Aldermaston ▪ Reading
Berkshire ▪ RG7 4PR
www.awe.co.uk

Ref : FOI2023-046

[redacted]

5th February 2024

Dear [redacted],

Further to our previous correspondence regarding your request for the following information:

> *I have been to the national Archives and have obtained the detachment commanders report but the AWRE report (National Archives catalogue number **ES 5/370**) former reference from the original department **T3/69** has been closed and is held by the MoD.*
>
> *I would like to obtain or have sight of the above report and would ask if you could direct me in order to achieve this?*

Your request has been handled as a request for information under the Freedom of Information Act 2000 (the Act).

A search for the requested information within the Atomic Weapons Establishment (AWE) has now been completed, and we can confirm that the requested document is held, please find it attached at Appendix 1.

Thes document has been redacted in line with Sections 24(1), 26(1)(b), 27(1)(a) and 40 (2) of the Act, which provides that a public authority may withhold information to the extent that its disclosure would adversely affect National Security, Defence, International Relations, and contains Personal Information.

Section 40(2), consideration on applying this exemption is subject to whether the disclosure of any information would lead to identifying individuals, placing information pertaining to them into the public domain. This constitutes personal data which would, if released, be in breach of the rights provided by the current data protection legislation (Data Protection Act 2018 DPA 2018 and the UK General Data Protection Regulation UKGDPR), namely the first principle which states that personal data should be processed lawfully, fairly and transparently. It is our view that there is no lawful basis to provide this information. This is a class based absolute exemption, and no public interest test is required.

Sections 24(1), 26(1)(b) and 27(1)(a) are qualified exemptions and as such there is a requirement to articulate the potential harm by conducting a public interest test (PIT). A PIT has been carried out, a summary is outlined below.

Section 24 (1) provides that information is exempt if required for the purposes of safeguarding national security. Section 24(1) is a qualified exemption, which means that it is subject to a public interest test. We acknowledge the public interest in openness and transparency, but we consider that there is also a public interest in AWE protecting national security. Having reviewed the redacted material, we are concerned that disclosure of those technical data could contribute to the compromising of UK's and global security, We have therefore concluded that the exemption applies and that withholding the material serves the public interest better than release in this instance.

Section 26(1)(b) states that information is exempt if its disclosure under the Act would, or would be likely to, prejudice (a) the defence of the British Islands or of any colony, or (b) the capability, effectiveness or security of any relevant forces.

The factors for release are similar to those provided for the use of section 24 in as much as release of the information would provide greater openness and transparency. However, we consider that there is a high likelihood that the unredacted release of this document would provide information to individual(s) or state nation which could be used to garner specific technical knowledge about the UK's nuclear deterrent, this knowledge would consequently prejudice the capability and effectiveness of the UK's nuclear deterrent, compromising the defence of the UK and beyond.

Section 27(1)(a) of the Act recognises the need to protect information that would be likely to prejudice relations between the United Kingdom and other states if it was disclosed. Section 27(1)(a) is a qualified exemption and as such we have considered where the greater public interest lies. Disclosure would meet the public interest in transparency and accountability; however, the effective conduct of international relations depends upon maintaining a high level of trust and confidence between governments. If the UK does not maintain this trust and confidence, its ability to protect and promote UK interests through international collaboration will be hampered, recognisably not be in the public interest. The disclosure of the redacted information would potentially damage the relationship between the UK and other states. The relationships are on-going and release of the data - even taking its age into consideration- are highly likely be taken into account by those states. This would result in significant reduction of trust, consequently reducing the UK Government's ability to protect and promote UK interests both now and with future collaborative defence projects which would not be in the public interest. For these reasons we consider that the public interest in maintaining this exemption far outweighs the public interest in disclosure.

The balance of public interest was found to be in favour of redacting sensitive information for the purpose of safeguarding national security, defence and international relations.

Please remember to quote the reference number above in any future communications. If you have any queries regarding the content of this letter, please contact this office in the first instance.

If you are unhappy with the way your request has been handled you have a right to request an internal review within 40 days of receiving this letter, by writing to information.requests@awe.co.uk or our postal address: Information Requests Team, AWE Aldermaston, Reading, RG7 4PR. If you are still unhappy after an internal review has been completed, under the provisions of Section 50 of the Freedom of Information Act 2000 you have the right to take your complaint to the Information Commissioner's Office. Please note the Commissioner will generally not consider a complaint until you have exhausted AWE's internal complaints process.

Yours sincerely,

AWE Information Requests Team

[redacted]

AWRE T3/69

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

AWRE REPORT No. T3/69

Scientific Aspects of Operation WEB

Edited by [redacted]

AWRE,
Aldermaston, Berks.

January 1969

[redacted]

[redacted]

United Kingdom Atomic Energy Authority

AWRE, Aldermaston

AWRE REPORT NO. T3/69

Scientific Aspects of Operation WEB

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1. INTRODUCTION

1.1 WEB was mounted as part of the UK investigation of the French nuclear test series of 1968. Its objectives were:-

(i) to collect samples of debris from devices fired in the atmosphere;

(ii) [redacted]

(iii) to evaluate new equipment used on the sampling aircraft;

(iv) to develop operational procedures for this locality.

1.2 The explosions took place at, or near, Mururoa (22°S, 139°W) under meteorological conditions which would confine the majority of the fallout to the danger area defined in the French notice to aviators and mariners (figures 1 and 2). Between altitudes of 20000 to 60000 ft, debris clouds move eastwards crossing the South American west coast some 2 to 10 days later between 20°S to 30°S. Near the test site the clouds are very dense; as they drift eastwards they become progressively more diffuse to such an extent that sampling over the Atlantic would be unsatisfactory.

1.3 A detachment from 543 Squadron, Wyton, plus scientific staff were based [redacted] from 14th June to 25th September 1968. After some adjustments the final and reasonably satisfactory detachment complement was: 4 aircrews (20 officers), an equipment officer, an engineering officer, about 30 airmen, two RAF/AWRE personnel, two AWRE scientists and a meteorological officer. Flying operations took place from the [redacted]

1.4 Since WEB was the first serious UK effort for some considerable time to collect foreign debris this scientific report considers the operation in some detail. It should be read in conjunction with a more general report [1] and the RAF report [2].

1.5 In what follows, we describe the theoretical and background knowledge concerning the debris cloud, the aircraft, detecting equipment and sampling equipment. Thus sections 2 to 8 represent little more than our knowledge and ideas before the operation (May 1968); subsequent sections describe the operational sorties, the results obtained and their significance. The last section summarises the lessons learned and discusses possible improvements.

1.6 [redacted]

2. CONSIDERATION OF SAMPLE REQUIREMENTS

2.1 Ideally the sample should:

(i) contain an adequate fraction of the total device material;

(ii) be free of any other contaminating material;

(iii) be in the laboratory for analysis within 2 days;

(iv) be a "representative" sample.

2.2 Sample size is best defined in terms of number of fissions, ie, the debris from a certain number of fission events; this can be conveniently and directly determined by measurements of γ activity with a radiation monitor. The minimum adequate requirement is about [redacted] fissions (although this is not to say that a smaller sample is useless). Since 100 ktons of fission energy is roughly equivalent to 10^{25} fissions (most devices give a fission yield within a factor of 10 of this value), our required material fraction is of order [redacted] If the device weighs one ton the sample has a mass of about 10^{-7} gm. Clearly this calculation is only good to an order of magnitude but shows that the collected material is not visible to the naked eye.

2.3 [redacted]

[redacted]

2.4 Because of the diagnostic interest of short-lived radioactive species, any early, large sample is required within 2 or 3 days; contamination is not relevant for such a sample provided what has been defined as an ideal sample also becomes available preferably within 10 to 12 days of detonation. Nevertheless, since the time of sampling is very much at the mercy of the wind, it should be made clear that some useful information can still be derived even if the material is 20 days old.

2.5 There is virtually no control over the representative nature of a sample. The problem has some analogy with that of obtaining a representative sample of [redacted] gm from a tonne (10^6 gm) of coal; how well does the sample represent the average composition of the whole? All that can be said is that it is desirable to obtain more than one sample from widely different parts of the whole; by so doing one can at least average the results and one may, by applying suitable treatment, effectively eliminate sampling errors.

2.6 In summary, the ideal situation is to have two or more samples taken from different regions of the atmosphere, each with at least [redacted] fissions per gram of paper collected from the densest parts of the debris cloud.

3. THE DEBRIS CLOUD

3.1 Formation

A nuclear explosion liberates a large amount of energy over a very small period of time within a limited quantity of matter. As a result, all the constituents of the device (together with surrounding equipment) are vapourised, attaining a maximum temperature of tens of millions of degrees (several keV). This gives rise to instantaneous pressures of over a million atmospheres. The gaseous bubble therefore expands and cools rapidly by emission of radiation.

At the same time the bubble rises like a hot air balloon, initially at 300 - 400 miles per hour. After a minute a 1 Mton explosion has cooled to the extent that it no longer emits visible radiation - by which time it has risen about 20000 ft - and is still rising, being further cooled by expansion and mixing with air. The rapid initial cooling of the outside of the bubble, coupled with the drag of the air during the ascent, leads to the development of toroidal motion as the hotter central portion rises more quickly, and draws in cool air to the centre of the base. This motion flattens the bubble giving the typical mushroom shaped cloud. The strong updraft of cool air, caused by the rapid rise of the bubble, gives rise to inflowing winds which, for land surface or sea surface bursts, draws up many tons of terrestrial dirt or seawater, and, in all cases introduces considerable amounts of water vapour.

During the cooling process the vapourised device material condenses to solid particles whose average size depends on the yield, device mass, rate of rise etc. If much solid material is sucked up the vapour will condense quickly on to the cool dirt particles. At first the rising bubble carries all material upward; but after a time particles begin to fall slowly under gravity at rates dependent on their size. This, together with early condensed material left as the cloud rises and water droplets gives rise to the "stem" of the mushroom cloud.

Because of the toroidal motion the stabilised cloud has the form of a "doughnut"; the central portion may in fact contain very little activity. However, after several days transport in the upper winds the "doughnut" shape becomes blurred which is the justification for treating it mathematically, even at stabilisation, as a uniform cloud.

3.2 Height of stabilised cloud

The height eventually reached by the cloud depends on the yield and atmospheric conditions, eg, moisture content and stability; it is strongly influenced by the tropopause at which height it tends to spread laterally. If sufficient energy remains part (or even most) of the debris will penetrate the tropopause and enter the stratosphere. Maximum height is attained after about 10 minutes when the cloud is said to be "stabilised" although it continues to grow laterally. The cloud disappears, visibly,

[redacted]

after a few hours due to water droplet evaporation and wind dispersion but the debris is nevertheless still referred to as "a cloud".

Figure 3 shows average cloud data over continental USA [3] for air bursts; surface bursts attain lower maximum heights due to entrainment of non-device material. Flattening of the curve below 100 ktons is due to the effect of the tropopause in slowing down the rise of the cloud; note that at Mururoa the tropopause is at about 50000 to 55000 ft so that the flattening may occur at somewhat higher yields. Figure 4 is based on observations of airdrops at Christmas Island at the Dominic series [5]; detonation heights ranged from 2600 to 15000 ft and did not seem to have a discernible influence on ultimate cloud height. Figure 5 also shows cloud height as a function of yield; the data are from a US source [6] and included on this figure are height-yield points which the USAF work to, the data being given on a recent visit [4]. These curves give some idea of height and size expected; what actually happens depends very much on mode of firing and local meteorological conditions.

Debris clouds tend to concentrate at the tropopause or at minor temperature inversions. The particles need vertical momentum to break through and, in its absence, will tend to spread laterally below the inversion. Material which does break through is discouraged from rising much further because of the increase of temperature with height above the tropopause, again encouraging lateral spreading.

3.3 Fission density of stabilised cloud

The table below shows calculated values of average fission density in the stabilised cloud, assuming that all the yield is due to fissions. Bearing in mind that only a part of megaton range shots is due to fissions it is clear that the density of all stabilised clouds lies in a narrow range. Note that the term cubic foot refers to volume of space regardless of altitude. The expression standard cubic foot is really the mass of air in one cubic foot at STP (= 0.076 lb).

Fission Density at Stabilisation as Function of Yield
(Data from References [3] and [6])

[redacted]

[redacted]

3.4 Activity in the stem

This will clearly depend on how much terrestrial material is sucked up and the extent to which this dirt "scavenges" activity from the cloud, thus giving rise to extensive local fallout. In the absence of significant terrestrial dirt the only activity below the main stabilised cloud will be due to fallout of large (greater than about 10 micron) particles and material "trapped" at minor inversions.

3.5 Particle size and fallout

The particle size distribution with which the activity is associated depends on yield to mass ratio of the device (the mass includes associated material, eg, balloon and cables, tower structure), the principal material of construction and the amount of terrestrial material sucked up [7]. Thus a land surface burst will involve a good deal of dirt which both quenches the hot gases, leading to large particle formation, and provides large unvolatilised particles on to which activity can condense. Particles larger than about 40 microns fall by gravity to earth even from 80000 ft in 12 hours or less so that a land surface burst gives rise to considerable local fallout. A megaton range air burst gives rise to small particles (below 3 microns) since the density of device vapour is low at the time of condensation.

In WEB debris was collected some 48 hours or more after burst; by this time any particles of radius greater than 20 microns had fallen to earth.

3.6 Cloud movement

Following stabilisation the debris cloud is gradually dispersed by diffusion and transport by upper air winds. Although the wind prevailing across the Pacific is westerly the local winds in the test area are south westerly, thus defining the notified danger zone (figure 2). The clouds generally travel north eastwards to about 115° W, then with north westerly winds turn south eastwards to about 85°W before moving eastwards or north eastwards to cross the South American west coast at about the same latitude as the test site. Wind speeds in the likely search area (70°W to 100°W and 15°S to 25°S) at levels between 30000 to 45000 ft were known to be in the region of 40 to 90 knots.

Due to wind shear portions of the cloud will split off at different altitudes and will travel at the wind speed prevalent at those altitudes. Thus parts of the original cloud will arrive in the search area at different times at different altitudes.

Estimation of cloud positions at different altitudes depends on knowledge of upper air wind vectors. Lack of such data between the test site and west coast South [redacted] coupled with the paucity of data from areas [redacted] impractical for the detachment to draw realistic forecast charts. During WEB estimated cloud positions were obtained from USAF meteorological predictions. These forecasts are considered in detail in section 7 and analysed in section 13.

3.7 Cloud diffusion

In addition to moving bodily with the wind, clouds (or patches of cloud) also spread laterally and vertically by diffusion; such expansion would occur even if there were no wind at all. That is not to say that practical horizontal and vertical diffusion coefficients are equal; clearly, due to changes in wind speed, the diffusion coefficient will be highest along the wind vector, somewhat smaller across this vector, and smaller still vertically.

As diffusion proceeds the density of activity acquires a roughly Gaussian distribution, so the boundary can only be defined arbitrarily in terms of a density contour; ie, one cannot draw a roughly elliptical shape and say that there is cloud inside the boundary and none outside. The cloud density at any point is given by the Gaussian,

$$\frac{F}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} \exp\left[-\tfrac{1}{2}\left(\frac{x^2}{\sigma_x{}^2} + \frac{y^2}{\sigma_y{}^2} + \frac{z^2}{\sigma_z{}^2}\right)\right],$$

where x, y and z are Cartesian co-ordinates measured from an origin at the centre of the cloud, x being along the wind vector, y across this vector, z representing vertical distance and the σ's are standard deviations along the co-ordinates. F is the initial source term (total number of fissions). Assuming vertical diffusion is small we replace $\sigma_z\sqrt{2\pi}$ by the vertical distance occupied initially by the cloud (15000 ft, ie, 5×10^5 cm) and assume, to err on the pessimistic side, that half the initial fissions are contained within it. The ratio $F/2\sigma_z\sqrt{2\pi}$ is thus a constant which applies even if, say, a 1000 ft thick "sheet" of the cloud is transported much faster than the rest. Our equation now becomes two dimensional, thus:-

$$\frac{F}{2\pi\sigma_x\sigma_y 10^6} \exp\left[-\tfrac{1}{2}\left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}\right)\right],$$

where distances are in centimetres.

In terms of Fickian diffusion coefficients,

$$\sigma_x{}^2 = 2tK_x \qquad \sigma_y{}^2 = 2tK_y,$$

where t = time. Data on the Totem cloud at 11 hours suggest that K_x is about 10^8 cm^2 sec^{-1} and K_y is about one sixteenth of this value. From this we can calculate the x and y co-ordinates (and hence elliptic axes) for a given set of conditions. Thus for a 100 kton shot ($F = 1.4 \times 10^{25}$ fissions)

[redacted]

at 48 hours we have, at a density of 10^7 f/ft^3 (3.7×10^2 f/cm^2):-

$$\frac{1.4 \times 10^{25}}{4\pi t(K_x K_y)^{\frac{1}{2}} 10^6} \exp\left[-\tfrac{1}{2}\left(\frac{x^2}{\sigma_x^{\,2}} + \frac{y^2}{\sigma_y^{\,2}}\right)\right] = 3.7 \times 10^2.$$

Hence, putting in values

$$x^2/\sigma_x^{\,2} + y^2/\sigma_y^{\,2} = 13.1,$$

where σ_x = 37 miles, σ_y = 9.25 miles. This represents an ellipse of major axis $2\sigma_x\sqrt{13.1}$ = 268 miles and minor axis $2\sigma_y\sqrt{13.1}$ = 67 miles. The curves in figure 6, expressed in nautical miles, have been built up from such calculations. (Note, one mile is 5280 ft, one nautical mile is 6080.27 ft.)

The assumed values of K_x and K_y are too small by an order of magnitude to account for observations made in [redacted] However, a factor of 10 increase in the diffusion coefficients less than doubles the axis length. If the ratio we have assumed for $F/2\sigma_z\sqrt{2\pi}$ is too large (which could be the case if a low density part of the stabilised cloud is swept away by the wind) the axes would be smaller. In view of the unknowns it seems likely that figure 6 gives a reasonable idea of the dimensions involved.

It will be seen later that 50 hours after burst the aircraft should detect a part of the cloud with density 2×10^6 f/ft^3 and at 150 hours a density of 2×10^7 f/ft^3. Between 2 and 7 days after burst the axes of the ellipse within which the cloud is detectable are about 300 miles and 80 miles. Of course this only applies to a large "sheet" being swept by the wind from the original cloud; it cannot apply to wisps which become broken off by the vagaries of the wind.

[redacted]

4. THE VICTOR AIRCRAFT

4.1 General

Three RAF aircraft were equipped for sampling work; XL 161, XL 193 and XL 230, all Handley Page Victor B Mk. 2 Strategic Reconnaissance planes of 543 Squadron, Wyton. They were fitted with underwing fuel tanks (which carried the Mk. III sampling ducts) some 28 ft from the fuselage. Outlines of the Victor are shown in figures 7 to 9. Two aircraft were [redacted] the third being in the UK but available, subject to servicing, at short notice. In fact 161 and 230 were first used [redacted] 230 being replaced by 193 at the end of July; 161 and 193 were used for the remainder of the operation.

4.2 Technical performance

Performance of the aircraft is a complicated function of aircraft weight (112000 lb without fuel, 224000 lb with maximum fuel), altitude etc. The maximum safe range at optimum altitude is about 3800 nautical miles and maximum altitude with very little fuel is about 54000 ft. Details are given in appendix A. A rough idea of distance available for cloud searching as a function of altitude of the search and distance from base is shown in figure 10. In constructing this figure the transit to and from the search area is assumed to be at optimum altitude (about 40000 ft). As will be seen later the search mileage controls the search pattern.

4.3 Aircraft servicing

Following a sortie some 4 hours must be devoted to ground checks and refuelling; in the absence of faults the aircraft can take off again.

It should be appreciated that in the sampling role certain faults can develop in specialist equipment, eg, photographic, which do not require immediate servicing. While operating from an RAF base <u>all</u> faults would normally be rectified before flying. Hence, on a detachment such as operation WEB, there may be less time required on ground servicing than might be the case in the UK. It is therefore not possible to use UK statistics on ground servicing as a guide to expectation on detachment. At the same time there are no statistics for ground servicing on this type of detachment apart from WEB itself. During the operation there were only two take off delays due to faults - one lasting an hour and one lasting 20 minutes. Greater detail concerning servicing is to be found in reference [2].

The aircraft are normally limited to 100 flying hours between major overhauls. With provisos (eg, that the aircraft hours were not extended on its last tour) the engineering officer can authorise an additional 20 hours. Permission must be sought from MOD (Air) for additional extensions but for an operation of this type they would probably readily extend to 150 hours. It must be remembered that the journey [redacted] flying hours.

4.4 Sortie rates

The meteorological conditions which frequently pertain give a fairly limited total period of time (2 to 4 days) during which the debris is accessible to the aircraft. It then becomes important to establish a high sortie rate. Figure 11 shows sortie sequences with given numbers of aircraft and aircrew, assuming:

(i) aircraft "turn round" of 4 hours;

(ii) that aircrews require 8 hours sleep, so that, together with travelling to and from the airport, eating, briefing and debriefing, 12 hours must elapse between touchdown and take off;

(iii) that 8 hour search flights are involved.

The final complement on WEB, 2 aircraft and 3 flying aircrews (plus a fourth for operation duties) gives a good usage of resources. In fact, during sampling [redacted] flight hours per real hour was unity over 8 flights; such a rate cannot be maintained for more than 8 flights. Nevertheless, the limited resources tend to discourage weather/background flights and also flights to recover a second sample from a different altitude.

4.5 Communication

Vocal communication to and from airborne aircraft was only made:

(i) [redacted] within about 200 miles;

(ii) with the second airborne Victor when within 150 - 200 miles;

(iii) [redacted] within 150 - 200 miles.

Contact between ground and airborne aircraft was only by morse which was generally satisfactory up to 2000 miles. For this purpose use was made of [redacted] about 1.5 miles from the airport; communication [redacted] was by either a Pye vhf intercom set or by telephone.

Communications would have been vastly improved by the use of single side-band transmitters and receivers since vocal contact could then be made up to 2000 miles.

4.6 [redacted]

The only weather hazards to flying are the low stratus, night and morning (worst between 2 a.m. and 8 a.m. local), [redacted] which is advected across the airfield on the prevailing southerly winds which are generally between 5 and 15 knots. During the period of operations the cloud base never fell below 600 ft, nor was the visibility less than 2 miles.

[redacted]

5. CLOUD DETECTION

5.1 General

Although meteorological predictions may give the general location, a sampling aircraft must be able to detect a debris cloud from as far away as possible. Possible methods include:

(i) measurement of radioactivity;

(ii) use of properties of ionised air in and around the cloud, eg, in reflecting or scattering radio waves;

(iii) measurement of particle density, eg, in reflection of laser beams;

(iv) artificial tagging of cloud near its source, eg, with constant height balloon, with a dye or vapour capable of being easily detected.

As far as is known only (i) has been used. [redacted] The UK method is to measure γ ray activity with with a detector inside the aircraft and also to monitor the filter of a small, permanently open sampling duct with a Geiger counter, the two detectors being known collectively as the NIS 361 (figure 12).

5.2 Crystal detector

This consists of a 2 in. × $1\frac{3}{4}$ in. diameter cylindrical sodium iodide crystal, photomultiplier, amplifier and single channel analyser (NIS 322, right hand side of figure 12) [15] mounted on a clamping bracket situated about one foot aft of the main instrument panel which extends across the plane roughly in line with the engine air intakes, about 17 ft abaft the aircraft nose. The aircraft skin is about 0.1 in. thick dural with about $\frac{1}{2}$ in. loose glass wool thermal insulation. Airframe struts at about 2 in. intervals are much thicker. About one foot aft of the detector is a pressure bulkhead. When estimating the response of the crystal it was not appreciated that the crystal would be surrounded by such massive absorbing material.

The battery power supplies, ratemeter and "Rustrak" twin penminiature strip chart recorder are in two boxes, each roughly 10 in. × 10 in. × 6 in. mounted in the instrument panel (centre figure 12); the boxes also contain similar equipment for the Geiger counter (see section 5.4). The crystal ratemeter was calibrated logarithmically from 0 to 3000 counts per second. Two such sets of equipment were fitted to the two aircraft and a complete third set, together with some other spares, [redacted]

[redacted]

On approaching a debris cloud, from what we may consider as an infinite distance, the first indication of the presence of debris is marked by a signal only just above the "background" reading. By background reading we mean the reading due to cosmic radiation, aircraft contamination, particulate in the air etc, even in the absence of the fresh debris cloud. The definition of the size of the cloud must be that volume within which the debris can be detected; the more "sensitive" the detector the larger is the detectable cloud volume and therefore the greater the chance of locating it.

The only adjustable parameters of the crystal detector are the low level discriminator, energy window width of the single channel analyser and the time constant of the ratemeter. These parameters are discussed in appendix C with a view to maximising sensitivity for cloud detection. An estimate of the expected response is also given as a function of cloud density. The main conclusions are:-

(i) the use of a ratemeter with time constant τ is equivalent to using a scaler for a period of time 2τ;

(ii) to maximise the sensitivity of the crystal, the ratio S^2/B (where S is the source count rate and B is the background count rate) must be maximised;

(iii) from the calculated spectral output from the crystal in a uniform cloud containing 1 fission/cm^3 of fission products 2.13 days old, and the known background spectral output, it is shown that the optimum channel setting is from 140 to 800 keV;

(iv) in a cloud of density 10^6 fission/ft^3 with fission products 2.13 days old, at 30000 ft a signal equal to that of the background (300 counts/sec) is to be expected; hence we might hope to detect 2×10^5 fission/ft^3. However, section 10 shows from experimental data that our calculation overestimated the sensitivity by about a factor of 7; hence the practical limit of detection at 30000 ft, 2.13 days after the event, is about 10^6 f/ft^3. Due to the decay of fission products (figure 15) the sensitivity will fall by a factor of 5 by the time the debris is 8 days old; but sensitivity will increase with altitude, roughly inversely with the air density.

5.3 <u>Vertical sensitivity of crystal detector</u>

This was calculated by assuming a uniform cylinder of air of fission density 10^7 fission/ft^3 (debris 2.13 days old) situated a distance h feet above the crystal detector, ie, there is h feet of air free of fission products between the cylinder and the detector. The cylinder is assumed to have infinite radius and infinite height. After allowing for build up factors (appendix C, section C6) count rates on the crystal were estimated; since we overestimated by a factor of 7 we enter the practical results into the table below, ie, estimates divided by 7. These are the count rates expected over and above the background of about 200 counts/sec.

[redacted]

Altitude / Altitude Difference, h (ft)	30000 ft	40000 ft	45000 ft	50000 ft
750	45 c/s	94 c/s	-	-
1500	24	55		110 c/s
2250	11	-	-	-
3000	5	20	38	62
4500	-	8	15	32
6000	-	-	8	15
7500	-	-	-	9

While this gives some feel for the sensitivity in a vertical direction the model is somewhat unreal.

5.4 Directional meter

Having detected a debris cloud it is important that the aircrew should have some means of determining the location of the main part of the cloud, to maximise the fissions/gram collected in the filters. In particular it seemed useful to have an idea as to whether the major part of the cloud was above or below the flight level, thus restricting the "hunt" to two dimensions.

A crude instrument was constructed by shielding, with lead, one end of the crystal of a portable NIS 322 instrument. The tapered end of the case was covered with a lead cone about 3 in. long, wall thickness about $\frac{1}{4}$ in. in the skirt and about $\frac{1}{2}$ in. thick at the flat end. The cone was attached with a nut and bolt, the bolt having a large flat head which was inserted from inside the outer casing. Since readings had to be taken with the monitor held first vertically upwards and then vertically downwards an external logarithmic ratemeter was connected to the instrument (figure 17).

In the absence of experience, the single channel analyser was set between 0.14 and 0.80 MeV; this is undoubtedly not optimal. The instrument was devised and manufactured in 2 days and no theoretical consideration was given to its performance.

It is readily demonstrated, assuming the Gaussian distribution model, that the change in fission density with distance in the horizontal plane is too small for a directional meter to be of much value.

5.5 Geiger counter in Mk. X duct

The Mk. X duct (see section 6 and left hand side of figure 12) contains a cylindrical Mk. IX esparto grass filter (9 cm diameter x 14 cm long) which is monitored by a concentrically located Mk. 172 Geiger counter. The latter has a sensitive length of 12 cm (physical length 20 cm) a diameter of 1.6 cm, a roughly 50 mgm/cm^2 thick metal wall and a 90 µsec dead time.

The Geiger is battery operated and its count rate is shown on a 0 - 3000 counts/sec logarithmic ratemeter and recorded on the twin pen "Rustrak" recorder shown in figure 12.

Its response to 10^{10} fissions collected on the filter is shown in figure 16. The background at altitude is about 20 counts/sec. For fission products 2.13 days old one expects a count equal to background from about 2×10^9 fissions. Since the duct collects at about 540 ft^3 per minute (see section 6) a two minute sample from a uniform cloud of 10^6 fission per cubic foot is required before attaining a debris signal equal to 1/3 of background. In this time the aircraft would have travelled about 20 miles. This instrument is just about as sensitive as the crystal for cloud detection.

5.6 Plastic phosphor monitor

A standard NIS 295 portable logarithmic scintillation dose rate meter [17] with a miniature pen recorder (figure 18) was carried in the aircraft on some sorties. It gave dose rates direct, could act as a search instrument in the case of main crystal failure and, having a wide dynamic range, could be used to monitor a rich debris cloud even when the search crystal was beyond full scale reading.

5.7 Gamma ray spectrometer

During the latter part of the detachment an additional 2 in. x 1¾ in. diameter sodium iodide crystal detector became available and was carried on a few sorties. Its output was connected to a 400 channel Technical Measurement Corporation transistorised pulse height analyser. The spectral data are recovered after the flight on to an IBM typewriter. This crystal was placed in the main cabin during flights.

6. SAMPLING EQUIPMENT

6.1 Mk. III ducts

The port and starboard underwing fuel tanks hang 28 ft from the fuselage and each have one of these main sampling ducts bolted on the front end.

The ducts (figure 19) consist of a streamlined body with an 8 in. diameter hole at the front which is normally sealed by a synthetic rubber covered metal dome (bung) at the end of a piston actuator (Rotax actuator). The bung can be withdrawn into the duct, thus opening the sampling hole, by operating independent switches for each duct located on the control box (figure 12) in the crew compartment. Withdrawal of the bung exposes 8 filter baskets locked with spring loaded butterfly nuts into an annular plate surrounding the centrally located actuator (figure 20).

6.1.1 Filter baskets (right hand side of figure 21)

The shape of the baskets was worked out by Vokes Ltd to provide a reasonable optimum in terms of air flow, uniform distribution of particles etc [18]. Dimensions are: front opening 6 in. × 3½ in. × 4 in. × 4 in., depth 5 in., exposed paper area 56 in^2.

The main support basket is made of plastic to avoid contaminating the paper. The metal wire inner support is clamped to the plastic basket with Sellotape. Note that part of the collecting filter is covered at the outer end by the edge of the clamping piece.

6.1.2 Filtering medium

[redacted]

Its filtering characteristics are not adequately known in the UK. An early memorandum by Vokes Ltd [18] reports a 20% efficiency on the methylene blue test with air velocity up to 500 ft/s normal to the paper, suggesting that the paper is inefficient for 0.5 micron particles. Data from another source [21] quote a 35% efficiency at very low flow rate (see section 6.2.1). However, a recent US report [19] quotes a 90% efficiency for particles > 0.3 micron at 150 knots at 5000 ft altitude. Presumably by using a wedge shape basket rather than a paper normal to the air flow efficiency is increased, the final report from Vokes Ltd [20] suggesting 80% efficiency for methylene blue. As will be seen adequate collections of very small particles were made from the last two French shots of 1968.

The template used for cutting out [redacted] make up the wedge shaped basket is shown in figure 22. Synthetic flour paste was used for glueing and was shown to contain less than 10^{-9} gm of uranium/gm. Papers were cut, folded, glued and placed in a clean envelope by Paine Engineering in a "clean" room and were then [redacted]

6.1.3 Air flow through the Mk. III ducts

The only available information is contained in the Vokes report [20] and is reproduced as figure 23 after converting pounds of air per second to "standard cubic feet" per second. Since cubic feet (free volume) is equal to the product of standard cubic feet and relative density (σ = density at altitude/density at sea level) we can derive figure 24 relating cubic feet of volume sampled as a function of true air speed (speed relative to the air). Figure 25 relates altitude and pressure. Of course the absolute maximum throughput is open front area x velocity; at about 480 knots this is about 280 ft^3/sec.

Unfortunately the data in figure 24 were not available during the WEB operation; the assumption was therefore made that each Mk. III duct sampled 100 ft^3/sec regardless of true air speed. Since true air speed during sampling is about 480 knots we were in error by a factor of about 1.8.

6.1.4 Criterion for opening Mk. III ducts

The quality of the samples is determined by the fission density of the debris cloud. We assumed, arbitrarily, that for [redacted] sampling period we should open the port duct at such a level that it would collect [redacted] fissions (a "worthwhile" sample known as level A) and the starboard duct at such a level that it would collect [redacted] fissions (an "adequate" sample, level B). These correspond to constant cloud densities of 1.4×10^6 and 1.4×10^7 fission/ft^3 assuming sampling at 100 ft^3/sec. The calculations of crystal response in appendix C shows that at 30000 ft we expect 8.8 counts/sec above background in a field of 2.8×10^4 f/ft^3; hence, in a field of 1.4×10^6 f/ft^3 we expect about 450 counts/sec above background for 50 hour old fission products. Appendix C also shows that the γ flux at the aircraft varies roughly as the inverse of the mean free path which is, in turn, proportional to air density. The γ flux will also decrease with the age of the fission products; decay was allowed for by the decay curves shown in figure 15 without allowing for the small change in γ spectrum with time. In this way we drew up figure 26 showing the count rate at which to open the ducts as a function of decay time and altitude for the two levels cited above. Note that the curves assume a sampling rate of 100 ft^3/sec; we now know that the true value is nearer 180 ft^3/sec. In addition figure 26 is based on estimated crystal response which is known to be in error by about a factor of 7 (see section 10). The upshot is that all count rates should be reduced by a factor of 3.5. Nevertheless, the curves are included since they were actually used as a guide during the project.

6.2 Mk. X duct (left hand side of figure 12 and figure 27)

This duct is attached to the fuselage of the aircraft and is open at all times. The filter is a Mk. IX, esparto grass paper in an open ended cylindrical wire mesh can 5½ in. × 3½ in. diameter, paper area 60 in^2. The paper is washed with a solution of EDTA (ethylene diamine tetra-acetic acid) to complex and thus remove inorganic material, thus reducing, amongst other things, the uranium content. Response of the MX-172 Geiger tube located in the centre of the filter is shown in figure 16.

6.2.1 Properties of filtering medium

The only data available are reproduced below [21]:-

Paper	Face Velocity, ft/min	Pressure Drop, in. Water	Methylene Blue Penetration, %
[redacted]	16	-	35
	80	0.22	-
	160	0.58	-
Esparto grass	60	0.4	12 - 16
(EDTA washed)	120	1.0	10 - 20

At these very low flow rates the esparto paper is more retentive but develops a higher pressure drop. A comparative test [21] showed that for background contamination the ratio of activity collected by equal areas [redacted].

6.2.2 Air throughput

There is no specific information. We know that on one aircraft in Grapple-Y the ratio of activity collected on the 8 Mk. III papers to that in the Mk. X was 26 [22]. If the ratio of comparative collection is 1.2, the air throughput of the Mk. X must be 1.2/26 = 0.046 times that of the Mk. III. Strictly one should argue that it is less than this because the Mk. X was open at all times; however, the bulk of the collection must have been made when the Mk. III was open. Another value can be obtained from the area open to the air and the pressure drop, thus,

$$\frac{\text{Mk. III throughput}}{\text{Mk. X throughput}} = \frac{\text{(area) III} \times \text{(pressure drop)X}}{\text{(area)X} \times \text{(pressure drop)III}} = \frac{\pi \times 16 \times 2}{\pi \times 1.6}$$

since the pressure drop across EDTA paper is twice that of [redacted]. We thus conclude that the Mk. X throughput is about 1/20 of that of the Mk. III at 480 knots; the throughput is therefore about 9 ft^3/sec.

6.2.3 Use of Mk. X duct

It can serve two purposes:-

(1) by noting the rate of increase of the count rate from the Geiger one can estimate the strength of fission density and hence

use it as a cloud detector. However, it has been shown in section 5.5 that it is only as sensitive as the search crystal after a 2 minute (20 mile) collecting period;

(2) by noting the count rate from the Geiger one obtains an estimate of the total particulate collected since it is an integrating device. This is useful:-

(a) to tell the crew when sufficient debris has been collected. The aircraft can return to base and thus avoid too much contamination;

(b) to tell whether particulate is being picked up even when the search crystal is giving a high reading, eg, when the cloud is above the ceiling of the aircraft.

7. ESTIMATION OF CLOUD POSITION

7.1 Area of interest

The range of the aircraft is such that, coupl[redacted]y clo[redacted]search and sampling area must be withi[redacted] and [redacted](one degree is about 60 nautical miles). Debris at various heights only enters this vast area some 2 to 10 days after the detonation. Since it is impossible to patrol the whole of this area it is vital to have at least some idea of the cloud location at any particular time. This can only be arrived at from a knowledge of the upper winds.

7.2 Meteorology

The only data available to the detachment were [1] (figure 41):-

(1) [redacted] meteorological data for [redacted] there were no observations over the Pacific.

(2) [redacted] Similar data for the [redacted]uring the latter half of the operation.

Although rough estimates of the height of the tropopause and other temperature inversion stable layers at the test site and in the search area were inferred, the paucity of upper air wind information prevented any adequate assessment of the cloud trajectory.

7.3 [redacted]

[redacted]

[redacted]

[redacted]

Pressure Height	300 mb 30000 ft	250 mb 35000 ft	200 mb 39000 ft	150 mb 45000 ft	100 mb 53000 ft
[redacted]	2.8 / [redacted]	2.2 / [redacted]	2.1 / [redacted]	2.3 / [redacted]	3.3 / [redacted]
[redacted]	4.2 / [redacted]	3.2 / [redacted]	3.2 / [redacted]	3.2 / [redacted]	4.2 / [redacted]
[redacted]	-	-	-	-	6.8 / [redacted]
[redacted]	3.3 / [redacted]	2.7 / [redacted]	2.9 / [redacted]	5.3 / [redacted]	10.3 / [redacted]
[redacted]	4.1 / [redacted]	3.1 / [redacted]	3.4 / [redacted]	3.6 / [redacted]	6.6 / [redacted]

7.4 Prognostication errors

Latitude and longitude in [redacted] are to the nearest whole degree (60 nautical miles); the error in the horizontal plane may be as large as 42 miles (= $30\sqrt{2}$) from this cause alone. Clearly prognostications from meteorological data have a greater error than this but no order of magnitude was available before WEB. Estimates of errors derived during the operation are considered in the next section; an overall analysis in some depth is given in section 13.

[redacted]

8. THEORETICAL ASPECTS OF CLOUD SEARCH

Before considering the actual sorties we outline some theoretical aspects concerning the best use of the detachment capabilities. All decisions on sortie flights [redacted] such decisions must be based on aircraft, crew and equipment performance related to the sample requirements and prognostications as to the position of possible debris. The following concepts evolved during the detachment.

8.1 Search altitude

The yield of each shot was signalled to the detachment within 12 hours of the detonation; hence, from figures 3 to 5, together with height data from the ship operation, one obtains a good idea of the altitudes of interest. However, since the aircraft ceiling is 52000 ft and, as it happened, the lowest yield of the significant shots was [redacted], our interest was always centred on the prognostications for 30000, 34000, 39000, 45000 and 53000 ft.

It is obvious from figure 10 that if there is interest in the 53000 ft altitude then the search should take place at about 48000 ft since the search crystal can detect activity above the aircraft. This procedure conserves fuel and offers a longer search pattern.

8.2 Search pattern

The probability of detecting and sampling debris increases with increased time of searching in the vicinity of the expected location of the cloud. Hence, it is best to sample [redacted] (figure 10). Two factors oppose the application of this simple principle:

(1) by waiting until the debris [redacted] one loses time; samples can be obtained earlier, and thus provide stronger signals from short lived species, if the search area is chosen well [redacted]

(2) by waiting until the 39000 ft air mass [redacted] one runs the risk that, by the time sorties have been mounted at this level and 34000 ft, the other levels have passed over [redacted] since the different levels are often not far removed from each other in time.

This explains why some sorties were carried out at a [redacted]

Since the cloud is longer that it is broad the obvious search pattern is a series of W legs flown across the cloud. At first there was little idea as to how long the legs should be and how far apart the peaks of the W should be. A crude analysis of the prognostications of the first two shots suggested that the error across the wind vector was about 100 miles north (or above), and 200 miles south (or below), the wind vector whilst along the vector the standard error was about ± 200 miles. The asymmetric error

[redacted]

[redacted]

across the wind vector was felt to be due to the fact that the progs. seemed to turn the wind too soon towards the north east at [redacted] The distance between the W peaks is related to the cloud size; in fact we set this peak to peak distance arbitrarily at 80 miles less than the cloud size for 10^7 f/ft^3 (see figure 6). Figure 33 illustrates the build up of a search pattern as follows:-

(1) Consider P as the best estimated prog. point from the SUPA data (this point is alleged to be the furthest downwind that the required air mass could have moved, ie, the leading edge of the cloud);

(2) lay off 200 miles downwind to allow for error along the wind vector, to give point L;

(3) translate point L a distance upwind equal to the cloud size less 80 miles to give point A on the wind vector. In figure 33 we have assumed the cloud size as 400 miles, ie, 120 hours after a 1 Mton shot;

(4) set point B 200 miles below the wind vector on a perpendicular from A;

(5) the searching aircraft then aims for point B straight from base. It assumes the search height when 100 miles above the wind vector line at point O. If the angle OBA is very far off 45° then the aircraft would turn at point O so that OBA is 45°.

A further modification was made to the location as follows. According to the prog. the wind had a velocity V knots; when the aircraft reaches point O it can determine the actual wind velocity, U knots. We now assume that the wind velocity U rather than V has been in existence for, arbitrarily, 4 hours; the crew therefore adjust the line AB upwind by $4(V - U)$, ie, a downwind translation if $V < U$. No account is taken of wind direction since the 200 mile - 100 mile split across the wind vector is meant to allow for this.

The description is idealised in that figure 33 applies to still air. The aircrew navigator makes all necessary allowances for air movement. This particular pattern involves 1400 miles of search and covers about 300 miles distance across the wind and some 500 miles along the wind. At large distances from base it becomes impossible to perform a W pattern and the search may degenerate to a U pattern. As far as possible the 300 miles across wind was maintained to allow for errors in the position of the trough in the range [redacted]

There seems no *a priori* reason why the search pattern should progress upwind; indeed, if the search is to take place at a high altitude which demands the dumping of fuel it is best to travel westwards, dump fuel, rise to search height and search in a downwind direction.

[redacted]

8.3 Sortie programme

Whenever possible two sorties were mounted at 45000 ft and below, the take offs being about 4 hours apart. If the first aircraft made contact the second could move in to obtain a better sample (or simply to sample if the first only made contact at the end of its search). If the first aircraft failed to make contact the second continued the search pattern, thus extending the overall search area.

The above programme was not attempted if the cloud velocities at different altitudes were not sufficiently different. An alternative, made possible by the presence of 3 aircrews, was used, particularly for high altitude sampling. Instead of the second aircraft taking off 4 hours after the first it simply came to combat readiness at this time with a crew in the crew room. This gave about a 4 hour period during which its commitment, if at all, could be influenced by signals from the first aircraft or by any other information, eg, a [redacted] If a second sorties was not flown the standby crew were stood down and the third crew used for a later mission.

8.4 Survey pattern (figure 34)

If the aircraft detects a significant activity above background (A) it continues on its cross wind leg noting the rise and fall of activity between A and B. When the readings return to background the aircraft does a procedure turn at C and retraces its path (allowing for wind) to the centre of the cloud at D. The aircraft now turns either upwind or downwind; the decision rests with the aircraft captain; probably he should decide to go upwind because if he is wrong he must turn about and would then be going more or less toward base. However, figure 34 illustrates the decision to turn downwind. On reaching E the meter readings will probably be a good deal less than at D and it is evident to the crew that they are not heading toward the centre of the cloud. A procedure turn at E then lets them steam to the centre of the cloud at F, opening the collecting ducts at appropriate meter readings.

During the course of these manoeuvres the radar navigator would have been noting the readings of the directional meter when held in the up and down position, particularly over the region AB. Any significant difference between the readings in the two positions tells the captain whether to climb or lose height for optimum sampling.

This pattern was only evolved after the first two shots. Attempts to use it were made but, because of difficulties associated with increased "background" readings as the aircraft became contaminated, led to a somewhat confused picture which suggested that clouds do not conform very well to an ideal Gaussian distribution.

9. SAMPLING SORTIES

9.1 General

Table 9.1 lists all flights mounted with the intention of bringing back a sample together with sampling details. Training flights are not listed. Background sorties were mounted arbitrarily and the remarks below do not apply to such flights.

When flying against debris clouds it is necessary to plan ahead. From two days before the time of detonation [redacted] is plotted (on pro formas of the type illustrated in figures 28 - 32) and studied; out of each study an "earliest first take-off time" is estimated. This first take-off time may vary considerably with each [redacted] but tends to firm-up as take-off time approaches. The decision to fly must be taken at least 12 hours before take-off so that all necessary arrangements can be made, eg, aircraft fuelling, crew rest, crew meals, installation of new filters.

Whenever possible aircraft were planned to become airborne shortly after receipt of a [redacted]. This was fairly easily arranged since the messages usually arrived at about [redacted] and [redacted] local time. In this way the sortie was using the latest data available and, simultaneously, for [redacted] there was a good chance that the aircraft could return in time to catch the [redacted] service [redacted] London.

9.2 Briefing

During briefing the following specifications of information were given:-

(1) Prognostication details, search pattern and estimated size of cloud. The navigators then worked out their flight plan in conjunction with the captain, bearing in mind the fuel on board. All wind vector allowances were made by the navigators.

(2) Meteorological data for take-off and any additional information concerning the search area.

(3) Flight level.

(4) Duct opening levels, in counts/sec above background.

(5) A level on the filter monitor (Mk. X duct) at which the aircraft was to break off sampling and return to base.

(6) Instructions as to when to switch on the pulse height analyser (PHA) spectrometer (if carried).

A standard operating procedure was laid down during the early part of the project but, as developments occurred rapidly, it soon became out of date.

9.3 Individual sorties

Table 9.2 to 9.6 give an edited version of the air electronics officers recorded data in the format of the pro forma used. Detailed information, including navigational plots and strip chart recorder records are available. All altitudes recorded are true heights measured by radar (not pressure heights).

9.3.1 [redacted] (figure 28, table 9.2)

The cloud was expected to extend from 30 to 50 thousand feet. It travelled eastwards very rapidly. No contact was made on the first sortie; the later [redacted] at the 39000 ft flight level indicated that the cloud was slightly west of the search area. The second sortie made contact; the instrument records (table 9.2) show that the Up/Down meter indicated that the aircraft should lose height; having done so there was an immediate high response from the search crystal and Mk. X filter and a good collection was made. Unfortunately such a large collection only 38 hours after burst gave rise to considerable aircraft contamination and sent the instruments off scale, thus preventing any assessment of cloud size. In addition, the Geiger in the Mk. X duct was paralysed as shown by the fall-off of count rate. The [redacted] at 30, 35 and 39000 ft proving the presence of debris in the expected altitude range.

9.3.2 [redacted] (figure 29, table 9.3)

The first two sorties were flown against the meteorological prognostication for 39000 ft. No contact was made. The strike prog., which arrived somewhat late for forward planning of further flights, showed that the original meteorological prog. brought the cloud over too fast. Following a signal from AWRE to sample as high as possible no more sorties were mounted at this level. Missions against the 45000 ft prog. were made a few days later. As table 9.3 shows the Up/Down monitor indicated debris above the aircraft. However, despite flying at absolute aircraft ceiling (51000 to 52000 ft), the Mk. X filter monitor showed little increase even though the search monitor [redacted] strong signal. Very little activity was, in fact, [redacted] and one must conclude that the debris was probably above the tropopause (56000 ft). In view of the limited ability of the search crystal to "see" at a distance (section 5.3) the debris cloud must have been very dense and the prognostication (and "actual") at 53000 ft must have been moving the cloud too slowly. Any debris which was at 45000 ft was probably east of the search area. A fourth sortie in the same area virtually repeated the measurements but collected very little sample.

9.3.3 [redacted] (figure 30, table 9.4)

As figure 30 shows, the meteorological conditions offered no choice of sampling height to Victor aircraft. The debris moved much further south than usual. A reasonable sample was collected on the first sortie at 48000 ft; in order to do so we made the guess that, since the aircraft could not reach 53000 ft, if there were any debris at a slightly lower altitude it would move somewhat more slowly than at 53000 ft. A second sortie aimed for the same patch of cloud with the intention of improving the collection; it did so but the aircraft had fuel trouble [redacted] On landing the undercarriage was damaged and the sample could not be recovered for three or four days. The information from the ship that the cloud top was at 40000 ft is surprising in view of the expected cloud height and that successful collections were made at 48000 ft.

9.3.4 [redacted] (figure 31, table 9.5)

The first sortie was meant to be flown at 250 mb but was actually flown at 150 mb in error. Seven more sorties were flown in rapid succession giving a total flying rate of 1 hour airborne for every real hour; none of them were successful, instrument readings barely moving above background level. The fact that both aircraft were contaminated from previous sorties was detrimental to the searches which were carried out over the prognostication regions. Despite [redacted] 39000 ft one would not expect very much of the debris to be present below 50000 ft in view of the high yield; it could be, therefore, that in setting the distance between the peaks of the W of the search pattern at 150 - 200 miles we were over-estimating the size of the detectable cloud. In addition we were flying slightly south of the prognostication line (as suggested by analysis of earlier progs. and the cloud could have been lost between the search legs. Clearly sorties [redacted] were too [redacted] to allow much search time. Some days later (after the exhausted aircrews had recovered) the ninth and tenth sorties successfully sampled at 50000 ft against the 53000 prog., although by this time the debris was 10 days old.

9.3.5 [redacted] (figure 32, table 9.6)

The first sortie at 39000 ft was far too early. The second sortie made a good collection, the Up/Down meter guiding the crew to the optimum sampling height of 36000 ft.

9.4 [redacted]

[redacted]

[redacted]

[redacted]

TABLE 9.1 (Cont.)

[redacted]

TABLE 9.2

[redacted] Sortie II (Edited Data)

Location	Crew	Flight Info.	Survey Equipment
Station [redacted] A/C Victor XL 161 Flt. No. [redacted]	[redacted]	Date 9th July 1968 Take off [redacted] Touch down 15.35Z	NIS 361 NIS 322 (Up/Down)

Time Z	Height, kft	Track, Degrees	[redacted]	Airspeed, knots		Outside Temp.	NIS 361		NIS 322		[redacted]
				Ind.	True		Search, c/s	Filter, c/s	Up c/s	Down, c/s	
09.40	41	[redacted]	[redacted]	258	485	- 63	170	25	90	105	[redacted]
10.55	41			259	483	- 63	190	24	90	105	
11.40	41			256	477	- 65	180	22	85	100	
11.48	41			-	-	-	600	32	180	210	
11.54	41			-	-	-	900	45	300	380	
11.56	41			-	-	-	1050	50	400	600	
11.59	40.5			-	-	-	1500	55	200	800	
12.00	40			-	-	-	3000	130	OFF SCALE		
12.08	40			-	-	-	OFF	145	OFF SCALE		
12.15	40			-	-	-	2500	900	OFF SCALE		
12.20	40			-	-	-	OFF	2500	OFF SCALE		
12.32	40			-	-	-	3000	2200	OFF SCALE		
12.48	40			-	-	-	OFF	1500	OFF SCALE		
12.55	40			-	-	-	OFF	200	OFF SCALE		
13.30	40			260	477	- 66	OFF	45	OFF SCALE		
15.05	20						OFF	55	OFF SCALE		

[redacted]

TABLE 9.3

[redacted] Sortie III (Edited Data)

Location	Crew	Flight Info.	Survey Equipment
Station [redacted] A/C Victor XL 230 Flt. No. [redacted] [redacted]	[redacted] [redacted]	Date 18th July 1968 Take off [redacted] Touch down	NIS 361 NIS 322 (Up/Down) NIS 295

Time Z	Height, kft	Track, Degrees	[redacted]	Airspeed, knots		NIS 361		NIS 322		NIS 295, mR/h	[redacted]
				Ind.	True	Search, c/s	Filter, c/s	Up, c/s	Down, c/s		
06.45	43	[redacted]	[redacted]	234	470	220	35	38	40	0.06	[redacted]
07.00	48	[redacted]	[redacted]	216	480	450	40	100	75	0.075	[redacted]
07.05	48.3	[redacted]	[redacted]	-	-	3000	90	1000	400		[redacted]
07.10	-	[redacted]	[redacted]	-	-	650	40	-	-	-	[redacted]
07.28	50	[redacted]	[redacted]	210	485	350	38	60	60	0.08	[redacted]
07.33	50	[redacted]	[redacted]			2500	70	-	-	-	[redacted]
07.40	50	[redacted]	[redacted]			3000	110	-	-	-	[redacted]
07.45	51.5	[redacted]	[redacted]	208	480	700	45	130	110	0.09	[redacted]
07.55	51.5	[redacted]	[redacted]	206	480	3000	120	-	-	0.36	[redacted]
08.05	51.5	[redacted]	[redacted]	206	480	2000	60	-	-	0.15	[redacted]
08.11	51.5	[redacted]	[redacted]			3000	120	1000	500	0.60	[redacted]
08.14	50	[redacted]	[redacted]			800	45	700	300	0.1	[redacted]
08.21	47	[redacted]	[redacted]	226	475	250	38	-	-	0.06	[redacted]
09.00	45	[redacted]	[redacted]	248	485	210	35	-	-	0.06	[redacted]

[redacted] 9.8

[redacted]

TABLE 9.4

[redacted] Sortie I (Edited Data)

Location	Crew	Flight Info.	Survey Equipment
Station [redacted] A/C Victor XL 193 Flt. No. [redacted]	[redacted]	Date 10th August 1968 Take off [redacted] Touch down 05.15Z (Aug 11) Tropopause 53000 ft	NIS 361, NIS 295 NIS 322 (Up/Down) Pulse height analyser 173 min On 23.33Z Off 02.26Z

Time Z	Height, kft	Track, Degrees	[redacted]	Air Speed, knots		NIS 361		NIS 322		NIS 295 mR/h	[redacted]
				Ind.	True	Search, c/s	Filter, c/s	Up, c/s	Down, c/s		
03.10	45	[redacted]	[redacted]	228	470	210	60	41	46	0.07	[redacted]
23.30	47.4	[redacted]	[redacted]	-	-	350	300	-	-	0.07	[redacted]
23.40	47.5	[redacted]	[redacted]	-	-	350	500	60	70	0.08	[redacted]
23.45	47.4	[redacted]	[redacted]	-	-	420.	800	78	78	0.09	[redacted]
00.01	47.6	[redacted]	[redacted]	-	-	420	1600	75	75	0.09	[redacted]
00.15	47.6	[redacted]	[redacted]	-	-	390	1800	70	70	0.08	[redacted]
00.24	48.0	[redacted]	[redacted]	-	-	500	1900	85	85	0.09	[redacted]
00.53	47.0	[redacted]	[redacted]	-	-	400	2200	70	70	0.09	[redacted]
01.00	47.5	[redacted]	[redacted]	-	-	500	2300	70	72	0.09	[redacted]
01.05	47.5	[redacted]	[redacted]	-	-	500	2300	75	75	0.09	[redacted]
01.28	47.4	[redacted]	[redacted]	-	-	2000	2500	500	250	0.20	[redacted]
01.33	-	[redacted]	[redacted]	-	-	900	3000	-	-	0.20	[redacted]
01.39	48.3	[redacted]	[redacted]	-	-	3000	3000	1000	900	0.30	[redacted]
01.45	48.0	[redacted]	[redacted]	-	-	900	3000	-	-	0.15	[redacted]
02.21	45	[redacted]	[redacted]	235	482	800	3000	110	130	0.125	[redacted]
04.00	45	[redacted]	[redacted]	238	482	800	3000	-	-	0.125	[redacted]

TABLE 9.5

[redacted] Sortie IX (Edited Data)

Location	Crew	Flight Info.	Survey Equipment
Station [redacted] A/C Victor XL 193 Flt. No. [redacted]	[redacted]	Date 2nd September 1968 Take off [redacted] Touch down 02.00Z (Sept 3)	NIS 361, NIS 295 NIS 322 (Up/Down) Pulse height analyser 148 min. On 22.24Z Off 00.52Z

Time Z	Height, kft	Track, Degrees	[redacted]	Air Speed, knots		NIS 361		NIS 322		NIS 295 mR/h	[redacted]
				Ind.	True	Search, c/s	Filter, c/s	Up, c/s	Down, c/s		
20.45	46.4	[redacted]	[redacted]	221	461	320	60	48	55	0.08	[redacted]
21.05	49			-	-	500	115	80	80	0.09	
21.35	49.2			211	468	450	380	85	85	0.12	
21.45	49.2			214	468	430	390	75	75	0.1	
22.00	49.3			218	468	580	500	100	100	0.12	
22.30	50.0			213	468	560	700	85	100	0.12	
22.45	50.0			211	468	650	700	110	110	0.125	
23.00	50.8			210	467	650	750	110	110	0.13	
23.18	49.0			212	465	925	800	160	160	0.17	
23.25	49.0			220	470	750	820	140	140	0.14	
23.45	50.0			214	468	900	830	160	160	0.175	
23.50	50.0			-	-	850	850	150	140	0.17	
00.01	49.0			216	470	1000	860	170	170	0.18	
00.15	49.0			-	-	1200	870	180	180	0.20	
00.30	49.0			219	470	1200	900	180	180	0.20	
00.45	49.0			-	-	950	900	140	140	0.20	
01.00	49.0			218	460	850	900	130	140	0.19	
01.30	45.5			231	470	850	900	120	130	0.19	

[redacted]

TABLE 9.6

[redacted] Sortie II (Edited Data)

Location	Crew	Flight Info.	Survey equipment
Station [redacted] A/C Victor XL 161 Flt. No. [redacted]	[redacted]	Date 11th September 1968 Take off [redacted] Touch down 11.35Z	NIS 361 NIS 322 (Up/Down) NIS 295

Time Z	Height, kft	Track, Degrees	[redacted]	Air Speed, knots Ind.	Air Speed, knots True	NIS 361 Search, c/s	NIS 361 Filter, c/s	NIS 322 Up, c/s	NIS 322 Down, c/s	NIS 295 mR/h	[redacted]
06.00	37	[redacted]		280	488	450	115	115	150	0.15	
07.00	37			259	456	450	120	115	145	0.15	
07.10	37			-	-	600	200	200	220	0.2	
07.20	37			-	-	620	1800	200	230	0.175	
07.30	37			252	454	750	> 3000	230	250	0.2	
07.35	35.5			-	-	850	OFF	350	350	0.23	
07.45	36			256	456	800	OFF	290	290	0.18	
07.50	36			-	-	850	OFF	340	340	0.22	
08.00	36			250	456	1000	OFF	400	400	0.24	
08.15	37.5			260	460	1400	OFF	600	600	0.30	
08.30	37.5			260	460	1400	OFF	600	600	0.30	
08.40	-			-	-	800	OFF	300	300	0.22	
09.05	38			260	460	460	OFF	200	200	0.25	
09.15	38			288	495	495	OFF	200	200	0.23	
09.45	38			288	493	750	OFF	200	250	0.23	
10.30	38			288	493	750	OFF	190	240	0.23	

[redacted]

[redacted]

10. ANALYSIS OF DATA FROM SORTIES

10.1 Instrument response

10.1.1 Background readings

Apart from NIS-295 response, the following data were obtained from the early background flights. Data for the 295 are interpolated by later comparative data between it and the search crystal.

Altitude, kft	NIS-361			Directional Meter		NIS-295, mR/h
	Search, c/s	Filter		Up, c/s	Down, c/s	
		A/C 161, c/s	A/C 193 and 230, c/s			
0	40					
15	75	11	30	40	30	0.011
20	90	13	35	50	40	0.015
25	115	15	40	72	60	0.019
30	150	17	45	100	80	0.024
35	170	20	50	125	105	0.027
40	190	23	53	142	125	0.031
45	205	25	55	155	140	0.033

Note that the filter readings (ie, for the Geiger in the Mk. X duct) are higher for the duct fitted on aircraft XL 193 and XL 230; this is caused by fixed contamination from earlier use.

10.1.2 Search crystal response

On plotting all search crystal readings against either the directional meter or the NIS-295 response one obtains a series of points which define, rather poorly, two straight lines, whose slopes differ by a factor of 2. Investigation reveals that the two lines correspond to points from different aircraft - one line for XL 161 and the other for XL 193 and XL 230 (the equipment being changed from 230 to 193 when they were rotated in July). Further probing into the matter uncovered the fact that, following the heavy contamination of XL 161 on [redacted] a 2½ in. diameter by ⅛ in. thick disc of lead had been fixed to the narrow conical end of the search crystal casing (right hand side, figure 12) on this aircraft. By so doing not only was the "contaminated" response reduced but the reading from any debris cloud was halved. Thus the square of the cloud signal divided by background was reduced, thus rendering the instrument less sensitive for search purposes.

[redacted]

The length of the instrument was horizontal and at right angles to the fuselage. It is therefore significant that a lead disc, which geometrically, attenuated gamma rays from only one sixth of the 4π solid angle, should cut the total response by 50%; it gives clear evidence that surrounding structures were absorbing γ rays. This point is confirmed below.

10.1.3 Search crystal calibration

For any successful sortie we have a measure of the number of fissions collected in each duct and know the time for which it was open. Knowing the Mk. III duct collection rate to be 180 ft^3/sec, we can calculate a mean value of fissions per cubic foot, $\bar{f}$, during the collection. Also, from the search crystal readings during the collecting period, we can calculate a mean search crystal count rate, $\bar{c}$. If we put

$$\bar{f} = G\bar{c},$$

then G represents a calibration of the search crystal response in terms of fissions per cubic foot. To correct the raw results to our calculated value at 30000 ft. for fission products 2.13 days old (appendix C) we (a) allow for decay (figure 15), (b) allow for altitude (signal increases as the inverse of pressure) and (c) allow for the fact that the search crystal in XL 161 only read half of what it should have read. The data are summarised below, results for the port and starboard ducts being averaged for each sortie.

Sortie	Age of Debris, h	Altitude, kft	G Raw $\times 10^{-4}$	G Corrected for Age $\times 10^{-4}$	G Corrected for Age and Alt. $\times 10^{-4}$	G All Corrections $\times 10^{-4}$
[redacted]	172	48	5	1.1	2.5	2.5
	176	48	5.6	1.2	2.8	1.4
	220	49	7	1.2	2.8	2.8
	224	48	10	1.6	3.7	1.8
	62	37	6	4.6	6.1	3.0

As might be expected the corrected values of G do not agree very well; the measure of total fissions in each duct is only good to 30%, the integration of the search crystal readings with time is difficult because of aircraft contamination and the correction for altitude is crude. However, the mean result, $G = 2.3 \pm 0.4 \times 10^4$ fissions $(ft^3)^{-1}$ counts/sec is the only experimental calibration of the crystals.

The calculated calibration estimated that in a field of 2.8×10^4 f/ft^3 the crystal should indicate 8.8 counts/sec. From G the corresponding practical result is 2.8/2.3 = 1.2 counts/sec. Our calculation therefore overestimated the response by a factor of 7. This is, in fact, not surprising. The calculation assumed 4π geometry for a free crystal "hanging in space"; when the estimate was made nothing was known about the instrument case or its location in the aircraft. However, the crystal was incorporated into the NIS 322 housing (figure 12), which may well have reduced the response by almost a factor of 2. The instrument was located in the 2 ft space between the rear instrument panel and the pressure bulkhead, and signals from beneath the aircraft are attenuated by the flooring and equipment below the floor. Bearing in mind the shielding by airframe struts as well, it is not surprising that the signal was only one seventh of that likely for a free crystal in space. It should be possible to place the crystal in a better position in the aircraft, eg, at rear or front ends.

10.2 Results from pulse height analyser

Figure 35 shows the γ ray spectrum at 39000 ft using a crystal identical to the NIS 322 crystal (2 in. long by 1¾ in. diameter) obtained on flight 14 (BKG 08) over 120 minutes. It shows the typical 0.51 MeV peak (presumably due to annihilation radiation) and a major "peak" at about 0.13 MeV. This latter is clearly related to a cut-off of low energy γ rays by the aircraft structure. The minor inflexion at channel 88 may be ascribed to fission products since the flight took place after debris from the first two shots had had time to circumscribe the globe. Nevertheless, fission product "contamination" is not an important part of the spectrum. Summation into the "box" widths used in the theoretical calculations shows that this spectrum is "softer" than that depicted in figure 13. This may at least be partly ascribed to the different altitudes (39000 and 47000 ft).

The spectrum from flight 26 [redacted] during sample collection on [redacted] at 49000 ft, Table 9.5) is shown in figure 36. As expected distinct peaks ascribable to fission products are present. (Note that the data from the first 10 channels is faulty). Unfortunately perhaps as much as 35% of the activity recorded may be due to fission products fixed to the aircraft since even after leaving the search area the crystal detector showed a high reading. This spectrum is therefore "harder" than the signal from the debris cloud, ie, contains relatively more high energy pulses; it is therefore not possible to make a detailed analysis of a spectrum from the cloud. Again the low energy "peak" at 0.13 MeV must be caused by aircraft structure absorption. Since a good deal of signal occurs below the lower limit of 0.14 MeV set on the search instrument it is reasonable to lower the limit to 0.05 Mev and thus increase the total signal and the signal to background ratio.

The background at 49000 ft is bound to be greater than at 39000 ft by about 1.5; this can be proved by noting that the γ ray signal above 2.0 MeV on figure 36 (fission products do not emit γ rays above 2.0 MeV) is 1.5 times greater than on figure 35. Assuming this ratio still applies at 0.51 MeV it is readily shown that the peak at 0.51 MeV in the cloud spectrum is almost entirely due to background. Hence by setting the search crystal upper limit at 0.47 MeV rather than 0.80 MeV we avoid this significant background contribution without seriously detracting from total signal.

The net effect of changing the search crystal channel from 0.14 - 0.80 MeV to 0.05 - 0.47 MeV is:-

(i) to increase the cloud signal by 15%;

(ii) to increase the signal to background ratio;

(iii) to lessen the sensitivity of the crystal to fixed contamination.

10.3 Cloud size

In principle, having taken readings of instruments during a sampling sortie, it ought to be possible to assess the length and breadth of the cloud. Unfortunately the gyrations of the aircraft in seeking "hot" parts of the cloud coupled with the increased readings due to contamination make any estimation difficult. Further, the readings are not highly consistent in the sense of gradually moving up or down; occasionally very high readings over a few minutes are obtained suggesting, as might be expected, that the clouds are patchy. In the table below we quote very rough dimensions corresponding approximately to readings of 200 counts/sec, above background. Estimated values, using shot and sampling data coupled with the cloud sizes in figure 6, are also quoted. The estimated f/ft^3 is based on actual crystal response, ie, one seventh of calculated.

Sortie	Time after Burst, h	Altitude, kft	Estimated f/ft^3 to Give 200 c/s	Length, n miles		Width, n miles	
				Estimated	Found	Estimated	Found
[redacted]	84	50	3.5×10^6	330	> 140	90	-
	172	48	8×10^6	400	-	110	80
	176	48	8×10^6	400	-	110	140
	220	48	1.4×10^7	460	-	120	120
	62	37	3.5×10^6	300	> 200	75	60

Although the experimental results are poor there is general agreement with estimated values, thus justifying the continued use, in the absence of other information, of figure 6.

11. SAMPLE HANDLING AND EVALUATION

11.1 Sample removal

On landing the aircraft was monitored to check for active contamination; provided levels were not excessive the duct bungs were withdrawn and sample removal began. The operator, wearing denim overalls (with film badge and quartz fibre dosimeter) used lead lined gloves to remove the baskets from the ducts and place them into a polythene lined box in the boot of a waiting car. The car was driven to the ground equipment area (some 20 yd from the aircraft) and, wearing surgical rubber gloves, the operator removed the samples from the filter baskets and placed them into individual pre-labelled polythene bags. All handling was carried out rapidly to avoid too high a radiation dose. From this stage onward the samples were always left and transported in "C" pots. These pots contained a rectangular cavity $4\frac{1}{2}$ in. x $4\frac{1}{2}$ in. x 6 in. tall formed by $\frac{3}{4}$ in. thick lead plates; the outer casing of 1/16 in. steel surrounded a $1\frac{3}{4}$ in. layer of teak round the lead. The pot was about 11 in. x 11 in. x 16 in. overall, weighed about 120 lb and constituted a "Class A" container for radioactive material. As many as 24 filters can be packed into one pot.

Before packing the filters their radiation level was measured using the NIS-295 monitor. The number of fissions was estimated from figure 15 using the inverse square law for distances other than one foot.

11.2 Sample despatch

Filters for the UK are sent in the "C" pots, sealed with two external padlocks. Whenever possible they were sent [redacted] indeed this direct route was so convenient that the return of sorties were either planned or even cut short in order to use it. The alternative was to [redacted] The procedure was:-

(i) Signal or telephone the UK to inform them of the sample arrival. A special code was used initially but since even the code had to be classified (and hence the signal cyphered) the code was eventually more or less abandoned.

(ii) Prepare the consignment in accordance with IATA regulations [24] and ensure that:-

(a) a radioactive "yellow" label 7B, indicating contents, activity of contents and external radiation level was attached to the pot together with a "red" radioactive label completed as described;

(b) no reading at any point on the external surface exceeded 10 mR/h;

(c) [redacted] are completed together with a "shippers certificate for radioactive materials", [redacted] For despatch of such samples the material is mixed fission products, group II, category II, Type A package.

Samples were always couriered [redacted] The instructions and arrangements are given in appendix E. In future it should be possible to [redacted]

[redacted]

11.3 Ground filter samples

A small ground filter unit was set up [redacted] to measure the activity of airborne radioactivity. Details and results are given in appendix F. [redacted]

11.4 [redacted]

[redacted]

11.5 Sample evaluation in the UK

[redacted]

[redacted]

[redacted]

12. [redacted]

[redacted]

[redacted]

[redacted]

12.1 Equipment

12.1.1 Monitors

The following monitoring equipment was supplied by AWRE:-

(a) 1320

Three 1320 D β/γ monitors for measuring levels of contamination on the aircraft, general survey work, and personal monitoring. One 1320X was supplied by the RAF but was not used.

(b) 295

Three 295 A β/γ dose rate monitors to monitor aircraft contamination, aircrew dosage, optimise cloud sampling, and establish sample size collected. A 295B was used in the laboratory for checking dose rate levels.

(c) 0030

An 0030 EMI dose rate monitor was supplied but not used.

12.1.2 Personal Dosimeters

The following personal dosimeters were supplied by AWRE:-

(a) Film badges and TLDs

Two hundred film badges, each with a thermoluminescent sachet attached.

(b) Quartz fibre dosimeters

Quartz fibre dosimeters were supplied in the following ranges:-

(i) 0 - 5 R, quantity 20.

(ii) 0 - 500 mR, quantity 18.

(iii) 0 - 200 mR, quantity 4.

Three charging units were taken.

12.1.3 Cabin air sampler

A dust sampler type L10B was used to monitor the air in the crew cabin of the Victor aircraft during sampling operations.

12.1.4 Additional equipment

Other equipment supplied by AWRE included combination suits, cotton and rubber surgical gloves, overshoes, polythene bags of various sizes, Kleenex tissues, paper hand towels and several 40 gallon steel storage drums.

12.2 Aircraft monitoring

After an operational flight the contamination level was established as rapidly as possible so that the aircraft could be cleared for servicing and hence for subsequent flights.

The monitoring proforma was developed, after some trial and error, into the format shown in table 12.1. On it was listed a selection of "high spots" (oily greasy areas, natural dirt traps etc) which would readily show any appreciable pick-up when monitored (numbered 1 to 18). To assist in assessing the overall condition of the aircraft, some normally "clean" flat areas were also selected (letters A to H). All points selected were within reach from the ground (figure 37). Monitoring was carried out in a logical sequence from front to back by two, two-man teams. One man operated the 1320D monitor (and the NIS 295 if required) while the other recorded the data; the two half completed proformas were consolidated later. When the teams were proficient it took about 10 minutes to complete the survey.

[redacted]

TABLE 12.1

Aircraft Radiation Survey

	Monitor	Serial No.	Operators
A/C Type Victor A/C No. XL 161 Flt. No. 001 (OP) Date 10/7/68 (10.00 hours)	1320D	41	[redacted]

This survey has been carried out in accordance with A.P.4506B Chap. 1 Airframe S.P.288(1) and the results are recorded below.

Position	Count Shutter Open	Count Shutter Closed	Previous Count Shutter Open	Remarks
1. Port ASC MIC/TEL	600	50	5	This survey was carried out 20 hours after the aircraft landed. The 1320D monitor could not be used for the post flight survey since aircraft contamination levels were such that the monitor went off scale; the NIS 295 dose-rate monitor gave an average reading of 1 - 2 mR/h.
2. Port Nostril	800	70	6	
3. Port Ext Door Handle	750	60	4	
4. Port Ground Power Panel	900	85	6	
5. Port Nose under Carriage Panel	900	70	3	
6. Port Hydraulic Vent	FSD	200	22	
7. Post CSDU Intake	FSD	150	8	
8. Port Wing Pivot Head	700	40	3.5	
9. Port Aileron Hinge	FSD	80	7	
10. Stbd. Nose Pitot Head	300	25	2	
11. Stbd. Mk. 10 Duct	FSD	150	14	
12. Stbd. Hydraulic Vent	FSD	200	28	
13. Stbd. Engine Intake	600	50	3.5	
14. Stbd. CSDU Intake	850	150	12	
15. Stbd. Wing Sawtooth	FSD	120	3	
16. Stbd. Wing Pitot Head	800	40	4	
17. Stbd. Aileron Hinge	FSD	80	7.5	
18. Stbd. Fuselage Fuel Jettison	FSD	90	12	
A Cabin Entrance	350	36	NIS 295 data 0.4 mR/h	
B Adjacent to Port CSDU	380	40	0.5 mR/h	
C Inner Side Port U/W Tank	520	40	0.4 mR/h	
D Port Outer Main Plane	400	38	0.45 mR/h	
E Port Side Rear Fuselage	180	16	0.175 mR/h	
F Aft of Port Bomb Bay Door	275	30	0.35 mR/h	
G Stbd. Window Box	140	22	0.32 mR/h	
H Outer Side Stbd. U/W Tank	280	28	0.31 mR/h	

[redacted]

The operator holds the nearest part of the casing of the 1320D detection head about 1 in. from the surface and, moving it about over the area, records a mental average of the counts per second. This is done first with the β window open, then with the window shut. Reference [26] states that to convert the readings to units of μCi/cm × 10^{-4}, one divides the difference between the readings with shutter open and closed by 8. However, AWRE recommended that the conversion should be carried out as follows:-

β window open 10^{-4} μCi/cm gives 5 counts/sec.
β window shut 1 mR/h gives 80 counts/sec.

The β efficiency is approximately 11 times the γ efficiency for the B.12 counter used in the 1320D (table 12.1) so that, on this basis 1.7×10^{-2} μCi/cm is equivalent to a γ dose-rate of 1 mR/h. Appendix H shows that, on comparison with a US instrument, 0.1×10^{-2} μCi/cm is equivalent to 1 mR/h.

Ideally aircraft were monitored before and after each flight. However, some relaxation of the before flight monitoring was allowed if it had been recently surveyed. [redacted] actual decay curves could be plotted. "Average" levels were calculated by averaging the results with the β window open for positions 1 - 18 and A - H and dividing by 5 thus giving contamination in units of 10^{-4} μCi/cm. The results thus obtained for the two aircraft which became contaminated are shown in figure 38. On this basis the contamination level on XL 161 following the Astride event was 100 times the recommended unrestricted access level of 10^{-4} μCi/cm [26]. However, it must be remembered that this "average" is probably an overestimate in that the "low level" readings, A - H, correspond to large areas. Appendix H gives a comparison between the 1320D monitor and the [redacted] instrument; it also points out that [redacted] depending on the age of the fission products, than the UK code of practice.

[redacted]

12.3 Aircrew

The extent to which particulate material may have entered the cabin during sampling was originally something of an unknown. To guard against trouble in-flight meals were taken before sampling, and the crew were instructed to wear oxygen masks in the sampling area. Although no contamination was ever found inside the pressurised cabin by smear tests, a check was made for cabin air pollution by flying a portable air sampler in the aircraft. The crew had instructions to switch it on for 2 hours when a positive reading had been obtained on aircraft instruments of the presence, externally, of a radioactive cloud. The one sample obtained by these means is being analysed. At this time it can be said that the presence of fission products has been detected on the filter but the degree of air contamination that caused it is considered to be negligible.

The radiation dose received by the crew from the debris cloud and from aircraft contamination was quite small. This can be seen from the NIS-295 readings in tables 9.3 to 9.6 where it is clear that the total dose received must have been less than 2 mR. In [redacted] (which in fact gave rise to the highest radiation dose and aircraft contamination) almost twice as many fission products were collected as was the case [redacted] bearing in mind that [redacted] took place 38 hours after detonation and [redacted] 62 hours after detonation, the crew dose for the [redacted] must have been less than 8 mR.

On each flight each crew member was issued with two quartz fibre dosimeters (0 - 5 R and 0 - 500 mR) and a film badge to which was attached a thermoluminescent dosimeter. The quartz fibre dosimeter showed virtually no dose and analysis of the other devices has proved that all doses are very low.

The aircrew were briefed to take care entering or leaving the aircraft. All flying clothing including boots, helmet, and oxygen mask were monitored at periodic intervals; no appreciable reading above background was ever detected.

12.4 Ground crew

[redacted] ground crew. [redacted] Under denim overalls the recording of β radiation (the main direct radiation hazard) would have been reduced by a large factor. It would have been difficult to have controlled daily issue and return of badges and dosimeters efficiently since the ground crew worked a two-shift system with no regular supervisor. To have issued them on a monthly basis would have invited possible compromise by loss or by exhibition outside the airport by the younger members. Under the circumstances, bearing in mind that the radiation hazard was expected to be quite low, no dosimeters were worn by the ground crew. To keep the dose as low as possible contaminated aircraft returning from a successful sampling sortie were allowed to decay for as long as practical before carrying out servicing work. Following the Astride sortie the aircraft was allowed to stand for 50 hours, the debris then being 90 hours old, before servicing.

The highest radiation dose would be to the hands. Normally surgical rubber gloves were worn when working on contaminated aircraft surfaces, but, as the levels dropped, barrier creams were sometimes used. At 90 hours after the Astride sortie the dose-rate to unprotected hands from β's would have been about $2\frac{1}{2}$ mR/h. Taking 10 hours per week as the time a tradesman would be in the vicinity of the aircraft (the most exposed would be airframe or engine trades and they would be in very close proximity to the surface for only a fraction of that time), and 12 weeks as the most they could expect to work an aircraft contaminated to those levels (this was expected to be less since the aircraft and ground crew were to be rotated with others from the UK about the middle of the detachment), then the maximum anticipated dose to hands would be $2\frac{1}{2} \times 10 \times 12 = 0.3$ R. This should in fact be smaller since the shielding of the gloves and natural radioactive decay of the contamination had not been taken into account. The maximum permissible dose to the hands over this period as laid down by the ICRP is 40 rems. Similar "worst case" arguments concerning whole-body and eye dose show that the totals must have been well below ICRP maximum levels.

A pertinent report on radiation dose from contaminated aircraft [28] contains the conclusions that "release to uncontrolled areas appears warranted if the average γ field in potential working areas around the aircraft or its parts is less than 0.5 mR/h regardless of age". This limit assumes a 40 hour working week on aircraft contaminated with mixed fission products. If during the detachment monitoring had been carried out with the 295A dose-rate monitor instead of the 1320D, then providing no working surface exceeded 0.5 mR/h there was a case for dispensing with radiation safety precautions.

Only essential work was carried out on the aircraft surface. Procedures outlined in Special Technical Instructions and Servicing Instructions were invariably postponed until the aircraft returned to the UK. The philosophy for protection of the individual was the avoidance of any exposure unless strictly necessary. The old adage of time, distance, shielding, was employed whenever possible. Fortunately all aircraft maintained a high standard of serviceability throughout the detachment. Only minor rectification was required and most of this consisted of unit replacement inside the aircraft. Replacement of an engine would have caused major RADSAFE problems.

Ingestion of contamination was limited by strict control of personal hygiene in the working area. Whenever tradesmen worked on an aircraft denim overalls were worn over the serge uniform. In addition, cloth caps and sometimes surgical rubber gloves were worn. The main trunk of the body was well shielded from direct β radiation and transferrable contamination that was picked up remained on the protective clothing. When they had finished work on the aircraft the men returned to the cargo shed nearby. Once inside they were monitored for contamination of clothing using the 1320D set on its lowest scale with the window open. Any clothing contaminated appreciably in excess of 8 counts/sec above background (10^{-4} µCi/cm) was packed in polythene bags and left for a period until the levels had dropped. The overalls could not be hung out since the cargo shed was too small and was used for other purposes, such as storage of equipment, technical control, rest room etc.

After removal of the protective clothing hands were thoroughly washed in an adjacent washroom and the tradesmen subjected to a head to toe re-monitoring before smoking, drinking or eating. Special attention was paid to finger nails and scalp. If any count above background was observed the hands had to be re-washed. Slight contamination of the hair occurred on the odd occasion because the cloth caps supplied had not been worn.

All monitoring of personnel was performed initially by the RSO or his SNCO, but after instruction the SNCOs of the detachment were allowed to do the monitoring under supervision. Later, when they had become proficient, they carried out their own monitoring and clearance with periodic surprise checks by the RSO or his SNCO. In this way the tradesmen became RADSAFE conscious and developed in them an interest in the efforts being taken to protect them.

The Detachment Engineer and all ground-crew were briefed that, if any component that had been ram-air cooled or driven had to be removed for servicing, then the RSO should be informed so that suitable RADSAFE supervision and precautions could be instituted. Any hatch that was opened was monitored before a ground-crew member went inside.

Periodic checks for spread of contamination were made by monitoring the aircraft parking ground, cargo shed, the laboratory and aircrew changing room. Ground equipment and hand tools were also checked. The only contamination found was a slight amount on hand tools. These were cleaned with rags which were disposed of as radioactive waste. On completion of the detachment, all areas that had been used were cleaned and then surveyed for contamination. No detectable reading above background was found.

Urine samples taken from six ground crew members on return to the UK showed no significant active content.

Following [redacted] there was a 24 hour two-man guard on the aircraft to prevent access by unauthorised persons.

12.5 Typical sequence of health physics operations

(a) Check aircraft, special equipment (NIS 361 Search and Filter Monitors, NIS 322 Directional monitor, NIS 295A dose-rate monitor, and associated recorders) for serviceability and load a single Mk. 9 filter into the Mk. 10 duct and 8 pocket filters into each of the two Mk. 3 ducts, the filters being fitted into the baskets in the laboratory.

(b) Monitor the aircraft if not done recently.

(c) Charge up personal quartz fibre dosimeters and issue each member of the aircrew with one range 0 - 5 R, one range 0 - 500 mR, and a film badge with a TLD attached. Issue one front and rear crew member with a dosimeter range 0 - 200 mR.

(d) Brief aircrew on when to open their ducts and when to leave the sampling areas. Remind them of the radiation safety requirements to:-

(1) take care entering and leaving the aircraft;

(2) consume in-flight meals during out-bound leg before reaching the sampling area;

(3) use oxygen masks in the sampling area.

(e) Standby until aircraft take off in case of last minute snags.

(f) Receive and interpret radiation monitoring information from airborne aircraft.

(g) When aircraft has landed and taxied to dispersal ensure only the crew chief touches the aircraft (opens the door, connects intercom head set) and the ducts are opened before engine shutdown.

(h) Check quickly levels of contamination on the aircraft using a 295 monitor. Check the monitor readings in each duct from approximately 1 ft away and assess from this the fissions collected (using figure 15).

(i) Get the aircrew out of the aircraft and to the de-briefing room as quickly as possible.

(j) Monitor the aircraft using two monitoring teams for speed.

(k) Unload exposed filter baskets into partitioned box provided and later, either (1) if a sample has been collected pack them into a C pot keeping port and starboard samples in separate polythene bags, or (2) if a background sample only has been collected pack the filters and leave in polythene bags. For this operation surgical rubber gloves and overalls were always worn.

(l) De-brief aircrew and check their dosimeter readings (no discernible reading was ever found). Return dosimeters and film badges to storage box.

(m) Upon completion of aircraft monitoring inspect the readings on the proforma and either clear the aircraft for turn round servicing or have it shut down and guarded if the flight was successful.

[redacted]

(n) Make a more accurate assessment of size of sample collected by monitoring the packed filters at 6 inches distance using the 295 monitor.

(o) Despatch samples as outlined in section 11.2.

(p) Ensure person in charge of ground crew is briefed on levels of contamination on the aircraft and that he fully understands the radiation safety measures that his men have to take.

12.6 [redacted]

Whilst the contamination levels did not constitute a major health hazard they did affect the aircraft's sensitive radiation detection equipment to a marked extent. In an effort to reduce contamination XL 161 was deliberately flown through rain clouds for about an hour on 11th July. This reduced the level of contamination of the high spots quite markedly, but had rather less success in lowering the levels on the cleaner areas. The readings on the aircraft's NIS 361 search and filter monitor meters dropped by only approximately 10%. Cleaning of a 9 ft band around the aircraft centred on the search probe position was carried out. Swarfega cleansing compound and rags were used. Although much contamination was removed by this method little effect on aircraft instruments was observed.

On 13th August a limited decontamination of XL 193 was carried out. This involved cleaning, with rags and Swarfega, all the underside of the aircraft and up to within hand reach of the fuselage. The purpose of the cleaning was threefold; firstly to reduce the background readings on aircraft instruments; secondly to prevent pick-up of contamination on clothing or hands by servicing personnel, and thirdly to get rid of the main reason for guarding the aircraft. Background readings were reduced, from 400 to 350 counts/sec for the search monitor and from 90 to 65 counts/sec for the filter monitor. Unfortunately the rotation of UK based Victor XL 203 with XL 161 was cancelled and so the guard had to continue since XL 161 was, at this time, still appreciably contaminated and it was considered inadvisable to build up the quantity of contaminated rags stored in the cargo shed by a similar repeat exercise. Overalls, caps and rubber gloves were worn by the 8 man team who took approximately 8 hours to complete the cleaning. The gloves and rags were placed into polythene bags and stored in a steel drum in a small wired off division of the cargo shed. Contaminated overalls and caps were similarly bagged and left to decay. A few days later all contaminated waste was returned [redacted] for disposal. This method of disposal was repeated at the end of Operation Web for all remaining contaminated waste. Laboratory residues were returned to AWRE and rags and clothing to RAF Wyton.

12.7 [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

12.8 Decontamination at RAF Wyton

When cleaning had been completed [redacted] the aircraft returned to its UK station at RAF, Wyton, Hunts. Here the aircraft was again monitored and re-washed but this time panels were opened and cleaned, and engine inlets and exhausts were entered; whereas the cleaning [redacted] had been on the easily accessible external surface, Wyton took on the rather more difficult task of cleaning all areas, external and internal, which might have become contaminated.

The present levels on both aircraft are below 10^{-4} μCi/cm and they have been released to squadron service. However, any ram-air cooled or driven components which are removed from either aircraft in the future must be treated with full Radsafe precautions, especially if they are to be stripped down and serviced in one of the second line bays on the station.

12.9 Limitation of contamination

If the aircrew could determine when sufficient sample had been collected they could return to base rather than stay in the cloud and thereby aggravate the contamination problem. The Mk. X duct acts as a particulate integrator which is almost proportional to the Mk. III duct pick-up because the latter are open in the densest part of the cloud. If we set the upper collection limit at [redacted] fissions in the Mk. III then the Mk. X will have collected about [redacted] fissions. The Mk. X duct will record 3000 counts/sec (its upper limit due to paralysis and meter scale) for [redacted] fissions 120 hours after detonation (figure 16). At earlier times the instruments limitations will be exceeded so that no "go home" level can be derived (see tables 9.2, 9.4 and 9.6). In this respect, therefore, the Geiger counter in the Mk. X duct is too sensitive.

13. DEVIATIONS OF METEOROLOGICAL PROGNOSTICATIONS FROM KNOWN CLOUD PATHS

[redacted] give not only prognostications but also "actual" cloud paths, presumably based on later meteorological information and known collections. The situation, even without knowledge of the detailed information leading to [redacted] to a series of questions. What is the likely uncertainty of a prog? Are later progs. more meaningful than early progs? Are progs. better at particular altitudes? Since the answers have a profound effect on search patterns and the strategy as a whole we detail some naive calculations below.

13.1 Derivation of "errors"

In view of the limited range of the Victors we have only examined deviations of progs. from actuals [redacted] Further, we have limited the number of progs. examined by including only those whose origin time, t, was less than 24 hours or greater than 3 hours before the estimated cloud arrival time, τ, at the longitudes given. The difference $t - \tau = T$.

Figure 40 illustrates the manner in which the deviations have been calculated. First plot the "actual" for the given shot and altitude. Then plot the prog; from this we can calculate the estimated time of arrival of the cloud at [redacted] (point A). Knowing this time we can say where the cloud "actually" was by interpolating along the "actual" plot (point C). The deviation or error is now expressed as a cross wind (CW) error at right angles to the prog. trajectory and an along wind (AW) error along the prog. trajectory. The sign of the error is clear from figure 40, viz, prog. north of actual gives a +ve cross wind error while the prog. east of the actual gives a +ve along wind error. Each prog. falling within our time limitation is treated in the same way. We thus obtained a list of 170 "deviations" (both AW and CW) which included "ordinary" progs. against "ordinary" actuals and "strike" progs. against "strike" actuals, for different shots, different altitudes, different longitudes and different values of T. The deviations ranged from -720 to 1400 nautical miles along wind and from -750 to 660 nautical miles across wind.

13.2 Treatment of data

The deviations were grouped into shots, altitudes, longitudes and values of T between 3 and 14 hours and 14 to 24 hours. For each group a calculation was made of the mean, the standard deviation of the population and the standard error of the mean. The results are given in table 13.1.

[redacted]

TABLE 13.1

Analysis of All Deviations from "Actuals"

Group	Identification in Group	No. of Data Points	Along Wind, n miles			Across Wind, n miles		
			Mean	S.E. of Mean	S.D. of Pop.	Mean	S.E. of Mean	S.D. of Pop.
Shots	[redacted]	34	- 173	45	262	91	21	122
		35	241	79	466	29	30	176
		7	- 168	117	310	257	77	203
		42	17	39	250	- 36	30	197
		52	264	54	392	- 84	19	134
Altitudes	50 mb	7	43	10	26	42	25	67
	60 mb	11	- 35	80	266	- 29	14	45
	100 mb	29	- 21	40	214	51	45	245
	150 mb	22	- 6	31	145	29	28	131
	200 mb	51	327	77	548	- 25	30	216
	250 mb	28	- 72	63	331	1	27	144
	300 mb	22	88	53	248	- 37	28	130
Longitudes	[redacted]	56	83	48	360	- 23	20	149
		53	121	55	402	- 29	28	203
		57	74	57	430	48	24	184
Time	3 to 14 hours	88	93	39	366	12	15	145
	14 to 24 hours	82	93	47	421	- 13	23	212
All Data	-	170	93	30	392	0	14	181

[redacted]

If the forecasts were in very good agreement with the actuals we would expect the means not be significantly different from zero. Student's "t" test can be applied by dividing the means by the standard error of the means; if the result is greater than about 2 there is evidence that the mean is significantly different from zero. Thus, there is some evidence that the forecasts brought the air masses along the wind too slowly on [redacted] but too fast on [redacted]; the forecasts also put the air masses too far north on [redacted] Such hindsight is of little value.

The variability of any single forecast is given by the standard deviation of the population and one can check, by suitable tests, whether any one factor within a group is significantly superior. Application of Bartlett's test for the homogeneity of population variance to the three longitude factors shows that there is reasonable evidence to suppose that the variability of cross wind errors for [redacted] forecasts is smaller than for [redacted] However, the variance ratio test for the two time factors within the time group gives good evidence that the cross wind variability is smaller for later forecasts, ie, the 3 - 14 low group. Thus there is justification for analysing the later forecasts separately.

A second, probably more realistic analysis has been carried out on deviations applying only to those progs. against which the RAF would have flown. This set of data only takes those results in the 3 - 14 hour time group, does not include the data for 50 and 60 mb or ordinary progs. if strike progs. are available. The analysis is shown in table 13.2 and is restricted to different longitudes since earlier tests had shown no inhomogeneity of variances between shots and altitudes. We now find no difference between the variability of the data for [redacted] but note the progression of the means for cross wind deviations which for [redacted] are significantly different from zero. The analysis of all such data in the last line of table 13.2 shows that the cross wind mean is significantly different from zero and that there is a bias in the forecasts putting then some 58 miles "north" of the actuals. In addition the variability of the deviations expressed as standard deviation of the population is 185 n miles along the wind and 136 n miles across the wind; this means that on searching a rectangular area 370 n miles by 270 n miles set lengthways along the forecast wind vector but 58 n miles south of it there is a roughly 40% chance of intercepting a point source (assuming that the "actuals" are correct). If the detectable cloud had a major axis of 370 n miles and a minor axis of 90 n miles then the probability of detecting the cloud on searching this area would be about 0.8. This is not to say that the best search area is necessarily rectangular; it could be that the area enclosed by an ellipse is optimum.

An alternative and possibly better interpretation takes cognisance of the fact that the data analysed in table 13.2 show a strong correlation between the along wind and cross wind errors. In consequence the best search area may be inclined at an angle across the forecast wind vector.

TABLE 13.2

Analysis of "Flight Data" Deviations from Actuals

Group	Identification in Group	No. of Data Points	Along Wind, n miles			Across Wind, n miles		
			Mean	S.E. of Mean	S.D. of Pop.	Mean	S.E. of Mean	S.D. of Pop.
Longitudes	[redacted]	21 22 22	23 - 7 - 60	36 43 39	166 201 182	10 64 102	31 24 29	144 113 137
All Data	See text	68	- 9	22	185	58	16	136

13.3 Optimum search area

Any conclusions are bound to be weak; the calculated deviations are highly variable and already include some error (since both forecasts and actuals are only quoted to the nearest degree) for which we have not allowed; further, we are forced into assuming that "actuals" are absolutely correct and assume that deviations from them are normally distributed. Comparison of forecasts with strikes has been avoided partly because the quality of the strikes is often unknown and partly because their altitudes are not known accurately. The indications are:-

(a) that forecasts tended to predict the air masses as being further north than they were finally believed to have moved;

(b) that this northward prediction is negligible at [redacted] but increases at lower longitudes to as much as 100 n miles or more at [redacted]

(c) that a good search area has its longer dimension (a) parallel to, but about 60 miles south of, the forecast wind vector (b) about 1.4 times as long as the shorter dimension.

Some confirmation for these conclusions is found in the fact that a graphical evaluation of the data for [redacted] led to a very similar conclusion and formed the basis of our standard search philosophy (section 8).

[redacted]

14. RECOMMENDATIONS FOR FUTURE OPERATIONS

Operation WEB was quite successful. However, our lack of experience in this field leads one to wonder the extent to which we enjoyed "beginners luck". Be that as it may, it behoves us to better any aspect which will improve both the probability of detecting debris and the quality of the sample. The following suggestions are restricted to scientific matters; organisational and administrative aspects are considered elsewhere [1,2].

14.1 Measuring equipment

14.1.1 Search crystal

The probability of finding a debris cloud would be improved by increasing the sensitivity of this detector. First, it should be located in a position which is (a) not heavily shielded with respect to γ rays, and (b) not near major sources of aircraft contamination. The ideal would be in a polished container on the end of a long trailing cable; a promising alternative is at the rear end of the fuselage. If the crystal is located outside the crew cabin there will be difficulties due to low temperature and pressure. Second, the crystal size should be increased to at least a 3 in. × 3 in. diameter. This alone would increase the sensitivity by about a factor of 3.

Readings and their interpretation could be improved by using a linear meter with range switch rather than a logarithmic meter and by increasing the time constant to about 5 seconds, thus making the readings steadier.

14.1.2 Up-Down meter

This proved its worth but was very inconvenient; it had to be physically moved about by a crew member. A two-crystal assembly in a suitable lead housing, the output of the two crystals being electronically subtracted and presented on a meter with a central zero (similar to a car ammeter), would be better. The readings, as with the search crystal, would be less liable to misinterpretation if the detectors were located in the tail.

14.1.3 Geiger in Mk. X duct

This instrument is rather too sensitive for giving an indication of when to break off sampling. The Geiger should be replaced by a different detector with a wider operational range. Since the Mk. X integrates particulate collected the rate of rise of the ratemeter readings should be proportional to the local cloud density. By comparing such a rate-rate meter display with that of the search crystal detector the actual collection of debris can be confirmed.

[redacted]

14.1.4 Pulse height analyser

Data from a second 3 in. × 3 in. crystal showing the γ ray spectrum would be very valuable in confirming the optimum window width setting on the search crystal. A pulse height analyser should be used again but it must be switched on for only a short time at the beginning of a sampling phase in order to minimise γ rays from fission products which are physically contaminating the aircraft. Background spectra would also be of interest but must be measured by uncontaminated aircraft.

14.2 Sampling equipment

The situation is far from ideal. With only two Mk. III ducts on each aircraft the decision as to when to open them, in terms of search crystal readings, is fairly critical with respect to "background" effects. With a multiplicity of ducts one could open each for an equal length of time and sort out the "best" sample on landing. We now have six "refurbished" actuators plus two old ones; two are required for each aircraft. In view of the breakdowns experienced in the past it could be argued that there are not sufficient spares, bearing in mind that the whole success of the project ultimately hangs on the working of these actuators.

There are, therefore, technical reasons why the whole sampling system should be redesigned. The cost would be very high. Arguments against redesigning could justifiably make the points that (a) during the whole of WEB we only had one actuator failure, and (b) our background problems were largely due initially to dirty ducts, secondly to the fact that the AEO opened the starboard duct too early on [redacted], and lastly to the fact that our knowledge of atmospheric "background" content was inadequate. The "background" situation may not be quite as bad as was feared a short time ago [1].

It seems likely that a reasonable compromise could be made by either modifying the existing ducts so that only two filter pockets are sampling at one time, thus giving the equivalent of 8 ducts, or by using one or more existing aircraft "openings" to provide alternative sampling points, eg, the ram air turbines. With spare sampling facilities it could be advantageous to collect a "background" sample during the return from a successful sortie.

Not only should the filter papers be handled under scrupulously clean conditions (eg, do not use talc with rubber gloves, better to use thin plastic gloves) but the ducts themselves should be cleaned and polished both inside and around the front opening before each flight. In addition the nose bung must effect a tight seal and be cleaned between flights. Ducts should only be opened after the aircraft comes to rest following a sortie.

14.3 Flying programme

It may be advantageous to carry out a "pre-sampling" flight some 8 to 12 hours before the expected arrival of a debris cloud. It could provide a useful "background" sample, especially important if it is not possible to obtain a "background" on the return from a successful sortie because of lack of spare ducts. In addition highly relevant wind data would be obtained which would (a) enable the meteorologist to modify the [redacted] locally, and (b) provide information for the [redacted] and thereby improve later [redacted]. Against these advantages must be reckoned the cost, the loss of aircraft hours and the possible unserviceability of the returning aircraft.

It is desirable to search [redacted] to increase the search area consistent with availability of aircraft and crews [redacted] later searching at other altitudes [redacted] and [redacted]

14.4 Health physics and contamination

There is a need to arrive at a clear policy concerning contamination [redacted] The policy arrived at has implications concerning health physics procedures which should be agreed before beginning another similar operation.

If the aircraft had a gloss finish instead of a matt paint the extent of contamination may well be reduced.

14.5 Training

The success or failure in obtaining a satisfactory sample depends very much on aircrew; their interest, ability to interpret instrument readings and initiative in unforeseen circumstances are the principal ingredients. They are technically trained, able and resourceful men who can contribute useful ideas once they are aware of the problem. Bearing in mind the RAF posting system it is unlikely that many, if any, of the aircrew who participated in WEB will be available for a similar operation. It is therefore vital that at least one of the new crews should spend several days discussing the technical problem with scientific staff before a similar operation. In this way a mutual understanding of capabilities and limitations can be grasped, suitable operating systems can be evolved and the extra work load on the crew can be minimised.

All the RAF personnel should be given some basic training in radiation safety and health physics procedures; in particular certain ground crew should be taught how to use the monitoring instruments.

In order to retain some of the "know how" the squadron could fly "dummy" search sorties from time to time (as part of their training programme) and thus supply "background" filters. This is particularly important if the aircraft are to be employed in other theatres, possibly at short notice.

14.6 Scientific aspects

(a) Certain studies should continue to provide information for any future operation, eg, calculation of search crystal response as a function of altitude and its relation with cloud fission density to develop optimum duct opening criteria, theory of search patterns, atmospheric particulate measurements and the possibility of using the Mk. IX filter for estimating background, checking duct throughputs (especially any possible change of flow rate with time of opening), measurement of uranium content of filter material, meteorological considerations etc.

(b) Procedures and proformas should be developed before the operation by scientific staff in co-operation with the air crews.

(c) Health physics staff should advise the appropriate officer on techniques, precautions etc [redacted]

(d) There should be a more equible spread of work-load between the scientists and RAF officers; at times the scientists can help the RAF, eg, in technical training, while at other times the RAF could help the scientists with their work.

(e) There should be a very high standard of note taking and reporting, eg, notes should be taken both during meetings aimed at deciding flight levels and take-off times and at briefings.

[redacted]

15. ACKNOWLEDGMENTS

Many thanks are due to all RAF personnel [redacted] for their efforts under trying and difficult conditions, but also for their tolerance toward the scientific staff. In addition we wish to record our gratitude for the strong support given to the project by 543 Squadron, Central Reconnaissance Establishment and Strike Command.

[redacted]

Various departments of the Ministry of Defence, the Foreign Office [redacted] did much to smooth the path for the operation; their contributions are gratefully acknowledged.

Finally we wish to thank our colleagues at AWRE for the provision of hardware, information and other services.

[redacted]

[redacted]

APPENDIX A

PERFORMANCE OF VICTOR SR MK. 2

(Data from [redacted], Brampton, Huntingdonshire)

A1. MAXIMUM ALTITUDE (WEARING PRESSURE JERKIN AND ANTI-*G* TROUSERS)

This will depend upon the fuel load; the less fuel carried the greater the altitude that can be attained. Assuming full tanks on take off giving an all up weight of 224000 lb, the aircraft should be able to attain 50000 ft 20 - 30 min later. As fuel is used this height can be progressively increased to 53000 - 55000 ft after 4 hours flying. The actual height will depend on the outside air temperature, which effects the efficiency of the engines. It should be noted that at high all up weights at high altitude large alterations of direction should be avoided since this can cause the aircraft to lose altitude. The maximum altitude permitted when wearing a pressure jerkin, anti-*g* trousers, p/m type oxygen mask and using the Mk. 21 oxygen regulator (standard fit in the Victor "R2) is 56000 ft. This is equivalent to a partial pressure in the lungs of 70 mmHg.

A2. MAXIMUM SPEED AT DIFFERENT ALTITUDES

A2.1 During the climb after take off the aircraft is normally flown at 250 knots IAS (Indicated Air Speed) increasing to 290 - 300 knots IAS at 10000 ft. At approximately 33000 ft 290 knots coincides with 0.84 M (Mach) and the aircraft is then flown at 0.84 M until 45000 ft at which height speed can be increased to 0.86 M.

A2.2 At normal operating heights, which are assumed to be above 40000 ft, the maximum speed should be limited to 0.9 - 0.92 M in level flight. The table below is self-explanatory:-

Height, ft	Maximum Indicated Speed/Mach No.	Outside Air Temperature (Assumed), °C	Approximate mph Equivalent
10000	250 knots	- 1	335
20000	300 knots	- 19	450
30000	300 knots	- 41	470
40000	0.92 Mach	- 53	611
50000	0.92 Mach	- 51	614

A2.3 "Pilot's Notes" states "Because of the ease with which the aircraft may be accelerated, care must be taken not to exceed 0.92 M".

[redacted]

A3. MINIMUM SPEEDS AT DIFFERENT ALTITUDES

A3.1 At lower altitudes the heavier the aircraft, the higher the minimum speed. For example, at 1000 ft, the minimum speed, with the use of partial flap at 120000 lb all up weight (AUW) would be 147 knots. At 200000 lb this minimum speed would rise to 186 knots.

A3.2 At higher altitudes the minimum speed would be as follows:-

Height, ft	Approximate Minimum Indicated Speed (Assuming AUW 125000 lb - Flap Retracted)
10000	200 knots
20000	200 knots
30000	210 knots
40000	0.82 M
50000	0.82 M

A4. ABSOLUTE MAXIMUM RANGE AT OPTIMUM ALTITUDE

A4.1 Above 10000 ft the best range can normally be achieved by employing a "cruise climb". This necessitates a climb after take-off to approximately 40000 ft. The aircraft is then trimmed in such a way that it climbs slowly as fuel is used. (This procedure incidentally is not favoured by Air Traffic Control Authorities, since the aircraft is not at a constant height, and thus may conflict with other traffic.)

A4.2 From the above it can be seen that there is no "optimum" altitude, although as a general rule, "the higher the better" is the aim. The absolute maximum range, assuming 10000 lb of fuel remaining on landing, at an average ground speed of 480 knots, would be 3800 nautical miles. If the ground speed were lower due to a headwind, the range could obviously be much reduced.

A5. "SAFE WORKING" RANGE

Approximately 3400 nautical miles; this usually allows enough fuel for diversion to an alternative airfield.

A6. MINIMUM RUNWAY LENGTH

Both altitude above mean sea level and high ground temperature extend the length of runway required for take-off. The precise length required is normally calculated before take-off. 9000 ft is usually the minimum acceptable; this allows not only for take-off, with full fuel, but also leaves a margin should take-off have to be abandoned. Shorter runways can be used, but this may necessitate the aircraft carrying less fuel.

A7. NORMAL CABIN TEMPERATURE

At normal operating heights, above 40000 ft, approximately 15 - 20°C. This can be varied by means of the cabin temperature control.

A8. NUMBER OF AIRCREW CARRIED

All normal operations require a crew of 5; Captain, Co-pilot, Navigator Radar, Navigator Plotter and Air Electronics Officer. A 6th seat can be fitted, on the floor behind the plotter, but is very cramped. Its use is normally restricted to aircrew, crew chiefs, or other personnel who have been successfully decompressed to 56000 ft. The 6th seat position is normally used for a detachable, rotating stool which is required when using a periscopic sextant for astro-navigation.

A9. AIR INTAKE PER ENGINE

The following figures have been supplied by the Rolls Royce Engine Division:-

(a) Sea Level

220 lb/sec/engine at 92% rpm;

(b) 35000 ft

75 lb/sec/engine at 95% rpm.

A10. IN FLIGHT REFUELLING

The Victor SR Mk. 2 can be refuelled in flight. The range cannot be doubled; the limiting factor is oil consumption. The maximum permitted flying time is 14 hours. There are other factors to consider in any refuelling operation:-

(a) the distance the tanker aircraft has to fly to and from the position selected for refuelling. The fuel used by the tanker for this purpose has to be deducted from the amount it can transfer to the receiving aircraft;

(b) crew fatigue can become a problem if the flight is extended, and the pre-flight environment can also affect this;

(c) navigation aids available to the aircraft. In an area of good ground navigation aids cover (over land, near radio beacons), the rendezvous is straightforward. In an area of poor ground navigation aids (over the sea), the rendezvous may prove difficult.

[redacted]

A11. MAXIMUM FREIGHT LOAD

The Victor SR Mk. 2 has no provision for the carriage of freight; indeed space is so limited that even the crews baggage can present a problem. A small pannier can be fitted in the bomb bay, but its capacity is very limited, and used for the carriage of essential spares, oil, etc. The small quantity that can be carried has no effect on range.

A12. DEFINITION OF ABBREVIATIONS PR AND SR

PR is the abbreviation for Photographic Reconnaissance, an all embracing term covering all aspects of reconnaissance. SR is the abbreviation for Strategic Reconnaissance.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

B1

[redacted]

B3. [redacted]

[redacted]

[redacted] [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted] [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

APPENDIX C

SENSITIVITY OF CRYSTAL DETECTOR

C1. EQUIVALENCE OF RATEMETER AND SCALER

When a source is brought up to a detector connected to a ratemeter the pulse-rate indicated increases with time according to the equation:-

$$N = N_{\infty}(1 - e^{-t/\tau}),$$

where N_{∞} is the reading after an "infinite" time,
N is the reading after time t,
τ is the "time constant" of the meter (= RC seconds where R is the resistance in ohms and C the capacitance in farads of the ratemeter integrating circuit).

Even when $t \gg \tau$ the reading is not absolutely constant; it varies about a mean value such that the standard deviation of the counting rate is $(x/2\tau)^{\frac{1}{2}}$, where x is the number of pulses per second [8]. If one used a scaler to determine the count rate by counting for a time T the error on the count rate would be $(x/T)^{\frac{1}{2}}$. Hence, when the ratemeter is at equilibrium, to read the needle once is equivalent to using a "scaler" system for a period of time equal to 2τ.

C2. CRITERIA GOVERNING ACCURACY OF MEASUREMENT OF A WEAKLY ACTIVE SOURCE

Assume we have a source which, on its own, gives a count rate of S counts per unit time and that it is counted for t_s units of time. Assume also that there is a "background" count rate of B, counted for t_b units of time and that the background count obeys the Poisson law. Let $T = t_s + t_b$.

In general, the fractional error on determining S by counting the source, calculating the source plus background count rate and then subtracting the measured background rate is given by

$$[(1/St_s) + (B/S^2t_s) + (B/S^2t_b)]^{\frac{1}{2}}. \qquad \text{..... (C1)}$$

The corresponding relation for the optimum split of T between t_s and t_b, ie, when

$$t_b = T/[1 + [1 + (S/B)]^{\frac{1}{2}}]$$

is

$$[B^{\frac{1}{2}}/S + [(B/S^2) + (1/S)]^{\frac{1}{2}}]/T^{1/2}. \qquad \text{..... (C2)}$$

[redacted]

It is fairly obvious that if $S < B$ then the fractional error is reduced by maximising S^2/B. Also, if $S > B$, provided t_s and t_b are not disparate, then fractional error is reduced by increasing S.

The observer of the ratemeter in the aircraft wishes to detect activity over and above background; his first signal will be a net signal less than background. Therefore we must maximise S^2/B; we must reject the possibility of decreasing background by shielding because this would also reduce the signal and thus reduce S^2/B.

C3. PREDICTION OF GAMMA RAY SPECTRUM REACHING THE AIRCRAFT

The source spectrum of γ radiation from U-235 fission products at a number of different times after fission is given by Nelms and Cooper [12]. The spectrum observed within a diffuse cloud of fission products will be composed of two parts, an unscattered part and a scattered part.

The flux of unscattered photons received is

$$F_u(E) = \int \frac{S(E)}{4\pi r^2} e^{-\mu(E) r} f(V) dV,$$

where S(E) is the source strength (photons/sec/fission/MeV interval) at energy E MeV, μ(E) is the linear absorption coefficient of the atmosphere for these photons and f(V) is the density of fissions in the cloud. The integral is over the cloud volume V. As the cloud dimensions in the horizontal plane are much greater than the γ ray mean free path we assume $f(v) \sim$ constant, whence

$$F_u(E) \approx f \frac{S(E)}{\mu(E)} \text{ photons/cm}^2\text{/sec/MeV interval.}$$

A correction can be calculated for a cloud of finite depth 2H, but still assuming uniform fission density. At the centre of this cloud

$$F_u(E) = f \frac{S(E)}{\mu(E)} [1 - E_2(\mu H)],$$

where $$E_2(\mu H) = \int_1^\infty \frac{e^{-\mu H u}}{u^2} du$$ is a tabulated exponential integral.

The scattered beam, involving both single and multiple scatters, from a source of energy E contains photons of all energies less than E. Basic data for the differential energy spectrum are given by Goldstein and Wilkins [16] and consist of tables of the function $4\pi r^2 e^{-\mu_o r} I$ at several values of E and number of mean free paths $\mu_o r$, at the source energy E_o. Tables are given for water (approximately the same effective atomic number as air) for E_o = 0.255, 0.5, 1, 2 .... MeV. I_o is the energy flux of photons

[redacted]

[redacted]

of energy E per MeV interval received at $\mu_o r$ mean free paths from a point source. The flux of scattered photons received within a uniform cloud of fission density f is then

$$F_s(E) = \frac{f}{E} S(E_o) \int I_o dv$$

$$= \frac{f}{E} S(E_o) \int_o^R (4\pi r^2 e^{\mu_o r} I_o) e^{-\mu_o r} \, dr.$$

The integral was evaluated numerically, taking the upper limit as 7 mean free paths. Values for an infinite medium are only 1 - 2% greater. We obtain a function of E for each source energy E_o = 0.255, 0.5, 1.0, 2.0 MeV, and interpolate to find values for intermediate source energies. Weighting with the source strengths given by Nelms and Cooper a scattered spectrum can be built up for a given source spectrum. Linear absorption coefficients for air are given below:-

E, MeV	$\mu(E)$ cm^{-1} at 30000 ft (ρ = 0.459 × 10^{-3} gm cm^{-3})	Mean Free Path	
		cm	ft
0.255	5.19 × 10^{-5}	1.93 × 10^4	6.3 × 10^2
0.5	3.99 × 10^{-5}	2.51 × 10^4	8.2 × 10^2
1	2.91 × 10^{-5}	3.44 × 10^4	1.1 × 10^3
1.5	2.37 × 10^{-5}	4.22 × 10^4	1.4 × 10^3
2	2.03 × 10^{-5}	4.93 × 10^4	1.6 × 10^3
3	1.64 × 10^{-5}	6.10 × 10^4	2.0 × 10^3

Results have been calculated for a cloud at 30000 ft, 2.13 days after burst (table C1, column 5) using the source spectrum in table C1, column 4. These spectra are illustrated in figure 13. The shape of the spectrum is not expected to change significantly at other altitudes, although the absolute flux will be inversely proportional to the air density (both $F_u(E)$ and $F_s(E)$ are proportional to $1/\mu$). There may, however, be changes with time after burst through the variation of the source spectrum. The main error in these predictions is likely to be that caused by the assumption of an effectively infinite, homogeneous cloud which may not normally be a valid assumption in the vertical plane.

We have not attempted to compute the scattered flux below 0.15 MeV as the smallest value of E_o for which we have data is 0.255 MeV, and unknown errors would appear if the extrapolation to lower energies were taken very far.

[redacted]

C4

TABLE C1

Assumed Fission Product Spectrum at 2.13 Days after Burst together with Spectra at Aircraft, Crystal Response and Comparison with Background, Assuming Fission Density of 1 f/cm^3

Energy, MeV	Energy "Box" Limits, MeV	Box Width, MeV	Fission Product Spectrum, γ's/sec/MeV for 10^4 Fissions (x 10^2)	Spectrum at Aircraft, γ's/sec/MeV/cm^2 (x 10^2)	Crystal Output Spectrum, counts/sec/cm^2 (x 10^2)	Background [11], counts/sec	Ratio of Crystal Output to Background (S/B)	Ratio of Crystal Output Squared to Background (S^2/B)
2.04	2.28 - 1.87	0.41	0.02	0.29	0.0066	-	-	-
1.70	1.87 - 1.47	0.40	0.09	1.32	0.041	25	0.002	6×10^{-5}
1.28	1.47 - 1.14	0.33	0.04	0.93	0.064	31	0.002	1×10^{-4}
1.02	1.14 - 0.93	0.21	0.27	5.9	0.178	20	0.009	1×10^{-3}
0.85	0.93 - 0.74	0.19	1.17	2.75	0.781	27	0.03	0.02
0.64	0.74 - 0.57	0.17	1.19	3.75	1.32	34	0.04	0.05
0.51	0.57 - 0.47	0.10	1.80	78	2.37	24	0.10	0.23
0.43	0.47 - 0.37	0.10	0.10	34	2.17	33	0.07	0.14
0.32	0.37 - 0.29	0.08	1.10	100	5.27	57	0.09	0.49
0.26	0.29 - 0.23	0.06	1.86	205	7.95	43	0.18	1.47
0.21	0.23 - 0.19	0.04	1.40	260	9.19	56	0.16	1.51
0.17	0.19 - 0.15	0.04	0.21	280	11.29	83	0.14	1.53

C4. RESPONSE OF SODIUM IODIDE CRYSTAL

C4.1 General

An exact calculation of the response from the γ ray flux reaching the aircraft is very difficult and probably not worthwhile. The following approximations are made in the calculation below:-

(i) that the crystal is a sphere with radius 2.66 cm and cross sectional area 22 cm^2 (that is, the same total volume as the cylindrical crystal);

(ii) a (photopeak/total) response function as for a 2 in. × 1¾ in. diameter cylindrical crystal (figure 14)[9]. This function is not sensitive to geometry;

(iii) that the response of the crystal to the spectrum of γ rays within an energy box is the same as for γ rays all having an energy equal to the mean energy of the box;

(iv) that the pulse height distribution from γ's of 0.64 MeV and above consists of a photopeak together with lower energy pulses evenly distributed between zero energy and the Compton edge, ie, the photopeak energy less 0.25 MeV. Spectra for low energy γ's were taken from published spectra [10,13];

(v) that the aircraft itself did not alter the isotropic γ ray spectrum reaching it from the fission product cloud. This is not true; its influence would be to soften the calculated spectrum and to absorb completely many of the low energy rays (say < 100 keV).

C4.2 Interactions with spherical crystal

Consider γ rays entering a point on the spherical surface and traversing the sphere at a angle θ to the radius from the point. Since γ rays are absorbed according to $f = f_o \exp(-\mu x)$, where f_o = initial flux, f = flux passing through distance x without undergoing interaction, it is easy to show that the fraction of γ's entering a point which undergo an inelastic collision in the crystal is given by

$$\int_o^{\pi/2} \sin\theta(1 - e^{-2\mu R\cos\theta})d\theta \int_o^{\pi/2} \sin\theta\, d\theta,$$

which integrates to

$$F = 1 - [(1 - e^{-2\mu R})/2\mu R],$$

where F is the fraction of rays entering the sphere which undergo some form of inelastic scatter. The function is tabulated below and diagrammed in figure 14.

E, MeV	μ, cm^{-1}	2 μR	F
0.1	5.79	30.8	0.968
0.2	1.12	5.98	0.833
0.3	0.572	3.04	0.687
0.4	0.406	2.16	0.591
0.5	0.331	1.76	0.530
0.6	0.290	1.54	0.490
0.8	0.241	1.28	0.437
1.0	0.212	1.13	0.400
1.5	0.171	0.909	0.343

C4.3 Overall response

Making the assumptions given in appendix C, section C4.1 we arrive at the data given in column 6 of table C1. The background data in column 7 is for a 2 in. × 2 in. sodium iodide crystal at 47000 ft using a NIS 292 portable γ ray spectrometer [11]. The ratios of crystal signal, S to background, B and of S^2/B both have highest values at low energy. This is, perhaps, not surprising since the crystal output represents a highly "softened" spectrum; this point is illustrated in figure 13 where all four spectra (normalised to the highest energy "box") are plotted together.

To achieve good response we need to include energies down to 0.14 MeV (possibly lower but the data have not been worked out for lower energies). The following table shows S^2/B and S/B parameters for different energy ranges, all taken from the lowest "box".

Range (in "Box" Means), MeV	Crystal, counts/cm^2/sec × 10^2	Background, counts/sec	Crystal/Background Ratio	$(Crystal)^2$/ Background Ratio
0.17 - 1.70	40.6	433	0.09	3.82
0.17 - 1.28	40.6	408	0.10	4.02
0.17 - 1.02	40.5	377	0.11	4.36
0.17 - 0.85	40.3	357	0.11	4.56
0.17 - 0.64	39.6	330	0.12	4.75
0.17 - 0.51	38.2	296	0.13	4.93
0.17 - 0.43	35.9	272	0.13	4.73
0.17 - 0.32	33.7	239	0.14	4.75
0.17 - 0.26	28.4	182	0.16	4.44
0.17 - 0.21	20.5	139	0.15	3.01
0.17 Box	11.3	83	0.14	1.53

The 0.17 - 0.051 MeV mean box energy range is optimal for S^2/B, so a good upper energy limit is 0.57 MeV. However, it was decided arbitrarily to increase this, thus giving a single channel setting of 0.14 - 0.80 MeV, since as fission products age beyond 2.13 days the emitted γ spectrum gets harder [12].

C5. SENSITIVITY

From section C4.3 we see that in a virtually infinite cloud of density 1 fission/cm^3 we can expect 0.4 counts/cm^2/sec from the sodium iodide crystal. The crystal area is 22 cm^2 so we expect 8.8 counts/sec in such a cloud, which is equivalent to 2.8×10^4 fissions/ft^3, the fission products being 2.13 days old. Assuming a signal count rate equal to background (about 300 counts/sec), the aircraft should detect a cloud of $2.8 \times 10^4 \times 300/8.8 = 10^6$ fissions/ft^3. In view of these values a time constant of 1 second was considered adequate. Of course, sensitivity falls as the fission products decay (figure 15).

The practical data in section 10 show that the calculation overestimates the sensitivity by a factor of about 7. This gross error was largely due to our not allowing for absorption in the aircraft structure, which, in view of the crystal location must have reduced the signal by a factor of 3 or so, and to our not allowing for absorption by the crystal canning and surrounding equipment, which probably involved another factor of 2.

C6. AN ESTIMATE OF THE CRYSTAL RESPONSE BELOW A CLOUD

In the search the aircraft may fly either above or below an active cloud layer. The signal observed will be less than it would be in the middle of a layer. A rough estimate of the variation of photon flux with distance from the cloud layer at different altitudes will be sufficient to illustrate the probable effectiveness of both the search and directional monitors.

Let there be a uniform layer emitting S photons/cm^3/sec located between heights H_1 and H_2 above the aircraft. The flux received is

$$\int_{H_1}^{H_2} S\,dz \int_{H_1}^{\infty} B \frac{e^{-\mu r}}{4\pi r^2} 2\pi r\,dr,$$

where B is the number build-up factor, which takes account of multiple scattering.

As a rough calculation we take the average source photon energy as 0.5 MeV and compute B from the scattering data of Goldstein and Wilkins [16] counting only those photons which arrive within the acceptance band 0.8 - 0.14 MeV. It is found that

$$B \approx 0.8(\mu r)^2, \qquad 1 < \mu r < 7$$

is a reasonable fit to the numerical values of B.

[redacted]

Substituting, and carrying out the integrations gives

$$\text{photon flux received} = \frac{0.4S}{\mu}\left[(2 + \mu H_1)e^{-\mu H} - (2 + \mu H_2)e^{-\mu H_2}\right].$$

With a fission density in the cloud of 10^7 fissions/ft^3, 2.13 days after burst, $S = 2.7 \times 10^{-3}$ photons/cm^3/ sec in the energy band 0.8 - 0.14 MeV. Results for this set of circumstances, corrected for our overestimate by a factor of 7, are given in section 5.3.

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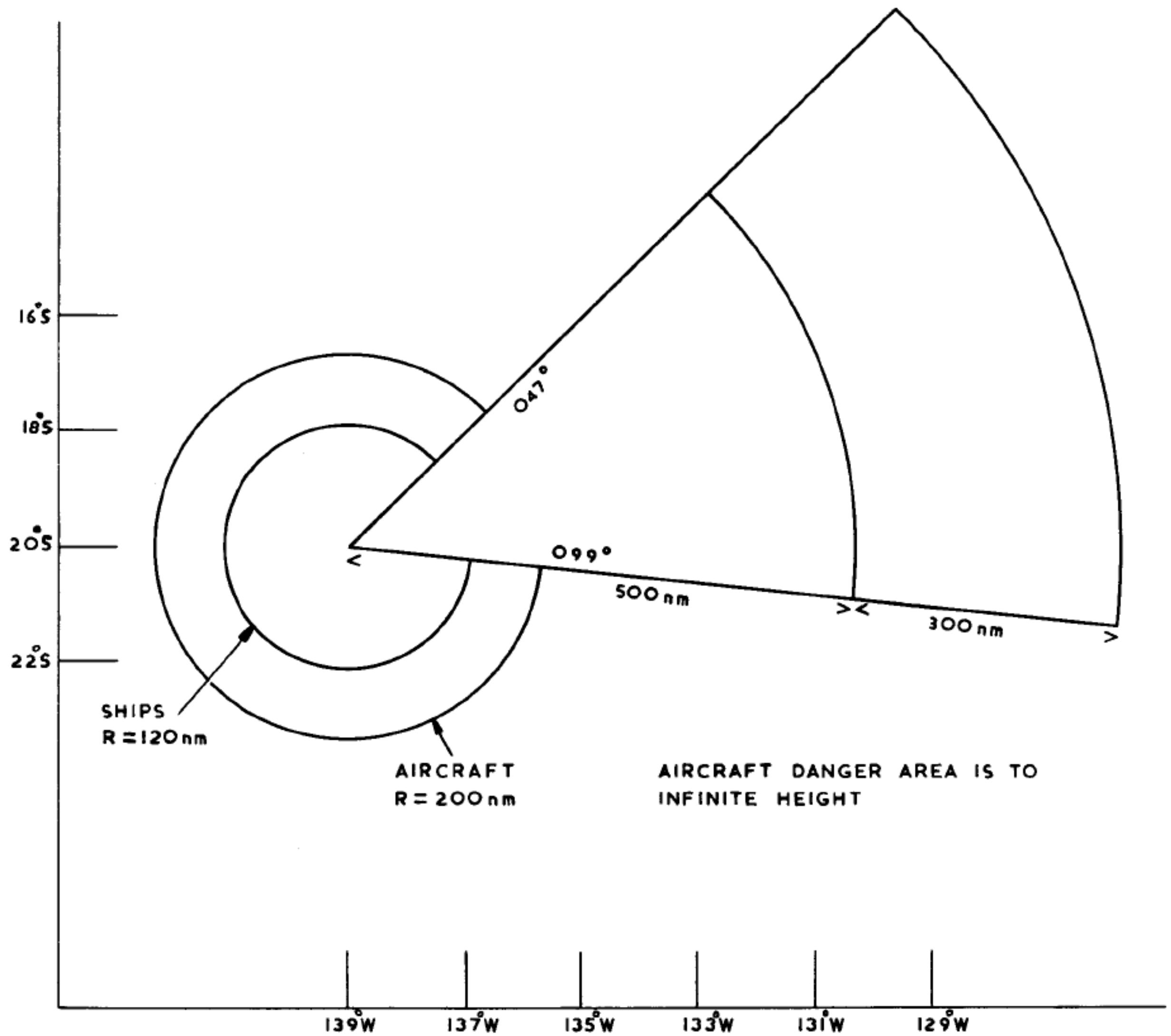

FIGURE 2. NOTAM DANGER AREA

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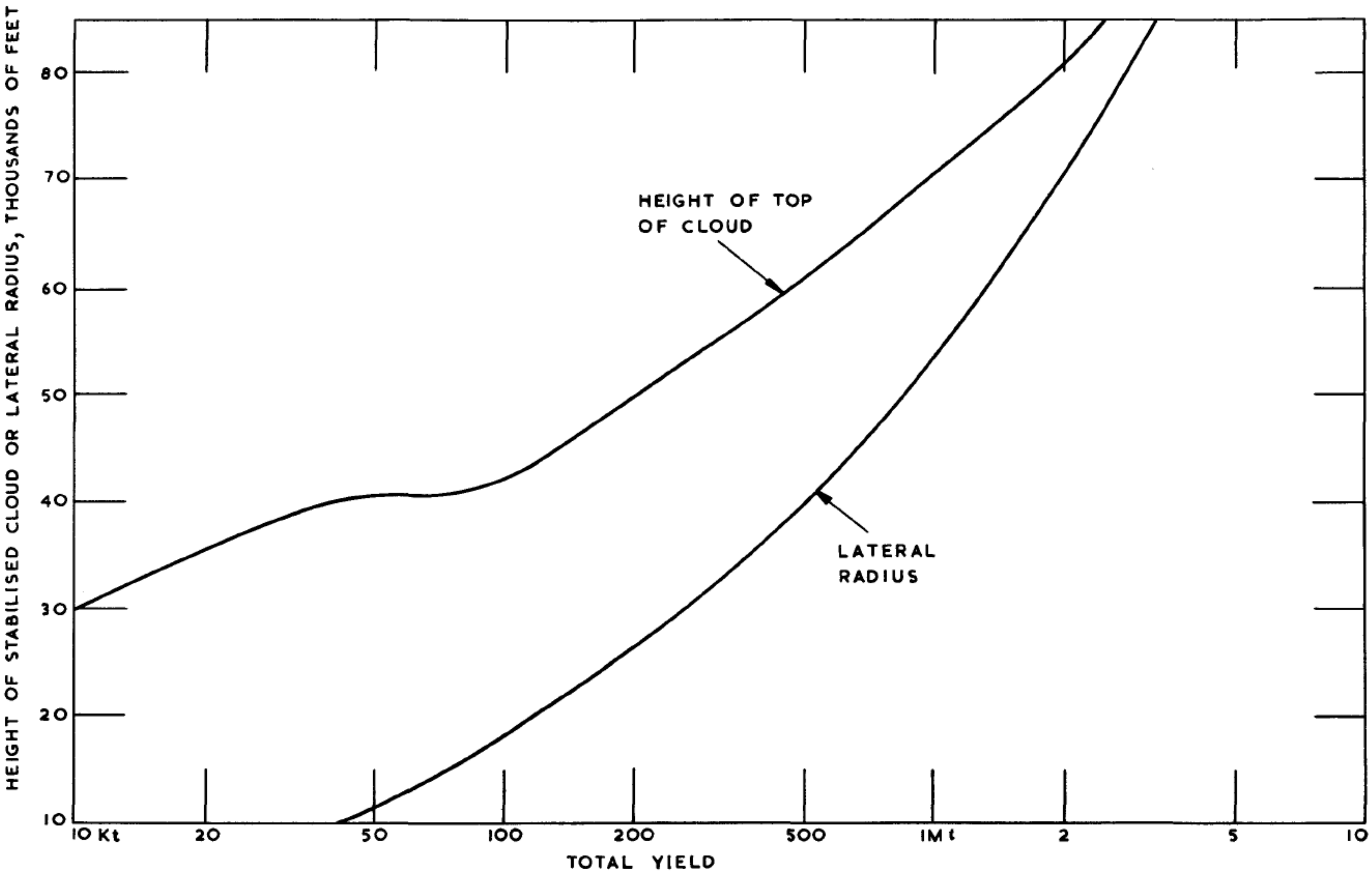

FIGURE 3. CLOUD HEIGHT (TOP) AND LATERAL RADIUS AS FUNCTION OF YIELD OVER CONTINENTAL U.S.A.(3)

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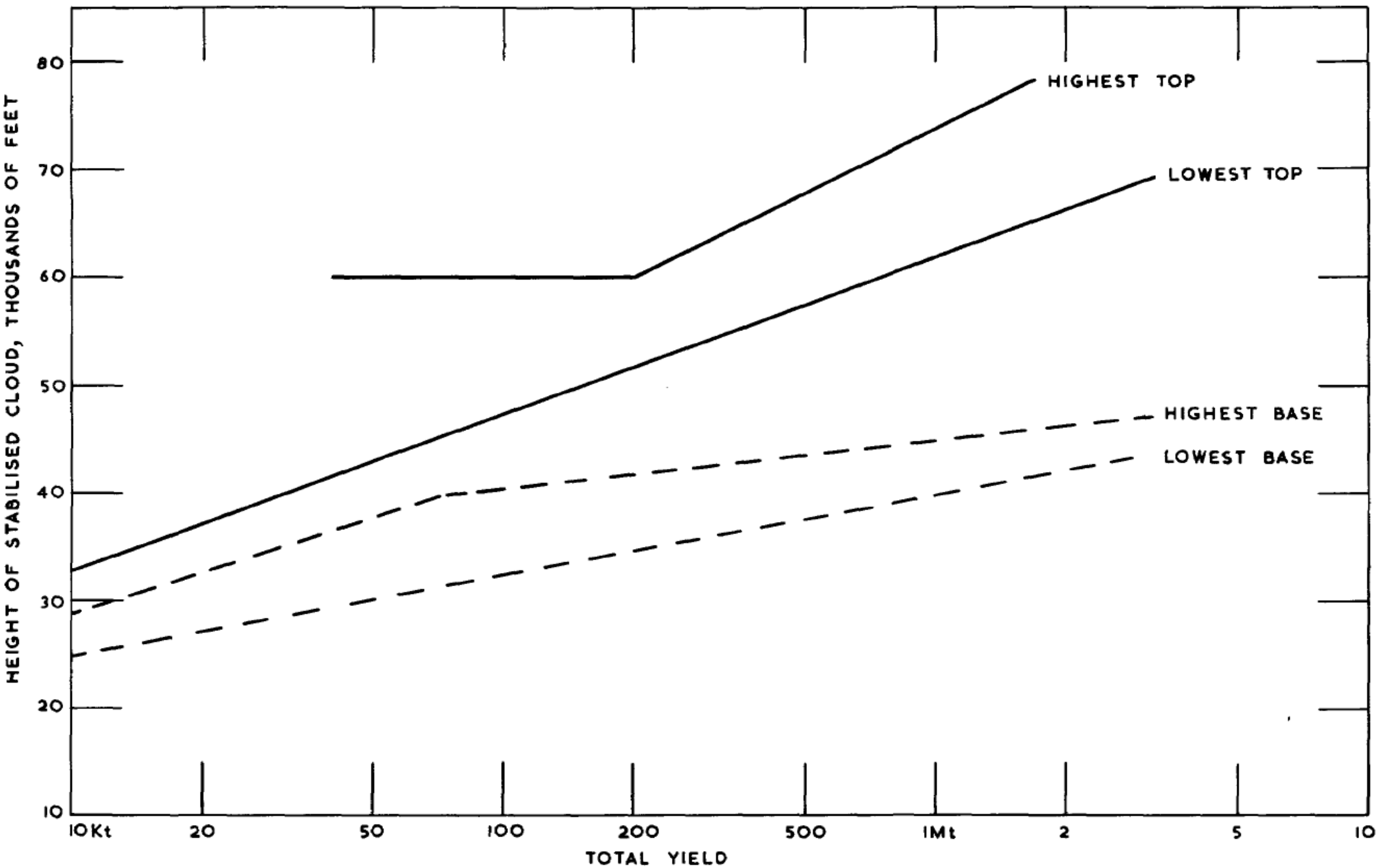

FIGURE 4. CLOUD HEIGHT AS A FUNCTION OF YIELD (REFERENCE 5)

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Figure 5 is not reproduced

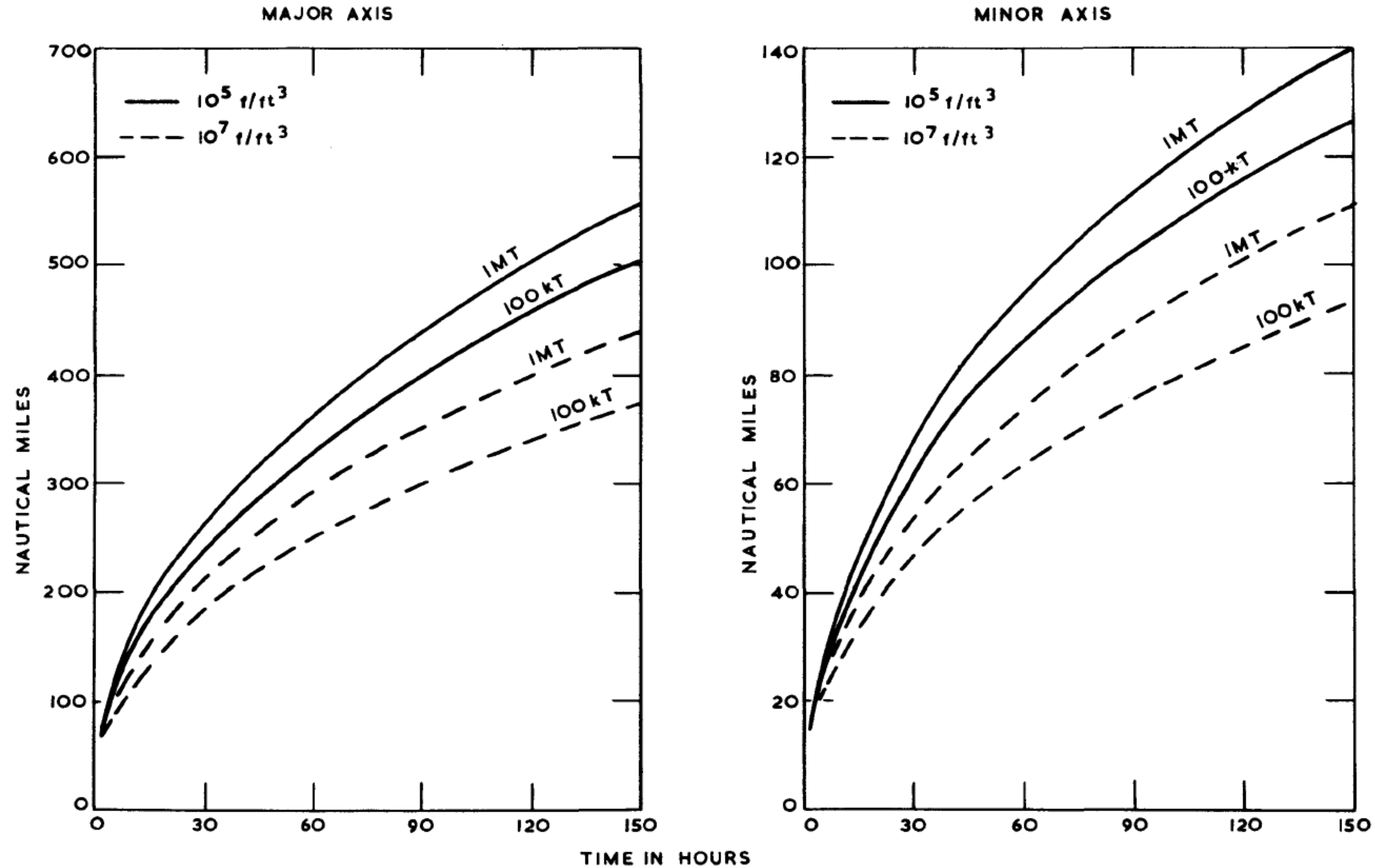
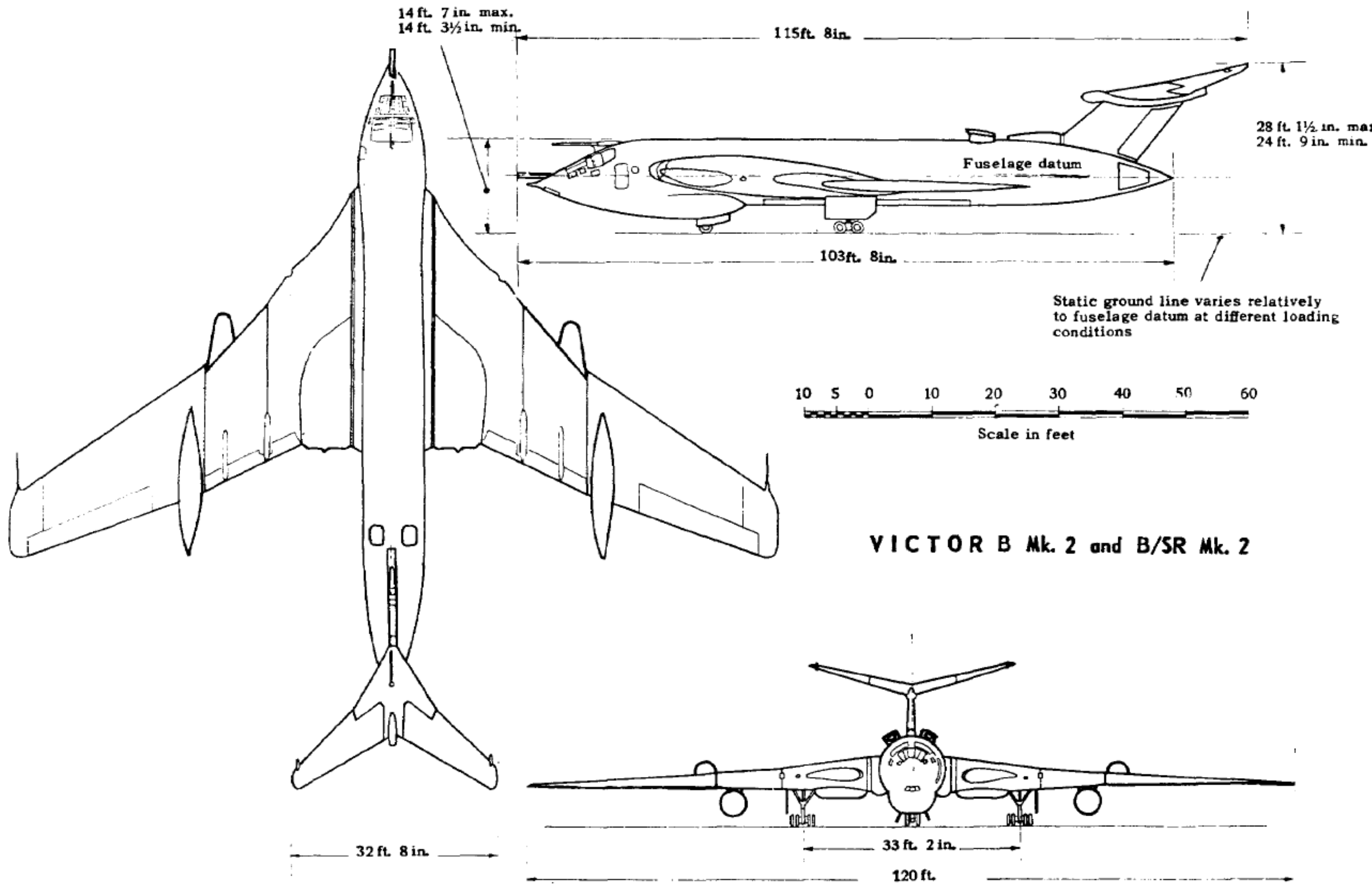
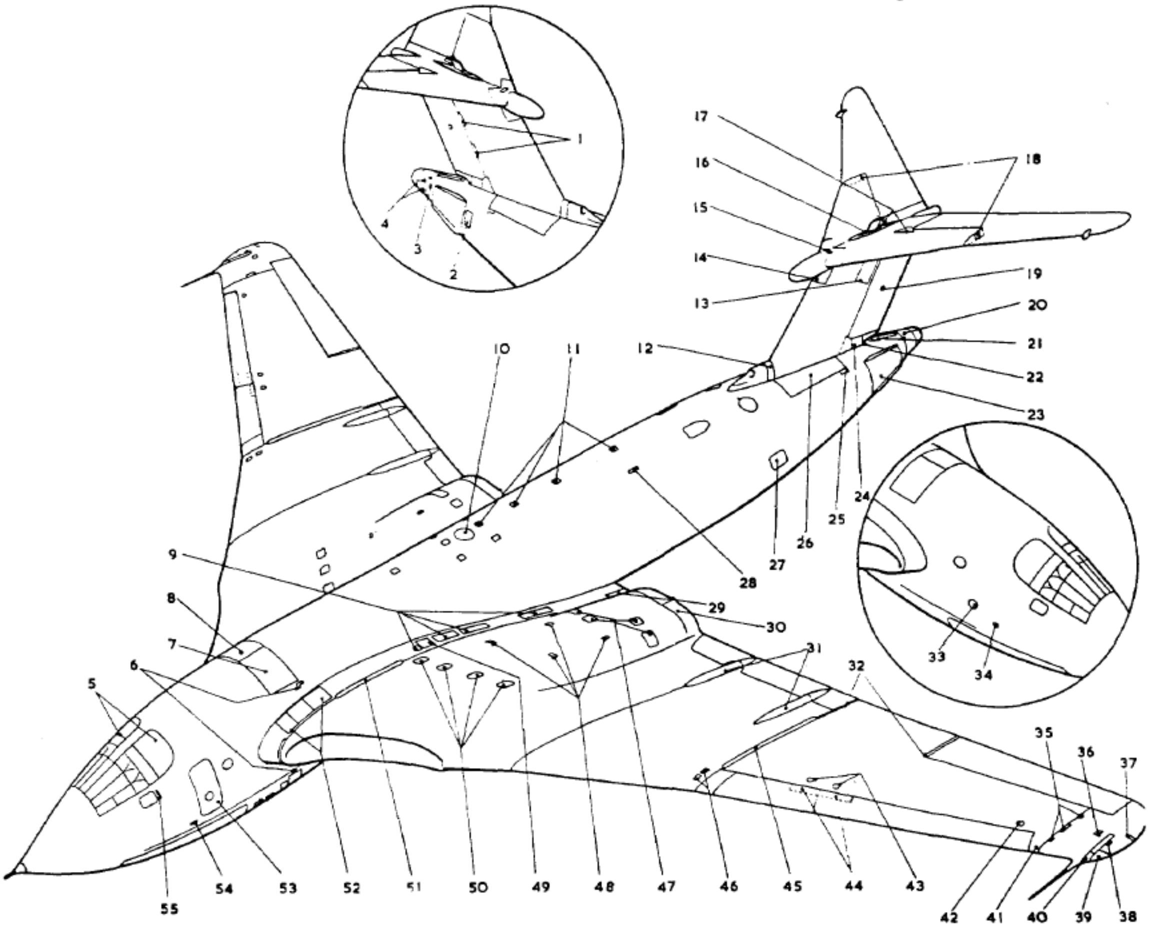


FIGURE 6. CALCULATED LATERAL SPREAD OF CLOUDS DUE TO DIFFUSION



VICTOR B Mk. 2 and B/SR Mk. 2

FIGURE 7



KEY

(All panels in the main planes and tail unit are on the port and starboard sides unless otherwise stated).

1. Rudder hinge attachments. *(Starboard side only, quick-release panels).*
2. Air brake jack. *(Starboard side only, hinged panel).*
3. Brake parachute door slip cocking. *(Starboard side only, quick-release panel).*
4. Tail warning. *(Starboard side only, screwed panel).*
5. Pilot's escape hatches.
6. Front to rear fuselage attachments. *(Screwed panels).*
7. Plenum chamber. *(Quick-release hinged door).*
8. Dinghy door.
9. Stub wing servicing. *(Screwed panels).*
10. D.F. loop, fuselage proportioner. *(Quick-release hinged door).*
11. Bomb hoist adapters. *(Screwed panels).*
12. Fin anti-icing duct. *(Quick-release panel).*
13. Rudder power unit. *(Port side only, quick-release panel).* one small integral panel gives access to reservoir filling points.
14. Anti-icing duct joint. *(Quick-release panel).*
15. Tail plane sling attachment. *(Screwed panels).*
16. U.H.F. aerial. *(Screwed panel).*
17. Anti-icing ducts and tail plane stub attachments. *(Screwed panel)*
18. Elevator hinge attachment. *(Screwed panel).*
19. Rudder sling attachment. *(Screwed panel).*
20. Tail scanner. *(Quick-release panel).*
21. Brake parachute. *(Spring loaded hinged doors).*
22. Brake parachute release unit. *(Screwed panel).*
23. Air brake.
24. Rudder stub-access rudder removal. *(Quick-release panels).*
25. Rear to tail fuselage attachments. *(Screwed panels).*
26. Fin to fuselage pipe joint. *(Screwed fairing panel).*
27. Rear fuselage compartment. *(Quick-release hinged door).*
28. Suppressed aerials. *(Quick-release panels).*
29. H.F. tuning unit. *(Screwed panel).*
30. Jet pipe fairing removal.
31. Flap track lead screws Stn. 212-290. *(Screwed fairing panels).*
32. Fairing-outer plane and aileron removal. *(Quick-release panels).*
33. Cabin air conditioning ground connection. *(Starboard side only, quick-release hinged door).*
34. Radar ground cooling coupling. *(Starboard side only screwed panel).*
35. Wing tip attachments. *(Quick-release panels).*
36. Pitot head pipes. *(Screwed panel).*
37. I.L.S. marker aerial. *(Screwed panel).*
38. Compass detector unit. *(Screwed panel).*
39. Navigation lamp. *(Quick-release cover).*
40. E.C.M. aerial. *(Screwed panel).*
41. Cooling duct intake heater mat. *(Screwed panel).*
42. Anti-icing air flap actuator, exit duct. *(Screwed panel).*
43. Nose flap actuator unit anchorage pins. *(Screwed panels).*
44. Nose flap actuator unit. *(Quick-release shroud panel).*
45. Outer to inner plane attachments. *(Quick-release fairing).*
46. Drop tank fuel pipe couplings. *(Quick-release panel).*
47. Thermo couples. *(Screwed panels).*
48. Engine hoist access. *(Screwed panels).*
49. Emergency de-fuelling. *(Hinged panel).*
50. Main plane servicing panels.
51. Inner plane pipe joint. *(Quick-release fairing).*
52. Freon unit bay cooling. *(Port side only, screwed panel).*
53. Crew entry door.
54. Crew entry door lock.
55. External release handle-pilots' escape hatches.

FIGURE 8. EQUIPMENT ACCESS PANELS – UPPER SURFACE

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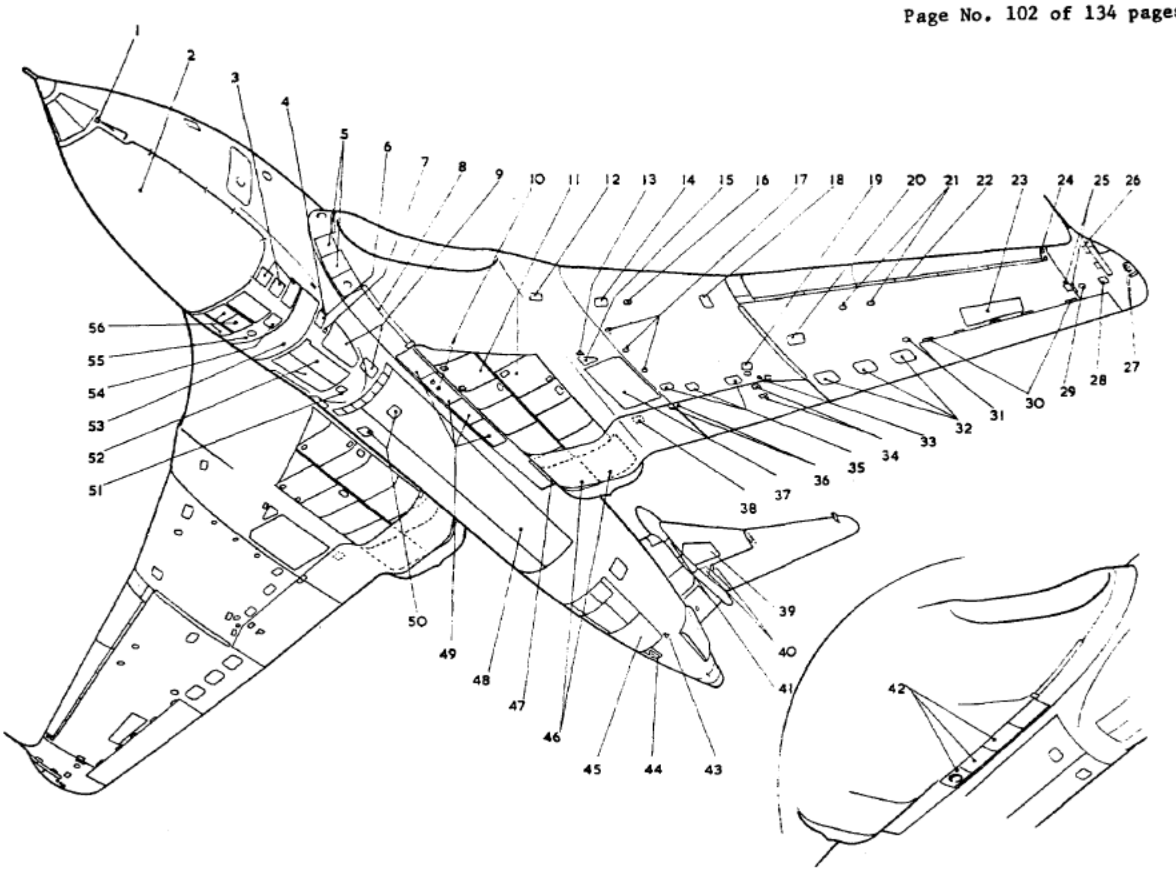


KEY

(All panels in the main planes and tail unit are on the port and starboard sides unless otherwise stated).

1. Intercommunication socket. *(Port side only).*
2. Scanner radome. *(Quick-release and screw attachments).*
3. Radar equipment. *(Port side only, hinged, quick-release panels).*
4. Engine starting. *(Port side only, hinged, quick-release panel).*
5. E.C.M. freon unit cooling bay. *(Port side only, quick-release panel).*
6. Battery compartment- port side, wheel brake servicing panel-starboard side. *(Hinged, quick-release panels).*
7. Nose wheel jacking point. *(Screwed panel).*
8. Inner plane pipe joint. *(Screwed panel).*
9. Equipment bays. *(Hinged, quick-release panels).*
10. Ground fuelling couplings. *(Port side only, hinged quick-release panels).*
11. Engine doors with integral panels for Sundstrand, engine oil tanks and fire access. *(No. 2 and No. 4 doors are hinged for routine servicing).*
12. Anti-icing exhaust, air flap. *(Electrically actuated).*
13. Jacking point. *(Quick-release panel).*
14. Jet pump inspection. *(Quick-release panel).*
15. Undercarriage retraction test observation. *(Quick-release panel).*
16. Fuel pipe inspection. *(Servicing panel).*
17. Fuel tank water drains. *(Quick-release panels).*
18. Drop tank attachment. *(Spring loaded hinged doors).*
19. Fuel tank booster pumps. *(Quick-release panels).* Tank No. 5
20. Fuel tank booster pumps. *(Quick-release panels).* Tank No. 6B.
21. Nose flap actuator unit anchorage pins. *(Screwed panels).*
22. Nose flap hinge attachment, actuator unit accumulator charging. *(Quick-release panels).*
23. Aileron power unit, tank 6B booster pump. *(Quick-release hinged panel).* One small integral panel gives access to reservoir filling points.
24. Cooling duct joints and heater mats. *(Quick-release panels).*
25. Wing tip attachment bolt. *(Quick-release panel).*
26. E.C.M. aerial. *(Screwed panel).*
27. I.L.S. aerial cable connector. *(Quick-release panel).*
28. Pitot head piping. *(Screwed panel).*
29. Pressure head water drain and terminal block. *(Quick-release panel).*
30. Aileron hinge attachments. *(Quick-release hinged panels).*
31. Fuel tank water drains. *(Quick-release panels).*
32. Flying controls. *(Quick-release panels).*
33. Long range tank rear steady. *(Quick-release panels).*
34. Outer flap removal. *(Access panels).*
35. Flying controls. *(Quick-release panels).*
36. Flap removal. *(Access panels).*
37. Main undercarriage bay door.
38. Flap mechanism. *(Quick-release panel in shroud).*
39. Elevator power unit. *(Quick-release hinged panel).* One small integral panel gives access to reservoir filling points.
40. Elevator anti-icing duct. *(Access panels).*
41. Tail plane to fin attachments. *(Quick-release fairing in four sections).*
42. A.A.P.P. access doors.
43. Rear to tail fuselage attachments. *(Screwed panels).*
44. Jacking point and bumper wheel. *(Screwed panel).*
45. Rear radome with integral servicing panels. *(Quick-release fasteners).*
46. Jet pipes. *(Quick-release panels).*
47. Flap removal panel.
48. Bomb doors.
49. Stub wing servicing panels.
50. Bomb bay inspection panel.
51. Hydraulic tank drains. *(Screwed panel).*
52. Nose undercarriage bay doors.
53. Window launcher.
54. I.F.F. access panel.
55. E.C.M. equipment servicing panel.
56. E.C.M. access doors.

FIGURE 9. EQUIPMENT ACCESS PANELS - LOWER SURFACE

[redacted]

[redacted]

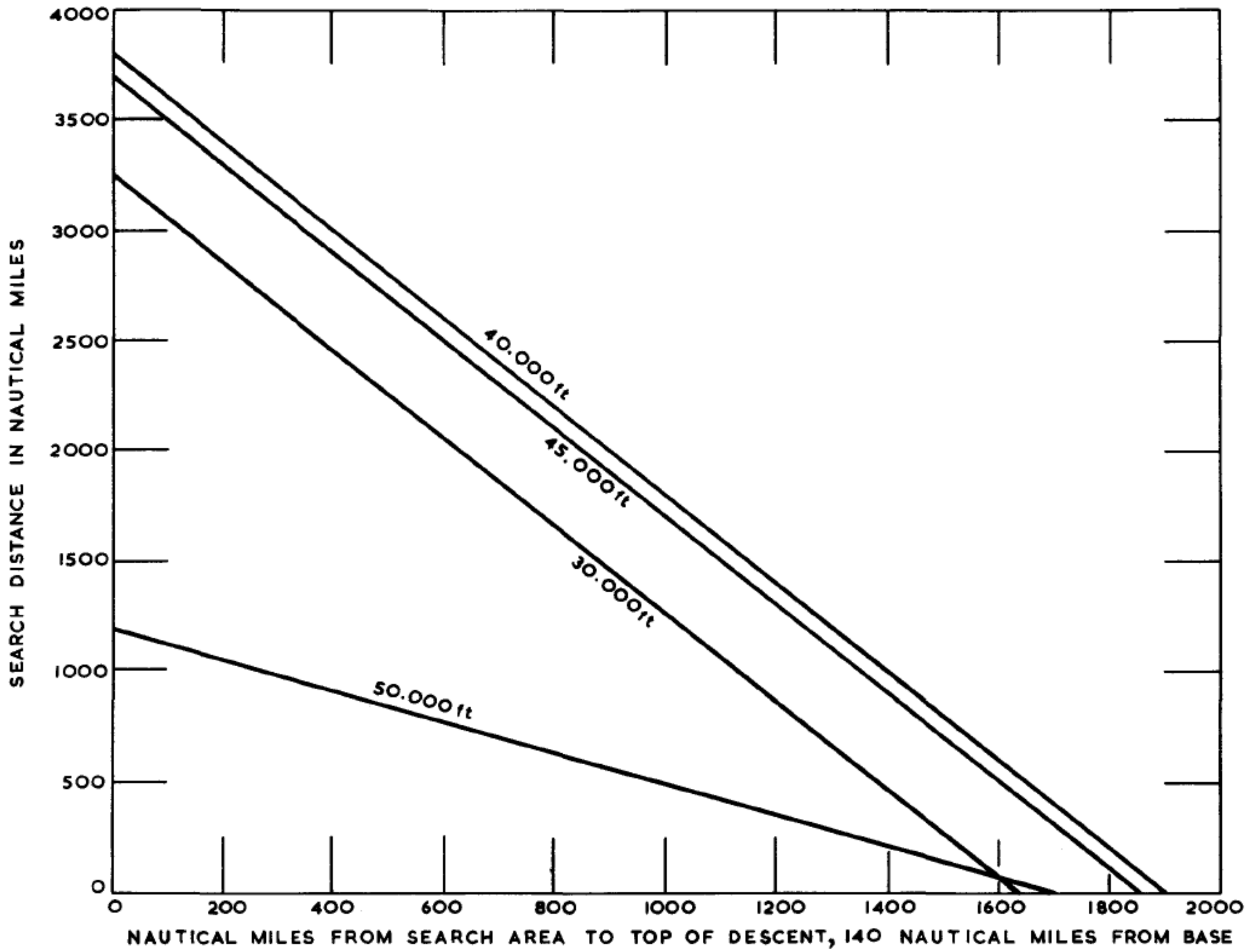
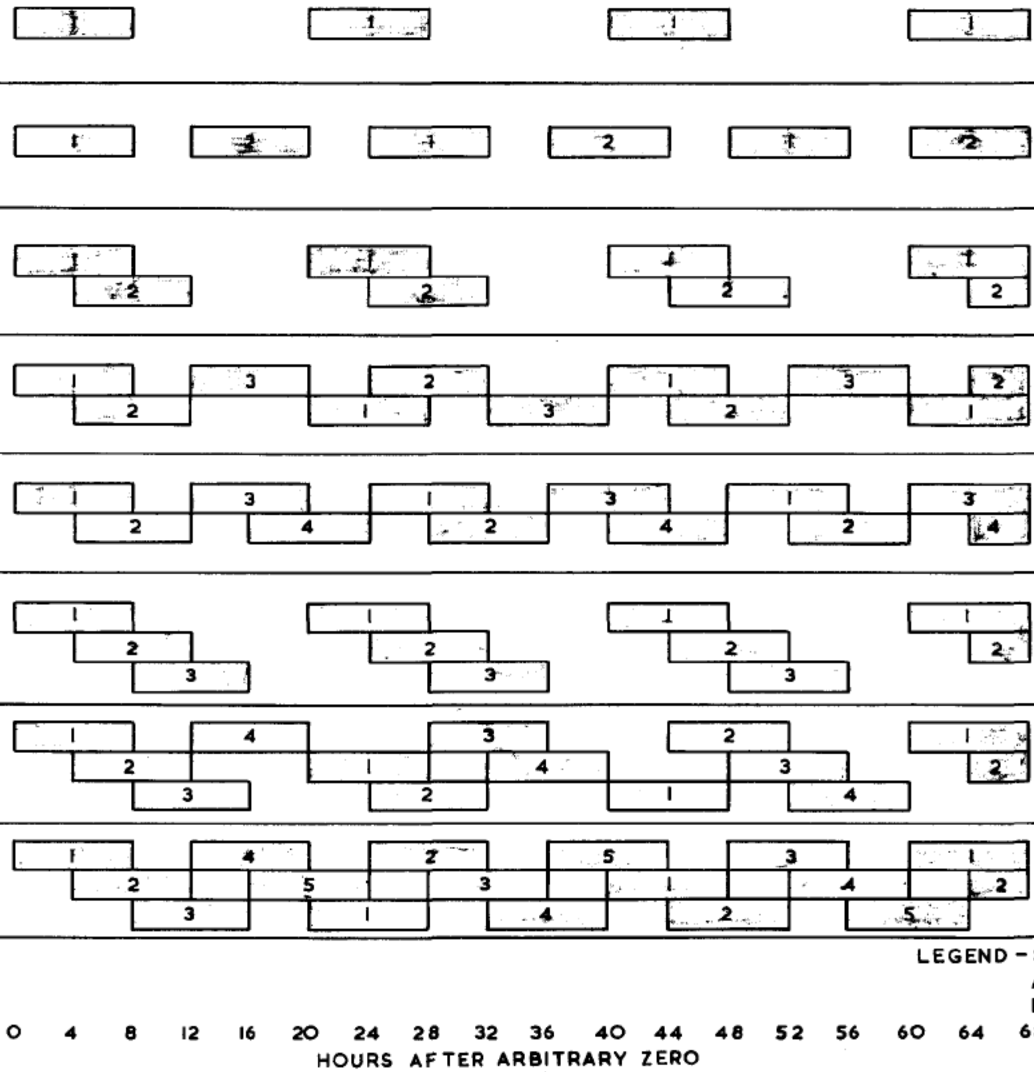


FIGURE 10. SEARCH DISTANCE AS FUNCTION OF ALTITUDE AND DISTANCE FROM BASE

[redacted]

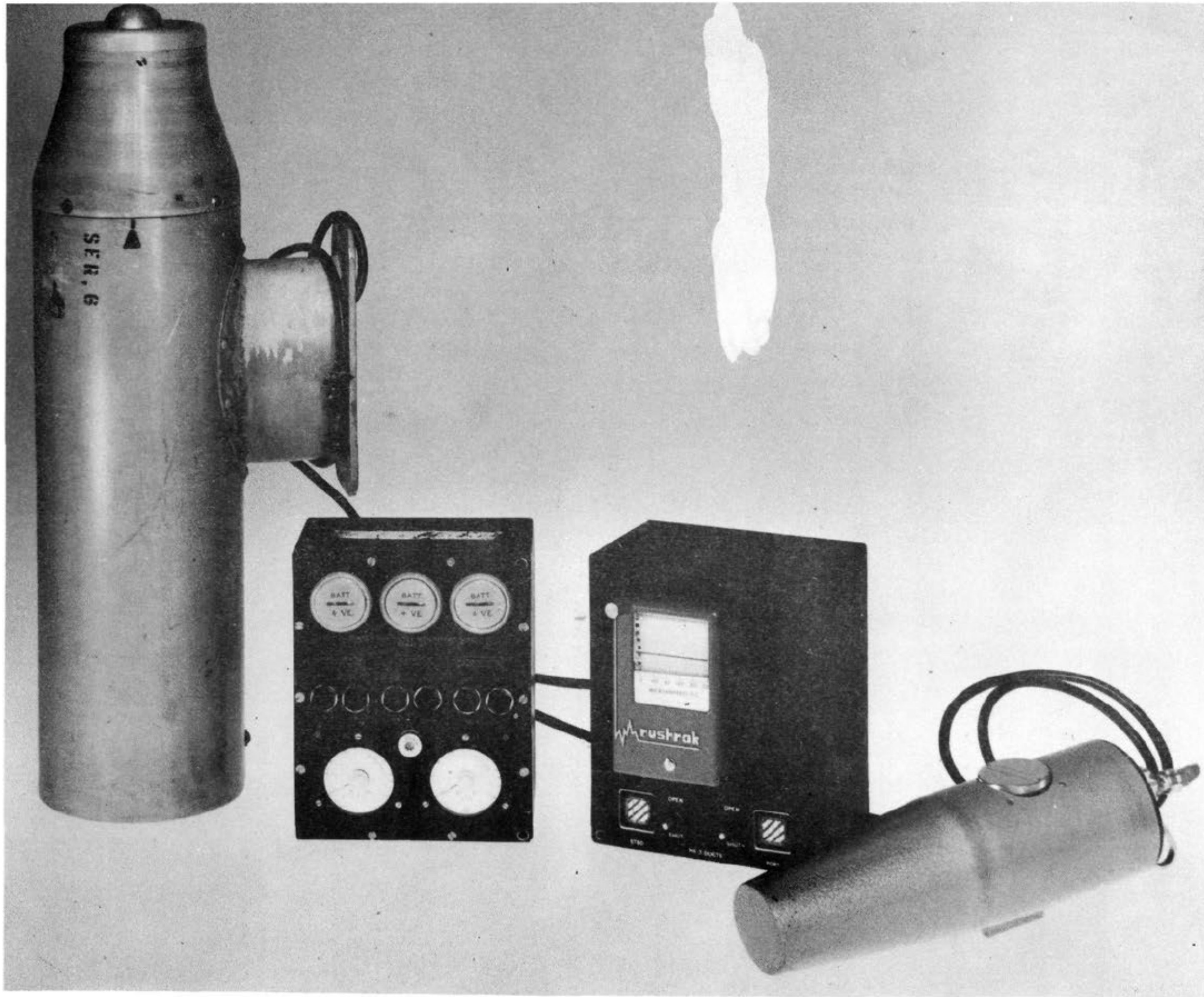
No. OF PLANES	No. OF CREWS	PLANE No.	FLIGHT HOURS PER HOUR	FLIGHT HOURS PER HOUR PER PLANE	FLIGHT HOURS PER HOUR PER CREW
1	1	1	0·4	0·4	0·4
1	2	1	0·67	0·67	0·39
2	2	1, 2	0·8	0·4	0·4
2	3	1, 2	1·2	0·6	0·4
2	4	1, 2	1·33	0·67	0·33
3	3	1, 2, 3	1·2	0·4	0·4
3	4	1, 2, 3	1·6	0·53	0·4
3	5	1, 2, 3	2·0	0·67	0·4



LEGEND – SHADED BOXES SHOW AIRCRAFT AIRBORNE AND NUMBERS SHOW AIRCREW SEQUENCE NUMBER

FIGURE II. AVERAGE SORTIE RATES AS FUNCTION OF PLANES AND CREWS

[redacted]



[redacted]

FIGURE 12. MK. X DUCT CONTAINING MX 172 GEIGER (LEFT), NIS 322 SEARCH CRYSTAL MONITOR (RIGHT) TOGETHER WITH CONTROL PANELS AND RECORDER. ALL THIS EQUIPMENT IS KNOWN COLLECTIVELY AS THE NIS 361

[redacted]

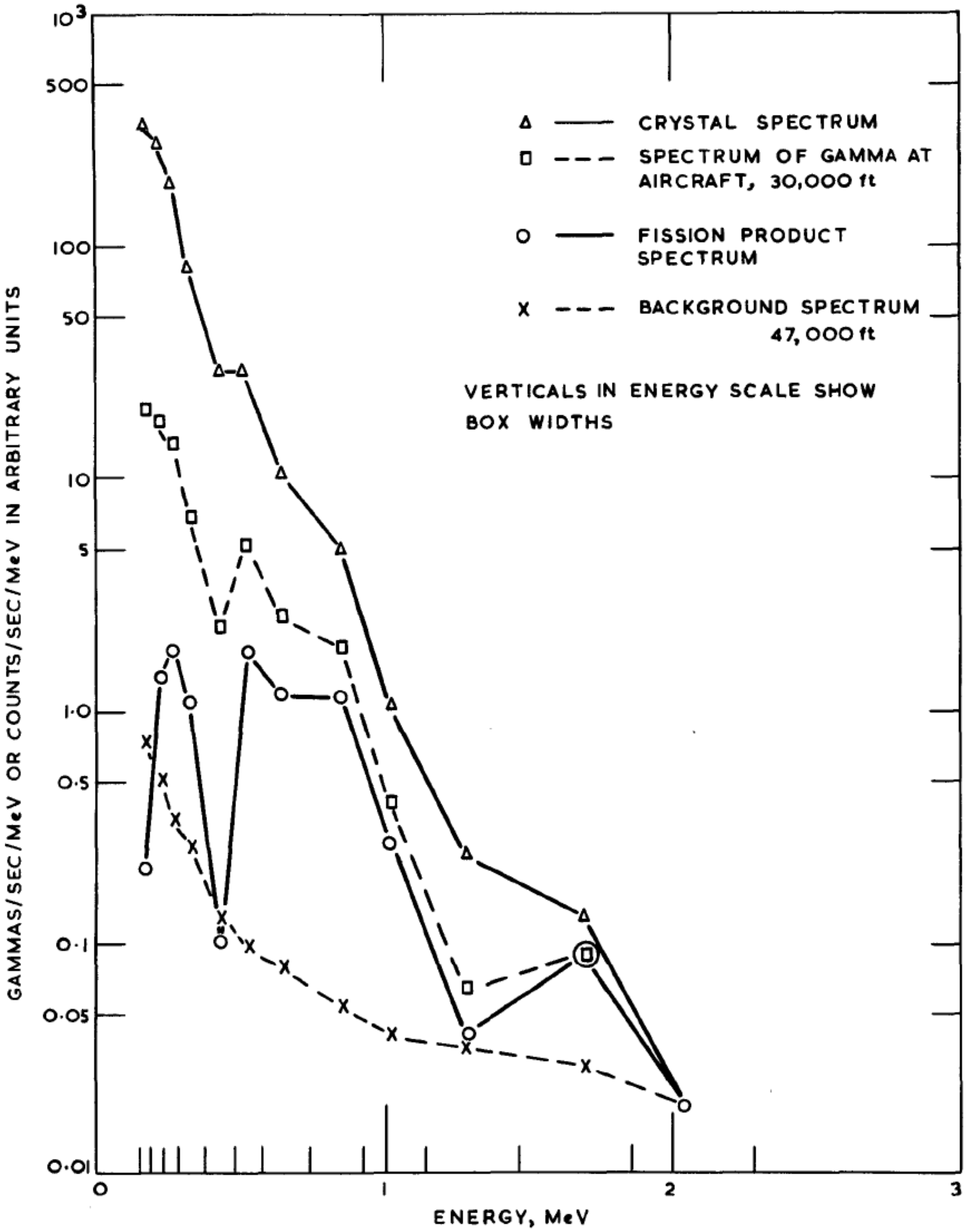


FIGURE 13. COMPARISON OF SPECTRAL SHAPES OF GAMMAS FROM FISSION PRODUCTS, GAMMAS REACHING AIRCRAFT FROM UNIFORM f.p. DENSITY, CRYSTAL SPECTRUM AND BACKGROUND, ALL NORMALISED TO HIGHEST ENERGY GROUP

[redacted]

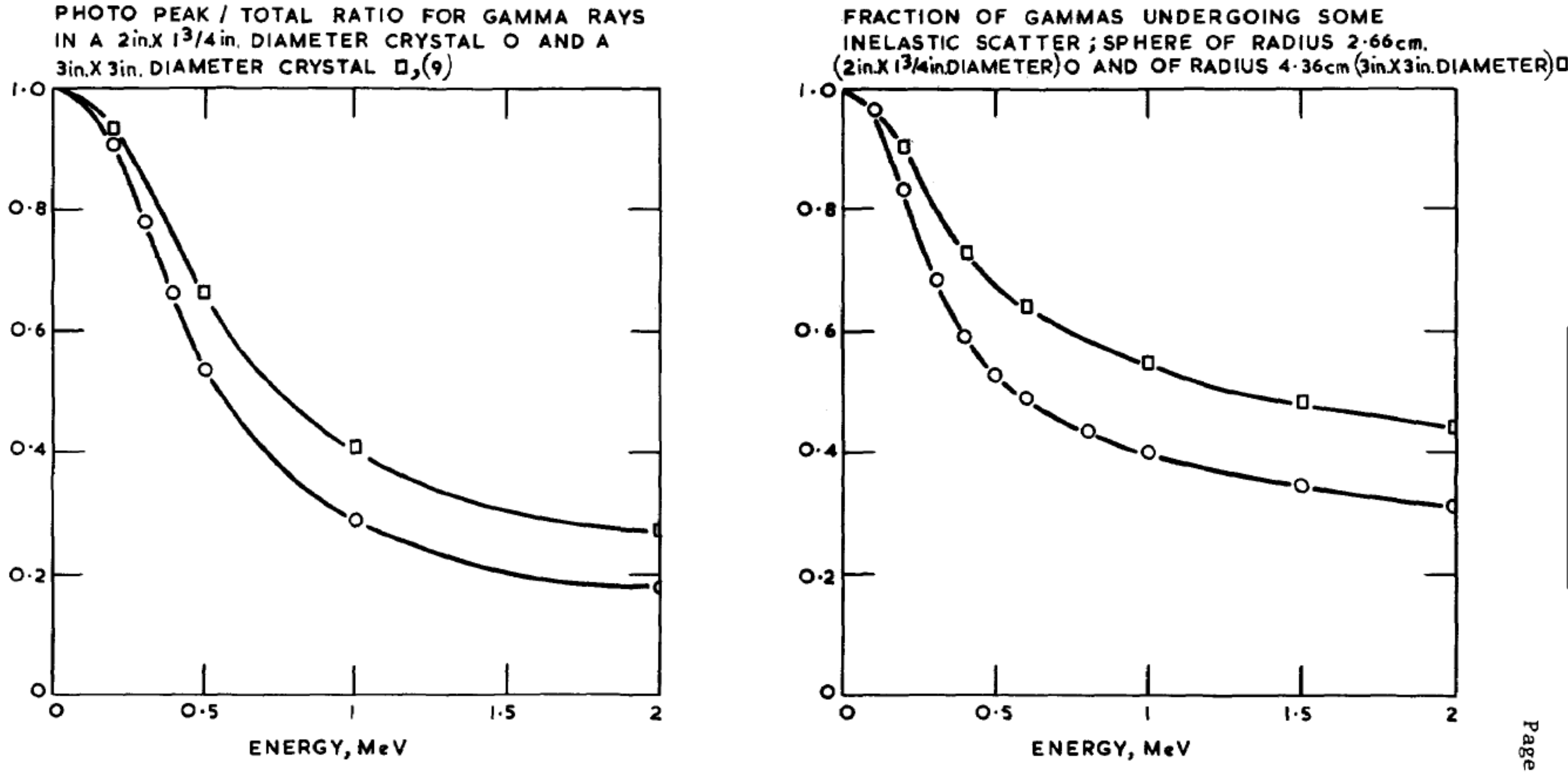


FIGURE 14. INTEREACTION OF GAMMA RAYS WITH SODIUM IODIDE CRYSTAL

[redacted]

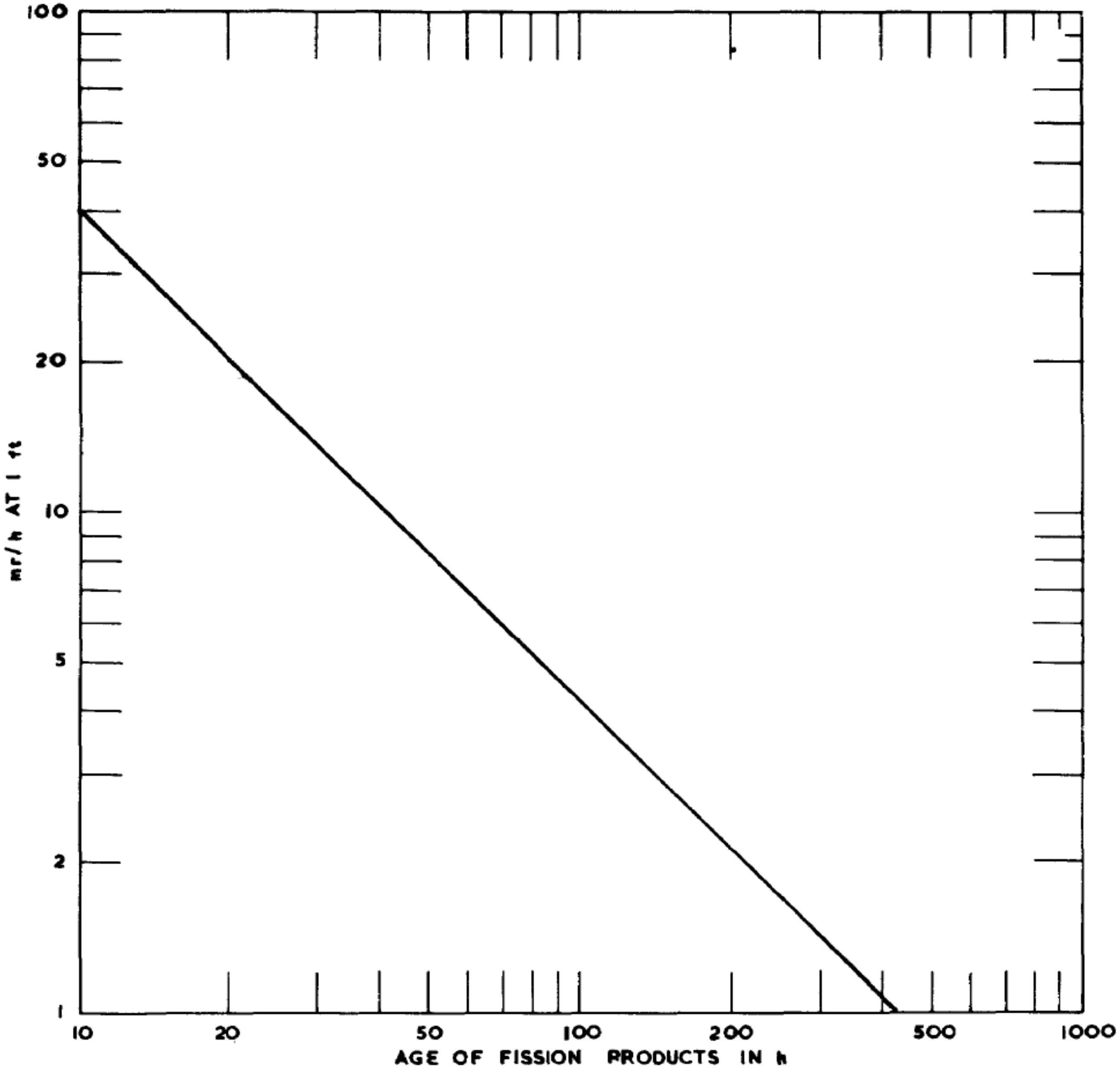


FIGURE 15. ACTIVITY OF 10^{14} FISSIONS AS A FUNCTION OF TIME

[redacted]

[redacted]

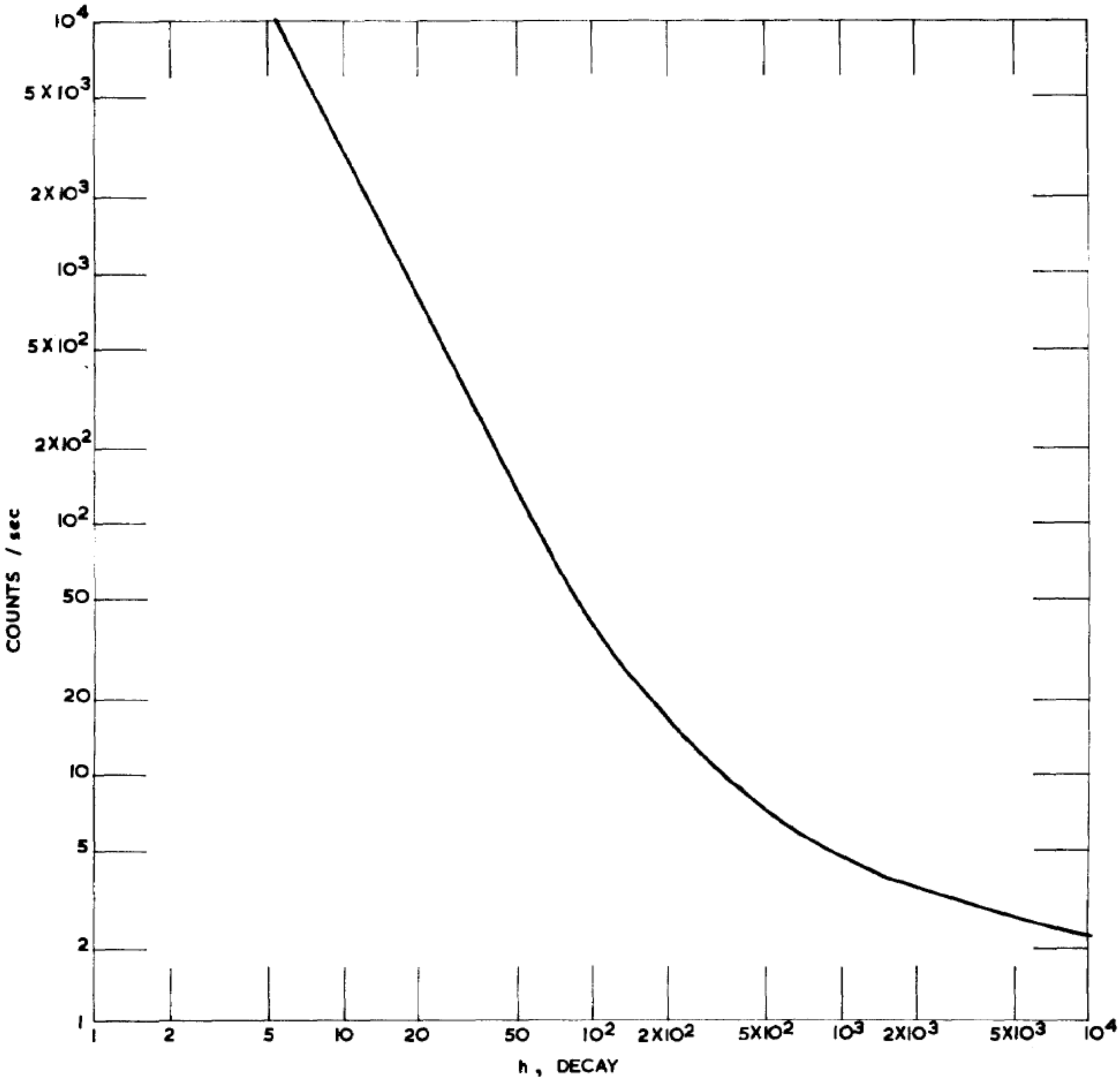


FIGURE 16. RESPONSE OF MX 172 GEIGER IN MK. X DUCT TO 10^{10} FISSIONS

[redacted]

[redacted]

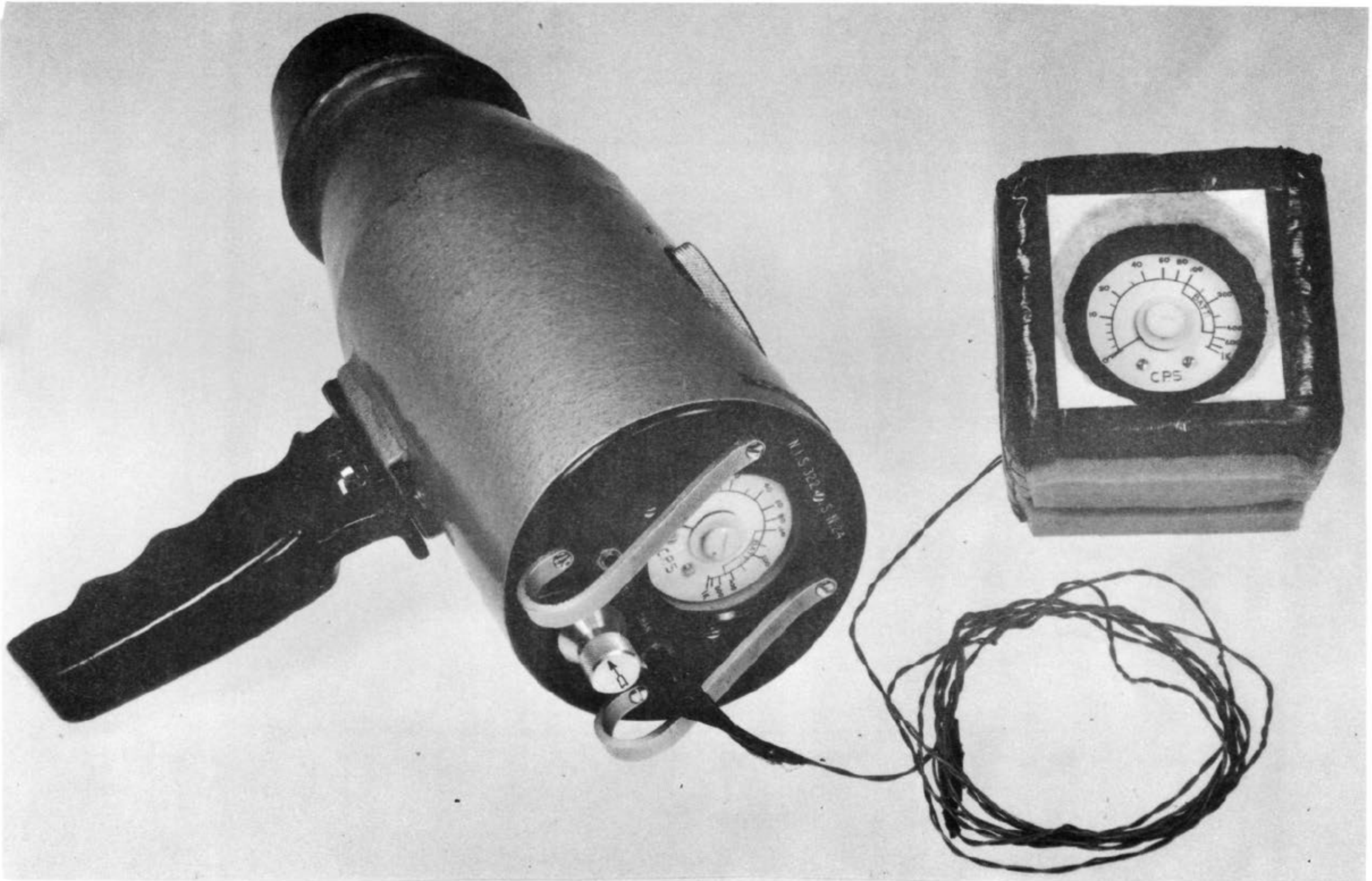


FIGURE 17. NIS 322 UP/DOWN DIRECTION METER WITH REMOTE METER

[redacted]

FIGURE 18. NIS 295 RADIATION SURVEY METER WITH "RUSTRAK" RECORDER

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

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[redacted]

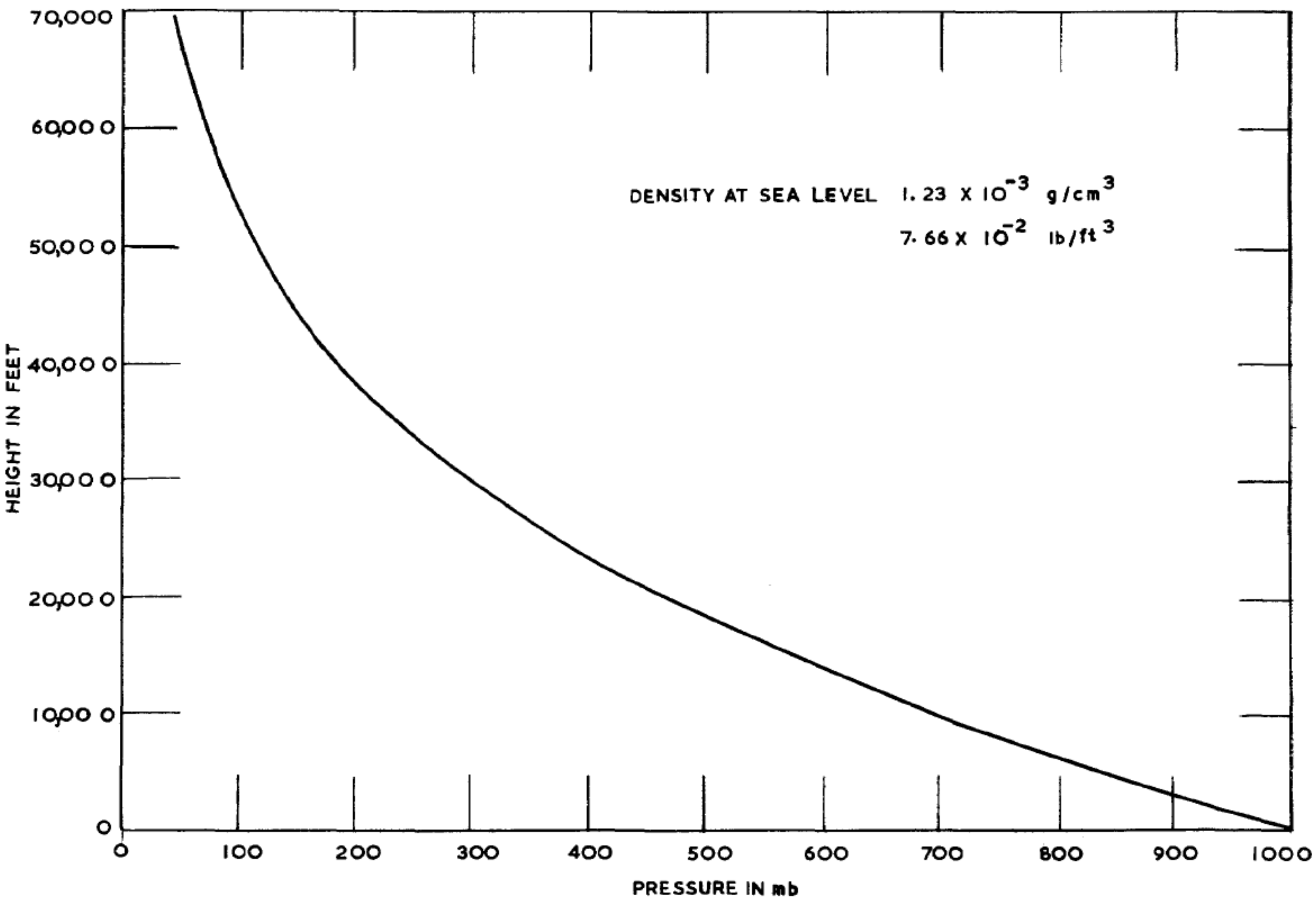

FIGURE 25. ALTITUDE AGAINST PRESSURE FOR STANDARD I.C.A.O. ATMOSPHERE

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

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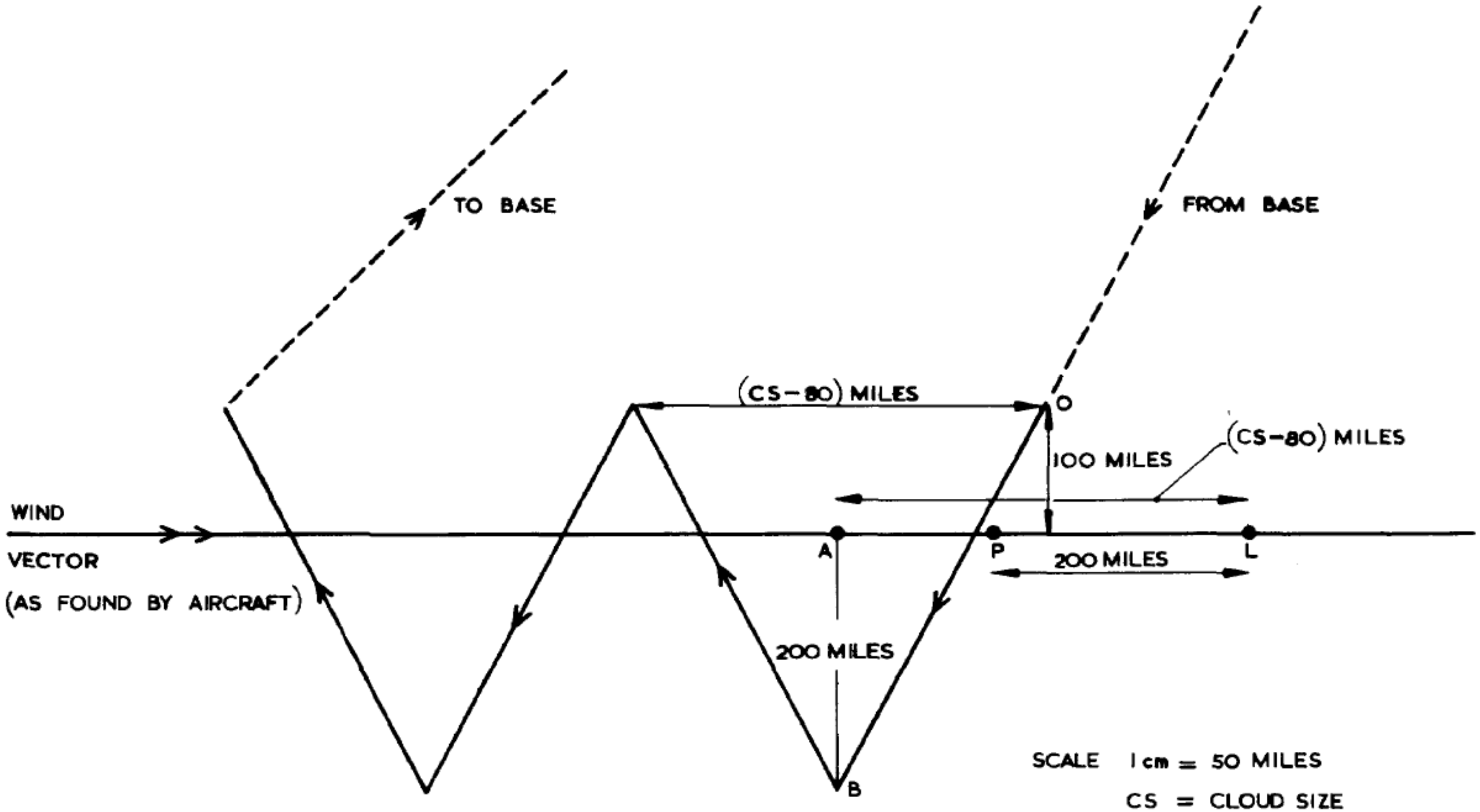
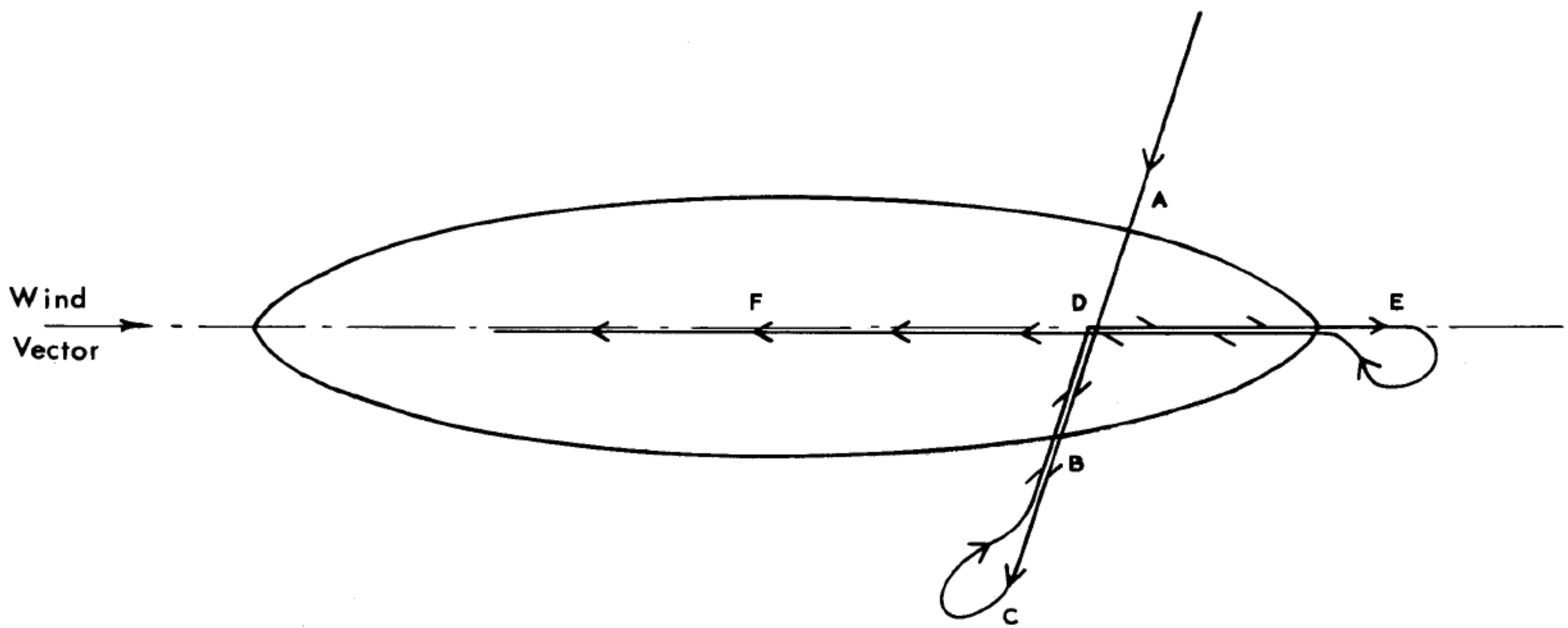


FIGURE 33. IDEALISED SEARCH PATTERN

(ELLIPSE REPRESENTS 10^7 f / ft^3 CONTOUR FOR 1 Mt SHOT AFTER TRAVELLING FOR 120 HOURS – 400 MILES LONG AND 100 MILES WIDE)



SCALE 1 cm = 25 MILES

FIGURE 34. IDEALISED SURVEY PATTERN

[redacted]

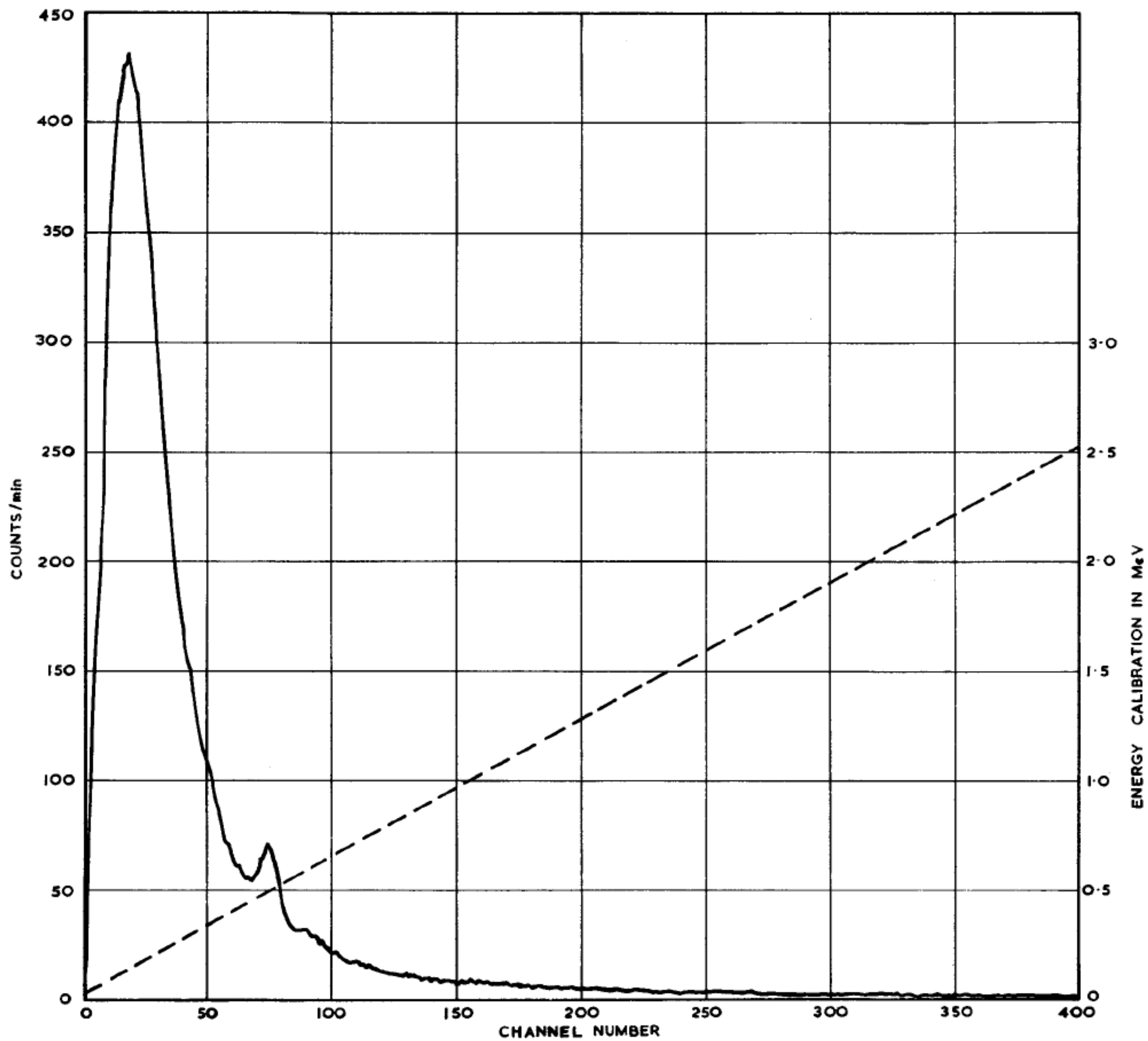


FIGURE 35. BACKGROUND SPECTRUM AT 39,000 ft

[redacted]

[redacted]

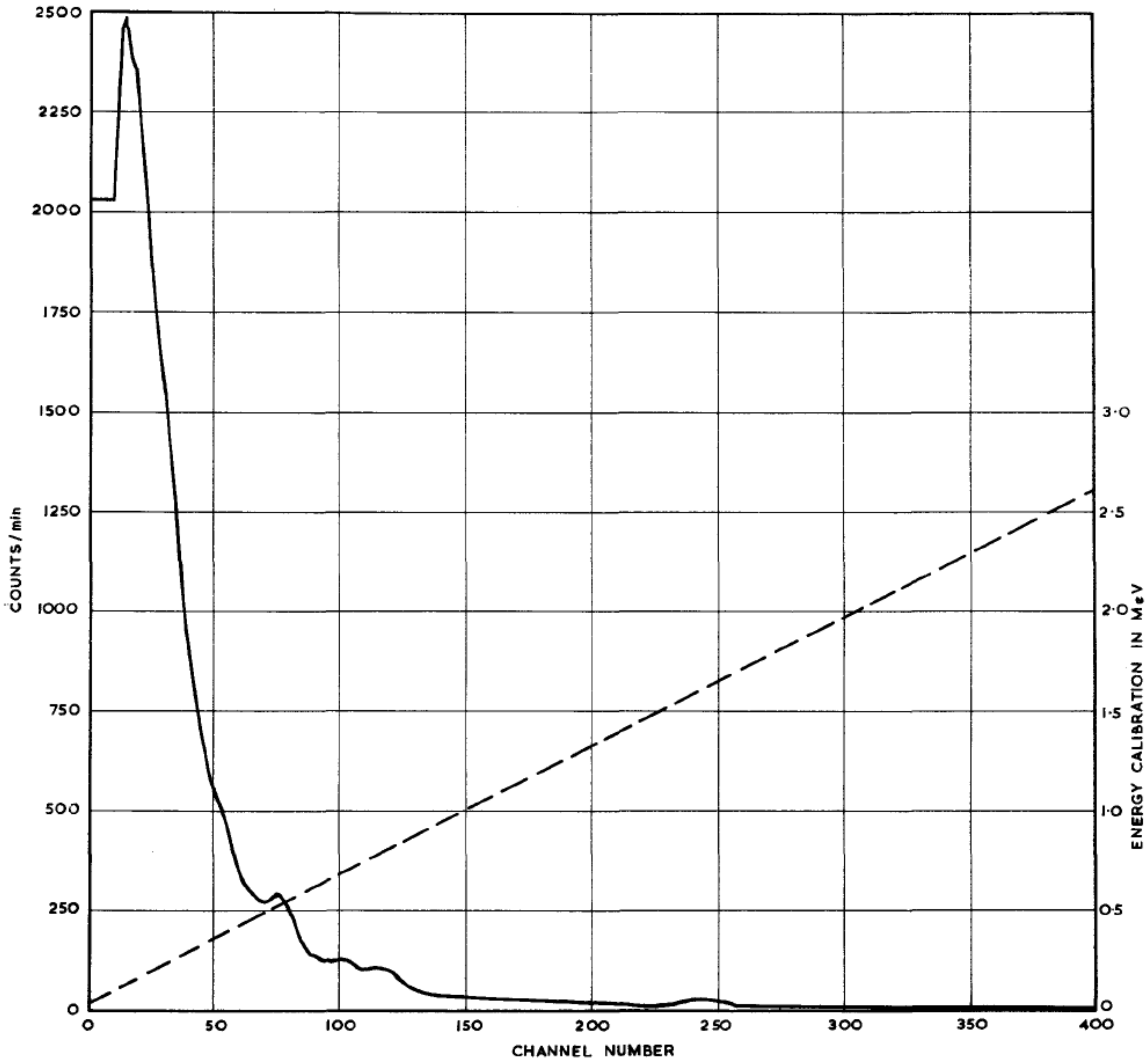


FIGURE 36. SPECTRUM FROM FLIGHT 26

[redacted]

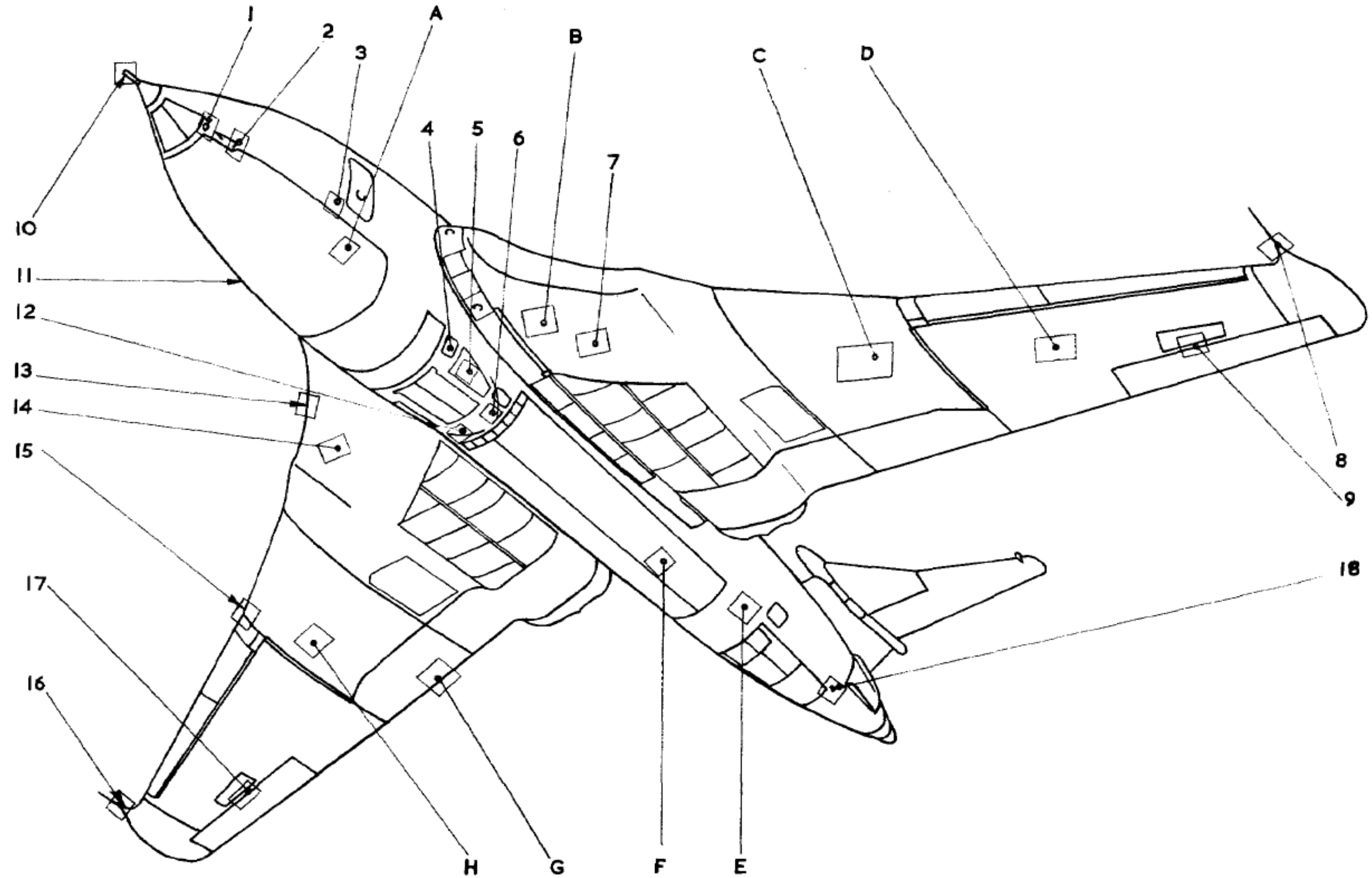


FIGURE 37. STANDARD SURVEY POSITIONS (TABLE 12·1)

[redacted]

[redacted]

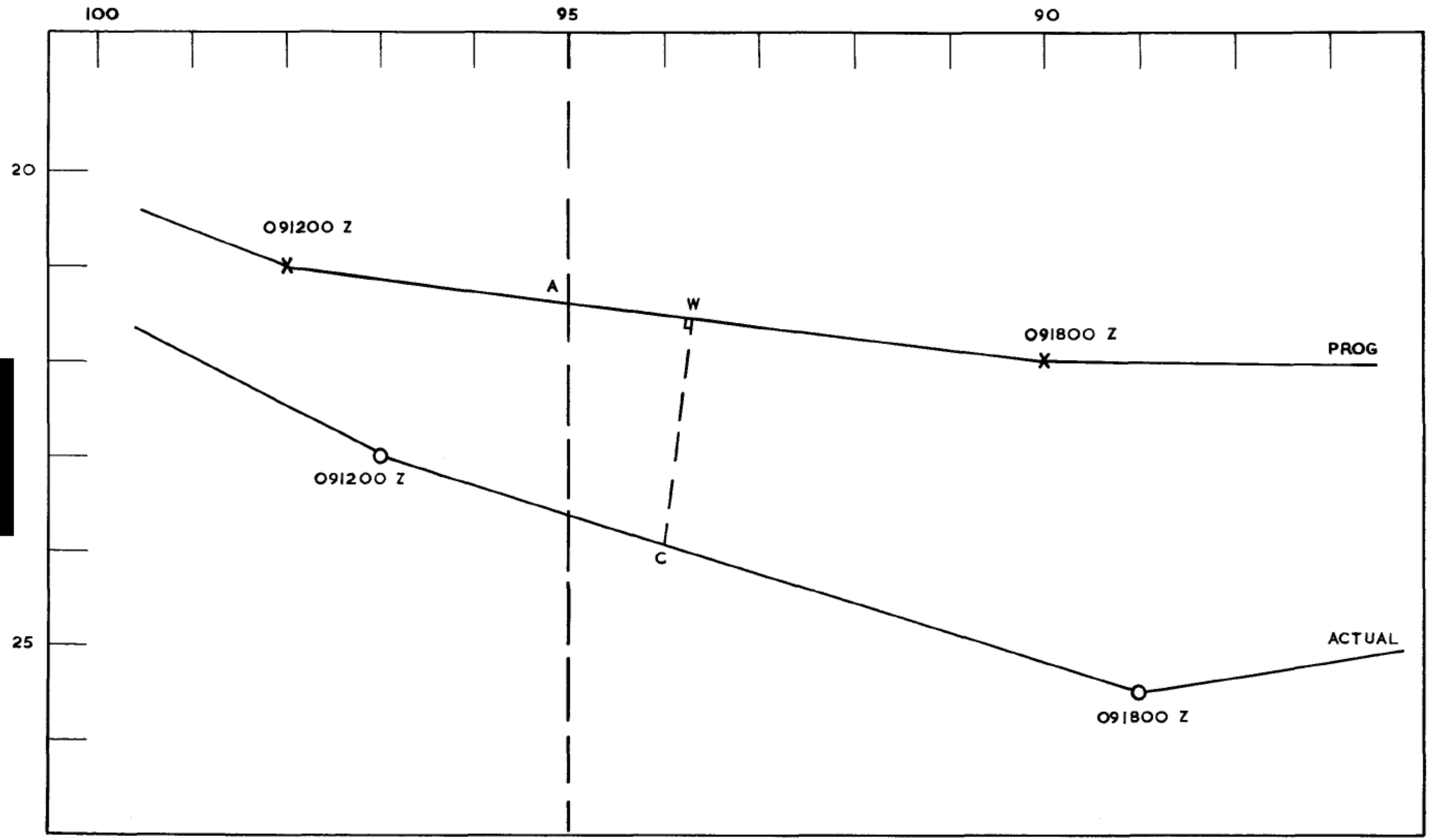
[redacted]

[redacted]

[redacted]

[redacted]

[redacted]



[redacted]

[redacted]

FIGURE 40. ILLUSTRATION OF DERIVATION OF FORECAST ERRORS

[redacted]

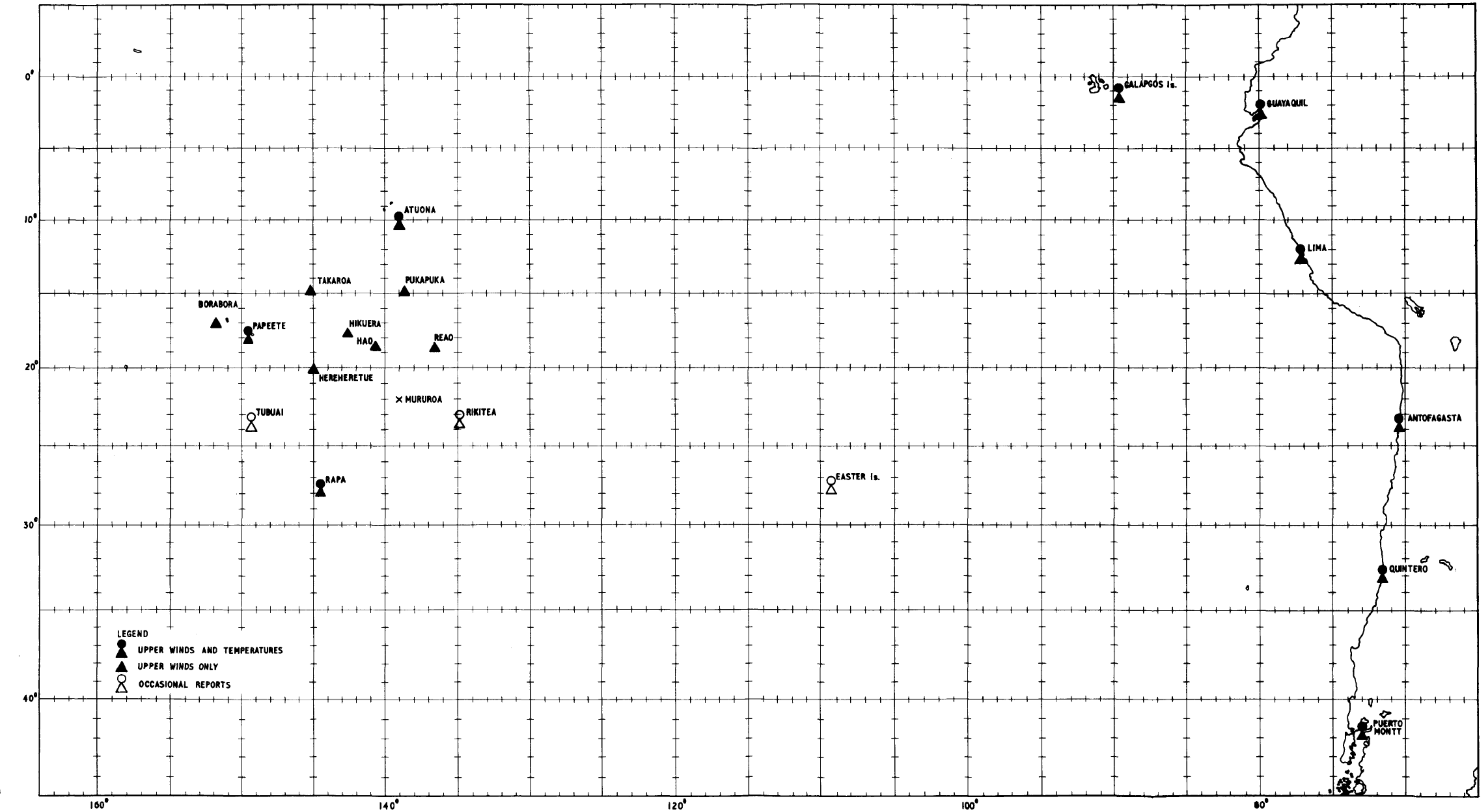


FIGURE 41. SOURCES OF METEOROLOGICAL DATA

[redacted]

Initial Distribution

Internal

No. 1-2 [redacted]

External

No. [redacted]