SLEEP PROFILES OF THE MONKEY AS AFFECTED BY GAMMA-NEUTRON RADIATION

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FOREWORD
(Nontechnical summary)

It has been established that during sleep many body functions demonstrate a predictable activity. This activity is thought to be associated with the type of sleep which is being experienced during the recording of the particular functions. For example, during the early stage of sleep (light sleep) the brain waves show a fast frequency and a low amplitude. As the sleep becomes deeper this activity decreases and the amplitude increases. Accordingly, extensive studies of sleep have been conducted, which indicate that during each successive night, the normal individual will demonstrate a constant sleep pattern or profile.

In this investigation a procedure for categorizing sleep has been applied to monkey data collected before and after a 5000-rad pulse of irradiation. The purpose of this work was to determine if sleep patterns as ascertained through an analysis of the brain waves (electroencephalogram), heart rate, and muscle activity (electromyogram) would be affected by irradiation. The results indicate a change in the amount of time devoted to sleep between preirradiation and postirradiation periods, and a marked alteration in the time distribution among sleep stages. The time spent in the earlier stage of sleep appears to be increased, whereas the time devoted to the deeper stages is decreased.

ABSTRACT

This study indicates that the sleep patterns of the monkey, as determined by the electroencephalogram, heart rate, and electromyogram, are altered following a pulsed dose of 5000 rads of gamma-neutron radiation. The data indicate a change in the total time devoted to sleep; however, the more notable change appears in the time distribution among the sleep stages.

I. INTRODUCTION

Extensive study by previous investigators has established that during sleep the electroencephalogram (EEG), electromyogram (EMG), heart rate, and other body functions exhibit predictable activity. On the basis of this activity sleep can be divided into a number of well defined stages, which the normal subject tends to exhibit in a relatively constant profile.[2,3,6-12]

The purpose of this investigation is to study the preirradiation and postirradiation sleep stages of monkeys through an analysis of the EEG, EMG, and heart rate. In this work gamma-neutron pulses of approximately 5000 rads were employed.

II. MATERIALS AND METHODS

Five monkeys (Macaca mulatta), two male and three female, were employed in this study. The animals were approximately 4 years of age and ranged in weight from 3.6 to 5.7 kg at the time of irradiation (Table I).

Table I. Experimental Animals

Animal #	Age (months)	Weight (kg)	Sex
B-10	50	3.7	female
B-12	48	3.8	female
B-14	48	3.6	female
B-25	48	5.7	male
B-32	55	5.2	male

Each animal was implanted with EEG, ECG (electrocardiogram), and EMG sensing devices at least 2 weeks prior to this experiment.* The EEG apparatus

* Two of the animals were implanted by Dr. H. A. Gorman of Colorado State University and the other animals were implanted at the AFRRI according to the procedures of Carmeci et al.[1]

consisted of five dural electrodes implanted as follows: left and right frontal region; vertex region; and left and right posterior parietal region. Electrodes for recording the ECG were attached to the spine of the right scapula and wings of the right and left ilia. The EMG was obtained from electrodes on the trapezius muscle.

As soon as possible following surgery the subjects were confined to primate restraining chairs and housed in isolation from other animals and normal laboratory sounds. They were fed a standard laboratory diet twice daily (8:00 a.m. and 3:00 p.m.) with water available ad libitum. The diurnal schedule was regulated to a 12-hour light and 12-hour dark cycle.* The female subjects (B-10, B-12, and B-14) in addition to their employment in the sleep experiment were used in other psychophysiological investigations. However, all other tests were suspended at least 2 hours before the collection of sleep data.

During the night, immediately prior to, and for one night following radiation exposure, the EEG, ECG, AND EMG of each animal was recorded. These data were collected continuously for a period of 6 to 8 hours, stored on magnetic tapes, and displayed for analysis on graph paper.

The data were divided into 1-minute epochs and scored using a schema after the work of Dement and Kleitman[3] for humans, which Weitzman[11,12] later applied to the analysis of monkey data. With this schema, the EEG tracings recorded during sleep are divided into five stages based on frequency and amplitude. Stage I represents drowsiness to very light sleep and consists of low amplitude irregular 4 - 7

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* A low level of illumination was maintained with subjects B-10, B-12, and B-14 during the dark period to allow television monitoring.

cycles per second (cps) activity with an occasional burst of 8 - 12 cps activity. This high frequency activity disappears as sleep becomes deeper. Stage II or light sleep consists of a mixture of the lower voltage 4 - 7 cps activity established in Stage I, and random 1 - 3 cps high amplitude activity. Superimposed upon this background activity are low amplitude spindle shaped waves of 12 - 16 cps. Stage III or moderately deep sleep presents an EEG containing less than 50 percent but more than one or two high amplitude 1 - 3 cps waves per 10-second sample. In addition spindle bursts are frequently observed in this stage. Stage IV, or deep sleep, encompasses all records with greater than 50 percent of the high amplitude 1 - 3 cps activity. The final stage, Stage REM (Rapid Eye Movement Sleep) consists of low amplitude fast activity resembling the EEG of wakefulness. In monkeys, occasional 6 cps sawtoothed waves are seen. This stage is accompanied by rapid, conjugate horizontal and vertical eye movements.

A graphic example of the physiological criterion used to classify the awake period and the several sleep stages are presented in Figure 1. The EEG patterns previously discussed are illustrated. It will also be noted that the ECG demonstrates less muscle artifact during the sleep stages and the subjects' heart rate becomes slower during Stages II, III and IV. In addition the EMG demonstrates a reduced muscle tonus during the sleep stages, which is particularly evident during stage REM. The EEG of stage REM is not sufficiently different from the awake EEG to provide a classification criterion. Therefore, REM sleep was determined on the following basis: (1) the EEG must demonstrate the aforementioned wave forms, (2) the heart rate must accelerate over that of preceding sleep stages and, (3) the EMG must

demonstrate a nearly complete loss of tonus by the neck muscles. Further confirmation of this stage was obtained through observation of rapid eye movements via television monitoring under a low level of illumination with Subjects B-10, B-12, and B-14.

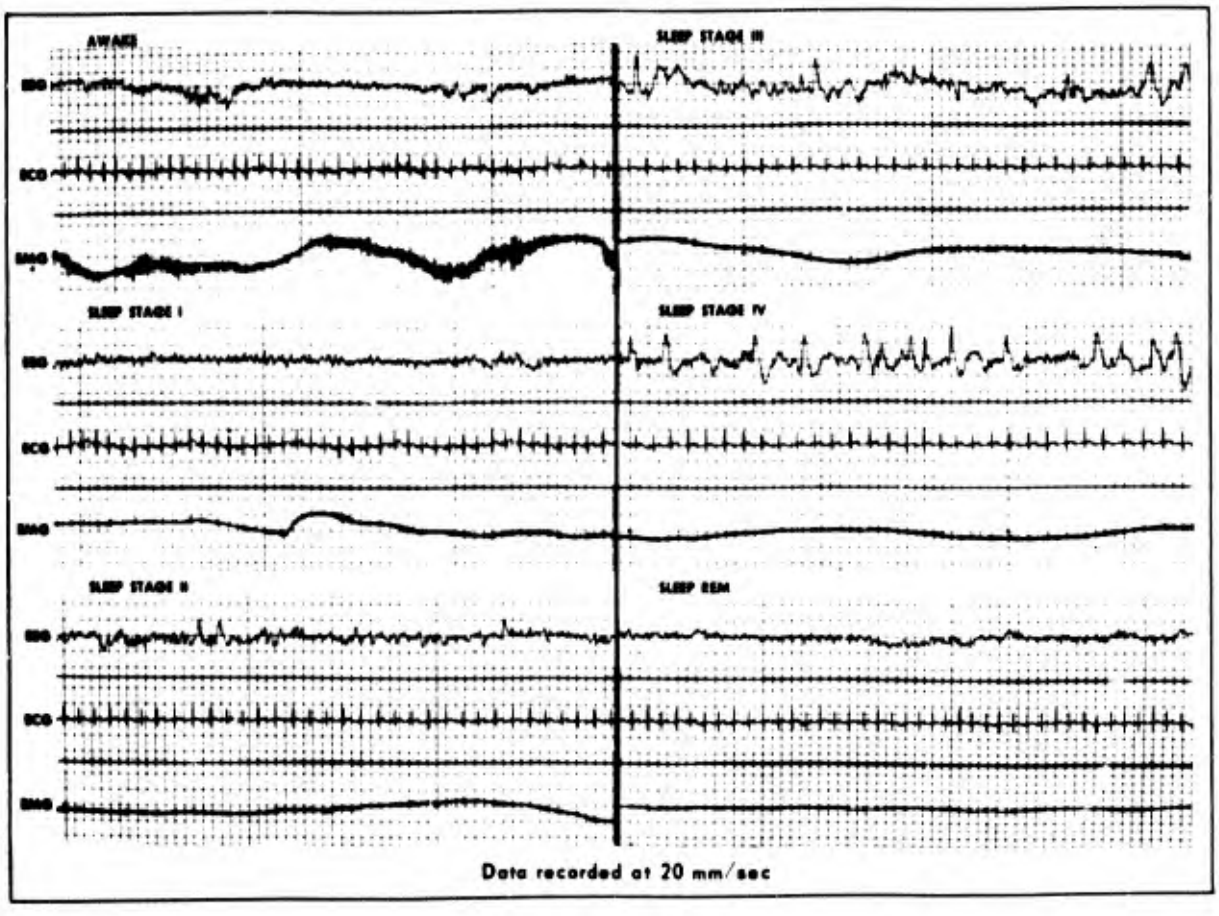

Figure 1. The physiological criterion of awake and sleep periods

In scoring the data, if more than 30 seconds of a 1-minute epoch represented a particular sleep stage, then the entire minute was scored as that stage. If a transition of stages occurred during an observation, and 30 seconds were of one stage and 30 seconds were of another, the minute would be scored as the same stage noted for the preceding minute.

Each animal was transferred from the isolation area to the site of irradiation approximately 2 hours prior to exposure. In the exposure room the subject was placed in a position calculated to produce a pulsed dose of 5000 rads mixed gamma-neutron radiation. Following irradiation the physiological parameters were monitored while the animal remained in isolation.

The radiation source was the AFRRI-TRIGA reactor. For these exposures the reactor was operated in the pulsed mode. The exposure room, typical dosimetry and the radiation field are described in AFRRI Report SR66-3.[4] This report also describes the characteristics of the reactor pulse used in this study.

The subjects were placed at a distance of 150 cm from the animal center line to the reactor core center line. The doses quoted are for a small tissue sample surrounded by air and in which there is charged particle equilibrium. This sample is located at the position to be occupied by the midchest of the animal. About 60 percent of this dose was from gamma rays; the remainder was from neutrons. The dosimetry techniques are described in ICRU Report 10b.[5]

Dosimetry indicated that the animals received between 4500 and 4800 rads. The dose received by each subject is presented in Table II.

Table II. Radiation Exposure

Animal #	Dose in rads ± 10%
B-10	4800
B-12	4800
B-14	4700
B-25	4500
B-32	4500

The dosimetry procedures used in this study are considered accurate to within plus or minus 10 percent. With this uncertainty, the above doses may be rounded off to 5000 rads.

III. RESULTS AND DISCUSSION

A comparison of preirradiation and postirradiation electrophysiological parameters indicates changes in sleep characteristics of monkeys. The sleep profiles of the several animals are presented for both preirradiation and postirradiation periods in Figures 2 through 6. In addition to graphically presenting the radiation effects, the figures reveal the individual variability in the sleep patterns. In the preirradiation periods, all sleep stages described by Weitzman are observed, and the time distributions for the several stages are in general agreement with previously reported data.[11,12]

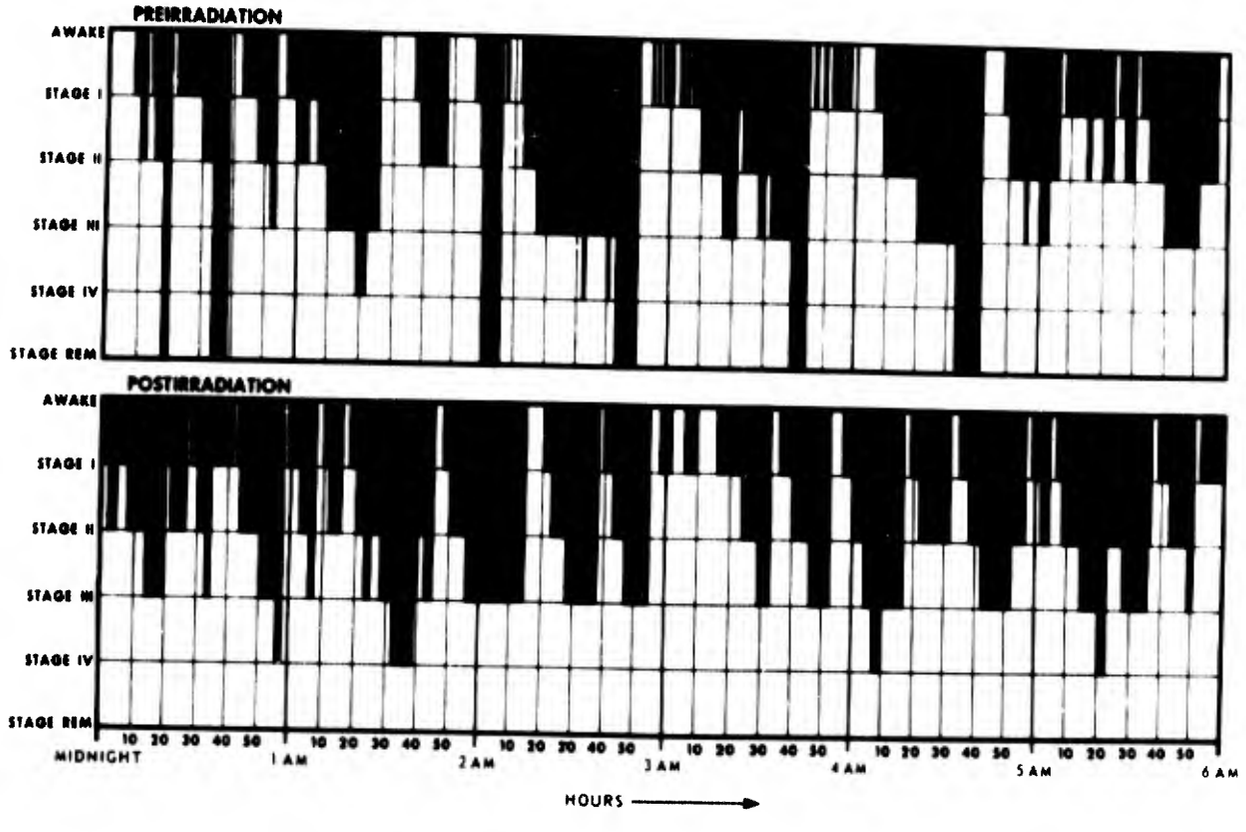

Figure 2. Sleep profile of Subject B-10

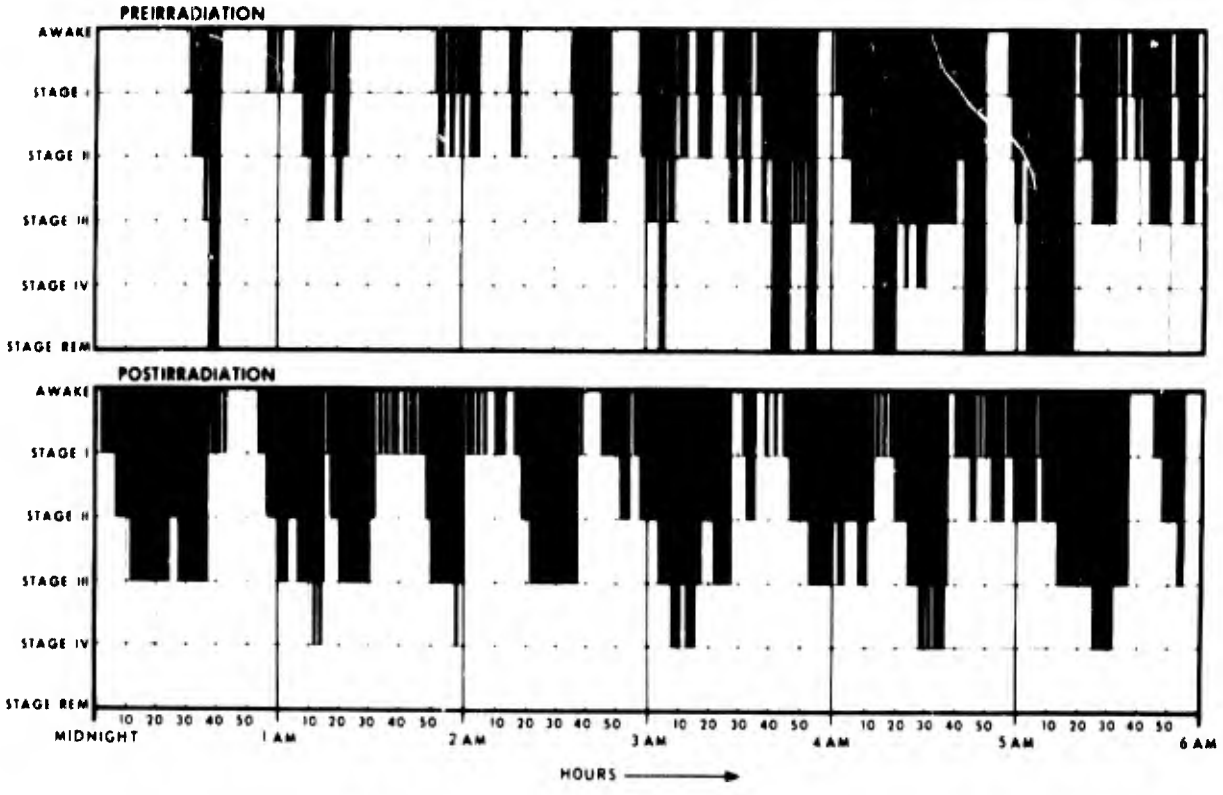

Figure 3. Sleep profile of Subject B-12

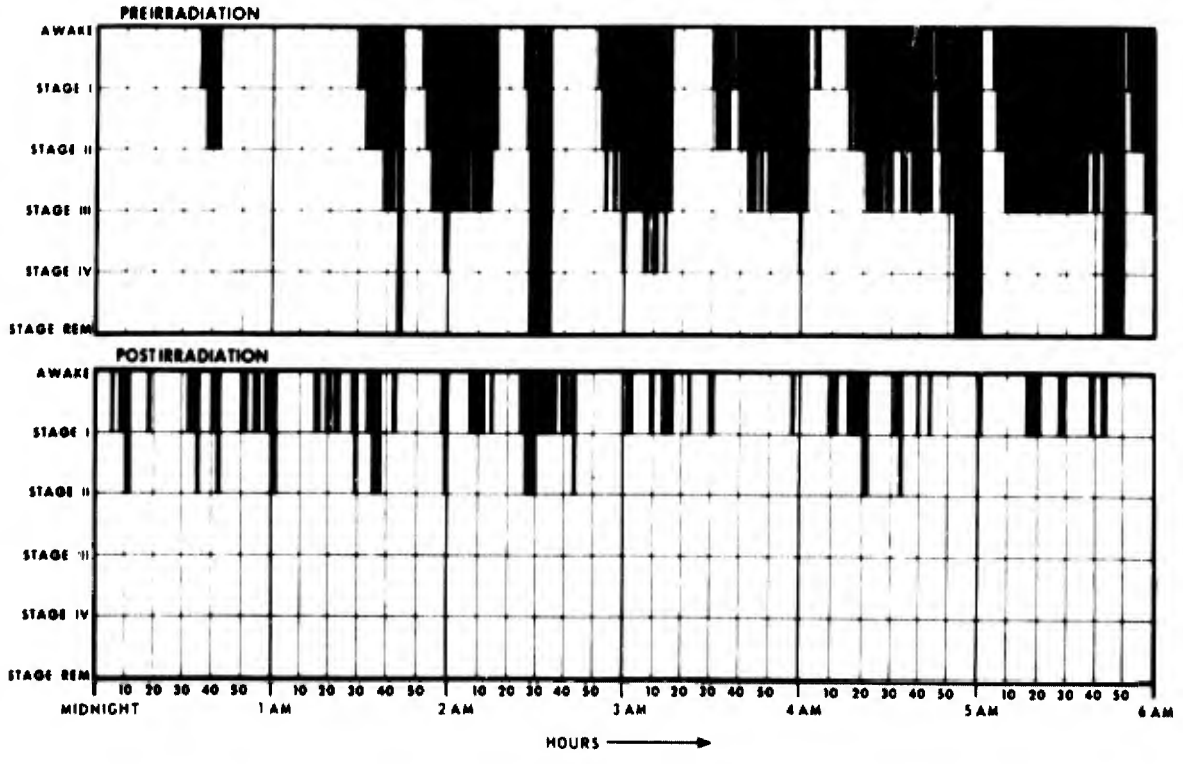

Figure 4. Sleep profile of Subject B-14

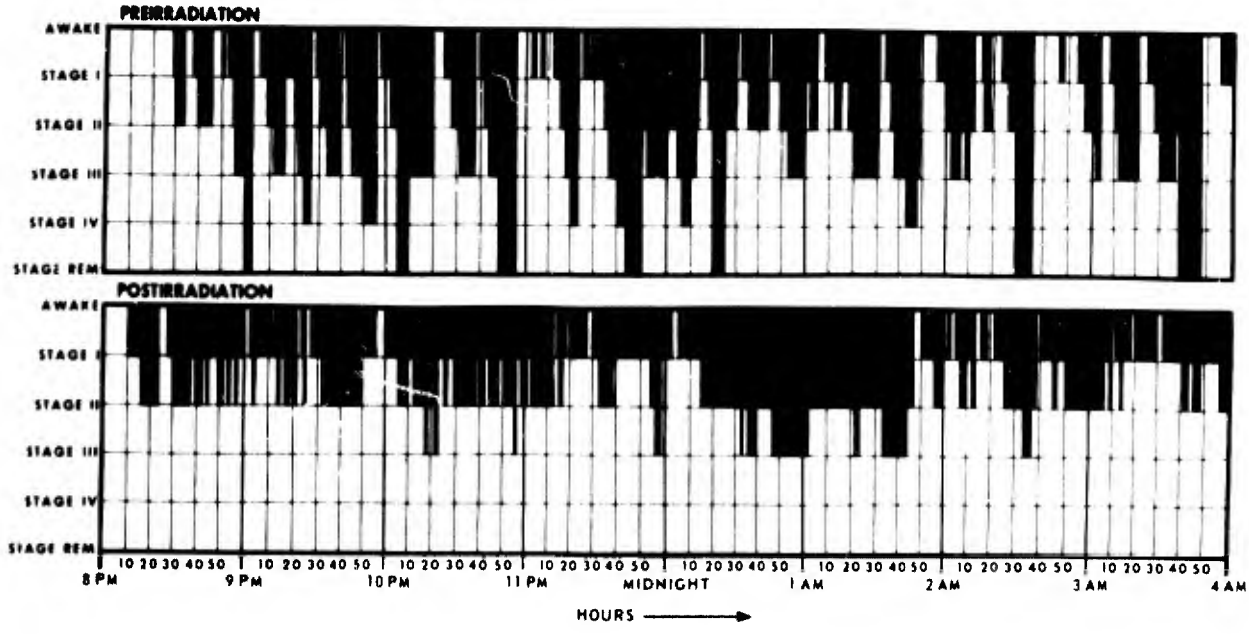

Figure 5. Sleep profile of Subject B-25

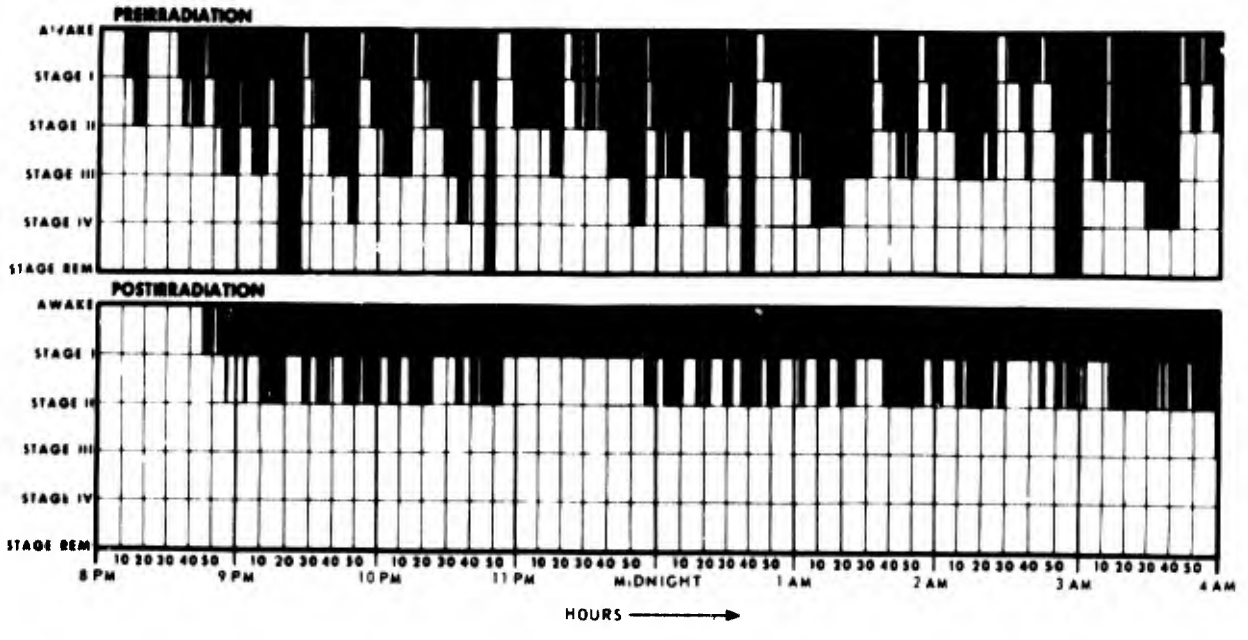

Figure 6. Sleep profile of Subject B-32

Following irradiation, four of the five animals increased their total sleep time while one animal (B-14) devoted 33 percent less time to sleep during this period (Table III). These data also indicate that following irradiation, the time devoted to various sleep stages differs from that seen preirradiation. The following is most obvious in the postirradiation charts: (1) Stages I and II were experienced by all subjects; (2) Stage III patterns were observed in only three of the five subjects; (3) Stage IV was evident for only two of the animals; and (4) Stage REM was not observed in the postirradiation sleep of any animal (Table IV).

The data presented in Tables III and IV indicate a change in the total time devoted to sleep (during the night following irradiation); however, the more notable change appears in the distribution of time between the various sleep stages. The data indicate that the monkeys tended to redistribute their sleep patterns by increasing the

Table III. Time Devoted to Sleep Preirradiation and Postirradiation

MONKEY	OBSERVATION	PREIRRADIATION (MINUTES)	POSTIRRADIATION (MINUTES)	PREIRRADIATION (PERCENT)	POSTIRRADIATION (PERCENT)
#B-10	ASLEEP	269	302	74.7	83.9
	AWAKE	91	58	25.3	16.1
	TOTAL	360	360	100	100
#B-12	ASLEEP	205	287	56.9	79.7
	AWAKE	155	73	43.1	20.3
	TOTAL	360	360	100	100
#B-14	ASLEEP	216	96	60	26.7
	AWAKE	144	264	40	73.3
	TOTAL	360	360	100	100
#B-25	ASLEEP	343	380	71.5	79.2
	AWAKE	137	100	28.5	20.8
	TOTAL	480	480	100	100
#B-32	ASLEEP	392	432	81.7	90.0
	AWAKE	88	48	18.3	10.0
	TOTAL	480	480	100	100

time spent in the early sleep stages and decreasing the time spent in the deeper stages of sleep.

Table IV. Time Distribution by Sleep Stages Preirradiation and Postirradiation

MONKEY	STAGE	PREIRRADIATION (MINUTES)	POSTIRRADIATION (MINUTES)	PREIRRADIATION (PERCENT)	POSTIRRADIATION (PERCENT)
#B-10	I	65	74	24.1	24.5
	II	92	108	34.2	35.8
	III	75	106	27.9	35.1
	IV	5	14	1.9	4.6
	REM	32	0	11.9	0.0
	TOTAL	269	302	100	100
#B-12	I	29	62	14.1	21.6
	II	65	82	31.7	28.6
	III	66	120	32.2	41.8
	IV	3	23	1.5	8.0
	REM	42	0	20.5	0
	TOTAL	205	287	100	100
#B-14	I	18	77	8.3	80.2
	II	58	19	26.9	19.8
	III	105	0	48.6	0.0
	IV	8	0	3.7	0.0
	REM	27	0	12.5	0.0
	TOTAL	216	96	100	100
#B-25	I	77	133	22.4	35.0
	II	99	205	28.8	53.9
	III	102	42	29.7	11.1
	IV	23	0	6.7	0.0
	REM	42	0	12.2	0.0
	TOTAL	343	380	100	100
#B-32	I	62	247	15.8	57.2
	II	121	185	30.9	42.8
	III	130	0	33.2	0.0
	IV	50	0	12.7	0.0
	REM	29	0	7.4	0.0
	TOTAL	392	432	100	100

Changes in heart rate during sleep were observed in all animals (Figure 7). In the preirradiation sleep periods, a progressive decrease in heart rate is depicted as the animals progress through the first four sleep stages with acceleration of the heart rate during the REM stage. This change in cardiac activity is characteristic of

sleep.[6-10] In the postirradiation period, the heart rate during sleep is increased over that observed during the preirradiation studies. In the postexposure period, as the animals progress through the more restricted range of sleep stages, a slight depression in heart rate is observed, but the magnitude and relationship of this depression to that observed preirradiation is considerably different. The postirradiation heart rate for all subjects remains high.

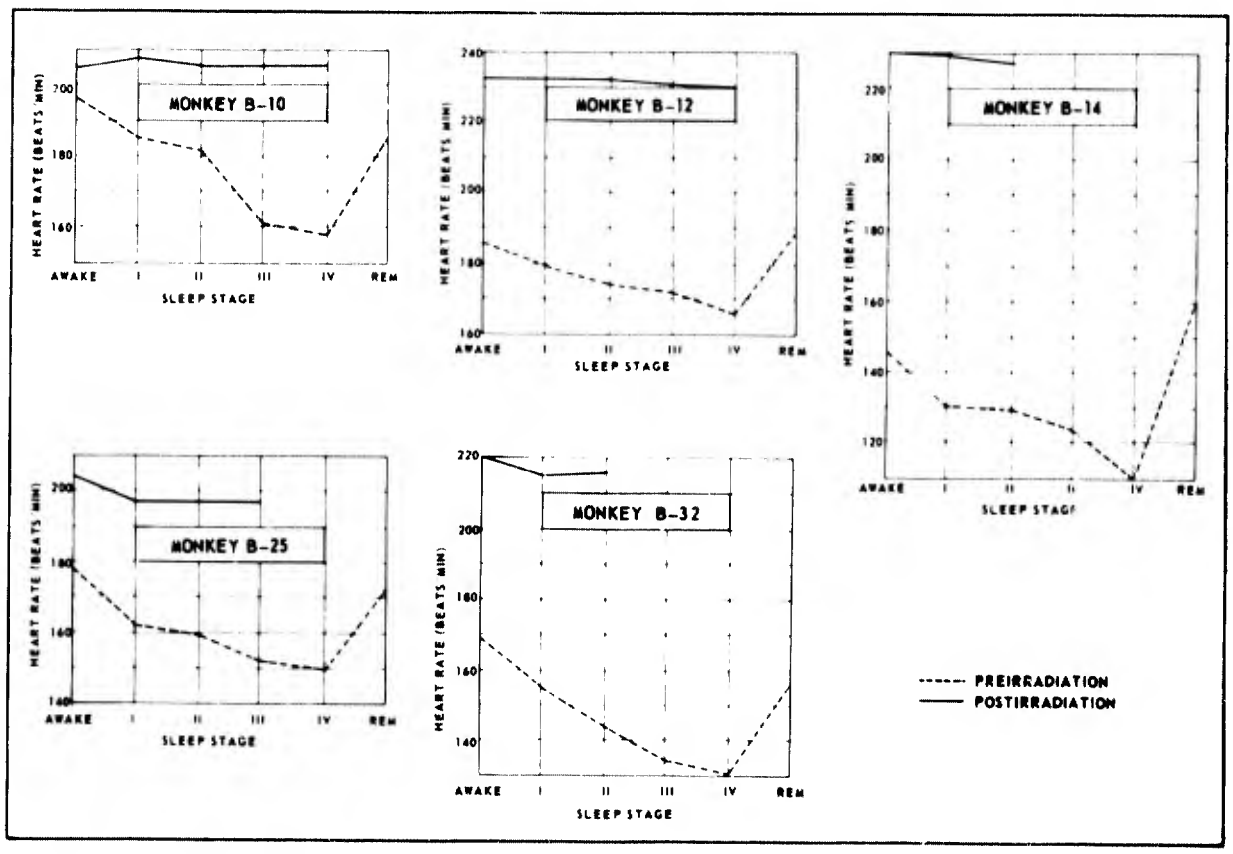

Figure 7. Heart rate changes during sleep preirradiation and postirradiation

IV. CONCLUSION

This study indicates that 5000 rads of mixed gamma-neutron radiation disrupts the electrophysiological sleep patterns of the monkey. The time devoted to sleep (during the night following irradiation) appears to be changed and the time distribution between the several stages of sleep is modified. The data further indicate that heart rate is increased over that observed preirradiation and does not change to the same degree with the stage of sleep.

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13 ABSTRACT

This study indicates that the sleep patterns of the monkey, as determined by the electroencephalogram, heart rate, and electromyogram, are altered following a pulsed dose of 5000 rads of gamma-neutron radiation. The data indicate a change in the total time devoted to sleep; however, the more notable change appears in the time distribution among the sleep stages.

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14 KEY WORDS	LINK A		LINK B		LINK C	
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