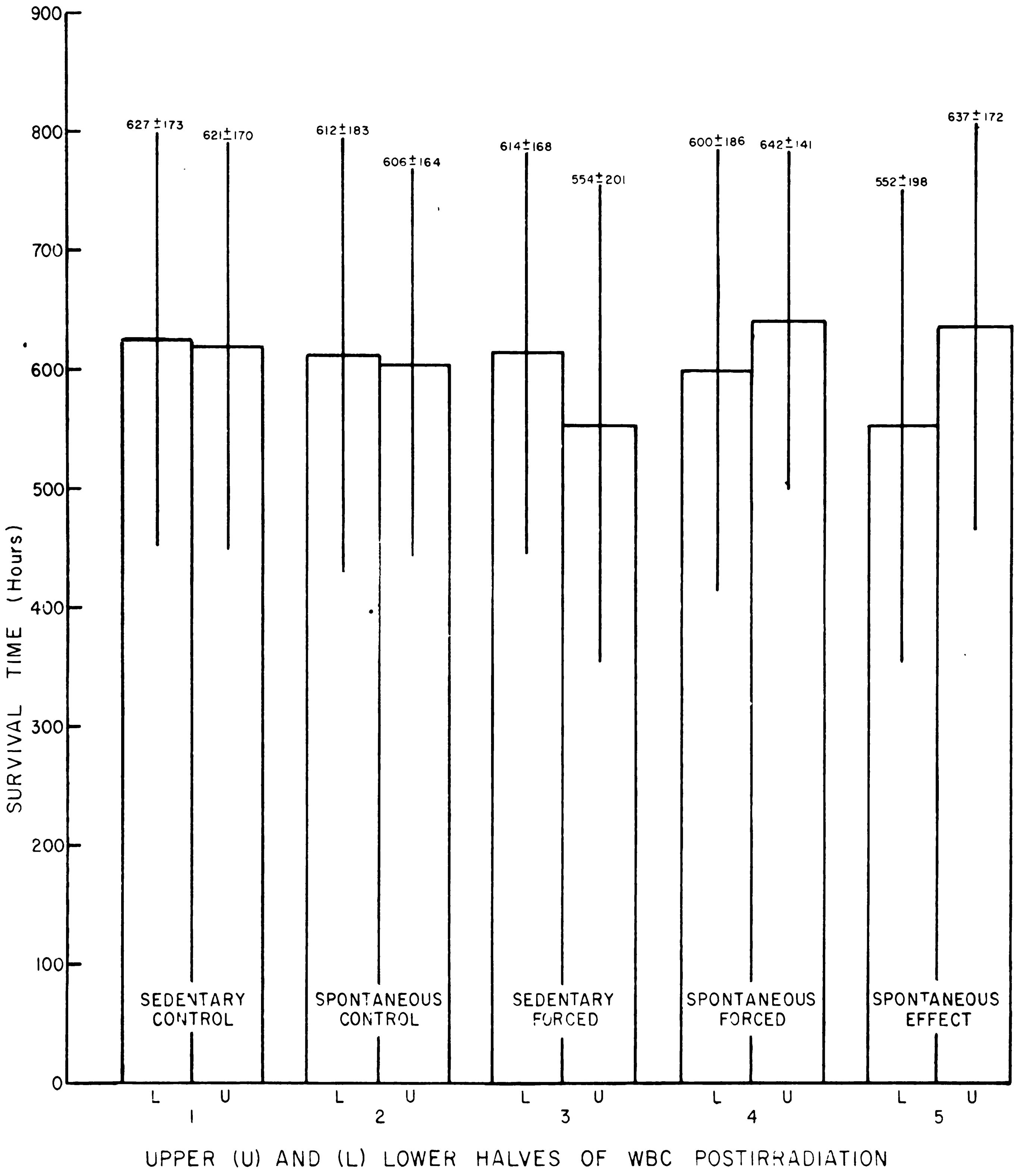

Figure 13: Upper and Lower Halves of WBC Postirradiation and Survival Time

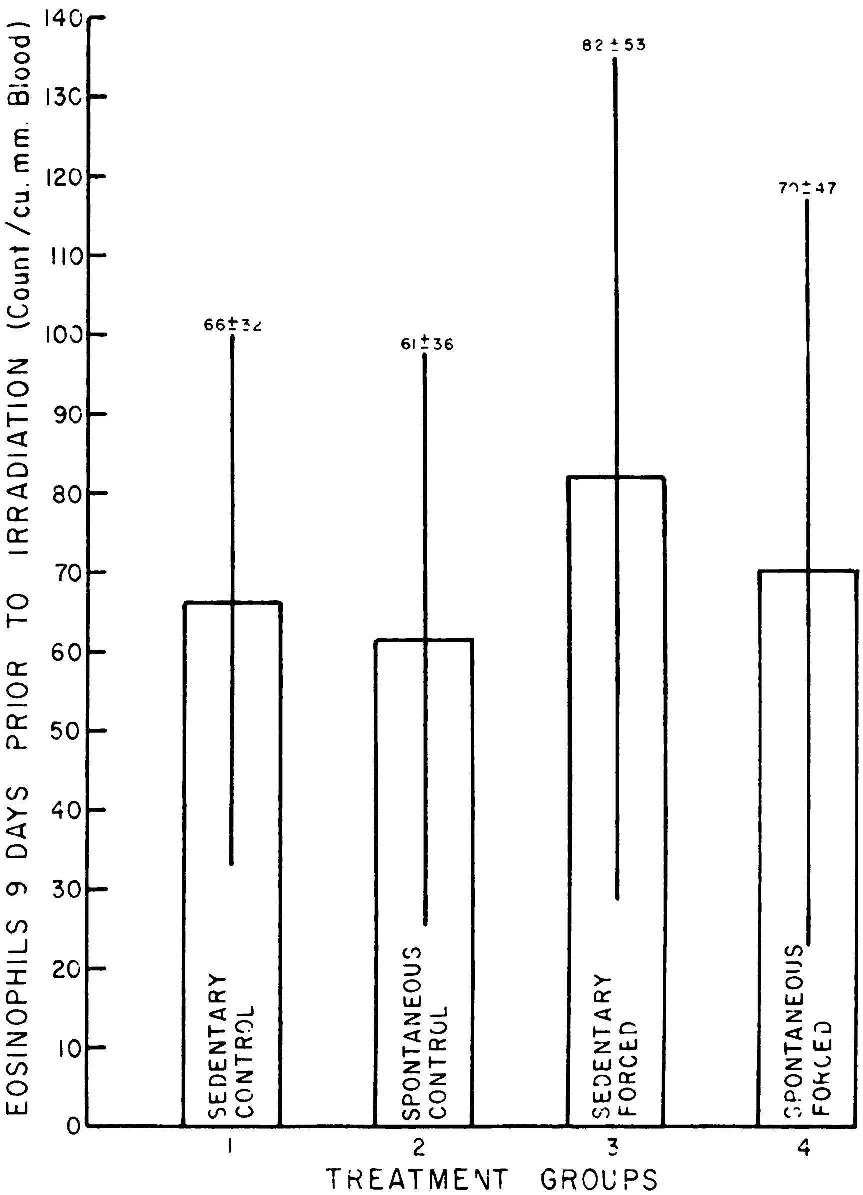

Figure 14: Eosinophils 9 Days Prior to Irradiation

analysis permits one to determine treatment effects on eosinophil level prior to irradiation. The results are shown in Table 14.

Table 14

Analysis of Variance for Eosinophil Count Nine Days Preirradiation

Source of Variance	SS	DF	MS	F
Among Groups	10455	3	3485	1.868
Within Groups	355815	180	1865	
Total	346271	183		

The results of Table 14 indicate that, at the specified level of confidence, there were no differences in preirradiation eosinophil level between groups. The power of the test was .90.

A two-way fixed effects analysis of variance was calculated where the five treatments were factor A; the upper and lower halves of eosinophil count relative to groups nine days preirradiation was factor B; and the criterion variable was survival time in hours. This procedure allows one to consider both treatment and level of preirradiation eosinophil count as factors in determining survival time following irradiation. Figure 15 shows the relationship between upper and lower halves of eosinophil count and survival time. The results of the analysis of variance are shown in Table 15.

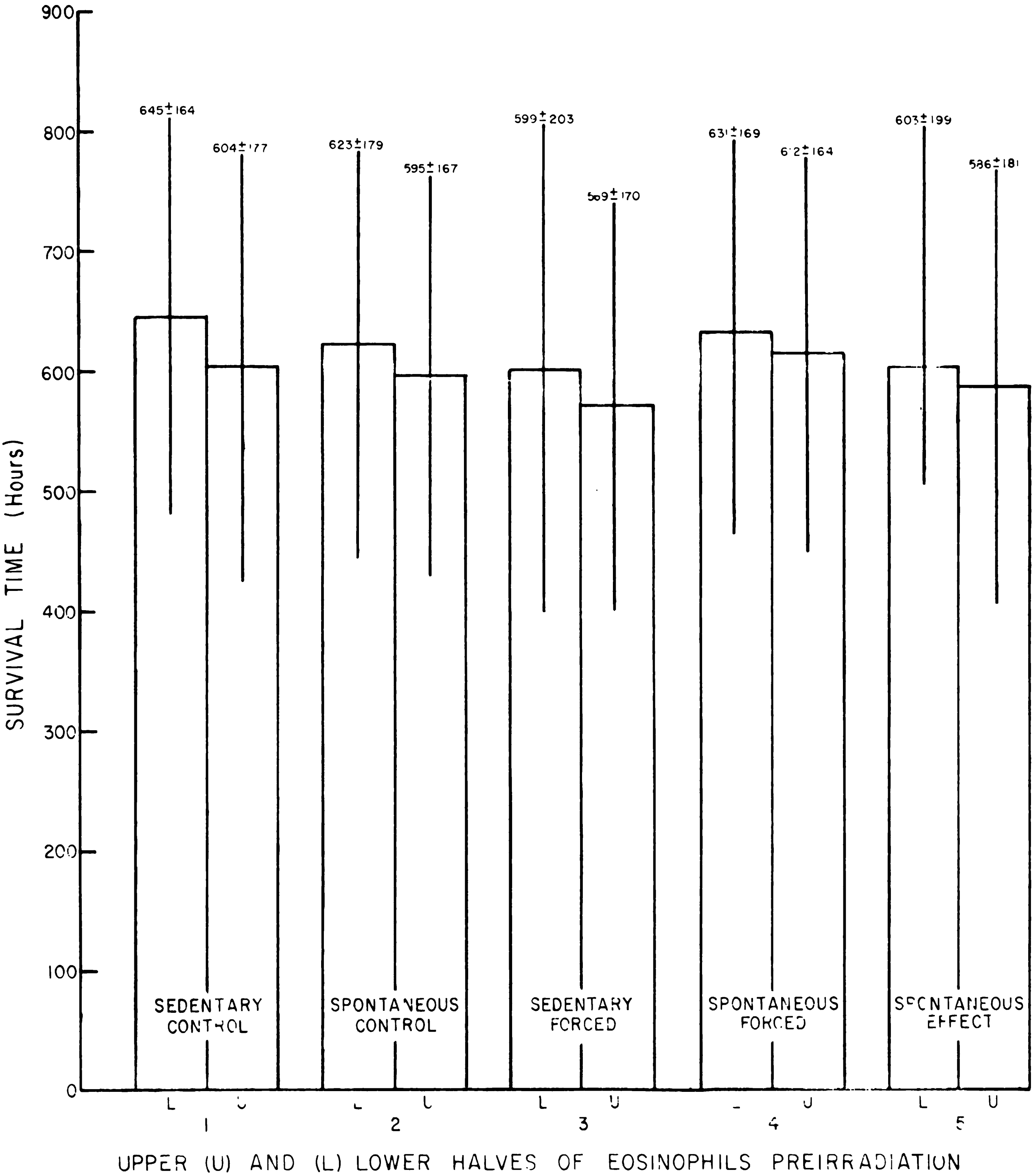

Figure 15: Upper and Lower Halves of Eosinophils Preirradiation and Survival Time

Table 15

Analysis of Variance for Preirradiation Eosinophil Level and Survival Time

Source of Variance	SS	DF	MS	F
Treatment	54857	4	13714	
Level	42540	1	42541	1.339
Interaction	4394	4	1099	.035
Error	6991957	220	31782	
Total	7093749	230		

The F values, as shown in Table 15, indicate there was no significant differences between upper and lower halves of preirradiation eosinophil level relative to groups and survival time in hours. The probability of making a Type II statistical error was .10.

Blood sampling five-days postirradiation indicated that all animals, except six had eosinophil counts of zero. The six exceptions were animals 164 and 176 of Group 2, animal 27 of Group 3, animal 97 of Group 4 and animal 211 of Group 1.

Spleen Weight

Figure 16 shows the treatment effects on spleen weight at death. A one-way fixed effects analysis of variance was calculated where the five treatments were factor A and the criterion variable was spleen weight at death. This analysis permits one to determine the treatment effects on spleen weight at death. The results are shown in Table 16.

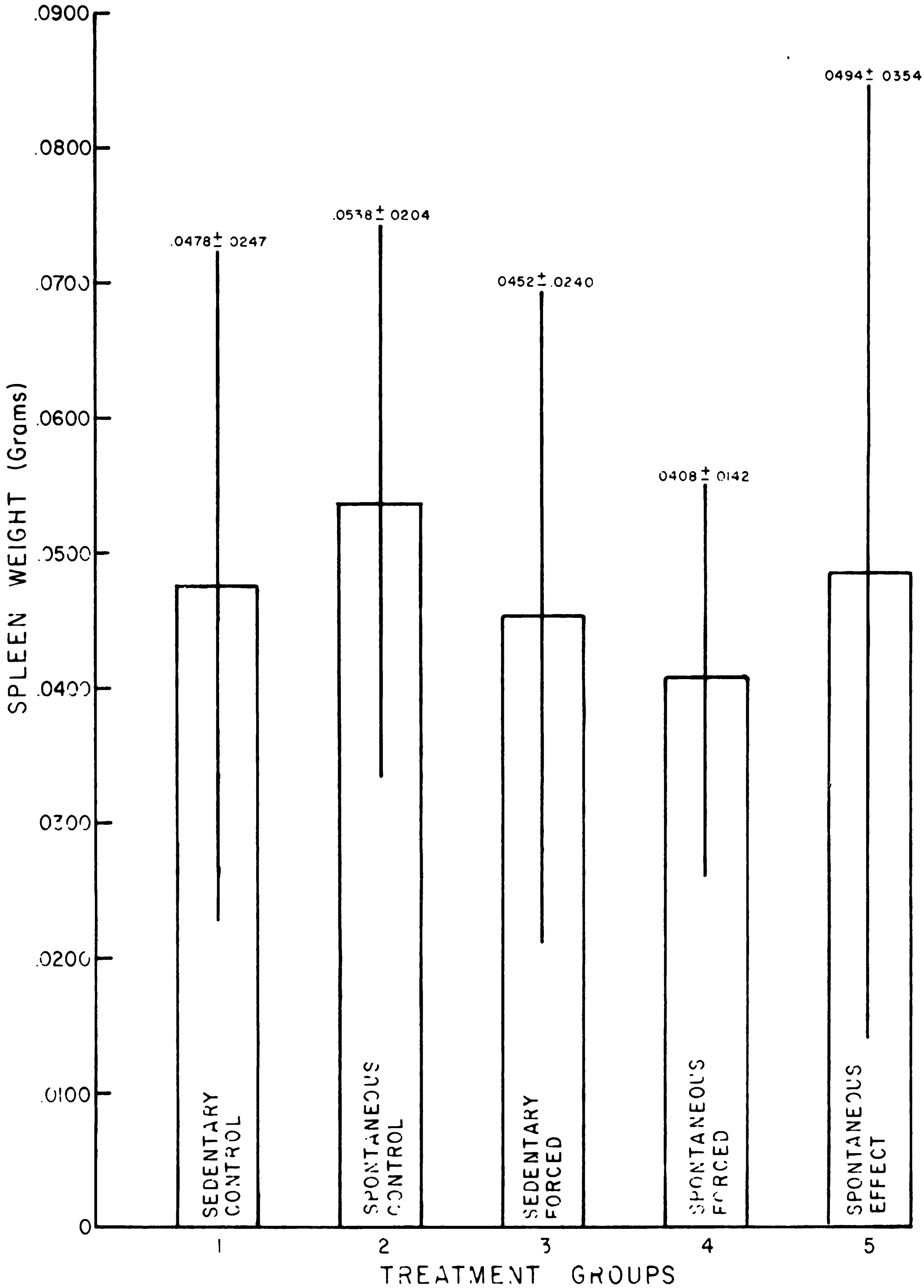

Figure 16: Treatment Effects on Spleen Weight at Death

Table 16

Analysis of Variance for Treatment Effects on
Spleen Weight at Death

Source of Variance	SS	DF	MS	F
Among Groups	.00126681	4	.00031670	.50358
Within Groups	.04087826	65	.00062890	
Total	.04214507	69		

The results, as shown in Table 16, indicate that there were no significant treatment effects on spleen weight at death. The power of the test was .90.

Figure 17 shows the treatment effects on spleen weight at sacrifice. A one-way fixed effects analysis of variance was calculated where the five treatments were factor A and the criterion variable was spleen weight at sacrifice. The results are shown in Table 17.

Table 17

Analysis of Variance for Treatment Effects on
Spleen Weight at Sacrifice

Source of Variance	SS	DF	MS	F
Among Groups	.00071695	4	.00017924	.328
Within Groups	.08475746	155	.00054682	
Total	.08547441	159		

The results, as shown in Table 17, indicate that there were no significant differences in spleen weight at sacrifice. The probability of making a Type II statistical error was .10.

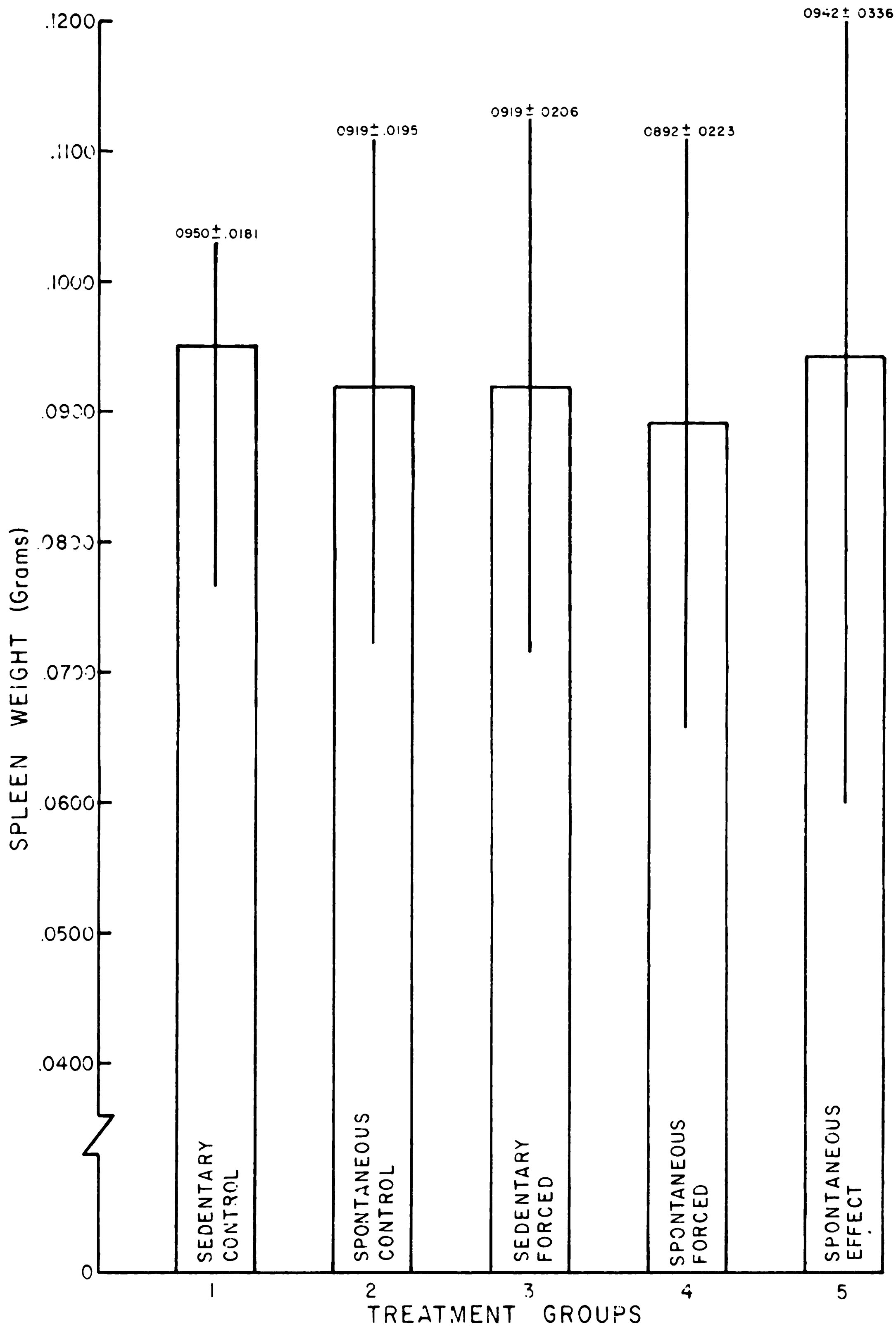

Figure 17: Treatment Effects on Spleen Weight at Sacrifice

Adrenal Weight

Previous work in this laboratory (24) has indicated that adrenal weight and body weight are not correlated. Therefore, adrenal weight was expressed as a percentage of body weight for the statistical analyses that follow.

Adrenal weight per body weight at death for the five treatment groups are shown in Figure 18. A one-way fixed analysis of variance was calculated where the five treatments were factor A and the criterion variable was adrenal weight per body weight at death. This analysis permits one to determine treatment effects on adrenal weight per body weight at death. The results are shown in Table 18.

Table 18

Analysis of Variance for Treatment Effects on Adrenal Weight Per Body Weight at Death

Source of Variance	SS	DF	MS	F
Among Groups	.00000496	4	.00000124	.639
Within Groups	.00012627	65	.00000194	
Total	.00013123	69		

The results, as shown in Table 18, indicate that there were no significant treatment effects on adrenal weight per body weight at death. The power of the test was .90.

The treatment effects on adrenal weight per body weight at sacrifice are shown in Figure 19. A one-way fixed

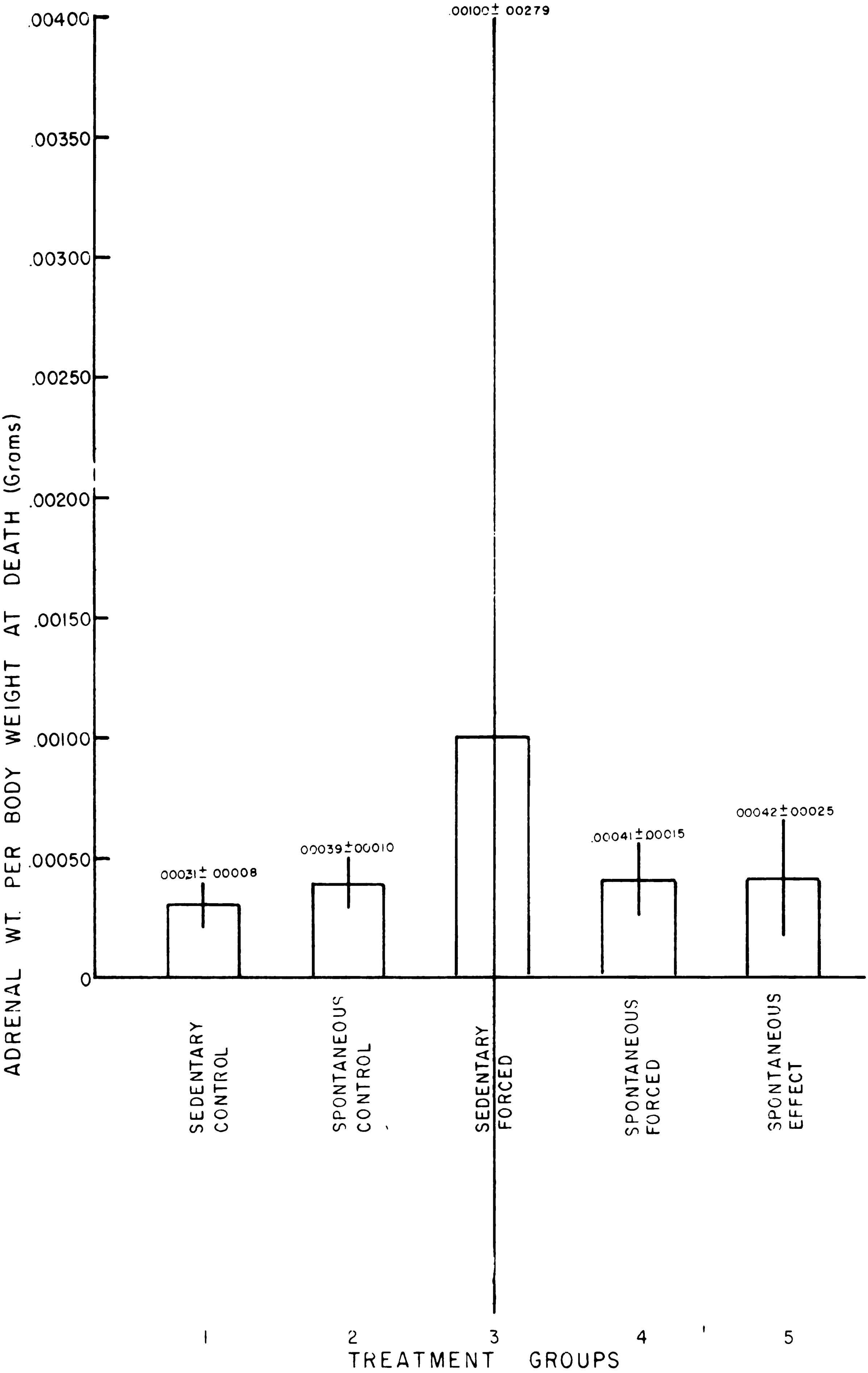

Figure 18: Adrenal Weight Per Body Weight at Death

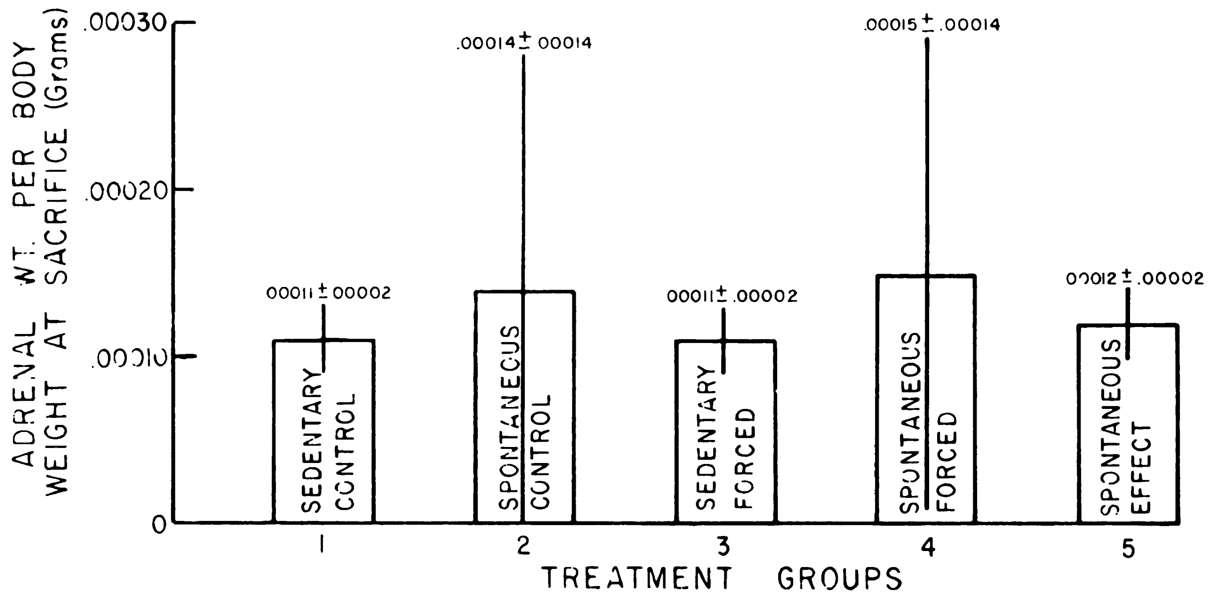

Figure 19: Adrenal Weight Per Body Weight at Sacrifice

effects analysis of variance was calculated where the five treatments were factor A and the criterion variable was adrenal weight per body weight at sacrifice. The results are shown in Table 19.

Table 19

Analysis of Variance for Treatment Effects on Adrenal Weight Per Body Weight at Sacrifice

Source of Variance	SS	DF	MS	F
Among Groups	.00000004	4	.00000001	1.073
Within Groups	.00000132	155	.00000001	
Total	.00000136	159		

The results, as shown in Table 19, indicate that there were no significant treatment effects on adrenal weight per body weight at sacrifice. The probability of making a Type II statistical error was .10.

Survival Time

The effects of the five treatments on survival time of all animals are shown in Figure 20. It should be noted that if an animal lived until sacrifice he was assigned a survival time of 715 hours. A one-way fixed effects analysis of variance was calculated where the five treatments were factor A and the criterion variable was survival time in hours. This procedure permits one to determine the treatment

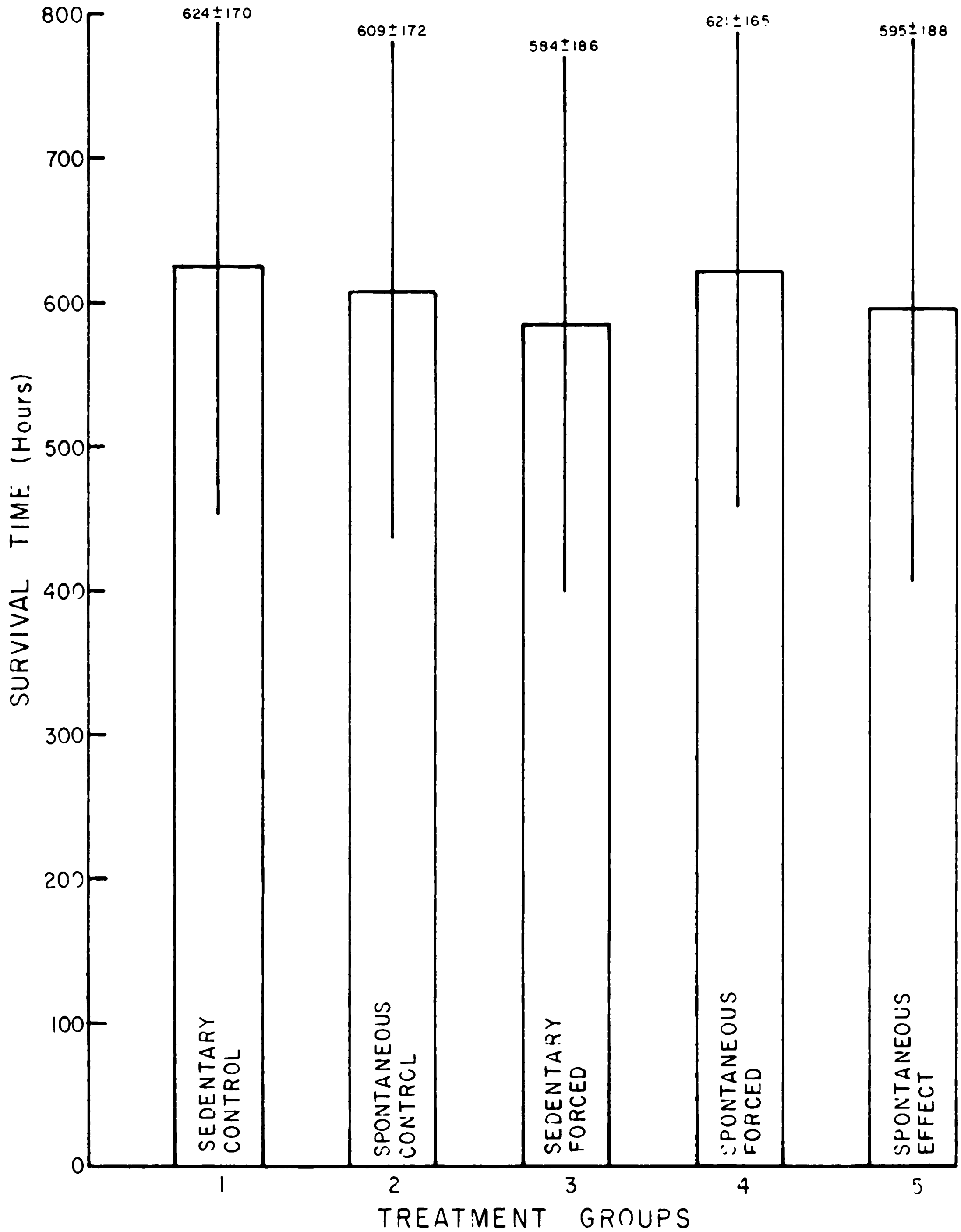

Figure 20: Survival Time of all Animals

effects on survival time following irradiation. The results are shown in Table 20.

Table 20

Analysis of Variance for Treatment Effects on Survival Time of All Animals

Source of Variance	SS	DF	MS	F
Among Groups	54857	4	13714	.438
Within Groups	7038892	225	31282	
Total	7093749	229		

The results, as shown in Table 20, indicate that there was no significant treatment effect on survival time of all animals. The power of the test was .90.

Figure 21 shows treatment effects on survival time of only those animals which died during the 30-day postirradiation mortality period. A one-way fixed effects analysis of variance was calculated where the five treatments were factor A and the criterion variable was survival time. This procedure allows one to determine treatment effects on survival time of only those animals which died. The results are shown in Table 21. The results, as shown in Table 21, indicate that there were no significant treatment effects on survival time of those animals which died. The probability of making a Type II statistical error was .10.

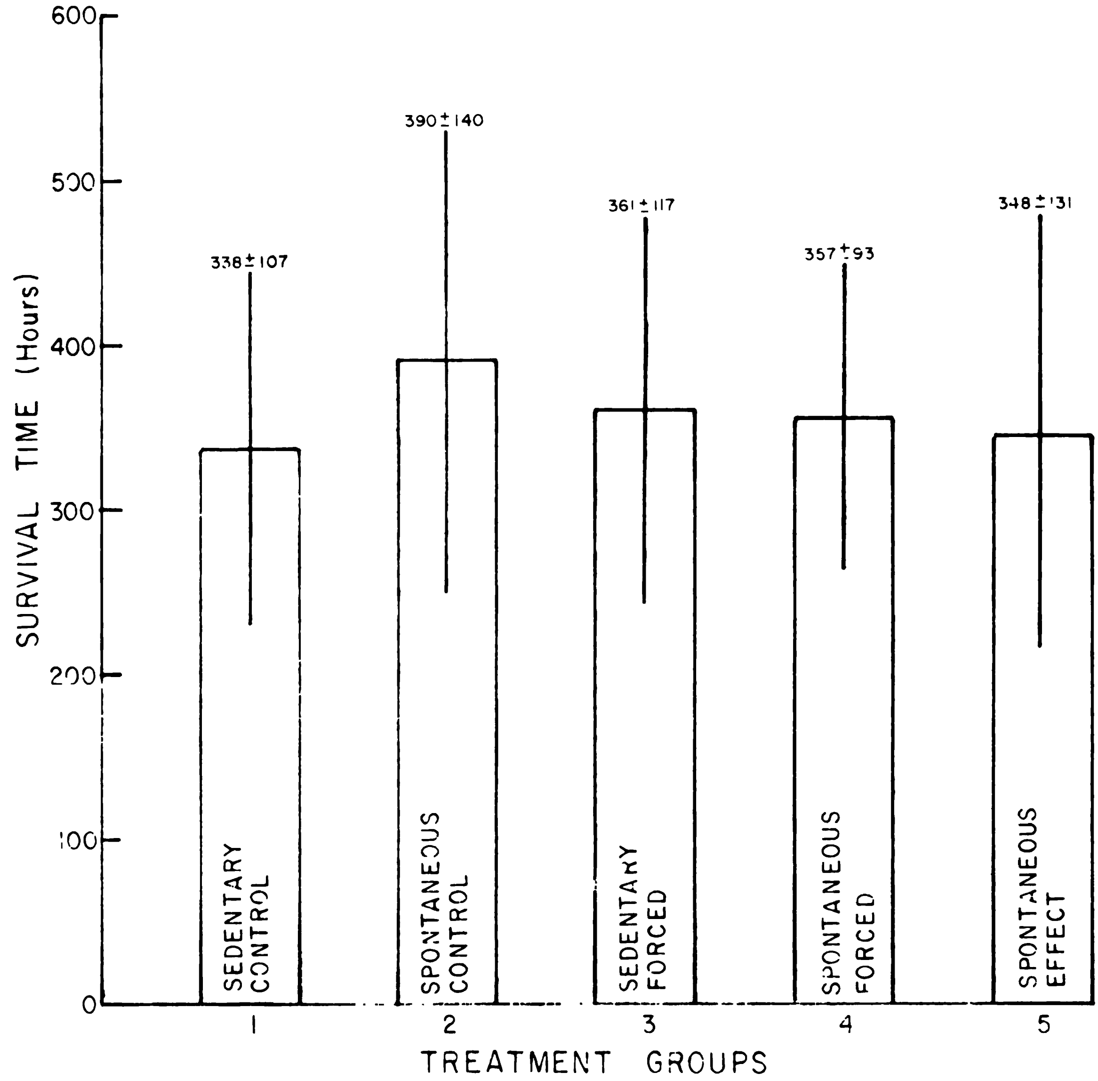

Figure 21: Survival Time of Animals Which Died

Table 21

Analysis of Variance for Treatment Effects on Survival Time of Only Animals which Died

Source of Variance	SS	DF	MS	F
Among Groups	21839	4	5459	.377
Within Groups	941953	65	14491	
Total	963793	69		

Mortality

A Chi-square test for k independent samples was calculated where the five treatments were the k=5 samples, "die" and "live" were the r=2 rows, and the criterion variable was observed frequency in each cell. This analysis allows one to determine the treatment effects on mortality following irradiation. The results are shown in Table 22.

Table 22

Chi-square Test for Treatment Effects on Mortality

Group	1	2	3	4	5
Die	17	12	15	15	11
Live	29	34	31	31	35

The computed Chi-square was 2.46 which was insignificant at the 5% level. Figure 22 shows the cell frequencies for the Chi-square test.

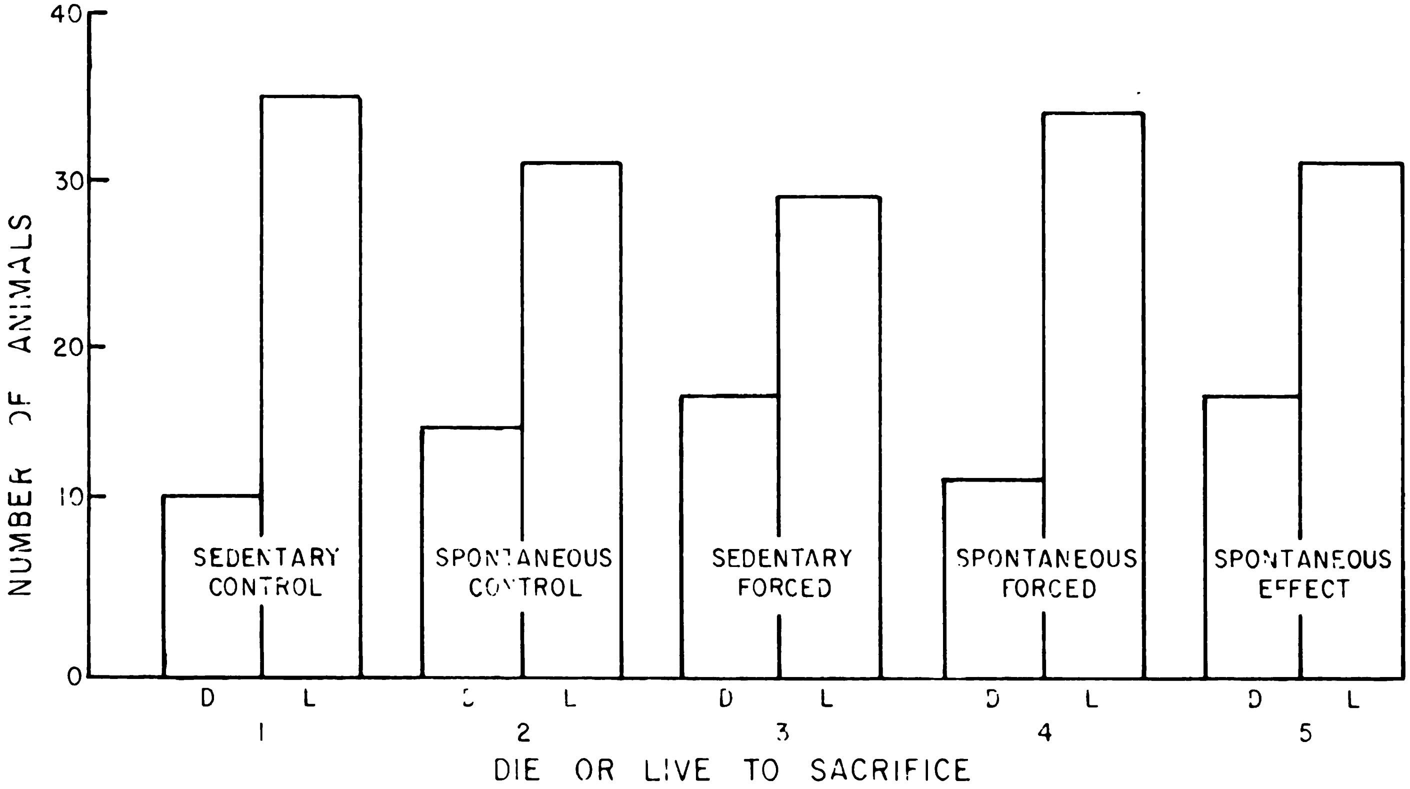

Figure 22: Treatment Groups and Mortality

Discussion

Spontaneous Activity

Previous work in this laboratory by Hanson and Van Huss (15) and Van Huss, Mickelsen and Heusner (49) have shown that animals which were forced to swim for one-half hour daily for 35 days had a significantly lower voluntary activity level than their spontaneous controls. Reference to Figure 1 will indicate that in the present investigation there were no differences between the two groups for the first 30 days of training. However, after 30 days and for the remainder of the preirradiation training period those animals which were forced to swim daily had consistently higher activity levels than the control animals. Apparently after 30 days the forced swimming, in some way, acted as an incentive for voluntary running. It should be noted that these differences were not significant at the specified level of confidence (Table 1) when the analysis of variance test was employed, but were highly significant when the sign test was utilized.

No previous work has been done relating level of preirradiation spontaneous activity and survival time following irradiation. Table 2 and Figure 3 show that level of voluntary activity does not significantly alter survival time.

Jones et al (18) and Kimeldorf et al (22) have shown that irradiation produces a rather dramatic decrease in voluntary activity of rats. These results have been substantiated in the present investigation (Tables 3 and 4 and Figure 4). Furthermore it would be wise for future investigators to carefully regulate the amount of time that the animal rooms are to be illuminated if spontaneous activity is to be a measured parameter. Figure 4 clearly demonstrates that 24-hour per day illumination results in substantially decreased spontaneous activity when compared with 12-hour per day illumination.

Published results on the effects of postirradiation exercise on mortality are conflicting. Trifonov (50) and Pinchook and Scherban (50) have demonstrated decreased mortality and increased survival time in animals subjected to exercise following irradiation while Kimeldorf and Jones (20), Kimeldorf and Baum (19), Sergeyev (50), Popov (50) and Markelov (50) have shown increased mortality and decreased survival time. Smith and Smith (35), (36) report no differences between rats exercised following irradiation and control animals. It should be noted that all of the above investigations were concerned with <u>forced</u> exercise following irradiation while the present study involved postirradiation spontaneous activity. Figure 6 and Table 5 indicate that there were no significant effects of post-irradiation voluntary activity level on survival time.

Body Weight

The results of the four treatments produced significant differences in body weight prior to irradiation (Figure 8 and Tables 6 and 7). The most heavily exercised group (treatment 4) had a mean body weight significantly lower than Groups 1, 2 and 3. The sedentary control group (treatment 1) had a mean body weight significantly higher than Groups 2, 3 and 4. The results indicate that body weight was a function of the exercise regimen.

Table 8 and Figure 9 show that, regardless of treatment, the animals in the upper half of their group with respect to body weight had significantly longer survival times than animals in the lower half. Mean survival time for animals in the upper half was 636 hours as opposed to 578 hours for animals in the lower half. A plausible explanation may be that the heavier animals did not receive as high a dose as the lighter animals. Andrews states (2) "In general, decrease in dose with depth results from attenuation by absorption." An interesting question, however, does arise. Why, if the sedentary animals (Group 1) were significantly heavier and, if being in the upper half of one's treatment group significantly improved survival time, didn't Group 1 have significantly better survival times? This investigation cannot shed any light on the proposed question, however, if one employed similar types of treatments while attempting to maintain equal body weights between groups, conclusive evidence could be obtained.

Blood Parameters

Garrey and Bryan (13) and Sturgis and Bethell (46) in their reviews of literature, have concluded that a marked leucocytosis is to be expected in circulating blood immediately following muscular exercise. Conclusive evidence has not been found regarding the longitudinal effects of training on the white blood cells. Thörner (47) and Andersen, Heusner and Pohndorf (1) have reported increases in the WBC; whereas, Hawkins (17) found no such changes. The results of the present study are in agreement with Hawkins. Analysis of the preirradiation WBC count indicates that there were no significant differences in WBC between the five treatment groups (Figure 10 and Table 9). Table 10 indicates that the interaction effects of upper and lower halves of WBC relative to groups and the five treatments were significant with respect to survival time following irradiation. Table 11 indicates the existing significant differences. Although there are significant differences no pattern with regard to either treatment or level exists and interpretation is impossible. Within the next year statistical procedures will be available that will enable one to consider the combined effects of level of WBC preirradiation and body weight preirradiation on survival time.

Table 12 and Figure 12 indicate that following irradiation there were dramatic decreases in WBC levels in all groups, however, no significant differences between the five treatments were detected. Bacq and Alexander (4) have reported that a large dose of radiation causes rapid damage to the bone marrow and lymphoid tissue, thus greatly suppressing the mitosis of leucocytes for eight to ten days. These observations have been substantiated in this investigation.

Figure 13 and Table 13 show that there were no significant differences between the five treatment groups regarding the level of WBC postirradiation relative to groups and survival time in hours.

Figure 14 and Table 14 indicate that there were no significant differences in eosinophil level prior to irradiation between the five treatment groups. Irradiation virtually eliminated circulating eosinophils in all animals except six. These six showed eosinophil levels of 5.5/cu.mm blood. Similarly, there were no significant differences between the five treatment groups concerning level of eosinophils relative to groups preirradiation and survival time in hours. (Figure 15 and Table 15)

Organ Weights

It will be recalled from Chapter III that the thymus was not weighed, since its postirradiation condition prohibited proper extraction and trimming.

There is conflicting evidence in regard to the effects of exercise upon organ weights. Donaldson (11, 12) and Kimeldorf and Baum (19) found increases in splenic weight after exercise; Donaldson (9, 10), Hatai (16); and Montoye et al. (25) reported decreases; and, Hanson and Van Huss (15) and Montoye et al. (26) found no changes. Borovansky (5), Donaldson (9, 10, 11, 12), Hanson and Van Huss (15), Kimeldorf and Baum (19), and Montoye et al. (25, 27) cite increases in adrenal weights following physical training; whereas Hatai (16) and Montoye et al (26) report no effects. Asahina et al. (3) have shown that excessive physical training can produce histological deterioration and hypofunction of the thymus.

Kimeldorf and Baum (19) found that in the rat the weights of both the thymus and the spleen are reduced following irradiation. They also reported increases in adrenal weights with exposure to x-rays. Patt et al. (31) observed similar splenic and adrenal responses in rats. Such adrenal changes were not found in mice by Smith and Smith (39) following irradiation. In a subsequent study, however, Smith (37) found significant fluctuations in adrenal weights which apparently were dependent upon the amount of time elapsing between irradiation and sacrifice.

Since splenic and adrenal weights were not made prior to irradiation, it was not possible to evaluate the effects of irradiation on the weights of these organs.

Figure 16 and Table 16 show that there were no significant differences between the five treatments with respect to spleen weight at death. Similar results were found with spleen weight at sacrifice (Figure 17 and Table 17).

The five treatments produced no differences in adrenal weight per body weight at death (Figure 18 and Table 18). Likewise, Figure 19 and Table 19 reveal no treatment effects on adrenal weight per body weight at sacrifice.

In summary, the five treatments had no effects on splenic and adrenal weights either at death or at sacrifice.

Mortality and Survival

Sergeyev (50), Tovbin (50), Trifonov (50) and Zimkin (50) found that pre-training increases survival time and decreased mortality following irradiation. Kimeldorf and Jones (20) found no differences in mortality between trained and untrained animals. The results of the present investigation are in direct contrast to the results of Sergeyev, Tovbin, Trifonov and Zimkin. Figure 20 and Table 20 show no significant differences between treatments with respect to survival time for all animals. Similar results were found with treatment effects on survival time of only those animals which died during the 30-day mortality period (Figure 21 and Table 21).

The Chi-square test showed no treatment effects on mortality (Figure 22 and Table 22). It should be pointed out that the four authors who found increased survival time with pre-training did not see fit to subject their data to statistical analysis. The resultant differences may well have been chance, rather than treatment, effects. However, it would be well to keep in mind that both the intensity and duration of training employed in this investigation was different than that employed by the authors who conclude that there were treatment differences in mortality and survival time.

CHAPTER V
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of this investigation was to study the effects of various levels of preirradiation physical activity, from weanling age to adulthood, upon the radiation resistance of mature rats.

Two-hundred and fifty 26-day old male albino rats (Sprague-Dawley strain) were randomly assigned to one of five treatments. Group 1 (sedentary control) received no special treatment, other than radiation, and was confined to individual sedentary cages both prior to and after being irradiated. Group 2 (spontaneous control) received no special treatment, other than radiation, and was housed in individual spontaneous exercise cages until irradiated and then confined to individual sedentary cages. Group 3 (sedentary forced) was housed in individual sedentary cages both prior to and after being irradiated. During the training period prior to irradiation, these animals were forced to swim daily for one-half hour with two per cent body weight attached to the base of the tail. Group 4 (spontaneous forced) was housed in individual spontaneous exercise cages until irradiated and then confined to individual sedentary cages. Prior to being irradiated these animals also were forced to swim daily for one-half hour with two per cent body weight attached to the base of the tail. Group 5 (spontaneous effect) was housed in individual spontaneous exercise cages both prior to and after being irradiated. These animals were not subjected to the preirradiation forced training regimen.

Three animals in one of the forced activity groups and two in the other drowned in training. One animal in one of the other groups died while under anesthesia during preirradiation blood sampling. Consequently, animals were eliminated randomly, and 47 rats in each group were irradiated. Postirradiation blood sampling resulted in the death of one additional animal. Once again, equal groups were maintained by random elimination. Therefore, 46 animals per group comprised the final sample.

Those animals which were subjected to the swimming regimen (Group 3 and 4) were swum in individual cylindrical tanks measuring 11 inches in diameter and 30 inches in depth. Water temperature was maintained between 36° and 38° C. during swimming. After each swim period, the animals were dried with a towel and replaced in their respective cages.

The preirradiation treatments were begun at 27 days of age and were carried on throughout puberty and early adulthood. On the 83rd day of the preirradiation treatments, 20 per cent of the animals, randomly selected with stratification by groups were placed in sedentary cages for an approximate 64-hour rest period prior to irradiation. The forced swimming regimen was terminated for these animals at this time. On the 84th, 85th and 86th days, a similar procedure was followed with 20, 30 and 30 per cent of the animals respectively.

Following the 64-hour rest period, each animal was exposed to 650 r while confined in a three-inch by nine-inch lucite chamber. Twenty-four animals were irradiated simultaneously. The total time required for irradiation was 180.5 minutes. Animal positions were rotated every 36.1 minutes to provide equal exposures for all.

Nine days before and five days following irradiation, a blood sample was drawn from the orbital sinus of each animal to determine the WBC and eosinophil counts. A 24-hour period of confinement in sedentary cages was provided for all animals, regularly in spontaneous cages, prior to the drawing of each blood sample.

During the 30 days immediately following irradiation, a laboratory technician was with the animals twenty-four hours a day. Mortality and survival time in hours for all groups of animals were recorded during this period. At the end of the thirty-day period, the surviving animals in all groups were sacrificed. Upon death or sacrifice, body weight as well as the weights of the spleen and adrenals were determined. The thymus was observed subjectively, but not weighed, since its posirradiation condition prohibited proper extraction and trimming.

Throughout the entire investigation, all animals received water and a commercial ground animal diet, ad libitum. Body weight for each animal was determined once a week throughout the preirradiation period, and the weight to be attached to the base of the tail during swimming was changed on the following day. The temperature in the housing quarters was maintained between 70° and 78° F. Daily voluntary exercise data for each animal housed in a spontaneous exercise cage was recorded at 7:45 A.M. daily.

For the first 71 days of the preirradiation period, an automatic timer illuminated the animal quarters 12 hours a day. Since it was necessary for the technician to observe each animal hourly following irradiation, lights were kept on 24 hours a day beginning on the 72nd day. The 24-hour illumination was started 12 days prior to irradiation in order to provide an adjustment period for the animals.

Statistical analysis (sign test) showed that the spontaneous forced animals (Group 4) were significantly more active than the spontaneous controls (Group 2). Both preirradiation and postirradiation activity level had no effect on survival time following irradiation. Twenty-four hour lighting significantly reduced activity levels when compared with 12 hour lighting. Irradiation significantly reduced activity levels. Body weight differences between groups prior to irradiation were observed with the most heavily exercised (Group 4) being lighter than Groups 1, 2 and 3. Preirradiation WBC and eosinophil counts showed no differences between groups. Similar results were found with postirradiation blood sampling. No differences between groups were noted with respect to spleen weight at death and sacrifice and adrenal weight per body weight at death and sacrifice. The comparison of both mortality and survival time in hours between the treatment groups showed no differences. Those animals which were in the upper half of their group with respect to body weight had longer survival times than those animals in the lower half.

Conclusions

Analysis of the results of this investigation has led to the following conclusions:

1. Forced swimming for one-half hour daily with two per cent body weight attached significantly increases spontaneous activity.

2. Forced swimming and/or spontaneous activity for a prolonged period reduce body weight.

3. Illumination of animal quarters 24-hours daily significantly reduces volitional activity as compared to 12-hour per day illumination.

4. Irradiation decreases spontaneous activity.

5. Prolonged training does not alter WBC or eosinophil levels either prior to or following irradiation.

6. Prolonged training has no effect on either adrenal weight per body weight or gross splenic weight following irradiation.

7. Level of preirradiation physical activity has no effect on postirradiation mortality and survival time.

8. Body weight appears to be the most significant factor influencing survival time following irradiation.

Recommendations

1. Unless histological or pathological investigations

are to be conducted, further research should dispense with the weighing of organs.

2. If spontaneous activity is to be measured, careful attention should be given to the amount of time daily that the animal quarters are to be illuminated.

3. A study should be undertaken in which spontaneous activity is measured for 50 days prior to irradiation with 650 r. Spontaneous activity will be measured for three days postirradiation. Use 12 hours of light and 12 hours of darkness throughout investigation. This will enable one to quantitate the effect of irradiation on voluntary activity.

4. It is recommended that the adrenals of all animals be subjected to histological examination (volume of three cortical zones) and plotted against survival time. This procedure will provide evidence of radiation damage and recovery trends.

5. It is recommended that the basic study be redone utilizing a radiation dose of 700-900 r.

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APPENDIX A

Raw Data

Legend for Raw Data

A = Animal Number

B = Treatment

C = Mean Daily Voluntary Activity During Total Preirradiation Period.

D = Level of Mean Daily Voluntary Activity Relative to Groups During Total Preirradiation Period.

E = Mean Daily Voluntary Activity During 11 Days Preirradiation Prior to Lights On.

F = Mean Daily Voluntary Activity Last 11 Days Preirradiation with Lights On.

G = Mean Daily Voluntary Activity During First 11 Days Postirradiation.

H = Mean Daily Voluntary Activity First 3 Days Postirradiation.

I = Level of Mean Daily Voluntary Activity Relative to Group During First 3 Days Postirradiation.

J = Body Weight Last Week Prior to Irradiation.

K = Level of Body Weight Relative to Groups Last Week Prior to Irradiation.

L = WBC 9 Days Prior to Irradiation.

M = Level of WBC Relative to Groups 9 Days Prior to Irradiation.

N = WBC 5 Days Postirradiation.

O = Level of WBC Relative to Groups 5 Days Postirradiation.

P = Eosinophils 9 Days Prior to Irradiation.

Q = Level of Eosinophils Relative to Groups 9 Days Prior to Irradiation.

R = Spleen Weight at Death or Sacrifice.

S = Adrenal Weight Per Body Weight at Death or Sacrifice.

T = Survival Time in Hours.*

* Those animals with survival times of 715 lived to sacrifice.

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DATE OF TABULATION ____________

TOPIC ____________

TABULATED BY ____________

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
1	1	3								552	2	16350	2	200	2	194	2	.4420	.00022	252	1
2	2	3								402	1	15550	2	650	2	50	1	.2330	.00034	135	2
3	3	3								490	2	9850	1	150	1	61	1	.9166	.00009	715	3
4	4	3								390	1	11250	2	250	2	178	2	.4595	.00033	372	4
5	5	3								382	1	12850	2	250	2	56	1	.2340	.00017	285	5
6	6	3								397	1	5550	1	200	2	61	1	.8296	.00012	715	6
7	7	3								418	2	10500	1	100	1	133	2	.4373	.00035	358	7
8	8	3								356	1	8800	1	350	2	61	1	1.7956	.00010	715	8
9	9	3								427	2	19900	2	50	1	44	1	.8183	.00010	715	9
10	10	3								344	1	9250	1	50	1	56	1	.8203	.00013	715	10
11	11	3								409	1	11250	1	200	2	21	1	.8545	.00008	715	11
12	12	3								400	1	11250	1	250	2	61	1	1.0517	.00010	715	12
13	13	3								434	2	10650	1	200	2	144	2	.8985	.00010	715	13
14	14	3								404	1	11850	2	350	2	50	1	.9551	.00012	715	14
15	15	3								357	1	14500	2	250	2	61	1	.8565	.00011	715	15
16	16	3								399	1	13950	2	150	1	83	2	.3931	.00036	301	16
17	17	3								359	1	11600	2	100	1	150	2	.8274	.00011	715	17
18	18	3								410	2	12250	2	250	2	78	2	.8463	.00011	715	18
19	19	3								471	2	14100	2	250	2	112	2	1.1545	.00052	546	19
20	20	3								444	2	10850	1	200	2	166	2	.8529	.00011	715	20
21	23	3								418	2	12700	2	200	2	78	2	.5601	.00049	488	21
22	24	3								477	2	8700	1	100	1	94	2	.9223	.00012	715	22
23	25	3								462	2	8900	1	100	1	78	2	.8801	.00008	715	23
24	26	3								466	2	12800	2	300	2	39	1	.2623	.00016	367	24
25	27	3								346	1	13400	2	100	1	67	2	.4193	.01184	579	25
26	28	3								413	2	9650	1	50	1	56	1	1.3086	.00014	715	26
27	29	3								417	2	11050	1	350	2	39	1	.9973	.00012	715	27
28	30	3								400	1	9400	1	150	1	94	2	.6793	.00039	429	28
29	31	3								411	2	12500	2	350	2	50	1	.3402	.00028	284	29
30	32	3								422	2	13550	2	150	1	28	1	.2943	.00026	364	30
31	33	3								426	2	8000	1	200	2	67	2	.3256	.00025	341	31
32	34	3								374	1	12050	2	50	1	11	1	.3597	.00028	195	32
33	35	3								455	2	8300	1	50	1	33	1	.9752	.00010	715	33

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
1	36	3								344	1	9750	1	50	1	50	1	.6785	.00012	715	1
2	37	3								361	1	8500	1	200	1	78	2	.7604	.00014	715	2
3	38	3								420	2	11650	2	50	1	21	1	.8409	.00011	715	3
4	39	3								491	2	5650	1	100	1	67	2	.9396	.00013	715	4
5	40	3								403	1	12300	2	150	1	72	2	.7933	.00014	715	5
6	41	3								375	1	13600	2	150	1	128	2	.8184	.00044	465	6
7	42	3								460	2	6900	1	600	2	56	1	.9742	.00013	715	7
8	43	3								496	2	14150	2	250	2	222	2	.9608	.00011	715	8
9	45	3								481	2	13200	2	50	1	106	2	.9671	.00012	715	9
10	46	3								408	1	10400	1	100	1	67	2	.7116	.00013	715	10
11	48	3								338	1	10150	1	450	2	256	2	.2781	.00038	350	11
12	49	3								406	1	7700	1	250	2	39	1	.8446	.00012	715	12
13	50	3								333	1	12350	2	50	1	61	1	.7662	.00013	715	13
14	51	4	3572	2						438	2	10200	1	150	1	28	1	.8346	.00011	715	14
15	53	4	3528	2						347	1	7400	1	50	1	72	2	.6238	.00031	472	15
16	55	4	3943	2						420	2	9650	1	400	2	100	2	.8238	.00010	715	16
17	56	4	1861	1						459	2	9950	1	100	1	21	1	.7917	.00012	715	17
18	57	4	2023	1						340	1	13600	2	200	2	72	2	.7159	.00011	715	18
19	58	4	835	1						451	2	14150	2	100	1	78	2	.9148	.00095	715	19
20	59	4	1513	1						437	2	9650	1	150	1	44	1	.8533	.00008	715	20
21	60	4	5012	2						316	1	7200	1	50	1	28	1	.7532	.00018	715	21
22	61	4	4108	2						390	2	9550	1	100	1	21	1	.2682	.00028	244	22
23	62	4	3619	2						313	1	12000	2	350	2	44	1	.6205	.00014	715	23
24	63	4	3654	2						331	1	7400	1	50	1	72	2	.9000	.00011	715	24
25	64	4	1118	1						382	2	10250	1	50	1	150	2	.5358	.00030	431	25
26	65	4	887	1						443	2	9450	1	50	1	56	1	.9180	.00012	715	26
27	66	4	1453	1						359	1	5600	1	0	1	83	2	.9107	.00013	715	27
28	68	4	5927	2						303	1	9750	1	350	2	94	2	1.9180	.00022	715	28
29	69	4	1326	1						385	2	11700	2	100	1	83	2	.7717	.00012	715	29
30	70	4	797	1						450	2	8750	1	250	2	5	1	.8944	.00011	715	30
31	72	4	5165	2						403	2	9750	1	100	1	28	1	.7964	.00011	715	31
32	73	4	1628	1						367	1	10950	2	650	2	56	1	.9520	.00010	715	32
33	74	4	2852	1						374	2	12550	2	200	2	50	1	.9362	.00013	715	33

MICHIGAN STATE UNIVERSITY
DEPARTMENT OF HEALTH, PHYSICAL EDUCATION, AND RECREATION

GRADUATE STUDIES AND RESEARCH

TABULATION SHEET

DATE OF TABULATION ____

TOPIC ____

TABULATED BY ____

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
1	75	4	3765	2						395	2	12200	2	50	1	28	1	.8376	.00012	715	1
2	76	4	4658	2						351	1	13500	2	200	2	171	2	.8446	.00012	715	2
3	77	4	2216	1						340	1	10600	2	350	2	56	1	.8600	.00012	715	3
4	78	4	4759	2						334	1	9350	1	300	2	17	1	.5774	.00056	444	4
5	79	4	3936	2						297	1	7750	1	450	2	61	1	.8073	.00013	715	5
6	80	4	5579	2						380	2	10500	2	350	2	112	2	.3776	.00048	364	6
7	81	4	3912	2						400	2	14450	2	50	1	171	2	.7447	.00014	715	7
8	82	4	5320	2						420	2	11700	2	300	2	11	1	1.1550	.00017	715	8
9	83	4	1768	1						334	1	10850	2	150	1	161	2	.2916	.00040	353	9
10	84	4	1127	1						336	1	11500	2	100	1	44	1	.8563	.00011	715	10
11	85	4	3247	2						332	1	7900	1	150	2	89	2	1.3734	.00015	715	11
12	86	4	863	1						355	1	10350	2	300	2	39	1	.9021	.00013	715	12
13	87	4	1505	1						396	2	9100	1	200	2	44	1	.7754	.00012	715	13
14	88	4	4677	2						396	2	10900	2	50	1	44	1	.7652	.00013	715	14
15	89	4	5677	2						346	1	14500	2	250	2	78	2	.7193	.00012	715	15
16	90	4	4401	2						413	2	7550	1	200	2	28	1	.3010	.00038	319	16
17	91	4	1927	1						353	1	11300	2	600	2	111	2	.9452	.00013	715	17
18	92	4	1202	1						370	1	14300	2	300	2	106	2	.5666	.00070	428	18
19	93	4	781	1						347	1	9600	1	150	2	67	2	.9431	.00013	715	19
20	94	4	1086	1						413	2	5700	1	100	1	89	2	.2845	.00030	229	20
21	95	4	826	1						358	1	15000	2	200	2	228	2	.4600	.00039	361	21
22	96	4	2792	1						415	2	12450	2	100	1	44	1	.2064	.00024	196	22
23	97	4	3466	2						367	1	12900	2	200	2	72	2	.8757	.00012	715	23
24	98	4	3190	2						387	2	9050	1	50	1	61	2	.7767	.00011	715	24
25	99	4	3032	2						369	1	11400	2	50	1	78	2	.8273	.00012	715	25
26	100	4	2596	1						423	2	9850	1	50	1	28	1	.4059	.00064	447	26
27	101	2	6059	2						466	2	12900	2	100	1	28	1	.9926	.00010	715	27
28	102	2	978	1						463	2	14750	2	200	2	67	2	.9508	.00009	715	28
29	103	2	2286	2						519	2	14550	2	500	2	78	2	.8767	.00011	715	29
30	104	2	1060	1						432	2	14700	2	250	2	89	2	1.0901	.00010	715	30
31	105	2	1880	2						402	1	11050	1	150	1	33	1	1.1094	.00011	715	31
32	106	2	2349	2						419	1	9200	1	200	2	155	2	.9003	.00011	715	32
33	107	2	5473	2						443	2	12300	2	150	1	56	1	.8066	.00009	715	33

O 3650

MICHIGAN STATE UNIVERSITY
DEPARTMENT OF HEALTH, PHYSICAL EDUCATION, AND RECREATION

GRADUATE STUDIES AND RESEARCH

TABULATION SHEET

DATE OF TABULATION ____________

TOPIC ____________

TABULATED BY ____________

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
1	108	2	2095	2						482	2	7950	1	150	1	100	2	.8210	.00012	715	1
2	109	2	1709	1						414	1	10650	1	100	1	44	1	.9297	.00011	715	2
3	110	2	2113	2						394	1	13800	2	50	1	11	1	.6562	.00013	715	3
4	111	2	1825	2						447	2	10400	1	100	1	200	2	.7516	.00046	511	4
5	112	2	681	1						420	1	13750	2	400	2	50	1	.6955	.00010	715	5
6	114	2	1130	1						412	1	12800	2	50	1	33	1	.4256	.00045	283	6
7	115	2	1801	2						442	2	10400	1	100	1	61	2	1.0423	.00012	715	7
8	116	2	1640	1						492	2	11700	2	150	1	33	1	.7733	.00010	715	8
9	117	2	914	1						399	1	11400	1	400	2	33	1	.8094	.00054	535	9
10	119	2	2127	2						404	1	11050	1	300	2	89	2	.5910	.00011	715	10
11	120	2	3412	2						423	1	6750	1	300	2	100	2	.7222	.00034	415	11
12	121	2	1154	1						409	1	8050	1	150	1	21	1	.6400	.00016	715	12
13	122	2	2016	2						536	2	10550	1	250	2	72	2	1.0065	.00012	715	13
14	124	2	3062	2						436	2	8200	1	50	1	72	2	.5940	.00033	347	14
15	125	2	1556	1						440	2	12950	2	50	1	94	2	1.0953	.00010	715	15
16	126	2	1466	1						487	2	8850	1	350	2	39	1	1.2371	.00090	715	16
17	127	2	844	1						421	1	11000	1	100	1	89	2	.2468	.00025	287	17
18	128	2	2351	2						465	2	16800	2	100	1	67	2	.9405	.00010	715	18
19	129	2	4461	2						347	1	5700	1	50	1	44	1	.7011	.00014	715	19
20	130	2	1365	1						424	1	9750	1	100	1	44	1	.4315	.00035	243	20
21	131	2	1533	1						481	2	12050	2	200	2	33	1	.8555	.00012	715	21
22	132	2	1697	1						461	2	18000	2	100	1	33	1	.4033	.00025	225	22
23	133	2	831	1						441	2	12500	2	350	2	50	1	1.0527	.00011	715	23
24	134	2	1226	1						451	2	10700	1	350	2	78	2	.7626	.00044	531	24
25	135	2	1544	1						491	2	11850	2	150	1	122	2	1.5811	.00009	715	25
26	136	2	3174	2						402	1	11150	1	300	2	11	1	.3596	.00049	249	26
27	137	2	797	1						420	1	11800	2	50	1	17	1	.9091	.00012	715	27
28	138	2	6855	2						356	1	7450	1	50	1	39	1	.9042	.00044	646	28
29	139	2	6526	2						364	1	10300	1	350	2	33	1	.7911	.00014	715	29
30	140	2	1345	1						416	1	14600	2	250	2	44	1	.9086	.00009	715	30
31	141	2	2462	2						411	1	12800	2	750	2	100	2	.5293	.00037	412	31
32	142	2	1518	1						474	2	8600	1	150	1	67	2	.7519	.00010	715	32
33	143	2	1447	1						400	1	12400	2	250	2	56	2	.9809	.00012	715	33

O-3650

MICHIGAN STATE UNIVERSITY
DEPARTMENT OF HEALTH, PHYSICAL EDUCATION, AND RECREATION

GRADUATE STUDIES AND RESEARCH

TABULATION SHEET

DATE OF TABULATION ____

TOPIC ____

TABULATED BY ____

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
1	144	2	3247	2						424	1	11900	2	150	2	67	2	.3373	.00036	425	1
2	145	2	2625	2						412	1	9650	1	150	2	67	2	.4391	.00055	407	2
3	146	2	1770	1						471	2	11800	2	50	1	50	1	.9561	.00011	715	3
4	147	2	4539	2						353	1	11700	2	150	2	56	2	.3516	.00028	241	4
5	149	2	1041	1						426	2	11750	2	250	2	67	2	.8518	.00011	715	5
6	150	2	1828	2						446	2	9450	1	250	2	50	1	.9808	.00011	715	6
7	151	5	3432	2	7662	5218	581	378	2	384	1	11050	2	100	1	72	2	.2054	.00024	363	7
8	152	5	2057	1	2439	1252	448	281	1	425	2	11650	2	350	2	78	2	1.0587	.00011	715	8
9	153	5	4082	2	4604	1908	453	445	2	413	1	11100	2	50	1	61	2	.4571	.00036	247	9
10	154	5	2939	2	5175	1370	125	285	2	424	2	6200	1	150	1	100	2	.4039	.00029	251	10
11	155	5	2948	2	4860	2266	699	378	2	367	1	8800	1	250	2	39	1	.8941	.00014	715	11
12	156	5	2934	2	5181	1743	709	236	1	422	2	11200	2	100	1	56	1	.7900	.00011	715	12
13	157	5	916	1	1175	831	341	208	1	428	2	10300	1	50	1	21	1	2.4825	.00023	715	13
14	158	5	1112	1	1545	817	470	163	1	467	2	10200	1	100	1	61	2	1.0305	.00032	469	14
15	159	5	892	1	1300	549	388	273	1	382	1	13800	2	250	2	11	1	.7084	.00013	715	15
16	160	5	2099	1	2958	315	221	95	1	430	2	7400	1	450	2	72	2	.8433	.00012	715	16
17	161	5	1994	1	2308	1346	671	319	2	437	2	9900	1	100	1	106	2	.6855	.00047	459	17
18	162	5	6705	2	9237	487	73	129	1	386	1	8650	1	300	2	50	1	.4014	.00037	232	18
19	163	5	2226	1	3318	1987	545	327	2	374	1	12900	2	250	2	56	1	.7949	.00013	715	19
20	164	5	5654	2	12891	9866	1305	217	1	410	1	7950	1	100	1	11	1	.3692	.00035	207	20
21	166	5	3976	2	2989	1126	807	306	2	412	1	7600	1	250	2	50	1	1.1041	.00011	715	21
22	168	5	1444	1	961	4592	444	316	2	416	2	10500	2	100	1	72	2	.7790	.00014	715	22
23	169	5	2579	2	2526	2528	1136	782	2	392	1	8500	1	250	2	50	1	.7354	.00014	715	23
24	170	5	1805	1	1295	755	592	286	2	431	2	9950	1	100	1	72	2	1.4956	.00130	671	24
25	171	5	5025	2	3394	1039	403	228	1	420	2	10900	2	100	1	133	2	.8076	.00011	715	25
26	172	5	3529	2	5148	397	365	158	1	513	2	12900	2	50	1	178	2	.8066	.00010	715	26
27	173	5	1153	1	1217	668	327	278	1	434	2	14200	2	150	1	50	1	.9646	.00013	715	27
28	174	5	1573	1	4872	384	169	96	1	395	1	8200	1	50	1	112	2	.9398	.00012	715	28
29	175	5	1910	1	1376	1461	79	155	1	457	2	5500	1	300	2	50	1	.4295	.00038	252	29
30	176	5	2247	2	1676	1559	696	418	2	395	1	11600	2	150	2	344	2	.8339	.00015	715	30
31	177	5	2514	2	2081	2040	556	254	1	406	1	11800	2	100	1	122	2	1.6225	.00013	715	31
32	178	5	1878	1	1358	1127	674	419	2	410	1	9950	1	200	2	50	1	.9732	.00013	715	32
33	179	5	3098	2	5547	4046	427	1171	2	358	1	9850	1	200	2	33	1	.3159	.00039	289	33

O-3650

MICHIGAN STATE UNIVERSITY
DEPARTMENT OF HEALTH, PHYSICAL EDUCATION, AND RECREATION

GRADUATE STUDIES AND RESEARCH

TABULATION SHEET

DATE OF TABULATION ____________

TOPIC ____________

TABULATED BY ____________

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
1	180	5	1571	1	1776	1319	715	531	2	376	1	11300	2	200	2	6	2	1.1493	.00014	715	1
2	181	5	2482	2	1653	1047	613	405	2	383	1	11500	2	50	1	39	1	.5928	.00047	512	2
3	182	5	3477	2	3807	4814	991	562	2	375	1	10900	2	350	2	111	2	.8380	.00011	715	3
4	183	5	1262	1	1398	452	373	182	1	523	2	13350	2	200	2	21	1	.7599	.00010	715	4
5	184	5	3441	2	6498	2021	581	402	2	387	1	14100	2	50	1	56	2	.2116	.00028	380	5
6	185	5	1810	1	1133	564	482	192	1	454	2	9350	1	150	2	7	1	.9273	.00010	715	6
7	186	5	3930	2	5563	208	110	35	1	465	2	10950	2	100	1	33	1	.7926	.00012	715	7
8	187	5	1330	1	1249	859	427	223	1	526	2	16550	2	50	1	50	1	.7187	.00013	715	8
9	188	5	1106	1	944	777	492	335	2	431	2	11800	2	550	2	106	2	.7821	.00012	715	9
10	189	5	1841	1	1578	762	516	238	1	422	2	14800	2	200	2	61	2	.8412	.00012	715	10
11	190	5	3502	2	4021	776	402	110	1	506	2	8650	1	50	1	21	1	.9411	.00011	715	11
12	191	5	1920	1	1217	924	727	424	2	467	2	8100	1	0	1	61	2	.8286	.00013	715	12
13	192	5	1353	1	1308	1063	543	347	2	416	2	7100	1	350	2	39	1	.8044	.00010	715	13
14	193	5	2609	2	3027	2037	985	867	2	422	2	6100	1	300	2	89	2	.9892	.00013	715	14
15	195	5	4178	2	5286	2452	434	313	2	363	1	11450	2	400	2	44	1	.9675	.00011	715	15
16	197	5	809	1	519	406	127	63	1	365	1	11550	2	450	2	61	2	.1782	.00025	314	16
17	198	5	4939	2	5976	1103	613	264	1	410	1	9300	1	200	2	17	1	.7265	.00011	715	17
18	199	5	1821	1	1936	1020	194	239	1	383	1	10100	1	100	1	67	2	.4060	.00040	331	18
19	200	5	3924	2	4827	1181	193	352	2	384	1	7000	1	100	1	28	1	.2213	.00039	237	19
20	201	1								417	1	11400	1	100	1	39	1	.7477	.00016	715	20
21	202	1								452	1	13750	2	150	1	83	2	1.1009	.00011	715	21
22	203	1								429	1	13450	2	350	2	17	1	.7930	.00011	715	22
23	204	1								499	2	12500	2	150	1	44	1	1.1801	.00012	715	23
24	205	1								446	1	9950	1	100	1	50	1	.2706	.00023	309	24
25	206	1								442	1	11200	1	50	1	28	1	.4668	.00030	189	25
26	207	1								415	1	10200	1	150	1	133	2	.9913	.00011	715	26
27	208	1								418	1	11350	1	250	2	78	2	.4988	.00037	431	27
28	209	1								481	2	7850	1	100	1	78	2	.9145	.00010	715	28
29	210	1								468	2	12900	2	150	1	50	1	1.1143	.00012	715	29
30	211	1								573	2	13600	2	250	2	44	1	.9661	.00009	715	30
31	212	1								401	1	10650	1	50	1	94	2	.2471	.00021	343	31
32	213	1								455	1	17900	2	50	1	128	2	.8173	.00010	715	32
33	214	1								502	2	8450	1	300	2	56	1	.4920	.00040	240	33

O-3650

MICHIGAN STATE UNIVERSITY
DEPARTMENT OF HEALTH, PHYSICAL EDUCATION, AND RECREATION

GRADUATE STUDIES AND RESEARCH

TABULATION SHEET

DATE OF TABULATION ______

TOPIC ______

TABULATED BY ______

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
215	1								510	2	15850	2	150	1	78	2	.8344	.00010	715
216	1								430	1	9850	1	200	2	89	2	.2520	.00021	278
217	1								520	2	10200	1	200	2	100	2	1.0205	.00008	715
218	1								533	2	12700	2	650	2	72	2	.8533	.00010	715
219	1								538	2	13300	2	100	1	28	1	.8546	.00013	715
220	1								457	2	9900	1	350	2	39	1	.8775	.00012	715
221	1								502	2	11250	1	350	2	21	1	.7349	.00012	715
222	1								503	2	13150	2	50	1	56	1	.9713	.00011	715
223	1								412	1	12600	2	50	1	39	1	.8496	.00013	715
224	1								509	2	7150	1	50	1	33	1	.8673	.00012	715
225	1								464	2	11800	1	100	1	67	2	1.2481	.00011	715
226	1								415	1	13400	2	200	2	78	2	1.1522	.00009	715
227	1								478	2	14450	2	250	2	94	2	.9477	.00010	715
228	1								453	1	14450	2	450	2	106	2	.7765	.00011	715
229	1								405	1	15350	2	350	2	21	1	.8623	.00010	715
231	1								424	1	8600	1	100	1	112	2	.2454	.00030	284
233	1								451	1	9000	1	250	2	83	2	.2952	.00028	234
234	1								494	2	12300	2	300	2	72	2	.8321	.00010	715
236	1								455	1	13750	2	250	2	39	1	.8306	.00010	715
237	1								400	1	11450	1	100	1	33	1	.9941	.00013	715
238	1								560	2	16900	2	100	1	72	2	.8630	.00010	715
239	1								482	2	15050	2	100	1	50	1	1.0530	.00009	715
240	1								419	1	9250	1	200	2	61	1	.7991	.00014	715
241	1								440	1	14700	2	100	1	133	2	.8273	.00038	440
242	1								527	2	11000	1	50	1	11	1	.6836	.00010	715
243	1								457	2	8650	1	200	2	61	1	.7766	.00043	523
244	1								456	2	9400	1	150	2	94	2	.8832	.00035	443
245	1								493	2	10850	1	50	1	133	2	1.1122	.00010	715
247	1								525	2	5450	1	200	2	67	2	.8917	.00011	715
248	1								446	1	11950	2	300	2	39	1	.8596	.00011	715
249	1								435	1	12850	2	250	2	44	1	1.3758	.00011	715
250	1								433	1	12350	2	200	2	106	2	1.4890	.00011	715

O-3650

APPENDIX B

Body Weights

Animal Number	3/31	4/7	4/14	4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/22
1	81	136	181	230	277	336	375	412	451	483	515	534	552
2	72	122	161	205	247	284	306	331	352	370	390	394	402
3	78	127	176	226	279	327	360	391	420	441	474	489	490
4	66	112	163	203	251	293	305	330	350	363	388	390	390
5	67	110	154	183	224	257	280	301	320	340	361	378	382
6	79	124	172	206	248	283	302	328	340	360	374	383	397
7	79	127	176	217	263	294	315	341	367	380	410	417	418
8	73	121	167	204	231	267	282	299	315	337	350	352	356
9	76	126	181	229	260	319	354	381	400	407	422	429	427
10	73	109	141	167	195	224	244	266	271	293	316	330	344
11	81	135	184	226	267	303	322	344	359	368	396	405	409
12	72	124	177	212	260	294	316	336	354	368	390	402	400
13	83	135	186	228	278	319	346	367	382	399	436	430	434
14	77	129	177	220	263	301	326	344	360	377	353	398	404
15	65	110	159	198	227	264	290	311	320	331	346	350	357
16	71	121	165	206	249	288	313	337	354	376	381	391	399
17	78	121	162	194	234	271	293	307	328	346	358	356	359
18	72	120	172	221	256	302	328	347	369	392	412	418	410
19	71	114	165	211	263	305	338	367	388	420	450	458	471
20	78	127	179	229	273	318	350	375	392	408	427	435	444
23	75	125	169	210	243	286	313	345	368	380	406	406	418
24	76	125	184	237	280	324	355	386	410	436	462	466	477
25	76	129	178	230	278	331	371	396	416	440	462	465	462
26	69	128	167	212	258	313	349	355	400	413	453	467	466

APPENDIX B (continued)

Body Weights

Animal Number	3/31	4/7	4/14	4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/22
27	67	112	156	201	240	269	290	308	322	316	345	340	346
28	69	115	171	220	265	302	328	355	370	382	403	406	413
29	81	130	177	237	283	326	344	366	385	391	412	420	417
30	81	133	177	225	264	306	329	345	363	359	388	393	400
31	71	120	167	205	253	299	325	353	377	390	403	410	411
32	74	126	167	207	248	288	318	340	369	384	404	415	422
33	78	134	185	235	256	311	347	367	390	402	417	423	426
34	72	122	167	205	235	256	287	306	315	338	360	369	374
35	66	117	160	206	256	317	350	381	406	428	449	441	455
36	66	113	146	183	219	254	277	300	312	328	341	345	344
37	75	125	162	206	247	296	326	347	353	358	368	353	361
38	67	115	167	210	253	302	326	354	370	387	413	410	420
39	80	136	180	234	277	330	367	398	415	438	466	480	491
40	80	132	174	212	255	291	317	341	358	371	386	396	403
41	81	117	159	206	244	280	302	321	334	353	362	367	375
42	67	139	181	223	265	314	349	380	406	422	448	455	460
43	79	138	180	245	291	345	385	418	445	470	491	493	496
45	79	135	179	236	250	315	357	390	423	438	468	485	481
46	66	118	170	200	239	291	331	356	370	384	407	410	408
48	70	117	152	189	227	256	282	297	307	321	294	335	338
49	71	123	174	223	265	304	332	358	375	370	396	406	406
50	73	119	162	196	231	260	287	291	302	312	327	331	333
51	60	108	134	190	224	276	308	345	370	395	427	438	438
53	66	100	137	177	216	240	227	278	300	314	334	350	347

APPENDIX B (continued)

Body Weights

Animal Number	3/31	4/7	4/14	4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/22
55	73	108	149	191	240	276	302	335	345	363	398	394	420
56	72	113	163	212	258	300	336	372	391	420	441	451	459
57	62	95	135	181	216	257	275	293	306	332	342	348	340
58	84	140	184	234	280	272	310	375	404	408	436	432	451
59	74	114	160	197	237	307	333	333	364	387	412	423	437
60	65	94	135	173	210	242	255	272	282	296	316	316	316
61	73	111	164	212	257	299	317	337	336	362	393	394	390
62	64	106	147	178	210	213	247	255	274	283	305	314	313
63	67	97	138	168	194	230	262	283	292	299	300	316	331
64	68	101	142	184	205	247	230	295	313	335	364	371	382
65	76	120	171	220	257	298	332	366	387	399	426	441	443
66	61	99	140	179	215	240	267	288	308	319	340	352	359
68	70	99	140	164	192	222	241	262	272	283	296	300	303
69	69	101	141	178	215	256	284	310	326	340	359	388	385
70	74	113	167	208	245	282	316	352	366	396	410	428	450
72	71	110	151	193	235	274	299	324	335	351	373	380	403
73	62	91	120	151	179	231	239	301	329	338	351	356	367
74	76	112	156	191	231	266	295	314	331	346	362	366	374
75	77	117	152	196	247	268	269	308	325	352	392	389	395
76	68	106	140	176	211	238	254	282	296	305	336	347	351
77	66	101	140	175	200	235	238	279	298	317	331	334	340
78	62	96	128	158	187	206	259	292	304	314	331	330	334
79	61	94	130	167	200	235	224	237	249	265	284	295	297
80	63	104	140	178	217	266	296	312	336	367	374	378	380

APPENDIX B (continued)

Body Weights

Animal Number	3/31	4/7	4/14	4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/22
81	76	119	161	199	246	276	312	327	361	382	400	407	400
82	77	118	159	202	247	286	310	335	353	382	402	406	420
83	72	104	139	180	201	229	250	266	290	303	321	325	334
84	74	109	148	181	214	238	263	283	301	312	330	335	336
85	66	102	144	178	207	242	266	282	285	307	322	327	332
86	69	97	133	169	189	217	228	260	283	299	322	325	355
87	69	108	155	196	234	274	293	324	353	375	394	394	396
88	72	108	138	187	224	224	277	316	331	350	370	396	396
89	64	94	146	176	213	238	269	242	300	321	338	348	346
90	70	117	162	196	244	283	316	337	365	378	400	412	413
91	67	103	138	166	191	222	245	281	299	317	345	344	353
92	82	115	162	196	227	251	272	302	322	342	366	365	370
93	63	102	138	175	214	251	290	318	338	351	371	372	347
94	72	117	166	210	246	283	322	348	369	388	407	404	413
95	78	108	147	191	225	253	276	299	320	337	354	360	358
96	70	117	159	192	230	267	302	333	359	383	403	405	415
97	63	102	140	178	210	243	263	283	303	326	348	358	367
98	68	101	133	168	207	250	281	307	326	347	371	376	387
99	76	112	156	190	221	242	271	295	314	329	346	369	369
100	69	113	155	189	242	275	312	336	365	392	407	402	423
101	64	111	163	215	268	304	331	356	366	387	405	437	466
102	75	127	171	208	257	293	333	357	378	400	430	452	463
103	70	84	142	191	246	303	347	395	423	448	472	503	519
104	62	88	134	178	216	255	289	326	355	375	402	414	432

APPENDIX B (continued)

Body Weights

Animal Number	3/31	4/7	4/14	4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/22
105	72	106	148	181	215	245	280	309	337	355	375	392	402
106	63	83	133	173	213	240	286	317	347	372	396	410	419
107	71	110	159	206	252	276	323	348	367	387	411	427	443
108	80	120	162	199	227	268	316	356	400	420	460	460	482
109	69	103	140	175	207	244	273	310	334	357	381	399	414
110	66	104	146	183	223	260	286	310	333	346	360	377	394
111	80	121	163	205	249	272	311	350	380	400	425	438	477
112	80	116	164	200	24	279	302	320	352	370	390	412	420
114	75	108	151	195	242	264	310	333	355	369	389	405	412
115	67	109	155	200	249	286	319	351	374	394	412	424	442
116	74	110	154	202	259	303	347	380	405	434	456	482	492
117	76	91	131	172	216	260	287	310	321	350	366	390	399
119	67	104	142	178	216	248	279	310	337	354	374	382	404
120	65	82	123	171	222	274	312	334	350	354	379	401	423
121	78	116	154	186	226	256	296	323	347	371	391	403	409
122	66	85	138	193	254	301	361	405	435	466	499	510	536
124	77	116	159	199	236	270	303	328	347	377	399	410	436
125	70	109	150	188	231	268	299	336	370	387	411	428	440
126	71	118	165	206	252	296	324	372	390	422	458	466	487
127	71	103	144	188	218	268	301	335	357	367	396	402	421
128	74	113	163	203	244	282	309	358	386	409	433	457	465
129	77	117	161	198	237	256	274	294	297	311	330	344	347
130	73	116	160	199	240	278	315	344	368	378	402	420	424
131	80	126	161	226	269	313	336	373	396	426	452	473	481

APPENDIX B (continued)

Body Weights

Animal Number	3/31	4/7	4/14	4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/22
132	69	107	136	175	217	262	303	351	377	403	431	445	461
133	73	110	156	204	228	285	320	350	370	393	410	418	441
134	68	106	155	202	230	272	305	343	371	397	413	426	451
135	82	112	166	214	252	301	329	368	404	425	454	483	491
136	73	95	140	176	212	243	274	293	316	337	356	380	402
137	78	113	153	190	237	275	310	342	360	380	389	402	420
138	80	119	162	206	244	265	272	288	299	312	330	337	356
139	73	111	156	194	236	270	281	301	315	332	348	358	364
140	73	109	146	180	217	248	293	323	350	362	386	392	416
141	76	120	165	192	245	280	299	329	355	370	390	419	411
142	80	122	166	212	260	310	338	375	403	416	439	459	474
143	76	111	146	185	228	265	307	343	350	362	375	382	400
144	80	83	136	181	225	262	290	320	346	365	387	403	424
145	65	100	143	182	216	253	280	315	346	367	384	407	412
146	78	122	172	210	255	298	327	366	394	405	433	453	471
147	69	103	140	170	207	237	252	274	291	304	313	336	353
149	80	112	147	188	224	260	298	333	357	372	391	406	426
150	76	122	164	208	252	293	325	355	371	384	402	418	446
151	67	100	145	183	228	281	311	332	354	360	371	382	384
152	82	118	158	180	224	266	296	321	345	360	387	413	425
153	67	108	160	210	248	278	300	323	346	360	380	392	413
154	81	117	147	182	227	255	303	333	352	364	358	410	424
155	71	109	147	180	217	250	280	295	312	325	335	350	367
156	68	98	150	203	239	273	314	347	368	381	400	414	422
157	67	107	153	192	237	281	313	350	365	379	403	416	428

APPENDIX B (continued)

Body Weights

Animal Number	3/31	4/7	4/14	4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/22
158	77	120	161	197	244	293	329	352	380	394	418	445	467
159	71	111	152	184	224	242	287	315	330	341	363	370	382
160	70	116	165	209	250	290	309	334	355	370	393	417	430
161	77	119	168	203	247	258	315	346	363	384	410	430	437
162	68	80	123	172	207	243	263	289	300	312	332	361	386
163	70	112	143	169	197	243	271	298	320	333	346	360	374
164	71	122	168	220	277	330	351	370	340	374	386	373	410
166	70	109	154	194	233	266	292	318	335	360	376	390	412
168	73	107	136	164	197	230	270	310	336	365	378	392	416
169	76	128	168	212	255	298	334	355	381	391	419	420	392
170	82	125	159	191	233	277	312	344	374	387	412	433	431
171	71	111	155	195	235	258	276	300	330	326	371	400	420
172	74	130	174	219	275	310	346	381	411	430	457	476	513
173	73	121	167	206	247	282	313	343	365	380	402	412	434
174	67	100	137	179	214	245	275	304	313	343	364	374	395
175	75	120	168	210	250	291	321	356	385	405	433	447	457
176	73	112	150	188	223	263	292	323	342	352	374	394	395
177	77	122	156	197	236	256	300	324	347	325	380	397	406
178	77	119	159	196	238	270	303	326	350	360	390	399	410
179	70	107	147	181	218	252	272	299	310	328	336	349	358
180	64	99	135	171	200	224	268	272	310	305	346	348	376
181	81	116	147	178	210	236	261	284	307	324	350	364	383
182	79	118	157	193	235	278	292	313	332	347	362	374	375
183	75	128	173	229	274	325	370	402	421	456	474	503	523

APPENDIX B (continued)

Body Weights

Animal Number	3/31	4/7	4/14	4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/22
184	66	103	144	177	224	262	291	322	330	340	357	369	387
185	71	115	154	199	235	281	316	348	374	397	435	451	454
186	66	112	147	183	222	258	292	328	347	370	394	434	465
187	82	132	169	205	263	315	363	411	441	464	498	503	526
188	73	111	151	190	236	277	306	337	352	379	401	410	431
189	72	115	153	193	234	270	301	322	350	367	395	407	422
190	72	127	176	220	272	295	357	391	421	437	463	471	506
191	71	117	154	196	244	274	309	351	378	398	439	451	467
192	72	105	144	183	224	265	290	318	351	376	387	405	416
193	76	122	161	204	245	276	304	330	350	359	388	406	422
195	74	107	146	185	227	247	280	300	320	306	346	370	363
197	75	116	152	184	215	241	266	290	311	327	338	360	365
198	80	123	161	195	236	270	290	310	334	349	371	389	410
199	76	125	135	173	205	226	263	291	311	325	352	371	383
200	68	112	160	190	231	252	282	308	305	330	357	373	384
201	68	126	174	210	259	300	335	361	366	383	398	397	417
202	75	127	175	223	270	315	322	360	381	394	421	441	452
203	80	111	160	214	261	281	316	354	372	381	396	377	429
204	72	127	177	216	268	319	359	396	418	442	466	490	499
205	64	85	143	197	250	278	324	359	366	391	416	430	446
206	80	107	162	209	258	297	336	367	384	392	418	430	442
207	76	125	170	202	234	270	304	334	352	373	396	405	415
208	69	117	164	214	260	302	326	352	372	389	406	409	418
209	73	116	166	220	260	317	352	383	407	429	455	470	481

APPENDIX B (continued

Body Weights

Animal Number	3/31	4/7	4/14	4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/22
210	79	130	182	227	268	319	349	380	388	417	442	457	468
211	72	130	179	230	289	360	409	451	489	512	547	563	573
212	65	105	152	195	238	281	310	333	353	365	386	391	401
213	70	122	167	220	267	316	353	371	378	406	433	450	455
214	70	126	274	221	279	335	374	396	426	450	486	501	502
215	81	137	184	251	299	351	387	416	425	460	484	499	510
216	69	121	170	213	262	299	329	355	374	391	411	418	430
217	72	128	176	222	276	324	367	401	430	450	483	498	520
218	64	123	176	220	285	352	403	433	462	479	515	518	533
219	74	128	178	222	280	340	388	426	453	480	516	537	538
220	64	110	163	206	257	307	344	376	398	405	432	448	457
221	79	129	178	226	280	326	364	394	423	441	478	488	502
222	71	129	180	223	285	341	379	410	440	464	480	451	503
223	73	121	169	218	264	297	318	338	360	373	390	396	412
224	78	118	171	224	280	338	369	404	427	447	487	479	509
225	75	128	169	213	258	303	335	366	390	390	440	450	464
226	75	123	167	210	259	297	319	340	355	368	394	410	415
227	80	131	172	225	275	328	356	390	411	400	396	465	478
228	72	130	176	218	270	313	344	368	386	409	435	443	453
229	64	115	156	189	223	261	293	316	337	357	379	390	405
231	68	106	157	205	263	295	339	371	388	384	413	418	424
233	76	128	170	217	268	320	350	376	397	416	434	438	451
234	77	137	177	200	266	320	357	393	415	441	462	477	494
236	75	130	173	220	245	299	337	375	392	390	424	441	455

APPENDIX C

Starting Positions for Irradiation of Animals

Day	Time Finished	Nos. 1-50 Sed. Box	Forced Pos.	An.	Nos. 51-100 Spont. Box	Forced Pos.	An.
		I	A	48	I	B	86
		II	B	33	II	C	98
	1:00	III	C	16	III	D	55
	P.M.	IV	D	23	IV	E	73
Thurs.		V	E	41	V	A	--
24							
June		I	B	40	I	C	63
		II	C	35	II	D	
	6:00	III	D	24	III	E	93
	P.M.	IV	E	27	IV	A	83
		V	A	--	V	B	58
		I	C	1	I	D	96
		II	D	9	II	E	75
	12:00	III	E	32	III	A	89
	Noon	IV	A	38	IV	B	72
Fri.		V	B	13	V	C	80
25							
June		I	D	8	I	E	100
		II	E	43	II	A	77
	4:00	III	A	18	III	B	61
	P.M.	IV	B	30	IV	C	85
		V	C	6	V	D	84
		I	E	20	I	A	69
		II	A	3	II	B	90
	12:00	III	B	45	III	C	53
	Noon	IV	C	25	IV	D	65
Sat.		V	D	5	V	E	88
26							
June		I	A	11	I	B	99
		II	B	19	II	C	71
	3:00	III	C	10	III	D	76
	P.M.	IV	D	34	IV	E	79
		V	E	14	V	A	--

Nos. 101-150			Nos. 151-200			Nos. 201-250		
Spont.	Control		Spont.	Effect		Sed.	Control	
Box	Pos.	An.	Box	Pos.	An.	Box	Pos.	An.
I	C	124	I	D	188	I	E	237
II	D	112	II	E	153	II	A	201
III	E	113	III	A	180	III	B	244
IV	A	123	IV	B	190	IV	C	240
V	B	128	V	C	184	V	D	238
I	D	142	I	E	156	I	A	236
II	E	119	II	A	198	II	B	235
III	A	107	III	B	163	III	C	232
IV	B	115	IV	C	166	IV	D	223
V	C	127	V	D	200	V	E	222
I	E	134	I	A	189	I	B	208
II	A	141	II	B	181	II	C	205
III	B	133	III	C	177	III	D	228
IV	C	138	IV	D	169	IV	E	215
V	D	114	V	E	168	V	A	---
I	A	139	I	B	173	I	C	212
II	B	104	II	C	162	II	D	202
III	C	150	III	D	155	III	E	217
IV	D	109	IV	E	178	IV	A	218
V	E	140	V	A	---	V	B	209
I	B	145	I	C	161	I	D	233
II	C	130	II	D	171	II	E	239
III	D	120	III	E	170	III	A	211
IV	E	129	IV	A	158	IV	B	214
V	A	---	V	B	197	V	C	249
I	C	122	I	D	154	I	E	234
II	D	135	II	E	183	II	A	247
III	E	106	III	A	191	III	B	225
IV	A	105	IV	B	151	IV	C	210
V	B	101	V	C	152	V	D	220

APPENDIX C (continued)

Starting Positions for Irradiation of Animals

		Nos. 1-50			Nos. 51-100		
	Time	Sed.	Forced		Spont.	Forced	
Day	Finished	Box	Pos.	An.	Box	Pos.	An.
		I	B	12	I	C	64
		II	C	39	II	D	59
Sat.	7:00	III	D	15	III	E	87
26	P.M.	IV	E	49	IV	A	57
June		V	A	--	V	B	70
		I	C	17	I	D	56
		II	D	36	II	E	66
	12:00	III	E	22	III	A	74
	Noon	IV	A	37	IV	B	97
		V	B	46	V	C	51
		I	D	29	I	E	91
	3:00	II	E	4	II	A	82
	P.M.	III	A	42	III	B	81
		IV	B	2	IV	C	68
Sun.		V	C	26	V	D	60
27							
June		I	E	50	I	A	62
		II	A	7	II	B	92
	7:00	III	B	31	III	C	95
	P.M.	IV	C	21	IV	D	94
		V	D	28	V	E	78

Nos. 101-150			Nos. 151-200			Nos. 201-250		
Spont.	Control		Spont.	Effect		Sed.	Control	
Box	Pos.	An.	Box	Pos.	An.	Box	Pos.	An.
I	D	121	I	E	185	I	A	204
II	E	146	II	A	192	II	B	207
III	A	116	III	B	199	III	C	241
IV	B	149	IV	C	182	IV	D	245
V	C	102	V	D	165	V	E	224
I	E	111	I	A	174	I	B	227
II	A	143	II	B	160	II	C	213
III	B	125	III	C	196	III	D	243
IV	C	147	IV	D	193	IV	E	226
V	D	144	V	E	157	V	A	---
I	A	108	I	B	186	I	C	203
II	B	110	II	C	164	II	D	206
III	C	137	III	D	176	III	E	219
IV	D	126	IV	E	195	IV	A	229
V	E	117	V	A	---	V	B	248
I	B	136	I	C	172	I	D	231
II	C	132	II	D	179	II	E	216
III	D	103	III	D	159	III	A	221
IV	E	131	IV	A	187	IV	B	250
V	A	---	V	B	175	V	C	242