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**EFFECTS OF IRRADIATION AND
BLAST ON PULMONARY FUNCTION
IN SHEEP**

MASTER

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Lovelace Foundation
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Albuquerque, New Mexico

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FOREWORD

This report presents the results of studies conducted to investigate the effects of combined doses of radiation and blast on pulmonary function in sheep. Previous work in this area dealt with the acute and chronic effects of blast injury on pulmonary function. The data should be a useful adjunct in the development of criteria for the prognosis and treatment of nuclear weapons casualties.

ABSTRACT

The changes in pulmonary function that result following unilateral exposure to LD₅₀ doses of neutron-gamma irradiation and/or sublethal blast overpressures were investigated in sheep. Animals exposed to blast-only and radiation-plus-blast demonstrated large increments in venous admixture ($\dot{Q}_s/\dot{Q}$) on the day of insult followed by a major recovery toward baseline values during the first 24 hours following injury. The venous admixture of the blast-only animals approached baseline 7 days after exposure but that of the radiation-plus-blast sheep did not return to baseline until 21 days. The sheep exposed to radiation-only, blast-only, and radiation-plus-blast sustained similar reductions in mean carbon monoxide diffusing capacity (DL_{CO}) which were below that of the control mean at 2 days and 7 days post exposure. All of the radiation-only and radiation-plus-blast sheep that survived to or beyond 21 days displayed an overshoot or recovery to their individual baseline DL_{CO} values. The blast-only and radiation-plus-blast animals also exhibited an increased mean ineffective alveolar ventilation (VA_{Ineff}) which persisted from 1 to 14 days following the onset of trauma. The radiation-only sheep had an increased VA_{Ineff} from 2 through 7 days post exposure.

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The experimental work discussed in this manuscript was conducted according to the principles enunciated in the "Guide for Laboratory Animal Facilities and Care, " prepared by the National Academy of Sciences-National Research Council.

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EFFECTS OF IRRADIATION AND BLAST ON PULMONARY FUNCTION IN SHEEP

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INTRODUCTION

The type and mixture of injuries resulting from human exposure to nuclear weapons is dependent upon a number of factors, such as yield, burst height, shielding and structural characteristics of buildings, and geometry of exposure. Of these, uncertainties in regard to the last two are responsible for the greatest variability in current casualty estimates. Under most conditions of exposure, there is a high probability that a significant number of human beings will sustain mixed forms of injuries produced by radiation, blast, and thermal effects. Since any form of shielding will virtually eliminate early thermal effects, the major hazard to people inside buildings or other forms of protective structures would be from the effects of blast and radiation. Although pathological changes resulting from radiation or direct-blast injury have been well delineated (References 1 through 6), the relationship between tissue injury and impaired physiological function has not been adequately investigated; and it is this alteration in function which is responsible for death or morbidity.

Decrement in pulmonary function has been observed in animals exposed to both direct airblast and radiation (References 7 through 13); and the parameters involved, time sequence of events, and underlying causative factors have been different in the two cases. However, no attempts have been made to delineate the pathophysiological changes that might occur as a result of combined effects of radiation and blast on the lungs. The following study was therefore conducted to investigate sequential alterations in pulmonary function of sheep exposed to neutron-gamma radiation and/or airblast in order to obtain information which would be useful for casualty prediction as well as for the prognosis and treatment of nuclear weapons casualties.

MATERIALS AND METHODS

General

Twenty-one Columbia-Rambouillet cross ewes with an average body weight of 100 (82-110) pounds and 6 months to 1 year of age were selected at random for use in this study. The animals were sheared, then placed (seven per pen) in heated indoor facilities. Each subject was kept on a standard weight-maintenance diet of 2 pounds of pellet-type feed (Onate 70-20-10, Onate Feed Co., Albuquerque, New Mexico) per day. Water was provided ad libitum.

Catheterization

All animals were catheterized to facilitate arterial blood sampling (Reference 14). This was done by inserting a short length of vinyl tubing through the femoral artery into the abdominal aorta to a point anterior to the aortic-iliac bifurcation. After surgery, each animal received one million units of penicillin-streptomycin suspension I. M. and was allowed to stabilize for a minimum of 1 week before any pulmonary function tests were conducted.

Respiratory Physiology

Carbon monoxide diffusing capacity (DL_{CO}) determinations, using the steady-state technique, were conducted. During a DL_{CO} test, the subject was connected via a polyethylene mask to a Rudolph low-resistance, two-way pulmonary valve (Model No. 1400) modified to accommodate a Statham pressure transducer (P23db), for monitoring respiratory excursions, and an end-tidal trap. The animal was equilibrated on a 0.05 percent carbon-monoxide room-air mixture for approximately 3 minutes, then a 2- to 5-minute expired gas sample, depending on the animal's ventilatory rate, was collected in a 60-liter Douglas bag for analysis of carbon monoxide, carbon dioxide, and oxygen. End-tidal and expired- CO concentrations were recorded with an infra-red analyzer (Beckman IR215) hooked to a Honeywell 1508 Visicorder. The respiratory rate was also recorded on the Honeywell system. The expired CO_2 and O_2 fractions of the sample were determined by the Micro-Scholander method and by electrode systems

(Instrumentation Laboratories, Model 113-S1 blood-gas system and Beckman, Model 160 physiological gas analyzer with modular cuvette assembly). At the end of the DL_{CO} test, the mask was removed and the subject was released from the stanchion of the test platform and allowed to rest until the next series of tests. Venous blood samples were drawn immediately after the diffusing capacity test for hematocrit and hemoglobin determinations.

Other pulmonary function tests conducted involved the determination of venous admixture ($\dot{Q}_s/\dot{Q}$), ineffective alveolar ventilation (VA_{Ineff}), arterial-oxygen tension (PaO_2), arterial CO_2 tension ($PaCO_2$), and the pH of the arterial blood. The procedures utilized to obtain these parameters have been previously described in Reference 12.

Preexposure

Four DL_{CO} determinations were conducted on each animal at selected time intervals prior to radiation and/or blast exposure. The first two tests were done prior to catheterization. Each animal was treated with triflupromazine hydrochloride and atropine sulphate for the initial DL_{CO} determination but received no drug treatment in conjunction with any subsequent tests. Catheterization nor tranquilizers caused any significant change in DL_{CO} , so the mean value of all four preexposure tests for each animal was taken as that animal's baseline value. After catheterization, two preexposure runs were conducted on every subject for determination of the blood-gas parameters previously mentioned. The average value of each parameter from both runs was taken as an individual animal's baseline value.

Exposures

Twelve sheep were exposed unilaterally in pairs to an estimated LD_{50} , 60-day, dose of neutron-gamma irradiation, 535 (433-795) rads, delivered in pulse form at the Sandia Corporation Pulsed Reactor Facility (References 15 through 17). Each exposure was conducted with the two subjects suspended in canvas slings in aluminum restraining boxes and were oriented with their right sides to the reactor source. DL_{CO} , ventilation parameters, and $\dot{Q}_s/\dot{Q}$ tests were begun

on one member of each pair within 1 hour following exposure. Subjects in this group were designated as radiation-only animals. Within 3 hours following irradiation, the remaining animal from each pair was individually exposed with its left side against the endplate of a 42-inch-diameter air-driven shock tube (Reference 18). Inasmuch as the animals were against the endplate, the overpressure of interest was the reflected pressure which was 41.8 (40.3-43.0) p. s. i. (Table 1). Each animal was secured to the endplate by means of a harness made of cotton webbing. Pulmonary function tests were started on these animals within 30 minutes following blast and 4 hours following radiation exposure. These animals were assigned to the radiation-plus-blast group.

Using the same procedures that were followed for the combined injury sheep, a group of six sheep, designated as blast-only animals, were subjected to blast overpressure only. The reflected pressure was 41.0 (40.0-42.0) p. s. i. (Table 1).

Followup tests were done on each animal, if possible, at 1 day and 2 days following exposure, then at weekly intervals up to 4 weeks, and at 1- to 3-week intervals thereafter until death or sacrifice. Only two of the blast-only animals, No. 838 and No. 839, were followed for extended time records.

Three control animals were employed for this study. Testing was started on one animal at the beginning, another midway, and a third, at the end of the study. One of the controls was followed for 191 days, the other two were sacrificed at the end of 28 days.

At sacrifice or post-mortem, lung-tissue samples were processed for histological examination.

RESULTS

General Observations

Animals exposed to radiation or to radiation-plus-blast displayed similar clinical features. Anorexia and progressive weight loss were noted within 24 hours and persisted beyond 21 days in late nonsurvivors. Diarrhea was apparent as early as 2 days, and epilation had begun by 7 days post exposure. No marked

change in rectal temperature was observed; however, in two radiation-plus-blast animals, blood was noted in the feces and urine within 3 to 7 days post irradiation. There was an increase in susceptibility to bleeding in all irradiated subjects within the first 14 days following exposure and transient oral and nasal hemorrhage was common immediately following blast exposure.

Mortality

The dose-mortality relationships for the three groups are listed in Table 1. The early time to death ranged from 4 to 7 days in the radiation-only animals and resulted in a 50-percent mortality. The increased late mortality of this group was attributed to the dissection of catheter-induced false aortic aneurysms in Sheep Nos. 870 and 859.

The time of death of the radiation-plus-blast group ranged from 3 to 25 days and resulted in 83-percent mortality. The late death of Sheep No. 868 was also attributed to dissection of a false aortic aneurysm.

There were no deaths in the blast-only group that could be attributed directly to blast injury. Sheep No. 840 died at 7 days from traumatic peritonitis which was induced during catheterization, and Sheep No. 841 died at 57 days as a result of a dissecting false aortic aneurysm.

Pulmonary Function

The data shown in Table 2 and illustrated in Figure 1 present the individual and the mean changes in venous admixture ($\dot{Q}_s/\dot{Q}$) of the three experimental groups and the controls as a function of time. The controls and the radiation-only animals exhibited little or no change in $\dot{Q}_s/\dot{Q}$ through 21 days post exposure. However, both the blast-only and the radiation-plus-blast animals demonstrated an increase in $\dot{Q}_s/\dot{Q}$ on the day of insult followed by a major recovery toward baseline at 1 day post exposure. Most of the blast-only animals were within the baseline range 24 hours after being subjected to blast, but the mean $\dot{Q}_s/\dot{Q}$ did not approximate the baseline until 7 days following injury. The two radiation-plus-blast survivors that lived beyond 15 days did not recover to baseline values until 14 and 21 days, respectively, subsequent to exposure.

As seen in Table 3, the long-term survivors in the radiation-only and radiation-plus-blast groups displayed slight rises in $\dot{Q}_s/\dot{Q}$ greater than the upper limits of their individual ranges at time periods beyond 21 days. The same was true of the blast-only sheep that were followed for extended time periods. However, radiation-only Sheep No. 859 and blast-only Sheep No. 839 were the only animals revealing late changes that were clearly greater than the delayed increment shown by the control sheep at 50 days.

The data given in Table 4 shows that the blast-only and the radiation-plus-blast animals were hypoxic immediately after exposure but exhibited a progressive recovery through a 14-day period following initial injury.

With the exception of three animals, there were no remarkable post-exposure changes in arterial pH. As seen in Table 5, two of the blast-only, Sheep Nos. 841 and 896, had an uncompensated metabolic acidosis on the day of injury which had shifted to an uncompensated respiratory alkalosis on the following day. Sheep No. 866 of the radiation-plus-blast group displayed a terminal metabolic acidosis with a pH of 7.00 on the 14th day after exposure. This animal subsequently died in the a. m. of the 15th day.

With the exception of one group, the mean changes observed in the arterial CO_2 tensions (PaCO_2), which are presented in Table 6, were variable but did remain within the preexposure ranges. The radiation-plus-blast animals did demonstrate slight reductions in mean PaCO_2 both on the day of insult and the following day. If considered individually, Sheep No. 866 was decidedly hypocapnic on the 14th day with a PaCO_2 of 18.8 mm. Hg.

Although wide variability is inherent in the determination of ineffective alveolar ventilation (VA_{Ineff}), particularly in unanesthetized animals, both the blast-only and radiation-plus-blast animals exhibited a slight increase in mean VA_{Ineff} which persisted from 1 to 14 days (Table 7). Similarly, the radiation-only sheep displayed an insignificant increase which persisted from 2 to 7 days post exposure.

As presented in Table 3, the animals that were followed for prolonged periods demonstrated varied responses in VA_{Ineff} at times beyond 21 days.

All three experimental groups revealed slight reductions in mean carbon monoxide diffusing capacity (DL_{CO}) below that of the control means at 2 days and 7 days post exposure (Table 8). The radiation-plus-blast animals manifested a recovery toward baseline from 14 to 21 days. The radiation-only sheep exhibited an increase in mean DL_{CO} at 14 days which remained the same at 21 days. A similar pattern was established by the blast-only subjects with the exception that they showed the greatest reduction in mean DL_{CO} at 21 days following injury. Data presented in Table 3 show that the radiation-only animals that survived to or beyond 21 days demonstrated a recovery in DL_{CO} to near the upper limits of their baseline ranges and then established a cyclic pattern of change after the initial recovery phase.

Pulmonary Histology Alterations

The most significant histological alterations occurring in animals dying at early time periods following neutron-gamma irradiation consisted of early degenerative changes involving primarily bronchiolar epithelium, extensive congestion and edema, and focal areas of intraalveolar hemorrhage. By 7 days, evidence of regenerative hyperplasia was present, particularly in the terminal bronchioles. Although moderate congestion was still evident, these sections were devoid of granulocytes. The changes in later nonsurvivors were quite minimal, consisting primarily of perivascular and peribronchial interstitial edema with focal areas of subacute inflammation.

Only two nonsurvivors were available for study in the blast treatment group, and the changes in both subjects consisted of focal interstitial and patchy dense pulmonary fibrosis with perivascular and peribronchial chronic inflammation. Histiocytes in the areas of fibrosis and also around vessels contained an abundant quantity of hemosiderin. Occasional small focal abscesses were present, presumably of mycotic origin. The most significant difference between the pulmonary alterations observed in the radiation and blast treatment group and those receiving a solitary form of injury was the appearance of an extensive reactive proliferative hyperplasia involving both alveolar and bronchiolar epithelium. This was evident in animals dying both at 3 and 9 days post exposure and, to a

lesser extent, in the 15-day nonsurvivor. In addition, an agranulocytic necrotizing endobronchitis was noted in the animals that died 9 and 15 days following combined trauma but was most prominent in the 15-day nonsurvivor. Later nonsurvivors in this group showed minimal changes with interstitial and pulmonary fibrosis being considerably less marked than in animals that died following air-blast trauma only.

DISCUSSION

The most striking finding in this study was portrayed by the changes in the venous admixtures of the blast-only and the radiation-plus-blast animals (Table 2 and Figure 1). The large increments in venous admixtures displayed by both groups immediately after exposure are related to the degree of lung blast injury. As stated in Reference 12, an increased venous admixture is indicative of a continuation of blood flow through portions of the lungs that are no longer being ventilated. This is related histologically to the combined effects of atelectasis, intra-alveolar hemorrhage, hemorrhage-blocked airways, edema, and/or disrupted parenchymal tissue (Reference 6). The increase in venous admixture associated with these histopathological changes results in varying degrees of hypoxia and is exemplified by the immediate post-exposure reductions in PaO_2 of all the blast-only and radiation-plus-blast animals (Table 4). The marked reduction in venous admixture that occurs during the first 24 hours subsequent to injury is probably related primarily to the rate of resolution of edema and hemorrhage, and secondarily related to a reflex reduction of blood flow through nonventilated portions of the lungs and increased ventilatory rates. It has been previously demonstrated that the lung weights of rats, exposed to low-lethal blast doses, decrease as a function of time after blast injury to near control levels at the end of 7 days and that the major reduction in lung weight occurs during the first 24 hours subsequent to exposure (Reference 19). It has been further established in work with dogs, Reference 6, that there is a marked resolution of hemorrhage 7 days after onset of blast trauma, and generally a complete clearing by 21 days. As indicated in Figure 1, the mean $\dot{Q}_s/\dot{Q}$ of the blast-only sheep is at baseline by 7 days. However, if blast is superimposed on animals

previously exposed to LD₅₀ levels of radiation, the rate of clearing of lung hemorrhage and edema may be retarded as is implied by the slower return of the $\dot{Q}_s/\dot{Q}$ to baseline in the radiation-plus-blast animals. The single long-term survivor, Sheep No. 868, did not return to baseline until 14 days following injury (Table 2). Sheep No. 862 died at 25 days and demonstrated a normal $\dot{Q}_s/\dot{Q}$ value at 21 days post exposure (Table 2). The two blast-only sheep and the single radiation-plus-blast survivor that were tested for extended time periods did exhibit increases in $\dot{Q}_s/\dot{Q}$ at times beyond 35 days (Table 3). Although these changes might be related to the development of multiple fibrotic foci (Reference 6), their significance is questionable since the control demonstrated similar changes. Radiation alone apparently does not induce any pathological changes that are extensive enough to increase venous admixture during the first 3 weeks following exposure inasmuch as the mean $\dot{Q}_s/\dot{Q}$ of the radiation-only animals remained fairly stable throughout this time (Table 2 and Figure 1). The three long-term radiation-only survivors did show increments in $\dot{Q}_s/\dot{Q}$ at times beyond 3 weeks, which again may be due to nonspecific causes or might be due to pneumonia or edema (Table 3).

The radiation-only sheep manifested the greatest degree of change in DL_{CO} and VA_{Ineff} at 2 and 7 days post exposure (Tables 7 and 8). The early changes seen on the day of exposure and at 24 hours are probably due, in part, to nonspecific changes in ventilatory response inasmuch as the control animals also demonstrated marked changes at these time periods. According to References 1 and 2, early reaction of the pulmonary system to irradiation starts with an alteration involving alveolar cells and capillary endothelium with resultant edema, swelling, necrosis, and then proliferation of alveolar epithelium and capillary endothelium. Histological examination of lung tissue from Sheep No. 865, a 4-day death, did reveal the presence of congestion, and focal areas of hemorrhage and edema. The 7-day death, Sheep No. 867, presented a picture of persistent patchy hemorrhage and edema, and conspicuous regenerative hyperplasia of bronchial and bronchiolar epithelium. The changes described above might effectively reduce diffusing capacity in two ways: (1) by increasing the diffusion-path length via the development of interstitial edema and thickening of alveolar

and capillary linings, and (2) by decreasing the alveolar surface area available for gas exchange as a result of intra-alveolar edema, hemorrhage, and necrosis of viable tissue. The reduction in effective surface area is also reflected as an increase in effective alveolar ventilation (Table 7).

Previous work, using dogs exposed to X-irradiation, failed to reveal any diffusion impairments in the first few weeks following irradiation (References 7 and 9). It is possible that the radiation doses utilized were not high enough to effect these early changes and that the animals were monitored at inappropriate times. In addition, it has been found that animals exposed to fission-spectrum neutrons are considerably more susceptible to peribronchial and perivascular hemorrhage than dogs exposed to X-ray (Reference 3).

The blast-only and radiation-plus-blast animals demonstrated changes in DL_{CO} and VA_{Ineff} at 2 and 7 days that are similar to the radiation-only animals (Tables 7 and 8). In the case of the blast-only animals, the surprisingly prolonged reduction in DL_{CO} and the increase in VA_{Ineff} may be due, in part, to nonspecific changes in ventilatory parameters but may also be attributed to persistent interstitial edema and congestion. The changes in DL_{CO} and VA_{Ineff} of the radiation-plus-blast sheep are due to the combined effects of radiation reaction and blast trauma. Histological findings appear to indicate that the alteration in respiratory function of the radiation-plus-blast sheep is due to persistent congestion and focal areas of hemorrhage and edema out to 3 days post exposure. From 9 to 15 days, pulmonary deficiency could be attributed to multiple areas of adenomatous proliferation of alveolar duct epithelium and the filling of alveolar spaces with histiocytes, alveolar lining cells, and fibrin-like deposits. These changes would have the principle effect of reducing the surface area available for gas exchange. The anatomic changes seen in the 25-day death indicates minimal levels of injury.

All of the radiation-only and radiation-plus-blast animals that survived to or beyond 21 days demonstrated an overshoot or recovery to DL_{CO} baseline values after which time they exhibited a further decrease in DL_{CO} (Table 3). According to Reference 9, similar changes occur in the DL_{CO} of dogs unilaterally exposed

to protracted doses of X-irradiation. It was found that the subjects had an increased diffusing capacity at 1 and 3 weeks following irradiation. This was thought to be the result of the hyperemic stage of inflammation inasmuch as it was felt that during this period there would be an increased capillary blood volume.

There were no significant changes in the other parameters measured with the exception of the moderate changes in arterial pH which were exhibited by two of the blast-only animals and the reduction in pH and PaCO_2 of the radiation-plus-blast Sheep No. 866 on the 14th day after exposure. This animal was moribund at the time of testing and subsequently died during the a.m. of the 15th day.

These results indicate that the combined stresses of radiation and blast results in an early, more substantial increase in venous admixture than is seen in animals receiving similar levels of injury administered singly and that recovery to preexposure values progresses at a somewhat slower rate. Therefore, one might anticipate that humans similarly exposed would also display an enhanced impairment in respiratory function which might be aggravated by strenuous exercise. Further, one would not expect complete physiological recovery to occur within the same time period as that following blast injury.

TABLE 1

DOSE-RESPONSE RELATIONSHIPS OF THE RADIATION-ONLY,
BLAST-ONLY, AND RADIATION-PLUS-BLAST SHEEP

Animal No.	Exposure Weight, lb	Radiation Dose (Rads)			Blast Dose (Psi)		Time of Death
		Neutron	Gamma	Total	P _s ^a	P _r ^b	
RADIATION-ONLY GROUP							
867	110	588	207	795	-	-	7 days
871	95	390	100	490	-	-	5 days
872	107	417	107	524	-	-	-
870	107	370	63	433	-	-	101 days ^c
859	104	350	89	439	-	-	168 days ^c
865	102	417	111	528	-	-	4 days
$\bar{x}$	104	422	113	535	-	-	-
Range	(95-110)	(350-588)	(63-207)	(433-795)	-	-	-
BLAST-ONLY GROUP							
838	95	-	-	-	13.7	40.1	-
839	110	-	-	-	12.8	40.0	-
840	105	-	-	-	13.3	41.5	8 days ^d
841	94	-	-	-	13.4	42.0	57 days ^c
889	110	-	-	-	13.5	41.5	-
896	86	-	-	-	14.4	41.0	-
$\bar{x}$	100	-	-	-	13.5	41.0	-
Range	(86-110)	-	-	-	(12.8-14.4)	(40.0-42.0)	-
RADIATION-PLUS-BLAST GROUP							
861	100	588	207	795	12.8	40.3	9 days
862	105	390	100	490	13.6	42.5	25 days
860	107	417	107	524	13.9	41.3	3 days
869	105	370	63	433	14.7	43.0	5 days
866	96	350	89	439	14.1	41.7	15 days
868	95	417	111	528	14 ^e	42 ^e	133 days ^c
$\bar{x}$	101	422	113	535	13.8	41.8	-
Range	(95-107)	(350-588)	(63-207)	(433-795)	(12.8-14.7)	(40.3-43.0)	-

a. Incident Pressure.

b. Reflected Pressure.

c. Death result of dissected false aortic aneurysm.

d. Death result of non-blast induced traumatic peritonitis.

e. Estimated.

TABLE 2
CHANGES IN PERCENT VENOUS ADMIXTURE ($\bar{Q}_s/\bar{Q}$)
WITH TIME AFTER EXPOSURE

Animal No.	Pre-Exposure Mean	Days Post-Exposure					
		0	1	2	7	14	21
RADIATION-ONLY GROUP							
867	7.4	7.4	-	8.0	-	-	-
871	6.2	6.5	7.3	7.2	-	-	-
872	7.2	7.9	6.3	6.7	7.8	8.1	6.8
870	6.9	8.4	8.8	9.3	7.3	6.7	7.6
859	9.1	7.8	9.3	11.5	8.5	6.8	6.5
865	8.3	6.4	7.8	6.3	-	-	-
Mean	7.5	7.4	7.9	8.2	7.9	7.2	7.0
Range	6.2-9.1	6.4-8.4	6.3-9.3	6.3-11.5	7.3-8.5	6.7-8.1	6.5-7.6
SD	1.10	0.80	1.19	1.86	0.60	0.78	0.57
SE	0.45	0.33	0.53	0.76	0.35	0.45	0.33
BLAST-ONLY GROUP							
838	5.4	16.6	8.5	6.4	5.8	7.7	7.4
839	6.4	-	-	-	-	-	-
840	13.1	14.6	15.0	13.1	7.6	-	-
841	8.0	14.3	8.5	12.4	-	-	6.9
889	12.0	17.6	12.4	10.0	7.1	8.0	-
896	8.2	33.9	10.8	10.3	9.8	9.5	8.2
Mean	8.8	19.4	11.0	10.4	7.6	8.4	7.5
Range	5.4-13.1	14.3-33.9	8.5-15.0	6.4-13.1	5.8-9.8	7.7-9.5	6.9-8.2
SD	3.15	8.22	2.86	2.72	1.59	0.96	0.66
SE	1.29	3.68	1.28	1.22	0.79	0.56	0.38
RADIATION-PLUS-BLAST GROUP							
861	6.4	46.7	15.1	14.8	14.6	-	-
862	6.6	20.3	12.9	10.9	9.7	10.2	7.4
860	6.9	19.9	10.1	13.8	-	-	-
869	7.2	34.3	12.4	11.6	-	-	-
866	7.8	27.4	12.2	12.0	8.9	14.0	-
868	7.6	19.4	12.9	11.9	12.6	7.3	5.4
Mean	7.1	28.0	12.6	12.5	11.4	10.5	6.4
Range	6.4-7.8	19.4-46.7	10.1-15.1	10.9-14.8	8.9-14.6	7.3-14.0	5.4-7.4
SD	0.40	10.85	1.60	1.48	2.78	3.36	1.41
SE	0.17	4.43	0.66	0.60	1.39	1.94	1.00
CONTROL GROUP							
863	8.8	7.3	7.3	9.8	8.6	9.2	-
864	7.2	9.0	8.5	7.5	8.0	8.3	10.1
895	9.4	7.6	7.7	9.7	8.7	-	7.8
Mean	8.5	8.0	7.8	9.0	8.4	8.8	9.0
Range	7.2-9.4	7.3-9.0	7.3-8.5	7.5-9.8	8.0-8.7	8.3-9.2	7.8-10.1
SD	0.93	0.65	0.87	1.30	0.24	0.64	1.32
SE	0.54	0.38	0.50	0.75	0.14	0.45	0.94

TABLE 3

EFFECTS OF NEUTRON-GAMMA IRRADIATION AND/OR BLAST ON THE VENOUS ADMIXTURE ($\dot{Q}_s/\dot{Q}$), CARBON MONOXIDE DIFFUSING CAPACITY (DLCO), AND INEFFECTIVE ALVEOLAR VENTILATION ($V_{A\text{Ineff}}$) AT EXTENDED TIME PERIODS

Day	Radiation-Only Group									Blast-Only Group									Radiation-Plus-Blast Group									Control		
	Sheep No. 872			Sheep No. 870			Sheep No. 859			Sheep No. 838			Sheep No. 839			Sheep No. 862			Sheep No. 868			Sheep No. 864								
	$\dot{Q}_s/\dot{Q}^a$	DLCO ^b	$V_{A\text{Ineff}}^c$	$\dot{Q}_s/\dot{Q}$	DLCO	$V_{A\text{Ineff}}$	$\dot{Q}_s/\dot{Q}$	DLCO	$V_{A\text{Ineff}}$	$\dot{Q}_s/\dot{Q}$	DLCO	$V_{A\text{Ineff}}$	$\dot{Q}_s/\dot{Q}$	DLCO	$V_{A\text{Ineff}}$	$\dot{Q}_s/\dot{Q}$	DLCO	$V_{A\text{Ineff}}$	$\dot{Q}_s/\dot{Q}$	DLCO	$V_{A\text{Ineff}}$	$\dot{Q}_s/\dot{Q}$	DLCO	$V_{A\text{Ineff}}$	$\dot{Q}_s/\dot{Q}$	DLCO	$V_{A\text{Ineff}}$	$\dot{Q}_s/\dot{Q}$	DLCO	$V_{A\text{Ineff}}$
Pre-exposure $\bar{x}$	7.2	17.2	-0.5	6.9	15.2	22.8	9.1	9.8	11.1	5.4	12.8	11.4	6.4	8.4	6.7	6.6	13.9	6.4	7.6	9.6	13.1	7.2	14.4	7.4						
Pre-exposure Range	6.3 to 8.0	9.8 to 21.5	-2.6 to 1.6	6.3 to 7.5	11.1 to 19.6	16.1 to 29.5	5.8 to 12.4	7.2 to 11.9	7.4 to 14.8	2.9 to 7.9	11.2 to 14.4	6.6 to 16.1	6.1 to 6.8	5.4 to 10.0	0.8 to 12.7	6.5 to 6.7	10.5 to 21.4	4.5 to 8.2	7.3 to 7.8	7.1 to 11.8	-9.1 to 35.4	6.9 to 7.4	10.5 to 14.5	2.3 to 12.5						
0	7.9	10.9	3.4	8.4	10.9	33.8	7.8	7.6	29.8	16.6	7.0	29.2	-	4.7	-	20.3	8.0	14.3	19.4	11.9	39.1	9.0	8.9	27.6						
2	6.3	10.7	11.4	8.8	11.3	36.6	9.3	7.7	17.1	8.5	14.2	14.5	-	6.8	-	12.9	7.4	25.5	12.9	14.6	43.9	8.5	7.8	20.3						
7	6.7	9.4	23.3	9.3	6.9	39.6	11.5	7.7	14.9	6.4	7.0	24.0	-	6.5	-	10.9	7.7	22.1	11.9	10.4	31.8	7.5	14.3	24.4						
14	7.8	8.8	16.5	7.3	7.0	50.8	8.5	7.4	23.0	5.8	5.9	-1.2	-	6.9	-	9.7	8.9	43.1	12.6	6.6	22.3	8.0	13.2	9.3						
21	8.1	9.7	11.2	6.7	8.1	37.2	6.8	12.8	7.2	7.7	7.1	33.9	-	-	-	10.2	9.7	29.1	7.3	6.1	34.9	8.3	11.3	24.4						
28	6.8	12.3	23.8	7.6	10.0	8.8	6.5	7.9	2.8	7.4	5.4	9.8	-	10.0	-	7.4	15.2	25.2	5.4	8.6	8.1	10.1	15.5	15.1						
31	-	-	-	-	12.5	-	-	8.6	-	-	-	-	-	6.2	-	-	-	-	5.5	11.6	8.2	8.3	10.6	12.8						
35	5.2	13.0	5.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
42	-	-	-	4.2	16.0	11.1	-	-	-	10.7	9.2	27.7	-	7.7	-	-	-	-	-	-	-	-	-	-						
44	-	-	-	5.2	11.3	10.3	-	8.0	-	-	-	-	-	-	-	-	-	-	6.5	15.4	12.2	-	-	-						
49	5.9	20.1	9.3	-	-	-	17.0	10.8	26.1	9.2	9.3	24.9	-	7.0	-	-	-	-	-	-	-	-	-	-						
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11.2	14.2	4.4						
56	-	-	-	6.5	14.2	28.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
58	5.9	11.6	11.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.1	10.2	11.5	7.3	14.9	7.8						
62	-	-	-	-	-	-	20.6	7.5	13.6	6.4	8.1	10.2	-	8.6	-	-	-	-	6.2	8.6	3.5	-	-	-						
63	5.6	10.7	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
65	-	-	-	11.0	9.0	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
72	8.4	11.3	10.2	-	-	-	-	-	-	7.9	7.2	17.6	-	-	-	-	-	-	-	-	-	7.5	11.8	13.0						
76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
77	-	-	-	-	-	-	-	11.9	9.1	-	-	-	-	-	-	9.4	7.5	30.4	-	-	-	-	-	-						
79	6.0	10.6	-11.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
84	-	-	-	5.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
87	6.1	16.4	-5.0	-	-	-	-	12.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
91	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.1	9.5	16.7	5.3	14.0	24.3						
98	-	-	-	7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
101	5.1	10.9	5.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.9	16.4	12.7						
105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
107	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
112	-	-	-	-	-	-	-	-	-	11.9	12.5	10.1	-	-	-	-	-	-	8.6	6.9	25.4	-	-	-						
113	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
115	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
117	-	10.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
118	-	-	-	-	-	-	-	13.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
119	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.5	7.4	44.9	-	-	-						
124	-	-	-	-	-	-	-	10.3	-	-	-	-	-	-	-	-	-	-	-	-	-	7.9	17.5	-0.03						
134	-	15.0	-	-	-	-	-	7.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
138	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
141	4.5	10.9	20.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
142	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
152	-	-	-	-	-	-	7.1	11.2	-0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
164	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
176	6.5	12.1	-0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
185	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
191	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
202	9.3	10.8	-0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.1	10.5	27.3						

a (%).

b (ml/min/mmHg).

c (%).

TABLE 4

CHANGES IN ARTERIAL PaO_2 (mm. Hg)
WITH TIME AFTER EXPOSURE

Animal No.	Pre-Exposure	Days Post-Exposure					
	Mean	0	1	2	7	14	21
RADIATION-ONLY GROUP							
867	67.7	62.3	-	60.1	-	-	-
871	62.2	62.4	58.8	61.2	-	-	-
872	61.2	58.9	63.5	60.4	57.4	62.3	61.2
870	67.6	67.1	62.4	64.3	62.4	62.4	59.8
859	62.2	63.5	58.9	59.6	62.4	61.9	54.2
865	66.9	63.3	63.1	61.1	-	-	-
Mean	64.6	62.9	61.3	61.1	60.7	62.2	58.4
Range	61.2-67.7	58.9-67.1	58.8-63.5	59.6-64.3	57.4-62.4	61.9-62.4	54.2-61.2
SD	3.46	2.87	2.90	2.00	3.37	0.26	3.70
SE	1.41	1.17	1.30	0.82	1.95	0.15	2.14
BLAST-ONLY GROUP							
838	67.5	48.1	59.8	59.8	62.8	64.5	60.4
839	65.9	-	-	-	-	-	-
840	71.0	52.9	63.7	34.0	61.3	-	-
841	64.8	49.2	62.2	68.0	-	-	56.3
889	58.0	38.7	51.6	58.1	54.9	59.6	-
896	55.6	38.5	48.1	51.6	50.4	55.4	57.4
Mean	63.8	45.5	57.1	54.3	57.4	59.8	58.0
Range	55.6-71.0	38.5-52.9	48.1-63.7	34.0-68.0	50.4-62.8	55.4-64.5	56.3-60.4
SD	5.86	6.44	6.75	12.76	5.42	4.87	2.72
SE	2.39	2.88	3.02	5.71	2.71	2.81	1.57
RADIATION-PLUS-BLAST GROUP							
861	65.6	42.7	51.6	48.1	54.0	-	-
862	65.1	49.1	56.5	49.3	55.4	64.6	58.8
860	65.1	46.2	56.3	55.4	-	-	-
869	60.5	41.8	56.4	58.8	-	-	-
866	64.8	37.3	53.4	48.3	61.2	84.5	-
868	64.4	50.8	58.9	56.4	58.9	62.6	57.1
Mean	64.2	44.6	55.5	52.7	57.4	70.6	58.0
Range	60.5-65.6	37.3-50.8	51.6-58.9	48.1-58.8	54.0-61.2	62.6-84.5	57.1-58.8
SD	2.72	5.28	2.80	4.81	2.97	11.96	1.20
SE	1.11	2.16	1.14	1.96	1.49	6.91	0.85
CONTROL GROUP							
863	60.6	59.6	61.2	40.8	64.8	60.1	-
864	63.6	62.5	60.1	61.6	58.5	64.8	64.8
895	55.6	55.7	50.3	57.1	54.8	-	49.5
Mean	59.9	59.3	57.2	53.2	59.4	62.4	57.2
Range	55.6-63.6	55.7-62.5	50.3-61.2	40.8-61.6	54.8-64.8	60.1-64.8	49.5-64.8
SD	4.40	2.95	6.00	10.82	4.75	4.16	10.55
SE	2.54	1.70	3.46	6.25	2.74	2.94	7.46

TABLE 5
CHANGES IN ARTERIAL pH WITH TIME AFTER EXPOSURE

Animal No.	Pre-Exposure	Days Post-Exposure					
	Mean	0	1	2	7	14	21
RADIATION-ONLY GROUP							
867	7.46	7.46	-	7.49	-	-	-
871	7.50	7.50	7.44	7.49	-	-	-
872	7.50	7.48	7.47	7.45	7.43	7.40	7.43
870	7.47	7.43	7.44	7.46	7.38	7.44	7.46
859	7.42	7.42	7.45	7.43	7.43	7.43	7.45
865	7.39	7.40	7.44	7.40	-	-	-
Mean	7.46	7.45	7.45	7.45	7.41	7.42	7.45
Range	7.42-7.50	7.40-7.50	7.44-7.47	7.40-7.49	7.38-7.43	7.40-7.44	7.43-7.46
SD	0.04	0.07	0.01	0.06	0.07	0.06	0.01
SE	0.02	0.03	0.01	0.03	0.04	0.04	0.01
BLAST-ONLY GROUP							
838	7.45	7.49	7.47	7.50	7.48	7.48	7.49
839	7.40	-	-	-	-	-	-
840	7.44	7.45	7.43	7.56	7.40	-	-
841	7.46	7.21	7.51	7.49	-	-	7.44
889	7.45	7.41	7.47	7.54	7.50	7.54	-
896	7.47	7.22	7.50	7.51	7.42	7.50	7.35
Mean	7.44	7.36	7.48	7.52	7.45	7.51	7.43
Range	7.40-7.47	7.21-7.49	7.43-7.51	7.49-7.56	7.40-7.50	7.48-7.54	7.35-7.49
SD	0.02	0.13	0.03	0.03	0.05	0.02	0.04
SE	0.01	0.06	0.01	0.01	0.02	0.01	0.02
RADIATION-PLUS-BLAST GROUP							
861	7.47	7.46	7.47	7.50	7.48	-	-
862	7.46	7.48	7.42	7.47	7.44	7.42	7.48
860	7.48	7.50	7.44	7.50	-	-	-
869	7.47	7.40	7.46	7.46	-	-	-
866	7.46	7.42	7.43	7.40	7.47	7.00	-
868	7.46	7.43	7.43	7.47	7.41	7.47	7.42
Mean	7.47	7.45	7.44	7.47	7.45	7.30	7.45
Range	7.46-7.48	7.40-7.50	7.42-7.47	7.46-7.50	7.41-7.48	7.00-7.47	7.42-7.48
SD	0.006	0.07	0.12	0.03	0.03	0.25	0.04
SE	0.003	0.03	0.05	0.01	0.02	0.14	0.03
CONTROL GROUP							
863	7.44	7.47	7.45	7.43	7.48	7.45	-
864	7.45	7.47	7.46	7.39	7.42	7.43	7.41
895	7.47	7.47	7.42	7.39	7.47	-	7.46
Mean	7.45	7.47	7.44	7.40	7.46	7.44	7.44
Range	7.44-7.47	7.47-7.47	7.42-7.46	7.39-7.43	7.42-7.48	7.43-7.45	7.41-7.46
SD	0.06	0.00	0.06	0.07	0.03	0.01	0.04
SE	0.04	0.00	0.04	0.04	0.01	0.01	0.03

TABLE 6
CHANGES IN ARTERIAL PaCO₂ (mm. Hg)
WITH TIME AFTER EXPOSURE

Animal No.	Pre-Exposure	Days Post-Exposure					
	Mean	0	1	2	7	14	21
RADIATION-ONLY GROUP							
867	39.0	37.7	-	37.2	-	-	-
871	34.2	32.4	30.3	32.7	-	-	-
872	37.4	36.0	32.6	35.6	34.6	41.0	42.9
870	34.6	32.4	32.3	34.5	32.9	36.8	36.0
859	41.5	34.9	31.6	36.4	36.6	37.8	34.4
865	29.3	35.9	36.9	41.6	-	-	-
Mean	36.0	34.9	32.7	36.3	34.7	38.5	37.8
Range	29.3-41.5	32.4-37.7	30.3-36.9	32.7-41.6	32.9-36.6	36.8-41.0	34.4-42.9
SD	4.27	1.95	2.80	3.25	1.85	2.60	4.30
SE	1.74	0.80	1.25	1.33	1.07	1.50	2.48
BLAST-ONLY GROUP							
838	34.8	33.8	35.8	39.1	34.2	30.8	33.4
839	37.0	-	-	-	-	-	-
840	25.6	31.4	27.3	53.1	28.3	-	-
841	35.5	38.0	27.1	25.1	-	-	38.0
889	35.0	46.3	35.8	33.6	34.2	34.8	-
896	41.0	43.6	29.3	34.7	34.7	30.4	36.9
Mean	34.8	38.6	31.1	37.1	32.8	32.0	36.1
Range	25.6-41.0	31.4-46.3	27.1-35.8	25.1-53.1	28.3-34.7	30.4-34.8	33.4-38.0
SD	5.14	6.39	4.23	10.32	3.38	2.43	2.40
SE	2.10	2.86	1.89	4.61	1.69	1.40	1.39
RADIATION-PLUS-BLAST GROUP							
861	35.4	41.8	34.0	40.3	38.3	-	-
862	34.4	28.8	29.5	32.7	37.0	42.7	30.5
860	34.6	34.4	29.8	32.7	-	-	-
869	33.8	31.7	30.2	30.6	-	-	-
866	35.6	20.8	29.0	30.2	28.6	18.8	-
868	34.8	32.1	32.2	34.5	35.5	42.1	37.2
Mean	34.8	31.6	30.8	33.5	34.8	34.5	33.8
Range	33.8-35.6	20.8-41.8	29.0-34.0	30.2-40.3	28.6-38.3	18.8-42.7	30.5-37.2
SD	0.55	6.88	1.76	3.68	4.58	13.69	5.08
SE	0.22	2.81	0.72	1.50	2.29	7.90	3.59
CONTROL GROUP							
863	36.4	35.6	39.0	39.2	38.4	38.2	-
864	33.8	34.7	35.2	31.8	34.8	33.8	33.5
895	41.0	53.2	42.2	33.4	32.6	-	36.0
Mean	37.0	41.2	38.8	34.8	35.3	36.0	34.8
Range	33.8-41.0	34.7-53.2	35.0-42.2	31.8-39.2	32.6-38.4	33.8-38.2	33.5-36.0
SD	3.38	10.33	3.50	3.89	2.61	3.11	1.77
SE	1.95	5.97	2.02	2.25	1.51	2.20	1.25

TABLE 7

CHANGES IN PERCENT INEFFECTIVE ALVEOLAR
VENTILATION (VA_{Ineff}) WITH TIME AFTER EXPOSURE

Animal No.	Pre-Exposure Mean	Days Post-Exposure					
		0	1	2	7	14	21
RADIATION-ONLY GROUP							
867	45.8	31.5	-	20.8	-	-	-
871	8.0	17.7	3.0	7.0	-	-	-
872	-0.5	34.4	11.4	23.3	16.5	11.2	23.8
870	22.8	33.8	36.6	39.6	50.8	37.2	8.8
859	11.1	29.8	17.1	14.9	23.0	7.2	2.8
865	-17.7	15.6	31.7	32.2	-	-	-
Mean	11.6	27.1	20.0	23.0	30.1	18.5	11.8
Range	-17.7-45.8	15.6-34.4	3.0-36.6	7.0-39.6	16.5-50.8	7.2-37.2	2.8-23.8
SD	21.50	8.38	13.96	11.68	18.22	16.32	10.82
SE	8.78	3.42	6.24	4.77	10.52	9.42	6.24
BLAST-ONLY GROUP							
838	11.4	29.2	14.5	24.0	-1.2	33.9	9.8
839	6.8	-	-	-	-	-	-
840	2.4	30.8	31.0	58.8	29.7	-	-
841	9.0	1.2	15.1	9.1	-	-	2.8
889	18.2	55.1	35.8	33.6	35.4	42.4	-
896	11.4	56.5	42.5	49.1	44.1	13.1	19.2
Mean	9.9	34.6	27.8	34.9	27.0	29.8	10.6
Range	2.4-18.2	1.2-56.5	15.1-42.5	9.1-58.8	-1.2-44.1	13.1-42.4	2.8-19.2
SD	5.26	22.65	12.51	19.76	19.71	15.07	8.23
SE	2.15	10.13	5.59	8.84	9.86	8.70	4.75
RADIATION-PLUS-BLAST GROUP							
861	10.6	44.4	26.7	26.3	19.5	-	-
862	6.4	14.3	25.5	22.1	43.1	29.1	25.2
860	21.1	16.0	11.1	7.7	-	-	-
869	6.4	41.4	42.9	31.5	-	-	-
866	18.8	23.6	44.6	18.5	11.2	9.0	-
868	13.2	39.1	43.9	31.8	22.3	34.9	8.1
Mean	12.8	29.8	32.4	23.0	24.0	24.3	16.6
Range	6.4-21.1	14.3-44.4	11.1-44.6	7.7-31.8	11.2-43.1	9.0-34.9	8.1-25.2
SD	6.13	13.44	13.67	9.09	13.59	13.64	12.16
SE	2.50	5.49	5.58	3.71	6.80	7.87	8.60
CONTROL GROUP							
863	33.0	30.1	23.0	9.1	16.3	17.8	-
864	7.4	27.6	20.3	24.4	9.3	26.6	15.1
895	11.4	46.3	28.8	15.0	3.1	-	14.0
Mean	17.3	34.7	24.0	16.2	9.6	22.2	14.6
Range	7.4-33.0	27.6-46.3	20.3-28.8	9.1-24.4	3.1-16.3	17.8-26.6	14.0-15.1
SD	13.74	10.07	4.48	7.66	6.57	6.22	0.78
SE	7.93	5.81	2.59	4.42	3.79	4.40	0.55

TABLE 8

CHANGES IN CARBON MONOXIDE DIFFUSING CAPACITY
(DL_{CO}, ml./min/mm. Hg) WITH TIME AFTER EXPOSURE

Animal No.	Pre-Exposure Mean	Days Post-Exposure					
		0	1	2	7	14	21
RADIATION-ONLY GROUP							
867	12.6	9.3	8.3	12.0	-	-	-
871	13.2	7.3	10.4	8.6	-	-	-
872	17.2	10.9	10.7	9.4	8.8	9.7	12.3
870	15.2	10.9	11.3	6.9	7.0	8.1	10.0
859	9.8	7.6	7.7	7.7	7.4	12.8	7.9
865	13.2	7.2	14.6	7.4	-	-	-
Mean	13.5	8.9	10.5	8.7	7.7	10.2	10.1
Range	9.8-17.2	7.2-10.9	7.7-14.6	6.9-12.0	7.0-8.8	8.1-12.8	7.9-12.3
SD	2.61	1.64	2.46	1.77	1.13	2.39	2.08
SE	1.06	0.67	1.00	0.72	0.65	1.38	1.20
BLAST-ONLY GROUP							
838	12.8	7.0	14.2	7.0	5.9	7.1	5.4
839	8.4	4.7	6.8	6.5	6.9	-	10.0
840	13.1	9.8	9.3	8.6	11.8	-	-
841	19.6	11.2	10.0	8.3	6.9	11.1	5.7
889	10.7	12.1	10.5	10.0	9.1	12.5	10.1
896	8.3	5.2	5.4	7.2	5.0	5.8	4.1
Mean	12.2	8.3	9.4	7.9	7.6	9.1	7.1
Range	8.3-19.6	4.7-12.1	5.4-14.2	6.5-10.0	5.0-11.8	5.8-12.5	4.1-10.1
SD	4.10	3.19	3.02	1.41	2.47	3.23	2.73
SE	1.67	1.30	1.23	0.57	1.01	1.62	1.22
RADIATION-PLUS-BLAST GROUP							
861	11.7	10.6	8.3	8.4	5.9	-	-
862	13.9	8.0	7.4	7.7	8.9	9.7	15.2
860	11.8	14.5	9.1	10.1	-	-	-
869	11.2	7.6	5.7	5.2	-	-	-
866	15.6	13.9	7.3	8.3	10.0	17.8	-
868	9.6	11.9	14.6	10.4	6.6	6.1	8.6
Mean	12.3	11.1	8.7	8.4	7.8	11.2	11.9
Range	9.6-15.6	7.6-14.5	5.7-14.6	5.2-10.4	5.9-10.0	6.1-17.8	8.6-15.2
SD	2.12	2.86	3.15	1.74	2.05	5.99	4.67
SE	0.87	1.17	1.28	0.71	1.03	3.46	3.30
CONTROL GROUP							
863	10.2	7.7	6.4	6.2	8.5	6.4	8.2
864	14.4	8.9	7.8	14.3	13.2	11.3	15.5
895	8.0	8.5	8.2	6.0	8.4	-	10.8
Mean	10.9	8.4	7.5	8.8	10.0	8.8	11.5
Range	8.0-14.4	7.7-8.9	6.4-8.2	6.0-14.3	8.4-13.2	6.4-11.3	8.2-15.5
SD	3.17	0.61	0.23	4.78	2.83	3.59	3.70
SE	1.83	0.35	0.13	2.76	1.64	2.54	2.14

Figure 1. --Mean Change in Venous Admixture ($\dot{Q}_s/\dot{Q}$) of Sheep Exposed to Radiation and/or Blast.

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<p>The changes in pulmonary function that result following unilateral exposure to LD₅₀ doses of neutron-gamma irradiation and/or sublethal blast overpressures were investigated in sheep. Animals exposed to blast-only and radiation-plus-blast demonstrated large increments in venous admixture (Q_s/Q) on the day of insult followed by a major recovery toward baseline values during the first 24 hours following injury. The venous admixture of the blast-only animals approached baseline 7 days after exposure but that of the radiation-plus-blast sheep did not return to baseline until 21 days. The sheep exposed to radiation-only, blast-only, and radiation-plus-blast sustained similar reductions in mean carbon monoxide diffusing capacity (DL_{CO}) which were below that of the control mean at 2 days and 7 days post exposure. All of the radiation-only and radiation-plus-blast sheep that survived to or beyond 21 days displayed an overshoot or recovery to their individual baseline DL_{CO} values. The blast-only and radiation-plus-blast animals also exhibited an increased mean ineffective alveolar ventilation (VA_{Ineff}) which persisted from 1 to 14 days following the onset of trauma. The radiation-only sheep had an increased VA_{Ineff} from 2 through 7 days post exposure.</p>		

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