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Practical Choice of a Measuring Method for Aerial Surveys in Emergency Situations

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PRACTICAL CHOICE OF A MEASURING METHOD FOR AERIAL SURVEYS IN EMERGENCY SITUATIONS

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Abstract

PRACTICAL CHOICE OF A MEASURING METHOD FOR AERIAL SURVEYS IN EMERGENCY SITUATIONS. The necessity for quick aerial surveillance after an accidental release of radioactive material is generally acknowledged. The measuring equipment used for this purpose should be able to detect surface contaminations of ^{131}I as low as 0.4 $\mu Ci/m^2$. Till now portable survey meters and scintillation detectors of various sizes have been used. However, it is difficult to compare the published results because the low detection limit for ^{131}I contamination depends on: the kind and size of the detector; the measuring method used; the composition and distribution of the fission products deposited; a knowledge of the background and its local variations; and the influences of the actual flight conditions.

Starting from a background survey with a helicopter and from calibration measurements on a meteorological tower with ^{131}I and ^{137}Cs point sources, the sensitivity to surface contamination has been evaluated for an energy-compensated G-M dose ratemeter and a scintillation detector. The lower detection limit and the relative merits of measuring dose-rate, gross counts or the ^{131}I peak are discussed for various compositions of fission products and actual flight conditions.

1. INTRODUCTION

After an accidental release of radionuclides to the environment it will be necessary to know as soon as possible the extent of the contaminated area and the amount of surface contamination, especially from the nuclide ^{131}I. Therefore measurements are most suitably made from an aircraft. Based on the experience gained after the Windscale reactor accident [1-5], test flights and background measurements have been carried out in the past years by several research establishments. These measurements were performed with available equipment, e.g. with small portable instruments, but also with large and expensive scintimeters. Starting from test flights and calibrations at the Karlsruhe Nuclear Research Centre, the kind of measuring equipment best suited for an aerial survey after a reactor accident has been considered.

According to the permissible emergency levels in milk, a corresponding deposition of 0.4 $\mu Ci/m^2$ of ^{131}I should be determined by an aerial survey. Such a small surface activity produces a dose-rate of only a fraction of the natural background, even at 1 m above ground. So it is obvious that the practically achievable lower detection limit is not just a property of the detector alone, but depends largely on

(i) A knowledge of the local background at the time of measurement
(ii) The kind of the emergency situation, especially the composition of the released fission product mixture and the distribution over the contaminated area
(iii) The flight conditions, such as speed and altitude of the aircraft, the topography and how accurately the ground clearance can be maintained
(iv) The weather, which influences all these conditions.

Similar problems arise in aerial prospecting for uranium and with general fall-out measurements [7]. These tasks and the measuring methods applied are summarized in Fig. 1. The main difference may be seen in the fact that the aerial surveys following a reactor accident have to be carried out at once without losing time in preparation and regardless of unfavourable weather conditions. The results are needed immediately.

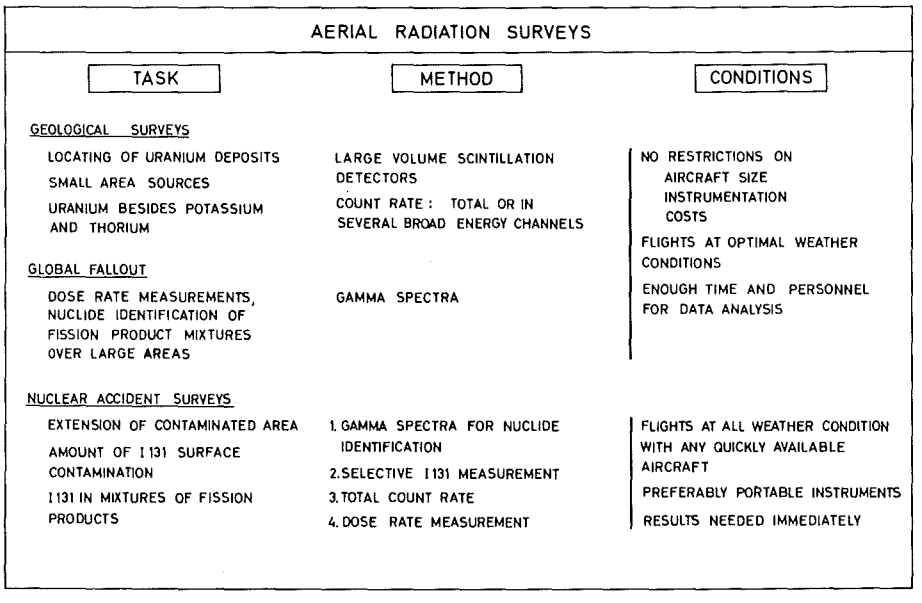

FIG. 1. Different kinds of radiation surveys.

Therefore the rich experience and sophisticated equipment and procedures used for uranium prospecting cannot be transferred directly to our purposes.

During most former test flights the total count rate of a scintillation detector was recorded and the threshold has been set low enough to integrate over the total stray radiation spectrum. As in a nuclear accident mainly the detection of ground contamination by ^{131}I is of interest, we also examined other measuring methods aiming for a comparison of the lower detection limit practically achievable for ^{131}I surface contamination.

The following possibilities were considered in particular:

(1) Gamma spectroscopy for nuclide identification with a scintillation detector

(2) Selective measurement of ^{131}I with a scintillation detector and a single-channel analyser set for the 360-keV peak
(3) Recording of the total count rate with a scintillation detector and an integral discriminator
(4) True dose-rate measurement with an energy independent detector (G-M counter with energy compensation filter).

As it is undesirable to contaminate a large area with fission products for test purposes, the calibration problem was solved in two steps:

(1) Determination of the lower detection limit for a surface contamination under ideal conditions on a meteorological tower
(2) Consideration of the influences impairing the ideal conditions during an actual flight over a contaminated area.

2. CALIBRATION EXPERIMENTS

To take into account the degradation of the spectra resulting from radiation scattering and absorption, the calibration irradiations were carried out under ideal conditions at a 200-m meteorological tower with point sources. Two sources, one 5.8 Ci ^{131}I and the other 10 Ci ^{137}Cs, were located on the ground at various distances from the tower. The height of the detectors above ground was varied from 60 to 130 m, but most measurements were made at a height of 80 m, corresponding to the flight altitude assumed for the following discussion. The results of these point-source calibrations were used to evaluate the sensitivity for a surface contamination ($\mu Ci/m^2$). For this calibration run the available health physics equipment was used.

The dose-rate instrument consisted of a large G-M counter tube, type BZ 120, with an energy compensation filter so that the dose-rate indication is energy dependent only within ± 30% in the energy range of 25 keV to 1.2 MeV for all radiation incidences [8]. The logarithmic ratemeter covers a range from 10 μR/h to 10 mR/h. Furthermore, a scintillation detector with a NaI crystal of 1.5 × 1.5 in. was used in connection with a 100-channel pulse height analyser. The crystal size is typical for portable scintillation meters. The detection properties of larger crystals will be considered in the discussion later on. The spectra were printed out in the energy range from 50 to 900 keV (see Fig. 2). From these spectra the gross count rate together with the total and net count-rates under the 360-keV ^{131}I peak were derived. These values gave the calibration factor for an ^{131}I point source for the cases of a dose-rate measurement, the measurement of the total count rate and a selective ^{131}I measurement (see Table I).

Proceeding from this point source calibration the calibration factors for surface activities were determined numerically. For this purpose the surface activity of a surface unit of 1 m^2 was represented by a point source. The detector indication produced by such a surface unit is known from the point source calibration. The integration over all surface units was done by summarizing the contributions of concentric equidistant rings with a width of 10 m. The results of Figs 3-5 show how the detector indication varies with increasing radius at a height of 80 m above a homogeneously contaminated circular area. Surface units with a radius larger than 350 m

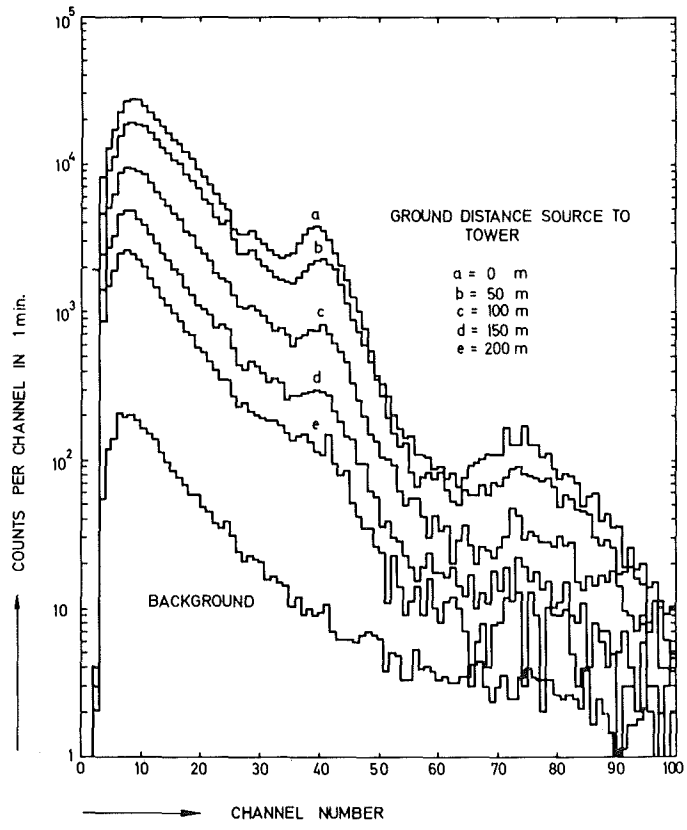

FIG. 2. Gamma spectra of ^{131}I point source measured with a NaI(Tl) scintillation detector ($1\frac{1}{2}$" × $1\frac{1}{2}$ in.) 80 m above ground, source on the ground at various distances from the base of the tower.

TABLE I: CALIBRATION FACTORS FOR AN ^{131}I POINT SOURCE AND AN HOMOGENEOUS INFINITE PLANE SOURCE OF ^{131}I MEASURED 80 m ABOVE GROUND

	G-M counter BZ 120	NaI(Tl) detector ($1\frac{1}{2}$ × $1\frac{1}{2}$ in.) under peak[a]	NaI(Tl) detector ($1\frac{1}{2}$ × $1\frac{1}{2}$ in.) total count rate
Background N_0	12 μR/h	120 counts/min	3300 counts/min
Point source ^{131}I	10,2 μR/h Ci	2100 counts/min Ci	6800 counts/min Ci
Plane source ^{131}I	0.76 $\frac{\mu R\ m^2}{h\ \mu Ci}$	42 $\frac{counts\ m^2}{min\ \mu Ci}$	3100 $\frac{counts\ m^2}{min\ \mu Ci}$

[a] Net count rate under 360-keV peak.

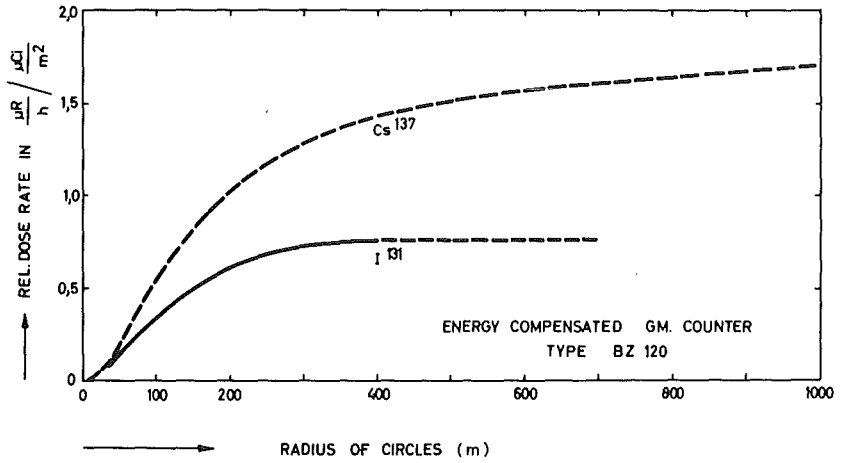

FIG. 3. Calibration of a dose ratemeter with a G-M counter type BZ 120 energy compensated for a surface contamination of ^{137}Cs or ^{131}I 80 m above ground depending on the radius of contaminated area.

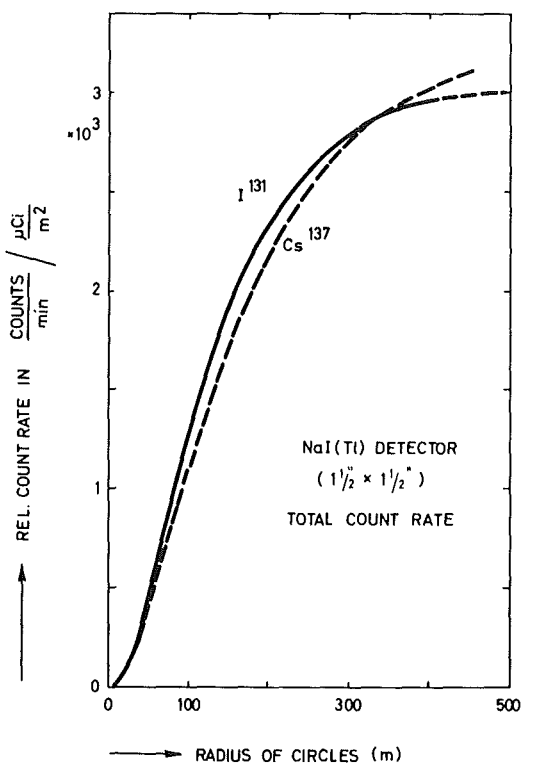

FIG. 4. Calibration of a NaI(Tl) scintillation detector ($1\frac{1}{2} \times 1\frac{1}{2}$ in.), total count rate, for a surface contamination of ^{137}Cs or ^{131}I 80 m above ground depending on the radius of contaminated area.

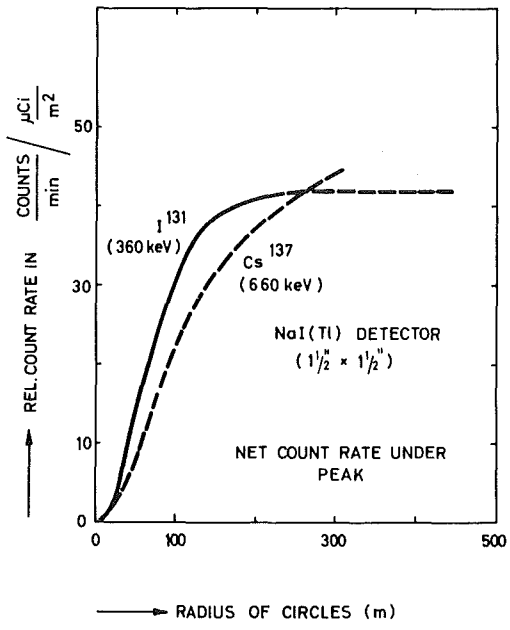

FIG. 5. Calibration of a NaI(Tl) scintillation detector ($1\frac{1}{2} \times 1\frac{1}{2}$ in.), net count rate under peak, for a surface contamination of ^{137}Cs or ^{131}I 80 m above ground depending on the radius of contaminated area.

do not contribute to the detector indication. If the extension of the contaminated area below the detector is larger than 350 m in all directions, the calibration factor for an infinite plane source can be used (see Table I).

Under these ideal conditions the lower detection limit for an ^{131}I surface contamination was assumed to be a detector indication which is equivalent to twice the standard deviation of the natural background, $2\,\sigma_0 = 2\sqrt{N_0}$. We found the following values for the lower detection limit of ^{131}I (80 m above ground, ratemeter time constant τ = 15 sec):

G-M counter BZ 120 (dose-rate measurement)	2.54 $\mu Ci/m^2$
NaI(Tl) 1.5 × 1.5 in. (peak, net count rate)	0.74 $\mu Ci/m^2$
NaI(Tl) 1.5 × 1.5 in. (total count rate)	0.05 $\mu Ci/m^2$

The better detection limit of the scintillation detector was to be expected.

3. DETERMINATION OF THE LOWER DETECTION LIMIT FOR ^{131}I SURFACE CONTAMINATION UNDER FLIGHT CONDITIONS

3.1. The different influences affecting the lower detection limit

The promising values of the lower detection limit found under ideal conditions cannot be reproduced under practical conditions of a measuring flight. The real lower detection limit for ^{131}I surface contamination depends

not only on the kind of detector and the measuring method, but also to a large extent on other influences such as:

(1) Influence of background level. The measuring accuracy of the net count rate depends on the statistical deviation of the total count rate and therefore on the amount of the background count rate, on the measuring time or the time constant of the measuring device.

(2) Local variations of the background, depending on the different materials of the ground, the vegetation and the cultivation, owing to natural radioactive materials and fall-out deposition.

(3) Temporal change of the background, caused by a change of the natural radiation components resulting from weather conditions, seasons, and influences of bad weather (wind, rain, mist) and by an additional deposition or reduction of global fall-out, the interim decrease of short-lived fission product nuclides after the accident; by deeper penetration of the deposited radionuclide into the ground, depending on the soil structure and weather conditions.

(4) Composition of the deposited fission products. By additional fission products, the background count rate of a selective ^{131}I measurement and the net count rate for a non-selective measurement will be increased.

(5) Extension of the contaminated area. The smallest contaminated area which can be detected depends on the plane speed, the time of measurement and the time constant of the equipment.

(6) Influences of the flight conditions. The flight height and the variations in the flight height caused by an inaccuracy of the height indicator, by hilly ground, unfavourable weather conditions (wind, bad weather) and by shielding of the detector by the plane itself.

In this paper, only the most significant influences of the background, the time constant and influences of the emergency situation will be discussed in detail. For this purpose we have assumed a reasonable flight height of 80 m above ground.

3.2. Background variation and time constant

Test flights carried out up to now in the neighbourhood of nuclear research centres have shown that the local and temporal variations of the natural background can exceed a factor of 3 [3, 4, 9]. The same variations were observed for windy weather with showers [9]. Even starting from background measurements made under certain weather conditions (test flight), it is not possible to deduce the particular background for a measuring flight at a later time with the necessary accuracy.

We can obtain a very optimistic estimate of these error influences if we assume that the temporal and weather-dependent variations of the background can cause a doubling of the background count rate measured previously [3]. Nevertheless, it is necessary to have information on the local distribution of the background along a given flight route obtained by test flights.

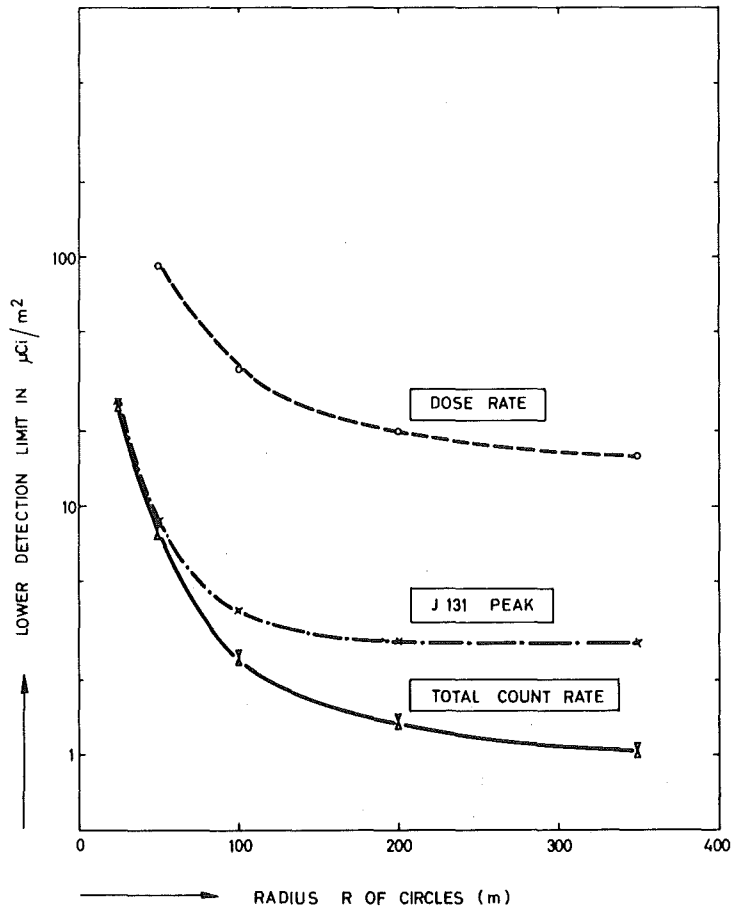

FIG 6. The lower detection limit for ^{131}I surface contamination in $\mu Ci/m^2$ derived from the variation of the background $\Delta N = N_0$ 80 m above ground depending on the radius of contaminated area for different detectors:

○ - ○ - ○ G-M counter BZ 120, dose rate
x - x - x NaI(Tl) ($1\frac{1}{2} \times 1\frac{1}{2}$ in.), net count rate under 360-keV peak
△ - △ - △ NaI(Tl) ($1\frac{1}{2} \times 1\frac{1}{2}$ in.), total count rate
▽ - ▽ - ▽ three NaI(Tl) (4 5/8 × 1 in.) total count rate

In agreement with this experience – besides the statistical deviation of the background $2\sigma_0 = 2\sqrt{N_0}$ – the assumed background variation N_0 has to be taken into account as a basis for the calculation of the lower detection limit.

Of course, the lower detection limit also depends on the time constant of the ratemeter. For this reason a long time constant seems desirable. On the other hand, the time constant and the speed of the aircraft determine the resolution for detecting small contaminated areas and therefore a short time constant is desirable. But if we want to detect small contaminated areas, we must bear in mind that for this case the lower detection limit

increases rapidly and we cannot apply the calibration factor for an infinite plane. Figure 6 shows the calculated lower detection limit depending on the radius of a circular contaminated area for different detection methods referred to a background variation $\Delta N = N_0$. The lower detection limit will be quite insufficient if the radius is smaller than 100 m. Using the results of Chamberlain et al. [2], we found a similar lower detection limit for a combination of three NaI(Tl) crystals of $4\frac{5}{8} \times 1$ in.

If we assume that only one calibration factor for the detection of ^{131}I should be used for the purpose of aerial surveys in emergency situations, the contaminated area must be practically larger than 700 m in diameter.

The distance will be crossed in 20 sec at an aircraft speed of 120 km/h or in 60 sec at 40 km/h. It is reasonable to use a time constant in this range. To obtain a useful estimation of the time constant, the statistical deviation $2\sigma_0$ is shown in Fig. 7 as a function of the ratemeter constant τ, the aircraft speed and the radius of the contaminated area R. In this example the diameter 2 R of the contaminated area is crossed during a time interval of four time constants 4τ. A longer time constant > 15 sec will impair the local resolution without considerably improving the sensitivity.

A systematic survey of small areas would require parallel flight routes not more than 1 km apart. Searching over an area of 200 × 200 km, for instance, the total flight route will be 40 000 km, this would mean "Round the world in 80 days".

For this reason it is also unrealistic to require airborne instruments to be able to measure small areas of surface contamination. But then a time constant of about 1 sec is not necessary at all. The lower detection limit can be improved markedly by using long time constants, e.g. $\tau = 15$ sec. This is especially true for G-M counters.

Figure 8 shows the smallest detectable ^{131}I contamination for ideal conditions, referred to the statistical deviation $\Delta N = 2\sigma_0$ of the background for the different measuring methods. The results are related to a flight height of 80 m and a ratemeter time constant $\tau = 15$ sec. These values will not be obtained under practical conditions of the measuring flight when we base the lower detection limit on the possible doubling of the background $\Delta N = N_0$. The sensitivity of the G-M counter used is lower by one decade compared to the measurement of the toal count rate with the scintillation detector. It is also noticeable that in this case the use of larger crystals does not offer a remarkable advantage. On the other hand, the selective ^{131}I measurement in the peak with background correction could be improved to some degree by using larger crystals.

3.3. Composition of the released fission product mixture

After a nuclear accident it will only be possible to determine incompletely the extension of the contaminated area and the degree of the contamination by theoretical conditions alone, even when the meteorological conditions and the kind of emission are known. Therefore, different measuring problems arise at the same time, depending on the individual emergency situation, the composition of the fission product mixture and the extent and amount of surface contamination. Because of the extent of the afflicted area (up to 100 km from the place of accident), an aircraft will be required for

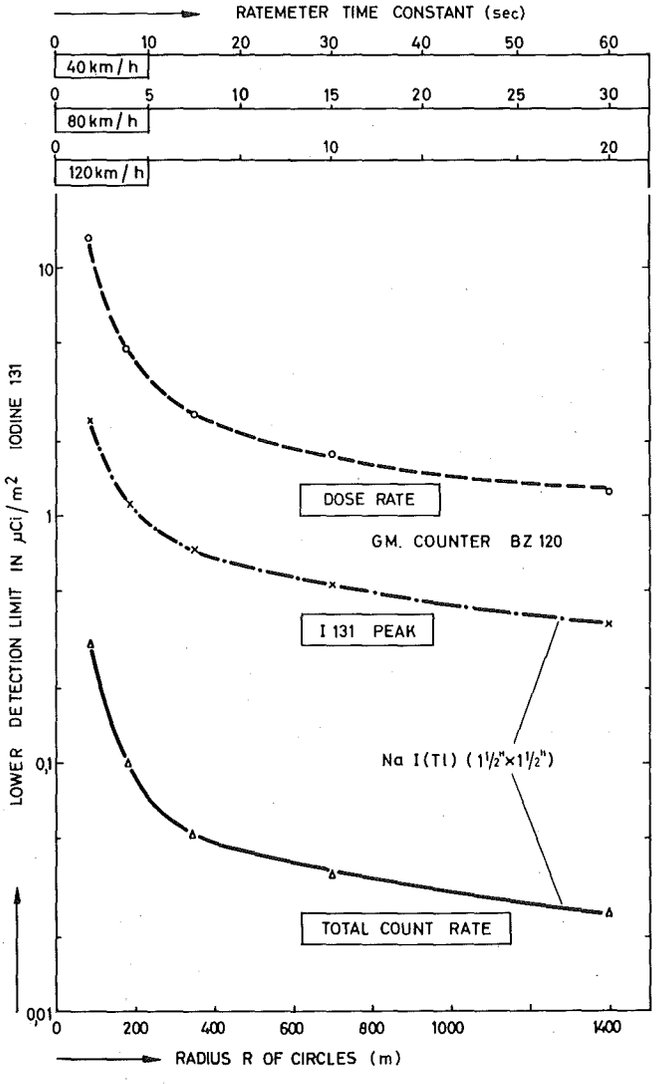

FIG. 7. The lower detection limit for ^{131}I surface contamination in $\mu Ci/m^2$ derived from the statistical deviation $2\sigma = 2\sqrt{N_0}$ of the background N_0 and the assumption that the flight time over the contaminated area is equal to four time constants 80 m above ground depending on time constant, flight speed and radius of contaminated area.

a quick survey of the contaminated area and the determination of the surface activity. Moreover, cars will be necessary to transport samples of grass, soil and milk from the neighbourhood and to perform measurements in contaminated locations which are of special interest [10].

One of the most important prerequisites for the judgement of an emergency situation will be the determination by spectroscopy of the ^{131}I fraction in the deposited fission product mixture. As is well known, the gamma

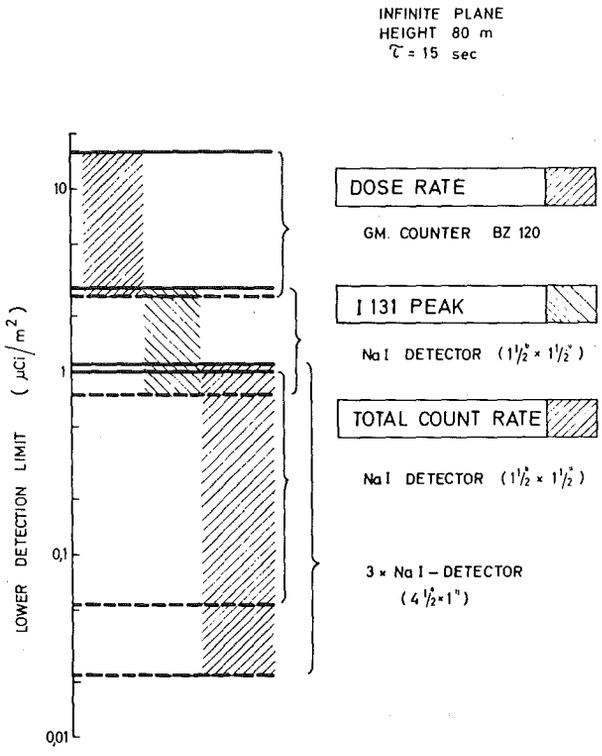

FIG. 8. The smallest detectable ^{131}I surface contamination in $\mu Ci/m^2$ derived from

_____ the variation of the background $N = N_0$
- - - - - - - the statistical deviation of the background $\Delta N = 2\sigma_0$

80 m above ground over homogeneous infinite plane source, time constant 15 sec, for the different measuring methods.

spectrum of the fission product mixture changes rapidly within the first hours after an accident and the determination of ^{131}I is disturbed by other short-lived iodine nuclides. Experiments carried out in the Karlsruhe Nuclear Research Centre showed that – even in favourable cases when iodine is the only substance released – ^{131}I cannot be identified with sufficient accuracy earlier than at least 6 to 10 hours after the accident [11]. After two short irradiations of a uranium sample in the reactor FR 2, iodine was separated radiochemically. Figure 9 shows the gamma spectrum of the iodine sample measured by a Ge(Li) semiconductor detector three hours after release of the iodine. In the gamma spectrum the peaks of ^{131}I will be overlapped more or less by other short-lived iodine isotopes like ^{132}I, ^{133}I, ^{134}I and ^{135}I, as well as by ^{135m}Xe, depending on the type of the accident and especially on the age and history of the fission product mixture released. This situation will be still worse in cases where additional fission products are released or where the spectroscopy is carried out with a NaI(Tl) detector of lower resolution. So at least 24 hours will be lost before exact statements on the activity of ^{131}I within the fission product mixture can be made.

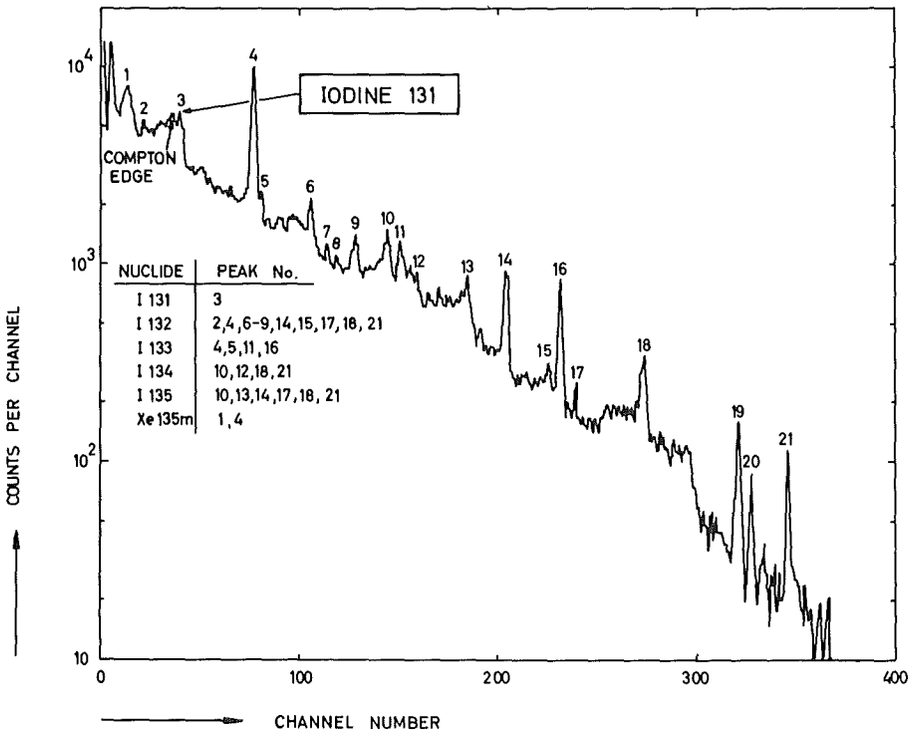

FIG. 9. The gamma spectrum of an iodine sample separated chemically from natural uranium measured 3 to 5 hours after a reactor irradiation with a Ge(Li) detector. Peak No. 3: ^{131}I, 360 keV [11].

With selective measuring instruments an aerial survey will therefore be appropriate not earlier than 24 hours after the accident. On the other hand, information flights with energy-independent dose ratemeters should be carried out even within the first hours. Knowing the dose-rate above ground, sufficiently exact values of the local ^{131}I surface activity can be estimated at a later time. Then only the temporal decrease of the short-lived components and the corresponding ^{131}I fraction need be taken into account. This information must be gained in the meantime from samples measured in the laboratory.

An examination of different emergency situations reveals that not in all cases should a sensitive ^{131}I selective indicator be preferred for locating the contaminated areas by aircraft. To explain this, Table II gives the dose-rates arising from a ^{131}I surface contamination of 0.4 $\mu Ci/m^2$ at a distance of 90 m above ground 24 hours after the release of: a normal fission product mixture (mainly ^{131}I from disintegration of ^{131}Te with a half-life of 25 min); a fission product mixture after a 300-d irradiation of a fuel element; volatile fission products (I, Te, Cs) in the composition present after a 300-d irradiation of a fuel element; iodine alone.

With the assumption that the relative contribution of ^{131}I to the total gamma dose-rate remains unchanged even at 80 m above ground, the lower detection limit 2 σ has been calculated for the G-M counter type BZ 120

TABLE II. CONTRIBUTION OF ^{131}I TO THE TOTAL DOSE-RATE OF DIFFERENT FISSION PRODUCT MIXTURES 90 cm ABOVE GROUND 24 h AFTER RELEASE.

Total dose-rate for an ^{131}I surface contamination of 0.4 $\mu Ci/m^2$ according to Ref. [2].

Fission product mixture	Total dose-rate ($\mu R/h$)	Contribution from ^{131}I (%)
^{131}I alone	3	100
Volatile fission products	27	11
Reactor fission products	115	2.6
Instantaneous fission products	400	0.75

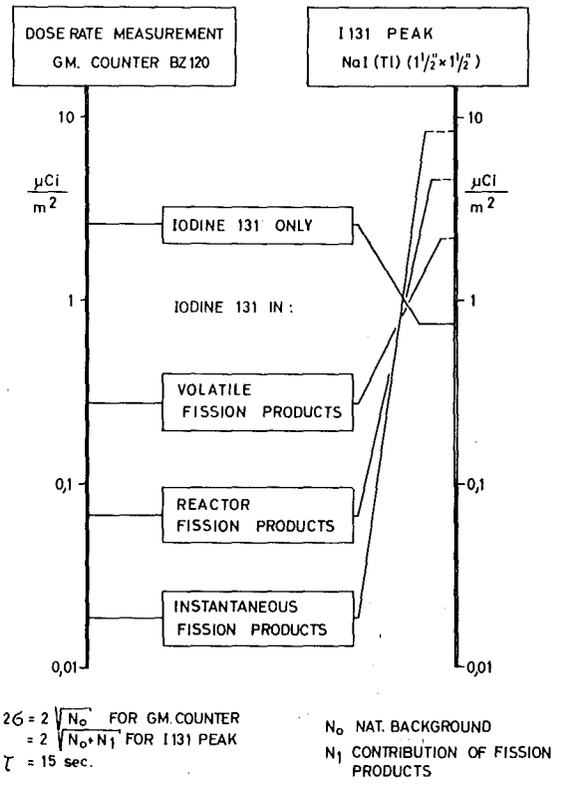

FIG. 10. The lower detection limit for a ^{131}I surface contamination in $\mu Ci/m^2$ derived from the statistical deviation 2 σ, 80 m above ground, time constant 15 sec depending on the composition of the fission product mixture for the energy compensated G-M counter BZ 120 and for a selective ^{131}I measurement with a NaI(Tl) crystal ($1\frac{1}{2} \times 1\frac{1}{2}$ in.).

and the selective measurement of ^{131}I with the NaI(Tl) crystal of $1\frac{1}{2} \times 1\frac{1}{2}$ in. (see Fig. 10).

Owing to the increase in the total radiation level caused by the fission products, a simple dose ratemeter will be able to detect a small ^{131}I contamination with sufficient sensitivity. For a selective measuring method, however, the other fission products increase the statistical deviation 2σ of the background. Measuring flights are therefore only one part of the required measuring program in emergency situations. Without further information they cannot indicate directly an iodine surface contamination for the following reasons:

(a) The contribution of ^{131}I and the composition of the deposited fission product mixture change very quickly immediately after the accident.
(b) The gamma analysis of samples and the successive measuring of the gamma spectrum can be performed reasonably only in a laboratory but not in an aircraft.
(c) The fast localization of contaminated areas and the determination of the local distribution of the surface contamination must be done by plane. To get an exact statement on the amount of the ^{131}I surface activity, the results of laboratory measurements must be used in any case.

4. PRACTICAL CHOICE OF MEASURING EQUIPMENT AFTER AN ACCIDENT

The determination of the total gamma spectrum during an aerial survey after an accident does not seem to be reasonable because of the long measuring time, the tedious evaluation by graph of the iodine peak to estimate an ^{131}I surface activity and, above all, the large number of spectra which cannot be processed at once. Measuring the gamma spectrum while crossing the contaminated area may be useful under certain circumstances to identify the fission product mixture. Generally this can be done much more easily and more accurately by measurements in the laboratory where Ge(Li) semiconductor detectors instead of NaI crystals can be used. Here, the change of the gamma spectrum of the same sample can be observed in the period following the accident.

An iodine measurement with a single-channel analyser is not useful because of the missing background compensation and a considerably lower sensitivity compared with the measurement of the total count rate. A selective ^{131}I measurement could be performed with a 3-channel analyser. This possibility has not yet been tested experimentally as the more complicated electronics will give a background compensation but also unfavourable statistics. Therefore the lower detection limit will be worse than the value that could be expected from the exact evaluation of the iodine peak in the gamma spectrum. Compared with the measurement of the total count rate with the same crystals, the lower detection limit will be worse by a decade. Despite the advantage of discriminating automatically the variations in the background, this measuring method would have the disadvantage of not indicating any ^{131}I surface contamination in the presence of a fission product mixture with a low or missing iodine fraction but also within the first hours following the iodine emission. Therefore localization of the contaminated area will not be possible with a ^{131}I selective indicator.

Doubtless the highest sensitivity for detecting an ^{131}I surface contamination can be achieved by measuring the total count rate. But on account of the missing background compensation, the theoretical sensitivity cannot be maintained under practical conditions. Owing to the temporal and local variation of the background, only an ^{131}I surface contamination of more than 1 $\mu Ci/m^2$ can be located, even if the background is approximately known from previous test flights.

These conditions can scarcely be improved, whether by using larger NaI(Tl) crystals or by using several crystals simultaneously. On the other hand, dose ratemeters can be employed usefully for an airborne survey to locate contaminated areas quickly, especially when fission product mixtures are present. By using counter tubes with a lower self-activity and especially by using several tubes, the stated lower detection limit of an ^{131}I surface contamination could be improved in future. For this purpose not only energy-compensated G-M counter tubes are suitable, but also battery-operated portable instruments with ionization chambers, proportional counters or energy-independent plastic scintillation detectors. For these measurement techniques, energy independence and insensitivity of the detector to β-radiation must, however, be provided.

When measuring the dose-rate, any dose ratemeter can be used which is available. Special calibration of each instrument for an ^{131}I surface activity is not necessary. The ^{131}I surface contamination can be calculated from the corresponding dose-rate indication if the composition of the fission product mixture is known. Measuring flights with dose ratemeters can be performed immediately after the accident at a moment when there is not yet any information on the composition of the fission product mixture.

Recording of the dose-rate at a given height together with the measuring time and the position will give the raw data for a later estimation of the corresponding ^{131}I surface contamination. The composition of the fission product mixture must be determined in the laboratory from the gamma spectrum of a sample taken immediately after the accident and by successively observing the change of the spectrum. By means of a suitable computer program and the assumption that the contaminated area is a homogeneous infinite plane source, the dose-rate at a given height can be calculated from the measured fission product spectrum. The corresponding contribution of ^{131}I to the total dose-rate and therefore the ^{131}I surface activity can be stated for any location at the time of measurement.

As for all measuring methods, the lower detection limit of such measurement is given by the temporal and local variation of the background. Therefore test flights along a fixed route in the vicinity of nuclear installations are necessary to a small extent to measure the amount of the natural background and, most of all, its local variations under favourable weather conditions. The value of expensive precision background measurements seems to be doubtful. The influence of the normal radioactive emission of nuclear installations can multiply the dose-rate of the background, depending on the weather and wind conditions during the test or measuring flight after an accident.

The question arises whether it is useful to demand a sensitive activity measurement, especially a selective ^{131}I measurement, for locating the contaminated area by plane for the following reasons.

In a nuclear accident when only iodine is released, primarily ^{132}I, ^{133}I, ^{134}I, ^{135}I are encountered but not ^{131}I.

The radiation sensitivity of the thyroid gland of children to incorporated iodine from fall-out has been underestimated till now. On Rongelap, Marshall Islands, 10 to 15 years after an incorporation of local fall-out, unexpectedly heavy radiation damage of the thyroid glands was observed in the inhabitants who were children at that time. In addition to ^{131}I, the isotopes ^{133}I, ^{135}I and to less extent ^{132}I contributed significantly to the thyroid dose [12].

In view of this the maximum permissible surface contamination for grass should be smaller than the value used today (0.4 $\mu Ci/m^2$), which is based on ^{131}I alone and a maximum permissible thyroid dose of 25 rem for children.

From the measuring point of view, however, the location of areas contaminated with smaller surface activities of ^{131}I is not possible, even if larger NaI(Tl) crystals are used.

Finally we can summarize that the use of aircraft for contamination measurements in emergency situations is essentially limited to the fast location of larger contaminated areas. The determination of an ^{131}I surface activity by plane can only be solved with sufficient accuracy by a dose-rate measurement and calculations based on the corresponding gamma spectrum at the moment of the measuring flight.

Under practical conditions and with the information of previous background measurements, the detectors and the measuring methods available today can detect an ^{131}I surface contamination of about 1 $\mu Ci/m^2$.

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DISCUSSION ON SM-117/59 AND 15

G.H. PALMER: My comment is relevant to both papers and relates to background levels and pre-emergency surveys. Following changes in ICRP recommendations and reappraisal by the Medical Research Council in the United Kingdom, we now have a new Emergency Reference Level for milk which is reflected in a higher 'permissible' level on grass.

This higher level gives a very much higher radiation level to measure in an emergency situation and makes it less important to know the precise pre-emergency background level.

A second point, often forgotten, is that in an emergency, although the contamination levels on the edge of the affected area are at the reference level limit, contamination in the centre of the zone will be much higher. The aerial survey after the Windscale incident ran into difficulty when all the instruments went beyond the full-scale reading while the aircraft was over the high-contamination zone.

Consequently we in the establishment I represent have reduced our environmnetal surveying to a large survey twice a year as an emergency exercise. This gives practice to all the people who might be involved in an emergency survey, which is very important. A secondary advantage is that we obtain sufficient information to prove to local authorities, etc., that all is well at the establishment and that there are no detectable effects in the countryside.

P.R. KAMATH: I would like to give some clarification of the background radiation values shown in Fig.2 of my paper. These were part of pre-operational surveillance data used as a yardstick against which operational practices could be assessed and exposures resulting from the operations evaluated. The measurements of sediment activity offshore and along the shore that have been carried out by Howells and Templeton at Windscale over a period of many years have demonstrated how activity builds up and spreads in the environment. I feel that background measurements are very necessary (of course properly programmed) as an indication of an approaching hazardous build-up in the environment.

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