RADIATION RESEARCH 69, 500–512 (1977)

Behavior and Mortality of Free-Ranging Raccoons, Snowshoe Hares, and Striped Skunks after Exposure to 300 R γ Radiation

J. R. TESTER, J. W. TERNES,[1] AND D. B. SINIFF

Department of Ecology and Behavioral Biology, University of Minnesota, Minneapolis, Minnesota 55455

TESTER, J. R., TERNES, J. W., AND SINIFF, D. B. Behavior and Mortality of Free-Ranging Raccoons, Snowshoe Hares, and Striped Skunks after Exposure to 300 R γ Radiation. *Radiat. Res.* 69, 500–512 (1977).

Free-ranging raccoons (*Procyon lotor*), snowshoe hares (*Lepus americanus*), and striped skunks (*Mephitis mephitis*) exposed to 300 R cesium-137 radiation were monitored by an automatic radio-tracking system. Five irradiated juvenile raccoons died within 30 days postirradiation, but no controls died. One irradiated and one control snowshoe hare were killed by predators within 30 days after irradiation. No skunks died. No consistent patterns of effects of the irradiation were detected in terms of size or location of home range or in the circadian rhythms.

INTRODUCTION

Attempts to determine the effects of ionizing radiation on the behavior and survival of wild animals living under natural conditions have been hindered by lack of suitable monitoring techniques. This paper reports on studies of free-ranging raccoons, snowshoe hares, and striped skunks given an acute exposure to 300 R γ radiation. All irradiated animals and their controls were monitored prior to and following irradiation by an automatic radio-tracking station (*1*) located in east-central Minnesota on the Cedar Creek Natural History Area.

Radiation effects on survival of similarly sized mammals held in captivity have been reported by Golley *et al.* (*2*), and Markham and Whicker (*3*) reported on the comparative survival of free-ranging and captive pikas (*Ochotana princeps*). O'Farrell *et al.* (*4*) suggested a synergistic effect between radiation insult and environmental stress in free-ranging pocket mice (*Perognathus parvus*), but they did not report on causes of mortality. Few data other than anecdotal observations are available on the effects of radiation on behavior of unrestrained wild animals. Such information is necessary if we wish to predict the possible effects of nuclear catastrophies on the natural environment.

Our hypothesis was that radiation sickness would occur following exposure and that irradiated animals would be active for a shorter time and would move

[1] Present address: Monell Chemical Senses Center, University of Pennsylvania, Philadelphia, Pa. 19104.

ISSN 0033-7587

over a smaller home range. This hypothesis was tested by comparing the activity and movements of irradiated and control animals prior to and following irradiation. Support for this hypothesis was obtained from laboratory and field studies on birds by Wahlstroem (*5*) and Schlumberger and Henschke (*6*) and on mammals by Nash *et al.* (*7*).

METHODS

All of the study animals were captured on the Cedar Creek Natural History Area using various methods such as live traps and drive nets. The first animals were captured in the spring of 1966 and the final irradiation experiments were carried out in 1970. At any given time, the maximum number of irradiated animals of a given species being monitored was six. Captured animals were brought to the laboratory where they were anesthetized with ether, weighed, examined for physical condition, and equipped with a radio transmitter attached in the form of a collar. Transmitters were constructed by the Bio-electronics Laboratory at Cedar Creek to fit individual animals. Immediately following recovery from the anesthesia, animals were released at the point of capture. In all cases, animals to be irradiated and their controls, which were of the same sex and age in 17 out of 26 cases, were monitored for at least 1 month prior to irradiation to provide baseline data on behavior and activity patterns. At certain times, however, the data records were incomplete for portions of the 30-day periods.

Radio-marked animals were monitored by the Cedar Creek Automatic Tracking System, which is capable of recording position and activity data simultaneously for 52 animals, giving data every 45 sec for each animal. The system, which is based on two continuously rotating antennas located on towers 0.5 miles apart, is accurate to $\pm 0.5°$. Portable directional receivers were used to determine the exact location of a den or sleeping site as well as dead animals.

On the day that an animal was to be irradiated, it and, if possible, the control animal were recaptured and brought to the Gamma Irradiation Facility, Department of Chemical Engineering, Minneapolis Campus, where the experimental animal was exposed to a 10,000-Ci cesium-137 source and the control animal was sham irradiated. Animal placement within the irradiation chamber was determined by ferric-ferrous dosimetry and the actual exposure was monitored with a Victoreen rate meter. Control animals were captured for sham irradiation in 13 of the 26 experiments, but were monitored by telemetry in every experiment. The animals were then returned to their points of capture and released. This procedure was normally completed within 4 to 6 hr. The exposure of 300 R given at a rate of 25 R/min, was considered to be sublethal for all three species (*2*, *8*).

Data generated by the automatic tracking system are recorded on 16-mm microfilm. Bearings from the two towers to determine location by triangulation plus the state of activity are determined for each animal from the film record and are recorded on punch cards for input to a computer. Activity can be categorized as motionless, which indicates sleeping or resting, movement at the same location which may result from feeding, grooming, or courtship display, and moving from one location to another. Movement of an animal causes a modulation of the radio signal which is recorded on the film record. Determination of home range size and patterns of activity were made using software programs developed for a CDC 6600 computer (*9*).

RESULTS

Mortality

Mortality of irradiated and control raccoons within 30 days postirradiation is shown in Table I. No controls and no irradiated adults died; however, two of three juvenile males and three of four juvenile females died within 30 days of exposure. All deaths were presumed due to irradiation, as hemorrhaging was the only abnormality observed in postmortem examinations. The two juvenile males died on the 13th and 15th days after exposure; one juvenile female died on the 11th day and two died on the 13th day. Those animals surviving longer than 30 days were presumed to have recovered from radiation effects because they survived for many months and eventually died from causes we have observed in unirradiated raccoons (*10*). Golley *et al.* (*2*) did not find any mortality in captive raccoons given 300 R. They report the LD_{50-30} to be 580 R.

The mortality pattern of snowshoe hares revealed that only one irradiated animal, a juvenile male, died within 30 days after exposure. This hare was killed, probably by a mink (*Mustela vison*), on the fifth night following irradiation. No

TABLE I

Mortality of Control and Irradiated Raccoons, Snowshoe Hares, and Striped Skunks Living under Natural Conditions

Species	*Number irradiated*	*Deaths within 30 days postirradiation*	
		Control	*Irradiated*
Raccoon			
Adult males	2	0	0
Adult females	1	0	0
Juvenile males	3	0	2
Juvenile females	4	0	3
Snowshoe Hare			
Adult males	1	0	0
Adult females	7	1	0[a]
Juvenile males	1	0	1
Juvenile females	1	0	0
Striped Skunk			
Adult males	2	0	0
Adult females	3	0	0
Juvenile males	0	—	—
Juvenile females	1	0	0

[a] Radio contact with one irradiated adult female hare was lost on the 13th day after irradiation.

autopsy could be made. One control was killed by a red fox (*Vulpes vulpes*) 23 days after the date of irradiation. It is possible that a second irradiated animal, an adult female, also died within 30 days. This animal dispersed from her normal home range on Februay 25, 12 days following irradiation, and was tracked for 3.5 miles. We were unable to relocate her on or after February 26 and therefore do not know if her radio quit functioning or if she moved beyond the range of search.

Predation has been the primary cause of observed mortality in snowshoe hares. The irradiated juvenile female was killed by a mammalian predator, probably a fox, in March, approximately five months after irradiation. Two other radio-marked juvenile hares were also killed by fox during this month. Since snowshoe hares have a high rate of mortality due to predation, we have no reason to believe that the death of this irradiated hare was related to irradiation.

The results indicate a lack of long-term effects of irradiation on snowshoe hares. Data from 1966 and 1967 reveal that both irradiated hare 225 (identification number) and control 232 lived through the winter following irradiation on October 11, 1966. Both females had litters in late April 1967 and both conceived again during their postpartum estrous. Presence of embryos was determined by palpating the abdominal region each time the females were captured. In addition, neither animal lost weight. Hare 225 weighed 1470 and 1586 g on October 18, 1966 and January 9, 1967, and hare 232 weighed 1254 and 1537 g on October 18, 1966 and May 23, 1967, respectively.

No mortality was observed in either the irradiated or control striped skunks within 30 days following irradiation. All of the experimental animals were irradiated in September or October 1970 and all survived and emerged from dens in March or April 1971. Since the winter denning period for striped skunks did not begin until late November, the delayed effects of irradiation during "hibernation" which have been reported by Musacchia and Barr (*11*) for 13-lined ground squirrels and by Smith (*12*) for various mammals probably did not influence survival. Although we do not know the LD_{50} of striped skunks, we assume that it is higher than the 300 R dose given. This assumption appears justified on the basis of lethal doses determined for other species of medium-sized wild mammals (*2*).

Home Range

Our hypothesis was that irradiated animals would move shorter distances and for shorter periods of time than would nonirradiated animals, and that this would result in reduced home ranges. This seemed logical in that irradiated animals might be expected to develop radiation sickness and its associated debilitations following exposure. Therefore, we measured the home range of all individuals for periods prior to and following radiation by the minimum area method of Mohr (*13*) and by a method developed by Siniff based on dividing the habitat into squares and summing the area of those squares in which the animal was located (*14*). Both methods utilize radio tracking fixes sampled at 10-min intervals from the microfilm record. The number of fixes on which each

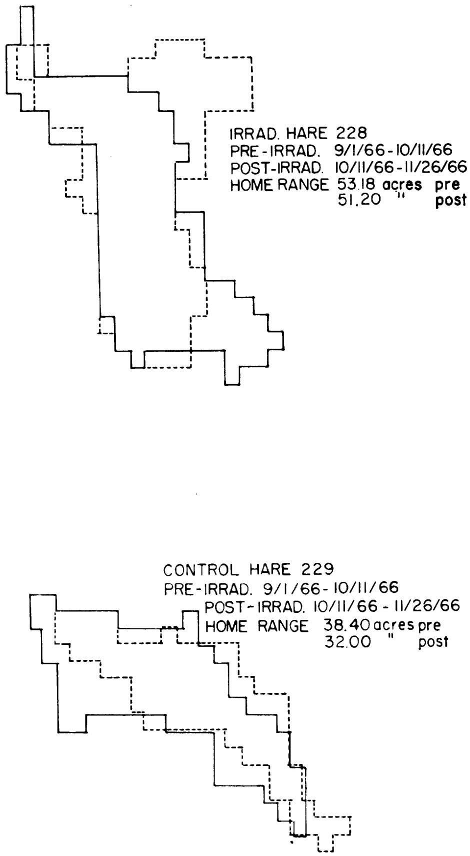

FIG. 1. Home ranges for juvenile hares 228 ♀ (irradiated) and 229 ♂ (control) preirradiation (solid line) and post-irradiation (dash line).

calculation is based varies due to the time when the radio signals were not received because of electrical interference or other limitations of the system.

A typical set of plots of home range as determined by the square summing method is shown in Fig. 1. The size and approximate shape of the home range for hare 228, a juvenile female, are similar for the 41-day period prior to irradiation compared to the 46-day period following irradiation. The home range of the control animal, a juvenile male, showed little change from pre- to postirradiation. Such similarities were revealed frequently when plots of home ranges were examined visually. In some cases postirradiation home ranges were smaller than pre-, as predicted by our hypothesis. In other cases, postirradiation home ranges were larger, contradicting the hypothesis.

An effort was made to determine the possible effects of time on home range size by calculating the home range for certain individuals for varying periods pre- and postirradiation. Data on daily home ranges did not reveal any obvious differences in home range size during the first days postexposure compared to later periods. In addition, daily home ranges were frequently as large or larger following irradiation as prior to irradiation.

Home range sizes for a number of individuals for 30, 10, and 2 days pre- and 2 and 30 days postirradiation are presented in Table II. In general, these data indicate a considerable amount of variation both among and within species before and after irradiation. It is obvious when comparing the 2-, and 10-, or 30-day home range sizes that this value is correlated with the number of days monitored. Tester and Siniff (*15*) considered this problem in detail and concluded that comparisons based on identical time periods are valid.

For some irradiated animals such as hare 248 and skunk 1287, the hypothesis of reduced home range size following irradiation appears supported for the 2-day periods, but data from other individuals such as hare 265 and skunk 1212 show a larger home range for the 2 days postirradiation. In other cases, the home ranges of the controls change in the same way as those of the irradiated animals, thus making evaluation of the radiation effects difficult.

Normal seasonal changes in movement patterns were observed for many of the study animals. As an example, data for irradiated raccoon 620 and its control 604, both adult females, were analyzed by weekly intervals for 4 months. Raccoon 620 was irradiated on October 2, 1968. No obvious change in weekly home range size occurred following irradiation. The home range size of 604 was rather consistent until winter weather in late November curtailed movement. Animal 620, however, demonstrated more variation in home range size from week to week, both before and after irradiation. In spite of this, the overall sizes of home ranges for the entire pre- and postirradiation periods showed little change prior to winter denning (Table III). Differences were observed, however, in the curtailment of movement with the advent of winter weather. Control 604 reduced its home range and appeared to begin winter dormancy about November 27 whereas 620 continued moving over an area of several hundred acres during this same period. This behavior is in marked contrast to that shown by another set of raccoons irradiated December 1, 1966. Both the irradiated and control animals entered the same winter den on December 2 and remained together in this den throughout the winter.

One example of possible radiation effects associated with movements and predation occurred in September 1968. Juvenile male hare 248 was irradiated on September 18, 1968 and was killed, probably by a mink, the night of September 22, 1968. Its home range for two consecutive three-day periods prior to irradiation was 21 and 18 acres compared to 8 acres for the three-day period following irradiation. The reduced postirradiation home range was within the area used previously. It is possible that this animal may have responded to the radiation stress by moving less and that it may have been less wary and therefore more vulnerable to predation. No reduction in home range was observed for its control.

It would be desirable to draw some conclusions about effects of irradiation on home range. However, even for those animals where data are complete, one can readily see that no clear relationship exists for any of the three species. It appears that if changes in movement pattern occur due to the stress of radiation, they are more subtle than our measurements of home range size can demonstrate.

TABLE II

Home Range Sizes as Computed by the "Minimum Area Method" for Irradiated and Control Snowshoe Hares, Raccoons, and Striped Skunks for the Indicated Periods Pre- and Postirradiation

Time period (days)	*Irradiated*			*Control*		
	Animal	*Number of fixes*	*Home range size (acres)*	*Animal*	*Number of fixes*	*Home range size (acres)*
30 pre	Hare	2428	65	229 ♂	1750	32
10 pre	228 ♀	870	40		920	22
2 pre		146	7		165	10
2 post		181	8		196	23
30 post		2296	67		2282	52
10 pre	Hare	411	42	250 ♂	216	53
2 pre	248 ♂	85	28		71	24
2 post		56	2		37	10
30 pre	Hare	721	25	260 ♀	575	99
10 pre	254 ♀	499	8		286	36
2 pre		94	7		102	13
2 post		89	1		111	4
30 post					528	99
10 pre	Hare	435	30	267 ♂	598	9
2 pre	264 ♀	—[a]	—[a]		—[a]	—[a]
2 post		63	3		—[a]	—[a]
30 pre	Hare	555	52	268 ♀	547	14
10 pre	265 ♀	335	22		388	9
2 pre		54	9		121	4
2 post		81	21		200	2
30 post		1647	64		1525	40
10 pre	Hare	289	55	269 ♀	712	61
2 pre	266 ♀	153	52		195	8
2 post		44	11		111	17
10 pre	Hare	1458	112	271 ♂	657	191
2 pre	275 ♂	155	48		146	22
2 post		184	8		184	65
10 pre	Hare	733	111	285 ♀	789	21
2 pre	268 ♀	155	101		155	8
2 post		132	7		163	14
30 pre	Skunk	275	596	1284 ♀	299	61
10 pre	1212 ♂	197	528		206	61
2 pre		65	241		62	54
2 post		150	332		58	1
30 post		318	918		570	22
10 pre	Skunk	592	556	1280 ♀	9	18
2 pre	1275 ♂	61	82		—[a]	—[a]
2 post		142	375		—[a]	—[a]

Table II—*Continued*

Time period (days)	*Irradiated*			*Control*		
	Animal	*Number of fixes*	*Home range size (acres)*	*Animal*	*Number of fixes*	*Home range size (acres)*
10 pre	Skunk	441	229	1280 ♀ [b]	9	18
2 pre	1281 ♀	—[a]	—[a]		—[a]	—[a]
2 post		—[a]	—[a]		—[a]	—[a]
10 pre	Skunk	817	570	1279 ♀	—[a]	—[a]
2 pre	1283 ♀	91	69		—[a]	—[a]
2 post		123	121		—[a]	—[a]
10 pre	Skunk	109	585	1288 ♂	271	247
2 pre	1286 ♀	55	167		—[a]	—[a]
2 post		19	71		26	6
10 pre	Skunk	648	825	1288 ♂	271	247
2 pre	1287 ♀	68	301		—[a]	—[a]
2 post		62	97		26	6
30 pre	Raccoon	1046	6198	654 ♂	1017	7685
10 pre	625 ♂	337	1703		528	1748
2 pre		18	25		125	1189
2 post		200	1234		125	881
30 post		1765	7552		843	9800
10 pre	Raccoon	428	584	664 ♀	271	621
2 pre	660 ♀	—[a]	—[a]		—[a]	—[a]
2 post		42	107		21	40
64 pre	Raccoon	2765	1587	604 ♀	2651	1325
10 pre	620 ♀	563	730		645	744
2 pre		57	229		392	615
2 post		—[a]	—[a]		202	184
72 post		3110	1568		2790	1178
10 pre	Raccoon	338	1239	676 ♂	—[a]	—[a]
2 pre	683 ♂	25	161		—[a]	—[a]
2 post		91	529		—[a]	—[a]
10 pre	Raccoon	578	883	699 ♂	714	889
2 pre	698 ♂	1	—[a]		129	181
2 post		97	196		263	425
10 pre	Raccoon	621	805	6015 ♂	552	676
2 pre	6014 ♀	2	—[a]		—[a]	—[a]
2 post		186	170		129	145

[a] Data on film record incomplete.

[b] Skunk 1280, whose transmitter malfunctioned immediately after release, was to serve as a control for 1275 and 1281.

TABLE III

Home Range in Acres for Irradiated (620) and Control (604) Raccoons for Selected Time Intervals, 1969

Time period	*Days*	*Home range in acres*	
		604 ♀	620 ♀
08-15-0140 to 12-20-0915 (All data)	128	233.2	403.3
08-15-0140 to 10-09-1800 (Preirradiation)	56	311.2	453.0
10-09-1800 to 11-27-1800 (Postirradiation prior to winter denning period)	48	277.9	429.0
11-27-1800 to 12-20-0915 (Postirradiation during winter denning period)	24	37.3	211.0

Activity Rhythms

Patterns of activity and rest for irradiated and control animals were plotted for selected 24-hr periods before and after irradiation. Ratios of total minutes of activity to total minutes of rest per 24 hr for periods when the radio signals enabled us to determine activity are presented in Table IV. This ratio, expressed as percent of time active, is similar to the $\alpha:\rho$ ratio frequently used in analyzing circadian rhythms (*16*). As in the case of home range, data for some irradiated animals fit our hypothesis of reduced activity immediately following irradiation whereas data for other irradiated animals contradict it.

Activity histograms covering periods of from 30 to 60 days before and after irradiation were prepared for selected snowshoe hares and raccoons in an effort

TABLE IV

Ratios of the Total Minutes of Activity to Total Minutes of Rest for Selected Irradiated and Control Snowshoe Hares, Raccoons, and Striped Skunks[a]

Animal	*Percent of time active per 24 hr*			
	Preirradiation		*Postirradiation*	
	1 day	*10 days*	*1 day*	*10 days*
Hare 228-Irradiated ♀	20.7	31.0	30.3	33.7
Hare 229-Control ♂	5.6	22.1	34.4	39.3
Hare 265-Irradiated ♀	57.6	40.6	29.2	42.3
Hare 268-Control ♀	46.1	52.7	46.4	50.8
Raccoon 625-Irradiated ♂	26.6	58.7	71.1	60.8
Raccoon 654-Control ♂	28.5	59.9	75.1	62.5
Skunk 1212-Irradiated ♂	26.9	26.0	68.3	43.9
Skunk 1284-Control ♀	18.5	25.6	19.1	12.7

[a] Calculated per 24 hr for periods when the radio signals enabled us to determine activity, expressed as percent of time active.

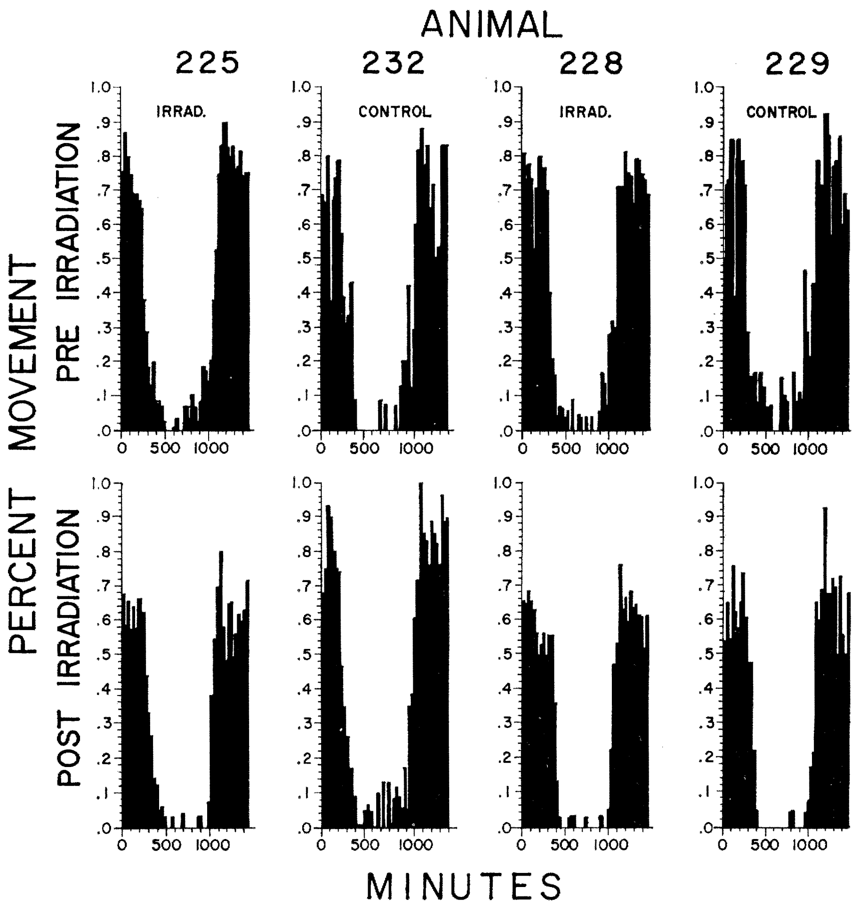

FIG. 2. Activity histograms for snowshoe hares 225 ♀ and 228 ♀ (irradiated) and 232 ♀ and 229 ♂ (controls) pre- and postirradiation.

to detect delayed effects which might become apparent during this time period (Figs. 2 and 3). For each 30-min interval in the abscissa, the ordinate shows the percent of sampling periods, i.e., days in which the animal was moving. In general, the histograms clearly demonstrate the nocturnal activity pattern of both species. Phase relationships or timing of onset and cessation of activity are obvious and are apparently not affected by irradiation in any predictable manner. For example, hare 228 shows a reduction in total activity following irradiation, as hypothesized; however, its control, hare 229, shows a similar reduction (Fig. 2).

Data for two irradiated and two control raccoons (Fig. 3) do not reveal consistent differences in percentage of activity following irradiation. Raccoon 620 was more active during mid-day. It is interesting to note that 660 and 664 maintained their circadian rhythms even though they entered their winter den a few hours after irradiation. Timing of onset and cessation of activity remained in phase with sunset and sunrise, respectively, although the amplitude was obviously decreased.

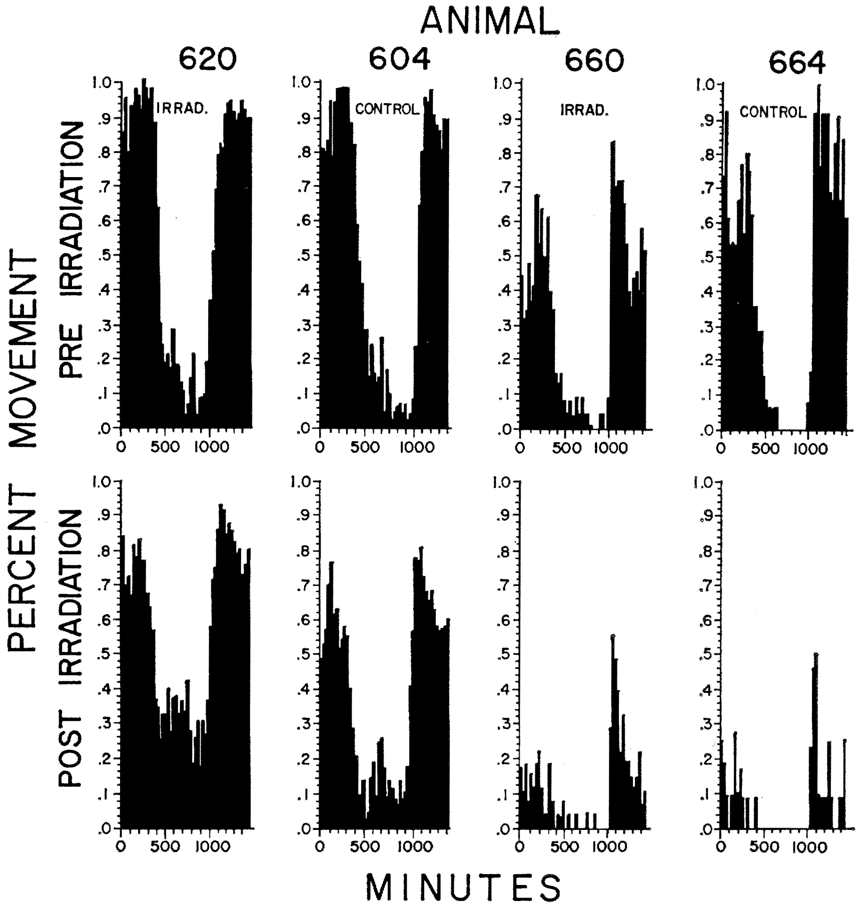

FIG. 3. Activity histograms for female raccoons 620 and 660 (irradiated) and 604 and 664 (controls) pre- and postirradiation.

CONCLUSIONS

The results obtained suggest that it is difficult to detect radiation effects in unconfined, medium-sized mammals following exposure to 300 R, using the behavioral criteria selected. Our studies do suggest, however, that juvenile raccoons living in the wild are more sensitive to exposure to 300 R than are adult raccoons or juvenile or adult snowshoe hares and striped skunks. This sensitivity resulted in death within 30 days for five out of seven juvenile raccoons.

One might expect that the irradiated animals would be more vulnerable to predation due to radiation effects such as ataxia, conjunctivitis, and pelage graying as suggested by Dunaway *et al.*[2] for small mammals. However, only two irradiated animals, both snowshoe hares, were killed by predators in our

[2] P. B. Dunaway, L. L. Lewis, J. D. Story, J. A. Payne, and J. M. Inglis, Radiation effects in the Soricidae, Cricetidae, and Muridae. In *Symposium on Radioecology* (D. J. Nelson and F. C. Evans, Eds.), pp. 173–184. U. S. A. E. C. Report CONF-67-5-3, 1969.

study and we do not believe that the death of one of these was related to irradiation. No mortality occurred in irradiated or control striped skunks.

No consistent patterns of effects of the irradiation were detected in terms of size of home range or in circadian rhythms. Some irradiated animals showed reduced home ranges and less total activity per day following irradiation, but some controls also exhibited these same changes. Furthermore some irradiated and control animals had larger home ranges and were more active following irradiation.

Similar conclusions that ionizing radiation has little or no observable effect on behavior have been reached in other studies on toads (*17*) and on several species of ducks (D. F. McKinney, unpublished data). It is possible, however, that in all of these investigations the irradiation may have caused behavioral effects which were not detected.

ACKNOWLEDGMENTS

This project was supported by the U.S. Atomic Energy Commission, COO-899-66. We wish to thank the staff of the Cedar Creek Natural History Area and the Bio-electronics Laboratory for assistance in the field and for telemetry equipment. R. Huempfner and M. Sunquist trapped and monitored animals and many graduate students helped with field aspects.

RECEIVED: August 18, 1976; REVISED: October 27, 1976

REFERENCES

1. W. W. COCHRAN, D. W. WARNER, J. R. TESTER, and V. B. KUECHLE, Automatic radio-tracking system for monitoring animal movements. *Bioscience* **15**, 98–100 (1965).

2. F. B. GOLLEY, E. L. RAUBER, E. L. MORGAN, and J. H. JENKINS, Effect of acute gamma radiation on wild opossum, gray fox, raccoon and bobcat. *Health Phys.* **11**, 1573–1576 (1965).

3. O. D. MARKHAM and F. W. WHICKER, Radiation $LD50_{(30)}$ of pikas (*Ochotona princeps*) in the natural environment and in captivity. *Am. Midl. Nat.* **84**, 248–252 (1970).

4. T. P. O'FARRELL, J. D. HEDLUND, R. J. OLSON, and R. O. GILBERT, Radiation effects in free-ranging pocket mice, (*Perognathus parvus*) during the breeding season. *Science* **179**, 289–291 (1973).

5. G. WAHLSTROEM, Effects of radiothyroidectomy by 131_I on the self-selected circadian rhythm of rest and activity in the canary. *Acta Soc. Med. Ups.* **74**, 161–178 (1969).

6. H. G. SCHLUMBERGER and U. K. HENSCHKE, Effect of total body x-irradiation on the parakeet. *Proc. Soc. Exp. Biol. Med.* **92**, 261–266 (1956).

7. D. J. NASH, A. NAPOLEON, and L. E. SPRACKLING, Neonatal irradiation and postnatal behavior in mice. *Radiat. Res.* **41**, 594–601 (1970).

8. V. P. BOND and J. S. ROBERTSON, Vertebrate radiobiology (lethal actions and associated effects). *Annu. Rev. Nucl. Sci.* **7**, 135–162 (1957).

9. D. B. SINIFF and J. R. TESTER, Computer analysis of animal movement data obtained by telemetry. *Bioscience* **15**, 104–108 (1965).

10. L. D. MECH, D. M. BARNES, and J. R. TESTER, Seasonal weight changes, mortality, and population structure of raccoons in Minnesota. *J. Mammal.* **49**, 63–73 (1968).

11. X. J. MUSACCHIA and R. E. BARR, Survival of whole-body-irradiated hibernating and active ground squirrels *Citellus tridecemlineatus*. *Radiat. Res.* **33**, 348–356 (1968).

12. D. E. SMITH, The effects of ionizing radiation in hibernation. *Bull. Harv. Univ. Mus. Comp. Zool.* **124**, 493–506 (1960).

13. C. O. MOHR, Table of equivalent populations of North American small mammals. *Am. Midl. Nat.* **37**, 223–249 (1947).

14. O. J. Rongstad and J. R. Tester, Movements and habitat use of white-tailed deer in Minnesota. *J. Wildl. Manage.* **33**, 366–379 (1969).
15. J. R. Tester and D. B. Siniff, Aspects of animal movements and home range data obtained by telemetry. *Trans. North Am. Wildl. Nat. Resour. Conf.* **18**, 379–392 (1965).
16. J. Aschoff, *Circadian Clocks.* North-Holland, Amsterdam, 1965.
17. J. R. Tester, M. A. Ewert, and D. B. Siniff, Effects of ionizing radiation on natural and laboratory populations of Manitoba toads, *Bufo hemiophrys. Radiat. Res.* **44**, 379–389 (1970).