ENVIRONMENTAL RADIATION MONITORING
IN HONG KONG

Technical Report No.6

RETROSPECTIVE ANALYSIS
OF RADIATION FALLOUT IN HONG KONG
AFTER THE CHERNOBYL ACCIDENT IN 1986

B.Y. Lee and K.C. Tsui
ROYAL OBSERVATORY HONG KONG

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Environmental Radiation Monitoring in Hong Kong

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Royal Observatory
Hong Kong.

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6.3 Surface weather maps for southeast Asia, mid-May 1986, associated with a sharp increase in fallout in the local atmosphere over Hong Kong.

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A1 Places in Europe mentioned in this report.
1. INTRODUCTION

According to a Soviet report [Nature 1986], the nuclear reactor accident at Chernobyl, 130 km northwest of Kiev, Ukraine, U.S.S.R., started at 1:23 a.m. on Saturday 26 April, 1986. It resulted in a major release of radioactivity into the atmosphere. Soviet sources estimated that all of the noble gas radionuclides escaped the plant, and of the other radionuclides, the release amounted to about $2 \times 10^{18}$ Bq [IAEA 1986], in which caesium-137 (Cs) constituted $7 \times 10^{16}$ Bq [Cambray et al. 1987b] and iodine-131 (I) 7 to $20 \times 10^{17}$ Bq [U.S. Department of Energy 1987]. The immediate death toll was 31 and up to 1 000 people were injured, of which more than 200 suffered severely. About 135 000 people had to be evacuated from their homes. High-temperature combustion at the site, coupled with dry weather conditions, resulted in the debris being carried high aloft, some 1 200 m or more into the atmosphere [Sinkko et al. 1987] and dispersed widely across northern Europe shortly after the accident. The Chernobyl fallout reached Asia in early May.

Immediately after the accident was known, the Royal Observatory Hong Kong intensified atmospheric sampling at the King's Park Meteorological Station. An insignificant but nonetheless measurable amount of fallout was detected in Hong Kong. This report includes measurement results obtained retrospectively using instruments acquired in 1987 under the Background Radiation Monitoring Programme (BRMP) [Royal Observatory 1989]. The results were compared with those obtained by the Harwell Laboratory of the United Kingdom Atomic Energy
Authority on samples collected at King's Park for UKAEA, and countermeasure considerations and implications on radiation dose were discussed. Meteorological factors responsible for the transport of the fallout to Hong Kong were also assessed qualitatively.

A brief description of radiation detection activities in various places of the world outside U.S.S.R. immediately after the accident is given in Appendix I.
2. SAMPLE COLLECTION AND TREATMENT
[Main reference: Royal Observatory 1984]

(a) Air particulates

Airborne particulates were collected on a Whatman Grade 41 cellulose filter at the King's Park Meteorological Station (22°19'N 114°10'E, 66 m above Mean Sea Level). The filter was changed at around 0900 Hong Kong Time (HKT, 8 hours ahead of UTC) every day. The effective collection area of the filter was 17.1 by 22.3 cm, and the volume of air sampled was read each time from an airflow meter.

For gross (i.e. total) beta counting, only a circular portion of diameter 54 mm cut off from the filter was used in measurement. After gross beta counting, the daily filters were bulked into four groups each month (typically 7 days each, except the last group which consisted of 7 or more days).

Soon after the Chernobyl accident became known, a separate high-volume air sampler (Sierra Anderson, model UV-2H) was deployed to obtain an additional set of daily samples. These latter samples were not bulked, thus offering a resolution at 24-hour intervals.

Strontium-90 (Sr) and plutonium-239 (Pu), are important man-made radionuclides, emitting beta and alpha particles respectively. As they may produce health effects if inhaled or ingested in significant quantity, they were selected for analysis in the present report. Sr-90 collected on a filter was chemically extracted and then mixed with a liquid scintillant in a plastic vial for subsequent measurement using a liquid
scintillation counter. Any Pu-239 collected was also chemically extracted, and electro-deposited onto small stainless steel plates for subsequent alpha spectrometry analysis. Details of chemical processes involved can be found in the BRMP Interim Report [Royal Observatory 1989].

(b) **Total deposition**

Total deposition (i.e. rain-water and dust particles, whether scavenged by rain, carried by downward air current or deposited by gravity) was collected at King's Park in a 500-mm diameter pan containing at least 10 mm of water. Samples were collected at 2-day intervals, normally at 0900 HKT.

Each sample was evaporated in a heated beaker to small volumes and then to dryness on a 54-mm diameter aluminium holder under heat lamps.

(c) **Rain-water**

Samples of rain-water were collected in a standard 203-mm diameter rain-gauge at 24-hour intervals beginning at 0800 HKT at the Royal Observatory Headquarters (22°18'N 114°10'E, 32 m above Mean Sea Level), roughly 1 km south of King's Park. The treatment of rain-water was similar to that for total deposition.

(d) **Samples for UKAEA**

Environmental samples were routinely collected at King's Park for UKAEA. Air particulate samples were sent twice a week ever since 1964 and rain-water samples despatched once every three months since 1962. The method of sampling is described in Cambray et al. [1987b].
At UKAEA's request, in the morning of 14 May 1986 a soil sample including grass was taken from undisturbed ground at King's Park to a depth of about 5 cm from an area of about 900 cm². It was despatched by air immediately on the same day. Another soil sample was taken on 17 June and despatched on 20 June.

(e) Rain-water for International Atomic Energy Agency (IAEA)

Monthly rain-water samples were despatched to IAEA in Vienna, Austria, once every three months as part of the World Survey of Isotope Concentration in Precipitation, a joint programme of IAEA and the World Meteorological Organization (WMO).
3. METHOD OF MEASUREMENT

(a) Air particulates

For gross counting of beta-particle emitters in an air particulate filter, a lead-shielded Geiger-Müller (G-M) counter was employed and a chlorine-36 source (chemically in the form of potassium chloride) used as a reference. Gross beta counting was performed on each daily sample 4 days after its collection to allow sufficient time for decay of short-lived nuclides most of which were of natural origin.

Gamma-ray emitters such as radiocaesium on the filter was analysed using a gamma spectrometry system consisting of a 'n-type' high-purity germanium detector. The system was put into operation in early 1987.

Gamma spectrometry was carried out on samples for each day between 7 May to 31 May, and on bulked samples, normally covering a 7-day period, for the rest of the period between 21 April and 21 June. Prior to gamma measurement, the collected air filters were pressed using a hydraulic press into thin cylindrical disks. A mixed gamma-ray reference source with the same geometry as the pressed filter papers was used for efficiency calibration. A mixed gamma-ray standards solution in a 450-ml Marinelli beaker was used for energy calibration.

The normal counting time adopted for gamma measurement was 10 000 s (2.8 h). For low, but detectable activity, this was extended to as much as 55 000 s (15.3 h) if necessary. For background counting, blank filters were counted in the system for
150 000 s \((41.7 \ \text{h})\).

Strontium-90 present in the filters was measured, after chemical extraction, using a low-level liquid scintillation counting system. Calibration was made using a strontium-90 standard. For plutonium-239, measurement was performed on an alpha spectrometry system consisting of four PIPS (passivated implanted planar silicon) detectors in vacuum. Energy calibration was made using a standard containing thorium-230.

Further details of measurement methodology and procedures can be found in the Radioactivity Bulletin [Royal Observatory 1984] and in the BRMP Interim Report [Royal Observatory 1989].

(b) **Total deposition and rain-water**

The gross beta activities in total deposition and rain-water samples were measured in the same manner as that for air particulates. Details of measurement methodology and procedures can be found in the Radioactivity Bulletin [Royal Observatory 1984].

No sample of deposition and rain-water, evaporated to dryness on an aluminium holder remained for retrospective analysis of radionuclides.

(c) **Soil**

At UKAEA, a subsample of soil with a volume of \(3 \times 10^{-3} \text{m}^3\) (i.e. 3 litres) was taken in the laboratory and, without further preparation, analysed in a Marinelli beaker using gamma spectrometry method [Cambray et al. 1987a].
4. MEASUREMENT RESULTS

All results presented in this report are corrected to the sampling date for radioactive decay.

(a) Air particulates

A time series of daily gross beta activities from April to July 1986 is shown graphically in Fig. 4.1 (see Footnote).

An increase was first observed on the air particulate filter for 16 May (collected over a 24-hour period ending about 9 a.m. that day) and the level remained above 100 mBq/m³ for two more days, after which the activity fell back to background level. Overall, the monthly mean of daily values for May 1986 is 1 to 2 orders of magnitude smaller than those obtained during atmospheric nuclear tests in the 1960s and early 1970s.

The detection of Chernobyl fallout was confirmed by analysis of individual radionuclides in the sample. Determined by means of gamma spectrometry, concentrations of radiocaesium (Cs-137: half-life 30.2 y; Cs-134: half-life 2.1 y) in air during the period from 21 April to 21 June are shown in Fig. 4.2. Cs-137 was first detected on the filter for 9 May (collected over a 24-hour period ending about 9 a.m. that day), reaching a peak on 11

Footnote:— The gross activity is derived from subtraction of the background count (i.e. blank) from the total count (i.e. sample). A negative value means that the background count is greater than the total count, possibly a result of low activity in the sample and random error in counting. It is worth noting here that gross activity data as presented in Fig. 4.1 only serve the purposes of screening the samples and comparing with historical data. They contain no information on the identity of radionuclides present in the samples and hence no conclusion on the dosimetric significance of the results can be inferred [Colle 1980].
Fig. 4.1 Gross beta activity of atmospheric particulates in Hong Kong, April – July 1986. Samples were collected at 9 a.m. each day at King's Park.
Fig. 4.2 Concentration of caesium-137 and caesium-134 in the local atmospheric particulates, April – June 1986, together with daily rainfall at the Royal Observatory and mean wind at Waglan Island. The minimum detectable activity was 0.4 mBq/m² for both nuclides. Peak 24-hour values for both of these gamma-emitting nuclides amounted to less than 1/1 000 000 of the lower derived intervention levels (DIL, see Section 5) for sheltering against inhalation from a radioactive plume. The appearance of each wind barb in the upper plot signifies a significant change in the wind direction and/or speed from the last period.
May. The ensuing heavy rain probably had scavenged any airborne radioactivity present during the time, but the non-detection for three consecutive days (12–14 May) was a strong indication that the abrupt and dramatic rise in Cs-137 level on 15 May signified a second instalment. Cs-134 was first detectable this time, and a 5-fold increase in radiocaesium levels occurred on the next day (16 May), reaching a peak on 17 May (14.4 and 7.6 mBq/m³ respectively for Cs-137 and Cs-134). The pattern for ruthenium-106 (Ru, half-life 1.0 y), shown in Fig. 4.3, was somewhat similar, with a peak value of 9.5 mBq/m³ on 16 May. A gamma spectrum for the air filter collected on 17 May is shown in Fig. 4.4.

The airborne radioactivity decreased sharply after 19 May, although minute quantities of the above radionuclides were still detectable in the air until early June.

Results of radiocaesium concentrations in samples bulked over 7-day periods are presented alongside UKAEA's results [Cambray et al. 1987a] in Fig. 4.5. There is general agreement between the two sets of results, although one should note, from the figure, differences in the collection period for some samples.

The day-to-day ratios of Cs-134 to Cs-137 (Table 4.1), in the range of 0.48 to 0.53, also compares favourably with the value 0.52 obtained by UKAEA on the bulked sample for 12–19 May. The attribution of the detected activity to the Chernobyl accident was confirmed by a host of similar values observed elsewhere [Deveuri et al. 1986, SSI 1986, Fry et al. 1986, Thomas
Fig. 4.3 Same as Fig. 4.2, but for ruthenium-106. The minimum detectable activity was 3.7 mBq/m³. The peak 24-hour value amounted to less than 1/100 000 of the lower DIL for sheltering against inhalation from a radioactive plume.
Fig. 4.4 Gamma-ray spectrum of a daily air-particulate sample collected in Hong Kong on 17 May 1986. Measurement was performed in 1987 using a high-purity germanium detector. Radionuclides identified in brackets are of natural origin, i.e. non man-made. The horizontal axis corresponds to gamma-ray energies in the range of about 60 keV on the left to 2 MeV on the right. The vertical scale is a measure of the number of counts.
Fig. 4.5 Comparison of UKAEA and Royal Observatory determinations of caesium-137 in air particulates, April - June 1986. All results were corrected to the sampling date for radioactive decay.

Close inspection of the gamma-ray spectra suggested the presence of extremely small amount of antimony-125 (half-life: 2.8 y) in the following samples: 12 – 19 May (bulk), 14 – 21 May (bulk), 23 – 24 May, and 31 May – 7 June (bulk). This radionuclide was detected in very small quantities in various samples collected in Europe at the time of the accident [Cambray et al. 1987a, Sinkko et al. 1987].

Because the gamma spectrometry measurements were performed retrospectively, it was not possible to detect such short-lived radionuclides as iodine-131 (half-life: 8.0 days) and Ru-103 (half-life: 39.4 days). Both of these were detected on air filters collected for UKAEA between 5 May to 2 June, with peak values of, respectively, 5.8 and 7.8 mBq/m³ for the 7-day period 12 – 19 May [Cambray et al. 1987a].

The time series for strontium-90 (a beta-particle emitter with a half-life of 29 years) concentrations, presented in Fig. 4.6, offers a pattern similar to those for radiocaesium (Fig. 4.2) except that the maximum appeared on 18 May instead of 17 May, and that a second maximum appeared near the end of May. Note that the observed values were generally two orders of magnitude smaller than those for radiocaesium.

No plutonium-239 was detected on the air filters during the time. The minimum detectable activity was 2 uBq/m³.

Table 4.2 compares Sr-90, Ru-106, Pu-239 results with U.S.S.R. reported discharge and with observations made in western Europe. Results for Sr-90 in particular were in the same order
TABLE 4.1  RADIOCAESIUM RATIOS IN FALLOUT DETECTED IN HONG KONG DURING MID–MAY, 1986

<table>
<thead>
<tr>
<th>Date</th>
<th>Cs-134/Cs-137 ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-15 May 1986</td>
<td>0.48</td>
</tr>
<tr>
<td>15-16 May</td>
<td>0.52</td>
</tr>
<tr>
<td>16-17 May</td>
<td>0.53</td>
</tr>
<tr>
<td>17-18 May</td>
<td>0.52</td>
</tr>
<tr>
<td>18-19 May</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Note: Samples changed daily at 9 a.m. All results are corrected to the sampling date for radioactive decay.

TABLE 4.2  COMPARISON WITH AIRBORNE CONCENTRATIONS REPORTED BY U.S.S.R. AND WEST EUROPEAN COUNTRIES
(All values are relative to Cs-137 activity)

<table>
<thead>
<tr>
<th>U.S.S.R. reported discharge</th>
<th>Stockholm, Sweden (observed)</th>
<th>Munich, Germany (observed)</th>
<th>Neuherberg, Germany (observed)</th>
<th>Hong Kong (observed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr-90</td>
<td>0.05</td>
<td></td>
<td></td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>(26 Apr)</td>
<td></td>
<td></td>
<td>(17,18,19 May)</td>
</tr>
<tr>
<td></td>
<td>0.22</td>
<td></td>
<td></td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>(6 May)</td>
<td></td>
<td></td>
<td>(29,30 May)</td>
</tr>
<tr>
<td>Ru-106</td>
<td>0.67</td>
<td>0.056</td>
<td>0.30</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>(26 Apr)</td>
<td>(28-30 Apr)</td>
<td>(29 Apr - 3 May)</td>
<td>(16,17,18 May)</td>
</tr>
<tr>
<td>Pu-239</td>
<td>0.00037</td>
<td>0.00022</td>
<td></td>
<td>&lt; 0.0002</td>
</tr>
<tr>
<td></td>
<td>(26 Apr)</td>
<td>(28-30 Apr)</td>
<td></td>
<td>(17,18,19 May)</td>
</tr>
<tr>
<td></td>
<td>0.0007</td>
<td></td>
<td>&lt; 0.0002</td>
<td>&lt; 0.0031</td>
</tr>
<tr>
<td></td>
<td>(6 May)</td>
<td></td>
<td>(6-7 May)</td>
<td>(29,30 May)</td>
</tr>
</tbody>
</table>

Note: U.S.S.R. and western Europe data were extracted from U.S. Department of Energy [1987]
Fig. 4.6 Concentration of strontium-90 in the local atmospheric particulates, April - June 1986. The minimum detectable activity was 30 uBq/m². The peak 24-hour value amounted to less than 1/10 000 000 of the lower DIL for sheltering against inhalation from a radioactive plume.
of magnitude.

(b) Total deposition and rain-water

Gross beta activities in bi-daily total deposition and daily rain-water samples are presented, respectively, in Figs. 4.7 and 4.8 for the period April to July 1986. The relatively high instrument background of the gross counter, as evidenced by the negative readings in these Figures, made it difficult to discern with certainty any abnormal excursion in the radiation level.

It is worth noting here UKAEA's quarterly Cs-137 measurement results on total deposition and rain-water collected in Hong Kong for the quarters in 1986 [Cambray et al. 1987b], presented in Table 4.3. As will be discussed in Section 5, the reported values were small.

No abnormality was observed in the month-to-month tritium concentrations in precipitation routinely collected in Hong Kong for IAEA [IAEA 1990b]. A peak value observed in Osaka, Japan, in May 1986 was subsequently found to be associated with the seasonal spring peak, rather than with Chernobyl fallout [Morishima et al. 1989].

(c) Soil

No man-made radionuclides were detected on the soil sample collected at King's Park on 14 May for UKAEA [Cambray 1986]. As over 200 mm of rain fell between 11 and 14 May, any fallout present in the air would have been scavenged by the rain onto the ground. The negative results on this soil sample, however, lent support to the observation made earlier that probably little or
Fig. 4.7 Gross beta activity of bi-daily total deposition in Hong Kong, April – July 1986. Samples were collected once every two days at 9 a.m. at King's Park.
Fig. 4.8: Gross beta activity of rain-water in Hong Kong, April - July 1986, presented together with the rain volume. Samples were collected at 8 a.m. each day at the Royal Observatory.
TABLE 4.3  QUARTERLY CONCENTRATION OF Cs-137 IN TOTAL DEPOSITION AND IN RAIN-WATER OBTAINED IN HONG KONG DURING 1985 AND 1986 [Cambray 1987b]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total deposition (unit: Bq/m²)</td>
<td>&lt; 1</td>
<td>&lt; 4</td>
<td>&lt; 2.5</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Rain-water (unit: mBq/L)</td>
<td>&lt; 5</td>
<td>&lt; 5</td>
<td>&lt; 5</td>
<td>&lt; 10</td>
</tr>
</tbody>
</table>

TABLE 4.4 Cs-137 CONCENTRATIONS IN THE SOIL SAMPLE COLLECTED AT KING'S PARK ON 17 JUNE 1986 FOR UKAEA [Cambray et al. 1987a]

<table>
<thead>
<tr>
<th></th>
<th>Cs-137</th>
<th>Cs-134(#)</th>
<th>I-131</th>
<th>Ru-103(#)</th>
<th>Cs-137(*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil to a depth of 5 cm, including grass</td>
<td>160</td>
<td>&lt; 18</td>
<td>-</td>
<td>32</td>
<td>&lt; 29 Bq/m²</td>
</tr>
</tbody>
</table>

(#): attributable to Chernobyl due to relatively short half-lives of the particular radionuclides.

(*): attributable to Chernobyl, estimated from Cs-134 concentration in soil and from an observed Cs-134/Cs-137 ratio of 0.6 in particulate material.
no fallout were present in the air during the time and that the abrupt increase in fallout activity immediately afterwards in mid-May (Fig. 4.2) was indeed a second instalment.

Positive results were obtained on the sample collected on 17 June and these were reproduced in Table 4.4. They included estimation of Cs-137, Cs-134 and Ru-103 concentrations attributable to Chernobyl.
5. COMPARISON OF RESULTS WITH THE DERIVED INTERVENTION LEVELS

Peak values for the observed radionuclides were compared with the Derived Intervention Levels (DIL) recommended by the Radiological Protection Advisory Group [1990]. A countermeasure should be considered once the monitoring results exceed the DIL for a particular radionuclide and pathway. Countermeasures can range from sheltering, distribution of stable iodine, evacuation, relocation and control of food.

Results of the comparison with DILs are given in Table 5.1. It can readily be seen that the concentration of radionuclides in samples collected in Hong Kong was extremely small, generally about 1/1 000 000 to 1/100 000 of the level that necessitates the consideration of some kind of countermeasure.
<table>
<thead>
<tr>
<th>Radio-nuclide</th>
<th>Medium</th>
<th>Max. value</th>
<th>Counter-measure</th>
<th>Pathway</th>
<th>Fraction of lower DIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs-137</td>
<td>air particulates</td>
<td>14 mBq/m³</td>
<td>Sheltering</td>
<td>Inhalation from a radioactive plume</td>
<td>8.3 x 10⁻⁷</td>
</tr>
<tr>
<td>Cs-134</td>
<td>collected over 24 h</td>
<td>7.6 mBq/m³</td>
<td></td>
<td></td>
<td>6.5 x 10⁻⁷</td>
</tr>
<tr>
<td>Ru-106</td>
<td></td>
<td>9.5 mBq/m³</td>
<td></td>
<td></td>
<td>8.2 x 10⁻⁶</td>
</tr>
<tr>
<td>Sr-90</td>
<td></td>
<td>210 uBq/m³</td>
<td></td>
<td></td>
<td>5.9 x 10⁻⁶</td>
</tr>
<tr>
<td>I-131</td>
<td>air particulate filters</td>
<td>5.8 mBq/m³</td>
<td>Sheltering</td>
<td>Inhalation from a radioactive plume</td>
<td>8.8 x 10⁻⁶</td>
</tr>
<tr>
<td>Ru-103</td>
<td>bulked over 7 days</td>
<td>7.8 mBq/m³</td>
<td></td>
<td></td>
<td>7.3 x 10⁻⁶</td>
</tr>
<tr>
<td>Cs-137</td>
<td>total deposition</td>
<td>140 Bq/m²</td>
<td>Sheltering</td>
<td>External gamma radiation from ground deposits (DIL for treated water)</td>
<td>1.2 x 10⁻⁶</td>
</tr>
<tr>
<td>Cs-137</td>
<td>rainwater (untreated)</td>
<td>120 mBq/L</td>
<td></td>
<td></td>
<td>1.7 x 10⁻⁴</td>
</tr>
<tr>
<td>Cs-137</td>
<td>soil</td>
<td>&lt; 29 Bq/m²</td>
<td>Sheltering</td>
<td>External gamma radiation from ground deposits</td>
<td>&lt; 2.4 x 10⁻⁵</td>
</tr>
<tr>
<td>Cs-134</td>
<td></td>
<td>&lt; 18 Bq/m²</td>
<td></td>
<td></td>
<td>&lt; 4.0 x 10⁻⁷</td>
</tr>
<tr>
<td>Ru-103</td>
<td></td>
<td>32 Bq/m²</td>
<td></td>
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<td>2.3 x 10⁻⁷</td>
</tr>
</tbody>
</table>

* UKAEA results on samples collected in Hong Kong
6. SYNOPTIC CONDITIONS ASSOCIATED WITH THE ARRIVAL OF FALLOUT IN MAY 1986

Meteorological assessment made in China suggested an air trajectory originating from Ukraine to arrive at Beijing's longitude in early May [Lin et al. 1987]. The U.S. National Oceanic and Atmospheric Administration estimated the trajectory to be in a general west-to-east direction at latitudes between 50 to 55°N, reaching 120°E by 2 May [quoted in Chung 1987]. Radiation monitoring activities in China were intensified with the above timing in mind.

Reliable dates of first detection of Chernobyl fallout in various places in China as collated from Chinese literature (quoted in Appendix 1) are shown in Fig. 6.1. Increase in I-131 was first detected in Beijing on 1 May. The fallout later reached Nanjing, Shanghai and Hangzhou around 5 - 6 May. Taibei registered the first increase in I-131 on 7 May. The gradually eastward movement of a surface high pressure over north China (Fig. 6.2a-c), located at about 35°N 110°E on 1 May, is believed to be responsible for the transport of fallout southwards towards the lower latitudes.

The appearance of minute amounts of Cs-137 in the atmosphere over Hong Kong around 9 - 10 May (Fig. 4.2) is difficult to explain meteorologically, however, as the weather pattern for 9 May clearly showed a stagnant flow (Fig. 6.2d). On the other hand, the increase of Cs-137 in the local atmosphere on 11 May was coincident with the arrival of fresh northeasterly winds down the Taiwan Strait. These northeasterlies were associated with
Fig. 6.1 Dates of first detection of Chernobyl fallout in various places in China. See Appendix 1 for references.
Fig. 6.2 Surface weather maps for southeast Asia, early May 1986.
the establishment of a small high-pressure area over southeast China (Fig. 6.2f).

The sharp increase of Cs-137 in the local atmosphere in mid-May (Fig. 4.2) was coincident with another arrival of the northeast monsoon in the latter part of 14 May, when the weather became fine. The monsoon was associated with a high-pressure system over the east China coast (Fig. 6.3), which had good upper-air support extending up to at least 850 hPa (roughly 1500 m above surface). The monsoon on the surface was very persistent this time, lasting until late 18 May when it was gradually replaced by a southerly airstream.

Gross beta activities in the atmospheric particulates over various places in China (referred to in Appendix 1), as presented in Fig. 6.4, correlated quite well with the movement of this high-pressure system. A second increase in activity occurring around 10 May over north and northwest China (Hami, Hohhot, Xian, Beijing and Jinan) was observed around 13–14 May in central and east China (Changsha, Hangzhou, Nanjing and Shanghai). This was detected further downstream in south China (Fuzhou, Guangzhou and Hong Kong) around 15 May.

The reduction in fallout in Hong Kong after 19 May was generally consistent with the decreasing trend elsewhere in China.
Fig. 6.3 Surface weather maps for southeast Asia, mid-May 1986, associated with a sharp increase in fallout in the local atmosphere over Hong Kong.
Fig. 6.4 Gross beta activity in air particulate samples, as reported at various places in China after the Chernobyl accident. All samples were counted four days after collection to allow time for decay of short-lived nuclides. For references see Appendix 1.
7. DOSIMETRIC IMPLICATIONS

Based on UKAEA's results, Tso et al. [1987] estimated that the increased Cs-137 in air and in deposition in 1986 in Hong Kong to be small, giving the local population an additional dose equivalent commitment of 20 μSv.

This contrasts with UNSCEAR's (United Nations Scientific Committee on the Effects of Atomic Radiation) estimate of 6 μSv for southeast Asia [Bennett 1990] for the first and subsequent years. This estimate includes effects of a number of contributing radionuclides such as Cs-137, Cs-134 and I-131, and takes account of possible pathways such as external irradiation, inhalation and dietary ingestion.

In either case, the additional dose equivalent commitment due to Chernobyl fallout is in the microsievert range and is 1% or less of the global annual natural background, which is roughly 2 - 3 mSv.
8. CONCLUSIONS

Intensified sampling of the local atmosphere immediately after the Chernobyl accident in 1986 and subsequent measurement using sophisticated instruments acquired in 1987 enabled a day-to-day time series of fallout pattern for Hong Kong to be drawn up. A minute amount of radiocaesium was first detected in airborne particulates around 9 May, followed by a sharp increase of fallout radionuclides (radiocaesium, ruthenium-106 and strontium-90) around 15-16 May and a rapid fall after 19 May. Another peak was observed in strontium-90 concentrations towards the month's end, although these were generally two orders of magnitude smaller than those for radiocaesium.

The observed radiocaesium levels compared favourably with those obtained by UKAEA on samples collected routinely in Hong Kong for UKAEA, and were attributable to Chernobyl on the basis of observed radiocaesium ratio.

Gross counting of beta-particle emitters was made to enable comparison with historical data. The monthly mean value of gross counts for airborne particulates was 1 to 2 orders of magnitude smaller than the levels obtained two to three decades ago when there were extensive atmospheric nuclear tests. Time series of gross beta counts on rain-water and total deposition did not reveal any significant peaks, probably a result of relatively high instrument background.

In all cases, the level of radionuclides in atmospheric samples collected in Hong Kong was extremely low, generally only about 1/1 000 000 to 1/100 000 of the level necessary for taking
some kind of countermeasure. Estimates by local researchers and by UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) put the additional dose equivalent for the local population at the range of 6 - 20 uSv (1 uSv = $10^{-3}$ mSv), or 1% or less of the global annual natural background dose (2 - 3 mSv).

A survey of radiation monitoring activities in China suggested that the fallout reached north China in early May and spread southward to east China and Taiwan by 7 May. Meteorologically, the increase of man-made radionuclides in the local atmosphere on 11 May and the second increase in around mid-May were coincident with the arrival of fresh northeasterly winds down the Taiwan Strait.

ACKNOWLEDGEMENT

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REFERENCES


Cambray, R.S. 1986 Private communication.


Chung, C. 1987 Radioactive fallout over Taiwan after Chernobyl accident, 'Proceedings of Workshop on Occupational and Environmental Radiation Protection', December 7-9, University of Hong Kong, Hong Kong.
<table>
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<tr>
<th>Reference</th>
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<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colle, R.</td>
<td>1980</td>
<td>Reporting of environmental radiation measurements data, 'Upgrading Environmental Radiation Data', Health Physics Society Committee Report HPSR-1, USEPA.</td>
</tr>
<tr>
<td>Ettenhuber, E., Marschner, P. and Siebert, H.-U.</td>
<td>1989</td>
<td>The contamination pattern of the ground in the German Democratic Republic after the Chernobyl accident, in IAEA [1989], p. 126.</td>
</tr>
</tbody>
</table>
References (cont'd)


Komarov, V.I. 1989 Radioactive contamination and decontamination in the 30 km zone surrounding the Chernobyl nuclear power plant, in IAEA [1990], pp 3–16.


Luykx, F. 1989 Response of the European Communities to environmental contamination following the Chernobyl accident, in IAEA [1990], pp 269–287.

References (cont'd)

Koga, T., Niwa, T.,
Kawai, H. and
Nishiwaki, Y.

Nishizawa, K., 1986 Iodine-131 in milk and rain after
Takata, K., Hamada, N.,
Ogata, Y., Kojima, Y.,
Yamashita, O.,
Ohshima, M. and Kayama, Y.

Nuclear Energy Agency 1987 The radiological impact of the
1986 The radiological impact of the
Chernobyl accident in OECD
countries, NEA, Organization for
Economic Co-operation and
Development.
Orlando, P.,
Gallelli, G., Perdelli, F.,
De Flora, S. and
Malcontenti, R.

Perkins, R.W.,
Robertson, D.E.,
Thomas, C.W. and
Young, J.A.

Pourchet, M.,
Pinglot, J.F.
and Gascard, J.C.

Pringle, D.M.,
Vermeer, W.J.
and Allen, K.W.

Radiological Protection Advisory Group 1990 RPAG Report No. 1 —— Derived Intervention Levels, Hong Kong Government.

Royal Observatory 1984 'Radioactivity Bulletin 1983'.
Hong Kong

Royal Observatory 1989 'Background Radiation Monitoring Programme: an Interim Report',

Sinkko, K., 1987 'Airborne radioactivity in Finland after the Chernobyl accident in
Aaltonen, H.,
Mustonen, R.,
Taipale, T.K. and
Juutilainen, J.
References (cont’d)

Swedish National Institute of Radiation Protection (SSI) 1986 'Chernobyl – its impact on Sweden', SSI-rapport 86-12.


Tso, M.Y.W., Chan, M.W. and Poon, C.B. 1987 External irradiation dose arising from Cs-137 fallout in Hong Kong, 'Proceedings of Workshop on Occupational and Environmental Radiation Protection', December 7–9, University of Hong Kong, Hong Kong.


References (cont'd)


APPENDIX 1 RADIATION MONITORING ACTIVITIES IN VARIOUS PLACES
OF THE WORLD IMMEDIATELY AFTER THE CHERNOBYL ACCIDENT
[Main references: 'Nuclear News' 1986, NEA 1987]

At the time of the accident, there was an intense
anticyclone over Ukraine and the prevailing southeasterly wind
was blowing towards Scandinavia. Finland was the first country
outside the U.S.S.R. to detect a high radiation level. Levels of
6 times the normal background were recorded in Helsinki and
Kajaani in the afternoon of 27 April, and maximum readings of 10
times greater than the normal were reported at 10 p.m. the
following day.

The radioactive materials reached Sweden at roughly the same
time (27 April) and affected northern Poland that evening
[ApSimon and Wilson 1986]. Sweden broke the news to the world in
the morning of 28 April, based on elevated radiation levels
detected in the previous afternoon. On 29 April, Polish
authorities reported a radioactive cloud had passed over
northwest Poland and more radioactivity was brought down to the
surface by rain. This prompted a ban on milk and fresh vegetable
consumption and the issue of stable iodine tablets to children.

After a few days of the accident, the wind direction turned
clockwise, causing the cloud to travel both eastward across the
U.S.S.R. and southwards to Turkey. During the last few days of
the main release (early May), the cloud was blown towards the
southwest, affecting eastern Mediterranean. After moving over
Greece, it turned northwest and again northward, towards
Scandinavia.

The initial cloud that affected Scandinavia soon split into
three segments in late April. One segment travelled eastward across northern U.S.S.R. and was later detected in China and Japan. A second crossed over central Norway and the Norwegian Sea, to be detected later in North America. The third segment moved southwestward over central Europe. This segment subsequently moved over northern Italy and southern France, before turning northwestward to affect the United Kingdom.

Radioactivity release from the site continued for some 12 days. Komarov [1990] reported four stages in the discharge of radioactivity: i) the initial discharge of fuel materials (26 April), ii) attempted curtailment of burning graphite (a neutron moderator) and filtering of discharge (26 April – 2 May), iii) re-eruption due to residual heat in the core bringing temperatures in excess of 1700°C (2 – 4 May), and iv) a final rapid decrease in release as a result of chemical stabilization and cooling measures, as well as complete oxidation of graphite (after 4 May).

During the two weeks after the accident, virtually every country in eastern and western Europe detected above-normal radiation levels. Heavy rain fell across western Europe, producing significantly higher ground-level readings in many areas. These led to warnings not to drink fresh milk or rain-water and recommendations to wash vegetables carefully. In Sweden, temporary grazing restrictions were imposed, and the public was advised not to eat freshwater fish from some local communities where high caesium concentrations had been observed in fish [SSI 1986]. On 12 May the European Economic Community suspended the import of fresh food from several countries within
1000 km of Chernobyl, until the end of May when maximum permitted caesium levels were adopted: 370 Bq/kg for milk and infant food and 600 Bq/kg for other foodstuffs. Within the European Community the highest levels of I-131 and radiocaesium contamination were observed in the southern part of West Germany, in Greece and Italy [Luykx 1989]. The decreasing radiation levels in late May prompted West Germany to terminate precautions against consumption of fruit, grain, vegetables and milk, and Poland to partially lift rationing of powdered milk for children [from press]. However, the movement and slaughter of lambs in Wales, Cumbria and Scotland were prohibited in June as a result of abnormally high levels of radiocaesium in lamb meat. Most of these restrictions were progressively removed by late July ['Nature' 1986].

A chronology of detection of Chernobyl fallout is presented in Table A1.1. A map of Europe is shown in Fig. A1.

Reliable dates of first detection in various places in China are already shown in Fig. 6.1. The amount of fallout in China was found to be higher in the north than in the south. Overall, the dosimetric significance based on observational data were found to be minimal and no radiation protection measures were considered necessary [Wang 1987].

On the observation side, a second increase in radioactivity occurred in places like Sweden [Devel1 et al. 1986, SSI 1986], Finland [Sinkko et al. 1987] and Hungary [Sztanyik et al. 1990] during the first two weeks in May. In Paris, France, a second maximum was reported between 10 and 19 May, with relatively long-
lived radioactive elements reduced by three order of magnitudes [Thomas and Martin 1986]. A similar observation was made on 18 May in Tennessee, USA [Bondietti and Brantley 1986]. Chinese stations registered the second increase generally around mid-May (see Table A1.1).

No radioactivity attributable to Chernobyl was detected in Singapore (1°N) [Cambray et al. 1987a]. Negative results for the southern hemisphere were reported for Brazil [Conti et al. 1989], New Zealand [Mathews 1987] and the sampling stations operated by UKAEA in Australia, New Zealand, Botswana, South Africa, Falkland Islands and the Antartica [Cambray et al. 1987a].
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<td>Helsinki and Kajanni, Finland</td>
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<td>Sweden</td>
<td>27 April</td>
<td>At Forsmark nuclear power station and at Studsvik research centre [Devell et al. 1986, SSI 1986].</td>
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<td>Poland, north</td>
<td>27 April</td>
<td>[ApSimon and Wilson 1986]</td>
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<td>East Germany</td>
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<td>[Gunnerod et al. 1989]</td>
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<td>Debrecen and Budapest, Hungary</td>
<td>29 April (1 May)</td>
<td>[Csongor et al. 1986]</td>
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<td>Spiez and Zurich, Switzerland</td>
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<td>[Sztanyik et al. 1989]</td>
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<td>29-30 April (2-5 May)</td>
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<td>[Thomas and Martin 1986]</td>
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<td>Eisenstadt and Salzburg, Austria</td>
<td>30 April</td>
<td>Quoted in DOE [1987]</td>
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<td>Ankara, Turkey</td>
<td>30 April (5-6 May)</td>
<td>[Aycik and Golge 1990]</td>
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<td>Sofia, Bulgaria</td>
<td>1 May</td>
<td>Quoted in Vasilev et al. [1989]. Highest average dose outside U.S.S.R., amounting to about 1/3 of the natural background [Bennett 1990]</td>
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<td>Oak Ridge, Tennessee, USA</td>
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Fig. A1  Places in Europe mentioned in this report.