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Summary Report on Biological Experiments

W. J. H. Butterfield

(Medical Research Council)

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1. <u>Introduction</u>

Previous atomic explosions have provided information about injuries from blast effects, heat and prompt nuclear radiations, but relatively few data are available about the biological hazards of fall-out. The purposes of these investigations therefore were to observe the Monte Bello explosion from the point of view of all medical effects, in a general way, and to scrutinize those of the fall-out in particular.

The following questions were selected for special study :-

(a) Would radio-iodine exist in the <u>fall-out on the ground</u> or in a vapour state? The absence of radio-iodine would not only influence ground radiation doses by some 20 per cent in the first few days, but also the rate of decay of fall-out at this time.

(b) Would the iron and debris present during the quenching of the fire ball adsorb the fission products and interfere with their availability to plants and animals? This would influence all risks due to radioactive elements lodging in tissues, especially bone, after inhalation or swallowing fall-out.

Investigations were conducted at the trial, and later in laboratories in the United Kingdom. In particular, samples of fission products were collected after the explosion and flown back to the United Kingdom for plant and animal studies.

2. <u>Studies in Relation to Operational Problems</u>

2.1 <u>Availability and Absorption of Radio-Elements by Biological Systems</u>

Various animals and fish were caught within seven days of the explosion. Radio-iodine was recognised in the thyroid of a severely contaminated rat. The radioactive decay of all other tissues examined, including bone, suggested the absorption of a diversity of radio-elements by biological systems. Radio-iodine also appeared to be available to, and concentrated by, seaweed in the lagoon.

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2.2 Contamination and Decontamination of Vegetation

It was found that the radioactive contamination of leaves was particulate, and, in worst cases, it could be recognised as black spots visible to the naked eye; this could be of assistance to radiological monitors.

As up to 66 per cent of the radioactive contamination could be removed by washing vegetation for 10 minutes, some measure of salvage of vegetables might be achieved, and such washing would be worthwhile in the absence of radiological monitoring, or until this could be completed. There appeared to be very little selection of the radio-elements removed from vegetation by water or detergents. Heavy rain cannot be expected to effect the complete decontamination of the surface of vegetation. A rough estimate suggests that 60-90 per cent would be removed by heavy precipitation. Radio-elements from the fall-out, blackened with debris, which fell in one area, were absorbed by plants and recognised in leaf veins. However, this internal contamination was small by comparison with that adhering to the surface of leaves.

2.3 Inhalation of Fission Products by Human Beings

Inhalation could be another route of entry for fission products into animals and man. At various times, men entered the radioactive areas without respirators and it was possible to find traces of radioactivity in their urine within a few days. In an experiment designed to utilize a situation which arose fortuitously, it was possible to secure convincing evidence that such radioactivity in urine had been due to the inhalation of fission products, rather than by other possible routes of entry. These, and other, results indicated that respirators were effective barriers against the inhalation of fission products from this atomic weapon.

The amount of radioactivity found in the urine of subjects collected for 30 hours after exposure without respirators ranged up to 25×10^{-3} microcuries. These small amounts had some rough correlation with the radiation dose from the fission products on the ground. These results were in general agreement with previous predictions as between the uptake by inhalation, and the surface radiation intensity. Although only traces of radioactivity were found in men exposed to the fall-out several days after the explosion, it would seem advisable to wear a respirator while the fall-out settled.

It may be of some operational significance to record that, as expecte the urine of a man who inadvertently bathed in and swallowed mildly contaminated water (2 milli-r./hour at 3 feet) did not contain measurable radioactivity.

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2.4 Protective Clothing: Thermal Stress

Men working in radioactive areas wore dark-coloured protective garments. The first parties to return to the Health Ship on D-day showed many features of thermal stress including intense thirst, marked irritability and tremor. Investigations were initiated. Men wearing the protective clothing in solar radiation with wind speeds of 9-10 knots, shade temperature of 77-86°F. and Relative Humidities of 61, lost up to 16 lbs. The mean 4 hour sweat rates ranged from 2-4 litres on various days. A sweat rate of 4 litres per hour is approximately the general upper limit of tolerance. It is concluded that the thermal stress of protective clothing deserves consideration.

2.5 Decontamination Procedures - Time Involved

After returning from radioactive areas, all men were monitored, decontaminated by washing and remonitored. The average times taken for the various procedures were measured, as follows:

(a) Being undressed down to underwear and socks	61	seconds
(b) Preliminary monitoring	169	"
(c) Showering	390	"
(d) Drying	126	"
(e) Second monitoring	164	"
In the case of personnel still contaminated		
(f) Application of decontaminating chemicals	60	"
(g) Second shower - usually to neck	235	"
(h) Second drying	120	"

Some men needed 5 showers to pass the (very low) tolerance at final monitoring.

These times do not include waiting periods. It must be emphasized that they apply to men insulated by protective clothing. The times would be greater for uninjured persons not in protective clothing escaping after an attack. It is clear that great time losses would accrue in the general confusion whether such persons were left to fend for themselves, or if cleansing were organized. Decontamination would certainly have to be organized for all casualties, with ensuing delays in evacuation, sorting and treating them.

3. Botanical Investigations of Material Collected at Monte Bello

3.1 Introduction

The objects of the investigations were :

(a) To make some measure of the degree of contamination of t[he] ground by radio-elements of biological significance.

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(d) To discover how various soils might influence this availability, and

(e) To assess the effect of rain upon the movement of fission products into the soil.

3.2 Materials in These Investigations

The materials which became available for study were:

(a) Esparto grass filters, contaminated with airborne fission products.

(b) Cotton gauze sheets, 1 yard square, collected from T2 on D + 3.

(c) Miscellaneous plant samples collected from the neighbourin[g] islands within three weeks of the explosion.

These materials became available in the United Kingdom 9, 13 and 48 days after the explosion. The majority of tests were conducted with aqueous extracts of the filters and the cotton gauze sheets, neither of which were contaminated by the blackened fall-out. However, it should be pointed out that it is highly unlikely that practical agriculture would be considered soon after an attack in areas visibly contaminated. The long term problems in such an area are under study.

3.3 Degree of Radioactive Contamination of the Ground

The mean contamination levels by radio-elements of biological significance on the cotton gauze samples examined were, as microcuries per cm.^{2}, ^{140}Barium: 0.89, ^{89}Strontium: 0.007, ^{131}Iodine: 0.99, ^{106}Ruthenium: 0.013. All these values have been extrapolated back to the day of the explosion, at which time they exceed the levels judged to be tolerable for cattle grazing by factors of 10 to 2,000.

3.4 The Fraction of Total Radioactivity on the Ground which Consisted of Radio-Elements of Biological Significance

The solubility of fission products in water and aqueous carrier solutions was regarded as a useful index of biological significance. 60 per cent of the total activity in the cotton gauze samples, and 80 per cent of that in the esparto grass filters, were soluble in this way.

Analysis of the radio-elements in these solutions several weeks after the explosion revealed that, as calculated back to the day of the explosion, ^{131}Iodine was predominant and ^{140}Barium, ^{89}Strontium and ^{106}Ruthenium were also present: the proportions were approximately 600:175:15:3, respectively. Traces of other Rare Earths were also identified.

3.5 Absorption of Radio-Elements by Plants

The absorption of the radio-elements in an aqueous extract of cotton gauze was studied.

(a) Water Culture. Barley and cabbage were grown in the aqueous extracts, alone and with various nutrients and concentrations of calcium ions. In 12 days, Barley took up 20 per cent of the radio-barium present,1(per cent of the radio-strontium, 12 per cent of the radio-iodine and 8 per cent of the radio-ruthenium from the aqueous extract alone. Cabbage took up rather less ruthenium and rather more of the other radio-elements studied After 21 days, the uptake was somewhat increased. Smaller amounts of barium and strontium were absorbed in the presence of calcium ions. It may also be noted that very little of the ruthenium or iodine was transferre from the roots to the shoots.

(b) Soil Culture. Wheat was grown in soil from Wytham and Cannock Chase to which aqueous extracts of the contaminated gauzes had been added. After 150 days, the radioactive content of the whole plants was less than 1 per cent of the total activity added, and probably less than 0.5 per cent of the original total fission products in the gauze. The radioactivity in

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Important for future laboratory studies is the finding in parallel experiments that the absorption and behaviour of carrier-free ^{90}Sr was in every way similar to the same element in the mixed fission products.

3.6 The Effect of Rain Upon the Movement of Fission Products into Soil

One hundred days after the explosion, aqueous extract of fission products was added to the surface of soils in 12 in. high cylinders, and the mixture exposed to natural rainfall for a further 80 days.

Eighty-eight per cent of these soluble fission products were retained in the top 1 in. of the Wytham soil, and 68 per cent in the top 1 in. of the Cannock Chase soil.

Of the traces of radioactive material leached through the 12 in. of soil, over 90 per cent was as ^{106}Ruthenium, which therefore may be regarded as the radio-element most likely to migrate from contaminated areas into the water table and so drain away.

3.7 Summary of Botanical Investigations

The results show that after the Monte Bello explosion, contamination of the ground occurred which was at dangerous levels for agriculture in places where the fall-out was not visible to the naked eye.

The presence on the ground of radio-iodine, and other radio-elements of biological importance, was confirmed, as was their availability to plants. However, apart from the risks of animals and human beings eating vegetation contaminated directly on the surface, a variety of factors in Nature tended to diminish the risks to be expected from eating fresh crops of vegetation growing in the fall-out area after the Monte Bello explosion.

Sixty per cent of the fission products which lay invisible on the ground to a highly contaminated region were soluble, and may be considere as of biological significance. Although plants growing in water cultur might take up as much as 50 per cent of these soluble fission products in 21 days, in the more practical experiments, wheat shoots grown for 1 days in soil to which soluble fission products had been added contained less than 1 per cent of the radioactivity applied (i.e. about 0.5 per c of the total fission products). This low fraction of fission products absorbed may be related to the fact that almost all the fission produc were trapped in the top inch of soil, even after exposure to rain for days. Thus the percentage uptake might be higher with shallow rooted plants such as grass.

These results agree with the findings at the trial that internal contamination in plants is much less than direct surface contamination. Under the conditions of these experiments the expected uptake of fission products by new crops growing in contaminated soil would be no higher than 1 per cent, and by new crops growing in areas draining contaminated zones, probably less than 0.05 per cent. More investigations are needed before these data can be used to determine accurate safety levels. In particular, it is necessary to establish the percentage of radioactivity in plants which can be absorbed by animals and man as a result of ingesting crops containing such radio-elements as the latter will select from the soil. These investigations are being pursued.

4. Zoological Investigations with Material Collected at Monte Bello

4.1 Introduction

The purpose of these investigations was to confirm and extend, both qualitatively and quantitatively, those made on animals at the trial. Particular attention was paid to the proportion and chemical identificat of fission products taken up by various tissues.

4.2 Materials and Methods

The samples investigated were:

(a) Airborne fission products collected on esparto grass fil These and aqueous extracts thereof were fed to 4 rabbits 20 hr. after the explosion.

(b) Aqueous extracts of "invisible" fall-out as prepared fo botanical experiments, containing 15-20 per cent of the to radioactivity present in the fall-out. This was fed by to 11 guinea pigs 200-400 hr. after the event.

(c) Blackened earth and sedge-like herbage collected from the islands. These, and aqueous extracts thereof, were 2 guinea pigs and 6 rabbits 1,300-2,500 hr. after the eve

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(b) Aqueous extracts of "invisible" fall-out as prepared for the botanical experiments, containing 15-20 per cent of the total radioactivity present in the fall-out. This was fed by pipette to 11 guinea pigs 200-400 hr. after the event.

(c) Blackened earth and sedge-like herbage collected from one of the islands. These, and aqueous extracts thereof, were fed to 2 guinea pigs and 6 rabbits 1,300-2,500 hr. after the event.

The animals were sacrificed at various times after being fed, dissected, and digests prepared of excreta, intestines, muscles, liver, kidneys, thyroid and bones. These digests were investigated in an M.6.H liquid counter.

4.3 Results of Examining Tissue Digests for Radioactivity

(a) General

Computations comparing the total radioactivity given to that detected in the excreta and tissues showed that recovery was within the limits of the errors in methods of feeding. A large proportion (usually more than 50 per cent) of the radioactivity given appeared in the faeces and bowel contents and a small percentage was detected in the urine. The findings in all tissues except the thyroid and bones were of more interest than practical significance: after early sacrifice the livers, kidneys and muscles contained small percentages of relatively rapidly decaying fission products.

More detailed investigations were directed towards the findings in the thyroid gland and the skeleton, the former because of its value in providing information about radioactive iodine, the latter because of the clinical importance of injury to the blood forming cells from bone-seeking fission products.

(b) Thyroids

Up to 2.4 per cent of the radioactivity in the samples fed within 2 weeks of the explosion could be traced in the thyroid gland.

On D + 10 the thyroid from an animal fed with airborne fission products showed a decay compatible with a mixture of ^{132}I and ^{131}I. The decay of other thyroid glands was always with an 8 day half life, presumably due to ^{131}I.

15-20 per cent of the radio-iodine in the aqueous extracts of invisible fall-out fed to animals could be found in their thyroids after 24 hours.

It was therefore concluded that radio-iodine was present not only in the airborne cloud, but also in the invisible fall-out, and that it was water soluble and available for absorption by guinea pigs and rabbits: it did not prove feasible to investigate the presence and availability of radio-iodine in the black fall-out.

(c) Bones

The outstanding feature of these studies was the variation in the percentage of radioactivity deposited in the bones after feeding different samples of fission products. The average percentages were:

Airborne Fission Products	8%	
Aqueous Extracts of Invisible fall-out	14%	i.e. some 3% of the total activity on the ground.
Blackened fall-out	0.2%	

The counts of all skeletal digests showed an early rise, which could be attributed to ^{140}Lanthanum being formed from ^{140}Barium. The subsequent decay could have been explained by various mixtures of ^{140}Ba and ^{89}Sr, but chemical analysis revealed the presence of various Rare Earths as well: cerium, yttrium and praesidinium have been identified.

More detailed studies showed that, after feeding airborne fission products and aqueous extracts of invisible fall-out, the proportion of barium and strontium in bones was roughly the same as in the material given. In contrast, after feeding material contaminated with blackened fall-out - where the percentage deposition in bone was so small (0.2 per cent) - the absorption of barium and strontium was even more severely curtailed than that of Rare Earths.

4.4. Supplementary Experiments

The low absorption after feeding blackened fall-out and the very small percentage deposition in skeletons are obviously of interest not only in respect of a possible atomic attack, but also in the accidental exposures to mixed fi...

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4.4. Supplementary Experiments

The low absorption after feeding blackened fall-out and the very small percentage deposition in skeletons are obviously of interest not only in respect of a possible atomic attack, but also in the event of accidental exposures to mixed fission products in atomic energy programmes.

Some possible factors responsible for the diminished deposition in bones are as follows:

(a) The presence of magnesium sulphate in the Monte Bello sand.

(b) The presence of calcium ions in the Monte Bello sand; both these facts were known from previous soil analysis.

(c) The presence of iron from the target vessel.

Because low absorption was found using black fall-out but was absent using extracts of the invisible fall-out which were mixed with Monte Bello sand, interest was naturally aroused in the possible role of iron in interfering with the absorption of barium and strontium as well as Rare Earths.

In an experiment with guinea pigs fed radio-barium/lanthanum solution with minimal carrier, it was shown that 5 mg. spectroscope-pure iron oxide half an hour before feeding would reduce deposition in the skeleton by a factor of 3. When the same treatment was also continued twice a day for 3 days after feeding, the deposition in the skeleton was reduced by a factor of 10.

These studies continue.

4.5 Summary of Zoological Experiments

When various samples of mixed fission products from the Monte Bello explosion were fed to guinea pigs and rabbits the majority of the radio-activity given was excreted in the faeces and urine. The most serious accumulation of absorbed radio-elements occurred in the thyroid gland ar bones. The thyroid glands took up 20-25 per cent of the available radio-iodine from the aqueous extracts of "invisible" fall-out. The proportion of fission products which lodged in the bones was highest wi airborne fission products (about 8 per cent), less with "invisible" fall-out (about 3 per cent) and remarkably small in the case of "black fall-out (0.2 per cent). The investigations also showed that element other than barium and strontium accumulated in bone: cerium, yttrium and praesidinium have been identified.

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It is suspected that some chemical property of the black fall-out material was responsible for the diminished absorption of radio-elements observed. This chemical factor may be iron oxide, which has been shown to interfere with the uptake of ^{140}Ba by bone. These studies continue.

It must be remembered that no experimental data could be secured about the uptake of fission products in the first day after the Monte Bello explosion, that is, during the "escape phase", at which time the mixture of radio-elements is more complex than later. Furthermore, it was not feasible to study the absorption of any fission products from the "black" fall-out in the first 5 weeks after the Monte Bello explosion; the interfering property of this material might or might not have diminished absorption during the earlier stages.

It should be noted that although the radioactive content of the "black" fall-out was generally greater, its very visibility would indicate its dangerous properties if the populace were made aware of its nature.

On the other hand the greater uptake probably from "invisible" fall-out stresses the need for monitoring and vigilance in fringe areas.

In conclusion it must be emphasized that these laboratory studies were made to explore the hazards from fall-out, especially after inhaling or swallowing it. But other important effects of the Monte Bello explosion created serious biological risks: these may be assessed on the basis of the data accumulated from previous atomic explosions.