Notes:

1. When the sponsoring organization was not the home establishment of an officer his home establishment is shown in brackets.

2. On study leave in England and brought to Australia at expense of United Kingdom Departments.

Dr. A. Thompson, War Office (University of Birmingham), joined the group for approximately 3 weeks.

2.2 Laboratory Facilities in Maralinga

A Radiobiological Area (RB) was provided in Maralinga comprising:-

RB1	Laboratory Block 4 laboratories, counting room, dark-room, balance room, office and changing facilities.	30 x 70 ft (approximately)
RB2	Mortuary and Dirty Laboratory	16 x 18 ft.
RB3	Animal House	16 x 36 ft.
RB4	Food Store	12 x 10 ft.

Wired enclosure 100 x 25 yd to protect experimental animals and herbage from dingoes.

The area was designed by AWRE to meet the Group's requirements. Electronic equipment was installed and maintained by the Nuclear Instruments Section, Health Physics Division, AWRE. These arrangements proved highly satisfactory - the sole cause of serious difficulty was the non-completion of permanent laboratory facilities.

2.3 Labour

Throughout the operation and especially in the first month, the Group suffered from severe labour shortage. The causes of this were:-

(a) Incomplete state of RB Area.

(b) Incomplete state of sites for exposure of dummies, animals and other targets at Round 1.

(c) The Group did not include any junior staff for general duties.

(d) The military task force was smaller and more extended than was expected.

The completion of the RB Area and the target sites would have been impossible without the aid of volunteer officers from the Indoctrinee Force. After Round 2 the RAF provided assistant labour.

[redacted]

United Kingdom Atomic Energy Authority

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT NO. T18/57

OPERATION BUFFALO

Interim Report

Target Response - Biology Group

Group Leader - R. Scott Russell

(Summary on Page 2)

Received on 29th March, 1957

[redacted]

Summary

1. The general organization of the Group is discussed.

2. The hydrostatic pressure effects of blast on goats, rabbits and mice were investigated; no special effects appear to be attributable to the long duration of the positive phase of the blast wave.

3. The dynamic effects of blast on human dummies in the open, and placed in vehicles and other equipments and structures, were assessed. It is concluded that the hazard was greatly reduced by being prone on the ground.

4. The effects of blast on window glass and plate glass were examined. Glass in standard window frames was shattered at 6800 ft but not at 11700 ft.

5. Medical supplies were exposed in the open to assess the extent of damage from blast, heat and ionizing radiations.

6. Food stocks were exposed below ground surface to estimate the extent of neutron-induced activity. For calibration purposes spectrographically pure elements were also exposed.

7. Cereal grain ripe for harvest was exposed in the fallout area to enable the extent of contamination of milled flour to be determined.

8. Herbage samples, both native vegetation and pasture of European type, were collected from the fallout area to enable the relationship between deposition and contamination per unit area to be assessed.

9. Five to ten miles from ground zero 5 to 10% of the fallout from Round 1 was found to be soluble in water followed by dilute carrier solutions of pH7; the corresponding figure for Round 2 was 20 - 30%. In the order of 50% of the activity for Round 2 was soluble in buffer solutions at pH4.

10. Radioautographic studies showed that the highest concentration of fission products on plants occurred in re-entrant angles such as the sheathing leaf bases of grasses. Evidence was obtained that Round 2 fallout passed into solution when rain fell on leaves.

11. Fission products collected in aircraft filters, and contaminated soil, were obtained for research in the United Kingdom.

12. Eleven wethers, one goat and three ewes were used in experiments to study the metabolism of fission products by grazing animals. Representative tissues were assayed.

13. Rabbits, both shot in the field and fed with fission products in the laboratory, were dissected and assayed.

14. The relative contributions to the exposure of the thyroid from ^{131}I, ^{133}I, ^{135}I and their decay products were examined.

15. Thyroids collected from sheep stations under arrangements made by the Australian Safety Committee were assayed.

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FOREWORD

This report has been compiled by Dr. R. Scott Russell and Lt. Col. J. R. Crook, RAMC, from data produced shortly after the completion of the firing programme at Maralinga. It is issued as advance information and does not necessarily represent the final view of the Trials Director.

The investigations on blast effects were carried out on Round 1, with some supplementary investigations on Round 3. The investigations on fallout were carried out on Rounds 1 and 2. Round 1 was exploded on a tower at 1700 hours local time on 27th September, 1956, and produced a yield of about 20 kilotons. Local conditions at the time of firing were: temperature 70°F, relative humidity 18%. Round 2 was exploded at ground level at 1630 hours local time on 4th October, 1956. Local conditions were: temperature 70°F, relative humidity 35%. Round 3 was dropped from a Valiant bomber to burst very accurately several hundred feet above ground zero at 1530 hours local time on 11th October, 1956. Local conditions were: temperature 75°F, relative humidity 18%. Both Rounds 2 and 3 were low yield explosions

E. R. Drake Seager,
Target Response Co-ordinator.

Maralinga,
October, 1956.

1. Scope of Interim Report

The assessment of the majority of the results obtained by the Group cannot be completed until several months after the return of its members to the United Kingdom. This report is therefore in the main confined to a statement of the organization and objectives of the group and of the general methods employed. It may be regarded as a general introduction to the subsequent parts of the report in which detailed results will be presented.

2. Organization of the Group

2.1 Sponsorship and Composition

The following departments proposed investigations which were included in the programme of the Group by the Buffalo Biological Sub-Committee:-

The Medical Research Council
The Agriculture Research Council
The War Office
The Ministry of Agriculture, Fisheries and Food.

Since the programme demanded the use of experimental animals, the provision of local herbage and the examination of native vegetation, Australian collaboration was essential. This was provided mainly through the Commonwealth Scientific and Industrial Research Organization (CSIRO). The Principal advisers in Australia were:-

Dr. F. R. G. White, Chief Executive Officer, CSIRO.
Professor J. G. Wood, University of Adelaide and Chairman of the South Australian Committee of CSIRO.
Mr. H. R. Marston, FRS, Chief of CSIRO Division of Biochemistry and General Nutrition.
Professor C. D. Donald, University of Adelaide.
Professor G. W. Emmens, University of Sydney.
Mr. Angus Packham, Technical Secretary of CSIRO. Division of Biochemistry, consolidated the group's arrangements in Australia. This was a most time-consuming task in the three months before the trial.

The composition of the group is shown in Table 1.

TABLE 1

Composition of Target Response Biology Group

Name	Sponsoring Dept. (Note 1)	Duties
Dr. R. Scott Russell	ARC (University of Oxford)	Group Leader - fallout studies on soil and herbage.
Dr. W.J.H. Butterfield	War Office (MRC)	Deptuy Leader - effects of blast, co-ordination of experiments with animals.
Lt. Col. J.C. Crook	MRC (RAMC)	Administrative Officer - exposure of medical and food targets.
Dr. D.W.H. Barnes	MRC	Metabolism of fission products by animals.
Professor P.L. Krohn	War Office (University of Birmingham)	Effects of hydrostatic pressure from blast on animals.
Mr. J. McGregor	War Office (University of Birmingham)	Effects of hydrostatic pressure from blast on animals.
Major E.G. Hardy	War Office (RAMC)	Effects of hydrostatic pressure from blast on animals and effects of blast on human dummies.
Dr. H.J.H. Bowen	ARC (AERE)	Radiochemist.
Mr. W.H.A. Raymond	MRC	Radiochemist.
Dr. C. Hunter	Canadian DRB representative	Metabolism of fission products by animals.
Australian Component	Parent Establishment	
Mr. I. G. Jarrett	CSIRO	Supervision of experimental animals.
Mr. B. J. Potter	CSIRO	Supervision of experimental animals.
Mr. J.V. Possingham	CSIRO (Note 2)	Fallout duties on soil and herbage.
Mr. P. Dunn	Dept. of Supply	Radiochemist.
Mr. N. Ford Mr. G. Sharman	CSIRO) University of Adelaide)	Intermediate survey based on Emu.

Scientific work undoubtedly suffered in consequence of these labour problems. It is to be emphasized that the Trials Headquarters did everything within its power to assist the Group despite the fact that its resources were strained to their limit.

2.4 Transport

Except in the first month of the trial the Group had the transport it had requested in the United Kingdom. Events proved that the requirement was underestimated and a 50% larger allocation would have been more suitable. The final sentence of Section 2.3 applies to this question also.

2.5 Allocation of Group Effort

Attention must be directed to the large effort which was necessary to place animals at their exposure sites for the blast experiment on Round 1 (see Section 4) and to maintain them. Repeated postponements aggravated the problem. The effects of such exertions on other scientific duties were found to be considerable. Problems of this type are to be expected at weapon trials. They emphasize the need for the relative priorities of different parts of the programme being decided in advance. The importance of so doing was not fully appreciated prior to the trial.

3. General Nature of Scientific Programme

The selection of the programme of the Group was guided by the principle that attention should be confined to questions of importance from the viewpoint of civil defence or the operation of the Services which could not be adequately assessed by investigations under more normal laboratory conditions.

The tasks undertaken can be classified under the following headings:-

(a) Effects of hydrostatic pressures from blast on animals.

(b) Effect of blast on human dummies and glass.

(c) Medical and food targets.

(d) Hazards due to fallout.

4. Hydrostatic Effect of Blast on Animals

4.1 Animals were set out in cages sheltered by walls at the sites shown in Table 2 prior to Round 1.

After the shot the animals were recovered as rapidly as circumstances permitted, and autopsied.

TABLE 2

Animal Sites

Site No.	Distance from Ground Zero, ft	Number of Animals Exposed		
		Goats	Rabbits	Mice
102	1100	3	8	20
103	1360	3	8	20
104	1500	3	8	20
105	1750	-	10	20
106	1950	3	10	20
107	2100	-	10	20
108	2320	3	10	20
109	2606	-	10	20
110	3252	3	10	20
111	3652	-	10	20
112	6020	-	10	20
113	8516	-	10	-
114	17050	-	10	-

4.2 A preliminary assessment of the results has been prepared by Professor Krohn.

The animals were exposed to a greater or less extent to the following hazards:-

(a) Burning from heat flash

This factor was almost entirely eliminated by the design of the earth walls in front of each site. None of the animals suffered from skin burns, On the other hand there were indications from the condition of the windpipe that some animals at near-in sites may have inhaled very hot air or toxic vapour.

(b) Ionizing radiations

Film badges were placed at various positions at each of the sites. Many records could not be read accurately because of over-exposure. The doses behind the shielding at some sites were greater than 10000 r: death was nevertheless not instantaneous but occurred in about 2 - 4 hours. There was also an unknown amount of neutron irradiation: the monitoring of the animals during post-mortem revealed a possibility of induced activity at least in the blood and faeces.

(c) Displacement

The exposure cages usually withstood the stresses to which they were subjected but some of the methods of securing the entrances to the cages were inadequate. Injuries from displacement were therefore rare and took place only when the door catch failed.

None of the animals which remained within their cages showed any sign of injuries. Earlier experience at Foulness with the shock tube had suggested that if an animal had even a short distance in which to move injury might be severe. In the event the goats, which had most room, were as unharmed as the other animals.

(d) Direct effects on blast

The main purpose of the experiment was to see whether blast waves of long duration were more effective in causing injury than waves from small conventional charges. It would appear that they are not, either at pressures likely to cause serious injury or at lower pressures. Even at the close ranges where death from irradiation was rapid and inevitable the damage to the lungs was relatively slight and serious respiratory embarrassment unlikely.

This general conclusion must be qualified by three provisos:-

(i) That the character of the blast wave was not affected by the walls in front of the animals. The evidence from gauges set up amongst the animals at two sites is that the records are very similar to those obtained in the open. The peak pressure is perhaps a little higher and the front of the wave a little rounded.

(ii) That the actual pressures will be proved to be at the predicted levels.

(iii) That the blast wave from Round 1 had the same sharply rising front that is characteristic of ordinary shock waves.

Studies of Effects of the Blast Wave in Displacing Man

5.1 Introduction

The blast wave from atomic explosions could injure man by:-

(a) Rupturing viscera (cf Section 4).

(b) Displacement effects, either between different parts of the body (e.g., dislocations) or bodily (e.g., collisions).

(c) Wounding by objects displaced by the blast wave (cf. Section 6).

(d) Crushing by falling masonry, etc.

5.2 Objects of the Present Investigations

The purpose of the present studies was to investigate the physical and physiological phenomena involved in the displacement of personnel by a blast wave.

5.3 Methods

(a) Thirty human dummies were exposed to Round 1 in 6 orientations to the weapon. Each orientation was displayed at 5 ranges.

(b) To survey subsequent collisions, in military terms, 48 dummies were exposed in conjunction with various items of military equipment - guns, tanks, vehicles and earthworks.

5.4 Apparatus

The dummy men were designed to resemble man ballistically. The weight and centres of gravity of the various limbs, trunk and head were all appropriate for a 6 ft man weighing 174 lb ($12\frac{1}{2}$ stone).

They were dressed in uniform since clothing influences the drag coefficient of men exposed to the blast wave and because it had been reported that clothing was torn away by the blast wave from survivors in Japan.

The instrumentation of the dummies was undertaken by the Target Response Instrumentation Group. Some dummies contained accelerometers in the chest. Attempts were also made to follow the movement of the dummies by high-speed cinematography. Displacement was also measured from 4 in. nails driven into the ground at the starting points.

5.5 Design of the Experiments

(a) Thirty dummies were exposed alone, that is, without reference to guns, vehicles, etc, at the following sites:-

(i) Standing at 6000, 3900, 3110, 2650 and 2390 ft.

(ii) Crouching at 3900, 3110, 2650, 2390 and 2200 ft.

(iii) Prone at 2650, 2390, 2200, 2050 and 1840 ft.

Each position was duplicated, the dummies being placed facing the weapon and sideways on to it.

(b) Forty-eight dummies were exposed in conjunction with army equipment as follows:-

(i) 6 dummies were exposed in tanks, representing driver and tank commander;

(ii) 3 dummies were exposed in scout cars.

(iii) 5 dummies were exposed in Landrovers.

(iv) 6 dummies were exposed in 3-ton vehicles.

(v) 7 dummies were exposed in conjunction with 25-pr field guns.

(vi) 6 dummies were exposed in conjunction with GKN guns.

(vii) 3 dummies were exposed in conjunction with L70 light antiaircraft guns.

(viii) 4 dummies were exposed in the 4-man firing positions.

(ix) 4 dummies were exposed in medium machine-gun pits.

(xi) 4 dummies were exposed in shelters, steel, large.

5.6 <u>Results</u>

(a) Table 3 shows the displacements, in feet, of the dummies exposed alone

TABLE 3

Displacement, ft, of Dummies Exposed Alone

Ranges, ft	Posture, Orientation to Weapon, and Displacement					
	Prone		Crouching		Standing	
	Facing	Sideways	Facing	Sideways	Facing	Sideways
1840	42	66	-	-	-	-
2050	2.5	69	-	-	-	-
2200	2	20	15	39	-	-
2390	1	8	16	18	35	20
2650	1	24	9	9	30	16
3110	-	-	6	9	16	10
3900	-	-	1	3	4	3
6000	-	-	-	-	2	0

(b) The findings with the dummies exposed in conjunction with equipments and earthworks may be summarized as follows:-

(i) The dummies in tanks were relatively unharmed.

(ii) The dummies in vehicles and gun positions showed graduated damage, from severe displacement and limb injuries at short ranges (less than 3000 ft) to negligible displacement (at 5000 ft).

(iii) The dummies were severely displaced in the shelters and medium machine-gun pits, which were deliberately oriented unfavourably at short ranges; those in the better oriented 4-man firing positions were relatively unharmed.

Detailed information about effects of exposure, clothing, etc., will be presented later.

5.7 Discussion

The lethal range of γ-radiation for those exposed directly to the present weapon was about 3600 ft. Serious burning would have been sustained by all dummies from the heat flash. Battle dress serge was singed out to the furthermost blast site, 6000 ft. Thus, most of the effects with which we are concerned here lie well within the range of serious injury and eventual death from the other effects of the weapon.

For those exposed directly to the flash of the explosion within 1000 yd, displacement effects must be regarded as mechanical injuries superimposed on flashburns and mortal illness from γ-radiation a short time later. This does not obviate the possibility of blast displacement injuries existing by themselves; indeed, two points must be made to counter the idea that displacement studies such as those conducted here could only be referable to doomed persons. First, there is the possibility of blast effects from weapons larger than the nominal bomb. In such an event, blast effects comparable to those obtaining in the present trial would exist beyond the range of radiation illness, and the heat flash might be occluded by buildings or the weather. Secondly, even with bombs of nominal size, it is not difficult to imagine many situations where persons might be screened, even at short ranges, from gamma radiation and the heat flash emitted in the first stage of the explosion, yet subsequently suffer from displacement by the blast wave. Such situations could arise from the movement of personnel between the flash and the arrival of the blast wave, and such movements are not simulated by inanimate dummies; deductions about the exact effect of the blast wave on persons based on experiments using dummies are therefore fraught with inexactitudes and difficulties of interpretation.

5.8 Conclusions

It is hard to envisage many personnel being unharmed by displacement effects of blast within 600 to 700 yd (2000 ft) of Round 1. Persons in tanks and those in trenches broadside-on to the explosion would probably be the only exceptions. Beyond that range, persons meeting the blast wave in certain postures (e.g., prone) in the open away from secondary missiles might suffer little or no displacement. By contrast, there emerges a great deal of evidence that personnel concerned with all sorts of military equipment, guns, vehicles, or even earthworks, could suffer severe injury <u>unless they took evasive action</u>.

The overriding conclusion to be drawn from the present tests is that there is no substitute for the prone position, wherever feasible, or for bracing against the shock. Further trials are required to prove that evasive action reduces the risk of injury from collision with army equipment.

6. Investigations to Assess Hazards from Glass Fragmentation

6.1 Introduction

The blast wave from an explosion can displace objects which in turn may injure man. Such displaced objects are termed secondary missiles. Flying glass from broken windows represented a very important source of injury after the attacks on Japan.

6.2 Object of Present Study

The object of the present investigation was to study the mechanisms involved in injuries from flying glass and to assess the range of this hazard.

6.3 First Experiment

6.3.1 Methods

Two types of glass, domestic window and polished plate, were exposed in specially designed glass fragmentation boxes (manufactured at WRE,SA). These consisted of boxes of $\frac{1}{8}$ in. galvanized mild steel, fashioned to hold the glass samples at one end and telephone directories at the other. The directories were used to provide a simple method of determining the depth of penetration of fragments.

Twelve fragmentation boxes with window glass and 12 with plate glass samples were displayed at each of 5 sites. The ranges of the sites were $\frac{3}{4}$, $1\frac{1}{2}$, 3, 6 and 10 miles from GZ, and at each site equal numbers of targets were set facing GZ, side-on to it, and away from it.

6.3.2 Results

No polished plate glass samples were broken.

It was appreciated at the outset that the small areas of plate glass exposed in no way represented shop windows and therefore gave no indication of hazards to civilians in cities. The plate glass was included to study effects of glass thickness and texture on resistance to blast.

Only at the forward site ($\frac{3}{4}$ miles or 3000 ft) was window glass broken. All 4 replicates facing the weapons, and 3 out of 4 side-on and facing-away replicates, were shattered. Fragments penetrated all the telephone directories. Their weight and depth of penetration are being assessed.

6.4 Second Experiment

6.4.1 Object

The object of the second series of experiments was to investigate the fragmentation of glass mounted in non-distortionable frames under conditions more nearly simulating those of window panes in houses than obtained in the fragmentation boxes used earlier.

6.4.2 Method

Four 8 ft cubed wooden packing cases were selected and windows let into one side wall, centred 4 ft above the ground and reaching to 1 ft from the top. The window frames were steel, with six $11\frac{1}{2}$ in. high, $17\frac{1}{2}$ in. wide window panes. Three window panes on one side were glazed with wire-reinforced plate glass, and on the other side with domestic window glass. 24 telephone directories were nailed to the inside of the wall facing the windows.

The 4 boxes were exposed with the windows facing the explosion of Round 3 at distances bracketing the damage range on Round 1. Afterwards these distances were found to have experienced peak pressures corresponding to the following distances from Round 1: 3100 ft; 4200 ft; 6800 ft; and 11700 ft.

6.5 Results

(a) The closest display (3100 ft) was wrecked (see Figure 1). The telephone directories were destroyed and scattered about in the immediate vicinity and no glass fragments were detected in the remains. However careful search revealed glass fragments impaled in the remains of the wooden wall originally facing the window, and glass fragments, mostly of estimated weight less than 1 g, scattered over an elliptical area of 1000 yd.^{2} It was concluded that similar effects on more than 6 window panes, as would arise in city streets, would probably result with the atmosphere being filled temporarily with well dispersed fast-moving glass fragments. It was also possible to envisage that glass fragments from high buildings with many windows might fill the streets to a considerable depth with fine fragments.

(b) The second display 4200 ft (see Figure 2) was less severely damaged, with the outer walls collapsing. Close examination revealed glass splinters embedded in the wall facing the window. The telephone directories had been torn from their original positions; many showed surface excoriations, presumably, but not certainly, due to the glass fragments. Glass fragments were also scattered over an elliptical area of nearly 1000 yd^2 about this site.

(c) The third display, 6800 ft, was found to have been moved back bodily 2 in. by the blast. The steel window frames were undistorted. The lower two of the 3 domestic window panes were shattered (see Figure 3) but, though split, none of the reinforced plate glass was dislodged. The floor was covered with glass fragments. Two glass splinters were also visible embedded in the telephone directories (see Figure 4). The floor space was therefore divided into 9 equal square areas and the glass fragments in each swept up and collected for assay of particle size and shape. The distribution of glass markings on the wall was counted and recorded and the directories were examined and the depth of penetration of fragments recorded.

(d) The fourth display, 11700 ft suffered no damage, nor did nearby glass fragmentation boxes remaining from the first experiment.

The results from all displays were in agreement with those obtained from Round 1.

6.6 Discussion

The results obtained at Site No. 3, exposed at an equivalent of 6800 ft from Round 1, showed that, for each pane of domestic glass broken, 100 fragments crossed the 8 ft cube and lodged firmly in the wooden wall or excoriated a telephone directory opposite. This suggests that, under the circumstances of the present test, at least some of the 100 fragments per pane of glass might injure the exposed skin of an occupant of the rooms standing anywhere within a fairly wide arc of the window. Again, from the findings of the directory study, it would seem that about one fragment in five, or some 20% of glass broken, would have sufficient energy and properties of laceration to penetrate most indoor garments and inflict injury through them. In this particular test, two fragments would have caused serious injury had they struck a person.

6.7 Conclusions

Two points emerge from the present studies. First, the wide area of dispersal (1000 yd^2) of glass fragments at the forward displays. Second, the dispersal, fragment characteristics and penetrating properties of the second display at an equivalent range of 6800 ft from a weapon of approximately 20 kiloton yield.

These results must be compared with the findings after Round 1. On that occasion at 3000 ft from ground zero 4 out of 4 slightly smaller window panes facing the explosion were broken, but at 7900 ft no windows were broken. After Round 3, 2 out of 3 slightly larger windows were found to be shattered at an equivalent distance of 6800 ft.

The present study shows that glass fragmentation represents a hazard for persons indoors who do not take evasive action, or who give up a protected position too soon, at ranges comparable to those for flash-burning. If windows were loose, the range for hazard from flying glass would exceed that of flash-burning. The deduction is clear: steps should be taken to fix windows and prevent their breakage by rattling or slamming.

Many investigations obviously remain before the hazards from flying glass can be appreciated with any accuracy; the present experiments with new glass in month-old putty (unpainted) merely serve to show the problems.

7. An Investigation into the Effects of Blast, Heat and Radiation upon War Office Medical Supplies and Water Sterilizing Tablets

7.1 Introduction

This investigation was designed to be a continuation of a similar investigation carried out on a previous trial. In addition to testing similar equipment at closer ranges, it was decided to include additional equipment and items supplied from Australian and Canadian sources.

7.2 Supplies Tested

The British medical supplies to be tested consisted of:-

(a) Regimental Medical Panniers complete with contents.

(b) Burns Boxes. These consist of a wooden box containing special burns dressings in polythene covering, oiled silk hand envelopes in Cellophane packing, penicillin and distilled water.

(c) Jablo Transfusion Boxes. These are special light-weight cork covered boxes for transfusion bottles. Each box contained 8 bottles of dried plasma specially supplied from the Lister Institute and 4 bottles of saline.

(d) Special samples of tetanus toxoid, tetanus antitoxin, penicillin, aureomycin and sulphonamide power. These samples were packed in the Regimental Medical Panniers.

The Australian Medical Supplies to be tested consisted of:-

(a) Regimental Medical Panniers packed with a miscellaneous collection of drugs, instruments, and dressings.

(b) Paper packages of liquid serum and other sera supplied from the Commonwealth Serum Laboratories.

The Canadian Medical Supplies consisted of a special RCAF bandolier containing narcotics and other items.

7.3 Location of Samples

One sample of each item was placed at each of four sites at 1290 ft, 1450 ft, 1730 ft and 2390 ft from GZ. These sites were chosen on the basis of damage sustained by similar samples on a previous trial. They were placed about 50 yd to the left of the main road leading to One Tree. The medical supplies were placed on the surface of the ground at each site and each site was marked with pegs for subsequent identification (Figure 5).

In addition, a small earth bank was made at each site and against each were placed two bottles of saline, two burns dressings, two burns hand envelopes, and the Australian serum package.

Control samples of all items exposed were also placed on the ground well outside the firing area.

7.4 Assessment of Neutron-Induced Activity

In order to assess various neutron-induced activities of samples, the following items were placed in a cardboard box in the underground iron chests at the food exposure sites RM 106, 108, 113 and 115 at distances 1050 ft, 1200 ft, 1640 ft and 1790 ft from GZ respectively.

(a) One bottle of saline.

(b) One bottle of dried plasma.

(c) One bottle of plasma reconstituted with saline.

(d) One army water bottle containing distilled water.

(e) One army water bottle containing water sterilized by a water sterilizing tablet followed by a thiosulphate tablet.

(f) One tin containing bottles of water sterilizing tablets and thiosulphate tablets.

(g) One Australian serum package.

7.5 Exposure and Recovery

The items to be exposed were placed in position on 11th September and remained there until firing on 27th September and subsequent collection on 28th September at D + 15 hours and 1st October at D + 4 days.

They were inspected on three occasions before firing in order to ensure that they had not been disturbed and to note any effects of the weather on the items.

After firing, the medical items at the food sites (see Section 7.4) were the first to be recovered in order to make an initial assessment of their neutron-induced activity.

Recovery of the other items of medical equipment was made at D + 4 days, after some preliminary photographs in the field had been taken. A rapid ground assessment was made and the distances of displacement of the items measured. All the items were then collected, as far as was practicable, and removed to an active store for subsequent detailed examination.

After examination and thorough photographing, all items of interest were sent back to the United Kingdom, the Australian Army Medical quarters, or the RCAF. The samples of plasma, tetanus toxoid, tetanus antitoxin, penicillin, aureomycin and sulphonamide which survived, together with control samples were also sent back to the UK.

7.6 Results

(a) Without going into any details, it has again been shown that the British and Australian medical panniers are robust containers. They both survived at the outermost site (2390 ft). At the next site (1730 ft) the British pannier was completely burned out, but the Australian pannier was practically intact. At the two inner sites both types of pannier sustained severe damage.

(b) The Burns Boxes were destroyed at all sites and their contents scattered. They did, however, protect their contents from heat flash and the dressings, though scattered, were largely undamaged at the two outermost sites.

(c) The boxes containing Jablo Transfusion equipment survived the heat and blast damage at the two outer sites, but the bottles within were mostly broken. The boxes were destroyed at the two inner sites, and no contents were found.

(d) The Canadian bandoliers were destroyed at all sites.

(e) Of those items exposed in the open, the bottles of saline survived at all sites, but the caps were mostly damaged. The polythene coverings of the burns dressings were burnt off at all sites and the dressings blown away.

The Australian serum packages, or their contents, were recovered at all sites, and showed varying degrees of damage.

(f) Neutron-induced activity.

(i) Items exposed on the ground.

There was considerable induced activity in many items from all sites at D + 4 days; the amount of activity depending on the site. Drugs and bottles showed the highest activity initially, but the activity rapidly decayed and metal and rubber activity became more important. At D + 22 days certain samples of rubber showed the highest activity.

It is noteworthy that no radioactive contamination of medical supplies with fallout or dust took place.

(ii) Items exposed underground at the food sites.

Of these, liquid plasma and saline showed the highest activities, followed by dry plasma and the water sterilizing and thiosulphate tablets (both dry and dissolved) in that order. For all these samples the activities, which from decay curves appeared to be due to radioactive sodium, rapidly decayed and were negligible after 7 days.

8. An Investigation into the Effects of Neutron and Gamma Irradiation upon Foodstuffs

8.1 Introduction

The object of this experiment was to determine if food exposed to γ-rays and neutrons from an atomic explosion, but protected from heat and blast damage, would be rendered unsuitable for human consumption by virtue of induced radioactivity, changes in texture or taste, or impaired technical quality.

8.2 Methods

Six cartons of foodstuffs, 2 ft cubed and weighing 170 lb each, were sent for investigation. They contained tins and packages of a large variety of foods. Four of these cartons were placed in the 3 ft cubed iron chests at RM Sites 106, 108, 113 and 115, at distances of 1050 ft, 1200 ft, 1640 ft and 1790 ft from GZ respectively. The two other cartons were placed in similar iron chests at sites well out of the target area as controls.

The iron chests had thick (approximately 1 in.) walls and lids, and were buried 3 ft in the ground so that the lid was level with, or just below, the surface of the ground. When the lids were closed they were covered with one layer of sandbags in order to protect the contents from heat and blast damage (Figure 6 and 7).

It was stipulated by the Australian authorities that the food should not be subjected to temperatures greater than 80°F and so cold storage space had been requested. However it was not available when wanted, so it was decided to place the food out at the exposure sites immediately. This was done on September 7th, two days after its arrival.

A maximum and minimum thermometer placed with the food at one site was read periodically until 27th September when Round 1 was fired. 75°F was the highest recorded temperature.

Gamma and neutron measurements. In order to obtain an accurate measure of these radiations within the food cartons, special γ and neutron indicators were inserted into the centre of the foodstuffs at each of the four exposure sites.

Spectroscopically pure chemicals. It was decided that, instead of measuring the neutron induced activities of the foodstuffs themselves (with its attendant difficulties), it would be better to measure the activities of certain spectrographically pure elements. The elements chosen are relatively abundant in foods and of high neutron capture cross-section. The following 6 elements were used: sodium, phosphorus, zinc, tin, calcium and sulphur. The composition of these elements in the various foods to be tested was known.

Each carton to be tested, and the controls, had inserted into it one sample of each of the 6 chemicals to be measured. They were placed in special isotope cans and were known weight.

All 6 food cartons were recovered on 28th September at D + 15 hours. They were brought back to the Decontamination Area where they were given a rapid initial monitoring in order to establish the gross measurements from tins of food, etc. The γ and neutron indicators were then removed and given to the Radiological Measurements Group for assessment.

The spectrographically pure elements were then analysed and counted. An initial count for all elements at all sites was done in order to establish the relative levels of activity at each site. The decay curves for those elements which showed satisfactory levels of activity at Site RM 106 were studied.

Further studies were also made on the gross activities of tins and samples of foodstuffs at 5-day intervals.

The foodstuffs were returned to Adelaide on 19th October for further tests to be carried out by the Department of Trade. The level of activity in the food at Site RM 106 was judged to be quite safe: it was 8 counts/sec for tinned goods. The levels at other sites were markedly less.

8.3 Results

(a) Gamma measurements. The analyses of the γ-radiation dosimeters exposed in the food boxes show that a shielding factor of 10 to

20 was introduced by the contents of the package, the iron chest, the earth and the sandbags.

(b) Spectrographically pure chemicals. The final results on these have yet to be worked out, but they can already be listed in order of induction of activity:-

$$Na > Zn > P > S > Sn > Ca.$$

Sodium and zinc, which showed the highest initial activities, both have short half-lives and decayed rapidly. Both had reached insignificant levels at the end of a week.

Phosphorus, although not of very high initial level, decayed slowly and after a week showed the highest level of the chemicals. It was still significantly high after 3 weeks.

Sulphur, tin and calcium showed only slight activity, even at Sites 106 and 108.

These results will have to be assessed in terms of microcuries of induced activity per gram of the element and this, in turn, related to the amount of that element in any particular food-stuffs before any final result can be achieved.

(c) Neutron-induced activities of tins of food, etc. Various tins and packages were selected and measured. Initially a high degree of activity was found in many samples at all sites (over 1000 counts/sec). This high initial activity decayed rapidly and reached low levels after a week. This activity is probably related to the sodium content of the foods.

After a week the activity of samples decayed more slowly and was greatest in the tinned foods. It seems that it was due to the tins or metal containers and not due to the foodstuffs as it was of equal level for several tins of different contents at any one site.

Of all the items examined soap showed the highest activity. Its activity decayed rapidly however, and again it is probable that sodium was responsible.

8.4 The Exposure of Cereals Ripe for Harvest

The importance of cereals as a staple food in time of war prompted the Ministry of Agriculture, Fisheries and Food of the United Kingdom to request that ripe cereals should be exposed to fallout so that the relationship between deposition and contamination of the ears could be determined and the extent to which fission products are removed in milling could be assessed.

Ripe wheat ears on stalks 9 in. long were stood upright in boxes filled with sand, the ears being placed at 2 in. intervals. From above the assembly resembled a crop mature for harvest. Boxes were exposed to Rounds 1 and 2 at distances ranging from 5 to 10 miles from ground zero. Three boxes were contaminated in Round 1 and two boxes in Round 2 to a degree satisfactory for investigation. The produce was sent to the ARC Radiobiological Laboratory, Compton for examination.

9. Investigations to Assess Hazards Resulting from Fallout

9.1 Objects of Investigation

9.1.1 The interests of the Medical and Agriculture Research Councils centered on this subject.

The principal objectives were:-

(a) To estimate what fraction of the fission products deposited on the ground surface is likely to lodge on herbage which may be consumed by grazing animals.

(b) To determine the extent to which the physical form of fallout modifies its biological availability.

(c) To determine whether unidentified fission products are accumulated in the tissues of animals to an extent which makes it necessary to consider them in the assessments of hazard due to the metabolic accumulation of fallout.

9.1.2 These topics were selected in view of the following circumstances:-

(a) Free-grazing animals are particularly liable to ingest fission products because of the wide areas from which they derive food. ^{131}I which accumulates in the thyroid and ^{89}Sr and ^{90}Sr which accumulate in bone are known to be the most hazardous isotopes from the viewpoint of metabolic accumulation and these substances are secreted into milk. Thus the food chain:-

contaminated herbage → cow → milk → human infant

appears capable of giving rise to a radiological hazard to the human population even when depositions are insufficient to be hazardous in other ways. The adequate assessment of such hazards demands knowledge of:-

(i) The relationship between deposition per unit area and the ingestion of animals.

(ii) The relationship between the quantity of fission products ingested and that deposited in the organs of the animal or secreted into milk.

These relationships will be affected by the following other factors:-

(iii) The fraction of the deposited fission products deposited on edible herbage.

(iv) The nature and density of the herbage.

(v) The physical form of the fallout which may affect not only its retention on herbage but also its subsequent metabolism by animals.

(b) Although ^{131}I, ^{89}Sr and ^{90}Sr are the most serious potential causes of hazards, due to metabolic uptake other isotopes are contributory causes. The short-lived isotopes of iodine ^{132}I, ^{133}I and ^{135}I may be expected to contribute to the hazard to the thyroid. ^{140}Ba contributes to the exposure of bone and evidence has been obtained after previous trials that unidentified short-lived fission products may be accumulated in various tissues.

9.2 General Plan of Investigations

9.2.1 Main Experiment at Maralinga

Since it was desired to establish quantitative relationships between the deposition of fission products and their accumulation in animals it was necessary that the animals should be fed with known quantities of fallout which could be related to the deposition per unit area. It was also necessary to feed them with materials bearing a known relationship to those which would be retained in typical European pastures, as it may be assumed that these areas would be the major agricultural targets if nuclear warfare were to occur. So that the maximum information on metabolism could be obtained it was important that urine and faeces could be separately collected. To satisfy these requirements the following plans were made:-

(a) Boxes approximately 0.3 m^2 in surface area were planted with Lolium perenne (rye grass) and Trifolium ripens (white clover) 9 months before the trial so that a close sward similar to a European pasture resulted (see Figure 8). These boxes were to be exposed in the fallout area side by side with sticky paper fallout absorbers, which would measure the deposition per unit area, and cotton gauze sheets backed with plastic sheeting, which would provide additional data on total deposition and also material for a study of the physical form of fallout. The deposition on the herbage could be studied and the herbage could also be used to feed animals.

(b) Because of the special digestive habits of ruminants they alone were suitable experimental animals. Sheep were chosen as being easier than cattle to transport and to maintain at Maralinga. Wethers were to be employed in the greater part of the work. Metabolism pens could be constructed to contain them in such a manner that urine and faeces could be collected separately (see Figures 9 and 10). So that the metabolism of different fission products could be studied the time of commencement of experiments and their duration could be varied, the first experiment being planned to start 6 to 7 hours after firing so that the fate of short-lived isotopes could be examined.

The transfer of isotopes to the milk of ewes was also to be studied. Unfortunately, however, these animals could not be used in metabolism pens.

This work was to be carried out on Round 2, the ground burst, since the fallout from this weapon was expected to be in a form more readily absorbed by animals. A preliminary exposure of herbage boxes at Round 1 was included to test techniques.

In the event, modification of the plan was necessary because a considerable wind shear after Round 2 caused the deposition of fallout per unit area to fall short of that anticipated. Unexpected heavy rain caused further complications. Part of the programme was therefore carried out with fallout collected in aircraft filters by the RAF.

The feeding of parallel animals with contaminated herbage and air-filter material enabled the different parts of this experiment to be linked together.

It may be noted that the delay in the firing schedule because of bad weather caused difficulties due to deterioriation in the condition of the animals - in particular the majority of the lactating ewes provided for the work became unsatisfactory.

An addition to the original programme became possible due to a small number of rabbits being surplus to the War Office programme (Section 4). They were fed with contaminated herbage and materials from air filters.

9.2.2 Surveys of Local Flora and Fauna

Since the ensurance of safety in Australia is an obvious responsibility of the Trials Organization the contamination of vegetation of the type consumed by sheep was studied. This work fell into two parts - collections at sites within reach of Maralinga, carried out conjointly with the herbage box programme, and a survey based on Emu approximately 100 miles distant (the Intermediate Survey).

Rabbits were also collected after both Rounds 1 and 2. The assay of their organs provided information on the pattern of distribution of fission products between different organs. Since, however, neither the time of feeding nor the quantity ingested was known these data are of limited value; it is hoped, nevertheless, that they may serve as a basis for designing future laboratory investigations.

From the viewpoint of laboratory analysis the rabbit has considerable advantages over the sheep. Their greater intake per unit weight causes much higher concentrations to be obtained in the tissues. Furthermore, whereas only small fractions of the organs of sheep could be assayed by the available procedures, the entire rabbit could be handled.

9.2.3 <u>Laboratory Aspects of the Work at Maralinga</u>

The main experiment engaged the greater part of the time of three chemists in the digestion of tissues and chemical separation of fission products for $2\frac{1}{2}$ weeks. M6 liquid Geiger-Muller counters were employed. Under these conditions they proved considerably less satisfactory than is the normal experience in laboratories where small animals are used. Equipment of greater efficiency, capable of holding larger samples, is desirable in work with large animals. Furthermore the repetitive counting of samples with M6 counters to obtain decay curves is most time-consuming and could not be adequately handled despite long hours on the part of 4 or 5 counter operators.

The considerable superiority of a γ-spectrometer for many purposes was demonstrated for the examination of the content of thyroids.

With regard to the assay of herbage samples a different problem arises. The deposition of replicate samples is highly variable and the subdivision of very large samples to eliminate variability is difficult by virtue of the ease with which superficial contamination is detached. The Nuclear Instruments Section, AWRE, produced a very satisfactory solution to this problem by providing an anthracene β-scintillation counter with a crystal lattice approximately 6 in. square and an efficiency of up to 30%. Samples of herbage weighing 1 to 10 g contained in polythene bags could be rapidly assayed. The effects of variations in position were found to be small in relation to sampling errors. Calibration and correction for self-absorption could be satisfactorily carried out.

9.2.4 <u>Organization of Intermediate Survey</u>

This survey, which was based on Emu, was undertaken to obtain samples of herbage correlated with sticky papers 100 - 200 miles from ground zero. It was intended to operate on Rounds 1 and 2. Two biologists each with a 4 × 4 Commer truck carried out the work in conjunction with the Australian Radiation Detection Unit. The plan was as follows:-

(a) Prior to each firing sticky papers were to be placed at mile intervals along 200 miles of road radiating from Emu:-

NW (Giles Road) 40 miles
SE (Mabel Creek Road) 100 miles
S (Maralinga Road) 60 miles.

(b) At firing time the biologists would travel with cascade impactor teams and collect samples at impactor sites.

(c) Subsequently they would collect samples where the cloud crossed the road system.

This system largely broke down because of the two vehicles becoming unserviceable at the time Round 1 was fired and because of the direction of the cloud. The breakdown of transport is accounted to the bad roads and the frequent trips to replace papers made necessary by the long Stand-By for Round 1.

The survey obtained, however, some interesting material from cascade impactor sites at Round 1 and from the Maralinga Road at Round 2.

9.2.5 Provision of Material for Investigation in the United Kingdom

Special filters designed by AWRE and attached to RAF Canberra aircraft were employed to collect airborne fission products; these were flown to the United Kingdom so that experiments with cows at ARC Radiobiological Laboratory, Compton, and with rabbits at MRC Radio-biological Unit, Harwell, could be started within 4 days. Material from both Round 1 (tower shot) and Round 3 (air drop) was supplied.

Samples of heavily contaminated soil were collected for long term experiments on the absorption of plants of ^{90}Sr.

9.3 Deposition of Fallout on Herbage and Soil

In this and subsequent sections the work carried out is briefly reviewed. Since it is impossible yet to correlate the results from the different parts of the investigation, work with herbage and soil, sheep and rabbits will be separately considered.

9.3.1 Setting Out of Herbage Boxes and Gauze Absorbers

Prior to Round 1, 20 boxes were placed at distances 5 to 20 miles from ground zero (5th and 10th Avenues on the 25 mile road system). Two hundred boxes were placed in position before Round 2.

9.3.2 Collections of Herbage to Determine Relationship Between Deposition and Retention

After Rounds 1 and 2 collections of herbage were made both from boxes and from two prevalent natural species which are eaten by sheep: Atroplex rumulatum (salt bush) and Stipa sp (a grass). All collections were made at sites near which sticky papers were mounted to measure total deposition. Approximately 80 collections were made, and duplicate or triplicate samples were assayed for total activity with a β-scintillation counter. Representative samples were taken for radiochemical separation and assay. It was evident after Round 1 that particles readily became dislodged from leaves and that very marked variation in distribution occurred over small distances.

Until the results have been correlated with the sticky-paper survey and statistically analysed, no conclusion can be advanced.

9.3.3 Solubility of Fallout

Fallout from Round 1 collected on gauzes placed 5 to 10 miles from ground zero showed a total solubility of 5 to 10% in water followed by dilute carriers at pH 7. The corresponding value for Round 2 was 20 to 30%. A further 20 to 25% could be displaced from the Round 2 gauzes in buffer at pH 4. Thus approximately 50% was in a relatively labile form. These measurements are regarded as minimal estimates of biological availability.

9.3.4 Radioautographic Studies

Radioautographs showed that the contamination of herbage after Round 1 was in the form of discrete spots especially in re-entrant angles. The sheathing bases of grass leaves held marked quantities. Before samples could be collected following Round 2 rain occurred. Radio-autographs showed considerable contamination throughout the tissues in addition to spots of high activity. This result, which contrasted sharply to that obtained in Round 1 is attributed to material passing into solution and being absorbed by the leaves or adsorbed onto their external surfaces.

9.3.5 Contamination of Regenerating Herbage

Herbage boxes which had been cut to ground level were allowed to regenerate for periods of 1 to 3 weeks. After regeneration the weight of herbage per box was only a fraction of that present at the time of deposition of fallout. Contamination per unit weight of tissue was as great or greater after regeneration than initially, when allowance was made for the decay of radioactivity. An endeavour was made to determine whether this was due to superficial contamination being carried up by regenerating tissues or to its absorption.

9.4 Ingestion of Fission Products by Sheep

The programme of the sheep feeding experiment is set out in Table 4. Times of feeding and sacrifice were varied so that information could be obtained on the metabolism both of short-lived activities and of those of relatively long half-life. To obtain information on the retention of activity in the rumen two animals were compared of which one was fed through an abomasal fistula.

The total activity was determined in all samples and in most cases decay rates were also followed. Chemical separation was undertaken with the tissues of higher activity.

A γ-spectrometer was employed to determine the relative quantities of ^{131}I, ^{133}I, ^{135}I, ^{133}Xe and ^{135}Xe in thyroid extracts. The analysed results are not yet available.

9.5 The Ingestion of Fission Products by Rabbits

9.5.1 Collection of Native Animals

After Rounds 1 and 2 wild rabbits were trapped or shot 7 to 10 miles NE of ground zero. Since 3r was the permitted total exposure to radiation and the major commitment of the personnel concerned with this work was on Round 2, 0.3r was laid down as the maximum exposure of personnel in collecting rabbits on Round 1. This curtailed the work.

Traps were set 48 hours after Round 1 and over the next 3 days 4 rabbits were taken. After Round 2 traps were set within 18 hours. By day D_2 + 6 thirteen animals had been shot or trapped.

The thyroids of all animals were examined and 9 were dissected and assayed, the following tissues being separated: thyroid, liver, skeleton, carcass, kidney, pelt, stomach, large intestine and ovary. Radiochemical separations were carried out on the more active tissues.

9.5.2 Experiments with Domestic Animals

A small number of animals surplus to the blast investigations (Section 4) were available. After Round 1 five were fed with small quantities of contaminated herbage on a single occasion. On autopsy the activity in tissues proved inadequate for assay by the methods available. The experiment was repeated after Round 2 with material extracted from air filters being given intragastrically. Animals were sacrificed at daily intervals and assayed.

10. Assay of Thyroids Collected Under Arrangements Made by the Australian Safety Committee

Thyroids were collected from 3 sheep stations 150 to 200 miles from Maralinga at approximately weekly intervals after firing. These were assayed.

TABLE 4

Animal Feeding Experiments

	Wethers											Goat (see Note 2)	Ewes		
	1a	2a	2b	1b	3	9	4	5	6	7	8		Blue	Black	Brown
Material fed	Cut herbage				Filter paper	Cut herbage	Filter paper	Filter paper extract				Filter paper and filter paper extract	Filter paper		
Time of feeding	F + 8 hours				F + 25 hours			F + 73 hours				D+2 F.P. and D+3 extract	D + 2 days		
Method of feeding	Natural				Mixed with feed	Natural	Mixed with feed	By tube to rumen	By fistula to abomasum	By tube to rumen		Mixed with feed and in drinking water	Mixed with feed		
Activity at feeding time	0.5-5.0 mc	0.3 - 3.0 mc		0.5-5.0 mc	~ 1.0 mc	Figure not yet available		~ 1.0 mc				10 mc	0.5 mc		
Time before sacrifice	8½ hours	34 hours	82 hours	129 hours	10 days			3 days		1 day	5 days	7-8 days	8 days	5 days	2 days
Comment on feeding	Eaten well				Eaten well		Little eaten in 24 hours	Administered without difficulty				Paper poorly eaten. Extract taken overnight	Filter papers poorly eaten and discriminated against in feeding		

Sample disposal (see Note 1)	1a	2a	2b	1b	3	9	4	5	6	7	8
Blood		T & D	T & D		T	T	Rejected and no samples taken	T	T	T & D	T
Urine	TD & S	T & D	T & D	T & D	T & D	T & D		TD & S	TD & S	TD & S	T & D
Thyroid	T & D	T & D	T & D	TD & S	T & D	T & D		TD & S	TD & S	TD & S	TD & S
Kidney	T & D	T & D	T & D	T & D	T & D	T & D		T & D	T & D	T & D	T & D
Liver	TD & S	T & D	TD & S	T & D	T & D	T & D		T & D	T & D	TD & S	T & D
Bone	T & D	T	T	T	T & D	T & D		TD & S	T & D	T & D	T & D
Skin	T	T								T & D	
Muscle	T	T	T & D					T	T	T	T
Rumen	T & D	T & D	T & D	T	T	T		T & D	T	T & D	T & D
Small intestine	T & D	T & D	T & D	T	T	T		T & D	T & D	T & D	T & D
Faeces	T	T & D	T & D	T & D	T & D	T & D		T & D	T & D	T & D	T & D
Tapeworm				T							

Sample disposal (see Note 1)	Goat (see Note 2)	Blue	Black	Brown
Thyroids – Parent	T & D	T & D	T & D	
Thyroids – Offspring:- Grey	T & D	T & D	T & D	
Thyroids – Offspring:- Brown	T & D			
Bones – Parent	T & D	T		
Bones – Offspring:- Grey	T & D	T		
Bones – Offspring:- Brown	T & D			
Milk	TD & S	T	T	T

Notes :

1. Key to sample disposal

T = Counts per gram of tissue determined.
D = Radioactive decay followed.
S = Chemical separation performed.

2. The goat was weaning twins, hence separate values are shown for the parent and the two offspring, which were distinguished by their colour.

Figure 1 - Effect on Packing Case "Cabin" at 3100 ft (Equivalent Distance from Round 1) (see Section 6)

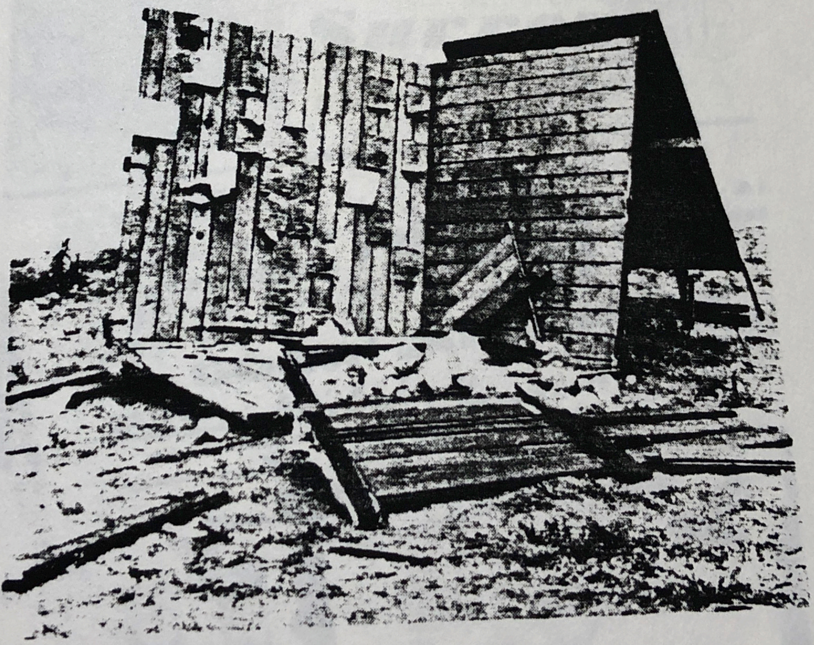

Figure 2 - Effect on "Cabin" at 4200 ft Equivalent Distance (see Section 6)

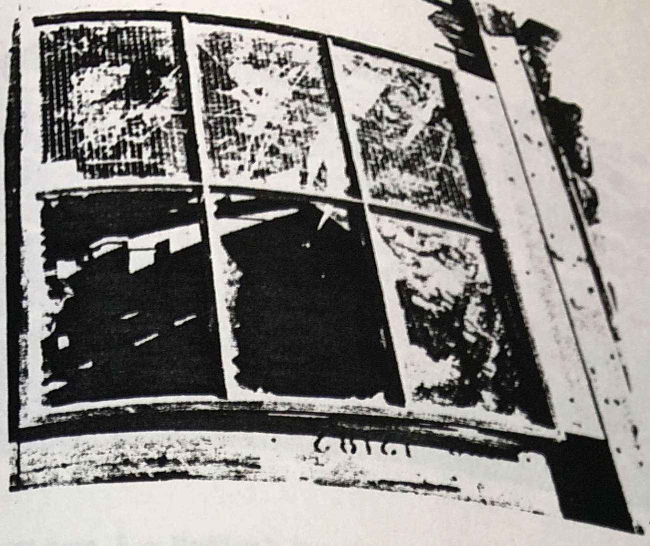

Figure 3 - Shattered Window Panes in "Cabin" at 6800 ft Equivalent Distance (see Section 6)

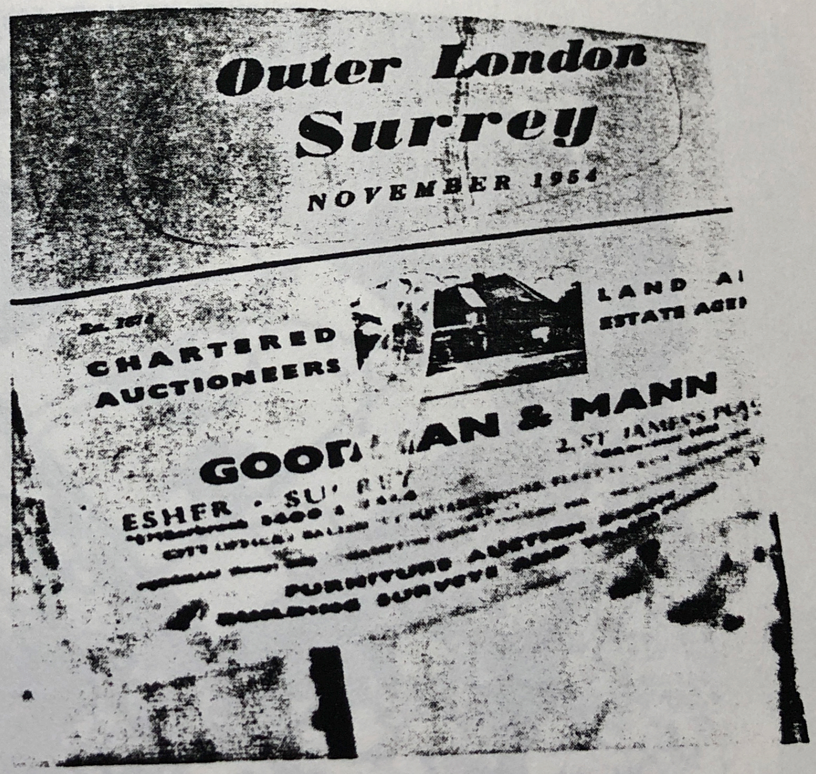

Figure 4 - Splinters in Rear Wall from Window Panes Shown in Figure 3 (see Section 6)

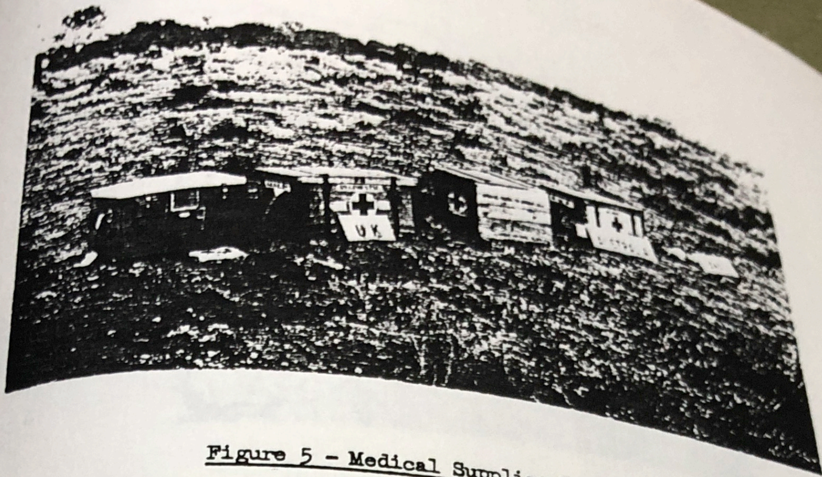

Figure 5 - Medical Supplies Ready for Exposure (see Section 7)

Figure 6 - Food Box in Iron Chest (see Section 8)

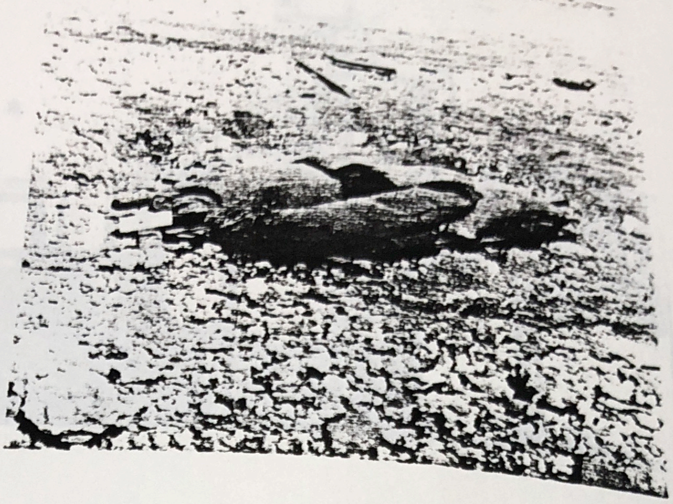

Figure 7 - Food Site Ready for Exposure (see Section 8)

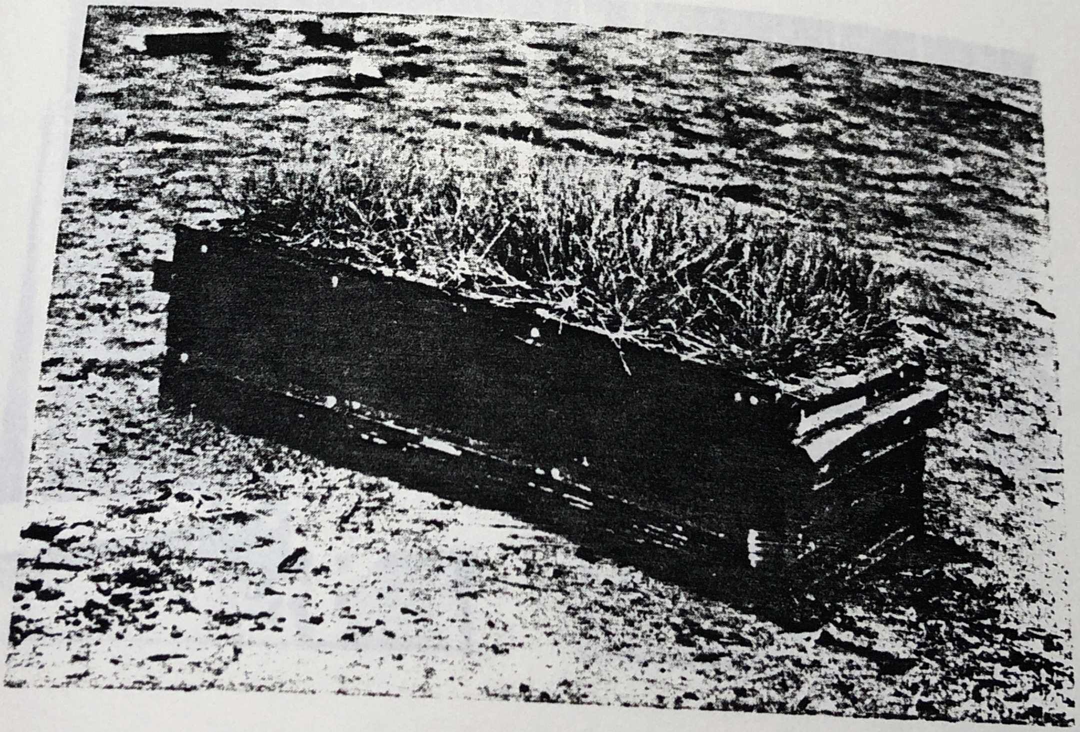

Figure 8 - Herbage Boxes Used in Fallout Investigations (see Section 9)

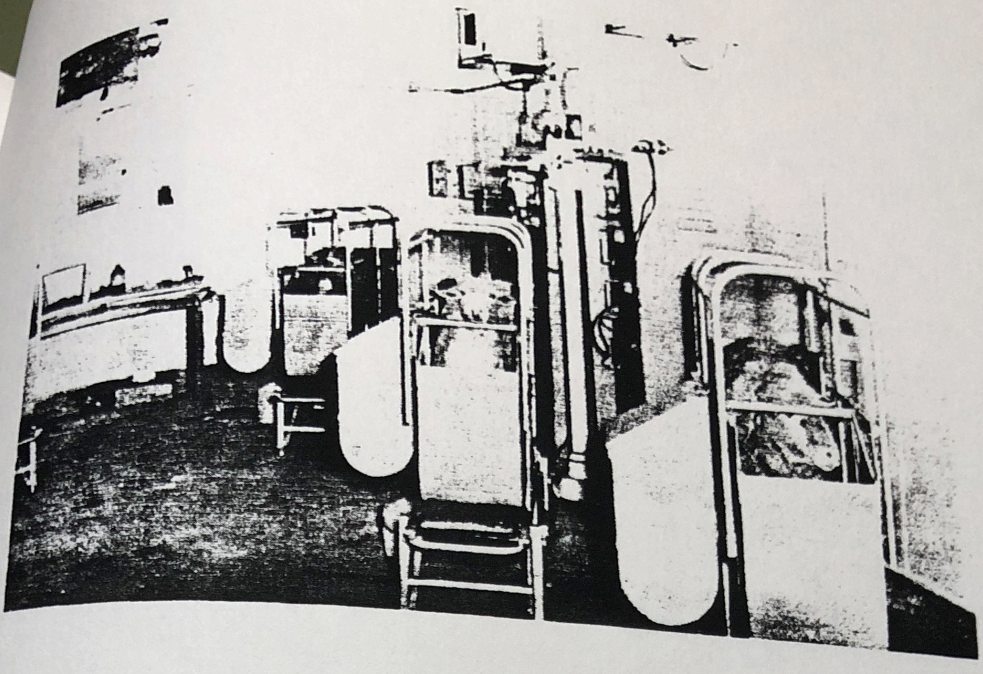

Figure 9 - Metabolism Pens (see Section 9)

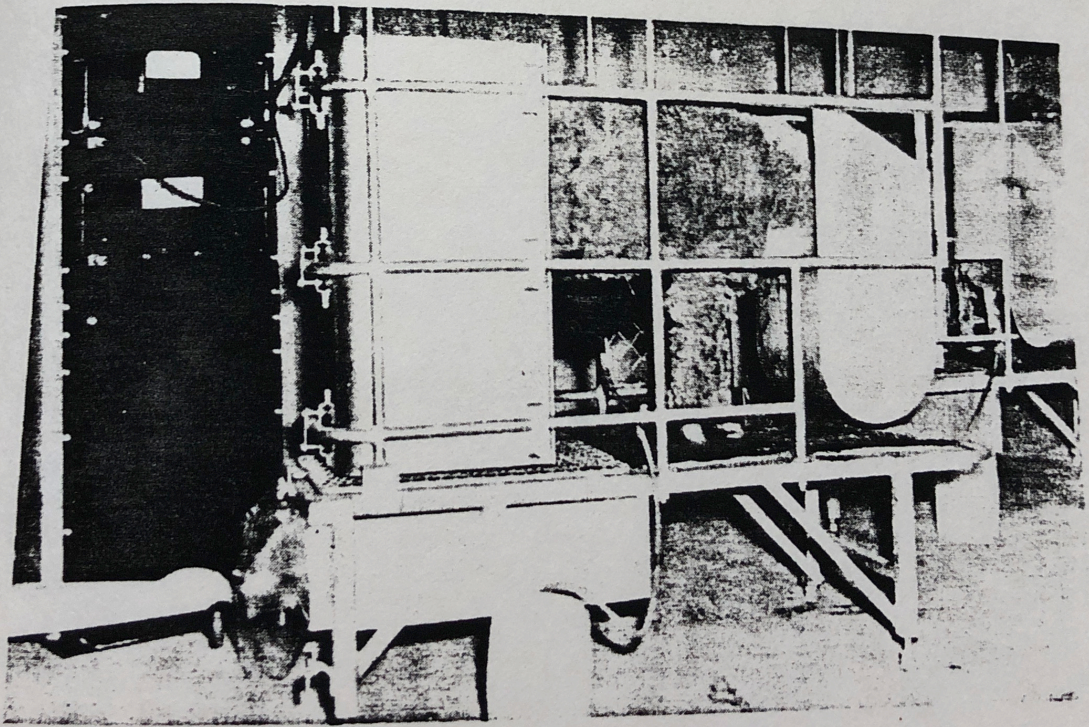

Figure 10 - Metabolism Pens Showing Method of Collecting Urine (see Section 9)