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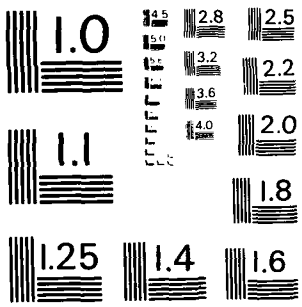

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Report USAFSAM-TR- 83-2

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DELAYED EFFECTS OF PROTON IRRADIATION IN MACACA MULATTA
II. MORTALITY (15-YEAR REPORT)

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January 1983

Interim report for Period 1964 – 1982

Approved for public release; distribution unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
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NOTICES

This interim report was submitted by personnel of the Radiation Biology Branch, Radiation Sciences Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job orders 1921E18C and 775704Y1.

The animals involved in this study were procured, maintained, and used in accordance with the Animal Welfare Act and the "Guide for the Care and Use of Laboratory Animals" prepared by the Institute of Laboratory Animal Resources - National Research Council.

This report has been reviewed and is approved for publication.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: USAFSAM-TR-83-2

2. GOVT ACCESSION NO.: A125 716

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): DELAYED EFFECTS OF PROTON IRRADIATION IN *MACACA MULATTA* II. Mortality (15-year Report)

5. TYPE OF REPORT & PERIOD COVERED: Interim report 1964 - 1982

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s):
Michael G. Yochmowitz, Ph.D.
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8. CONTRACT OR GRANT NUMBER(s):

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
USAF School of Aerospace Medicine (RZB)
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
62202F
1921-E1-8C and 7757-04-Y1

11. CONTROLLING OFFICE NAME AND ADDRESS:
USAF School of Aerospace Medicine (RZB)
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

12. REPORT DATE: January 1983

13. NUMBER OF PAGES: 54

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report):
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

18. SUPPLEMENTARY NOTES:

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
Mortality
Protons
Cosmic radiation
Radiation effects

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

A radiation primate colony of 57 controls and 301 (217 proton) exposed subjects has been followed since 1964. Lifespan of both the exposed and, more specifically, the proton-exposed subjects in the chronic colony was shortened. Energies of 55 MeV and greater decreased life span as did doses in excess of 360 rads. Females were more sensitive to lower doses than males. They died earlier in doses as low as 25-113 rads and in all energies tested except 55 MeV. Survival curve analysis found no difference among the onset of death

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20. ABSTRACT (Continued)

in the 3 highest energies (138, 400, and 2300 Mev); however, its onset was earlier in the 32-MeV exposure and later in the 55-MeV exposure than the total penetrating energies (≥138 MeV). Dose ordering effects were evident. In contrast to the controls, mortality rates began to accelerate at ~8 years in the 360-400-rad group; at ~2 years in the 500-650-rad group and ~1 year in the 800-rad group. The leading causes of death among the proton-exposed animals were primary infections (~30%), endometriosis (25%), and organ degeneration (~17%). Malignant tumors accounted for 18% of the deaths. If endometriosis is included in this group, the mortality from all forms of neoplastic conditions is 43% in the proton-exposed animals.

DELAYED EFFECTS OF PROTON IRRADIATION IN *MACACA MULATTA*

II. MORTALITY (15-YEAR REPORT)

INTRODUCTION

In 1964 the USAF School of Aerospace Medicine (USAFSAM) and the National Aeronautics and Space Administration (NASA) initiated a series of studies on the acute effects of proton irradiation in rhesus monkeys. Subjects received monoenergetic exposures (32, 55, 138, 400, and 2300 MeV) representative of the proton spectrum in space. Acute effects were documented during the 120-day postexposure period. Those animals retained in the colony after this period along with subjects of similar age exposed to X-rays, electrons, and mixed protons became part of a lifetime study of delayed radiation effects. These animals and the nonirradiated controls are referred to as the "Chronic Radiation Colony."

Dalrymple and Lindsay (1) provided the rationale for the selected energies. In brief, the average cross-sectional diameter of this primate is about 10 cm. The 32-MeV proton with a depth of penetration of 1 cm was chosen to give information concerning skin and subcutaneous tissue. These protons did not have sufficient range to reach radiosensitive bone marrow and the gastrointestinal tract. The 55-MeV studies, with a 2.5-cm depth of penetration, permitted exposure to these regions, but approximately 25% of the total body volume was unexposed. The higher energies (≥138 MeV) provided a homogeneous depth dose distribution and increasingly greater production of high LET secondary radiation. The 400-MeV particle is of interest because it approximates the highest energy particle occurring in significant concentrations in the Van Allen belts. The 2300-MeV particle simulated very high energy galactic cosmic particles.

The acute effects have been published (2-6). Chronic postexposure effects and progress reports have also been published. These include: case report of granulocytic leukemia at 3 years (7); 4- and 5-year reports highlighting tumors and cutaneous and subcutaneous effects (8, 9); a 6-year finding of significant body weight decreases (10); a 6-7 year diagnosis of endometriosis (11, 12); a 9-year summary of mortality experience (13); and a 15-year summary of endometriosis findings (14).

This paper will explore the incidence of death, its onset, and its causes in the chronic radiation colony. We will discuss whether life shortening occurred; whether it accelerated the normal aging process by advancing all natural causes, all lethal diseases, or a specific disease. Sex differences will also be addressed.

MATERIALS AND METHODS

Table 1 summarizes exposure dates, test facilities, tissue penetration depth, and dose rate used in the original studies. Dosimetry methods and exposure details have been published (15, 16). Subjects were 2-year-olds as determined by dental exams. They were rotated in the proton beam in galvanized steel-wire-mesh cylinders at 2 rpm. This procedure allowed uniform whole-body exposures.

The Chronic Radiation Colony is maintained in an outdoor facility. Subjects are individually housed in cages protected by exterior closure flaps and heated to a minimum temperature of 55°F (13°C) by thermostatically controlled gas heaters. Animals are fed twice daily with a commercial laboratory primate diet treated with isoniazid. This diet is supplemented with fresh fruit biweekly. Water is available ad lib. Physical exams and tuberculin tests are conducted three times yearly on each subject. Dental hygiene is provided if necessary. Blood samples are taken for hematological and biochemical testing. Routine veterinary care including minor surgery and medications is provided, but heroic life-saving measures are not attempted.

Reported doses are surface doses from both primary and secondary radiation based upon the calculations of Turner et. al (17). Depth doses in 32- and 55-MeV studies were calculated to be 115% and 122% of surface doses, respectively.

RESULTS

Incidence

Table 2 summarizes the colony's mortality experience by energy and dose. The first death in this colony occurred 6 months post exposure in a male subject exposed to 1500-rad 1.6-MeV electrons followed at 7 months by a male subject exposed to 800-rad 55-MeV protons. A 200-rad 400-MeV subject was the first exposed female to die (17 months). In contrast, the first nonirradiated control died 18 months after the study was initiated and was a male. The first control female died at 59 months. (See Appendix A.)

At initiation, the chronic colony consisted of 358 animals: 57 controls (34 males and 23 females) and 301 exposed (173 males and 128 females). Calculated mortality is 24.5% in controls and 48.5% in the exposed. A chi-square test indicates that these incidences are significantly different ($p<.01$). Mortality by sex was 24% in control males, 26% in control females, 43% in all exposed males, and 56% in all exposed females. Chi-square tests found significantly more exposed males than control males ($p<.05$) and more exposed females than control females ($p<.01$) dying as illustrated in the top of Figure 1. Of the 146 deaths in the exposed animals, 105 have occurred in high-energy (32, 55, 138, 400, and 2300 MeV) proton-exposed rhesus monkeys. The initial number of subjects in the high-energy proton-exposed group was 217. Thus the 105 cases represent an incidence of 48.4%. This is significantly different from the control incidence of 24.5% ($p<.01$) by a chi-square test. In these proton-exposed animals, the mortality incidence by sex was 41.1% in males and 58% in females. Similar test procedures found more deaths in those cases than in

TABLE 1. BACKGROUND INFORMATION ON SUBJECTS INCLUDED IN LIFETIME STUDY

Radiation type	Incident energy	Tissue penetration depth	Dose[a] range (rads)	Dose rate (rads/min)	Test facilities	Exposure date
Proton	32 MeV	1 cm	280-560	100	Oak Ridge, Isochronous Cyclotron, TN	Jul 64
Proton	55 MeV	2.5 cm	25-600	12.5[b], 100	Oak Ridge, Isochronous Cyclotron, TN	Apr 65
Proton	138 MeV	Total body	210-650	55	Harvard Synchro-cyclotron Cambridge, Mass.	Jan 65
Proton	400 MeV	Total body	50-600	16	University Chicago Synchro-cyclotron Chicago, Ill.	Mar 65
Proton	2300 MeV	Total body	56-560	25	Brookhaven Cosmotron Upton, N.Y.	Oct 65
Electron	1.6 MeV	2 mm	1000-1500	100	Brooks AFB, TX	May 68
X-ray	2 MeV	Total body	446-716	10.7	Texas Nuclear Corp., Austin, Tex.	Jun 64
Electron	2 MeV	6 mm	900-1500	60	Brooks AFB, Tex.	Nov 69
Proton	5 MeV	0.4 mm	1500-2000	50	Oak Ridge, Isochronous Cyclotron, TN	Jun 67
Proton	Mixed	Variable	300-1200	25 to 30	NASA-SREL Hampton Roads, Va.	Apr 69

[a]Doses cited were measured at the body surface.

[b]Lower dose groups (25-, 50-, and 100-rad groups and one-half of 200-rad group) were exposed at the lower dose rate of 12.5 rads/min with the remaining subjects exposed at a rate of 100 rads/min.

TABLE 2. RATIO OF DEATHS TO SUBJECTS AT RISK

Original Proton Studies
Incident Energy (MeV)

Dose (rads)	32		55		138		400		2300		Totals	
	M	F	M	F	M	F	M	F	M	F	M	F
Controls		0/1	0/6		0/3	2/4	1/5	1/5	2/6	0/1	3/20	3/11
25-113			3/13	4/8			5/12	3/7	1/9	5/8	9/34	12/23
200-280	0/2	2/2	2/8	1/6	2/6	3/3	1/5	6/11	0/5	5/10	5/26	17/32
360-400			5/10	2/4	3/7	2/5	3/8	5/7	3/5	3/5	14/30	12/21
500-650	0/4	1/4	8/10	4/4	3/6	4/5	2/3	2/2	1/2	2/2	14/25	13/17
800			9/9								9/9	
TOTALS	0/6	3/7	27/56	11/22	8/22	11/17	12/33	17/32	7/27	15/26	54/144	57/104

Other Radiation Studies

Dose (rads)	1.6 MeV E		2 MeV X		2 MeV E		5 MeV		Mixed energy		Totals	
	M	F	M	F	M	F	M	F	M	F	M	F
Controls				1/2	1/1	0/3	4/8	2/5	0/5	0/2	5/14	3/12
300									1/6	0/1	1/6	0/1
360-400			0/1								0/1	
446-538			4/5	7/11							4/5	7/11
600-716			7/9	5/6					0/4	1/2	7/13	6/8
900					0/2	1/2			0/3	2/5	0/5	3/7
1000	2/6										2/6	
1200					0/1	0/3			2/4	1/3	2/5	1/6
1500	6/6				1/2	1/2					7/8	1/2
TOTALS	8/12		11/15	13/19	2/6	2/10	4/8	2/5	3/22	4/13	28/63	21/47

their respective control groups (with $p<.10$ and $p<.01$) as shown in the bottom of Figure 1.

Next we examine whether there are any relationships among the various energies and dose groups of Table 2. Figure 2 summarizes the incidence among the various energies for combined groups of males and females as well as males and females individually. When data from both sexes are combined, animals receiving energy levels of 55 MeV and above had significantly higher incidences than the controls. In the males, however, only the 55-MeV energy differed from the control males (see middle panel, Fig. 2); whereas the females had significantly more deaths in the totally penetrating energies of 138 MeV and above (as shown in the bottom panel). In the 55-MeV females, differences were not significant, although the 50% incidence is close to the 54% incidence of the 55-MeV males. This result is a consequence of the smaller female sample sizes. The males appear to be less sensitive to the total penetrating energies. We will discuss this hypothesis further.

Figure 3 gives the incidence among the dose groups for combined males and females as well as each sex individually. In examining both sexes together, doses of 360 rads and above had significantly higher incidences (≥51%) than the controls (25%). This result also holds for the males alone (incidences ≥47% in doses of 360 rads and higher vs 24% in the control males). On the other hand, females receiving doses as low as 25-113 rads had significantly greater incidence (52% vs 26% in control females). Again there is a hint that males are less sensitive to radiation than females. We examine this hypothesis next.

Mortality in both sexes is contrasted by dose and energy in Figure 4. In all doses including controls fewer males died (see upper panel). In particular, in the two lowest dose groupings (25-113 rads and 200-280 rads) significantly more deaths occurred in the females. This difference is less apparent in doses in excess of 360 rads.

The lower panel of Figure 4 gives the energy-sex comparisons. No male deaths were available for a 32-MeV contrast. With the exception of the partially penetrating 55-MeV energy, mortality was greater in the females. Significantly more female deaths occurred in both the 138- and 2300-MeV energies.

Time Course (Onset)

The proportions illustrated in Figures 5-27 are survival curves. They are Kaplan-Meier (18) product limit estimates of the probability that a subject will survive beyond time t. Most figures are divided into 3 panels which contrast the same energy or dose combinations. The first panel gives the contrast for both sexes; the middle panel is for males; and the right panel is for the females. The bottom curves in each panel indicate the group which is dying earlier (faster) since a smaller proportion of this group is expected to live beyond time t. Breslow's statistic (19) is used to report significant differences between survival curves. Only those figures which contain at least one panel with $p<.10$ are given. The remaining panels are provided to show why significance was not achieved in the other cases. This result may occur because sample sizes were too small, mortality exoerience was too erratic, or significance was almost achieved.

Figure 5 illustrates the mortality/survival experience in the entire colony (358 subjects: 301 exposed and 57 controls). The dotted curves were the exposed subjects; the solid lines the controls. Of note is the steady decrease in the exposed subjects' probability of surviving beyond time t in contrast to the controls' sporadic decrease in all 3 panels. For both sexes and the males, the exposure curves were almost uniformly lower than their respective controls and significantly earlier; $p<.01$ in both sexes, and $p=.0677$ in the males. It was not until almost 9 years post exposure that the exposed females were uniformly lower than the control females. Borderline significance ($p=.094$) was obtained between the two female survival curves in the right panel of Figure 5. Figure 6 fixes on the proton-exposed (217 subjects) versus the controls (57 subjects). These survival curves are quite similar to the entire colony's curves in Figure 5. There is a consistent decline in the proton subjects' probability of surviving beyond time t; both sexes and the male proton-exposure curves were almost always uniformly lower than their respective controls; it is only after ~9 years that the females became uniformly lower than the controls. The combined sex group (proton exposed) had significantly shorter life spans ($p=.018$) than did the controls whereas the individual sexes were close to borderline significance ($\alpha=.10$).

Figure 7 contrasts the sexes for the 57 controls, 301 exposed subjects, and 217 proton-exposed subjects. The male control survival curve closely followed the female curve. Statistical significance ($\alpha=.10$) was not detected for the given sample sizes. The second and third panels of Figure 7 indicate significance ($p=.10$) between the sexes. At ~10 years post exposure all the exposed females and the subgroup of proton-exposed females were dying at a faster rate than their respective males.

In the proton studies survival curves can be examined with respect to dose, energy, and sex. Tables 3-5 summarize p-values for these comparisons. Figures 8-21 use the same conventions as before. These figures are given when at least one of its three panels illustrates statistical significance ($p=.10$). The other panels are provided in order to note points of similarity and difference.

Figures 8-10 compare each energy with the controls. At 55 MeV (Fig. 8) the pooled sexes and the males had significantly ($p<.01$) earlier deaths than their respective controls. The consistently earlier deaths in these cases contributed to the highly significant results. It was not until almost 9 years post exposure that the death rate of 55-MeV-females exceeded that of control females. The total penetrating 138-MeV proton group (Fig. 9) had significantly ($p=.10$) earlier deaths in the combined sexes and the females. In these cases, death rates increased at ~2 and ~6 years post exposure. Data from the 400-MeV subjects (Fig. 10) reinforces the finding that uniformly earlier deaths did not appear until 10 years post exposure while significance occurred in only the combined sexes ($p<.10$).

All 32-MeV males are alive. This fact increases the ability to detect higher death rates in comparison with the more penetrating energies. Figure 11 illustrates this group's significant ($p<.05$) difference from the 55-MeV

TABLE 3. PROTON ENERGY COMPARISONS

p-Values Based Upon Breslow's Statistic in Comparing Kaplan-Meier Survival Curves

MeV	Both sexes	Males	Females	Figure
0 vs 32	.8722	.1953	.4288	-
0 vs 55	.0023	.0045	.3358	8
0 vs 138	.0609	.3525	.0973	9
0 vs 400	.0741	.4019	.1729	10
0 vs 2300	.2417	.6101	.1549	-
32 vs 55	.0818	.0363	.9761	11
32 vs 138	.1537	.0784	.5105	12
32 vs 400	.1889	.0903	.8280	13
32 vs 2300	.3180	.2089	.7394	-
55 vs 138	.4396	.1208	.3790	-
55 vs 400	.1717	.0708	.8334	14
55 vs 2300	.0788	.0098	.6803	15
138 vs 400	.7376	.9217	.5184	-
138 vs 2300	.3826	.1913	.5330	-
400 vs 2300	.6478	.2963	.7911	-

TABLE 4. PROTON DOSE COMPARISONS

p-Values Based Upon Breslow's Statistic in Comparing Kaplan-Meier Survival Curves

Dose (rads)	Both sexes	Males	Females	Figure
0 vs 25-113	.5899	.7719	.3622	-
0 vs 200-280	.3339	.6625	.2350	-
0 vs 360-400	.0831	.2091	.2666	16
0 vs 500-650	.0003	.0121	.0203	17
0 vs 800	*	.0001	*	22
25-113 vs 200-280	.6960	.6685	.8714	-
25-113 vs 360-400	.1634	.1062	.8728	-
25-113 vs 500-650	.0009	.0051	.0612	18
25-113 vs 800	*	.0001	*	22
200-280 vs 360-400	.3200	.0673	.8789	19
200-280 vs 500-650	.0036	.0073	.0485	20
200-280 vs 800	*	.0001	*	22
360-400 vs 500-650	.0338	.1732	.1002	21
360-400 vs 800	*	.0001	*	23
500-650 vs 800	*	.0001	*	23

*No females were available for comparison.

TABLE 5. SEX COMPARISONS

p-Values Based Upon Breslow's Statistic in Comparing Kaplan-Meier Survival Curves

Proton Energies	p	Figure
32 MeV (M) vs 32 MeV (F)	.0578	24
55 MeV (M) vs 55 MeV (F)	.2495	-
138 MeV (M) vs 138 MeV (F)	.1014	24
400 MeV (M) vs 400 MeV (F)	.1597	-
2300 MeV (M) vs 2300 MeV (F)	.0091	24

Proton Doses (rads)	p	Figure
25-113 (M) vs 25-113 (F)	.0272	25
200-280 (M) vs 200-280 (F)	.0202	25
360-400 (M) vs 360-400 (F)	.4094	-
500-650 (M) vs 500-650 (F)	.4381	-

males; also the difference in the pooled sexes where the 55-MeV death rate exceeded the 32-MeV death rate after 4 years. Figures 12 and 13 indicate higher death rates in 138- and 400-MeV males ($p<.10$) than in the 32-MeV males. The suggestion that increasingly higher energies will have greater death rates is not supported. Males exposed to the partially penetrating 55-MeV protons have a higher death rate ($p<.10$) than the 400-MeV males (Fig. 14) and the 2300-MeV males ($p<.01$; Fig. 15); the death rate among the 55-MeV pooled sexes was also greater ($p<.10$) than the combined 2300-MeV group (Fig. 15).

What is not significant may be as important as what is. In this light we note (c.f. Table 3) that no differences could be detected among the survival curves of the 3 total penetrating energies.

In the proton studies, a dose threshold is observed in the vicinity of 360-400 rads. In Table 4 this dose range is the lowest where a survival curve was different from that of the controls, $p=.0831$ (c.f. Fig. 16, left panel). The two greater dose classes were very significant; i.e., for 500-650 rads, $p<.01$ in the combined sexes and $p<.025$ in the individual sexes (Fig. 17); while at 800 rads, $p<.01$ in the males (c.f. Fig. 22, left panel). Mortality acceleration began at ~8 years in the 360-400-rad group, ~2 years in the 500-650-rad group, and ~1 year in the 800-rad group.

The separation in survival curves between the lowest dose range tested, 25-113 rads, and the two highest was also very significant. Figure 18 illustrates the difference with the 500-650-rad group. For combined sexes and males, $p<.01$; for females, $p<.10$. At 800 rads (Fig. 22, middle panel), $p<.01$ for the male contrast. Mortality rates greater than in the 25-113-rad group were evident at ~2 years for 500-650 rads, and ~1 year for 800 rads.

The difference between 200-280 rads and 360-400 rads in Figure 19 continues to suggest a dose ordering effect since the highest dose had a consistently higher mortality rate in the combined sexes approximately 12 years post exposure and a significantly greater rate than the males, $p<.10$. This result is reinforced in Figure 20 where 500-650-rad pooled sexes and males have a significantly smaller probability of survival ($p<.01$) than their 200-280-rad counterparts as did the females with $p<.05$. This fact is also the case when comparing 200-280-rad and 800-rad males as in the right panel of Figure 22.

The pooled sex comparisons between 360-400 rads and 500-650 rads was significant ($p<.05$) in Figure 21, as was the male comparison in Figure 23 ($p<.01$). Both of these figures illustrate that at higher doses, animals began dying earlier and in greater numbers.

Figure 24 indicates that females expired earlier and faster than males at 32, 138, and 2300 MeV. The same result held for the lowest doses tested (25-113 rads and 200-280 rads), as shown in Figure 25.

Contrasting the partially penetrating 32- and 55-MeV energies with the total penetrating 138-, 400-, and 2300-MeV energies found earlier deaths among the 32- and 55-MeV males ($p<.05$; Fig. 26). Our final survival curve comparison in Figure 27 illustrates that at the higher energies females started to die earlier than their male counterparts at ~6 years post exposure ($p<.01$).

Analysis of Probable Causes of Death

Pathology reports were reviewed by experienced veterinarians. For each animal that died, a probable cause was assigned from one of the following categories:

1. primary infectious process including parasitism
2. specific organ system degeneration
3. endocrine disorders
4. tumors of bone, skin, muscle, and blood
5. tumors of nervous tissue
6. tumors of viscera
7. endometriosis
8. bloat (acute gastric dilatation)
9. unknown

In some cases subjects had several disorders which contributed to their demise. In these instances, reviewing officials were asked to identify the single most probable cause of death. This procedure may lead to an undercount in the above 9 categories. For example, Wood et al. (14) report 38 cases of endometriosis among the proton exposed; while only 26 cases of endometriosis were classified as a cause of death among the same group of subjects.

Given the possible undercounts, Table 6 summarizes these findings by dose and energy for the original proton studies and all the controls. Table 7 provides this information for the remaining studies in the Chronic Radiation Colony.

Figure 28 illustrates the probable cause of death as a percentage of the total deaths for the proton-exposed subjects. The leading causes in this group were primary infections (30%) followed by endometriosis (25%) and organ degeneration (17%). Examination of the colony's remaining 41 deaths among electron, x-ray, and mixed proton studies lead to a remarkable similarity with the proton exposed. Here, infections accounted for 24% of the 41 deaths; organ degeneration 20%, and endometriosis 24%. In both the proton-exposed and the other studies tumors of bone, skin, muscle, and blood explained approximately 10% of the deaths.

DISCUSSION AND CONCLUSIONS

The original experiments were acute studies. They were done with subjects irradiated at the same age and cannot delve into relationship between the effects produced and the age of the subjects. Furthermore, they were not

TABLE 6. FREQUENCY OF DEATH BY CAUSE*

Original Proton Studies

	Incident Energy (MeV)									
	32		55		138		400		2300	
Dose(rads)	M	F	M	F	M	F	M	F	M	F
25-113			2(1) 1(2)	1(2) 2(7) 1(9)			2(1) 1(4) 1(8) 1(9)	1(1) 2(7)	1(1)	1(1) 3(7) 1(9)
200-280		1(1) 1(7)	1(4) 1(9)	1(1)	1(1) 1(6)	1(2) 2(7)	1(1)	2(2) 3(7) 1(8)		2(1) 1(3) 2(7)
360-400			3(1) 1(2) 1(5)	1(1) 1(7)	2(1) 1(4)	1(1) 1(7)	1(1) 2(4)	5(7)	2(2) 1(4)	3(7)
500-650		1(7)	2(2) 2(4) 3(5) 1(8)	2(1) 1(2) 1(5)	2(1) 1(4)	3(2) 1(9)	1(1) 1(2)	1(1) 1(1)	1(1)	1(1) 1(9)
800			3(1) 3(2) 3(5)							

ALL CONTROLS

	M	F
0 rads	3(1) 3(2) 2(9)	2(1) 1(2) 1(7) 2(8)

*Causes are in ( ) and are coded as:

1 = infections
2 = organ degenerations
3 = endocrine disorders
4 = bone, skin, muscle, and blood tumors
5 = nerve tumors
6 = viscera tumors
7 = endometriosis
8 = bloat (acute gastric dilatation)
9 = unknown

TABLE 7. CAUSES OF DEATH IN OTHER RADIATION STUDIES*

Study	Sex M	Sex F
1.6 MeV, 1000 rads	1(1) 1(8)	
1.6 MeV, 1500 rads	2(2) 2(4) 1(6) 1(8)	
2 MeV X, 446-530 rads	1(1) 1(2) 1(6) 1(8)	1(1) 1(4) 1(8) 4(7)
2 MeV X, 600-716 rads	3(1) 2(2) 2(6)	2(1) 3(7)
2 MeV E, 900 rads		1(7)
2 MeV E, 1500 rads	1(1)	1(2)
Mixed Energy 300 rads	1(8)	
Mixed Energy 600-716 rads		2(7)
Mixed Energy 900 rads		1(2)
Mixed Energy 1200 rads	1(4) 1(1)	1(2)

*Causes are in ( ) and are coded as:

1 = infections
2 = organ degenerations
3 = endocrine disorders
4 = bone, skin, muscle, and blood tumors
5 = nerve tumors
6 = viscera tumors
7 = endometriosis
8 = bloat (acute gastric dilatation)
9 = unknown

designed to investigate the lifetime effects of radiation on survivors. As a result, many of the experimental combinations contain no data or sparse amounts of data, making a detailed analysis difficult. Nevertheless, it was possible to support several medically relevant conclusions with valid statistical inferences. When all proton-exposed animals were considered as a group, the minimum dose to produce significant life shortening fell between 360 and 400 rads. When only females were considered, the significant life shortening could be demonstrated at doses between 25 and 113 rads. Increased mortality in the females was due almost entirely to the incidence of fatal cases of endometriosis. These findings support the conclusions made in a separate report on endometriosis that the radiosensitivity of the endometrium may be a limiting factor in determining maximum permissible doses for females in extended space operations. The report on endometriosis also demonstrated that total-body penetrating radiations, both proton and x-rays, were more effective in promoting endometriosis than nonpenetrating radiations. It is not surprising; therefore, that the mortality rate in females is significantly greater than in the males in the higher energy groups (≥138 MeV). This sex difference became apparent after a latent period of approximately 10 years.

Mortality rates in both the proton and other radiation type groups were greater than in the controls. For proton-exposed animals, this effect was observed only in those energies of 55 MeV and above where tissue penetration depths were 2.5 cm. Apparently, the population of cells irradiated by 32-MeV particle in nonfatal acute exposures was not critical to the long-term survival rate in our subjects. Here tissue penetration depths were approximately 1 cm.

Besides an increase in mortality over the controls, it has been shown that deaths occurred earlier in both the 301 exposed and the 217 proton subset. In comparing time of death, no difference could be found among the 3 totally penetrating proton energies (138, 400, and 2300 MeV). However, the time of death in the 32-MeV exposure was later and in the 55-MeV exposure earlier than these energies. Thus, there is little evidence that increasingly higher energies will have earlier death. In comparing time of death with respect to the proton dose groups, no differences were detected below 360 rads. Above this threshold, increasing doses were associated with earlier deaths. Mortality acceleration began after ~8 years in the 360-400-rad group, ~2 years in the 500-650-rad group, and ~1 year in the 800-rad group. It has also been demonstrated that females died earlier than their male counterparts in 32-, 138-, and 2300-MeV energies and in the 25-113-rad and 200-280-rad dose groupings.

Primary infections and parasitism were the leading cause of death in the colony, resulting in approximately one-third of the deaths in both the irradiated and control animals. The most striking difference in cause of death was the 18% rate of malignant tumor-related deaths in the proton-exposed animals. If endometriosis is also considered in this group, the mortality from all forms of neoplastic conditions is 43% in the proton-irradiated animals compared with 7% (1/14) in control subjects. The number of deaths in the controls was not sufficient to permit any comparison of deaths due to other causes.

Comfort (20) defines "precocious aging" if it ..." (i) caused the force of mortality to rise more rapidly in affected than in control animals; (ii) it brought forward the age of onset of diseases which affect the control, but did not greatly alter the sequence or the incidence of causes of death; (iii) it made any characteristic feature of the aging syndrome in that species... appear at a proportionately lower age." The anticipated lifespan for the *Macaca mulatta* is 30+ years (21). At the 15-year point we have identified "semi" precocious aging. Death rates are higher in the exposed than in the controls. Diseases which affect the controls are occurring earlier. However, sufficient time has not yet elapsed to evaluate the characteristic aging syndrome in the controls.

In summary, females appeared to be more sensitive to the life-shortening effects of proton irradiation than males, with a threshold dose occurring in the 25-113-rad range compared with a 360-400-rad threshold dose for all irradiated animals. The reason for the difference in mortality between irradiated and nonirradiated animals was the high incidence of deaths due to radiation-induced neoplastic change including malignant tumors and endometriosis. The death rate in all irradiated animals became significantly higher than in the control animals ~5 years post irradiation. (Here, significance is identified as the first time an exposure probability of surviving beyond time t was less than the one-sided 95% confidence interval for the control's probability of surviving beyond time t.)

ACKNOWLEDGMENTS

We wish to thank Mr. Ted Campbell, Mr. David Hughes, Sgt Chris Piland, and A1C Jim Dlugokinski for managing this data base and assisting in this summarization.

REFERENCES

1. Dalrymple, G. V., and I. R. Lindsay. Protons and space travel--an introduction. Radiat Res 28:365-371 (1966).

2. Dalrymple, G. V., I. R. Lindsay, J. J. Ghidoni, J. C. Mitchell, and I. L. Morgan. Some effects of whole-body 32-MeV proton irradiations on primates. Radiat Res 28:406-433 (1966).

3. Lindsay, I. R., G. V. Dalrymple, J. J. Ghidoni, J. C. Mitchell, and I. L. Morgan. Some effects of 55-MeV protons and primates. Radiat Res 28: 446-464 (1966).

4. Dalrymple, G. V., I. R. Lindsay, J. J. Ghidoni, J. D. Hall, J. C. Mitchell, H. I. Kundel, and I. L. Morgan. Some effects of 138 MeV protons on primates. Radiat Res 28:471-488 (1966).

5. Dalrymple, G. V., I. R. Lindsay, J. J. Ghidoni, J. C. Mitchell, and I. L. Morgan. Some effects of 400-MeV protons on primates. Radiat Res 28: 507-528 (1966).

6. Lindsay, I.R., and G. V. Dalrymple. Acute somatic effects in primates of protons to 400 MeV. Radiat Res Suppl. 7:330-335 (1967).

7. Siegal, A.M., H. W. Casey, R. W. Bowman, and J. E. Traynor. Leukemia in a rhesus monkey (Macaca mulatta) following exposure to whole-body proton irradiation. Blood 32(6):989-996 (1968).

8. Casey, H. W., P. S. Coogan, and J. E. Traynor. Late effects of 32 MeV proton irradiation in primates. Radiat Res 39:634-642 (1969).

9. Traynor, J. E., and H. W. Casey. Five-year follow-up of primates exposed to 55 MeV Protons. Radiat Res 47:143-148 (1971).

10. Kirk, J. H. Body weight decreases in some proton exposed primates. Space Life Sciences 3:271-277 (1971).

11. Mackenzie, W. F., G. A. Splitter, and M. G. Valerio. Endometriosis in primates. Proceedings of the Third Conference on Experimental Medicine and Surgery of Primates, Lyon, 1972 (E. E. Goldsmith and J. Moor Janowski, Eds). Medical Primatology, pp. 288-297, 1972.

12. Splitter, G. A., J. H. Kirk, W. F. Mackenzie, and C. A. Rawlings. Endometriosis in four irradiated rhesus monkeys. Vet Pathol 9:249-267 (1972).

13. Krupp, J. H. Nine-year mortality experience in proton-exposed Macaca mulatta. Radiat Res 67:244-251 (1976).

14. Wood, D. H., M. G. Yochmowitz, Y. L. Salmon, R. A. Boster, and R. L. Eason. Proton irradiation and endometriosis. (to appear in Aviat. Space and Environmental Medicine).

15. Mitchell, J. C., G. V. Dalrymple, G. W. Williams, J. D. Hall, and I. L. Morgan. Proton depth-dose dosimetry. Radiat Res 28:390-405 (1966).

16. Williams, G. H., J. D. Hall, and I. L. Morgan. Whole-body irradiation of primates with protons of energies to 400 MeV. Radiat Res 28:372-389 (1966).

17. Turner, J. E., C. D. Zerby, R. L. Woodyard, H. A. Wright, W. E. Kinney, W. S. Synder, and J. Neufeld. Calculation of radiation dose from protons to 400 MeV. Health Physics 10:783-808 (1964).

18. Kaplan, E. L., and P. Meier. Non-parametric estimation from incomplete observations. J Am Statist Assoc 53(1):457-482 (1958).

19. Breslow, N. A generalized Kruskal-Wallis test for comparing K samples subject to unequal patterns of censorship. Biometrika 57:579-594 (1970).

20. Comfort, A. Natural aging and the effects of radiation. Radiation Res Supp. 1:216-234 (1959).

21. Van Wagenen, G. Vital statistics from a breeding colony. J Med Primatol 1:3-28 (1972).

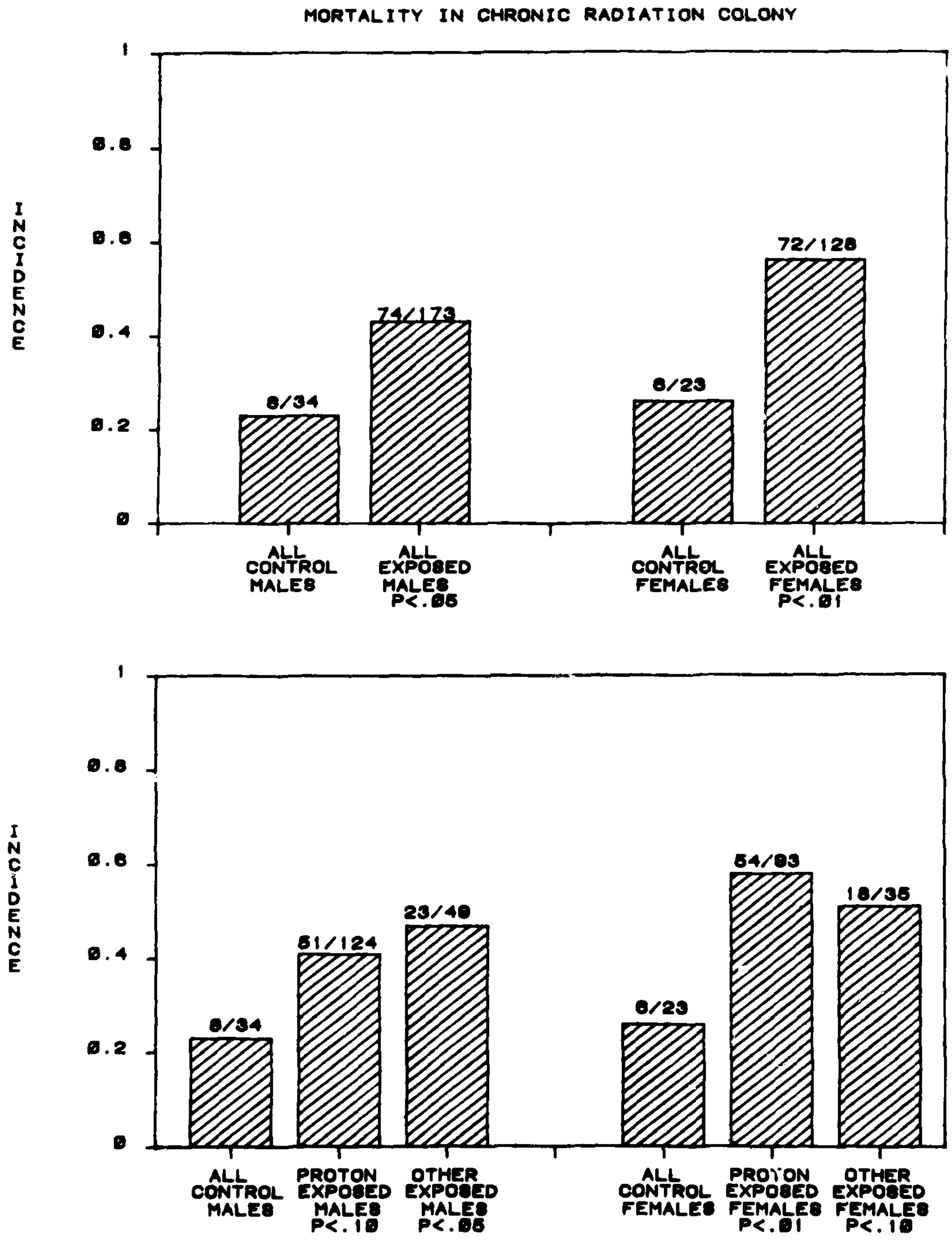


Figure 1. Mortality among 57 controls, 301 exposed, and 217 proton-exposed subjects. (Levels of significance determined by a chi-square test.)

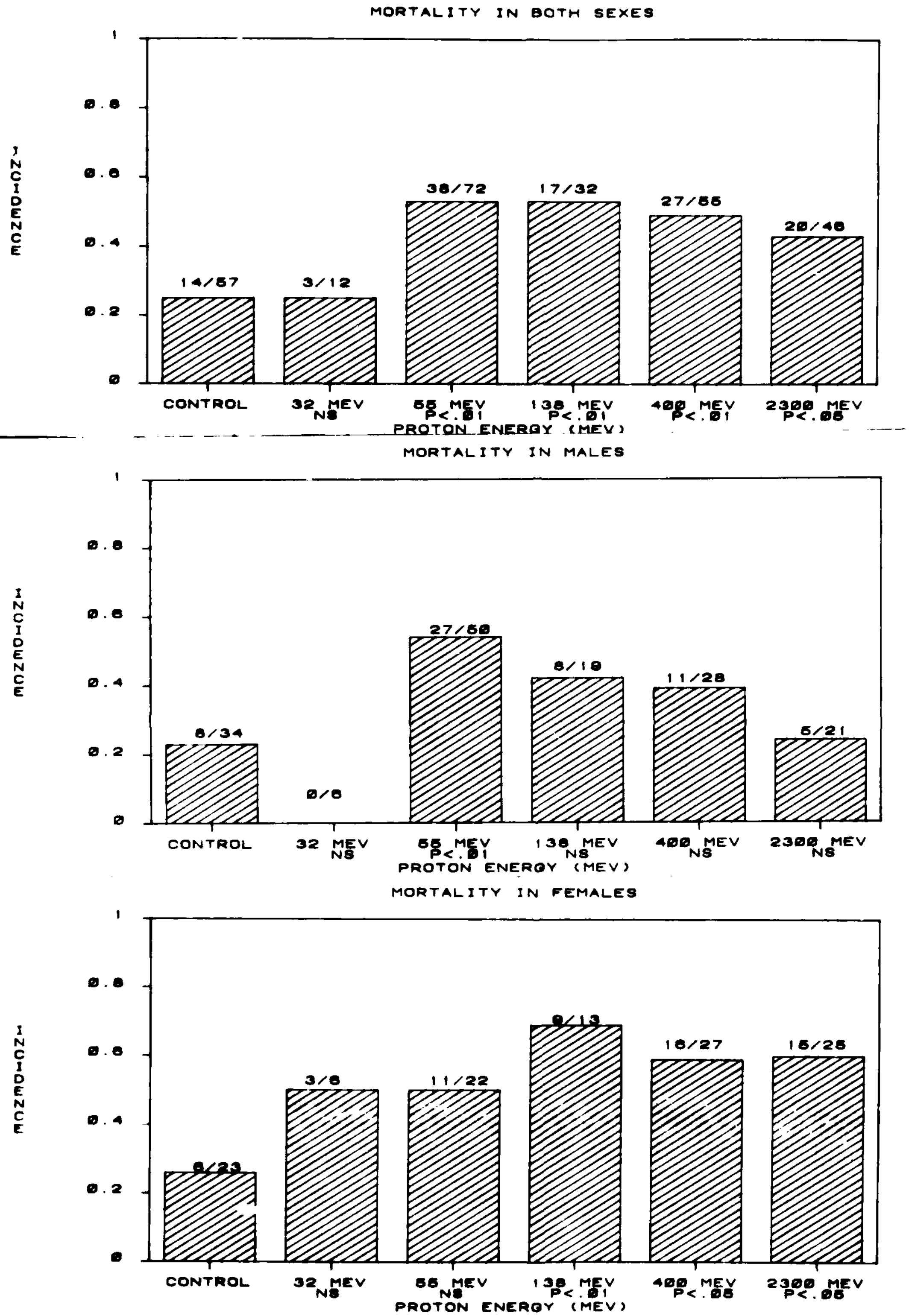


Figure 2. Mortality (by sex and energy) among 217 proton-exposed subjects. (Levels of significance determined by a chi-square test.)

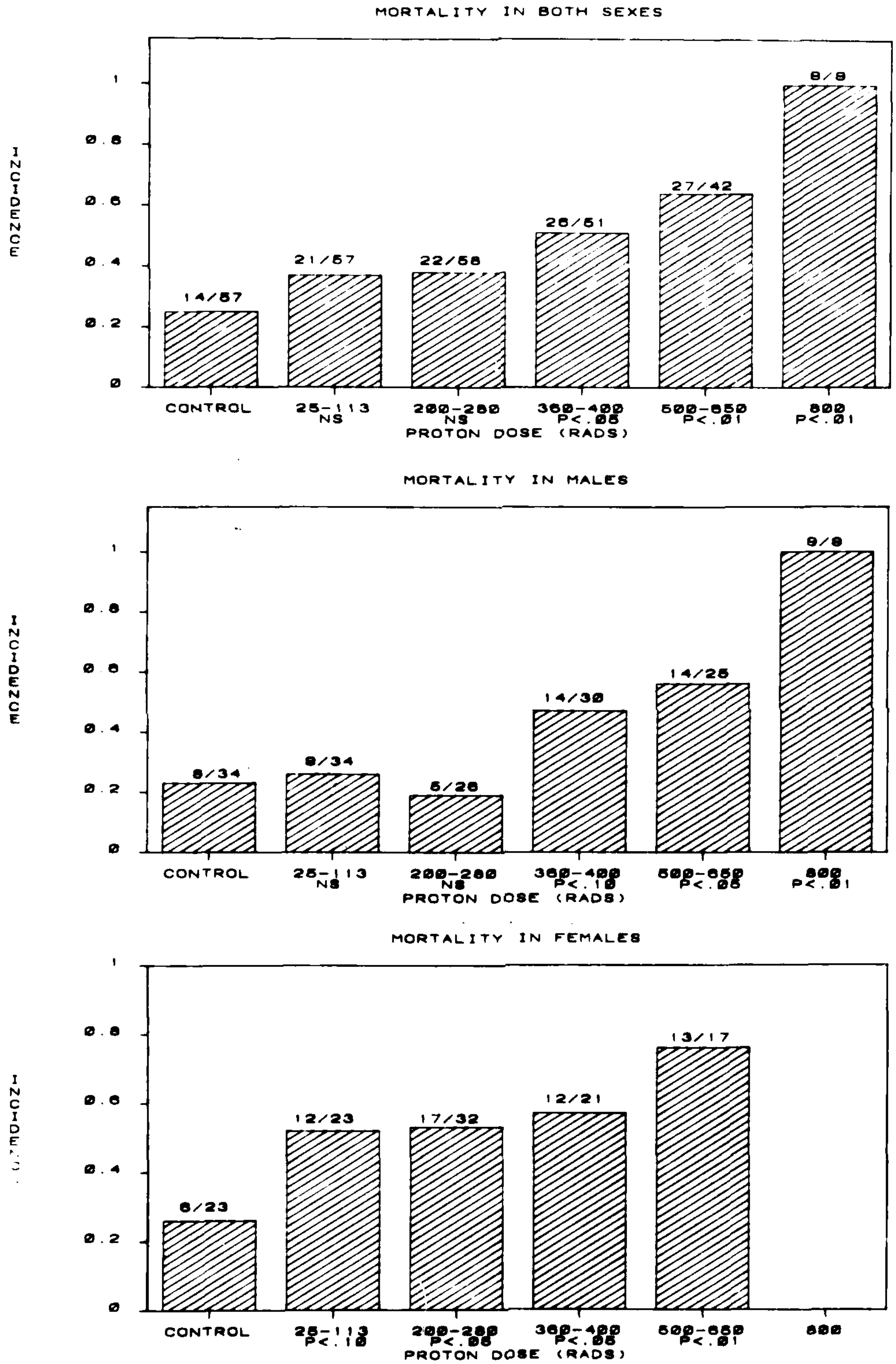


Figure 3. Mortality (by sex and dose) among 217 proton-exposed subjects. (Levels of significance determined by a chi-square test.)

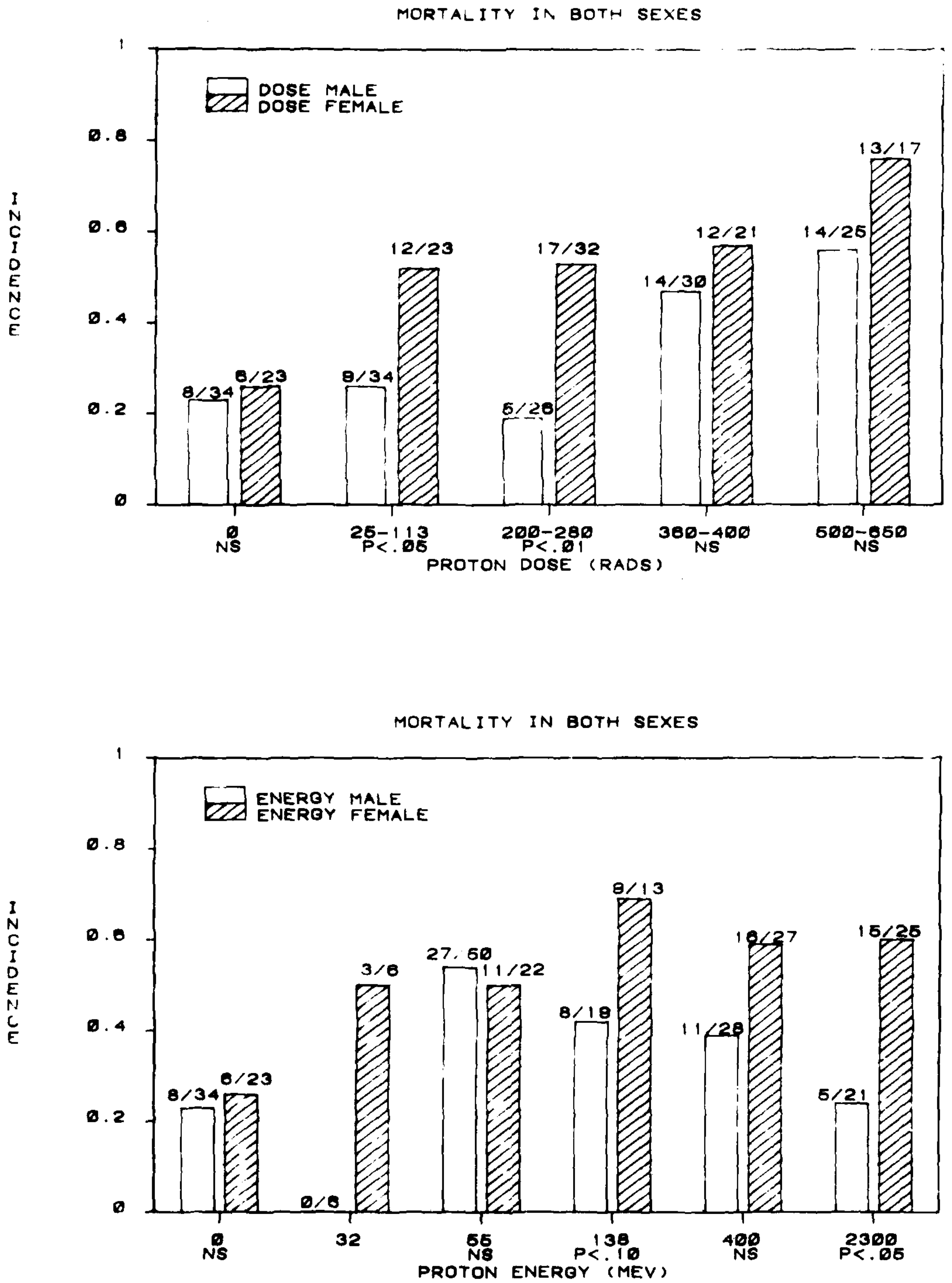


Figure 4. Mortality sex comparisons among proton-exposed subjects. (Levels of significance determined by a chi-square test.)

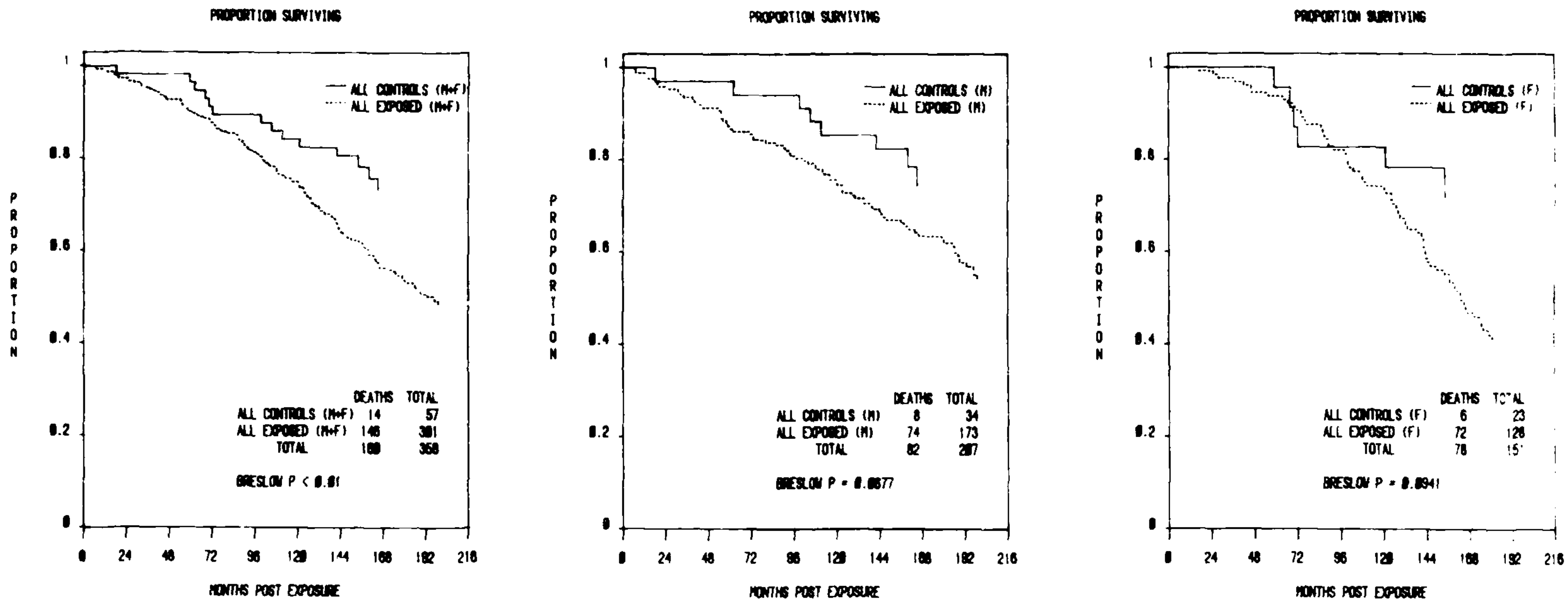


Figure 5. Kaplan-Meier survival curves for the proportion surviving beyond time t among 57 controls and 301 exposed. The bottom curve indicates which group is dying earlier (faster). The first panel gives the contrast for both sexes; the middle panel is for males; and the right panel is for the females.

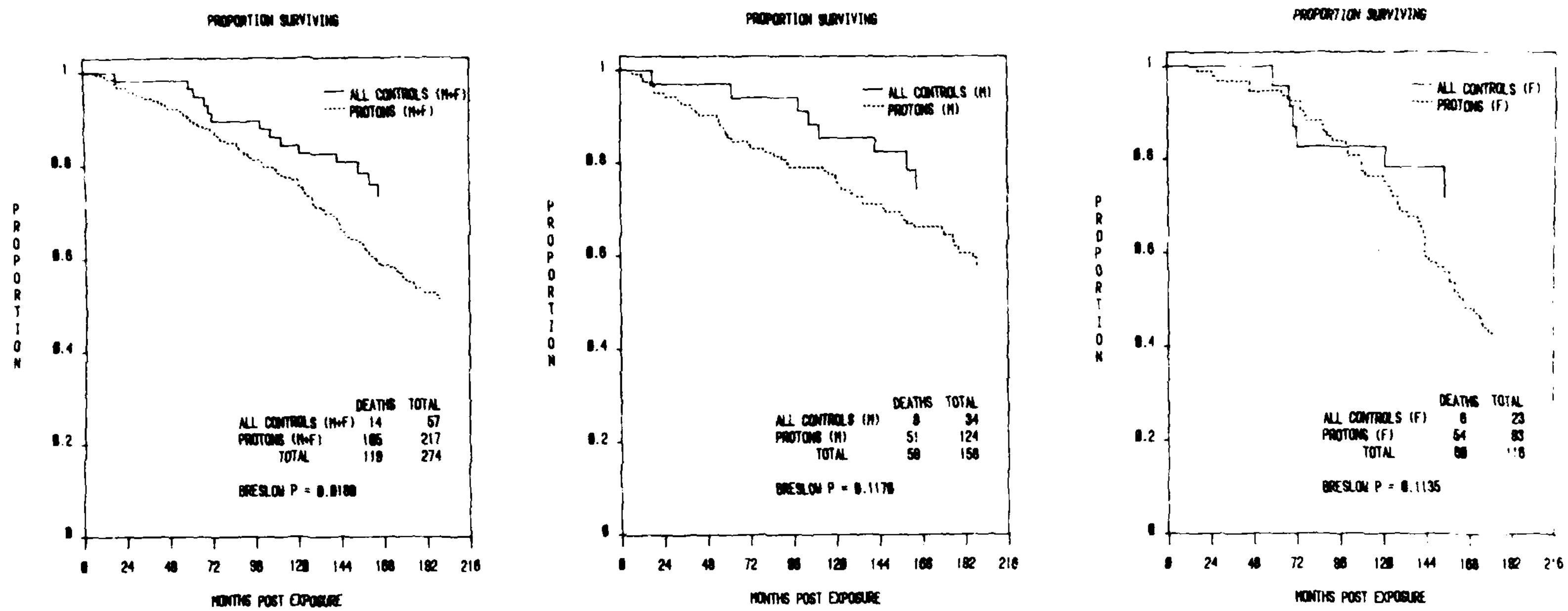


Figure 6. Kaplan-Meier survival curves for the proportion surviving beyond time t among 57 controls and 217 proton-exposed. The bottom curve in each panel indicates which group is dying earlier (faster). The first panel gives the contrast for both sexes; the middle panel is for males; and the right panel is for the females.

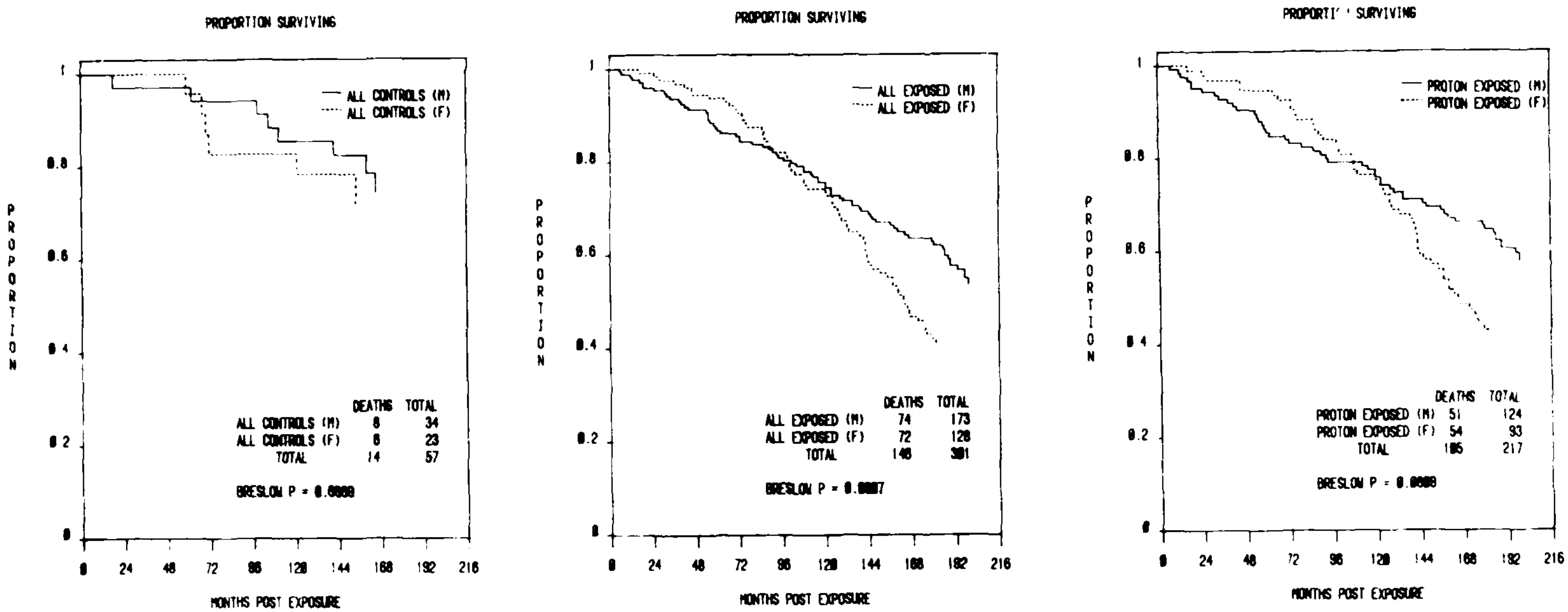


Figure 7. Kaplan-Meier survival curves contrasting the sexes for the 57 controls, 301 exposed subjects, and 217 proton-exposed subjects.

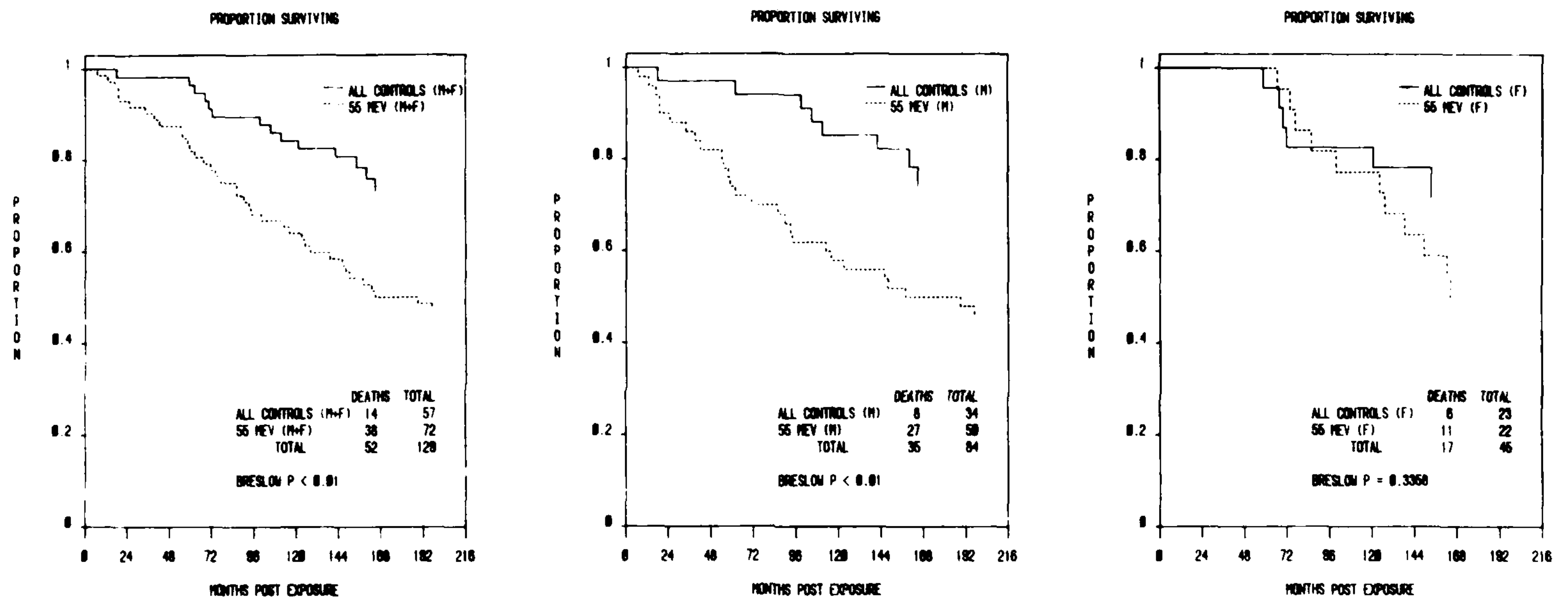


Figure 8. Kaplan-Meier survival curves for contrasting 57 controls with 72 55-MeV subjects.

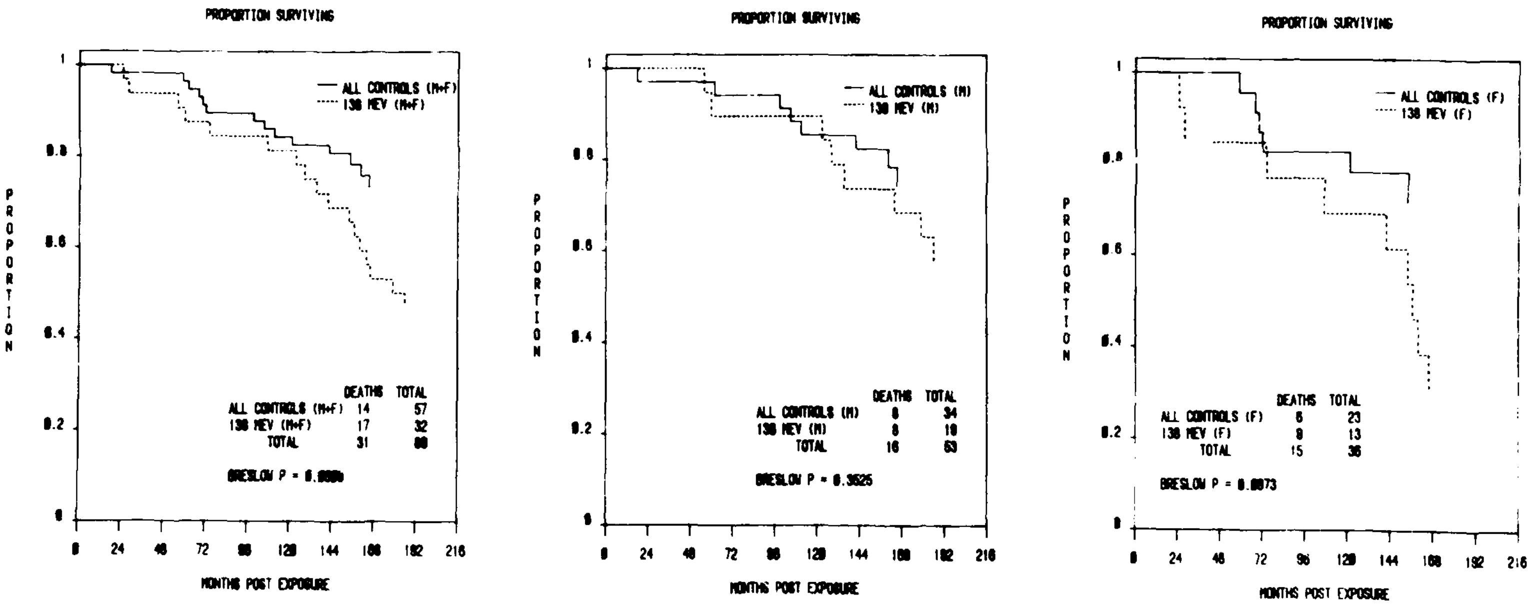


Figure 9. Kaplan-Meier survival curves for contrasting 57 controls with 32 138-MeV subjects.

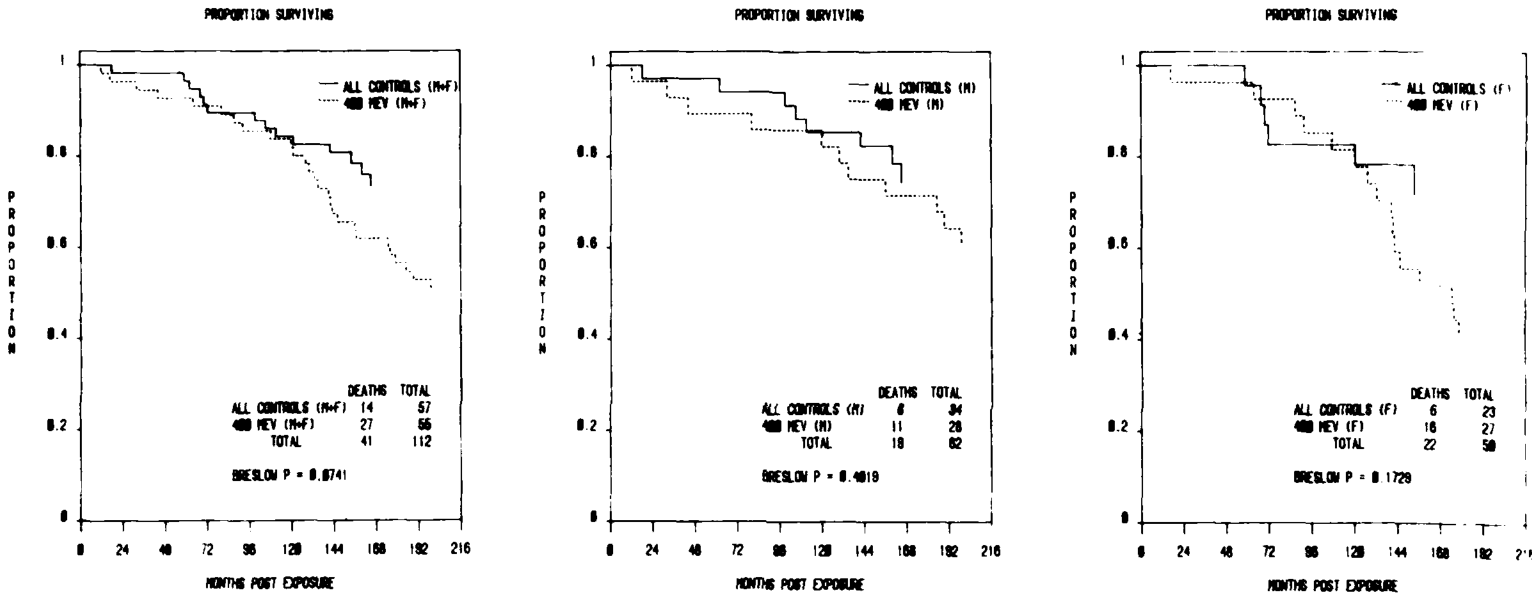


Figure 10. Kaplan-Meier survival curves for contrasting 57 controls with 55 400-MeV subjects.

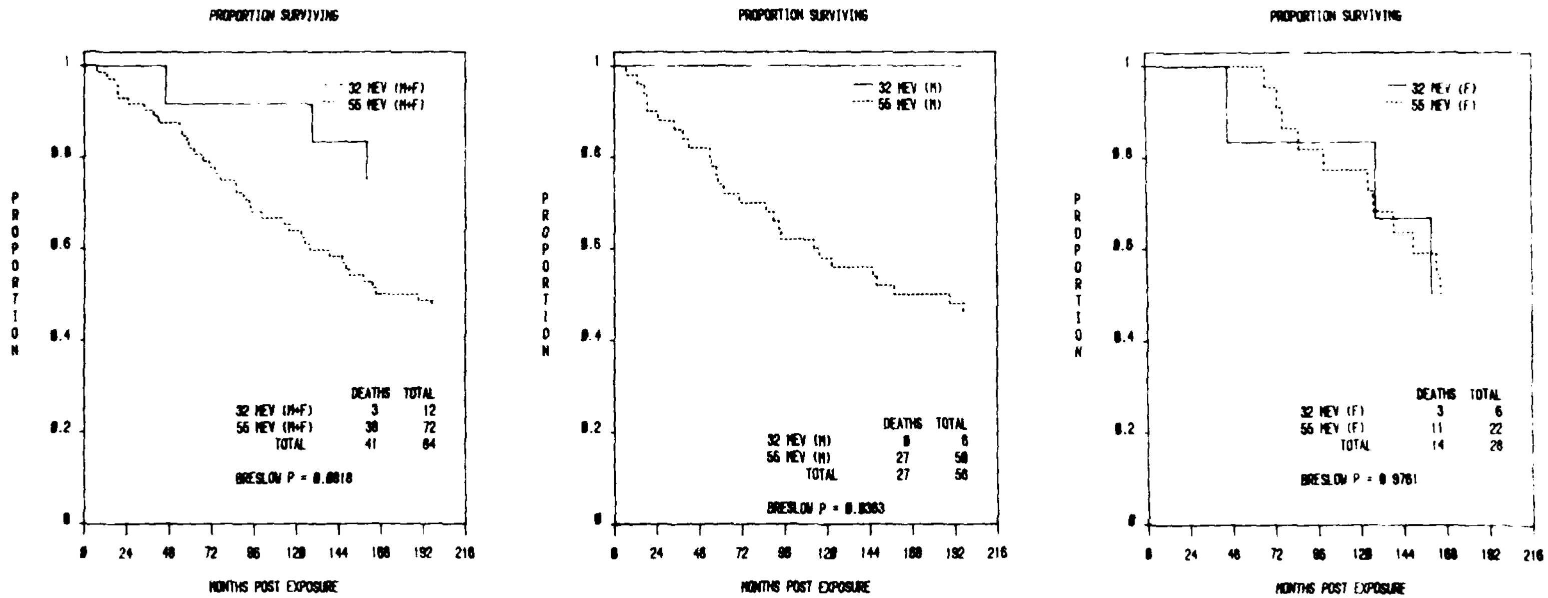


Figure 11. Kaplan-Meier survival curves for comparing 32- and 55-MeV energies.

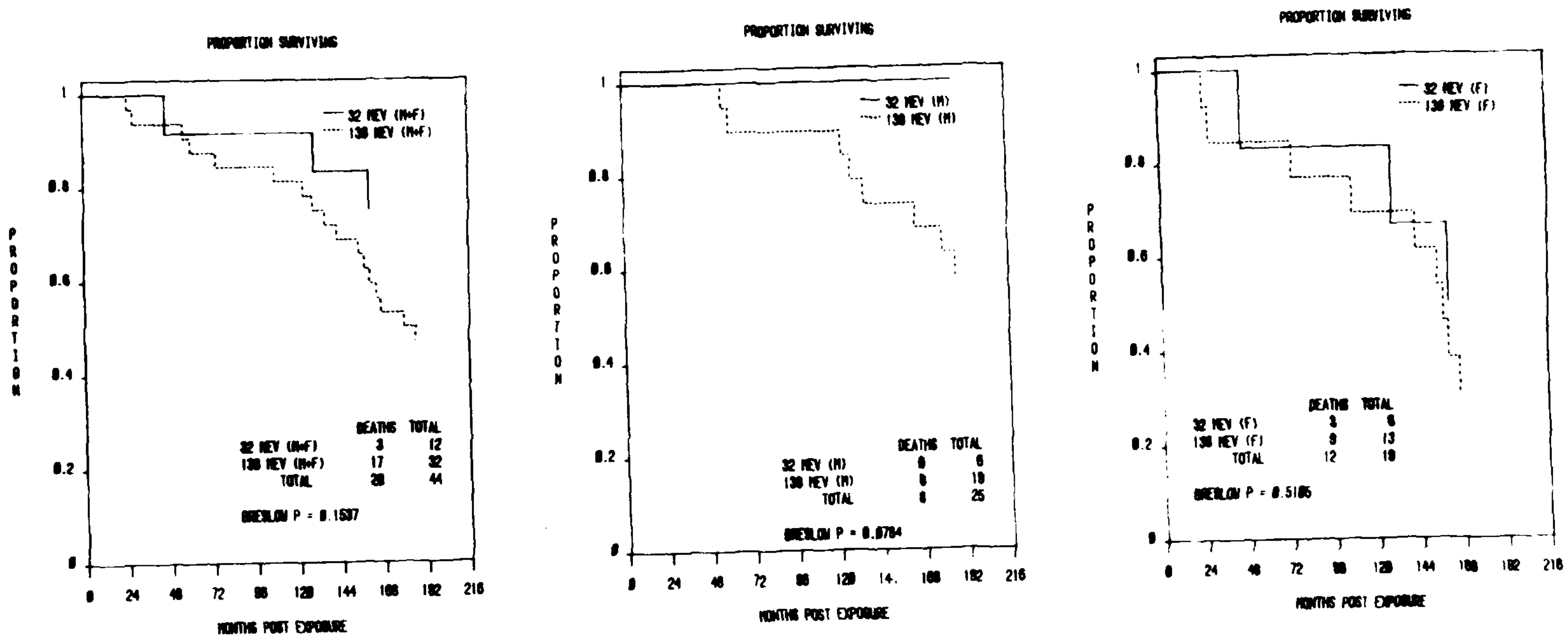


Figure 12. Kaplan-Meier survival curves for comparing 32- and 138-MeV energies.

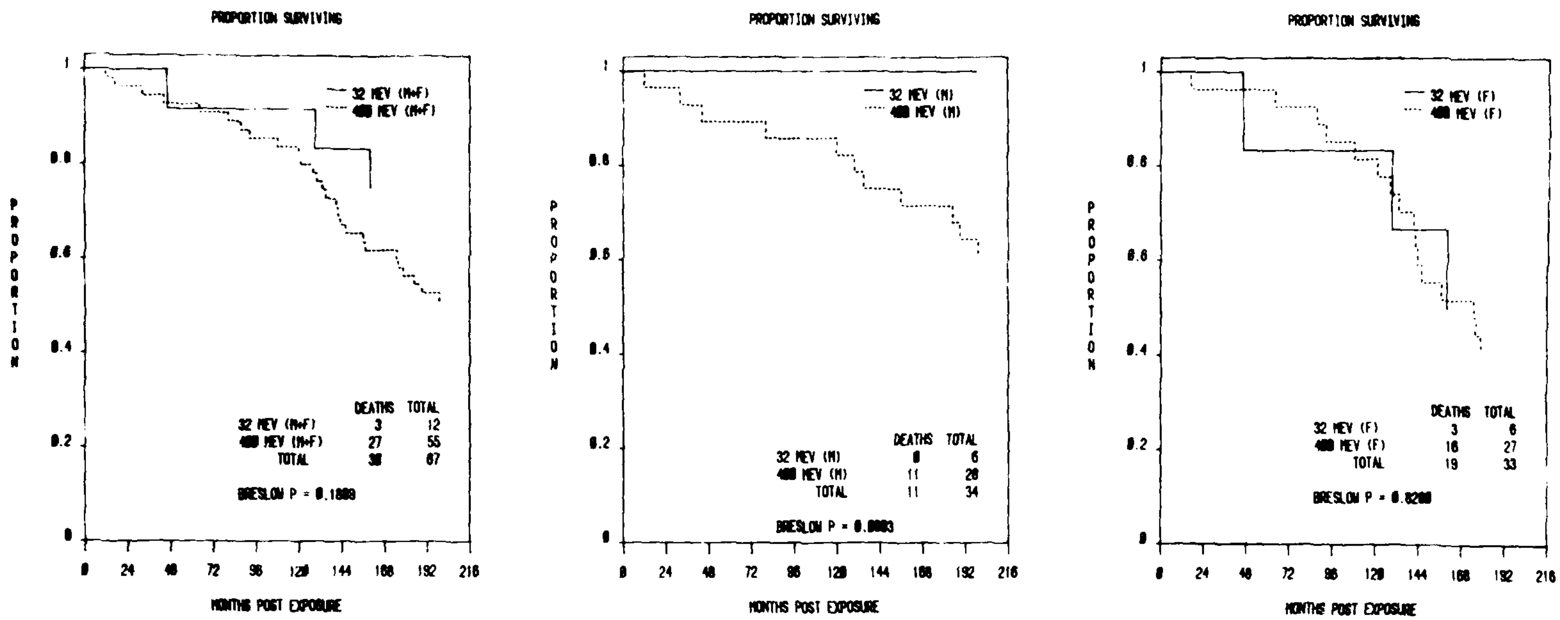


Figure 13. Kaplan-Meier survival curves *for comparing* 32- *and* 400-MeV energies.

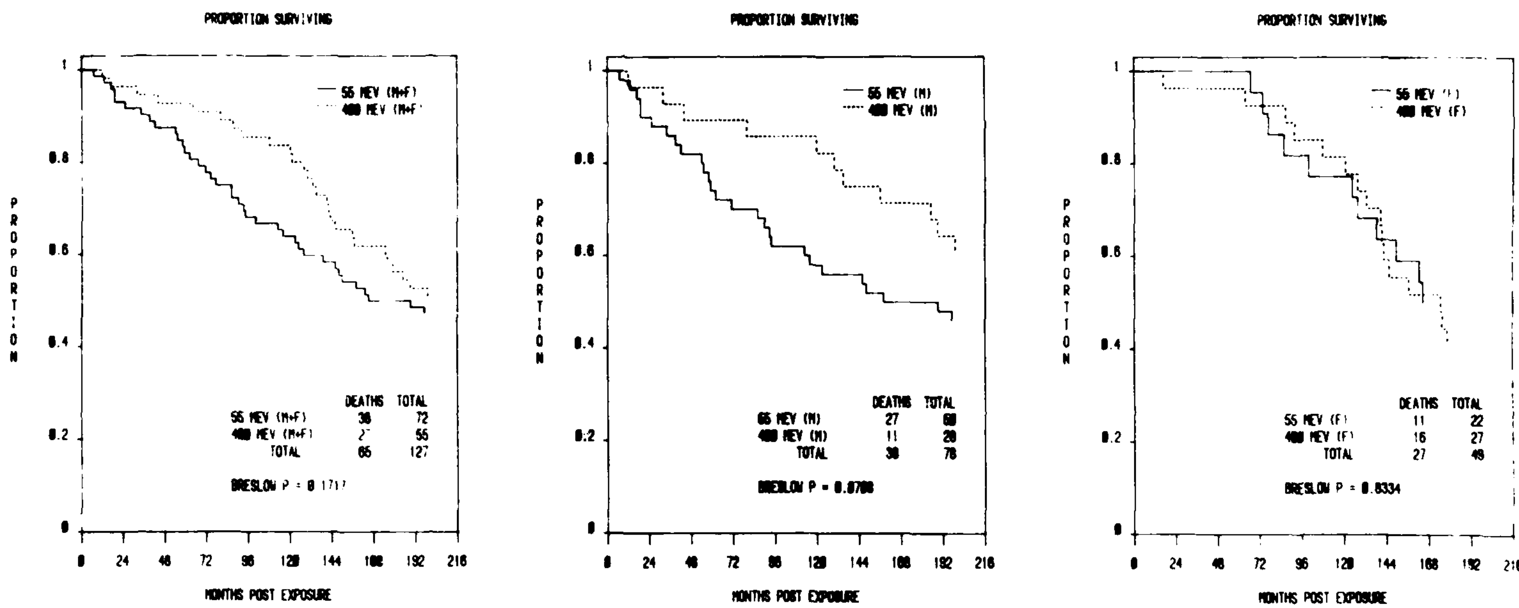


Figure 14. Kaplan-Meier survival curves for comparing 55- and 400-MeV energies.

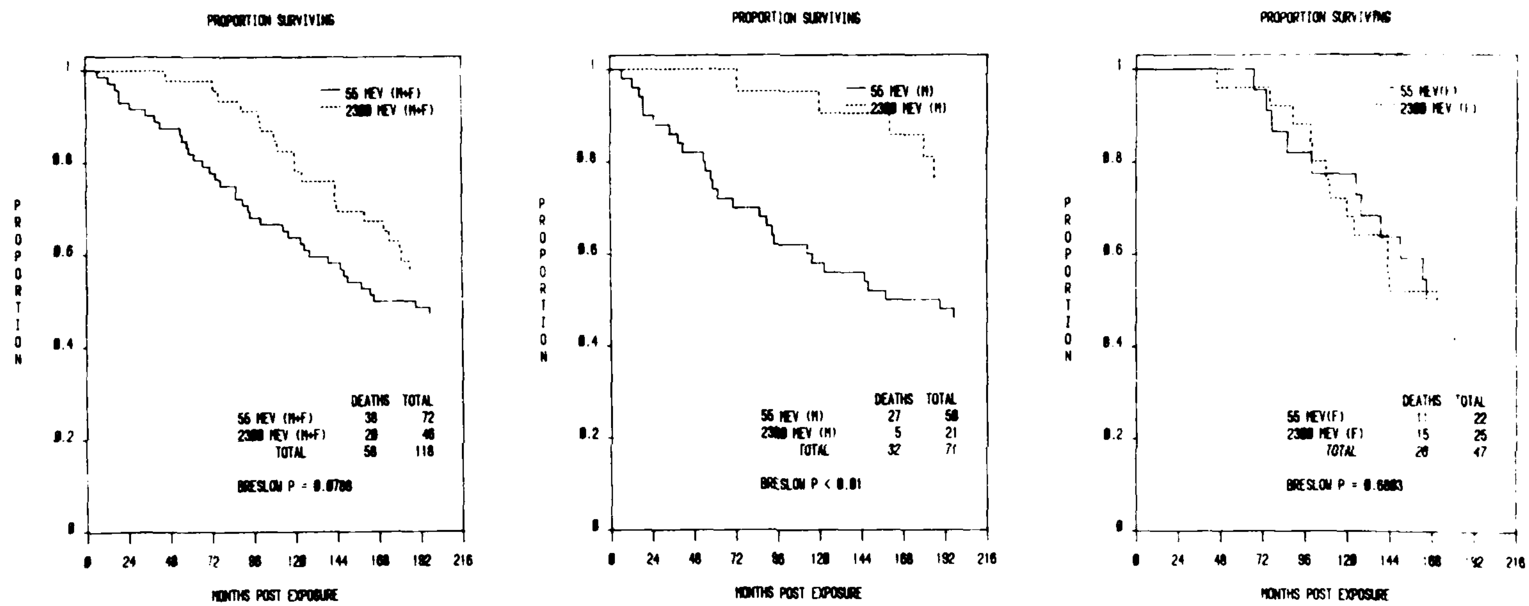


Figure 15. Kaplan-Meier survival curves for comparing 55- and 2300-MeV energies.

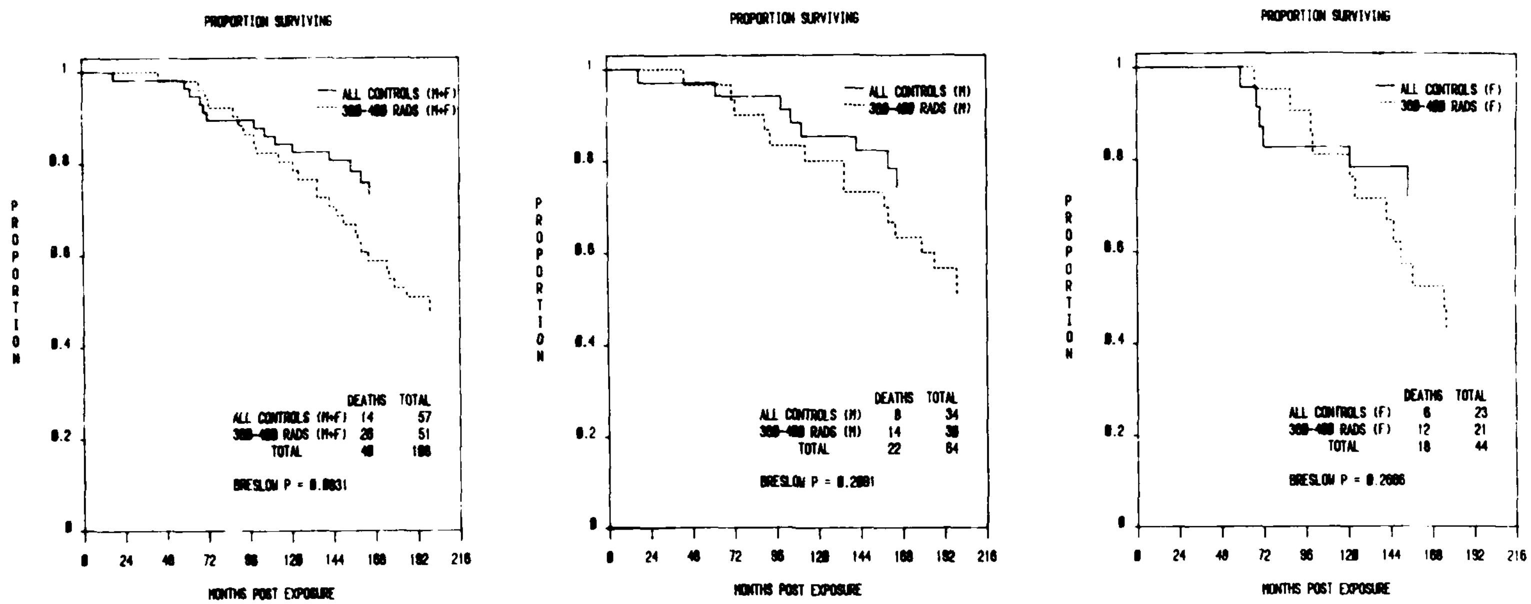


Figure 16. Kaplan-Meier survival curves for comparing the controls with 360-400-rad subjects.

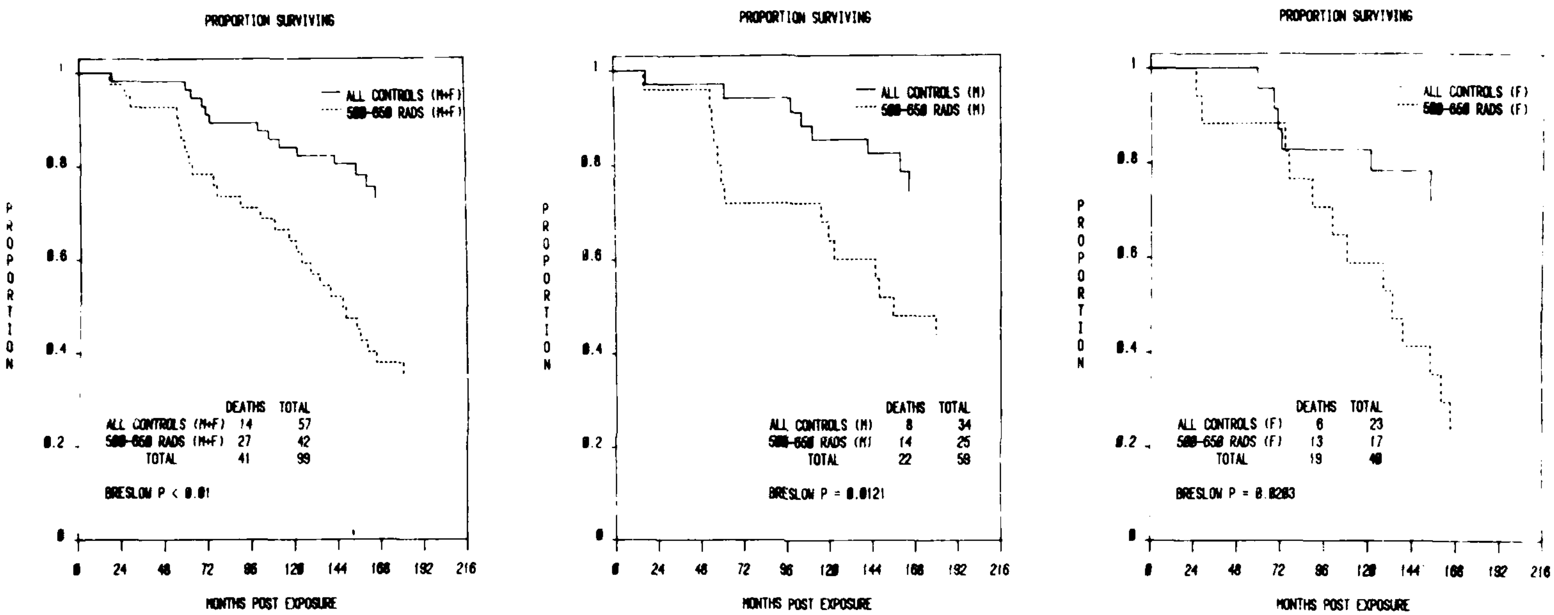


Figure 17. Kaplan-Meier survival curves for comparing the controls with 500-650-rad subjects.

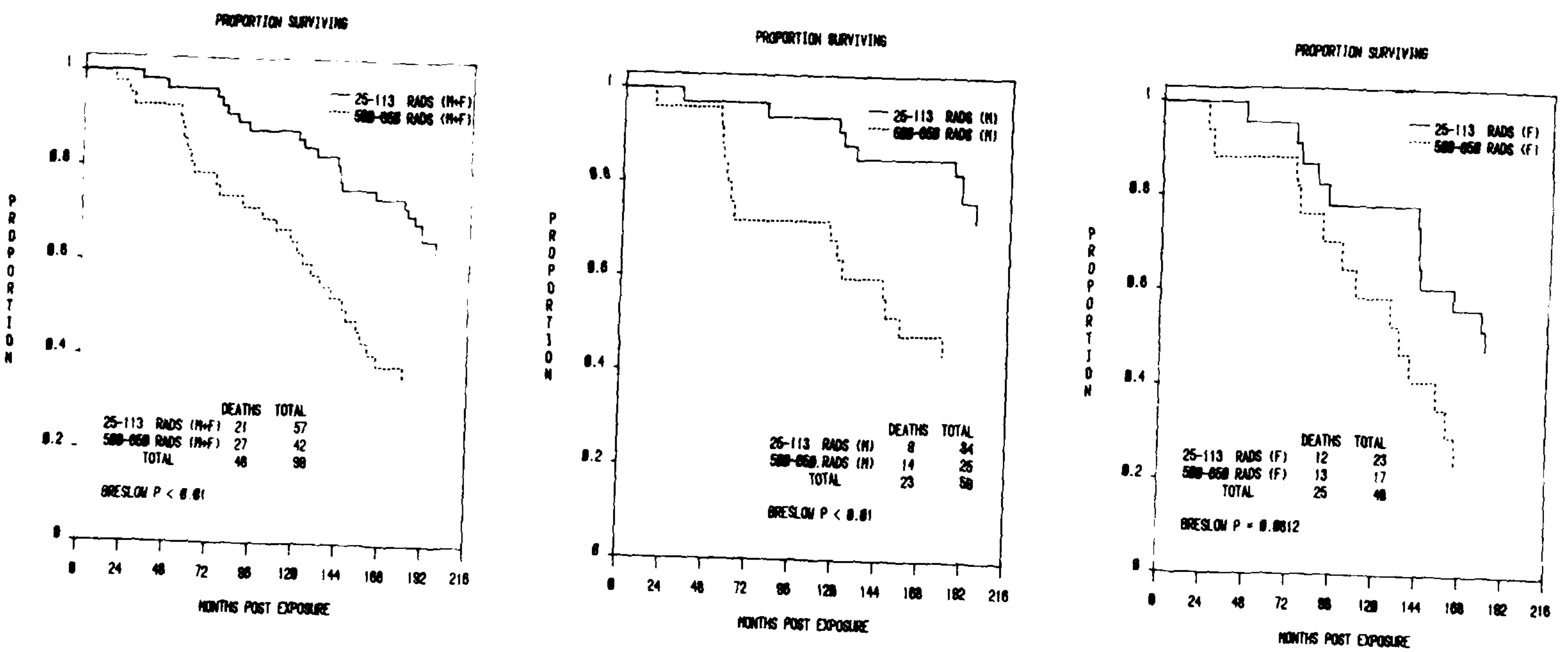


Figure 18. Kaplan-Meier survival curves for comparing 25-113-rad with 500-650-rad subjects.

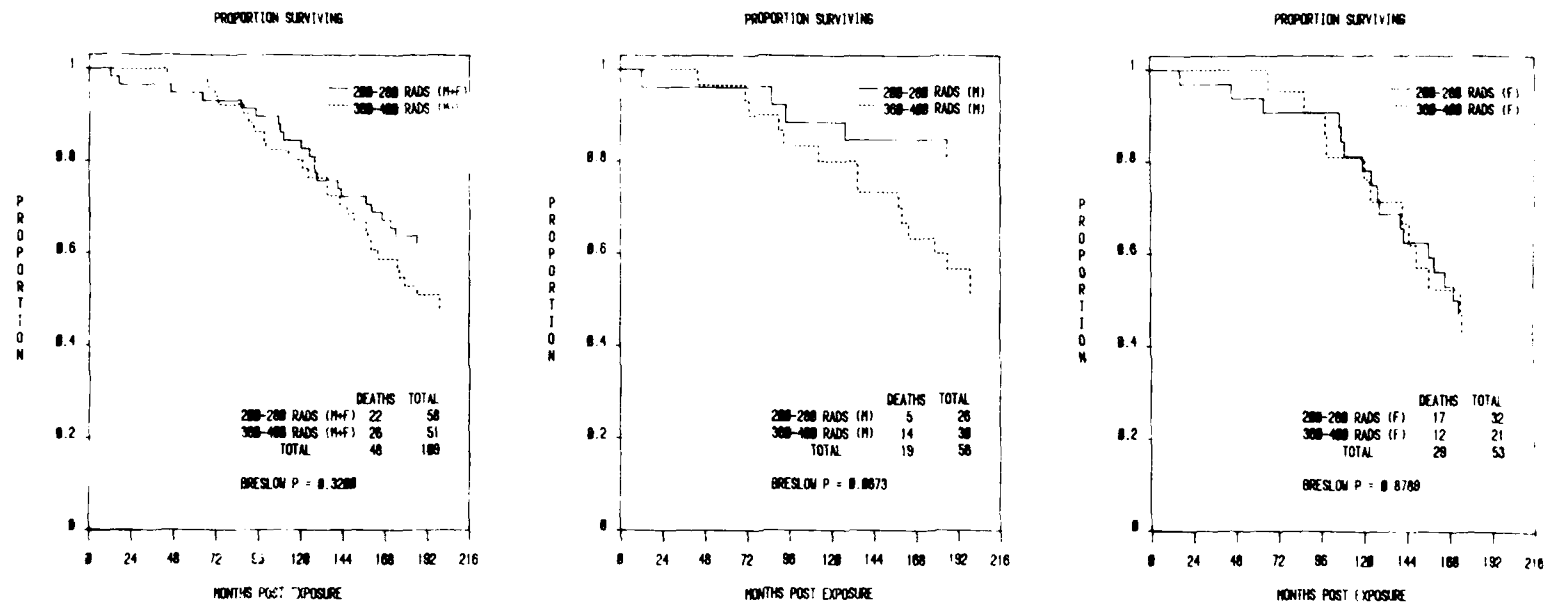


Figure 19. Kaplan-Meier survival curves for comparing 200-280-rad with 360-400-rad subjects.

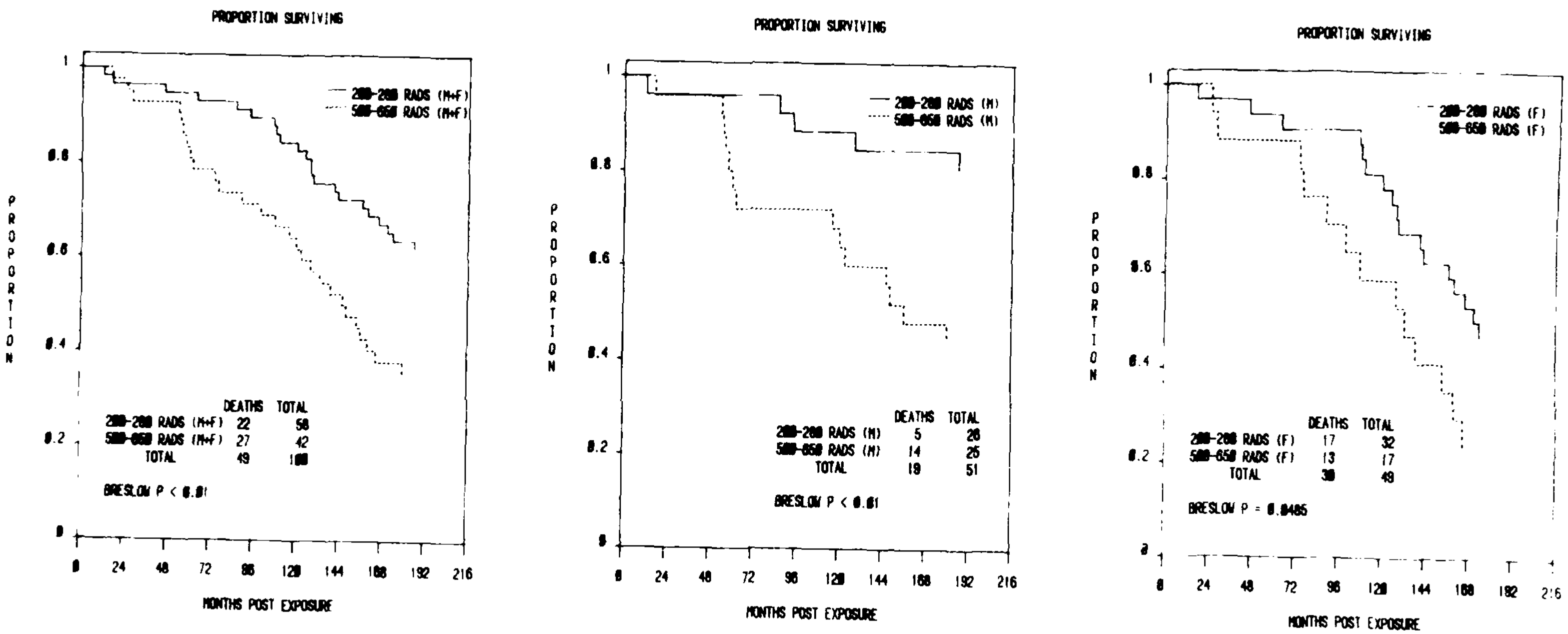


Figure 20. Kaplan-Meier survival curves for comparing 200-280-rad with 500-650-rad subjects.

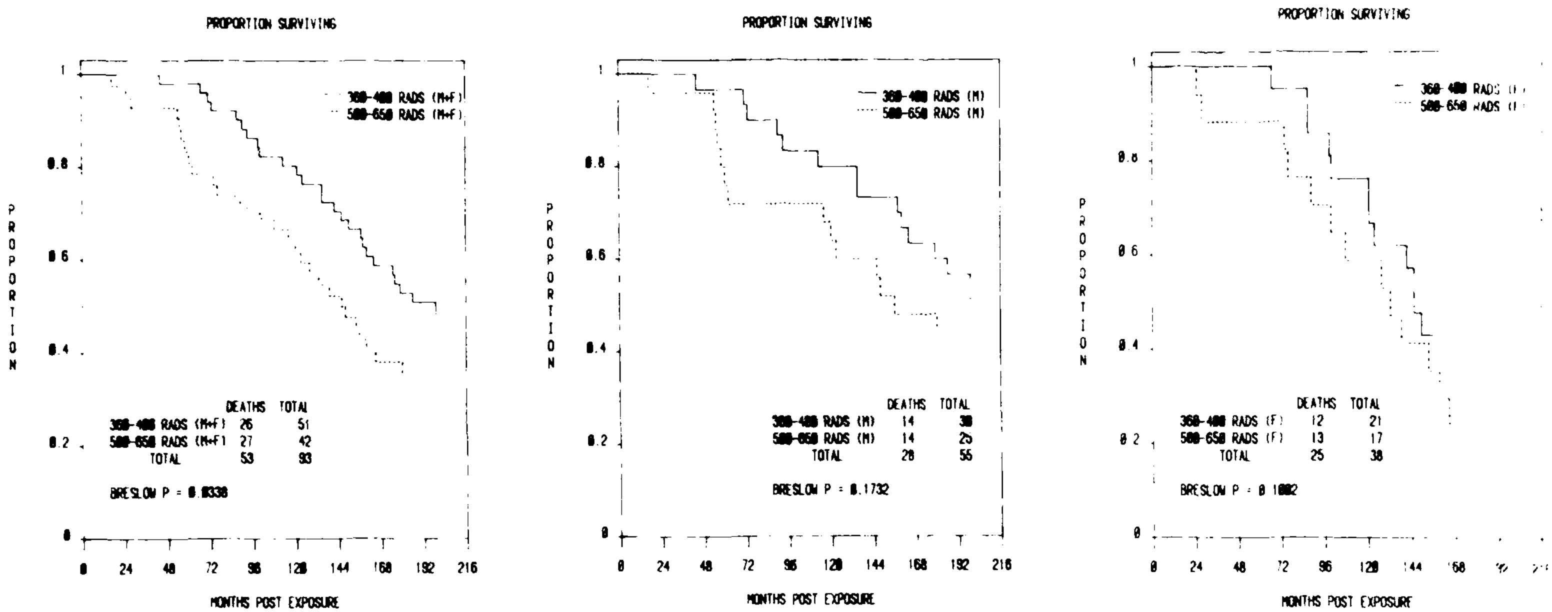


Figure 21. Kaplan-Meier survival curves for comparing 360-400-rad with 500-650-rad subjects.

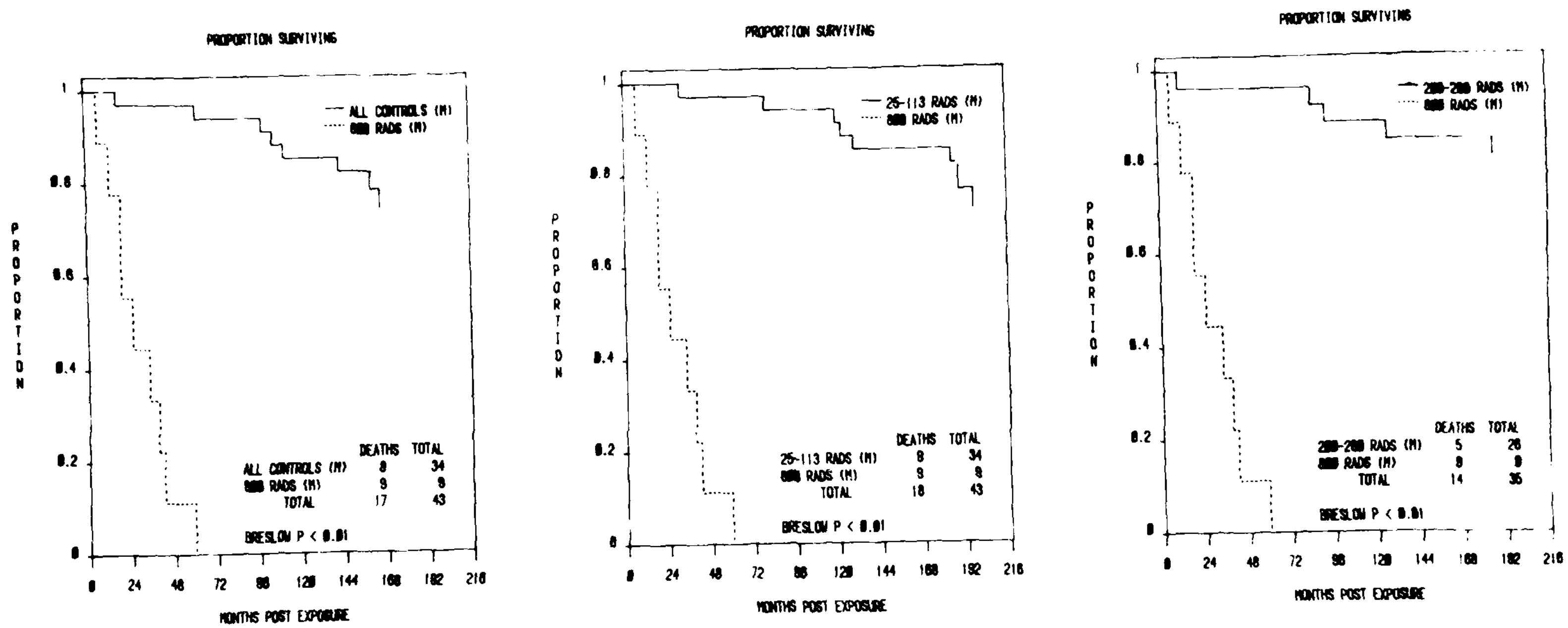


Figure 22. Kaplan-Meier survival curves for comparing 800-rad males with the control, 25-113-rad, and 200-280-rad males.

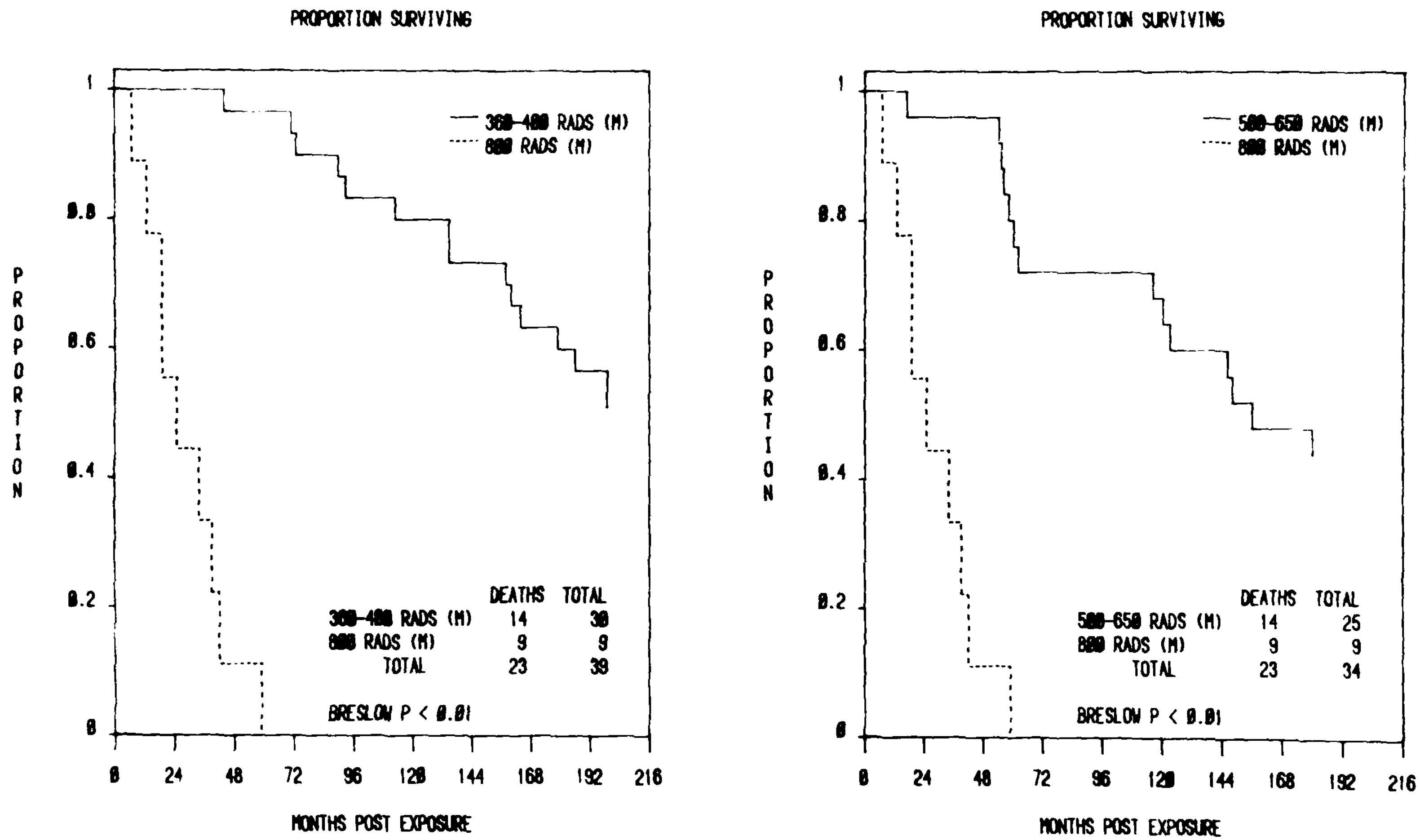


Figure 23. Kaplan-Meier survival curves for comparing 800-rad males with 360-400-rad and 500-650-rad males.

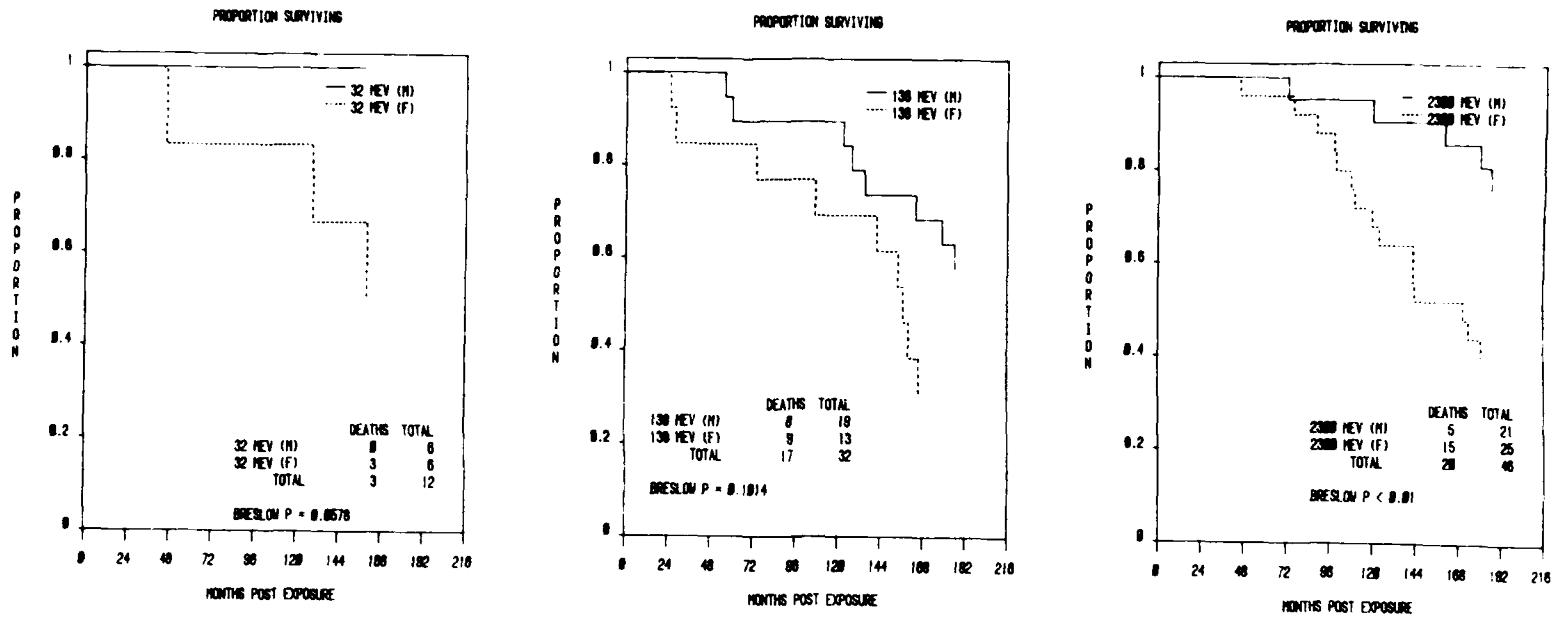


Figure 24. Kaplan-Meier survival curves for comparing the sexes among 32-, 138-, and 2300-MeV energies.

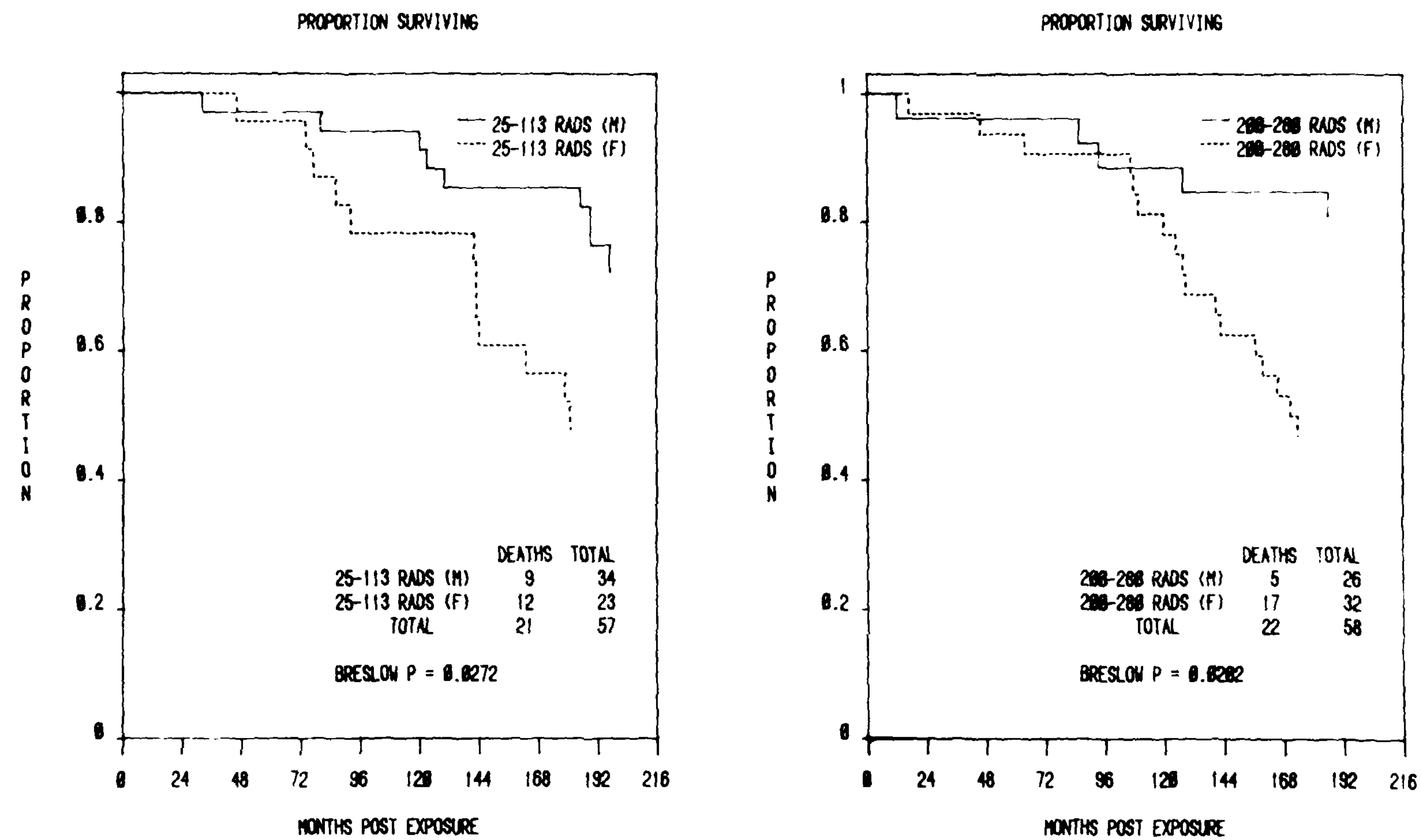


Figure 25. Kaplan-Meier survival curves for comparing sexes among 25-113-rad and 200-280-rad doses.

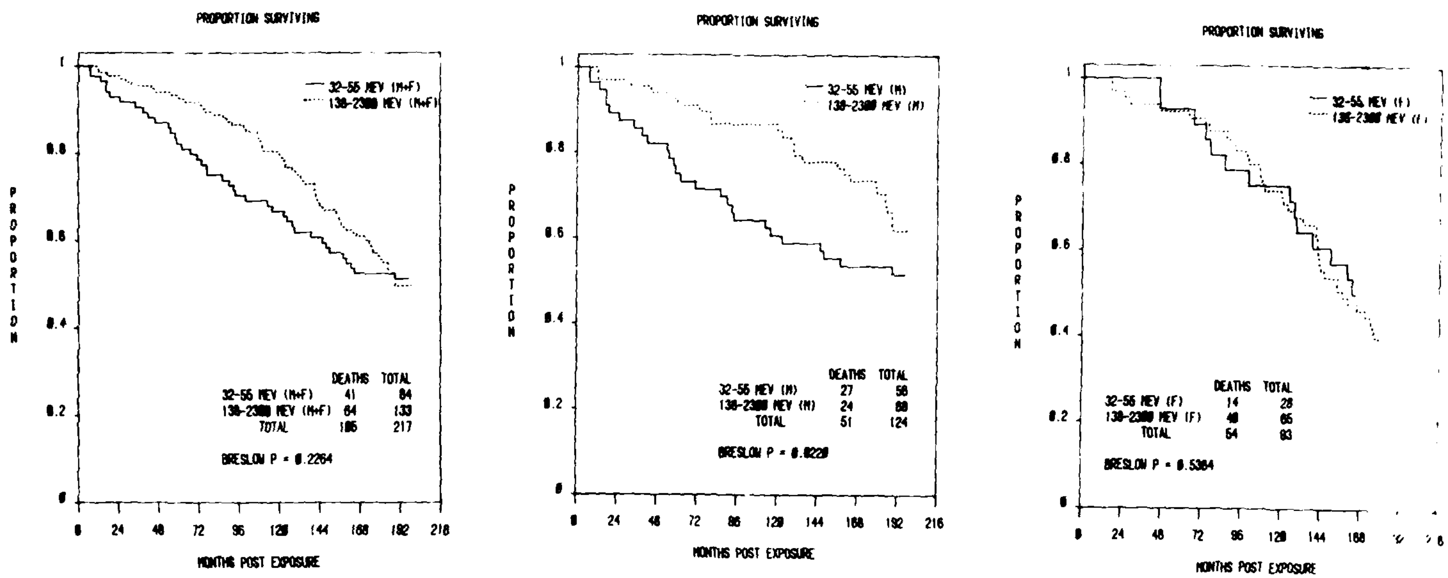
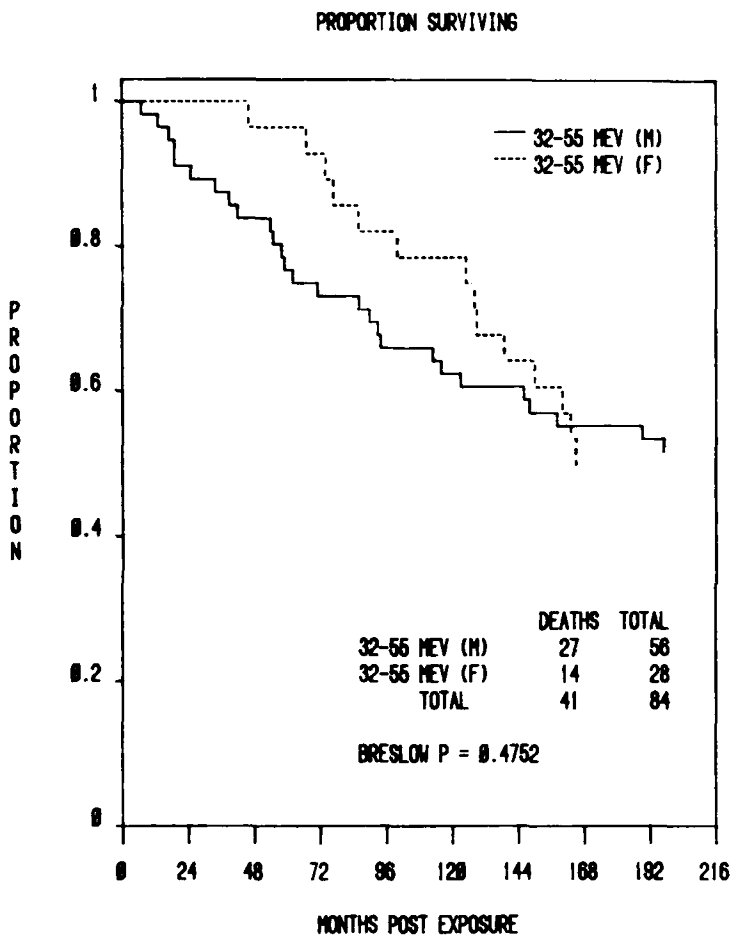


Figure 26. Kaplan-Meier survival curves for comparing partially penetrating, 32- and 55-MeV, with total penetrating, 138-, 400-, and 2300-MeV energies.



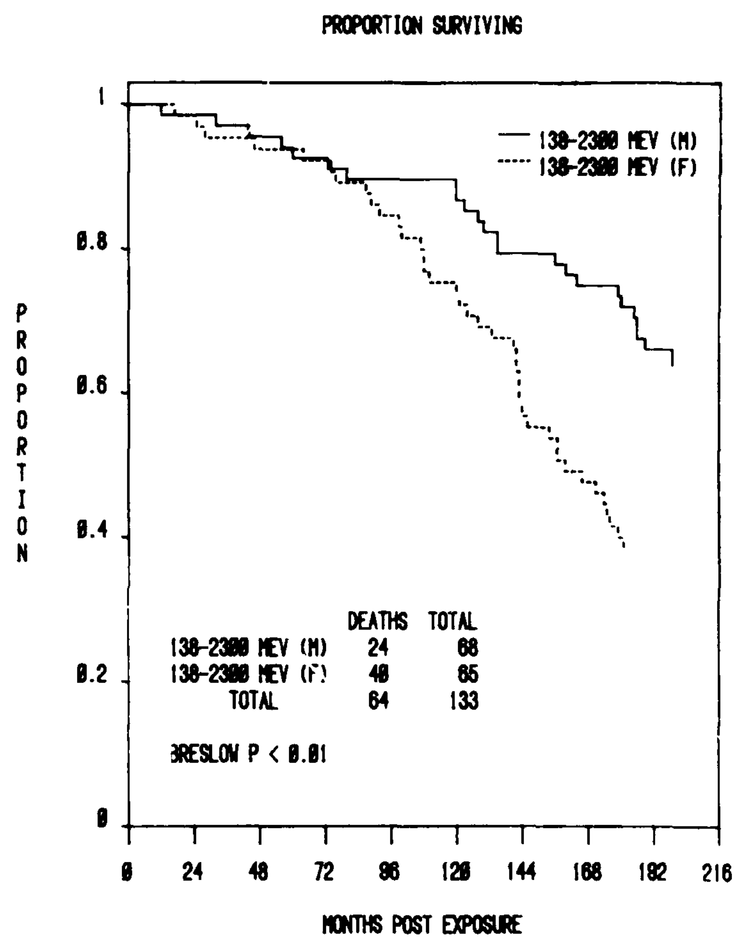


Figure 27. Kaplan-Meier survival curves for comparing sexes among the partially and total penetrating energies.

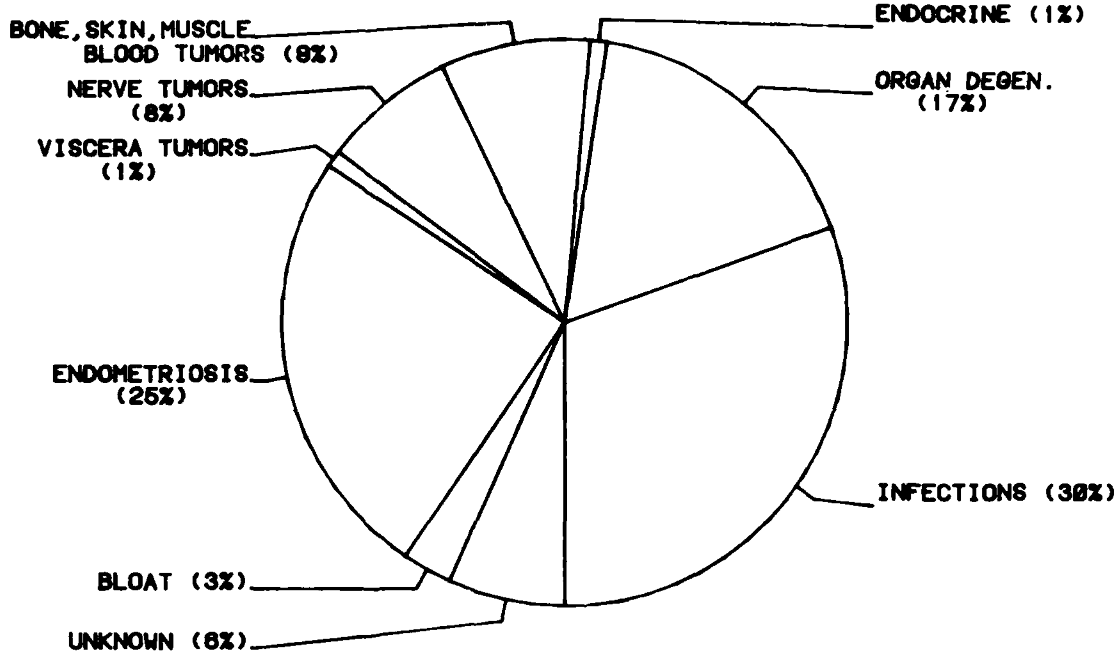


Figure 28. Pie Chart of the probable cause of death among the proton exposed.

APPENDIX A

EXPOSURE DATA

MORTALITY DATA

MONKEY ID	SEX	ENERGY	DOSE	IRRAD DATE	DATE OF DEATH	CAUSE OF DEATH
02K	M	1.6 MEV	1000 RADS	6805	ALIVE	ALIVE
36L	M	1.6 MEV	1000 RADS	6805	ALIVE	ALIVE
44N	M	1.6 MEV	1000 RADS	6805	ALIVE	ALIVE
54T	M	1.6 MEV	1000 RADS	6805	7705	ACUTE GASTRIC DILITATION
78M	M	1.6 MEV	1000 RADS	6805	ALIVE	ALIVE
94N	M	1.6 MEV	1000 RADS	6805	7011	INFECTIONS
18J	M	1.6 MEV	1500 RADS	6805	7605	ORGAN DEGENERATION
28P	M	1.6 MEV	1500 RADS	6805	7912	ORGAN DEGENERATION
44L	M	1.6 MEV	1500 RADS	6805	7109	BONE,SKIN,MUSCLE AND BLOOD TUMORS
54N	M	1.6 MEV	1500 RADS	6805	7212	VISCERA TUMORS
70J	M	1.6 MEV	1500 RADS	6805	7211	BONE,SKIN,MUSCLE AND BLOOD TUMORS
64J	M	1.6 MEV	1500 RADS	6805	6810	ACUTE GASTRIC DILITATION
S01	F	2 MEV X	CONTROLS	6403	6902	INFECTIONS
S11	F	2 MEV X	CONTROLS	6505	ALIVE	ALIVE
J16	M	2 MEV X	360 RADS	6404	ALIVE	ALIVE
E91	F	2 MEV X	446 RADS	6404	ALIVE	ALIVE
K38	M	2 MEV X	446 RADS	6403	ALIVE	ALIVE
R85	F	2 MEV X	446 RADS	6404	ALIVE	ALIVE
S29	F	2 MEV X	446 RADS	6404	7504	ENDOMETRIOSIS
C92	M	2 MEV X	538 RADS	6403	7407	ORGAN DEGENERATION
D51	F	2 MEV X	538 RADS	6403	7503	ENDOMETRIOSIS
E17	F	2 MEV X	538 RADS	6403	7801	ENDOMETRIOSIS
E55	F	2 MEV X	538 RADS	6403	7104	ENDOMETRIOSIS
F14	M	2 MEV X	538 RADS	6403	7801	ACUTE GASTRIC DILITATION
F32	M	2 MEV X	538 RADS	6403	8004	INFECTIONS
F39	F	2 MEV X	538 RADS	6403	7411	BONE,SKIN,MUSCLE AND BLOOD TUMORS
F51	F	2 MEV X	538 RADS	6403	ALIVE	ALIVE
F73	F	2 MEV X	538 RADS	6403	7210	ACUTE GASTRIC DILITATION
F75	F	2 MEV X	538 RADS	6403	6811	INFECTIONS
G17	F	2 MEV X	538 RADS	6403	ALIVE	ALIVE
G90	M	2 MEV X	538 RADS	6404	7912	VISCERA TUMORS
C71	F	2 MEV X	624 RADS	6404	6709	INFECTIONS
E41	F	2 MEV X	624 RADS	6403	ALIVE	ALIVE
E66	M	2 MEV X	624 RADS	6403	7212	ORGAN DEGENERATION
E98	M	2 MEV X	624 RADS	6403	7111	INFECTIONS
F21	F	2 MEV X	624 RADS	6403	7105	ENDOMETRIOSIS
F24	M	2 MEV X	624 RADS	6403	7605	ORGAN DEGENERATION
F38	M	2 MEV X	624 RADS	6403	7512	INFECTIONS
G19	F	2 MEV X	624 RADS	6403	7206	INFECTIONS
G66	M	2 MEV X	624 RADS	6403	ALIVE	ALIVE
K30	M	2 MEV X	624 RADS	6404	ALIVE	ALIVE

MORTALITY DATA

MONKEY ID	SEX	ENERGY	DOSE	IRRAD DATE	DATE OF DEATH	CAUSE OF DEATH
E64	M	2 MEV X	716 RADS	6404	7209	INFECTIONS
G62	M	2 MEV X	716 RADS	6403	8009	VISCERA TUMORS
H59	F	2 MEV X	716 RADS	6403	7711	ENDOMETRIOSIS
H61	F	2 MEV X	716 RADS	6403	7108	ENDOMETRIOSIS
K22	M	2 MEV X	716 RADS	6404	7604	VISCERA TUMORS
DS2	M	2 MEV E	CONTROLS	6911	7501	INFECTIONS
11S	F	2 MEV E	CONTROLS	6911	ALIVE	ALIVE
67R	F	2 MEV E	CONTROLS	6911	ALIVE	ALIVE
69R	F	2 MEV E	CONTROLS	6911	ALIVE	ALIVE
DV4	M	2 MEV E	900 RADS	6911	ALIVE	ALIVE
EC4	M	2 MEV E	900 RADS	6911	ALIVE	ALIVE
O3R	F	2 MEV E	900 RADS	6911	ALIVE	ALIVE
89R	F	2 MEV E	900 RADS	6911	7509	ENDOMETRIOSIS
EL6	M	2 MEV E	1200 RADS	6911	ALIVE	ALIVE
57R	F	2 MEV E	1200 RADS	6911	ALIVE	ALIVE
65R	F	2 MEV E	1200 RADS	6911	ALIVE	ALIVE
99J	F	2 MEV E	1200 RADS	6911	ALIVE	ALIVE
DT8	M	2 MEV E	1500 RADS	6911	7511	INFECTIONS
ED2	M	2 MEV E	1500 RADS	6911	ALIVE	ALIVE
19R	F	2 MEV E	1500 RADS	6911	ALIVE	ALIVE
61R	F	2 MEV E	1500 RADS	6911	7212	ORGAN DEGENERATION
DL2	M	5 MEV	CONTROLS	6912	ALIVE	ALIVE
EJ4	M	5 MEV	CONTROLS	6912	ALIVE	ALIVE
15E	F	5 MEV	CONTROLS	6804	ALIVE	ALIVE
3V4	M	5 MEV	CONTROLS	6706	ALIVE	ALIVE
36P	M	5 MEV	CONTROLS	6804	ALIVE	ALIVE
48P	M	5 MEV	CONTROLS	6804	7012	UNKNOWN
50K	M	5 MEV	CONTROLS	6804	7802	ORGAN DEGENERATION
6P5	F	5 MEV	CONTROLS	6706	ALIVE	ALIVE
6Q7	F	5 MEV	CONTROLS	6707	8004	ENDOMETRIOSIS
6V4	M	5 MEV	CONTROLS	6706	7609	ORGAN DEGENERATION
61S	F	5 MEV	CONTROLS	6912	ALIVE	ALIVE
9N5	F	5 MEV	CONTROLS	6706	7706	ACUTE GASTRIC DILITATION
96N	M	5 MEV	CONTROLS	6804	7607	UNKNOWN
S77	F	32 MEV	CONTROLS	6407	ALIVE	ALIVE
D91	F	32 MEV	280 RADS	6407	6806	INFECTIONS
E88	M	32 MEV	280 RADS	6407	ALIVE	ALIVE
F30	M	32 MEV	280 RADS	6407	ALIVE	ALIVE
H57	F	32 MEV	280 RADS	6407	7503	ENDOMETRIOSIS
E93	F	32 MEV	560 RADS	6407	ALIVE	ALIVE
F13	F	32 MEV	560 RADS	6407	ALIVE	ALIVE

MORTALITY DATA

MONKEY ID	SEX	ENERGY	DOSE	IRRAD DATE	DATE OF DEATH	CAUSE OF DEATH
F65	F	32 MEV	560 RADS	6407	7712	ENDOMETRIOSIS
F71	F	32 MEV	560 RADS	6407	ALIVE	ALIVE
G86	M	32 MEV	560 RADS	6407	ALIVE	ALIVE
J04	M	32 MEV	560 RADS	6407	ALIVE	ALIVE
J70	M	32 MEV	560 RADS	6407	ALIVE	ALIVE
J82	M	32 MEV	560 RADS	6407	ALIVE	ALIVE
P46	M	55 MEV	CONTROLS	6504	ALIVE	ALIVE
U74	M	55 MEV	CONTROLS	6504	ALIVE	ALIVE
U76	M	55 MEV	CONTROLS	6504	ALIVE	ALIVE
U96	M	55 MEV	CONTROLS	6504	ALIVE	ALIVE
V02	M	55 MEV	CONTROLS	6504	ALIVE	ALIVE
V86	M	55 MEV	CONTROLS	6505	ALIVE	ALIVE
L05	F	55 MEV	25 RADS	6505	7811	ENDOMETRIOSIS
Q32	M	55 MEV	25 RADS	6505	ALIVE	ALIVE
R78	M	55 MEV	25 RADS	6505	ALIVE	ALIVE
S55	F	55 MEV	25 RADS	6504	ALIVE	ALIVE
U94	M	55 MEV	25 RADS	6504	ALIVE	ALIVE
V04	M	55 MEV	25 RADS	6504	ALIVE	ALIVE
266	M	55 MEV	25 RADS	6505	ALIVE	ALIVE
F63	F	55 MEV	50 RADS	6505	7110	ENDOMETRIOSIS
L91	F	55 MEV	50 RADS	6505	ALIVE	ALIVE
M04	M	55 MEV	50 RADS	6505	ALIVE	ALIVE
R97	F	55 MEV	50 RADS	6504	ALIVE	ALIVE
U00	M	55 MEV	50 RADS	6504	ALIVE	ALIVE
U84	M	55 MEV	50 RADS	6504	8101	INFECTIONS
V16	M	55 MEV	50 RADS	6504	8109	ORGAN DEGENERATION
J51	F	55 MEV	100 RADS	6505	ALIVE	ALIVE
L95	F	55 MEV	100 RADS	6505	7206	ORGAN DEGENERATION
N57	F	55 MEV	100 RADS	6505	7107	UNKNOWN
N76	M	55 MEV	100 RADS	6505	ALIVE	ALIVE
U14	M	55 MEV	100 RADS	6505	ALIVE	ALIVE
U20	M	55 MEV	100 RADS	6505	ALIVE	ALIVE
V24	M	55 MEV	100 RADS	6505	7507	INFECTIONS
P79	F	55 MEV	200 RADS	6505	ALIVE	ALIVE
P91	F	55 MEV	200 RADS	6505	ALIVE	ALIVE
R38	M	55 MEV	200 RADS	6505	ALIVE	ALIVE
T05	F	55 MEV	200 RADS	6504	ALIVE	ALIVE
T55	F	55 MEV	200 RADS	6505	ALIVE	ALIVE
T57	F	55 MEV	200 RADS	6505	7510	INFECTIONS
T79	F	55 MEV	200 RADS	6505	ALIVE	ALIVE
T82	M	55 MEV	200 RADS	6504	ALIVE	ALIVE

MORTALITY DATA

MONKEY ID	SEX	ENERGY	DOSE	IRRAD DATE	DATE OF DEATH	CAUSE OF DEATH
U92	M	55 MEV	200 RADS	6504	ALIVE	ALIVE
V30	M	55 MEV	200 RADS	6505	ALIVE	ALIVE
V52	M	55 MEV	200 RADS	6505	ALIVE	ALIVE
V78	M	55 MEV	200 RADS	6505	7206	BONE,SKIN,MUSCLE AND BLOOD TUMORS
V80	M	55 MEV	200 RADS	6505	7303	UNKNOWN
W50	M	55 MEV	200 RADS	6504	ALIVE	ALIVE
R60	M	55 MEV	400 RADS	6505	ALIVE	ALIVE
T39	F	55 MEV	400 RADS	6505	7012	INFECTIONS
T53	F	55 MEV	400 RADS	6505	ALIVE	ALIVE
T61	F	55 MEV	400 RADS	6505	7711	ENDOMETRIOSIS
T87	F	55 MEV	400 RADS	6505	ALIVE	ALIVE
U04	M	55 MEV	400 RADS	6504	ALIVE	ALIVE
U40	M	55 MEV	400 RADS	6505	7104	INFECTIONS
U48	M	55 MEV	400 RADS	6504	ALIVE	ALIVE
U70	M	55 MEV	400 RADS	6504	ALIVE	ALIVE
U86	M	55 MEV	400 RADS	6505	7302	NERVE TUMORS
V00	M	55 MEV	400 RADS	6505	7807	INFECTIONS
V28	M	55 MEV	400 RADS	6505	7210	ORGAN DEGENERATION
V82	M	55 MEV	400 RADS	6505	7409	INFECTIONS
V96	M	55 MEV	400 RADS	6505	ALIVE	ALIVE
R50	M	55 MEV	600 RADS	6505	6911	BONE,SKIN,MUSCLE AND BLOOD TUMORS
R90	M	55 MEV	600 RADS	6505	7003	ACUTE GASTRIC DILITATION
S61	F	55 MEV	600 RADS	6505	7902	INFECTIONS
T22	M	55 MEV	600 RADS	6504	7007	ORGAN DEGENERATION
T73	F	55 MEV	600 RADS	6505	7611	ORGAN DEGENERATION
T81	F	55 MEV	600 RADS	6505	7308	NERVE TUMORS
U06	M	55 MEV	600 RADS	6504	6911	NERVE TUMORS
U53	F	55 MEV	600 RADS	6504	7512	INFECTIONS
U78	M	55 MEV	600 RADS	6504	ALIVE	ALIVE
V22	M	55 MEV	600 RADS	6505	ALIVE	ALIVE
V34	M	55 MEV	600 RADS	6505	6610	NERVE TUMORS
V54	M	55 MEV	600 RADS	6505	7708	NERVE TUMORS
V56	M	55 MEV	600 RADS	6505	7706	ORGAN DEGENERATION
V84	M	55 MEV	600 RADS	6505	7501	BONE,SKIN,MUSCLE AND BLOOD TUMORS
P50	M	55 MEV	800 RADS	6505	6612	ORGAN DEGENERATION
T80	M	55 MEV	800 RADS	6505	6706	INFECTIONS
U42	M	55 MEV	800 RADS	6504	6808	ORGAN DEGENERATION
U56	M	55 MEV	800 RADS	6505	6512	INFECTIONS
U60	M	55 MEV	800 RADS	6504	6803	INFECTIONS
U88	M	55 MEV	800 RADS	6504	6811	NERVE TUMORS
V20	M	55 MEV	800 RADS	6505	6606	NERVE TUMORS

MORTALITY DATA

MONKEY ID	SEX	ENERGY	DOSE	IRRAD DATE	DATE OF DEATH	CAUSE OF DEATH
V44	M	55 MEV	800 RADS	6505	6612	ORGAN DEGENERATION
W52	M	55 MEV	800 RADS	6504	7004	NERVE TUMORS
J07	F	138 MEV	CONTROLS	6501	ALIVE	ALIVE
J12	M	138 MEV	CONTROLS	6501	ALIVE	ALIVE
J17	F	138 MEV	CONTROLS	6501	ALIVE	ALIVE
L16	M	138 MEV	CONTROLS	6501	ALIVE	ALIVE
L22	M	138 MEV	CONTROLS	6501	ALIVE	ALIVE
L25	F	138 MEV	CONTROLS	6501	7009	ORGAN DEGENERATION
L27	F	138 MEV	CONTROLS	6501	7011	ACUTE GASTRIC DILITATION
G96	M	138 MEV	210 RADS	6501	ALIVE	ALIVE
H67	F	138 MEV	210 RADS	6501	7812	ORGAN DEGENERATION
H75	F	138 MEV	210 RADS	6501	7401	ENDOMETRIOSIS
J98	M	138 MEV	210 RADS	6501	7510	INFECTIONS
K48	M	138 MEV	210 RADS	6501	ALIVE	ALIVE
K67	F	138 MEV	210 RADS	6501	7805	ENDOMETRIOSIS
K70	M	138 MEV	210 RADS	6501	ALIVE	ALIVE
K84	M	138 MEV	210 RADS	6501	ALIVE	ALIVE
K92	M	138 MEV	210 RADS	6501	8008	VISCERA TUMORS
J56	M	138 MEV	360 RADS	6501	7810	BONE,SKIN,MUSCLE AND BLOOD TUMORS
J84	M	138 MEV	360 RADS	6501	ALIVE	ALIVE
K13	F	138 MEV	360 RADS	6501	ALIVE	ALIVE
K35	F	138 MEV	360 RADS	6501	ALIVE	ALIVE
K44	M	138 MEV	360 RADS	6501	ALIVE	ALIVE
K78	M	138 MEV	360 RADS	6501	7912	INFECTIONS
K94	M	138 MEV	360 RADS	6501	7605	INFECTIONS
L13	F	138 MEV	360 RADS	6501	7803	INFECTIONS
L19	F	138 MEV	360 RADS	6501	ALIVE	ALIVE
L23	F	138 MEV	360 RADS	6501	7611	ENDOMETRIOSIS
L28	M	138 MEV	360 RADS	6501	ALIVE	ALIVE
L50	M	138 MEV	360 RADS	6501	ALIVE	ALIVE
J54	M	138 MEV	500 RADS	6501	7001	INFECTIONS
J64	M	138 MEV	500 RADS	6501	ALIVE	ALIVE
J80	M	138 MEV	500 RADS	6501	ALIVE	ALIVE
K02	M	138 MEV	500 RADS	6501	ALIVE	ALIVE
K19	F	138 MEV	500 RADS	6501	6702	UNKNOWN
K34	M	138 MEV	500 RADS	6501	7504	BONE,SKIN,MUSCLE AND BLOOD TUMORS
K71	F	138 MEV	500 RADS	6501	ALIVE	ALIVE
H55	F	138 MEV	500 RADS	6501	6705	ORGAN DEGENERATION
J88	M	138 MEV	650 RADS	6501	6909	INFECTIONS
K43	F	138 MEV	650 RADS	6501	7712	ORGAN DEGENERATION
K73	F	138 MEV	650 RADS	6501	7104	ORGAN DEGENERATION

MORTALITY DATA

MONKEY ID	SEX	ENERGY	DOSE	IRRAD DATE	DATE OF DEATH	CAUSE OF DEATH
L75	F	400 MEV	CONTROLS	6503	7102	INFECTIONS
Q12	M	400 MEV	CONTROLS	6503	ALIVE	ALIVE
R39	F	400 MEV	CONTROLS	6503	ALIVE	ALIVE
R41	F	400 MEV	CONTROLS	6503	ALIVE	ALIVE
S66	M	400 MEV	CONTROLS	6503	ALIVE	ALIVE
S69	F	400 MEV	CONTROLS	6503	ALIVE	ALIVE
S99	F	400 MEV	CONTROLS	6503	ALIVE	ALIVE
T68	M	400 MEV	CONTROLS	6503	ALIVE	ALIVE
T70	M	400 MEV	CONTROLS	6503	ALIVE	ALIVE
T78	M	400 MEV	CONTROLS	6503	7701	INFECTIONS
L32	M	400 MEV	50 RADS	6503	ALIVE	ALIVE
P05	F	400 MEV	50 RADS	6503	7212	INFECTIONS
P12	M	400 MEV	50 RADS	6503	ALIVE	ALIVE
P24	M	400 MEV	50 RADS	6503	8101	INFECTIONS
R45	F	400 MEV	50 RADS	6503	7701	ENDOMETRIOSIS
S62	M	400 MEV	50 RADS	6503	8008	ACUTE GASTRIC DILITATION
S65	F	400 MEV	50 RADS	6503	ALIVE	ALIVE
L18	M	400 MEV	100 RADS	6503	6712	BONE,SKIN,MUSCLE AND BLOOD TUMORS
L74	M	400 MEV	100 RADS	6503	ALIVE	ALIVE
L78	M	400 MEV	100 RADS	6503	ALIVE	ALIVE
L92	M	400 MEV	100 RADS	6503	ALIVE	ALIVE
P04	M	400 MEV	100 RADS	6503	ALIVE	ALIVE
Q03	F	400 MEV	100 RADS	6503	ALIVE	ALIVE
R46	M	400 MEV	100 RADS	6503	7112	INFECTIONS
R59	F	400 MEV	100 RADS	6503	8002	ENDOMETRIOSIS
R71	F	400 MEV	100 RADS	6503	ALIVE	ALIVE
S73	F	400 MEV	100 RADS	6503	ALIVE	ALIVE
S88	M	400 MEV	100 RADS	6503	7601	UNKNOWN
T62	M	400 MEV	100 RADS	6503	ALIVE	ALIVE
L99	F	400 MEV	200 RADS	6503	ALIVE	ALIVE
M15	F	400 MEV	200 RADS	6503	ALIVE	ALIVE
M16	M	400 MEV	200 RADS	6503	ALIVE	ALIVE
N81	F	400 MEV	200 RADS	6503	7702	ENDOMETRIOSIS
N87	F	400 MEV	200 RADS	6503	7511	ORGAN DEGENERATION
P03	F	400 MEV	200 RADS	6503	7701	ENDOMETRIOSIS
P09	F	400 MEV	200 RADS	6503	7008	ORGAN DEGENERATION
P23	F	400 MEV	200 RADS	6503	ALIVE	ALIVE
P48	M	400 MEV	200 RADS	6503	6512	INFECTIONS
P85	F	400 MEV	200 RADS	6503	7805	ENDOMETRIOSIS
P95	F	400 MEV	200 RADS	6503	6608	ACUTE GASTRIC DILITATION
R63	F	400 MEV	200 RADS	6503	ALIVE	ALIVE

MORTALITY DATA

MONKEY ID	SEX	ENERGY	DOSE	IRRAD DATE	DATE OF DEATH	CAUSE OF DEATH
S43	F	400 MEV	200 RADS	6503	ALIVE	ALIVE
S60	M	400 MEV	200 RADS	6503	ALIVE	ALIVE
S68	M	400 MEV	200 RADS	6503	ALIVE	ALIVE
T74	M	400 MEV	200 RADS	6503	ALIVE	ALIVE
F88	M	400 MEV	400 RADS	6503	ALIVE	ALIVE
G04	M	400 MEV	400 RADS	6503	ALIVE	ALIVE
L17	F	400 MEV	400 RADS	6503	7912	ENDOMETRIOSIS
L87	F	400 MEV	400 RADS	6503	ALIVE	ALIVE
M17	F	400 MEV	400 RADS	6503	ALIVE	ALIVE
M27	F	400 MEV	400 RADS	6503	7206	ENDOMETRIOSIS
M30	M	400 MEV	400 RADS	6503	ALIVE	ALIVE
N77	F	400 MEV	400 RADS	6503	7911	ENDOMETRIOSIS
P06	M	400 MEV	400 RADS	6503	8011	BONE,SKIN,MUSCLE AND BLOOD TUMORS
P15	F	400 MEV	400 RADS	6503	7504	ENDOMETRIOSIS
P72	M	400 MEV	400 RADS	6503	ALIVE	ALIVE
P96	M	400 MEV	400 RADS	6503	7606	BONE,SKIN,MUSCLE AND BLOOD TUMORS
Q24	M	400 MEV	400 RADS	6503	6811	INFECTIONS
R08	M	400 MEV	400 RADS	6503	ALIVE	ALIVE
R55	F	400 MEV	400 RADS	6503	7705	ENDOMETRIOSIS
L84	M	400 MEV	600 RADS	6503	ALIVE	ALIVE
M22	M	400 MEV	600 RADS	6503	7503	ORGAN DEGENERATION
P89	F	400 MEV	600 RADS	6503	7604	INFECTIONS
R51	F	400 MEV	600 RADS	6503	7403	UNKNOWN
T66	M	400 MEV	600 RADS	6503	7804	INFECTIONS
U08	M	2300 MEV	CONTROLS	6510	ALIVE	ALIVE
U22	M	2300 MEV	CONTROLS	6510	ALIVE	ALIVE
V58	M	2300 MEV	CONTROLS	6510	7907	ORGAN DEGENERATION
V66	M	2300 MEV	CONTROLS	6510	7901	INFECTIONS
W43	F	2300 MEV	CONTROLS	6510	ALIVE	ALIVE
OA4	M	2300 MEV	CONTROLS	6510	ALIVE	ALIVE
6A0	M	2300 MEV	CONTROLS	6510	ALIVE	ALIVE
T49	F	2300 MEV	56 RADS	6510	ALIVE	ALIVE
U03	F	2300 MEV	56 RADS	6510	6907	INFECTIONS
U31	F	2300 MEV	56 RADS	6510	7710	ENDOMETRIOSIS
U45	F	2300 MEV	56 RADS	6510	ALIVE	ALIVE
U47	F	2300 MEV	56 RADS	6510	ALIVE	ALIVE
U55	F	2300 MEV	56 RADS	6510	7710	ENDOMETRIOSIS
W26	M	2300 MEV	56 RADS	6510	ALIVE	ALIVE
U05	F	2300 MEV	113 RADS	6510	7709	UNKNOWN
U37	F	2300 MEV	113 RADS	6510	8011	ENDOMETRIOSIS
U64	M	2300 MEV	113 RADS	6510	ALIVE	ALIVE

MORTALITY DATA

MONKEY ID	SEX	ENERGY	DOSE	IRRAD DATE	DATE OF DEATH	CAUSE OF DEATH
V64	M	2300 MEV	113 RADS	6510	7510	INFECTIONS
V72	M	2300 MEV	113 RADS	6510	ALIVE	ALIVE
V74	M	2300 MEV	113 RADS	6510	ALIVE	ALIVE
V76	M	2300 MEV	113 RADS	6510	ALIVE	ALIVE
V88	M	2300 MEV	113 RADS	6510	ALIVE	ALIVE
W04	M	2300 MEV	113 RADS	6510	ALIVE	ALIVE
6A8	M	2300 MEV	113 RADS	6510	ALIVE	ALIVE
S53	F	2300 MEV	225 RADS	6510	ALIVE	ALIVE
U15	F	2300 MEV	225 RADS	6510	ALIVE	ALIVE
U21	F	2300 MEV	225 RADS	6510	ALIVE	ALIVE
U23	F	2300 MEV	225 RADS	6510	8004	INFECTIONS
U33	F	2300 MEV	225 RADS	6510	8001	ENDOCRINE DISORDERS
U49	F	2300 MEV	225 RADS	6510	ALIVE	ALIVE
U57	F	2300 MEV	225 RADS	6510	7510	INFECTIONS
V46	M	2300 MEV	225 RADS	6510	ALIVE	ALIVE
V98	M	2300 MEV	225 RADS	6510	ALIVE	ALIVE
W15	F	2300 MEV	225 RADS	6510	7412	ENDOMETRIOSIS
W30	M	2300 MEV	225 RADS	6510	ALIVE	ALIVE
W33	F	2300 MEV	225 RADS	6510	ALIVE	ALIVE
W34	M	2300 MEV	225 RADS	6510	ALIVE	ALIVE
W39	F	2300 MEV	225 RADS	6510	7409	ENDOMETRIOSIS
0A2	M	2300 MEV	225 RADS	6510	ALIVE	ALIVE
U41	F	2300 MEV	395 RADS	6510	7401	ENDOMETRIOSIS
U43	F	2300 MEV	395 RADS	6510	7601	ENDOMETRIOSIS
U44	M	2300 MEV	395 RADS	6510	7110	BONE,SKIN,MUSCLE AND BLOOD TUMORS
U51	F	2300 MEV	395 RADS	6510	ALIVE	ALIVE
U83	F	2300 MEV	395 RADS	6510	7401	ENDOMETRIOSIS
V51	F	2300 MEV	395 RADS	6510	ALIVE	ALIVE
W08	M	2300 MEV	395 RADS	6510	7901	ORGAN DEGENERATION
W32	M	2300 MEV	395 RADS	6510	ALIVE	ALIVE
1A2	M	2300 MEV	395 RADS	6510	ALIVE	ALIVE
9A6	M	2300 MEV	395 RADS	6510	8104	ORGAN DEGENERATION
U16	M	2300 MEV	560 RADS	6510	ALIVE	ALIVE
U36	M	2300 MEV	560 RADS	6510	8010	INFECTIONS
U67	F	2300 MEV	560 RADS	6510	7303	INFECTIONS
W37	F	2300 MEV	560 RADS	6510	7201	UNKNOWN
AS0	M	SOLAR FLARE	CONTROLS	6904	ALIVE	ALIVE
AW4	M	SOLAR FLARE	CONTROLS	6904	ALIVE	ALIVE
BH6	M	SOLAR FLARE	CONTROLS	6904	ALIVE	ALIVE
H04	M	SOLAR FLARE	CONTROLS	6904	ALIVE	ALIVE
04N	M	SOLAR FLARE	CONTROLS	6904	ALIVE	ALIVE

MORTALITY DATA

MONKEY ID	SEX	ENERGY	DOSE	IRRAD DATE	DATE OF DEATH	CAUSE OF DEATH
7X7	F	SOLAR FLARE	CONTROLS	6904	ALIVE	ALIVE
8X5	F	SOLAR FLARE	CONTROLS	6904	ALIVE	ALIVE
AY4	M	SOLAR FLARE	300 RADS	6904	ALIVE	ALIVE
AY8	M	SOLAR FLARE	300 RADS	6904	7901	ACUTE GASTRIC DILITATION
BCO	M	SOLAR FLARE	300 RADS	6904	ALIVE	ALIVE
BE2	M	SOLAR FLARE	300 RADS	6904	ALIVE	ALIVE
BH4	M	SOLAR FLARE	300 RADS	6904	ALIVE	ALIVE
H28	M	SOLAR FLARE	300 RADS	6904	ALIVE	ALIVE
07K	F	SOLAR FLARE	300 RADS	6904	ALIVE	ALIVE
BE6	M	SOLAR FLARE	600 RADS	6904	ALIVE	ALIVE
BQ8	M	SOLAR FLARE	600 RADS	6904	ALIVE	ALIVE
BV6	M	SOLAR FLARE	600 RADS	6904	ALIVE	ALIVE
H40	M	SOLAR FLARE	600 RADS	6904	ALIVE	ALIVE
33H	F	SOLAR FLARE	600 RADS	6904	ALIVE	ALIVE
55K	F	SOLAR FLARE	600 RADS	6904	8103	ENDOMETRIOSIS
57H	F	SOLAR FLARE	600 RADS	6904	7709	ENDOMETRIOSIS
AWO	M	SOLAR FLARE	900 RADS	6904	ALIVE	ALIVE
BH8	M	SOLAR FLARE	900 RADS	6904	ALIVE	ALIVE
BL6	M	SOLAR FLARE	900 RADS	6904	ALIVE	ALIVE
05C	F	SOLAR FLARE	900 RADS	6904	ALIVE	ALIVE
63H	F	SOLAR FLARE	900 RADS	6904	7504	ORGAN DEGENERATION
87H	F	SOLAR FLARE	900 RADS	6904	ALIVE	ALIVE
93G	F	SOLAR FLARE	900 RADS	6904	ALIVE	ALIVE
AW6	M	SOLAR FLARE	1200 RADS S.E.	6904	ALIVE	ALIVE
BM8	M	SOLAR FLARE	1200 RADS S.E.	6904	7809	INFECTIONS
BP2	M	SOLAR FLARE	1200 RADS S.E.	6907	7807	BONE,SKIN,MUSCLE AND BLOOD TUMORS
67J	F	SOLAR FLARE	1200 RADS S.E.	6904	ALIVE	ALIVE
AB8	M	SOLAR FLARE	1200 RADS T.E.	6904	ALIVE	ALIVE
41J	F	SOLAR FLARE	1200 RADS T.E.	6904	ALIVE	ALIVE
6Y3	F	SOLAR FLARE	1200 RADS T.E.	6903	7907	ORGAN DEGENERATION

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