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TEAM R.H.5

CONTAMINATION SURVEY

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(Maps prepared by Captain W.N. Saxby)

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PART I

Contamination Survey

1. INTRODUCTION

1.1 Of the effect of an atomic explosion, the extent and intensity of the radioactive contamination associated with this kind of burst was the most difficult to predict. The tasks of the survey team were set down as:

(a) Water Survey

(i) To establish the limits of contaminated water and to follow their subsequent movements due to tide and diffusion.

(ii) To establish and follow the clean/dirty water boundary.

(b) Land Survey

(i) To carry out as complete a radiological survey of the islands as possible during the working period following the explosion.

(ii) To define the limits of clean areas as early as possible after the explosion.

Clearly the objective was to make the survey as complete and precise as circumstances would permit.

1.2 In addition to the general survey, information was required on the following:

(a) The relative amounts of contamination due to fissioned and unfissioned material.

(b) The relative β/γ dosage.

(c) The overall dosage decay rate, both β and γ, due to dispersal by weather and mixing in soil in addition to radioactive decay.

(d) Variation of contamination with terrain.

(e) Variation of contamination with depth in water.

(f) Air contamination, both α and β, occurring during survey, recovery and salvage operations.

Although dust samples were collected in accordance with the requirement (f), their analysis was carried out by team RH.7 so that they are not included in this report. In the same way RH.7 analysed the water samples collected and special work on the β/γ dosage ratio was carried out by RH.4.

2. METHOD

2.1 Personnel

The survey team consisted of nine British Army Officers, six Naval Officers and one officer from the R.A.A.F. The Army Officers formed the nucleus of team and were specially trained for the operation at the Joint School of Chemical Warfare. The syllabus of the special three-day course, which followed a normal ABC Warfare Course is given in Appendix A. The naval group were trained during the voyage out (see RH.1 report). The members of the team are listed in Appendix B.

2.2 Instruments

The instruments provided for the survey are described in Appendix C which includes a summary of team comments on their performance. These instruments are either laboratory instruments or prototypes of those developed for Service and Civil Defence use. The survey provided therefore a field trial of these instruments. It is noteworthy that none of these instruments was in any-way a standard for the measurement of dose-rate, nor was any such standard available. Provision of instruments and their repair and maintenance was the responsibility of team RH.3.

2.3 Transport

For movement from H.M.S. Tracker, the Health Control Ship, to the islands a total of 6 pinnaces 5 harbour launches and 4 LC(A)s were available to Health Control. The pinnaces had been equipped with metal canopies to protect the occupants from contaminated spray during the early stages of re-entry. The canopies reduced the sea-worthiness of the boats to some degree so that the numbers which could be carried were strictly limited (a total of twelve including the crew of four). Once the water contamination ceased to be hazardous, the landing craft and harbour launches, would be available.

On Trimouille three Land-Rovers were left behind (in suitably protected locations) for use by the re-entry parties. The number was increased to five as soon as conditions permitted. On all other islands movement was entirely on foot.

2.4 Communications

It was decided that both survey and recovery parties should carry wireless sets and be in radio communication with the Health Control. The main reason was precautionary in case of an accident in an active area to any individual. On the survey side it proved invaluable during the first few days after the explosion to direct the survey to a large degree from H.M.S. Tracker and to plot the results as received. The communications were based on two wireless sets. An Army set (No.62) operating from Health Control was in constant communication with both the pinnaces and LC(A). The water survey parties, and all parties during the trip from H.M.S. Tracker to the islands, could report direct to R.H. control. On shore, all parties carried a No.88 set (British version of the 'Walkie-Talkie') and a set was left in each boat with the coxswain. Communication was then R.H. control to the pinnace or LC(A) on the standby boat wave and then relay to the party ashore and the reverse. These communications proved successful and enabled control of both survey and recovery parties to be exercised from H.M.S. Tracker.

2.5 Security

All survey data and records were classified secret. The only danger of leakage was through the radio communications, as it was known that transmission of the boat wave could be picked up in Singapore. A map code and word code were prepared and used. The principles employed were letters for the main map and chart co-ordinates (different schemes were used for maps and charts); and suitable words for words like roentgen. The codes were changed daily. The use of two map codes on each day made it most unlikely that the simple arbitrary letter codes could be broken. Only distress signals of any kind could be sent in clear.

2.6 Operational Procedure

2.6.1 There was no experience available to us, so that to some extent the procedure had to be developed as the survey proceeded. However, every member of the survey team spent a considerable

time during the period before the explosion studying the terrain and working in the pinnaces. It was decided that for water survey a party of two in a pinnace would be satisfactory: one member was a naval officer who was in navigational command of the boat. The land survey parties consisted of three: this was necessitated by the need to carry at least two instruments, map-board, record-board and a radio set (No.88). As each party must work as a team, the membership of each party was kept constant as far as possible during the early stages. There were three water survey and three land survey parties, the membership of which is indicated in Appendix B. The organisation of personnel, equipment and communications in boats and ashore varied to some degree from day-to-day, but the D day layout shown in Appendix D is representative.

2.6.2 In addition to observing dose-rate readings in the pinnace and in the water at several depths, the water survey parties collected both air and water samples for examination by RH.7. As one object was to correlate the dose-rate and the sample activity the team of two surveyors needed a more or less fixed procedure. This was worked out subsequently to the rehearsal, at which it became evident that the pinnaces for water survey must be fitted up with the necessary equipment prior to the despatch of the party. Thus each water survey party had its own pinnace in which its equipment was stowed. The water probe connected to the contamination monitor was trailed in the water surface throughout the survey: it was kept in position by a suitable attachment to the boat.

2.6.3 The land survey parties took only such equipment as they could carry and therefore could travel in any boat to the shore. During the first few days after the burst the land survey parties were required to take dust samples. To facilitate this a portable generator was left ashore prior to D day near one of the Land Rovers, in which it was carried when dust samples were

required. The land survey was carried out by observers on foot, but the Land Rovers were invaluable in permitting them to reach the selected area quickly, thus saving physical effort and waste of permitted dose.

2.6.4 The survey took place in two stages. Up to D + 3 (D + 1 was lost owing to bad weather) the emphasis was on reconnaissance to determine the overall extent of the contamination and to obtain some estimate of where the activity was greatest. In addition to this being essential to the survey it also was necessary so that the plan for the recovery of records and test equipment could be put into operation. From D + 4 onwards the survey became more detailed and precise: relatively small areas were surveyed each day. It was anticipated from the study of the terrain prior to the explosion that there would be some difficulty in indivduals knowing their position unless there was some other recording or experimental device nearby. The procedure was therefore to take readings in the vicinity of fluxmeters, film stakes, blast recorders, etc. and to interpolate by pacing. This method could only be satisfactory in the areas where there were sufficient of these. In some areas, particularly northern Trimouille it was necessary to survey on a fixed compass bearing and take readings at paced distances. An alternative method was also tried in which the line corresponding to a selected fixed dose-rate is followed on foot and plotted on a map. This method is rather more difficult to carry out but gives a very satisfactory result. Owing to the rough nature of some of the terrain it was found that interpolation between readings on a fixed bearing was not always straight-forward, nor did the readings always change in a consistent manner.

2.6.5 The original plan was to take readings of γ dose-rate at heights of 1 and 3 feet from the ground. It was found that there was in fact, very little difference between the two readings, so that the requirement was reduced to one

observation at 3 feet. The incorporation of a thin window in the dose-rate meters, which is covered for the γ dose-rate measurement, permits some indication of the combined β and γ dose-rate to be obtained. It was hoped to obtain data at the heights of 1 and 3 feet with the window horizontal (facing the ground) and vertical. Observations made during the first few days showed that the increase in observed dose-rate was small and that there was a serious disadvantage in making the β observations. There was always some airborne activity (except possibly on the rocky islands) and the lodgement of a little active dust on the thin β window rendered the instrument useless for further survey during the sortie. Continuance of the β measurement would have rendered the entire survey open to suspicion, so the decision was made to rely entirely on the γ dose-rate observations made at a height of 3 feet. Special sites had been prepared with the express purpose of permitting the β/γ dose-rate ratio to be determined, so that the β dose was not entirely neglected. (See report under RH miscellaneous 1.).

2.6.6 Prior to the operation the permissible doses of both β/γ radiation had been laid down. For all survey tasks, the so-called Normal Working Rate was applicable initially. This was defined as 0.3 rep/day, of which not more than 0.1 rep/day should be due to γ radiation and not more than 0.2 rep/day due to β radiation. During the first few days, in the absence of reliable measurements, the theoretically computed β/γ dose-rate ratio was applied, so that the permitted γ doses were very small. It became clear that the survey could not be successfully carried through with this limitation and the use of the lower integrated dose of 3r γ radiation was agreed (see RH.1 Report). This gave some freedom of action and allowed the survey of relatively active areas to be achieved, even though the individual surveyors might use up their whole permissable dose in a single sortie. Special clothing was always worn in the active areas and respirators also were

worn when the dose-rate exceeded 0.5 mr/hr or when conditions were dusty: this limit was later raised to 100 mr/hr (see RH.1 and RH.7 Reports).

2.6.7 In addition to the records of the survey parties themselves, a certain amount of information was obtained from the observations made by health escorts. This was particularly of value when the recovery party operated in a highly active area. These observations have been incorporated in the survey and appropriate reference made in the map records.

3. RESULTS

3.1 D Day

3.1.1 The explosion occurred at 0930 hours (on 3rd October) and by 1230 hours the survey parties had been launched and were in the region of the Parting Pool (see Map A1). Sorties allotted to RH.5 were three water survey parties and two land survey parties. The emphasis was placed on water survey initially because the subsequent position of the Health Control Ship depended on the extent of the radioactive contamination of the water to the south of the target vessel position. Furthermore it was of great interest to determine if possible the extent to which the contamination would move northwards with the tide. The general tasks allotted were:

(a) W.S.P1 - to penetrate the lagoon and survey northwards.

(b) W.S.P2 - to survey to the east of Trimouille in a northerly direction.

(c) W.S.P3 - to ascertain the general position of the clean/dirty zone, which was defined as corresponding to a dose-rate of 0.1 mr/hr in the water.

(d) L.S.P1 - to land at the south end of Trimouille (T1) and survey northwards towards T2 along the west coast.

(e) L.S.P2 - to land at T1 and survey northwards along the east coast of Trimouille. This party was carried in the same pinnace as W.S.P2 with which it was in constant communication by radio during the survey.

The permissible doses (of γ radiation) were 0.1r for the water survey parties and 25mr for the land survey parties: the lower dose in the latter case took account of the possible β radiation hazard (see under RH.1).

3.1.2 For clarity the observations are summarised on maps: for D day see Maps A1, A2 and A3. Although the days survey operations only gave a limited amount of numerical data about the deposited radioactivity, quite a good picture of the

contamination to the south of an east to west line through the T.V. position was obtained. Within the lagoon, dose-rates over the water were highest northwards of the T.V. position along Bunsen Channel, at the most northerly point reached due east of Beaver Hill - the dose-rate was 0.6 r/hr. In part this would be due to the land contamination, which was clearly visible as a black deposit on the cliffs north of T2. The water contained much suspended solid material. The dose-rate in the water could not be measured as the instruments available were too sensitive. To the east of Trimouille the activity rose sharply in the vicinity of Violet Island, being more or less negligible to the south. The activity in the water was found to be in the surface layer, showing that the dust deposited had not mixed in depth nor settled to the bottom. On Trimouille the activity was very small to the south of the first ridge north of the T1 position, but thereafter rose steeply in a northerly direction. Several pieces of HMS Plym were found, which were radio-active: the dose-rates observed over southern Trimouille were probably due entirely to these. This conclusion was supported by the observation that the β dose-rate was negligible, even over the specially prepared site at T1.

3.2 D + 1 Day

Early on D + 1 the weather showed signs of deterioration. However, three water survey parties set out, travelling by L.S.M. to Claret Bay where the pinnaces had been anchored over night. From there they proceeded in a general north easterly direction with the objects of continuing the water survey in the lagoon and along the east-coast of Trimouille. The weather became worse and the three boats were forced to turn into Stevenson's Channel for shelter. About midday all hopes of continuing operations ceased and all efforts were directed to the safety of the surveyors and boats crews isolated on Hermite. Observations were made where possible and it was clear that Hermite and Stevenson's Channel were both more

or less free of activity.

3.3 D + 2 Day

By D + 2 the easterly wind had died down and the sea was calm enough for survey and recovery work to proceed. The permissible dose for the day was raised to 0.1r. W.S.P1 continued the survey of the lagoon and was able to reach N.W. Island. The dose-rates observed in the pinnace north of the T.V. position were 30-40 mr/hr, showing that there had been heavy fall-out over the northern half of the lagoon. On N.W. Island in the vicinity of the pier the dose-rate was found to 90-100 mr/hr and decreasing further inland. Off Gladstone Pier some 10 feet below the high water mark the dose-rate was 1.25 r/hr. This was in accordance with the observation that heavy fall-out - black rain - had occurred along the western coast of Trimouille. Observations made on Alpha and Delta Islands showed that the level of activity there was very slight. W.S.P3 continued the survey along the eastern coast of Trimouille and reached Pitt Point, where the dose-rate close in shore was found to be only 12.5 mr/hr. The black fall-out was not visible from this side of the island. On Trimouille L.S.P1 and L.S.P2 continued the survey northwards from T1 and reached a west to east line from T2 to Balfour Point. To the south of T2 headland dose-rates of 0.5 r/hr were observed. The activity declined rapidly in an easterly direction to give only a few mr/hr near Balfour Point. The results are summarised on Maps B1 and B2.

3.4 D + 3 Day

3.4.1 From the observations made on D and D + 2 days it was fairly clear that the heavy fall-out area was about a line to the north-west of the T.V. position, including the west coast of Trimouille. On D + 3 the main object of W.S.P3 was to investigate the Western Isles: Kingcup, Gardenia, Primrose and Carnation. The levels of activity observed supported the conclusions already drawn and it was noted that the fall-out was again in the form of a black deposit, which had been produced by

rain. The ground wind direction at the time was from the south and from the 'shadows' formed it was clear that the rain had been driven against the ground from this direction. W.S.P1 continued the survey of northern Trimouille: it was found to be possible to go ashore at Gladstone Pier, where a dose-rate of 1 r/hr was observed on the P.S.P. area. A landing was made on the beach to the north of Pitt Point, where the dose-rate was found to be only 80 mr/hr. During the run northwards through the lagoon an approach was made towards the small headland at the northern end of the main beach above T2. The dose-rate rose rapidly from 0.25 r/hr at 75 yards to 2.4 r/hr (corrected to 3.6 r/hr - see para 3.9.1) at 15 yards. A sortie ashore was not possible.

3.4.2 Both these parties observed that a black, highly active deposit had collected along the high water mark in many places: it was observed also by the pier at T1. A comparison of the dose-rates observed over the water and those over the land (such as Kingcup or Gladstone) showed that the bulk of the activity deposited initially in the waters of the lagoon had been removed by the tides. On D day the northerly flow (partly through the channel south of Alpha Island and out through Kelvin and North Channels) set in about 1200 hours and was well established by the time the survey boats entered the lagoon.

3.4.3 Both land survey parties continued to probe northwards on Trimouille along the road towards TH.47, and in this region the dose-rate rose very rapidly and readings as high as 30 r/hr were recorded. L.S.P2 did in addition survey the east coast route as far as the roads permitted and reported that the dose-rates were relatively low.

The results for D + 3 are recorded on Maps C1 and C2.

3.5 D + 4 Day

3.5.1 The reconnaissance part of the survey had been completed on D + 3 and the more detailed survey was now commenced.

The water survey had not yielded results of very great interest and the qualitative picture of the dispersal by tides and mixing seemed complete. The recovery programme also had to be brought into operation, thus the number of survey sorties was much reduced. L.S.P1 continued the survey along the east coast of Trimouille, reaching TH.52. By exploration westwards away from the eastern beaches it was found that the dose-rate rose sharply when the first crest was past. The surface of the sand corresponded to that formed by heavy rain, and this characteristic change marked the boundary of the fall-out area. L.S.P2 carried out a detailed survey of the beach to the south of T2. One interest here was the possibility that evidence of waves sweeping ashore immediately after the explosion would be found. A pocket of activity - dose-rate >2.5 r/hr was indeed found well above the beach to the south-east of T2 headland. The results are summarised in Maps D1 and D2.

3.5.2 The H.E. accompanying a recovery team to Alpha Island, region A4, made a survey of this part of the island up to the northern coast and showed that the dose-rate level was only a few mr/hr.

3.6 D + 5 Day

3.6.1 From now on the composition of the survey parties was much more variable and the main task of water survey parties became an amphibious one of surveying the smaller islands and making limited sorties by beach landings on northern Trimouille. Thus W.S.P1 carried out a survey on N.W. Island (to west of the pier), Gardenia, and succeeded in locating the Land Rover which had been left at Gladstone Camp. W.S.P3 investigated the activity on N.W. Island to the east of the Pier and on Primrose. Some data was also obtained from recovery parties. The results are shown on Map E.

3.6.2 The H.E. accompanying a recovery party to N.W. Island made survey observations on the route to, and at, the tower.

It was of interest that the dose-rate on the ground and on the tower was the same. Doubtless there was some deposited active material on the tower, but the slow change of activity with height observed between 1 and 6 feet from D day onwards, extended to greater heights.

3.7 D + 6 Day

D + 6 was a rest day which was much needed after six days of high pressure operations.

3.8 D + 7 Day

3.8.1 See Map F. W.S.P1 and W.S.P3 operating from the same boat were able to survey Alpha Island (about A4), the small island north-east of McDonald Point and Jonquil Island. This showed that Alpha Island was practically free from activity whereas on Jonquil the dose-rate was in excess of 1 r/hr. The west-east limit of the fall-out area was apparently as sharp as that observed on the eastern coast of Trimouille, where it was found to be approximately along a south to north direction.

3.8.2 The survey was continued on Gladstone beach-head area and southwards by Land Rover to the south of Tidepole Bay. The vehicle failed, owing to the poor condition of the battery, in this area and the surveyor had to withdraw on foot.

3.8.3 Two land survey parties of two each continued the survey of the eastern coast of Trimouille. One of these plotted the 0.5 r/hr line from a position in the neighbourhood of T2 to the east-coast south of TH.55. The link-up with the party surveying along the 10 feet contour of the east coast showed that consistent results were being obtained. The party on the east coast was able to reach TH.55, thus extending the earlier survey along this section.

3.9 D + 8 Day

3.9.1 See Map G. W.S.P1 carried out a detailed survey on foot of northern Trimouille. The path followed was southwards from

Gladstone Beach, across Tidepole Bay (low water) to T4. The tidepole was still in position but it was reported that the mangrove trees appeared to be dying. The dose-rate over the sand of the bay was only 0.3 r/hr, whereas about the high water mark on the southern side it was 1 r/hr, dropping to 0.8 some 20 yards inland and then rising to 1.3 r/hr at T4. The next leg was in a north-easterly direction towards Chatham Point as far as the first prominent hill feature, where the dose-rate was down to 0.6 r/hr. The last part of the course was to T5 (0.17 r/hr) and return to Gladstone. In the absence of known sites the readings were made at paced distances. It was observed that the 1155A monitor always gave a lower reading than the 1193A. For dose-rates above 0.6 r/hr (reasonable scale reading on the 1155A) the ratio of the readings was about 1.5.

3.9.2 L.S.P1 carried out a dual task in the area to the north of T2. A detailed survey of the main beach area was carried out by a team of two. The third surveyor plotted the 0.18 r/hr line in a similar fashion to the 0.5 r/hr line plotted the day before.

3.9.3 One surveyor was attached to the RH.2 recovery party visiting Bluebell. This survey was most important as it showed that the northern part of the island was heavily contaminated. In appearance it was the same 'black deposit' which had been reported earlier from the appearance of the west coast of Trimouille north of the T.V. position and Kingcup. The observed dose-rate about half-way along the northern peninsula was 2.5 r/hr (1155A).

3.9.4 The H.E. accompanying the M.E. recovery team at T4 reported a series of survey observations made at the sites visited.

3.10 D + 9 - D + 12 Days

3.10.1 Bad weather during this period prevented any survey being

carried out, with the exception of one helicopter sortie on D + 12 when the weather was showing a marked improvement. This respite from the continual task of plotting the survey data and forecasting conditions for the succeeding day, gave an opportunity for a critical study of the data obtained this far. Reviewing the results obtained on Trimouille showed that there were some anomalies to be sorted out in the area south and east of Tidepole Bay, but otherwise the results were reasonably consistent. The very active area south of T4 to the main beach just north of T2 remained to be surveyed and would use up a great deal of the remaining permitted dose. The fall-out had been heavy on certain of the Western Isles and it was clear that these must be surveyed in greater detail. To facilitate this and to enable beach landings to be made at selected sites in the very active area it was decided to use the two assault landing craft (LC(A)) when sea conditions permitted. These craft had not been employed earlier because of the potential hazard from radioactive sea spray.

3.10.2 It was found that the results up to D + 4 when correlated with the uncorrected telemetered gamma fluxmeter results followed the $t^{-1.2}$ relationship, but that from D + 5 - D + 8 the decay was rather slower than would be expected from this function. The decay line calculated for the fission products from U235 does in fact show a deviation of this kind. The same calculation has not been made for Pu239 but it seemed reasonable to assume that a similar variation would be present.

3.10.3 The wind structure at H - 1 hour had been available for some days (it was not available on D day) and an attempt was made to forecast the main fall-out area. To do this the fall-out positions for particles or raindrops falling from heights up to 15,000 feet at speeds of 400, 600, 800 and 1,600 ft/min were calculated and plotted as given in Table I.

In the case of rain or water-drops these terminal speeds correspond to drop diameters of 0.5, 0.75, 1 and 3 mm. Denser solid particles would be correspondingly smaller. To obtain a general picture of the fall-out area an estimate of the cross-section of the column of debris had to be made, which from observations made at the time was thought to be about, but not appreciably greater than, a mile across. With a radius of 1,000 yards it is found that the fall-out limit is just to the north of Alpha Island but includes the northern part of Bluebell. On Trimouille the limit is reasonably in accord with the survey. The water survey to the east of Trimouille on D day showed that the activity increased markedly as Violet Island was approached, which is in agreement with the fall-out plot. The fall-out area obtained in this way is shown in Map A4. The inner, more heavily contaminated, zone was obtained by assuming an effective radius of about 200 yards for the column.

3.11 D + 13 Day

3.11.1 See Map H. Two parties, essentially L.S.P2, carried out paced surveys in westerly directions from the eastern road on northern Trimouille in the vicinity of Pitt Point. This was the first phase of the survey of the very active zone. Very high dose-rates were not encountered, so that it seemed likely that the survey could easily be extended to Beaver Hill. Of a third party of two surveyors, one landed at the northern end of the main beach above T2 and followed the 10 r/hr line for about 400 yards. He was taken off by L.C.A. at the point where he reached the sea. This survey took about 20 minutes, so that the surveyor experienced the permitted dose for the operation at one time. However, the result was very important and it had been realised for some time that the relatively small central area could only be surveyed in this way. The Land Rover was recovered from the position near Tidepole Bay

at which it was abandoned on D + 7 (an earlier attempt on D + 8 had failed): it was parked near Gladstone Beach.

3.11.2 The H.E. accompanying the M.E. record recovery party reported important survey data for the line of T.F. positions from T4 to the foot of Beaver Hill. The observed value of 8.5 r/hr at Beaver Hill is in general agreement with the values of 10-12 r/hr reported by the surveyor some 400 yards further south.

3.11.3 During an RH.2 recovery sortie to Violet Island a survey was made. The dose-rate at the film stake was 0.6 mr/hr, whereas on the eastern edge it was 4 mr/hr with patches at 8-10 mr/hr and at the high water mark on the western side only 2-3 mr/hr.

3.12 D + 14 Day

3.12.1 See Maps J1 and J2. A detailed survey was carried out on the Western Isles: Gardenia, Carnation, Primrose and on the south-east tip of N.W. Island and on Pansy. For this task a survey team of four, working in pairs from a L.C.A. was employed.

3.12.2 Of a second party of four, two made a detailed survey along the road from the north-east coast of Trimouille above Pitt Point to the northern side of Beaver Hill returning to Gladstone Beach via the road along the west coast. All readings were taken on foot at paced distances. A Land Rover followed the party to ensure means of a rapid withdrawal should the permitted dose be used up more quickly than expected. The remaining pair carried out a paced survey from T5 to the first pair of aircraft frames located to the south of T4.

3.12.3 The H.E. accompanying an RH.2 recovery party on northern Trimouille covered a circuit somewhat similar to the survey party operating at Beaver Hill. The two sets of results are seen to be mutually consistent.

3.13 D + 15 Day

3.13.1 See Map K. The dose-rate readings recorded so far in the area about Tidepole Bay suggested that the fall-out was rather patchy. In an attempt to remove or confirm any anomalies a party of four surveyors working in pairs carried out a paced survey on fixed compass bearings. This showed that between T4 and Tidepole Bay the decrease was small whereas in the arc north and north-east of T4 there was a progressive decrease. This confirms that the axis of the heavy fall-out region was in a north-west direction from the T.V. position.

3.13.2 Several H.E.'s reported survey data of value from the more active central region: this is given in detail on the map record.

3.14 D + 16 Day

See Map L. A very careful survey was carried out on the remainder of the Western Isles: Kingcup and Bluebell and a number of small un-named ones. This survey completed the study of the fall-out on the Western Isles, with the exception of certain small islands to the south of Kingcup.

3.15 D + 18 Day

3.15.1 See Map M. Employing two special parties of two surveyors each, which had not experienced any radiation exposure, the area south of Beaver Hill was surveyed. The dose-rate did not exceed 15 r/hour and averaged considerably less than this so that the total dose experienced was not greater than 4 r. This completed the radiological survey of Trimouille.

3.15.2 Another pair of surveyors made a number of observations on the Western Isles with visits to Primrose, Gardenia and Bluebell.

3.16 D + 19 Day

See Map N. A number of dust samples were taken on northern Trimouille and the observed dose-rates at the positions were recorded. The correlation between activity in the dust and dose-rate is reported under team RH.7. A naval party examined the deck house structure and attempted some decontamination on the site.

Certain readings - taken with an Admiralty type survey meter, which reads lower than the 1155A when compared with the 1193A - are recorded.

3.17 D + 20 Day

See Map N. The survey of the Western Isles was completed by the measurement of the dose-rate on the small rocky islands between Kingcup and Jonquil. The dose-rate level was about 1 r/hour, in accordance with expectations from the high level of activity observed on Bluebell, Kingcup and Jonquil. It is of interest that during the approach in the L.C.A. to these islands the dose-rate was negligible, even at a few feet from the edge of the rock: this is more fully discussed later. A comparison of the performance of the monitors 1193A and 1155A was again made and it was found that the ratio was still about 1.5.

3.18 Aerial (Helicopter) Surveys

3.18.1 The preliminary surveys, which were in the nature of reconnaissance, did not provide any data of value greater than giving a general indication of the overall fall-out area. Primarily this was due to the principle of taking measurements at heights where the dose-rate was only a few (e.g. 4) mr/hour and as these heights were several thousand feet roughly the entire area was contributing to the observed gamma dose-rate. The results of these surveys are shown in Maps A3, B and C.

3.18.2 On the days D + 5, D + 8, D + 12, D + 16, D + 19 and D + 22 surveys were carried out in accordance with requests from the RH.5 team. These surveys were all of the same kind: measurement of the dose-rate at several altitudes on a vertical line through a selected ground position. The primary object was to obtain representative data for the variation of dose-rate with height. Following the water/land survey observation that during the approach to an island the dose-rate remained very low whereas when the surveyor went ashore it rose rapidly to the local value, it seemed possible that a helicopter survey

over an island and over the water nearby might provide information on which a reasonable theory might be based. The islands selected were Kingcup, Bluebell and Gardenia and the survey was made on D + 22. The helicopter survey data is summarised in Appendix E: the estimated average height of the ground above mean sea level is shown in each case.

3.19 Detection of Alpha Activity

A number of tests were made with both the monitors available to detect alpha activity in the fall-out (black deposit) and on pieces of the T.V. No reliable positive observation was reported. The instruments were light sensitive and during all field work the sunlight was intense, so that even with the probe protected from the direct rays of the sun the background was high. That alpha active material was present to the extent expected was shown by examination of dust samples (see RH.7 report).

3.20 Beta Activity

The reason that attempts to measure the beta dose-rate were abandoned has been explained under operational procedure. In the final survey on the eastern end of N.W. Island an observation with the 1193A monitor with the beta window exposed was made. The dose-rate was 10.5 mr/hour against 8.2 with the window closed at a height of 3 feet. The increase of about 25% in the reading shows that only a fraction of the beta radiation from the source is contributing to the dose-rate in air. The reduction must be due to shielding resulting from dust covering the activity and from the roughness of the ground. (For detailed discussion see under RH Miscellaneous 1).

3.21 Effects of Weathering

The removal or shift of activity by the wind would seem to have been small, if not negligible. The activity deposited in rain on the rocks was found to be firmly fixed and most unlikely to be blown away. No marked discrepancy between the day-to-day data over sand and rock was observed which leads to the conclusion that wind erosion was not more than a minor effect. Further information on this point

will be obtained when a special party returns to the islands at a later date.

3.22 Samples

3.22.1 Activity samples were collected from a number of sites with a view to checking the composition of the fission products. The bulk of these were handed over to the radiochemists for examination after the return to U.K. One sample from Bluebell is being analysed by the author, but is not yet complete.

3.22.2 A fragment of steel plate was also brought back and examined for radioactive iron (Fe59). When collected it was of a particularly clean silvery appearance, but by the time it was examined in U.K. corrosion had set in. It was soaked in 6N HCl for about 30 minutes and the rust removed by rubbing with fine abrasive. Any fission products on the surface were also removed. The acid solution did not show much activity, whereas that of the specimen was unchanged. Thus it would appear to be radioactive material dispersed in the bulk of the metal. A weighed sample of about 3 gm was cut off and dissolved in HCl. A specimen of $FeCl_3$ was prepared on a platinum counting tray of about 14 mgm $FeCl_3$ with a total count rate of about 600/min. The decay has been followed to date giving a half-life of about 45 days. The maximum energy of the beta radiation is 0.46 Mev. Both these results support the conclusion that the activity is due to Fe59. If self absorption in the sample is taken as about equal to the back-scatter caused by the platinum and there is experimental evidence to show that for a beta emission of this energy that self absorption causes a reduction by two and back-scatter from platinum causes nearly the same increase, then the specific activity is about 0.5 μc/gm.

4. DISCUSSION

4.1 From the results of the survey we wish to deduce:

(a) The gross decay law for γ dose-rate with time.

(b) The variation of the dose-rate with height and hence the area of contamination which contributes effectively to the dose-rate at any height.

(c) The distribution of radioactive material (fall-out) on the ground.

(d) The dispersion of the radioactive material in the water.

(e) The extent to which the fall-out may be predicted from the wind structure.

4.2 The Gross Decay Law (γ dose-rate)

4.2.1 The initial object of the survey was to determine the southern and eastern limits of the fall-out area, which was necessarily therefore, probing in character. Because of this, together with bad weather on D + 1 and the very low permissible dose of γ radiation, only one pair of reasonably reliable readings were obtained during the first 60 hours after burst. Many dose-rate readings during this period were of dubious value as fragments of the T.V. were scattered about and the actual contamination upwind of the burst was naturally low. However, from 76 hours onwards, with the exception of the period of bad weather from D + 9 - D + 12 inclusive, ample survey data was obtained.

4.2.2 It is clearly essential to correlate the survey data with that obtained at relatively late times with the data obtained by Team RH.2 over the first 10 hours if a decay law from H + 1 hour is to be obtained. For various reasons it has been found to be practicable to do this for certain sites only. The data, obtained by team RH.2 uncorrected for absorption in the steel case, for a number of sites are plotted in Fig. 1. The general trend of all the curves is the same: the maximum dose-rate appearing at 5-15 minutes after burst followed by a

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TABLE I

FALL-OUT PLOT DEDUCED FROM WIND VECTORS

Height	Mean Speed Knots	Direction	Fall-out Distances and Times for Raindrops with the following terminal Velocities (ft/min.)			
			400	600	800	1,600
0 - 1,000	17.7	164	0.736	0.491	0.368	0.184
0 - 2,000	16.0	143	1.33	0.89	0.67	0.335
0 - 3,000	16.0	129	2.0	1.33	1.0	0.50
0 - 4,000	13.2	123.5	2.21	1.47	1.10	0.55
0 - 5,000	12.4	120.5	2.58	1.72	1.29	0.65
0 - 6,000	11.4	114.5	2.86	1.90	1.43	0.72
0 - 7,000	11.0	110.5	3.22	2.14	1.61	0.81
0 - 8,000	10.1	114.5	3.38	2.25	1.69	0.85
0 - 9,000	9.0	121	3.38	2.25	1.69	0.85
0 -10,000	8.3	129.5	3.46	2.31	1.73	0.87
0 -11,000	7.8	139	3.58	2.39	1.79	0.90
0 -12,000	7.6	147.5	3.78	2.52	1.89	0.95
0 -13,000	7.1	155.5	3.86	2.58	1.93	0.97
0 -14,000	6.8	165.5	3.96	2.64	1.98	0.99
0 -15,000	6.9	182.0	4.33	2.89	2.16	1.08

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decay given approximately by a t^{-n} relationship in which n is ≥ 1.4. From one hour onwards the results for Bluebell, Kingcup and TH59 show roughly the same decay rate (values of n are 1.49, 1.42 and 1.40 respectively); whereas those for TH61, TH67 and T5 exhibit a rather more rapid decay, particularly during the first two hours. The three latter sites were in the path of the dust cloud in addition to rain, so that it seems likely that the rather higher initial dose-rates were due to airborne material sweeping across northern Trimouille. There is some indication that the dose-rate decays over the 4-8 hour period at about the same rate as that observed for Bluebell and Kingcup. The results for Primrose suggest that the deposition of radioactive material was spread over several hours.

4.2.3 The corrections to be applied for attenuation in the steel case and supporting structure have been examined in the RH.2 team report. It is considered that the observed values should be increased by 20-25%. The figure of 25% will be used in this report for the following reasons:

(i) The correction to be applied for 5-6 mm steel if the radiation is assumed to be just the primary radiation emitted by fission products at H + 1 hour is 25%. The normal composition* is assumed, but the rare gas isotopes are omitted.

(ii) On the average the steel shielding is rather more than 5-6 mm and photo-electric absorption in steel is likely to account for much of the soft radiation (and a considerable part of the scattered radiation will be soft), but on the other hand the ionisation within the aluminium chamber would be expected to be high by perhaps 5-10%. These effects may balance out.

*Unless otherwise stated it is assumed the fission products are of normal composition.

The γ spectrum for fission products becomes significantly softer during the first 24 hours after burst: the average photon energy decreasing from 1.1 Mev to about 0.7 Mev. It is known that both radioactive chlorine and sodium were formed and the presence of Al28 is also likely. The average energy may remain rather higher than that expected from fission products up to about 2 days after burst.

4.2.4 It was observed that heavy rain fell from the column of debris and water thrown up by the explosion on to the Western Isles at about 10 minutes after the burst. It seemed unlikely that there could have been much dust fall-out as far west as Bluebell. Also these islands are of largely rocky surface, so that removal of active dust by the wind would not be serious. The readings obtained with the fluxmeters on Bluebell and Kingcup, after correction for absorption in the steel case, are correlated with the very careful survey made on D + 16 to fix the position of the decay line. The two values for the decay factor for D + 16 obtained in this way are in close agreement: 0.00059 and 0.00058 respectively. The readings obtained earlier on these islands give intermediate points. For the comparison of day-to-day results it is essential to know the position accurately if the dose-rate is changing markedly with distance. This is not so important at the greater distances from the explosion. It was found that the results obtained over the PSP at Gladstone when fitted to the factor for 76 hours given by data from Kingcup, were also in agreement at D + 16 and could be relied upon to give the general trend of the line. The results for many other places have been incorporated and are summarised in Table II. The overall decay line is shown in Fig. 2. It is seen that the results are in reasonably close agreement throughout the area. This is perhaps rather surprising as a uniform composition of radioactive material would not be expected from a complex explosion of this kind. The curve

TABLE II. SUMMARY OF RESULTS USED TO DETERMINE THE GROSS DECAY CURVE

SITE	DAY	D DAY H + 1	D DAY H + 4	D DAY H + 8	D + 2	D + 3	D + 4	D + 5	D + 7	D + 8	D + 12	D + 13	D + 14	D + 15	D + 16	D + 18	D + 19	D + 20	D + 42	REMARKS
		hrs.	hrs.	hrs.																
BLUEBELL (fluxmeter)	Time after Burst (hrs)									195					388					The earlier reading of 1.0 r/hr was probably the highest in the neighbourhood of the fluxmeter and therefore too high. The other pair are comparable.
	Dose-rate r/hr (obs)	420	54.4	19.2						1.0					0.250					
	Decay Factor	1.0	0.130	0.0457						0.00235					$\underline{0.00059}$					
BLUEBELL	Dose-rate r/hr (obs)									2.5 x 1.5 = 3.75					1.20					
	Decay Factor									$\underline{0.00185}$					(0.00059)					
KINGCUP (fluxmeter)	Time after Burst (hrs)					75									386					
	Dose-rate r/hr (obs)	1510	210	78.6		4.0 x 1.5 = 6.0									0.875					
	Decay Factor	1.0	0.139	0.052		$\underline{0.0040}$									$\underline{0.00058}$					
																				GLADSTONE PSP
GLADSTONE (P.S.P.)	Time after Burst (hrs)					76	98		174			318				435	460	484	1010	The initial decay is somewhat anomalous (Fig. 1). The fluxmeter site was close to the shore so that water borne activity at times close to H hour may have enhanced the dose-rate. The readings taken later are on the PSP 50-100 yards inland.
	Dose-rate r/hr (obs)	~400				0.95	0.7		0.50			0.2				0.120	0.115	0.100	0.025	
	(calc)	240																		
	Decay Factor					(0.0040)	0.00295		0.0021			0.00084				0.000505	0.000485	0.00042	0.000105	
TH61 (fluxmeter)	Time after Burst (hrs)											315	340			435			1010	
	Dose-rate r/hr (obs)	1100		30								0.750	0.600			0.450			0.1	
	(calc)	900		45																
	Decay Factor											0.00083	0.00067			(0.00050)				
T4 (Ground Survey)	Time after Burst (hrs)									195		314		363	389					TH61 Comparison with the data in Fig. 1 shows that the calculated value is reasonable. The difference may be due to activity from airborne dust.
	Dose-rate r/hr (obs)									1.3 x 1.5 = 1.95		0.80		0.60	0.50					
	(calc)	860																		
	Decay Factor									0.0023		0.00093		0.00070	(0.00058_5)					
T4 (Helicopter)	Time after Burst (hrs)							122.5			295				390		460			
	Dose-rate r/hr (obs)							1.06			0.485				0.270		0.215			The value given in Fig. 6 for the value at H + 1 is 480 r/hr. The difference arises from the use of a theoretical curve.
	at 100 ft. (calc)	460																		
	Decay Factor							0.0023			0.00105				(0.00058_5)		0.000465			
β/γ Site nr TIDEPOLE Bay	Time after Burst (hrs)								174.5	195		318								
	Dose-rate r/hr (obs)								0.75	0.60		0.250								
	(calc)	310																		
	Decay Factor								0.0024	0.0019		(0.00080)								
QUARRY SOUTH of T2 CAMP	Time after Burst (hrs)		5		54															
	Dose-rate r/hr (obs)		0.500		0.022															
	(calc)	3.7																		
	Decay Factor		0.134		(0.0059)															
N.W. ISLAND	Time after Burst (hrs)				51			123.5												
	Dose-rate r/hr (obs)				0.090			0.030												
	(calc)	14																		
	Decay Factor				(0.0066)			0.0022												
PRIMROSE	Time after Burst (hrs)	~40						124					338.5							Agreement with other data not good.
	Dose-rate r/hr (obs)							0.125					0.025							
	(calc)	40																		
	Decay Factor							0.0031					(0.00062)							
GARDENIA	Time after Burst (hrs)							124					338							
	Dose-rate r/hr (obs)							0.250					0.060							
	(calc)	90																		
	Decay Factor							0.0028					(0.00067)							
AREA TH53 - TH47	Time after Burst (hrs)											317				435			1010	
	Dose-rate r/hr (obs)											10 x 1.5 = 15				6.5 x 1.5 = 9.8			~2 x 1.5 = 3	
	(calc)	20,000																		
	Decay Factor											(0.00080)				0.00052			0.00016	
DECAY FACTORS FROM SMOOTH CURVE		1.00	0.135	0.0495		0.0040	0.0031	0.0026	0.00205	0.00185	0.00092	0.00080	0.00072	0.00066	0.00058_5	0.00050	0.00045	0.00042		

NOTE: The underlined data provide the key positions for the decay line. The line is then given by the results for GLADSTONE P.S.P. and TH61. The subsequent data give added support to the line. That there is quite good agreement between the results obtained on islands where the fall-out was almost entirely due to rain and those observed on Trimouille where there were vast dust clouds and fires is significant. The decay factors in ( ) are arbitrarily assigned values.

shows the decay in γ activity due to radioactive decay plus wind erosion. The latter seems to have been slight and perhaps only resulted in a continual shifting of the active dust over a restricted area. Even in very sandy areas, where the airborne concentration was quite high and body contamination extensive, the survey data shows no evidence of any marked removal of contamination.

4.2.5 The most pronounced scatter in the readings occurs during the period 100-200 hours after burst. This is not understood and there is insufficient data to permit a detailed examination. The scatter can be distributed along the line if the observed results are fitted more closely to the line over this period. However, the survey data obtained from D + 13 onwards is probably the more reliable because of the experience already gained. Hence the data is fitted about the D + 16 position first. The scatter is unlikely to be due to the presence of a nuclide formed by neutron capture in varying proportions, as the deviation from the general trend of the line is too small. It might correspond to the peak activity of one or more of the fission product chains, present in good and perhaps variable yield. The tellurium - iodine - xenon chains, particularly for mass numbers 131, 132 and 133, do become most prominent at this time. The relatively large scatter (roughly ± 20% about the mean) is too great to be accounted for by removal of the xenon and possibly the iodine into the vapour phase. The helicopter data also exhibits differences at this time.
The data from the helicopter surveys which are incorporated in the decay curve are obtained by drawing a smooth curve through the plot of dose-rate against height and employing the smoothed values for a selected height (100 feet). For the results obtained on D + 12, D + 16, D + 19 and D + 22, the linear portions of the curves about 100-300 feet are parallel, whereas the two plots for D + 5 and D + 8 exhibit a much steeper slope.

The results are plotted in Fig. 3. This suggests some change on the energy distribution.

4.2.6 The absence of any true air wall ionisation chamber has led to an uncertainty in the true position of the gross decay line. The distribution of energy in the overall γ spectrum was unknown, but thought to contain only a small component in the region below 0.2 Mev. The responses of the survey instruments at energies above this level were known to be essentially independent of energy. However, marked deviations between the readings obtained by the two survey meters (AERE Nos. 1193A and 1155A) were observed. These were compared on D + 8 and D + 20 and gave on each day the same average value of 1.5 for the ratio of the reading of the 1193A and 1155A. The fundamental energy spectrum does not change appreciably over the period 7-28 days. The instruments were checked against a 1 curie Co60 source at 1m and gave identical readings. The discrepancy was clearly due to a different dependence on energy in the low energy region. This has been examined at A.E.R.E and it was found that both instruments deviate from the readings given by an air-wall ion chamber at energies below 0.2 Mev. The correct answer appears to be about midway between the readings given by these instruments. As a matter of convenience, because the much greater proportion of the survey data was obtained with the 1193A monitor all results quoted have been referred to that instrument: readings taken with the 1155A were increased by the factor 1.5. It is now clear that the 1193A readings are too high, by a factor as large perhaps as 1.3; but which it seems unlikely can be completely checked experimentally until the next weapon test provides the source of the correct kind. The results of some experiments made at A.E.R.E. are summarised in Table III below. It is seen that the two instruments only disagree in the low energy region, so that the soft energy component must be considerable.

TABLE III

DOSE-RATE METERS - VARIATION OF READING WITH ENERGY

Source	Dose-rate relative to value given by air-wall ion chamber instrument
Co60 (1.25 Mev)	Used for calibration. 1.0 in all cases.
Au198 (0.4 Mev)	1193A : 1.0 for all directions. 1155A : sides 1.0, battery end 0.5, bottom 0.9.
X-ray {0.2 Mev, 100 kev peak}	1193A : dose-rates too high for experiment. 1155A : front and sides 1.0, bottom 0.85.
X-ray (60 kev peak)	1193A : sides 0.9, bottom 1.4. 1155A : front, sides 0.9 - 1.0, bottom 0.8.

A comparison of the instruments with a good air wall ion chamber instrument in the active areas at Montebello would be worthwhile, even at this date. The increase seems to be due to the photo-electric effect with the steel grill of the β window. The lower line in Fig. 2 shows the effect of reducing the observed readings by 1.3: the general fit with the fluxmeter data is much improved.

4.2.7 It has been appreciated for some time that the fission products may not necessarily be present in normal yield in any particular sample from an atomic explosion. In this case it seems that the black deposit is essentially iron oxide, probably Fe_3O_4, which would be formed by condensation and oxidation at a few seconds after the event. It is most unlikely that krypton would condense, although where gases are ionised the rare gases do take part in cluster formation. The initial rapid decay which is shown throughout by the RH.2 data may be due to the absence of part of the chains which include krypton. On the other hand the iodine xenon chains reach the peak of activity at about three days after burst and may be present in normal amounts (precursors tellurium and antimony should condense). The decrease in slope from about 20 hours onwards might well be due to the neptunium formed. The Radiochemistry

Group examined a sample of water from the T.V. position and found that the β activity may be expressed by the equation:

$$\text{Activity} = 2.70 \times 10^{4}\, e^{-0.0125t} + 2.55 \times 10^{6}\, t^{-1.14} \text{ counts/min/ml.}$$

where the first term refers to neptunium and the second to the remainder of the activity. Included in the latter is the induced Na24 activity, which, owing to the relatively high energy of its γ emission (one photon each 2.76 and 1.38 Mev/disintegration), will cause the γ dose-rate to decay at a more rapid rate than the $t^{-1.14}$ relationship at times after about H + 14 hours. This sodium activity will have ceased to be of importance by H + 100 hours. If we assume that over the period H + 10 - H + 100 hours that the effective average γ photon energy is decreasing smoothly, then the γ dose-rate will follow a t^{-n} relationship in which n is greater than 1.14 but less than 1.45. The value of 1.3 was selected as it is midway between these two figures and is the exponent commonly associated with sea water explosions. The position of this $t^{-1.3}$ line was obtained by the application of the above equation employing the method given in para. 4.3.2 for the calculation of γ dose-rate at H + 50 hours. It was found that the line so obtained merged smoothly with the $t^{-1.45}$ line. The link-up between the RH.2 data and the RH.5 data is now readily made (see Fig. 2) The bump in the curve at 100-200 hours then appears to be due to a member of a fission chain which exhibits a peak activity at 7-8 days: Xe133 is a possibility. The yield - mass number curve is considered to exhibit a peak at 133, so that an enhanced yield of Xe133 is not impossible. The low energy of the γ emission from Xe133 - 80 and 40 kev - would result in a much enhanced reading on the 1193A monitor and a rapid fall-off in dose-rate with height. The small proportion contributed to the total γ energy emission is compensated for to some extent by the relatively rapid absorption due to the

photoelectric effect. Because of the presence even at D + 20 of a large component of soft radiation (i.e. ratio of 1193A and 1155A readings is still about 1.5), this increase in soft component at the earlier period would not necessarily show up in the ratio of the readings given by the two instruments. This analysis is shown in Fig. 4. The presence of neptunium, which would be most significant up to about 10 days after burst, would account also for the anomaly in the helicopter results on D + 5 and D + 8 because the soft γ radiation which it emits would enhance the dose-rate at low levels. It is assumed that for each neptunium disintegration there are two photons of 0.23 and 0.27 Mev and only 0.7 of the fission product disintegrations give rise to a photon of average energy 0.7 Mev. It may well be argued that the data is not good enough to sustain a detailed analysis of this kind and indeed this claim is not made. However, the gross decay curve is so markedly different from the $t^{-1.2}$ law, which should be applicable to fission products, that a qualitative explanation has to be attempted.

4.2.8 Over the period 1-1000 hours the gross decay curve exhibits the following features:

(i) up to about 12 hours it follows the $t^{-1.45}$ relationship

(ii) from about 12 hours to 100 hours the slope is less corresponding to about $t^{-1.2}$

(iii) from about 100-200 hours the decay is slower, very roughly $t^{-1.0}$

(iv) after 200 hours decay is rapid: $\sim t^{-1.6}$

In the absence of frequent observations the safest course would be to assume the $t^{-1.2}$ decay relationship. The safety factor thus introduced may be unnecessarily high and the relationship $t^{-1.3}$ is a reasonable one to use, except that over the 6-10 days period the dose-rates would be perhaps about 30% higher than expected. The dosage experienced would always be less

than that computed for the simple relationship, except during the period 5-12 days.

4.3 Variation of the Dose-rate with Height above the Target Area

4.3.1 From consideration of the several degrees of roughness of the terrain it is clear only a limited area contributes effectively to the γ dose-rate at any height. This problem, together with that of allowing for the scattered radiation in the calculation of dose-rate are examined in Appendix F. The conclusion reached is that the effective radius from the position at height, 'h', should be a constant multiple of h for all heights. The variation of dose-rate with height, for values of r_{max} of 15, 20 and 40 h have been calculated and the results compared with the experimental values.

4.3.2 The expression deduced for the dose-rate at any height 'h' is:

$$R = 2.66 \times 10^{-2} \cdot \sigma_a N E \left(-Ei(-0.5 \mu h) + Ei(-0.5 \mu r_{max}) \right) \text{ r/hr}$$

where $1/\mu$ is the mean free path of the primary radiation, σ_a is the energy absorption cross-section for Compton scattering (pair production and the photoelectric effects are negligible over the range of energies with which we are concerned), E is the energy of the primary radiation in Mev, N is the number of photons emitted per second per cm^2 of surface and Ei denotes the exponential integral. In dealing with a polychromatic source the simplest approximation is to assume an overall average value for E. For fission products over the period 1-30 days after the explosion this average value of photon energy is 0.7 Mev ($\mu = 3 \times 10^{-3}$ ft^{-1}). It has already been pointed out that the variation in observed reading between the two dose-rate meters 1193A and 1155A is certainly due to the presence of a soft component $\lesssim$ 0.2 Mev, which although partly originating in the scattering processes in air, will be produced also by back-scatter of that half of the radiation apparently lost in the

ground. The energy of radiation scattered through 180° is always 0.25 Mev (the Compton wavelength). Cave* has shown that a considerable proportion of the radiation is in the energy range 1.25 - 1.75 Mev. In the absence of any precise information about the energy distribution in the primary γ spectrum actually emitted the effect of a wide energy distribution may be examined by assuming three energies. For convenience in calculation the energies selected are those whose μ values in ft^{-1} are simple numbers and the products σ_a N E bear a simple ratio to each other. The numerical values are given in Table IV.

TABLE IV

GAMMA RADIATION SPECTRUM

E (Mev)	$\mu \times 10^3$ (ft^{-1})	$\sigma_a \times 10^5$ (cm^{-1})	N	σ_a N E	
1.54	2	3.25	0.32	1.59	(3)
0.7	3	3.79	1.0	2.65	(5)
0.25	4.5	3.58	0.59	0.53	(1)

The relative values of N are seen to be reasonable, and the ratio of the energy due to 1.54 and 0.7 Mev radiation is very similar to that given by Cave. The average energy remains 0.7 Mev. For a composite spectrum the expression for the dose-rate becomes:

$$R = 2.66 \times 10^{-2} \sum_i \sigma_{a_i} N_i E_i I_i$$

where I_i is written for the exponential integral. If the subscripts 1, 2 and 3 refer to energies 0.25, 0.70 and 1.54 Mev, respectively, then

$$R = 2.66 \times 10^{-2} \sigma_{a_2} N_2 E_2 \left(\frac{1}{5} I_1 + I_2 + \frac{3}{5} I_3 \right) .$$

*H.E.R. Report A10, 1951.

The form of the dependence of R on height h is determined by the term in brackets.

4.3.3 To emphasise the effects of limiting the area contributing to the dose-rate and of the nature of the energy spectrum; and to facilitate comparison with the survey data, the computed curves showing the variation of R with h have been plotted in Fig. 5 with R normalised to unity at h = 100 feet. It is seen that the most marked difference between the six curves is the change in dose-rate at heights below 15 feet for the several values of r_{max} and the energy. The small change in dose-rate from 1-3 feet is in accordance with observation. Above 100 feet the shape of the curves is very much the same. The numerical values of the exponential integral terms, I, are summarised in Table V.

TABLE V

SUMMARY OF THE EXPONENTIAL INTEGRALS, I.

Height (ft)	I - for QUANTUM ENERGY 0.7 Mev and r_{max} given by:			I - for SELECTED SPECTRUM (average energy 0.7 Mev) and r_{max} given by:		
	15 h	20 h	40 h	15 h	20 h	40 h
1	1.669	2.966	3.630	4.744	5.342	6.541
3	2.640	2.908	3.517	4.754	5.243	6.345
10	2.569	2.791	3.242	4.600	5.006	5.842
30	2.188	2.314	2.510	3.977	4.229	4.623
50	1.910	1.989	2.076	3.515	3.674	3.870
100	1.430	1.451	1.464	2.687	2.741	2.871
200	0.904	0.905	0.906	1.754	1.762	1.764
300	0.625	0.625	0.625	1.246	1.247	1.247
500	0.340	0.340	0.340	0.712	0.712	0.712
1000	0.100	0.100	0.100	0.239	0.239	0.239

From these curves it should be possible to estimate the value of r_{max}, although the result will be complicated by the energy dependence: for the latter the composite spectrum must be nearer the truth than the monochromatic source of energy 0.7 Mev.

4.3.4 In Figure 6 the results obtained over T4 which have been referred to H + 1 hour, together with the estimated value at 3 feet have been plotted and are compared with the computed curve for the composite spectrum and r_{max} = 15 h.
The computed curve was sited by inspection in the region h = 100 feet. Agreement at heights up to 300 feet is very good. Above this the observed values are somewhat smaller than the computed ones, which is to be expected as the actual area is less than that included in the calculations. The average values for T4 together with the other data are also shown on Fig. 5. Assuming the composite spectrum, the limited area concept is seen to be fully justified. The area contributing to the dose at 3 feet is seen to be of radius 15 h - 40 h depending on the degree of smoothness of the ground. The 'smoothness' of the ground increases in the order T4 - TH47 - PSP Gladstone in agreement with the observed increase in the value of r_{max}. The terrain for the position midway between TH47 and TH53 forms a hollow bounded by the rocky cliff area to the south and west and by Beaver Hill to the north. Therefore, the dose-rate at low heights would be expected to be rather high: the observed ratio for heights of 3 and 100 feet is about 3.

4.3.5 The survey data obtained over Kingcup on D + 22 provide another confirmation of the limited area concept. A map of the island is given in Fig. 7(a). The surveys were made over points A and B. For comparison of the results with calculated values the island may be assumed to be equivalent to a circular area of 300 feet radius with respect to position A, with average height above mean sea level of 10 feet. From position B the island is effectively rather more than half an annular

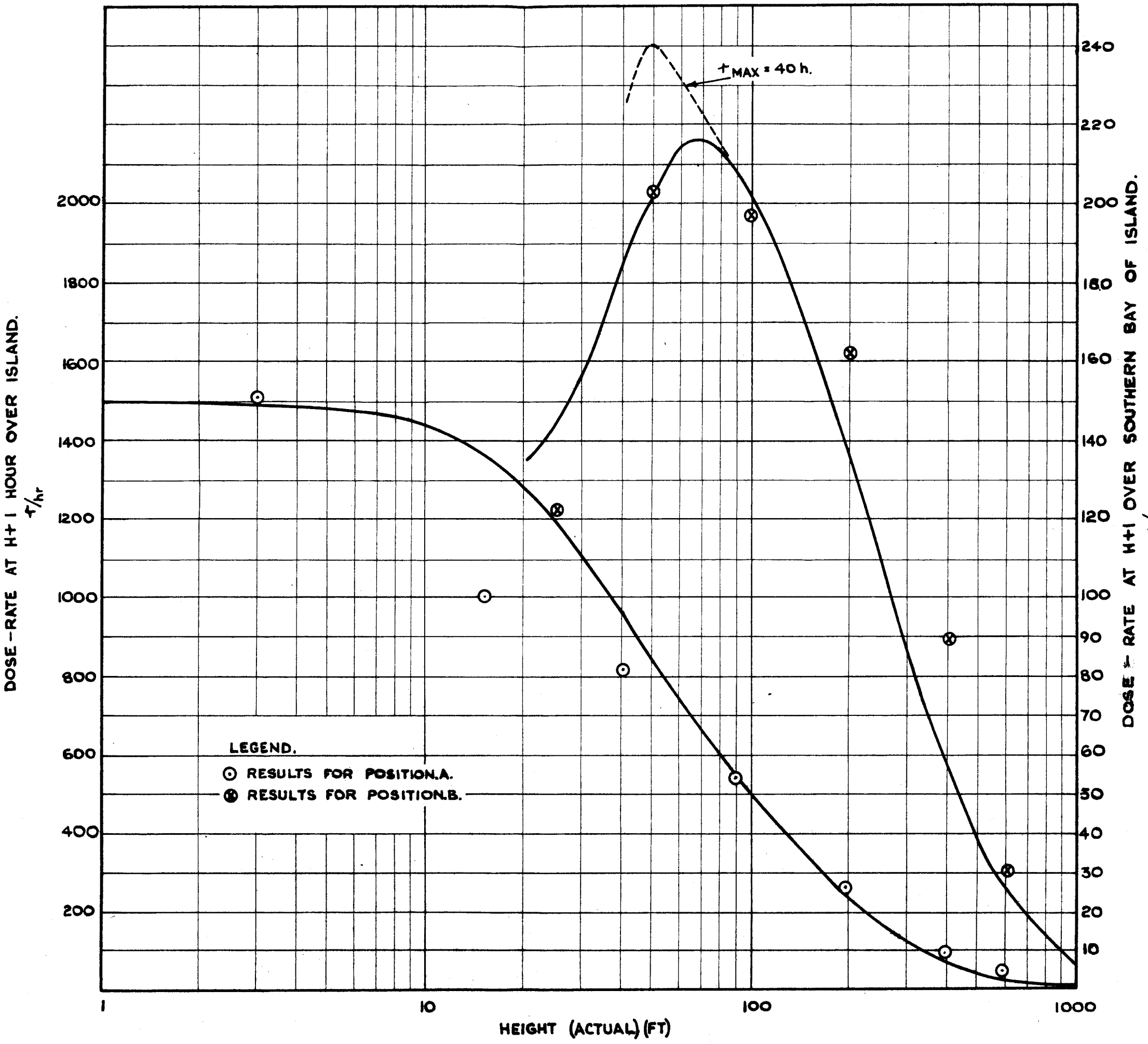


FIG. 8. HELICOPTER SURVEY OVER KINGCUP ON D+22.

area of internal radius 150 feet, external radius 450 feet and of the cross-section shown in Fig. 7(b). Employing these geometries the variation of dose-rate with height over both land and sea has been calculated and is compared with the experimental results in Fig. 8. The method of assembly of the observed and computed data is as follows. The experimental results for position A, including the value obtained from land survey, are referred to H + 1 hours. The computed curve for the composite spectrum and r_{max} = 15 h (where applicable) is positioned by inspection about h = 100 feet. Agreement at 3 feet is remarkedly good. The position of the curve for position B is set by the relative values of the integrals I. It has been smoothed on side of the maximum corresponding to the lower heights because the simple geometrical picture gives a stepped curve corresponding to the abrupt appearance of the contribution due to the three surfaces. The agreement with the observed values is again remarkedly good. The broader character of the observed maximum is to be expected as the surface of the terrain is not as uniform as is assumed.

4.3.6 The position of the maximum is determined by the value assumed for the angle corresponding to r_{max}. For r_{max} = 15 h, this is $\sin^{-1}$ 1/15 (3° 48') with the horizontal, whereas for r_{max} = 40 h it is only 1° 26'. The latter would shift the maximum to h ~ 50 feet. There is insufficient experimental data for the comparison to be beyond dispute. However, the lower height for the maximum would lead to a curve which fell away rather more abruptly for values of h < 50 feet and the maximum would be very much greater than that observed. This effect is shown on Fig. 8.

4.4 The distribution of radioactive material (fall-out) on the ground

4.4.1 From a very careful examination of the day-to-day survey results and application of the gross decay relationship a set of dose-rate contours corresponding to a selected time after

burst may be constructed. As is customary this has been done for H + 1 hour and is shown in Map P. It is seen that the radiation hazard from a deposition of this kind is very serious over a wide area. From the results obtained by the RH.2 team it is known that the fall-out arrived on the ground at times up to about 10 minutes after the explosion and that the initial decay law was about $t^{-1.45}$. Thus within the contour corresponding to a dose-rate of 150 r/hr at 1 hour the dose experienced during the period 10 minutes to one hour would be about 400 r. The area can only be estimated roughly but is about ~~3.85~~ 5.2 square miles. Of this area about ~~0.75~~ 1.7 square miles is in the lethal zone of the flash γ radiation. In this case the fall-out caused the potentially lethal area of the explosion to be increased by about ~~5.7~~ 3.5 square miles. The areas within the contours have been measured with a planimeter and the results are summarised in Table VI.

TABLE VI

AREAS WITHIN DOSE-RATE CONTOURS AT H + 1 HOUR

Dose-Rate (r/hr)	Area in units of ~~1.6 x 10⁵ yd²~~ 2.14 x 10⁵ yd²	Equivalent Radius (yds)
10,000	8.84	~~670~~ 783
6,000	12.05	~~785~~ 915
3,000	15.8	~~900~~ 1050
2,000	23.0	~~1080~~ 1260
1,000	37.6	~~1380~~ 1610
600	45.4	~~1525~~ 1785
400	52.4	~~1635~~ 1910
200	67.8	~~1860~~ 2115

It is significant that for a dose-rate of 400 r/hr at H + 1 the median lethal dose is experienced in about 17 minutes from the time of arrival of the activity. The additional area involved

is about 2 square miles. This is possibly about the limit of the area from which escape is unlikely.

4.4.2 The relationship between dose-rate at a given height and the activity on the ground has already been given. Also from an examination of the helicopter survey results it has been shown that the dose-rate at a height of 3 feet is due to activity on the surrounding area of about 15 yards radius. This distance is small compared with the distances separating the dose-rate contours (except on the southern E - W and eastern N - S boundaries), which permits the total activity to be estimated from the relationship between dose-rate and radius of the equivalent circular area (see Table VI). This relationship is shown in Fig. 9, from which it is deduced that the following apply:

$0 \leq r \leq 450$ yds $\quad R = 2 \times 10^4$ r/hr

$450 \leq r \leq 3000$ yds $\quad R = [redacted] \times 10^4 e^{-0.00[redacted]r}$ r/hr.

If we assume for the moment that the activity on the ground, A in curies/yds^2 is given by

$$A = \alpha R$$

then the total activity over the area bounded by the 3000 yard radius is given by, A_T, where

$$A_T = \alpha \left\{ 2 \times 10^4 \times \pi \times 450^2 + [redacted] \times 10^4 \int_{450}^{3000} 2\pi r e^{-0.00[redacted]r} dr \right\}$$

$$= [redacted] \times 10^{10} \alpha$$

The value of α depends on the assumptions made about the energy spectrum for the γ radiation. For comparison with American data it is convenient to assume an average value of 0.7 Mev and it is found that there is little difference between a single energy of 0.7 Mev and the composite spectrum which averages 0.7 Mev. At H + 1 hour, however, the average energy is somewhat greater than 1 Mev for fission products of normal composition. The approximate energy spectrum and the associated constants are given in Table VII below.

TABLE VII

APPROXIMATE ENERGY SPECTRUM
FOR FISSION PRODUCTS FROM PLUTONIUM AT H + 1

E (Mev)	N	$\sigma_a \times 10^5$ cm^{-1}	$\mu \times 10^3$ ft^{-1}	E N τ_a	Relative energy Absorption
2.3	1	2.85	1.6	6.55	1.25
1.3	4	3.39	2.2	17.6	3.36
0.7	2	3.74	3	5.24	1
0.25	1	3.58	4.5	0.90	0.17

The dose-rate would be given by

$$R = 2.66 \times 10^{-2}\ \sigma_{a3}\ N_3\ E_3\ (1.25\ I_1 + 3.36\ I_2 + I_3 + 0.17\ I_4)$$

where the subscripts 1, 2, 3 and 4 refer to energies of 2.3, 1.3, 0.7 and 0.25 Mev, respectively.

4.4.3 The values of a have been calculated and are given together with the corresponding value of A_T in Table VIII.

TABLE VIII

DEPENDENCE OF TOTAL ACTIVITY, A_T, ON GAMMA SPECTRUM

Gamma Spectrum	a	A_T (curies)
Single quantum energy 0.7 Mev	1.22×10^{-1}	6.2 ~~6.4~~ $\times 10^9$
Composite spectrum (Table IV) average energy 0.7 Mev	1.29×10^{-1}	6.6 ~~6.4~~ $\times 10^9$
Composite spectrum (Table VII) average energy 1.1 Mev	8.5×10^{-2}	4.3 ~~6.5~~ $\times 10^9$

It is seen that the value of A_T is about ~~6.4~~ 6.4 $\times 10^9$ curies if the average energy is 0.7 Mev, whereas for an average energy of 1.1 Mev the value of A_T falls to ~~6.5~~ 4.3 $\times 10^9$ curies. These values are consistent as the energy absorption rate is proportional to

N E τ_a (or roughly to N E which may be expressed as curies Mev). If the energy release was equivalent to 24 KT and the American value of 6 x 10^9 curies for the activity produced by a nominal bomb is accepted, then about 40% of the total activity liberated was deposited about the target vessel in an area of about 2 1/2 square miles. About 98% of this was within the contour corresponding to 150 r/hr at H + 1 hour.

4.5 The Dispersion of the Radioactive Material in the Water

4.5.1 From a general examination of the survey results it is clear that, whereas it proved possible to carry out a fairly complete survey of the land, the water survey was rather less successful.

4.5.2 It is clear from the results obtained that the dispersion of the water borne radioactivity took place in a northerly direction and must have been quite a rapid process initially. For the short periods each day when survey was permitted it proved a simple matter to determine the clean/dirty water boundary, (which was as expected rather diffuse) and to survey the lagoon using the γ dose-rate in the craft as a measure of the activity. The instruments provided for the measurement of gamma dose-rate, and hence activity, in the water did not fulfil their function. There were two reasons for this within the lagoon the activity was too high for the instruments to measure, and a radioactive deposit collected quite quickly on the probes so that the instrument reading became meaningless. Some information should be available from the water samples collected; but these were relatively few in number and again the apparatus provided was unreliable. The movement and dispersal of the activity by the tides could have been determined by the observation of the γ dose-rate in the boat had survey been permitted for 2-3 hours at a time throughout the first twenty-four hours after burst. The bad weather on D + 1 only made matters worse.

4.5.3 However, a number of interesting results were obtained. Thus it was found that the water-borne activity to the east of Trimouille was entirely on the surface at a few hours after burst. On this side of the island the water was not disturbed by the explosion and the activity had been deposited by fall-out and by removal at the water surface as the cloud passed over it. An examination of the particle size of the material in the fall-out on the Western Isles shows that it is very small, less than 10 μ. Even iron oxide particles of this size would not be expected to sediment quickly.

4.5.4 Within the lagoon, the survey on D day (Map A1) shows that the activity was greatest to the NW of the target vessel. This is in agreement with the overall picture of the land survey, although the observed dose-rates are very much smaller. At a position in Bunsen Channel corresponding approximately to the 10^4 r/hr contour for H + 1 hour (See Map A1 and R) the observed dose-rate was 0.6 r/hr at five hours after burst. Allowing for decay the dose-rate becomes ~ 6 r/hr at H + 1. The ratio of the activity in the water (per unit volume) to that on the ground (per unit area) to give the same dose-rate at about 3 feet above the surface is of the order of 20 (for average energy about 0.7 Mev). Within the lagoon it is reasonable to assume that the activity is dispersed in the volume of water as the vast column of water and debris thrown up by the explosion collapsed there. The depth of water varied markedly with position and with the tide, but was only a few fathoms in any case. If we assume a figure of about 2.5 fathoms, then the activity deposited per square yard on land may be dispersed in 5 cubic yards of water. Combining this with the activity ratio given above it is found that the observed dose-rate over the water is about 20 times too small. In making this comparison it has been assumed that mixing occurred readily in depth but not horizontally so that some discrepancy of this kind is to be expected, particularly

some five hours after burst. However, from the observed decrease in dose-rate across the lagoon (in the NW direction) it is possible to estimate the reduction due to mixing. It is found that this would be about 1/5 so that the activity in the lagoon at H + 5 hours appears to have been only 1/4 of that deposited. The estimation is uncertain to at least a factor of this magnitude, from which it follows that the bulk of the activity deposited in the lagoon may have been dispersed throughout the volume and only a small fraction removed by the first tidal flow to the north.

4.5.5 Examination of the water survey data obtained on D + 2 and D + 3 in the lagoon shows that the activity was fairly uniform from the southern end of Trimouille along the deep water channel to the T.V. position and the entire lagoon to the north of that position. Comparing the value of 0.6 r/hr at H + 5 hours with the values of ~ 30 mr/hr on D + 2 and ~ 10 mr/hr on D + 3 it is seen that the decrease with time is somewhat more rapid than the gross decay law for the ground contamination. This result shows that the dispersion of the radioactivity in the waters of the lagoon took place within a few hours of the explosion. It was thought that the flow of water with the tides would result in a fairly rapid cleansing of the lagoon with the dispersal of the activity in the ocean to the north. It seems clear that this did happen from the dose-rates observed on D + 2 in the vicinity of Pansy Island, but only slowly. The to and fro movement of the tides caused a continual dilution of the activity in an ever increasing volume of water. The helicopter surveys support the conclusion that the dispersion was mainly to the north, but activity was detected at times several miles to the south of the lagoon (See RH.3 team report). The tidal and current flows in an island group of this kind are undoubtedly complicated and there is almost certainly some stratification in the water.

It may be that the lagoon water is only slowly replaced by water from the surrounding ocean. A similar state of affairs existed at Bikini.

4.5.6 On the map showing the computed dose-rate contours at H + 1 hour the parts over the water have been obtained by interpolation or estimation. The scanty water survey data is in agreement with the sharp southern boundary. The contours across the lagoon to the north are probably only applicable during the few minutes when the fall-out actually arrives, but this in no way vitiates the use of the contour plot for purposes other than giving the dose-rate over the water.

4.5.7 From observations made during the days following the explosion it is clear that the activity was not only slowly removed from the lagoon by tidal action but was also deposited on beaches and cliffs at the high water mark. The deposit was black and plainly visible. Furthermore, the effect was widespread and was observed quite markedly about the pier at T1, where there was no activity a few hours after burst.

4.6 Prediction of Fall-out Area from Wind Structure

4.6.1 A first attempt to estimate the fall-out area from the wind structure with height is shown in Map A4. In Map Q the final dose-rate contour state at H + 1 hour is superimposed upon the result to be expected from the drift of particles with the wind. The agreement is seen to be very good. The direction of the southern E-W boundary is correct within a few degrees (winds are for H + 1 hour). The rather narrow band of heavy fall-out to the west as far as Bluebell would not have been expected. This was seen to be rain and a simple treatment cannot take into account the growth of small drops into large ones. Furthermore, the column of debris and water was not cylindrical. There were large clouds possibly corresponding to the halves of the ship and the southern one of these was swept round by the winds in a westerly direction. The main

axis of the fall-out was certainly along the expected direction. The more distance fall-out beyond the islands to the N.E. was picked up by the helicopter survey on D day.

5. CONCLUSIONS

5.1 The deposition of radioactive material on the ground was the heaviest for any type of atomic explosion, for which detail is available. In the Bikini underwater explosion perhaps 10-25% of the activity was effective in the target area, whereas in this case the amount is greater than 50%.

5.2 The area in which the median lethal γ radiation dose is obtained within one hour is some 3 square miles greater than for the air burst at about 2,000 feet.

5.3 The gross decay relationship for the γ dose-rate is not a simple one. The best approximation would be $t^{-1.3}$, which errs on the side of safety except over the period 6-10 days after burst. During the first day the rate of decay is considerably faster ($\sim t^{-1.4}$).

5.4 From the helicopter surveys it is seen that the technique of hovering over a known location would permit an estimate of the dose-rate on the ground to be made. The observed dose-rate at 100 feet should be multiplied by 2.5 and that at 500 feet by a factor of 10. When the activity is such that the survey must be made at greater heights the dose-rate will not change markedly with position, so that a number of parallel runs over the target area will be necessary. A scheme of this kind will constitute the most satisfactory preliminary in any case.

5.5. Dispersion of the deposited activity in the water is rapid but tides only cause a steady dilution in an ever greater volume of water accompanied by a regular to and fro flow pattern. Deposition occurs on beaches at the high water mark.

5.6 Erosion of the fall-out activity from the land only occurs to a minor extent.

APPENDIX 'A' to RH.5 REPORT

INSTRUCTION PROGRAMME FOR ESCORTS AND SURVEYORS

Summary

Time required:

Lectures 8 x one hour

Practical Instruction and Exercises - 2 x 2-3 hours.

Lectures

Introduction

1. The nature of the Nuclear Explosion.
2. Review of the Effects of Atomic Weapons (with slides)
3. } Sources of Radioactive Contamination -
4. }
   (a) Fission Products;
   (b) Neutron induced Activity;
   (c) Alpha Activity.

   Outline the β/γ hazard, the gross decay rates.
5. Radiation Dose - Roentgen
   (a) Significant differences in the β/γ doses;
   (b) The inhalation hazard;
   (c) The permissible tolerances for the trial.
6. The Instruments available.
7. Decontamination.
8. The operation: duties and responsibilities
   (a) Contamination survey;
   (b) Predicted Iso-dose Contours;
   (c) Estimation of dose from Dose-rate;
   (d) Health Escorts duty.

NOTE: Because the measurements must be of scientific value the instruction is more detailed than normal. The practical aspects to be borne in mind.

Practical/Exercises

1. Use of instruments with sources.
2. Exercises on the estimation of permissible time.

NOTE: The initial one of each of these should be to accustom the individual to the problem: the second ones should be in the nature of a test which is preferably not specified as such.

APPENDIX 'B' to RH.5 REPORT

COMPOSITION OF THE SURVEY TEAM

Name	Service/Regt.	Initial Survey Team
Major K. Stewart	R.E.	I/C Team
Lt.Col. Linden Kelly, D.S.O.	Lan. Fus.	W.S.P2
Major A.R.T. Lundie, M.C.	R.A.M.C.	W.S.P3
Major J.A.L.G. Talbot	14/20 Hussars	L.S.P1
Major L. Cave	R.A.O.C.	W.S.P1
Major K. Whitfield	R.A.O.C.	L.S.P1
Capt. F.W. Hobart	R.A.	L.S.P2
Capt. S.R. Whitehead	R.A.S.C.	L.S.P2
Lieut. G.W. Rylatt	R. Sigs.	L.S.P1
Lieut. Brook	R.N.	
Lieut. Ozzard	R.N.	
Lieut. Pattson	R.N.	W.S.P2
Lieut. Plummer	R.N.	W.S.P1
Lieut. Wakelin	R.N.	W.S.P3
S/Lieut. Clowes	R.N.	
Sq/Ldr. A.D. Thomas	R.A.A.F.	L.S.P2

APPENDIX 'C' to RH.5 REPORT
PART I

RADIATION INSTRUMENTS AVAILABLE TO R.H.5 SECTION

Serial	A.E.R.E. Cat. No.	Type	Range	Principle	Remarks
1	1193A	β/γ Dose-rate Meter	0 - 12.5 0 - 125 0 - 1250 } mr/hr	Ionisation Chamber - steel case 1 mm thick, thin air wall - β window in base.	Covered the operating close-range fairly completely. Was used as a standard.
2	1155A	β/γ Dose-rate Meter	0 - 3 0 - 30 } r/hr	Ionisation chamber - aluminium case (~ 6 mm thick) and ion chamber - β window in base.	Prototype Army type survey meter. Completed the range coverage with the 1193A.
3	1205	β/γ Dose-rate Meter	0 - 3 0 - 30 0 - 300 } r/hr	Ionisation chamber. - rather thick walls - β window in base.	Prototype R.N., R.A.F. survey meter.
4	1250	γ Dose-rate Meter	0 - 500 r/hr (log scale)	Ionisation Chamber	Used by some health escorts in the more active areas. Of no value for detailed survey.
5	1092C	γ Contamination Monitor	0 - 10 mr/hr	G.M. Tube and rate circuit	Employed in all roles to detect level of contamination.
6	1201	γ Integrated Dose-meter	0 - 10 r	Ion Chamber	Seldom used as one exposure doses of several roentgen were unusual.
7	1030	γ Integrated Dose-Meter	0 - 120 mr	Ion Chamber	Used by water survey parties to provide an immediately available measure of dose experienced by individuals in a pinnace.
8	1092C	Modified γ contamination monitor	0 - 10 mr/hr	Standard 1092C G.M. tube in steel case on special cable	For determination of γ dose-rate in water. Probe was attached to pinnace so as to be just immersed.
9	1011	Modified γ survey monitor	3 scales, special calibration: nominally 0-0.1, 0-0.5 and 0-1.5 mr/hr	3 special G.M. tube in steel case on 20 ft cable.	For determination of γ dose-rate in water at depths to about 16 ft.
10	1021	Modified laboratory instrument α probe only	-	Portable instrument for α detection - scintillation probe	The α probe provided with both these instruments were sensitive to sunlight, so that their use in the field was not easy.
11	Canadian Instrument	α detection	-	Portable α detector - aural indication only - scintillation probe.	

APPENDIX 'C' to RH.5 REPORT
PART II

SUMMARY OF RH.5 GROUP DISCUSSIONS ON PROBLEMS ARISING FROM SURVEY EXPERIENCE HELD ON H.M.S. CAMPANIA ON 2ND NOVEMBER, 1952.

1. RADIAC INSTRUMENTS

1.1 Dose-rate Meters (including contamination monitor)

The instruments which were in daily use for survey and health escort duty were the dose-rate meters Nos. 1193A and 1155 (both ion chamber) and the contamination monitor 1092C. Basically these instruments proved reliable and easy to use. However, the following points are considered to be important as far as Service instruments are concerned.

(a) The scale change technique employed on the 1155 instrument is much more preferable to that on the 1193A.

(b) The linear scale is preferable to the pseudo-logarithmic scale of the 1092C: the latter would be improved if more sub-division were given.

(c) Scale changes together with linear scales are preferable to logarithmic scales.

(d) Scale sub-divisions should be in 1/5ths. and 1/10ths., definitely not the kind given on the 1193A.

(e) The switches on the 1193A and 1155 were not ideal and proved to be the most difficult part to decontaminate. A set of press button switches underneath of flexible cover should be worth consideration.

(f) It was agreed that for the operational instruments a top range of 0-100 r/hr would be practicable, but there would prove to be a need for a third range of 0-1 r/hr. The instruments proposed for the Army cover the ranges 0-10 mr/hr (1092) and 0-10, 0-100 r/hr (1155) with a gap between them, which is not a serious deficiency but is undesirable. An increase in the range of the 1092 monitor to 100 mr/hr would also be an improvement.

(g) Instruments should be constructed with ease of decontamination in mind. Surfaces should be smooth, fabric should be avoided

and the unit should be water tight as simple decontamination procedures are likely to involve immersion. It was found that the β windows were very easily contaminated: dust collected in the crevices.

1.2 Quartz-fibre Dosimeters

Proved generally reliable, although several of the 0-50 r range gave anomalous readings (during rehearsal in the absence of any radiation). The upper dose instrument should probably measure up to 100 r.

1.3 Water Survey Instruments

The instruments used were 1092C and 1021 meters with the probes in water-tight metal cases. These did not prove to be entirely satisfactory - primarily because the range coverage was inadequate. The direction of contaminated water - from landing craft for example - may be of operational significance and is one reason for the proposed extra range of 0-1 r/hr.

1.4 Slide Rules

A simple slide rule will be most useful for forecasting time available for any particular operation some time ahead.

2. CLOTHING

The clothing used was satisfactory with one exception: the opening round the neck led to unnecessary contamination. A hood with a section laying over the main garment would have given total protection.

The respirators (including antidim and head harness) were not of the most satisfactory grade, with the result that fogged eyepieces and general discomfort were common.

Service clothing should have been tested.

APPENDIX 'D' to RH.5 REPORT

ORGANISATION OF SURVEY AND RECOVERY PARTIES ON D DAY

1. Essentially the same procedure was used throughout the working period but equipment and communications varied with the needs.

2. Equipment

(a) Water Survey Parties

(i) Radiation Instruments (one each):
- 1092C with probe on 8 ft cable } Water monitors
- 1011B " " on 12 ft cable } Water monitors
- 1193A dose-rate meter
- 1092C contamination monitor
- 1030 integrating dose meter

(ii) For air sampling:
- Vacuum cleaner unit including extension hose and clamp and 48 volt battery
- Set of mounted, numbered, filter papers.

(iii) For water sampling: Sampling gear and six bottles.

(b) Land Survey

Radiation Instruments (one each):
- 1193A, 1155A } dose-rate meters
- 1030 integrating dose meter
- 1092 contamination monitor.

(c) Recovery Parties

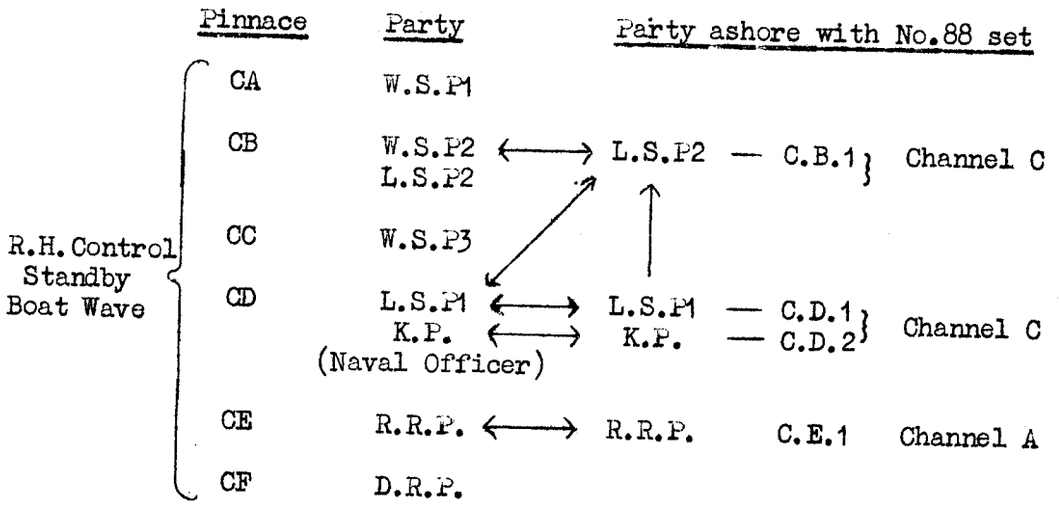
(i) Rocket Recovery Party (R.R.P.):
- 1193A, 1155A } dose-rate meters
- 1092C contamination monitor

(ii) Danbuoy Party (D.R.P.):
- 1193A, 1155A } dose-rate meters
- 1092C contamination monitor

(iii) β/γ dose-rate: (Ratio Party)(K.P.)
- 1193A dose-rate meter (and special instruments)

3. Communications

The signal plan was:



4. Code

(a) Chart code - letters of alphabet reading E and N on 30" grid.

115° 29' 30" E ----- A

20° 33' 00" S ----- A

(b) Map code - similar for 400 yard grid lines

3600 E ----- A

9200 S ----- A

Finer sub-divisions by numbers in clear; in both cases.

(c) Principle code words -

(i) Dose-rate mr/hr - "RED", "SCARLET" or "PURPLE"

The height, depth or distance (in ft) to precede and the actual dose-rate to follow as numbers in clear, e.g.

"3 PURPLE 15"

(ii) Clean/dirty water boundary - "YELLOW", "GREEN.

(iii) Land with dose-rate less than 1 mr/hr - "GREY", "SILVER".

(iv) Fragment of T.V. - "JACKAL".

(v) Arrival on shore - "position reference ⊙ HAVE ARRIVED".

(vi) Departure from shore - "position reference ⊙ FINISHED".

HELICOPTER SURVEYS - SUMMARY OF RESULTS

APPENDIX 'E' TO RH.5 REPORT

GROUND POSITION	AVERAGE HEIGHT ABOVE M.S.L. (ft)	DAY	DOSE-RATE IN R/HR OBSERVED AT HEIGHT ABOVE M.S.L.														
			25	30	50	75	100	125	200	300	400	500	600	800	1200	1600	3200
T.4	10 ft.	D + 5	-	-	-	-	-	1.0	0.745	0.550	0.400	0.275	-	-	-	-	-
		D + 12	-	-	0.600	-	0.500	-	0.400	-	0.150	-	-	0.060	-	0.007	-
		D + 16	-	-	0.35	-	0.3	-	0.2	0.15	0.075	-	0.007	-	-	-	-
		D + 19	-	-	0.300	-	0.225	-	0.150	0.125	0.075	-	0.050	0.025	0.0125	-	-
Gladstone Camp PSP	20 ft.	D + 8	-	0.250	0.247	-	0.150	-	0.100	0.070	0.045	-	-	0.018	-	0.0023	0.0001
		D + 22	0.060	-	0.052	-	0.037	-	0.032	-	0.014	0.005	-	-	-	-	-
T.4 Road Junction	10 ft.	D + 8	-	-	-	-	0.475	-	0.360	0.275	0.225	-	-	0.065	-	0.013	0.0008
Hockey Pitch nr. Tidepole Bay	10 ft.	D + 12	-	-	0.250	-	0.150	-	0.125	-	0.075	-	-	0.050	-	0.004	-
Gladstone Point	10 ft. - 20 ft.	D + 8	0.0018	-	0.0014	-	0.0012	-	0.0008	0.0006	0.0006	-	-	0.0003	-	0.0001	-
T.5	50 ft.	D + 12	-	-	0.050	-	0.050	-	0.009	-	0.004	-	-	0.003	-	0.0004	-
T.2	20 ft.	D + 12	-	-	0.300	-	0.250	-	0.200	-	0.075	-	-	0.008	-	0.0015	-
TH47	30 ft.	D + 16	-	-	6.30	-	3.9	-	2.55	1.72	1.05	-	0.550	-	-	-	-
		D + 19	-	-	4.44	-	3.6	-	2.18	1.50	0.780	-	0.525	0.375	0.090	-	-
TH53	30 ft. - 40 ft. (on seaward side of BEAVER HILL)	D + 16	-	-	3.45	-	2.85	-	1.83	1.2	1.05	-	0.450	-	-	-	-
		D + 19	-	-	3.60	-	3.00	-	1.87	1.15	0.800	-	0.575	0.350	0.080	-	-
		D + 22	-	-	-	2.70	2.18	-	1.25	-	0.775	-	0.500	-	-	-	-
Midway TH47 - TH53	20 ft.	D + 16	-	-	3.90	-	2.85	-	2.13	1.50	1.0	-	0.550	-	-	-	-
		D + 19	-	-	3.90	-	3.38	-	2.17	1.80	0.875	-	0.525	0.325	0.085	-	-
Midway TH53 and T4	10 ft.	D + 16	-	-	0.6	-	0.6	-	0.5	0.425	0.25	-	0.2	-	-	-	-
		D + 19	-	-	0.700	-	0.575	-	0.400	0.300	0.225	-	0.200	0.125	0.035	-	-
Bluebell W to E																	
13110 N 1490 E	40 ft. ridge	D + 22	-	-	0.480	-	0.325	-	0.260	-	0.093	-	0.050	-	-	-	-
13110 N 1680 E	"	"	0.500	-	0.450	-	0.265	-	0.200	-	0.085	-	0.045	-	-	-	-
13110 N 1790 E	"	"	0.024	-	0.027	-	0.030	-	0.011	-	0.0115	-	0.007	-	-	-	-
Kingcup N to S																	
13150 N 2550 E	10 ft.	D + 22	0.0375	-	0.300	-	0.200	-	0.095	-	0.035	-	0.015	-	-	-	-
13050 N 2500 E	"	"	0.045	-	0.075	-	0.073	-	0.060	-	0.033	-	0.011	-	-	-	-
Gardenia W to E																	
13960 N 2200 E	20 ft.	D + 22	0.047	-	0.043	-	0.033	-	0.020	-	0.008	-	0.0025	-	-	-	-
13960 N 2280 E	"	"	0.0025	-	0.003	-	0.0035	-	0.0035	-	0.003	-	0.002	-	-	-	-

APPENDIX 'F' to RH.5 REPORT

THE GAMMA DOSE-RATE FROM AN AREA SOURCE

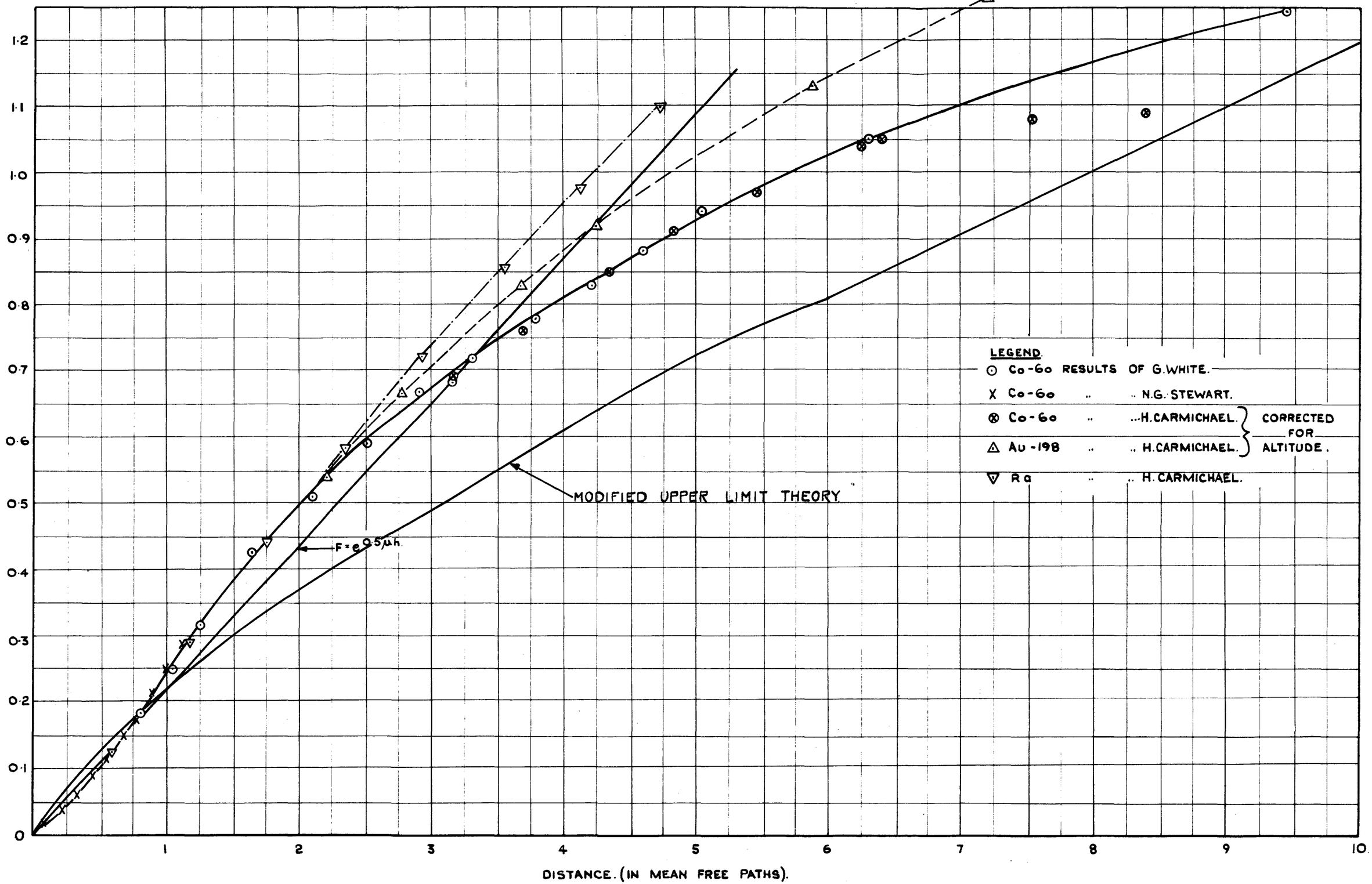
1. The increase in the dose-rate in a medium due to the scattered component of the radiation is well known and has been the subject of several studies in recent years. Because the data from the helicopter surveys exhibit a considerable scatter, and the source is neither plane nor uniform, the application of the more elaborate theoretical studies of Corner, Cave and Liston(1) or Spencer and Fano(2) is hardly worthwhile. Furthermore we are concerned generally with distances of only a few mean free paths, whereas the emphasis in the theoretical work is on greater distances. Therefore, some of the experimental data available was examined to determine whether or not there existed a simple relationship between the so called build-up factor and distance for distances up to 5-8 mean free paths. The experimental results employed were for the scattering in air of the radiation from Co60, Au198 and radium obtained by H. Carmichael(3), for Co60 in air by N.G. Stewart(4) and for Co60 in water by G. White(5).

2. The energy absorption rate at a distance r from a point source emitting N photons/sec of energy E is given by

$$R = \frac{\sigma_a NE}{4\pi r^2} e^{-\mu r} \cdot F(\mu r, E) \quad \ldots\ldots\ldots \quad (1)$$

where σ_a is the Klein-Nishina absorption coefficient for Compton scattering expressed in distance^{-1} units for the medium and $F(\mu r, E)$ is a function to account for the energy absorbed from scattered radiation. In the experiments referred to above the radiation was measured by either a small air-wall ion chamber or a G.M. tube. As a first approximation the several sets of data should be comparable if the observed activity in either dose-rate units or as a count rate is multiplied by $r^2 e^{\mu r}$ and plotted against distance expressed in mean free paths. Thus equation (1) may be written

$$\log (R\, r^2\, e^{\mu r}) = \log F + \text{const.} \quad \ldots\ldots\ldots \quad (2)$$



APPX. F. FIG. 1. PLOT OF BUILD-UP FACTOR, F, AGAINST DISTANCE.

At r = o, F = 1 so that it is permissible to shift the several curves of log ($R\ r^2\ e^{\mu r}$) against distance and obtain a plot of log F against distance: this has been done in Fig. 1 (Appendix F). In the case of the data for Co60, the results obtained in water overlap both Stewart's and Carmichael's data and it is found that all data may be fitted to one curve. The curves for Au198 and radium have been shifted similarly, but their position is indeterminate except that it is reasonable to expect that the general shape of the curves will be the same for these energies as Compton scattering is predominant and hence the exact position cannot be far removed from the one shown. It appears therefore that for distances up to ~ 5 mean free paths and for a source emitting at a number of energy levels that we may write

$$\log_e F \simeq \beta r$$

β is found to be about $0.5\ \mu$.

The build-up factor is given approximately therefore by

$$F = e^{0.5\ \mu r}.$$

This is a very convenient expression for our case of the dose-rate due to an area source.

3. Cave and Liston[6] prepared tables to enable certain γ-ray problems to be solved quite easily. Briefly the method is to put the relative dose equal to

$$e^{-\beta D}$$

where β is dependent on both energy of the initial radiation and the distance. The values given for the case of a point source (spherical symmetry are in general for energies and distances greater than are of interest here. Extrapolation does not seem to be feasible. A comparison between experiment and theory has been made by Cave and Siddons[7] with the result that agreement is not very good. Examination of the experimental techniques suggests that the observed dose-rate may be too high because of enhanced sensitivity in the low energy region. The theoretical values for $\log_{10} F$ for Co60 have been plotted in Fig. 1.

It is possible to compare the theoretical figures with experiment in the following way. The energy given up to the medium about the point source is NE Mev/sec and the fraction given up for all the initial scattering acts is $\frac{\sigma_a}{\mu}$ NE. The ratio of these two quantities is $\frac{\mu}{\sigma_a}$, which for Co60 is 2.14. By graphical evaluation of the integrals

$$\int_0^\infty e^{-D}\,dD, \quad \int_0^\infty Fe^{-D}\,dD \quad \text{and} \quad \int_0^\infty e^{-\beta D}\,dD$$

it is found that the experimental results lead to a value about 2.0, whereas the data given by Cave lead to a value of about 1.7. The experimental data is to be preferred.

4. Clearly it would be incorrect to assume that the activity was distributed over a plane surface, where the word plane is used in the mathematical sense. The terrain did in fact, exhibit several degrees of roughness. It is unlikely that even a level sand or earth surface may be considered planar and in our case the sandy areas were covered with tufts of grass or other vegetation so that the surface was marked with shallow hollows of all sizes. The rock had been much eroded and the surface was marked with more or less shallow saucer like hollows. In addition to this small scale roughness there were hills and slight slopes everywhere. The position at which the dose-rate is observed is shielded from part of the radiation emitted at any place on the ground by the roughness of the surface and that with increasing distance the decrease will be greater than that due to distance and air absorption. The object of the helicopter surveys which gave the variation of dose-rate with height was to examine this problem of the area which contributes to the dose-rate at any height. Since clearly a small volume of air (or tissue) will receive radiation from an ever increasing area as the distance from the ground increases, the simplest approximation is to assume that the effective solid angle with which the instrument views the ground is constant and less than 2π. The application of this assumption to the direct radiation from the ground is straightforward, but the scattered radiation must be accepted as coming from all directions. However, Stewart[4] found that in his experiments with a point source that the effect of

ground became negligible at a height about 12 feet for distances off a few hundred feet from the source. This suggests that even the scattered radiation results from the radiation emitted in a relatively small solid angle by the source. Therefore, as a first approximation, we assume that both direct and scattered radiation originate from the same limited area. The restricted area, is considered as planar in the calculation. It is not intended that the dimensions of the restricted area calculated in this way should be taken too literally. The restricted plane area is equal in effect to a larger rough area for which the variation of dose-rate contribution with increasing distance is unknown and cannot be predicted. The roughness form which will be most effective in an otherwise level area is that of the shallow depressions from a few inches to a foot or so across, for which case geometrical consideration of γ-rays emitted at glancing angles to the overall level of the surface shows that the actual radius will not be so very much greater than that computed. The granular nature of the surface will not affect the γ-ray dose-rate appreciably, but would account for the non-existence of any serious β dose. Large scale features provide excellent shielding, or alternatively exhibit a more effective surface owing to the slope. The moderate roughness will increase the amount of scattered radiation present.

5. The activity on the ground is certainly not uniform, but in the cases which have been examined in some detail the variation with distance was not too great. Along the direction of a radius from the T.V. position the activity decreases with increasing distance, so that about a selected ground position the two halves compensate each other to a considerable extent.

6. The usual way to determine the energy absorption or dose-rate R at a height 'h' is to consider that due to an annulus of ground radius 's' and width 'ds', which will be given by:

$$dR = \sigma_a \, NE \, \frac{2\pi s \, ds}{4\pi \, r^2} \cdot e^{-\mu r} \cdot F. \quad \text{Mev/cc/sec} \quad \ldots\ldots\ldots \quad (3)$$

where $r = \sqrt{h^2 + s^2}$.

Elimination of s gives

$$dR = \frac{\sigma_a NE}{2} \frac{e^{-\mu r} F}{r} dr. \qquad \ldots\ldots\ldots \qquad (4)$$

The total dose is obtained by integration with the upper limit for 'r' given by the restricted area concept. If the angle between the maximum radius r_{max} and the plane is θ then

$$\theta = \sin^{-1} \frac{h}{r_{max}} = \text{const.}$$

so that r_{max} is given by h cosec θ.

The energy absorption rate is given by

$$R = \frac{\sigma_a NE}{2} \int_h^{h \text{ cosec } \theta} \frac{e^{-(\mu-\beta)r}}{r} . dr. \qquad \text{Mev/cc/sec} \quad \ldots\ldots \quad (5)$$

Inserting the value for $\beta = 0.5\,\mu$ and writing $0.5\,\mu r = t$ the integral becomes

$$\int_{0.5\,\mu h}^{0.5\,\mu h \text{ cosec } \theta} \frac{e^{-t}}{t} dt = -Ei(-0.5\,\mu h) + Ei(-0.5\mu h \text{ cosec } \theta)$$

where $-Ei(-x)$ is the exponential integral

$$\int_x^{\infty} \frac{e^{-t}}{t} dt.$$

Finally the dose-rate in roentgen/hour is given by

$$R = 2.66 \times 10^{-2} \sigma_a NE \left\{ -Ei(-0.5\,\mu h) + Ei(-0.5\,\mu h \text{ cosec } \theta) \right\} \qquad (6)$$

where σ_a, N and E are expressed in cm, sec, photon units.

7. Siddons[8] has calculated the dose-rate due to an infinite plane source for heights up to 2 metres. His results are found to be about 14% higher than those given by Chamberlain[9]. The values obtained with the expression for F given in para 2 are about 5% greater than those given by Chamberlain. Bearing in mind the divergences exhibited in Fig. 1 it is clear that this relatively simple means of calculation is preferable to the theoretical one in which the parameter β varies with distance.

8. References

(1) Corner, Cave and Liston. Proc. Roy. Soc.

(2) L.V. Spencer and U. Fano. {Phys. Rev. 1951, 81, 464. J. Research N.B.S. 1951, 46, 446.

(3) H. Carmichael. Private Communication to A.E.R.E.

(4) N.G. Stewart. Unpublished work - private communication.

(5) G. White. Phys. Rev. 1950, 80, 154.

(6) L. Cave and R.H.A. Liston. H.E.R. Report H13/51.

(7) L. Cave and R.A. Siddon. H.E.R. Report H23/52.

(8) R.A. Siddon. Private memorandum.

(9) A. Chamberlain. HPR/AERE Report 551.

PART II

Health Escorts

1. INTRODUCTION

During the period following the explosion it was necessary for parties of scientists to enter, and work in, the area made hazardous by radioactive contamination. As part of the general procedure for health control an escort - the health escort - accompanied each recovery party with the sole duty of ensuring that no unnecessary risks were taken and the permitted radiation dose was not exceeded. As far as the radiation hazard was concerned the health escort controlled the activities of the party. In this a very considerable load was taken off the recovery party, who could devote themselves entirely to the task of record recovery.

2. PERSONNEL

Both scientific and service personnel carried out escort duty. Where possible individuals were selected so that those with the greater experience of radiation hazard went to the more highly contaminated areas. The individuals who carried out this task are listed in Appendix 'A'. All were trained during the voyage to the site or just prior to the event. Naturally certain of the more eminent and senior people had other interests in addition to the escort duty and had volunteered because only a limited number of those originally selected were available at the time.

3. EQUIPMENT

The equipment employed was the same as that used for the survey. (See Part I).

4. PROCEDURE

The essentials of the procedure have already been given in the overall report by A.D.R.H. Prior to the assembly of the recovery party and health escort in the operation room on H.M.S. Tracker for briefing a summary of health escort duties and the more important hazards was issued to each escort. A copy of this is given at Appendix 'B'. This was found to be necessary because individuals left their normal task, for in many cases one period of health escort duty only, and having been trained some weeks earlier required an 'aide memoire'. At the time of briefing the escort recorded, on a pro-forma supplied, the members and area of operation of the recovery party and the permitted γ radiation dose.

From the review of the estimated dose levels given by A.D.R.H. the types of instruments required were noted. The radiation dose-rate levels at which respirators were to be worn were also given. From the conclusion of briefing until the return of the party to the ship the health escort was responsible for the safety of the party from radioactivity hazards. To do this he had to:

(a) Ensure each member carried a film badge and appropriate quartz fibre dosimeter and was correctly clothed.

(b) Monitor continuously the area of operation and thereby make certain that the party withdrew before the permitted dose was exceeded.

(c) Ensure individuals wore respirators when necessary.

(d) Monitor each member prior to re-embarkation in small craft so that contamination was not spread unnecessarily.

(e) Ensure that he was in communication with Health Control via the No.88 radio set, which was carried and operated by a naval rating.

5. CONCLUSIONS

The health escort procedure proved to be very satisfactory. Although some parties initially regarded the escort as an unnecessary hindrance to their activities, they soon found that he was in fact a very useful person. It enabled a number of recoveries of records to be made from quite 'hot' areas without undue radiation exposure occurring.

The efficiency of the escorts varied considerably - generally with their knowledge of radioactivity and radiation hazards. During the training period, and subsequently, it was found that special attention had to be paid to the correct technique of using dose-rate meters.

The data recorded by the escorts on the report sheet provided was added to the survey data as far as possible. However, because each party proceeded to its location as speedily as possible and then quickly withdrew, the volume of such information was quite small.

APPENDIX 'A'

HEALTH ESCORTS

Ministry of Supply

Messrs: Abercrombie, S.D.
Amner, R
Bisby
Carling, C.A.
Chamney, D.F.
Cobbold, R.S.C.
Collyer, D.J.
Darby, K.
East, P.C.
French, R.R.
Fisher, B.C.
Fothergill, R.A.
Harding
Hart, W.D.
Heywood, G.C.H.
Hibbert, C.B.
Hill, F.L.

Messrs: Hopstroff, J.W.
Kay, S.W.
Kerrigan, G.M.
Lavender
Lunn, G.H.
Madgin, J.R.
McEnhill, J.
McPherson, H.G.
Moss, E.
Moyce, W.J.
Musgrove, S.
Pott, C.G.
Pridgeon, P.R.
Scott, J.M.
Shilling, J.W.
Stanbury, G.R.
Thwaites

Royal Air Force

Sq/Ldr. Brown
Mitchell
Pryor
Skelley

Ft/Lieut. Blythe
Mercer
Whitaker

W.O. Humphrey
Sparrow

Royal Navy

Mr. Barnes

Canada

Dr. O.M. Solandt

Australia

Prof. A. Martin

APPENDIX 'B'

INSTRUCTIONS FOR HEALTH ESCORTS

1. ON TRACKER

1.1 Make certain that you know:

(a) The route you are to follow

(b) The maximum dose your party may experience

(c) The circumstances under which your party must wear respirators

(d) The signal procedure.

1.2 Check that your instruments are in working order.

1.3 Check that each member of your party has a film badge and quartz fibre dosimeter on departure from Tracker. Don't forget your first aid dressing.

2. DURING TRIP IN

2.1 Make sure that the coxswain and your communication rating are familiar with the signal procedure.

2.2 Remember to note the dose received en route to the site you are visiting and leave sufficient dose in hand for the return journey - and a bit to spare.

3. AT THE SITE

3.1 Keep the radiation exposure of your party down to the absolute minimum - do not take unnecessary risks: it isn't worth it.

3.2 Make full use of your dose-rate meter to forecast the working time available to your party.

3.3 Make full use of your communications: keep your boat and Health Control informed of progress made in recovery, and don't hesitate to ask for advice if in doubt.

3.4 Remember that if medical attention is required there is a medical officer standing by to come to your assistance, by helicopter if necessary. Make use of the first aid dressing when necessary.

3.5 Do everything you can to prevent your party from becoming more contaminated than necessary. Contaminated outer gloves may be discarded at the site on the completion of task. Prior to getting in the boat for the return journey monitor each member of the party:

heavily contaminated articles can be left behind; boots and gloves should always be washed in the sea. The greater the contamination brought back, the more the recovery operation will be slowed down.

3.6 Pay particular attention to the dose-rate from any samples which your party has collected. If it is high they should be placed as far from the occupants of the boat as possible.

3.7 Do not waste time. Collect as much information as you can. Make full use of the proforma provided.

3.8 In a dirty area contamination is most readily detected by its β radiation, whereas in areas where the γ dose-rate is low the contamination monitor is suitable. It is hoped that the latter condition will exist on the landing piers and beaches.

4. ARRIVAL AT TRACKER

You report to the Decontamination Control on the condition of your party.

SECRET.

TCD. CF.
CKD.
APP.

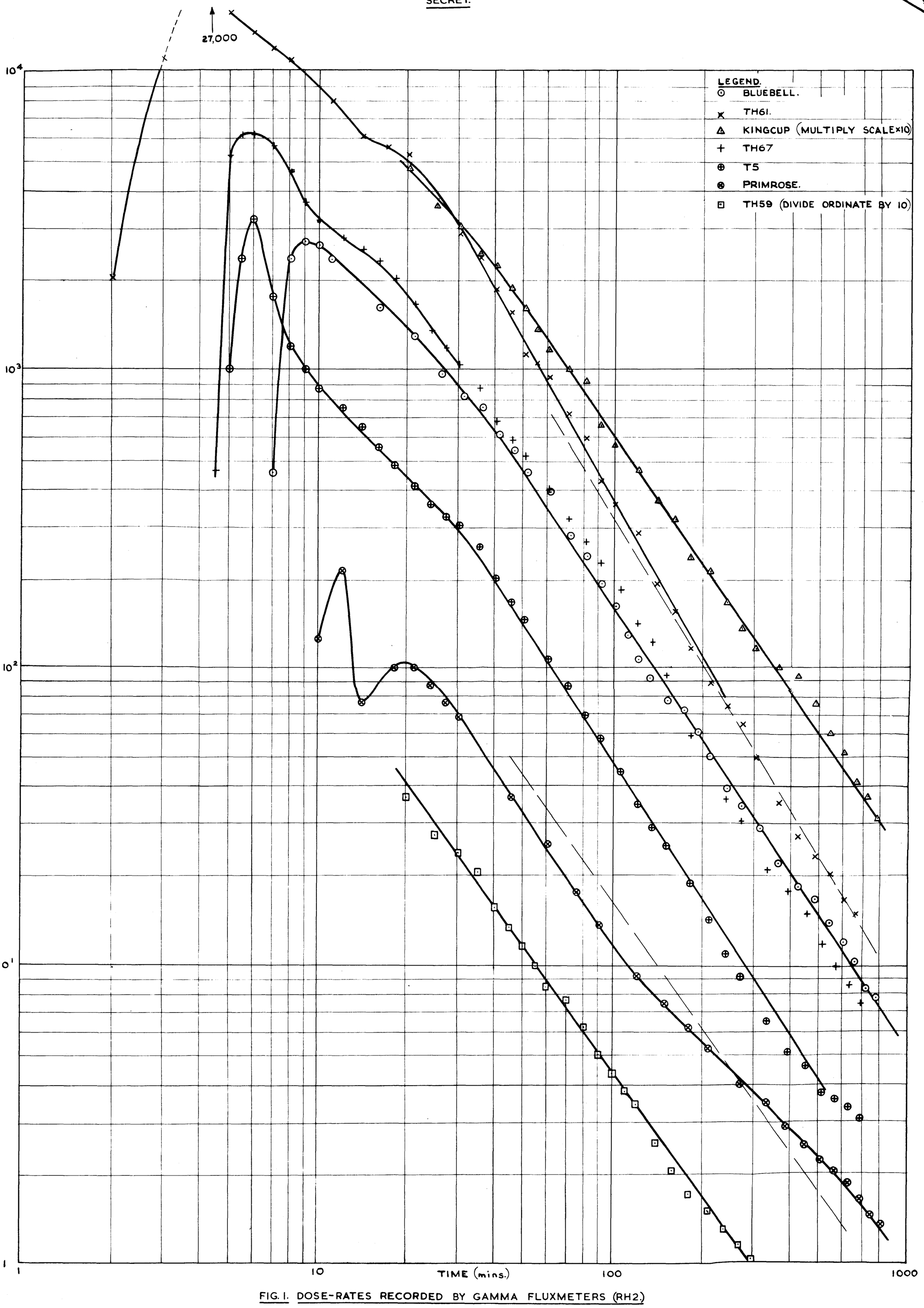
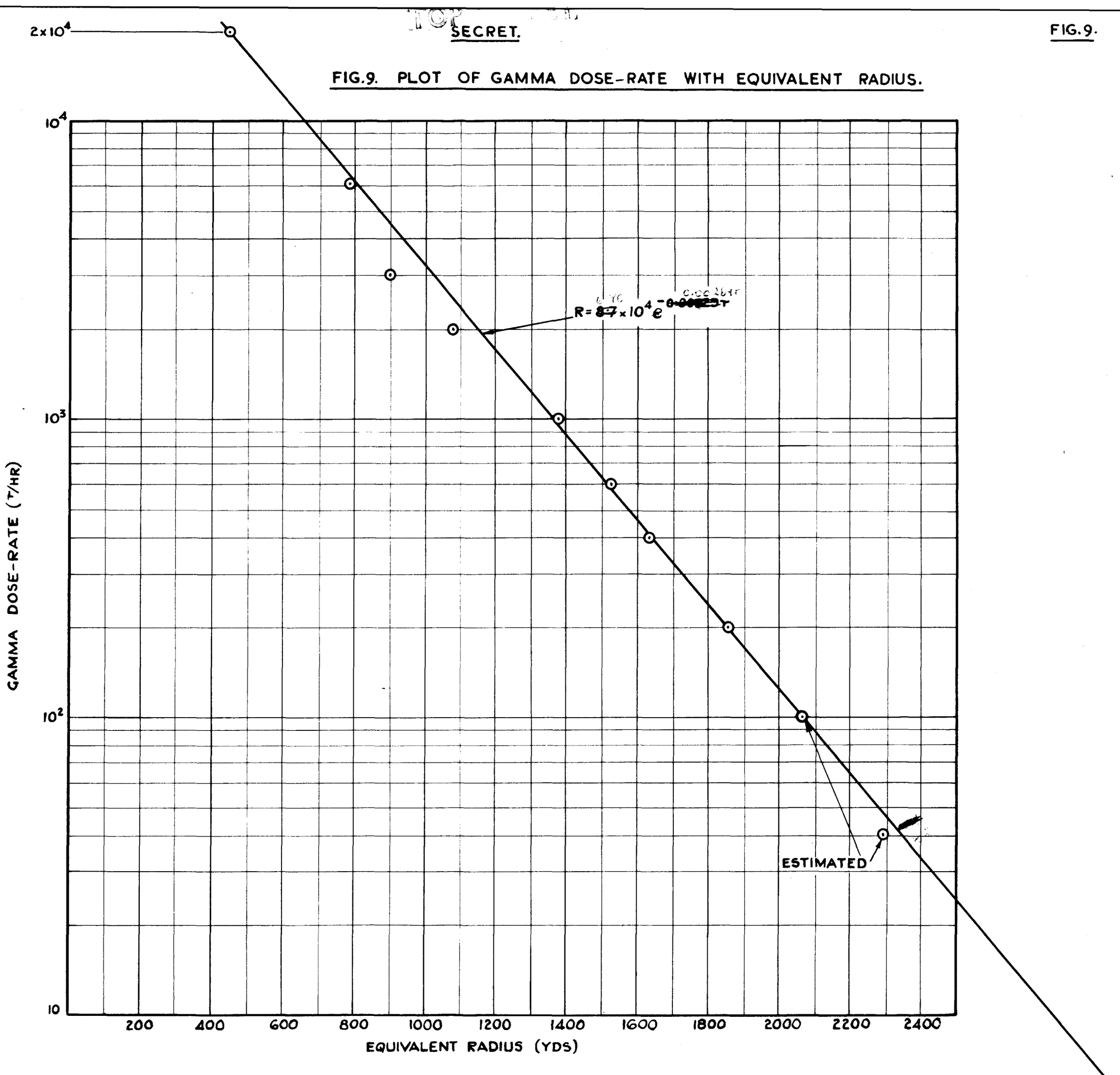


FIG. 1. DOSE-RATES RECORDED BY GAMMA FLUXMETERS (RH2.)

RRR. 8576

DRN
TCD. B.H. G.W.
APP
K.S.

FIG.9. PLOT OF GAMMA DOSE-RATE WITH EQUIVALENT RADIUS.



DRN.
TCD.B.H.J.P.O
APP.

~~TOP SECRET~~
SECRET.

FIG. 4.

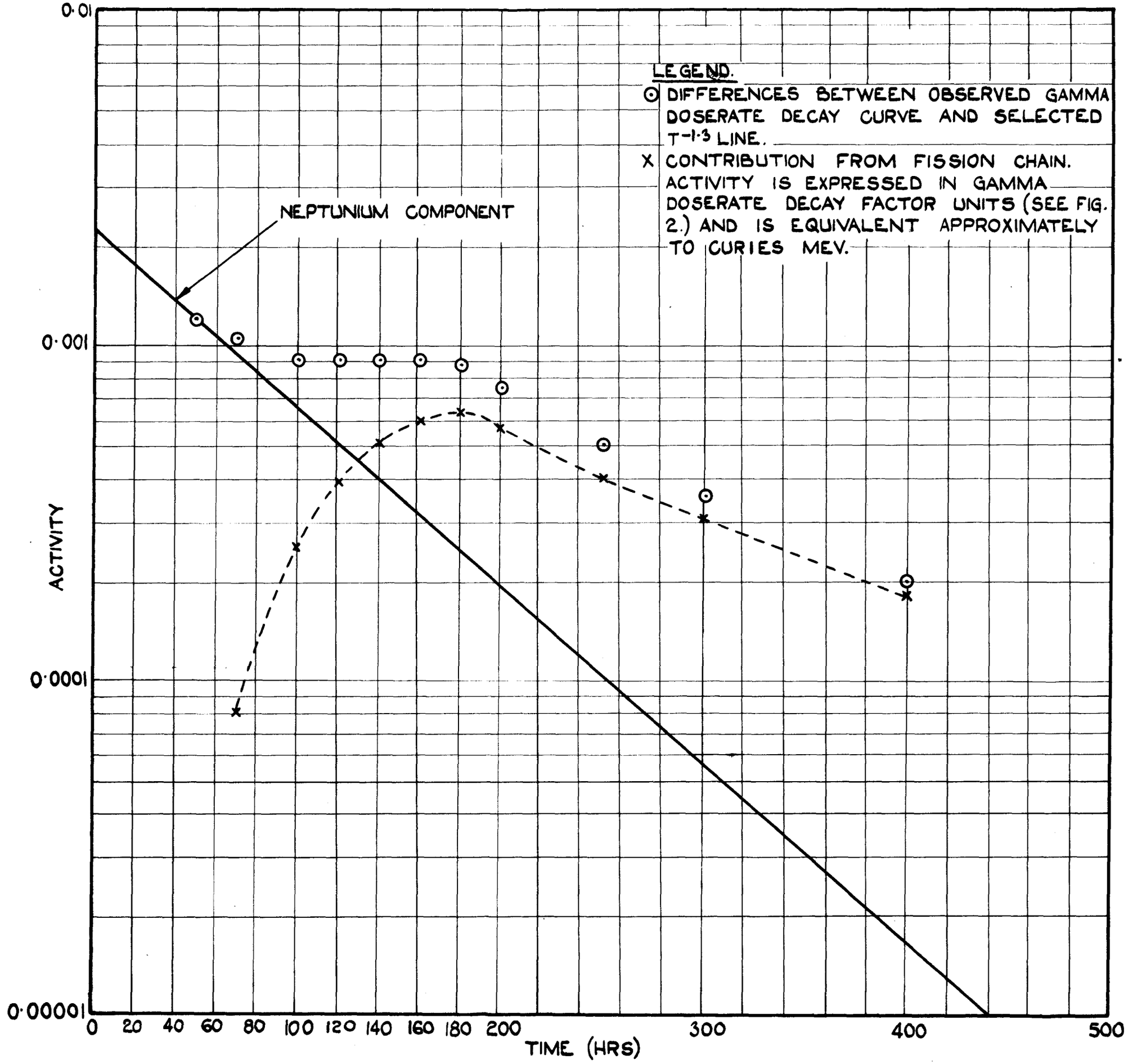


FIG. 4. SCHEMATIC ANALYSIS OF GAMMA DOSERATE CURVE.

FIG. 5.

DRN.
TCD. GW
APP.

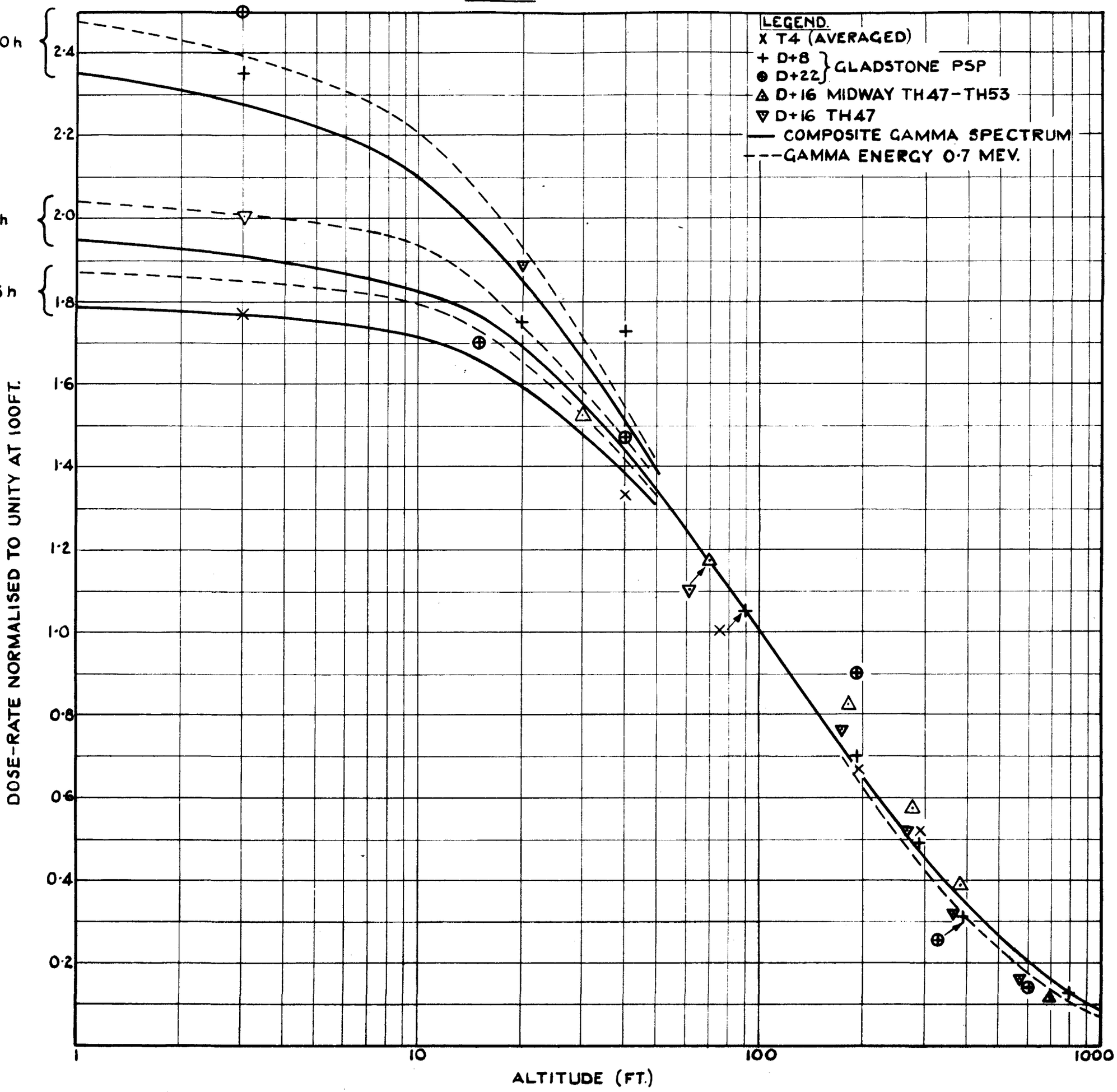


FIG. 5. DEPENDENCE OF DOSE-RATE ON HEIGHT COMPARISON BETWEEN THEORY AND EXPERIMENT.

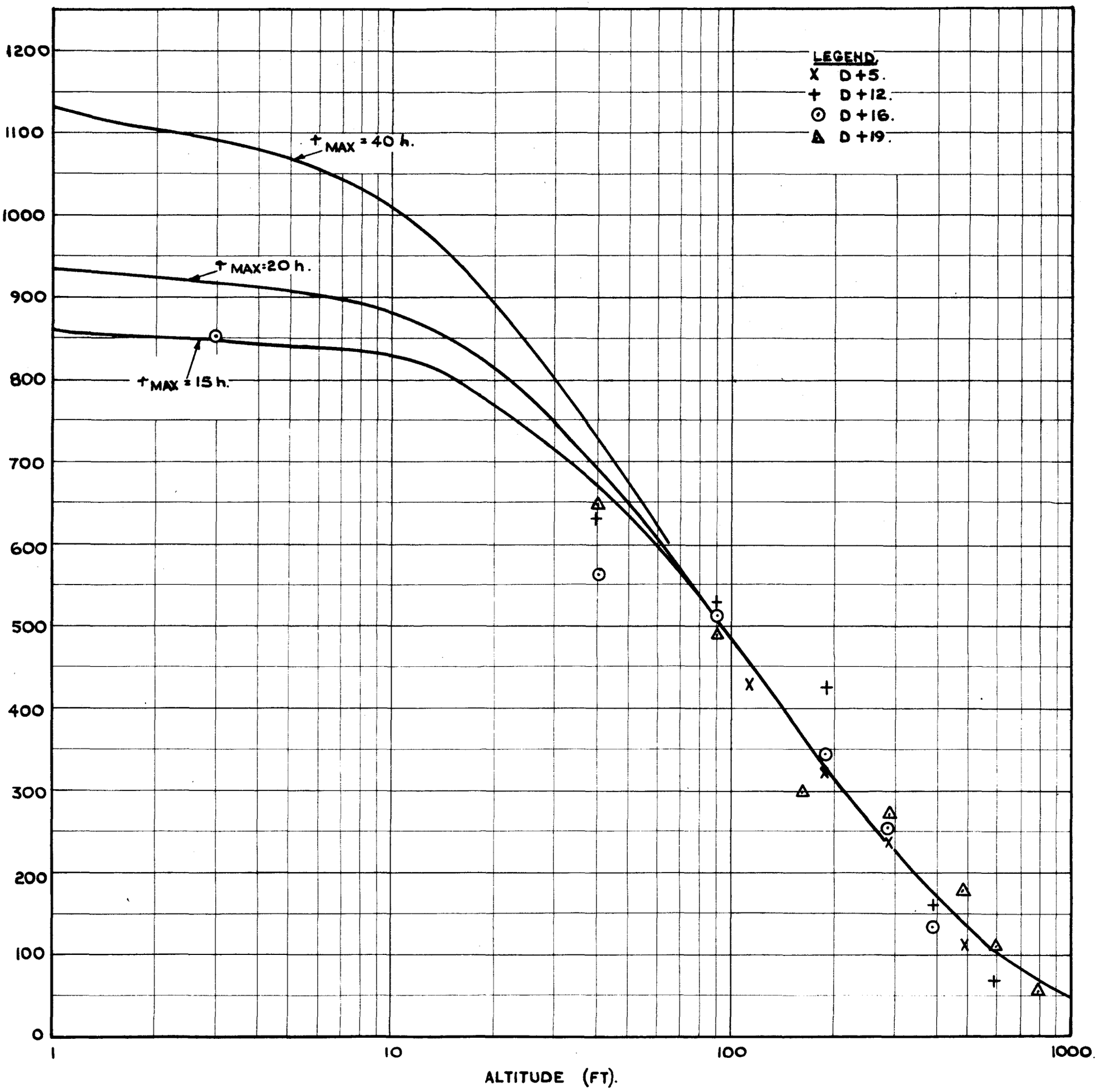


FIG. 6. HELICOPTER SURVEY OVER T4.

COMPARISON OF RESULTS CONVERTED TO H+1 HOUR WITH THE THEORETICAL CURVES FOR THE COMPOSITE GAMMA SPECTRUM AND SEVERAL VALUES OF τ_{MAX}.

MAP OF KINGCUP ISLAND

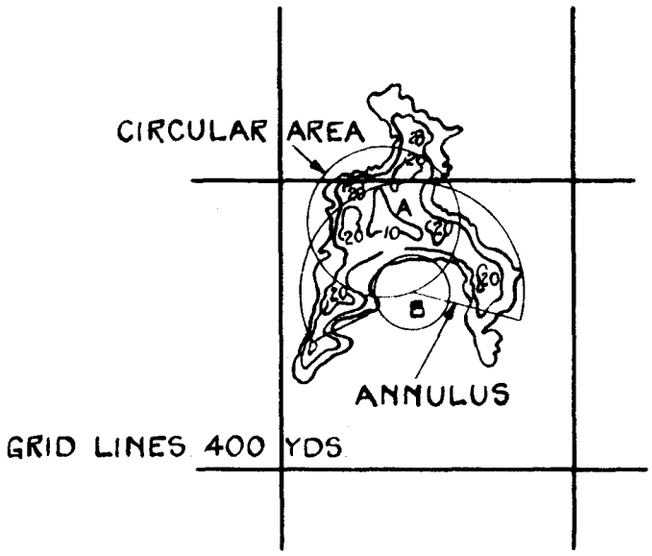


FIG. 7A. MAP OF KINGCUP SHOWING EQUIVALENT AREAS.

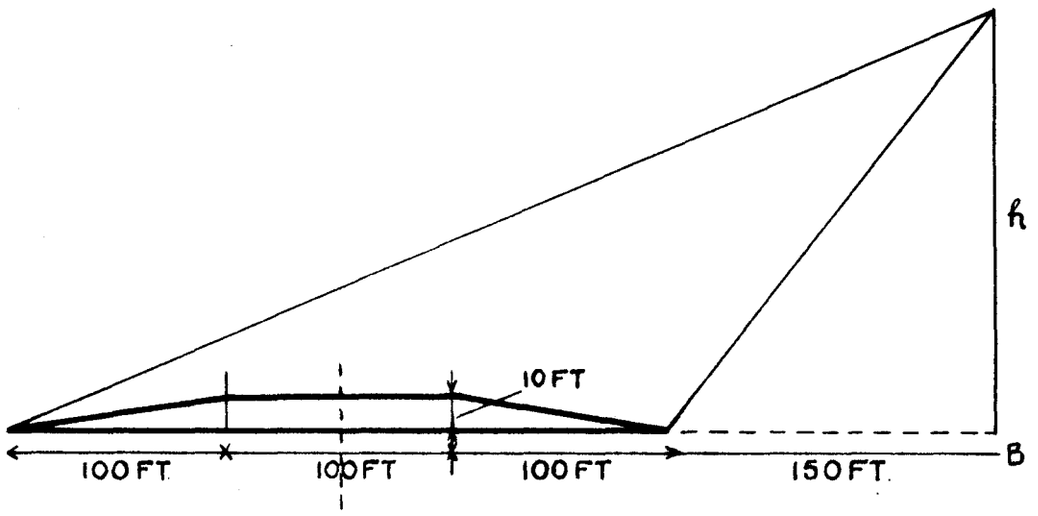


FIG. 7B. SIMPLIFIED CROSS-SECTION OF ANNULAR SOURCE.

C B H. 18664 - Wt. 44340 - Dd. 2841 -500 - 7/58

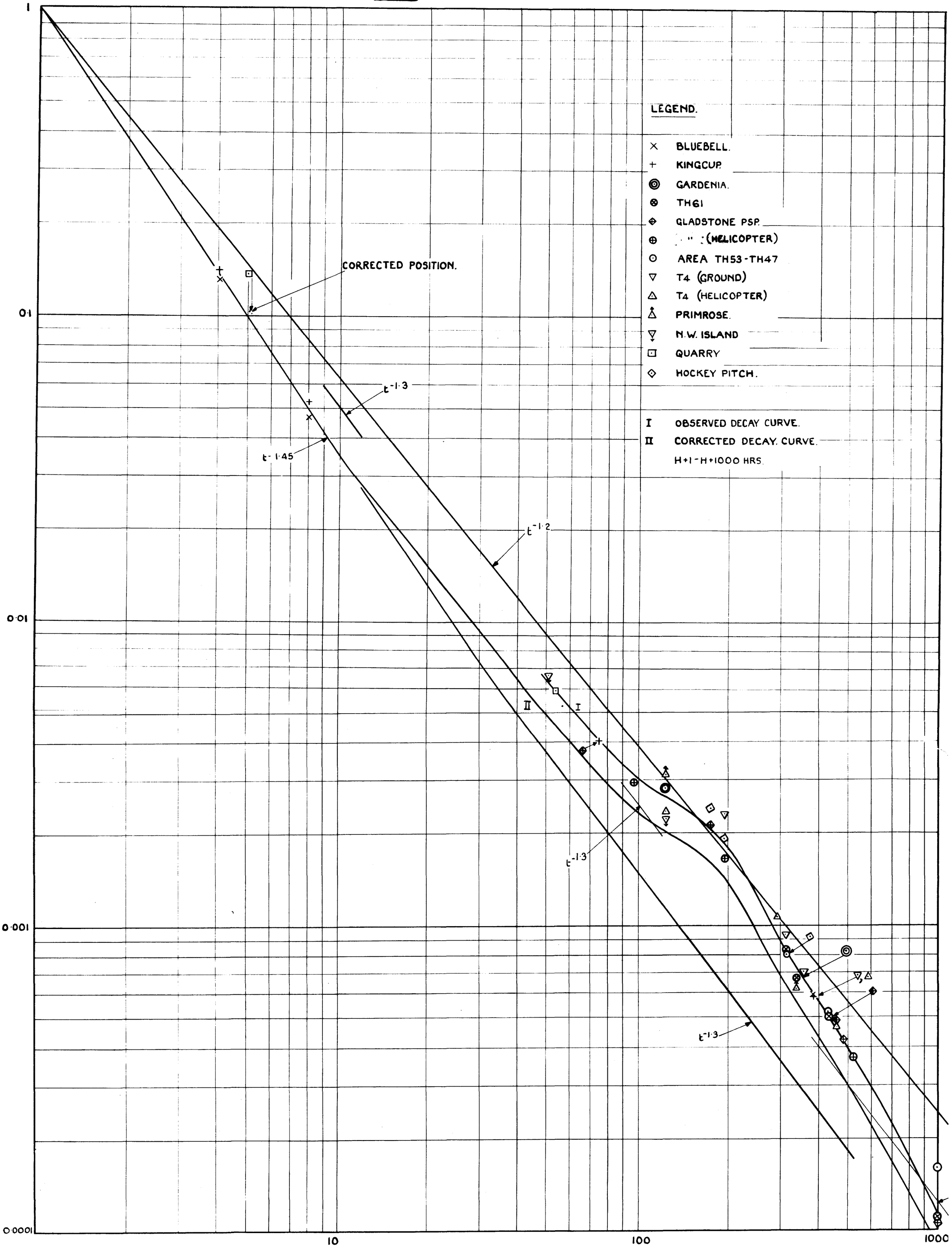


FIG. 2. DECAY OF GAMMA DOSE-RATE WITH TIME.
(NORMALISED TO UNITY AT H+1 HOUR)

RRR. 8577

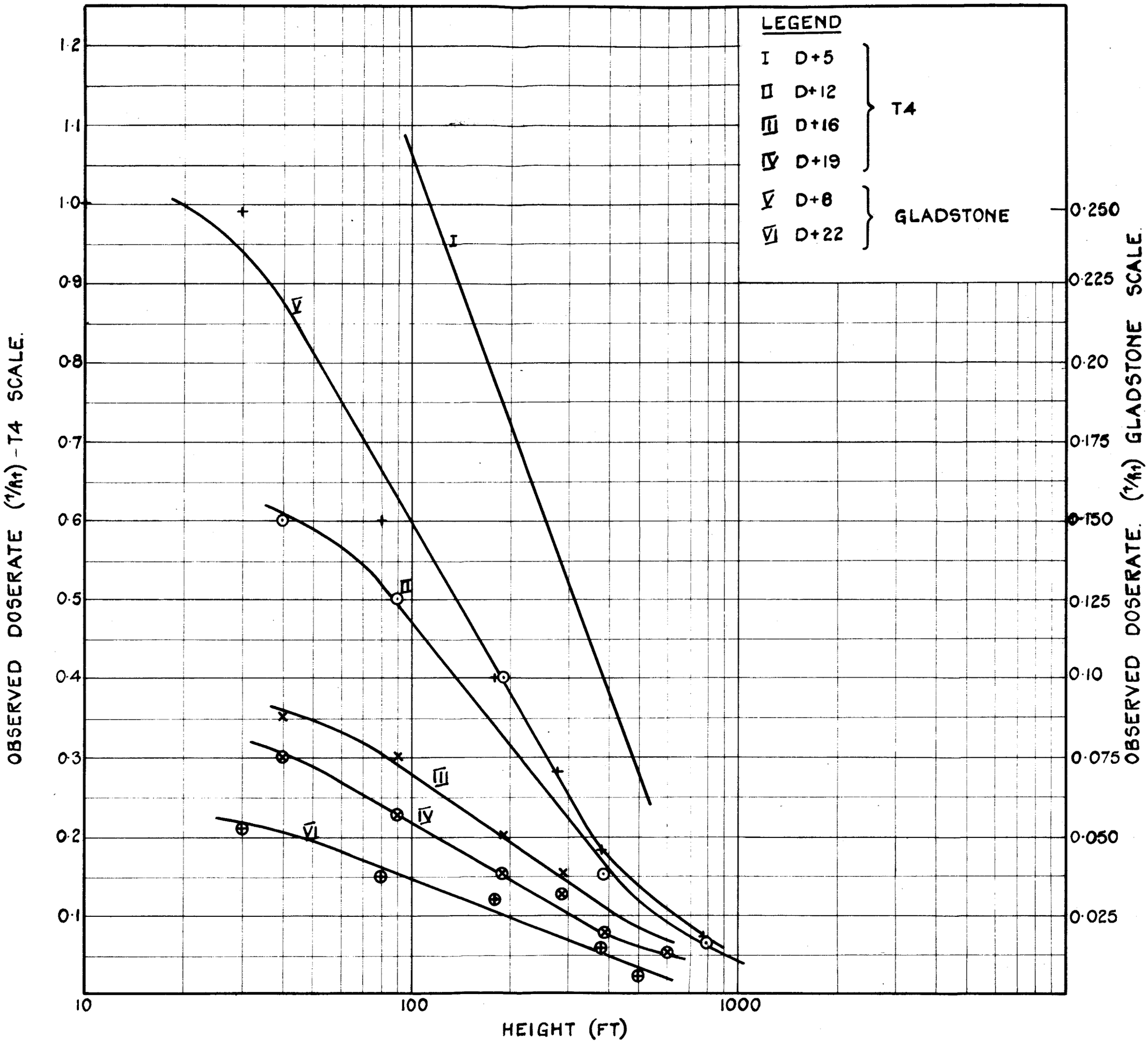


FIG. 3. CURVES SHOWING VARIATION OF DOSERATE WITH HEIGHT.