HONG KONG OBSERVATORY

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ENVIRONMENTAL RADIATION MONITORING IN HONG KONG – 1987 TO 2002

by

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摘 要

廣東的核電站位於香港市區東北約50公里。為配合核電站的興建及運作，香港天文台於一九八三年展開了一項全面的環境輻射監測計劃 (ERMP)。計劃的內容包括監測全港的環境伽馬輻射水平，以及測量在各類環境樣本中阿爾法、貝他及伽馬放射性核素的活度濃度。

ERMP 的第一階段名為本底輻射監測計劃 (BRMP)，在一九八七年至一九九一年期間進行，目的是要在首批核燃料於一九九二年運抵廣東前，確定香港本底輻射水平。ERMP 的第二階段由一九九二年開始持續進行至今，目的是監測香港環境放射性水平的長期趨勢。

ERMP 數據揭示本港環境放射性水平變化與全球趨勢吻合。在廣東省核電站投入運作前後，香港的環境放射性水平並沒有顯著差別。

ABSTRACT

In connection with the construction and operation of the nuclear power stations at Guangdong, which are located at about 50 km northeast of urban Hong Kong, the Hong Kong Observatory implemented a comprehensive environmental radiation monitoring programme (ERMP) in 1983. The programme comprises territory-wide monitoring of the ambient gamma radiation level, as well as measurement of the activity concentrations of alpha, beta and gamma emitting radionuclides in various environmental media.

The first phase of the ERMP, the Background Radiation Monitoring Programme (BRMP), was conducted from 1987 to 1991 to establish the baseline radiation levels in Hong Kong before the arrival of the nuclear fuel in 1992. Since 1992, the ERMP is conducted as an on-going programme to monitor the long term trend in the radiation levels in Hong Kong.

By contrasting the ERMP data with the trend observed globally, it is concluded that there are no significant differences in the environmental radioactivity of Hong Kong, before and after the operation of the nuclear power stations at Guangdong.

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1. INTRODUCTION

In connection with the construction of the nuclear power stations (NPS) at Guangdong some 50 km northeast of Hong Kong, the Hong Kong Observatory (HKO) implemented a comprehensive environmental radiation monitoring programme (ERMP) in 1983.

As human beings are affected by radioactivity through both external and internal exposures, environmental radioactivity is defined by the ambient gamma radiation level and content of radionuclides in the environment. For external exposure to direct radiation, the baseline level is the long-term average of the ambient gamma radiation level measured at the radiation monitoring stations distributed throughout the territory. For internal exposure, the human being is exposed to radiation from radionuclides in various environmental media taken in through the processes of respiration, ingestion of food and drinking of water. The baseline level for internal exposure is represented not by a single value but a distribution of the activity concentrations of selected radionuclides measured in samples collected in the atmospheric, terrestrial and aquatic exposure pathways. The ERMP comprises territory-wide monitoring of the ambient gamma radiation level, and measurement of the activity concentrations of alpha, beta and gamma emitting radionuclides in various environmental media. As the Guangdong nuclear power stations employ the pressurized water type reactor, the programme is designed to monitor those critical radionuclides representative of the release from this type of reactors.

The first phase of the ERMP, the Background Radiation Monitoring Programme (BRMP), was carried out in the 5-year period from 1987 to 1991, before the arrival of nuclear fuel at the NPS. The objective of the BRMP was to establish the baseline radiation levels in Hong Kong against which any future changes in the environmental radiation levels, particularly those arising from the operation of the NPS, could be determined. A report covering all five years of measurements was published in December 1992 (Hong Kong Observatory, 1992).

In 1992, the ERMP entered the second phase, hereafter referred to as ERMP-II. With the NPS beginning commercial operation in February 1994 the ERMP-II has been conducted as an on-going programme. The objectives of the ERMP-II are: (a) to determine if there are any long term changes in the environmental radioactivity of Hong Kong, and (b) to maintain a monitoring capability at the HKO which is essential for emergency response to nuclear incidents. The results of measurements have been published in annual reports since 1992 (Hong Kong Observatory, 1994 - 2003).

This report reviews the measurement results of the ERMP including the BRMP and assesses the extent to which the environment radioactivity of Hong Kong has changed, if any, subsequent to the operation of the nuclear power stations.

2. SAMPLING PROGRAMME

2.1 Ambient Gamma Radiation Measurement Programme

Two networks have been set up to provide a continuous measurement of the ambient gamma exposure rate. They are the radiation monitoring network (RMN) which measures the instantaneous environmental gamma dose rate using high-pressure ionisation chambers (HPIC), and the thermoluminescent dosimeter (TLD) network which measures the accumulated gamma exposure over a specified period of time. The RMN provides data with high temporal resolution which is essential for emergency response while the TLD network is a low cost means of achieving wide spatial coverage of ambient gamma dose rates. Both networks have their own merits and are complementary to each other in achieving the overall programme objectives.

The locations of the monitoring stations are shown in Figure 2.1. The RMN had four stations in the BRMP but was gradually extended to a total of ten stations by 1993. In the BRMP and ERMP-II, the numbers of TLD stations were 49 and 27 respectively.

2.2 Environmental Media Sampling Programme

The measurement of activity concentration of alpha, beta and gamma emitters in various environmental media is another major component in the ERMP. The sampling programme of the ERMP is designed to collect representative samples in the three major exposure pathways, namely the atmospheric pathway, the terrestrial pathway and the aquatic pathway.

The sample types in the atmospheric pathway include airborne particulate, wet deposition, total deposition, airborne radioiodine, water vapour in air and carbon dioxide in air. The samples collected in the terrestrial pathway include rice, pasteurized milk, vegetable, fruit, poultry, meat and land soil. The samples collected in the aquatic pathway include drinking water, underground water, sea water, suspended particulates, freshwater fish, seafood, seaweed and sediment. The foodstuffs are selected based on their representativeness in the diet of the local population and whether they are consumed locally in large quantities. Particular attention has been given to food produced locally, in Shenzhen and nearby Hong Kong waters.

The sample types collected in the ERMP are under constant review to ensure the representativeness. The sampling of total deposition was introduced in 1995. This would provide more deposition samples collected in the atmospheric pathway for analysis, especially during the dry season. The sampling of cuttle fish was introduced in 1997 when the Guangdong Environmental Radiation Monitoring Report for 1996 (Guangdong, 1997) reported the detection of silver-110m in this sample type.

The rapid development and urbanization in Hong Kong have inevitably resulted in the relocation or even deletion of some of the sampling locations. The details of the changes in 1987 to 2002 are shown in Table 2.1. Furthermore, due to fishing restrictions imposed in the Daya Bay region by the Guangdong authorities, seafood samples in Daya Bay have been collected through arrangements with a marine culture farm in the region since 1998.

Atmospheric samples are collected continuously. Foodstuffs are collected once every quarter for those available throughout the year, but fruits are collected only once or twice a year when they are in season. However, the number of seafood samples collected in the Daya Bay region varied greatly throughout the years depending on their availability from the marine culture farm.

In total, about 2,100 samples and 3,900 samples were collected in the BRMP and ERMP-II periods respectively (Table 2.2). In recent years, the number of samples collected for the programme has been maintained at a steady level of some 400 each year.

A summary of the sampling programme in the BRMP and ERMP-II is shown in Table 2.1 and the sampling locations are shown in Figure 2.1. Further details of the sampling programme are given in the BRMP Report (Hong Kong Observatory, 1992) and the ERMP Annual Reports (Hong Kong Observatory, 1994 - 2003).

3. RADIO-ANALYTICAL MEASUREMENT METHODS

Laboratory analytical methods are used to obtain information on the activity concentration of artificial radionuclides in the samples. The major radionuclides monitored include the alpha emitter plutonium-239, the beta emitters tritium, strontium-90 and carbon-14 as well as the gamma emitters iodine-131 and caesium-137. After the samples are collected and delivered to the King's Park Radiation Laboratory, they are subjected to sample treatment processes using various physical and chemical methods and followed by radioactivity measurement. Each sample, depending on the sample type, would go through one or more of the following analyses:

(a) gamma spectrometry for detecting and measuring the activity concentration of gamma-emitting radionuclides;

(b) liquid scintillation counting (prior to 1995) / low level gross beta counting (1995 onwards) to determine the activity concentration of tritium and strontium-90;

(c) alpha spectrometry to determine the activity concentration of plutonium-239; and

(d) analysis of carbon-14 using both liquid scintillation counting and accelerator mass spectrometry techniques.

The measurement systems, analysis methodologies as well as laboratory procedures have been reviewed and upgraded throughout the years. The low level gross beta counting system was introduced in 1995 to replace the liquid scintillation counting system for strontium-90 measurement, to reduce the amount of chemical waste generated. The analysis methodologies for strontium-90 in mineral and water matrices were revised in 1999 following the experience gained from the International Atomic Energy Agency (IAEA) inter-laboratory comparison exercises. These are further discussed in Chapter 4 on quality assurance. A summary of the changes in analysis methodologies in 1987 to 2002 are given in Table 3.1.

Further details of the measurement systems and analysis methodologies are given in the BRMP Report (Hong Kong Observatory, 1992) and the ERMP Annual Reports (Hong Kong Observatory, 1994 - 2003).

4. QUALITY ASSURANCE

4.1 Quality Assurance Programme

The design of the ERMP quality assurance (QA) programme is based on the guidelines given in "The Procedures Manual of the Environmental Measurements Laboratory, HASL-300" (U.S. Department of Energy, 1997) which are followed worldwide. The QA programme comprises the following components: staff qualification, sampling technique, preparation and storage of samples, coding and record keeping, quality control sample, instrument calibration and stability, background evaluation, data storage, intra-laboratory and inter-laboratory comparisons. The details of the QA programme are given in Appendix A.

The results of the intra- and inter-laboratory measurement results which are the major performance indicators of the ERMP in terms of measurement precision and accuracy are outlined below.

4.2 Internal Quality Assurance

Duplicate sample analysis is used to ensure the precision of measurements. In the ERMP, one out of ten samples submitted for analysis was selected as a quality control (QC) sample for duplicate analysis. In the past 16 years, over one thousand duplicate analyses were conducted. Over 99.5% of the QC sample results agreed with those of the routine measurements. Whenever there was a discrepancy between the QC and routine measurement results, and if a sufficient amount of sample material could be made available, the analysis was repeated to identify the factors that led to the discrepancy, with a view to improving on the precision of the analysis.

Blank samples are analysed on a regular basis to determine if there are any contamination of the samples or the measurement systems introduced during the course of sample preparation and analysis. Spiked samples with known amounts of activity are measured regularly for routine checking of the performance of the analysts and measurement systems.

The detailed statistics of these results are given in Tables A1-4 of Appendix A.

Since 2000, the laboratory analysts were separated into two teams to allow independent auditing of the work by each other. Routine analysis is conducted by one team and random auditing of the analysis results is conducted by the other.

Participation in inter-laboratory comparison exercises is a most effective QA measure. However, inter-laboratory comparison exercises are only organized by international and national laboratories once every few years. In order to maintain the skills of the analyst and to ensure the performance of the measurement systems, a proficiency test programme using International Atomic Energy Agency (IAEA) reference materials was introduced in 1999. Under this programme, IAEA reference materials of selected radionuclides, activity and matrices were measured on a half-yearly basis. In the three years following the introduction of this programme, all IAEA reference materials QA results were within the IAEA confidence limit. The details of the results are given in Table A5 of Appendix A.

4.3 Inter-laboratory Comparison Exercises

To ensure the accuracy of the measurement results, HKO has been participating in inter-laboratory comparison exercises since 1989. So far HKO has participated in 13 inter-laboratory comparison exercises held by the IAEA, and one each held by the World Health Organization and the China Institute for Radiation Protection (CIRP). The details of these results are given in Tables A6-7 of Appendix A. In summary, over 90% of the measurement results reported by the HKO were within the range of the accepted values. An investigation would be initiated whenever the reported measurement results deviated significantly from the accepted values. The investigation results would either indicate that the error was due to human error or a deficiency in the analysis technique/procedure. The sample preparation and measurement procedures would then be revised to minimize the recurrence of the human error. In other cases, the analysis technique/procedure would be re-designed to remedy the deficiency. Two analysis techniques were revamped following lessons learnt from the inter-laboratory comparison exercises, both involving strontium-90 measurements. They were namely: (a) the chemical separation procedure for extracting strontium-90 from mineral matrix and (b) the analysis technique for strontium-90 in water samples of elevated radioactivity level. The details of the revised techniques are given in the ERMP Annual Report 1999 (Hong Kong Observatory, 2000).

5. MEASUREMENT RESULTS

5.1 Ambient Gamma Dose Rates

The ambient gamma dose rates obtained from the RMN and TLD networks are given in Table 5.1. Each figure is the ambient gamma dose rate averaged over the BRMP or ERMP-II period at one location.

5.2 Radioactivity in Environmental Samples

In this report, if the signal level for a counting measurement is too low to distinguish it from the background noise with statistical significance, the estimated minimum detectable activity (MDA) based on the background noise measured, is reported. Radioactivity below the MDA is denoted by the "<" sign. "Measurable result" means that the activity concentration of the radionulcide being measured is above the MDA, in which case the radionuclide is said to be detected.

A list of typical "detection limits" for the various activity measurements under "typical" measurement conditions for the samples used in the ERMP is given in Table 5.2. The detection limit depends on the characteristics of the measurement system, the method of measurement, the sample characteristics and the measurement conditions. Changes in these detection limits arising from changes of measurement conditions are also shown in the Table. These detection limits serve to provide a quick reference for easy interpretation of the measurement results in this report.

The two major artificial gamma emitting radionuclides: caesium-137 and iodine-131 which are representative of the releases from pressurized water reactors are tabulated in the report. No other artificial gamma emitting radionuclides have been detected.

For alpha and beta emitting radionuclides, tritium activity concentration was measured and reported in all samples containing water. For strontium-90, plutonium-239 and carbon-14, because of the laborious chemical treatment required for preparing the samples, activity concentrations of these radionuclides were only measured and reported for selected samples.

The measurement results of the BRMP and ERMP-II samples collected in the atmospheric, terrestrial and aquatic pathways are presented in Tables 5.3 to 5.8. The data are categorized according to the radionuclide analysed, sampling pathway and sample type. Each table contains the following parameters:

(a) the total number of samples analysed;

(b) the range of activity concentration of all samples. For those with activity concentrations less than the typical MDA, the latter is used as the lower limits;

(c) the mean activity concentration and standard deviation of samples with measurable activity; and

(d) the number and percentage of all samples with measurable activity.

For samples with activity concentrations that exceeded the upper limit of the BRMP range, the 2-sigma measurement uncertainty at the 95% confidence interval is also listed in the footnotes to the Tables, to aid judgement as to whether the upper limit is exceeded to within the measurement uncertainty.

6. REVIEW OF MEASUREMENT RESULTS

6.1 Ambient Gamma Radiation Level

The ambient gamma dose rates in the territory were measured by the RMN and the TLD network in the BRMP and ERMP-II. The ambient gamma dose rate arises from cosmic rays and naturally existing terrestrial radionuclides present at trace levels in soil. While the cosmic component is relatively uniform over the whole of the territory of Hong Kong, the specific levels of the terrestrial component are related to the types of rock from which the soil originates. Higher radiation levels are associated with igneous rocks, such as granite, and lower levels with sedimentary rocks. The average ambient gamma dose rates in the BRMP and ERMP-II were both 0.12 μGy/h, and the range was 0.08 – 0.18 μGy/h in the BRMP and 0.08 – 0.19 μGy/h in the ERMP-II. The wide spatial variation of the ambient gamma dose rate reflected the characteristics of the underlying geology, as discussed in Wong *et al* (1999).

In Table 6.1 the results of the statistical test show that there are no statistically significant differences in the BRMP and ERMP-II ambient gamma radiation conditions.

6.2 The Trend of Artificial Radionuclides in the Global Environmental

One way to appreciate the trend in the environmental radioactivity in Hong Kong is to contrast the ERMP data with those observed globally.

The United Nations Scientific Committee on the Effects of Atomic Radiation discussed the trend of the artificial radionuclides in the environment (UNSCEAR, 2000). Nuclear testing, fuel re-processing, weapon manufacturing, accidents, waste and nuclear power generation are sources of artificial radioactive materials released to the environment, with the atmospheric nuclear testing from 1945 to 1980 being the most significant one. Taking into account fission yield, amount produced via neutron activation, mobility and half-life of the radionuclides released, carbon-14 and strontium-90 are the artificial radionuclides that are most readily measurable in the environment.

Tritium was released in large amounts in those atmospheric nuclear tests. However, the radionuclide was highly mobile and rapidly attained equilibrium with the natural water cycle in the hydrosphere. Tritium released in the form of tritiated hydrogen (HT) and tritiated water vapour (HTO) was rapidly diluted through assimilation into the local and global water cycles through processes such as precipitation, evapotranspiration and run-off. UNSCEAR reported that the decrease of annual dose from globally dispersed tritium was so rapid that by the 90's it was several orders of magnitude lower than those from other radionuclides including carbon-14, strontium-90 and caesium-137. This explains why tritium from the nuclear tests is not readily measurable in the present environment.

Deposition of caesium-137 and strontium-90 produced in the atmospheric nuclear tests was still significant until the late 80's (UNSCEAR, 2000). In terms of fission yield, mobility and half-life the behaviour of the two radionuclides are very similar. However, the transfer of strontium-90 to crops via root-uptake is significantly more efficient than that of caesium-137, as the latter radionuclide will fix to clay (UNSCEAR, 2000). Strontium-90 is hence a radionuclide more readily measurable in foodstuff samples than casesium-137.

Apart from the atmospheric nuclear testing, the nuclear reactor accident at Chernobyl on 26 April 1986 also resulted in a major release of radioactive materials into the atmosphere. According to UNSCEAR (2000), the contaminated area was mainly confined to the European part of the former Soviet Union, the three Scandinavian countries, Austria and Bulgaria. Therefore the measurement results in the ERMP were not affected. In fact, only an insignificant amount of fallout was detected in Hong Kong a few days after the accident (Lee and Tsui, 1991).

6.3 Artificial Radionuclides in Hong Kong

Tables 5.3 to 5.8 summarize the activity concentrations of the radionuclides in environmental samples collected in the BRMP and ERMP-II. All gamma emitters in the samples, except iodine-131 and caesium-137, are below the MDA. Measurable activity concentration of iodine-131 was found in two airborne particulate samples, one airborne radioiodine sample and three seaweed samples.

For caesium-137 and plutonium-239 in the BRMP and ERMP-II samples, the percentage of samples found with measurable activity concentrations are outlined below:

	Percentage of Samples with Measurable Activity Concentration	
	Cs-137 (Pu-239) in BRMP	Cs-137 (Pu-239) in ERMP-II
Atmospheric Pathway	0% (0%)	0% (0%)
Terrestrial Pathway	18% (20%)	13% (15%)
Aquatic Pathway	14% (16%)	21% (21%)

The samples found with measurable activity concentrations of caesium-137 included rice, milk, meat, land soil, seafood, seaweed and sediment while the samples found with measurable activity concentrations of plutonium-239 were land soil, seafood, seaweed and sediment.

Statistical test is carried out in the analysis of the measurement results, to check whether there were any statistically significant changes in the radioactivity figures. Following the guidelines of the American Chemical Society (ACSCR, 1983) on the conditions of the data to be used in hypothesis test, only data in a sample with size greater than 7 and uncertainty smaller than 10% would be subjected to quantitative statistical analysis.

For the measurement results of iodine-131, caesium-137 and plutonium-239, the number of data with measurement uncertainty smaller than 10% is less than 7, which do not satisfy the ACSCR (1983) criteria for the hypothesis test. Despite the insufficient amount of data for conducting the comparison it is noted that the activity concentrations of these radionuclides in the ERMP-II samples were below the upper limits in the BRMP, to within the measurement uncertainty.

Although tritium was measurable in more than 50% of the environmental samples collected in all three pathways in the BRMP and ERMP-II, most of the measured activity concentrations were very close to the detection limit and their accuracy were low. The number of data with measurement uncertainty smaller than 10% is less than 7, which do not satisfy the ACSCR (1983) criteria for the hypothesis test. It should however be noted that the activity concentrations of tritium in the ERMP-II samples were below the upper limit in the BRMP, to within the measurement uncertainty.

Carbon-14 and strontium-90 were measurable in a large percentage of the environmental samples. Carbon-14 was measurable in all foodstuff samples, and strontium-90 was measurable in rice, milk and vegetable samples. There are enough data with quality satisfying the conditions for hypothesis testing set out by ACSCR (1983). Further analyses are presented in the following sections. For carbon-14 and strontium-90, it is again noted that their activity concentrations in the ERMP-II environmental samples were below the upper limit observed in the BRMP, to within the measurement uncertainty.

The activity concentrations of the artificial radionuclides in the Hong Kong environment as observed in the ERMP are largely in line with the UNSCEAR picture. Carbon-14 and strontium-90 were the artificial radionuclides most readily measurable in the environment. Tritium was measurable in a large variety of environmental media, but the level was extremely low due to dilution in the natural environment. All other artificial radionuclides were only sporadically measurable.

6.4 Carbon-14 Measurement Results

The major nuclear testing period in 1945-1980 resulted in high concentration of artificial carbon-14 in the stratosphere and the troposphere (NCRP, 1985). Carbon-14 produced or released in the atmosphere would enter the carbon cycle of exchangeable carbon reservoirs of atmosphere, biosphere, ocean, ocean sediment and organic shale. After the moratorium on nuclear testing, the enhanced carbon-14 level above the naturally produced background started to decline globally. Though the decline rate has been fairly constant, it was modulated by the dilution effect arising from the use of fossil fuels. The latest published value of the decline rate is 13 years, which is reported by Otlet *et al* (1997) for the period of 1985 – 89.

Using the halving time of 13 years, the ERMP-II measurement results were decay corrected to the BRMP period for comparison. Table 6.2 shows that there were no statistically significant differences between the BRMP and ERMP-II measurement results for the foodstuff samples. It is therefore concluded that the operation of the nuclear power stations at Daya Bay has not contributed to the carbon-14 inventory in the environment of Hong Kong.

6.5 Strontium-90 Measurement Results

Strontium-90 produced in atmospheric nuclear testing was dispersed globally and its deposition on ground was practically completed by the late 80's (UNSCEAR, 2000). The transfer of the accumulated deposit to food via root uptake is described by UNSCEAR using the following equation:

$$C_i = b \sum e^{-\lambda' n} F_{i-n}$$

where C_i is the concentration of strontium-90 in food in the year i, and $\sum e^{-\lambda' n} F_{i-n}$ is the decay corrected accumulated deposit. The decay constant λ' reflects both radioactive decay and environmental loss of the radionuclide. The value of b and λ' is 0.00011 Bq a kg^{-1} per Bq m^{-2} and 0.06 a^{-1} respectively (UNSCEAR, 2000).

The λ' of 0.06 a^{-1} is equivalent to a halving time ($\ln 2/\lambda'$) of 11.6 years. Using this halving time, the ERMP-II strontium-90 measurement results for rice, milk and vegetable samples were decay corrected to the BRMP period for comparison. Statistical test results as shown in Table 6.3 confirm that there were no significant differences between the BRMP and ERMP-II measurement results for all three types of samples. It is concluded that there is no deposition of strontium-90 in the environment of Hong Kong arising from the operation of the nuclear power stations at Daya Bay.

7. CONCLUSION

The sampling programme, measurement methods, quality assurance programme and measurement results of the ERMP from 1987 to 2002 have been reviewed.

Owing to rapid development and urbanization in the last ten years or so, some sampling sites have been affected by environmental changes. The sampling programme has been regularly revised to ensure that the ERMP samples are representative of the environment in the territory.

A comprehensive quality assurance programme meeting international standards was in place to ensure the reliability of the analyses in the ERMP. The precision and accuracy of the measurements were assured through intra-laboratory and inter-laboratory comparisons. Analysis techniques have been constantly revised to improve the quality of the measurement results.

From the analysis of the measurement results, it is concluded that:

(a) The ERMP-II level of ambient gamma radiation was no different from that in the BRMP;

(b) For artificial radionuclides in environmental media, the activity concentrations in all ERMP-II samples were below the upper limit of the range observed in the BRMP;

(c) Carbon-14 and strontium-90 released from the atmospheric nuclear tests in the last century were still measurable in the BRMP and ERMP-II environmental samples. Statistical tests confirmed that there were no significant differences in their activity concentration levels;

(d) The trend of the artificial radionuclides in the Hong Kong environment as observed in the ERMP is largely in line with the global trend reported by UNSCEAR (2000).

Taken together, the environmental radioactivity in Hong Kong showed no statistically significant difference before and after the operation of the NPS at Daya Bay.

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* The Hong Kong Observatory was listed as “Royal Observatory Hong Kong” in publications released before 1 July 1997.

Figure 2.1 Environmental radiation measurement and sampling locations

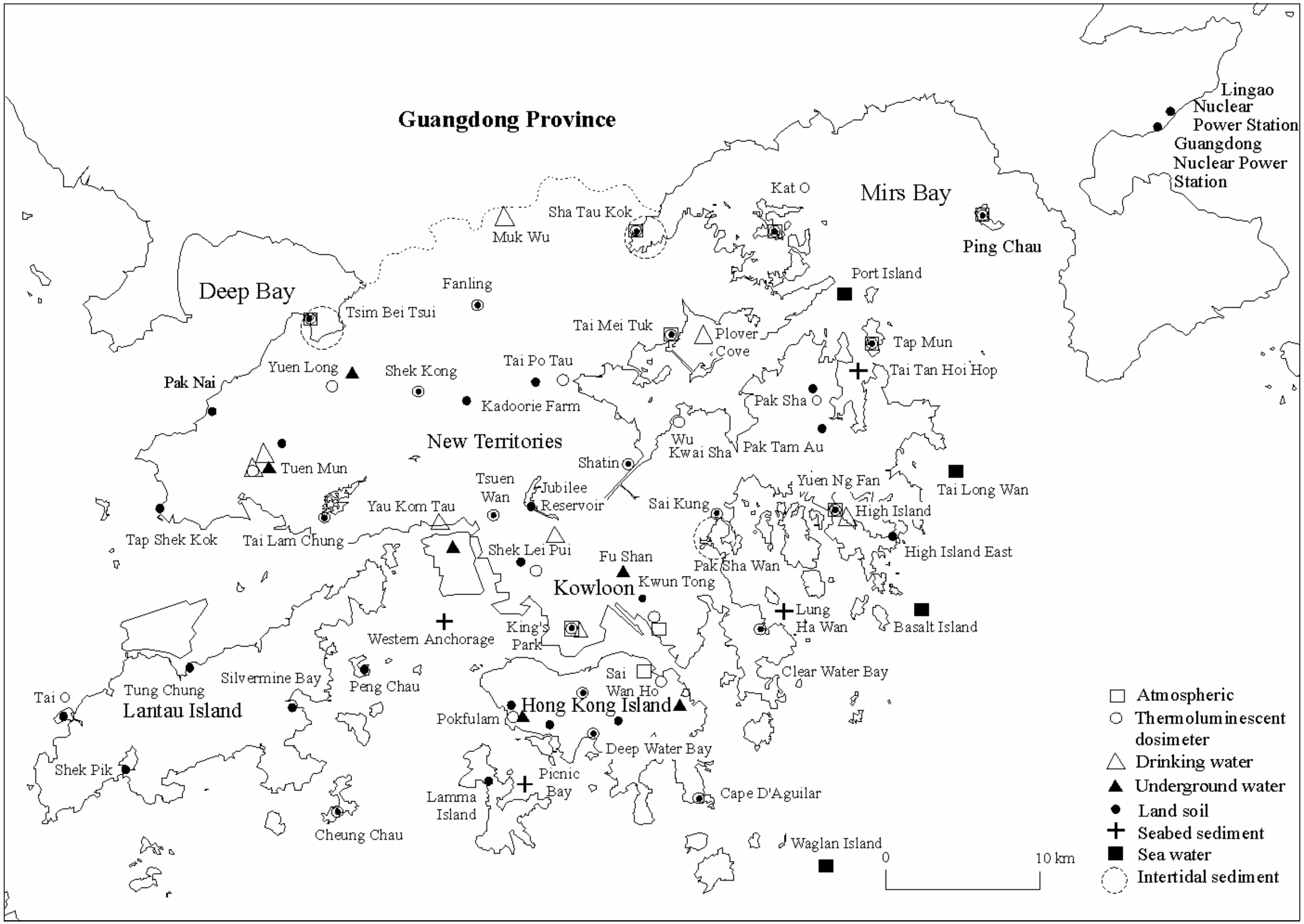

Table 2.1 Summary of sampling programme

Sample type	BRMP		ERMP-II		Sampling frequency	Remarks
	Sampling location	**No. of location**	**Sampling location**	**No. of location**		
Atmospheric pathway						
Airborne particulate	King's Park, Tsim Bei Tsui, Sha Tau Kok, Yuen Ng Fan	4	King's Park, Sha Tau Kok, Yuen Ng Fan	3	weekly (bulked monthly)	• Environmental change in Tsim Bei Tsui.
Wet deposition (precipitation)	King's Park, Tsim Bei Tsui, Sha Tau Kok, Yuen Ng Fan	4	King's Park, Sha Tau Kok, Yuen Ng Fan	3	weekly (bulked monthly)	• Environmental change in Tsim Bei Tsui.
Total deposition	-	-	King's Park	1	weekly (bulked monthly)	• Introduced in 1995.
Airborne radioiodine	King's Park	1	King's Park	1	weekly	
Water vapour in air	King's Park	1	King's Park	1	monthly	
Carbon dioxide in air	King's Park	1	King's Park	1	monthly	
Terrestrial pathway						
Rice	Mainland	1	Mainland	1	quarterly	
Pasteurized milk	Shenzhen, Sha Tau Kok, Yuen Long, Fanling	4	Sha Tau Kok, Shenzhen	2	quarterly	• Urbanization caused closure of two farms.
Choi sum	Shenzhen, Local	2	Mainland, Local	2	quarterly	
Pak choi	Shenzhen, Local	2	Mainland, Local	2	quarterly	
Banana	Mainland	1	Mainland	1	quarterly	
Lychee	Mainland	1	Mainland	1	summer	• Collected when in season.
Mandarin	Mainland	1	Mainland	1	autumn and winter	• Collected when in season.
Sugar cane	Mainland	1	Mainland	1	spring	• Collected when in season.
Chicken	Mainland, Local	2	Mainland, Local	2	quarterly	
Duck	Mainland, Local	2	Mainland, Local	2	quarterly	
Beef	Mainland	1	Mainland	1	quarterly	
Pig's liver	Mainland, Local	2	Mainland, Local	2	quarterly	

Table 2.1 cont'd

Sample type	BRMP		ERMP-II		Sampling frequency	Remarks
	Sampling location	No. of location	Sampling location	No. of location		
Pork	Mainland, Local	2	Mainland, Local	2	quarterly	
Land soil (upper and lower level)	Hong Kong Island, Kowloon and the New Territories	39	Hong Kong Island, Kowloon and the New Territories	39	once every 6 years	• One-off exercise in BRMP. • Since 1999, sampling was spreaded over six years. • Some of sampling locations were relocated due to changes in land use and/or development.
Aquatic pathway						
Drinking water (treated)	Kowloon distribution tap, Tuen Mun distribution tap, Shatin Treatment Works, Yau Kom Tau Treatment Works, Tuen Mun Treatment Works	5	Kowloon distribution tap, Tuen Mun distribution tap, Shatin Treatment Works, Yau Kom Tau Treatment Works, Tuen Mun Treatment Works	5	quarterly	
Drinking water (untreated)	Shatin Treatment Works, Yau Kom Tau Treatment Works, Muk Wu B Pumping Station, Tuen Mun Treatment Works	4	Shatin Treatment Works, Yau Kom Tau Treatment Works, Muk Wu B Pumping Station, Tuen Mun Treatment Works, High Island Reservoir, Plover Cove Reservoir	6	quarterly	• Number of sampling locations was increased.
Underground water	Yuen Long Estate, Siu Hong Court, Cheung Hong Estate, Wah Fu Estate, Wan Tsui Estate, Shun Lee Estate	6	Yuen Long Estate, Siu Hong Court, Cheung Hong Estate, Wah Fu Estate, Wan Tsui Estate, Fu Shan Estate	6	yearly	• Obsolete site at Shun Lee Estate was replaced by an available site at Fu Shan Estate.
Sea water (upper, middle and lower level)	Port Island, Tai Long Wan, Basalt Island, Waglan Island	4	Port Island, Tai Long Wan, Basalt Island, Waglan Island	4	yearly	

Table 2.1 cont'd

Sample type	BRMP		ERMP-II		Sampling frequency	Remarks
	Sampling location	**No. of location**	**Sampling location**	**No. of location**		
Suspended particulate in sea water (upper, middle and lower level)	Port Island, Tai Long Wan, Basalt Island, Waglan Island	4	Port Island, Tai Long Wan, Basalt Island, Waglan Island	4	yearly	
Aristichthys nobilis (freshwater fish)	Shenzhen, Yuen Long	2	Shenzhen, Yuen Long	2	quarterly	
Nemipterus japonicus (marine fish)	Daya Bay area East of Daya Bay West of Hong Kong Hong Kong waters	4	Daya Bay/Daya Bay east West of Hong Kong Hong Kong waters	3	quarterly	• Fishing restrictions imposed in the Daya Bay region by the Guangdong authorities. Samples in this area supplied by an aqua-produce farm.
Platycephalus indicus (marine fish)	Daya Bay area East of Daya Bay West of Hong Kong Hong Kong waters	4	Daya Bay/Daya Bay east West of Hong Kong Hong Kong waters	3	quarterly	• Same as above.
Trichiurus haumela (marine fish)	Daya Bay area East of Daya Bay West of Hong Kong Hong Kong waters	4	Daya Bay/Daya Bay east West of Hong Kong Hong Kong waters	3	quarterly	• Same as above.
Portunus sanguinolentus (crab)	Daya Bay area East of Daya Bay West of Hong Kong Hong Kong waters	4	West of Hong Kong Hong Kong waters	2	quarterly	• Same as above.
Metapenaeopsis barbata (shrimp)	Daya Bay area East of Daya Bay West of Hong Kong Hong Kong waters	4	West of Hong Kong Hong Kong waters	2	quarterly	• Same as above.
Loligo edulis (squid)	Daya Bay area East of Daya Bay West of Hong Kong Hong Kong waters	4	Daya Bay/Daya Bay east West of Hong Kong Hong Kong waters	3	quarterly	• Same as above.

Table 2.1 cont'd

Sample type	BRMP		ERMP-II		Sampling frequency	Remarks
	Sampling location	**No. of location**	**Sampling location**	**No. of location**		
Sepia spp (cuttle fish)	-	-	Hong Kong waters	1	quarterly	• Introduced in 1997.
Tapes philippinarum	Cheung Chau, Port Shelter, Tolo Harbour	3	Cheung Chau, Tolo Harbour	2	quarterly	• Environmental change in Port Shelter. Site removed
Perna viridis	Cheung Chau, Junk Bay, Tolo Harbour	3	Cheung Chau, Tolo Harbour, Daya Bay	3	quarterly	
Babylonia formosae	Castle Peak Bay, Mirs Bay	2	Hong Kong waters	1	quarterly	
Ulva lactuca (seaweed)	Po Toi O	1	Po Toi O	1	winter and spring	
Enteromorpha prolifera (seaweed)	Po Toi O, Tolo Harbour	2	Tolo Harbour	1	winter	• Dried seaweed sample at Po Toi O was not collected in ERMP.
Porphyra dentate (seaweed)	Po Toi Island	1	Po Toi Island	1	winter	
Sargassum hemiphyllum (seaweed)	Po Toi O	1	Po Toi O	1	winter and spring	
Intertidal sediment (upper and lower level)	Pak Sha Wan, Tsim Bei Tsui, Sha Tau Kok	3	Pak Sha Wan, Tsim Bei Tsui, Sha Tau Kok	3	quarterly	• In winter 1994, there was a road widening work along coastline of Sha Tau Kok. A nearby compatible sampling point at Sha Tau Kok was selected for replacement.
Seabed sediment	Tai Tan Hoi Hap, Lung Ha Wan, Picnic Bay, Western Anchorage	4	Tai Tan Hoi Hap, Lung Ha Wan, Picnic Bay, Western Anchorage	4	yearly	

Table 2.2 Summary of number of samples collected in the ERMP

Period	Number of samples collected
BRMP	2100
ERMP-II	
1992	281
1993	272
1994	357
1995	312
1996	351
1997	380
1998	386
1999	387
2000	397
2001	400
2002	377

Table 3.1 Summary of measurement methods

Measurement type		Sample treatment	Analytical method	Measuring equipment
Ambient gamma dose-rate		-	Continuous measurement	• BRMP-2000: Reuter-Stokes Model 1013 PIC High Pressure Ionisation Chamber • 2001-present: Reuter-Stokes Model RSS-131 High Pressure Ionisation Chamber
Cumulative gamma dose		-	-	• BRMP-1994: Dysprosium-doped calcium sulphate ($CaSO_4$:Dy) TLD • 1995-present: Lithium fluoride (LiF:Mg,Ti) TLD
Mobile survey		-	-	• BRMP: Custom-designed radiological survey vehicle 1999-present: Mobile Radiation Monitoring Station (MRMS)
Aerial survey		-	-	• 1998-present: Aerial Monitoring system (AMS)
Gamma emitting radionuclides	Airborne particulate	Compressed and bulked	High resolution gamma spectrometry	• BRMP-1994: Canberra APOGEE gamma spectrum analysis software • 1995-1997: Canberra Genie-PC Gamma Spectrometry System • 1998-present: Canberra Genie-2000 Gamma Spectrometry System • Counting time for aquatic foodstuff samples was extended from 20000s to 72000s starting November 2001.
	Deposition	Bulked		
	Airborne radioiodine	Direct measurement		
	Rice	Direct measurement		
	Milk	Direct measurement		
	Fruit/Vegetable	Edible part		
	Meat/Poultry	Edible part		
	Land soil	Direct measurement		
	Water samples	Direct measurement		
	Suspended particulate	Micro filtration		
	Seafood	Edible part		
	Seaweed	Drying		
	Sediment	Drying		
Tritium	Deposition	Cyclohexane-water azeotropic distillation (electrolytic enrichment(1) for underground water samples)	Liquid scintillation counting	• BRMP-1996: Packard Model Tri-carb 2000 CA/LL Liquid Scintillation Counter System • 1997-present: Wallac Model Guardian 1414 Liquid Scintillation Counter System • A filtering and regulatory system to expel moisture and oxygen from the P-10 gas was introduced in 1998.
	Water vapour			
	Terrestrial foodstuff			
	Water samples			
	Seafood			
	Seaweed			

Table 3.1 cont'd

Measurement type		Sample treatment	Analytical method	Measuring equipment
Strontium-90[(2)]	Airborne particulate Deposition Terrestrial foodstuff Land soil Seafood Seaweed	Ashing, alkaline fusion, ion chromatography and precipitation (chemical treatment of seaweed and mineral samples had been revised in 1996 and 1999, respectively)	Gross beta counting	• BRMP-1994: Packard Model Tri-carb 2000 CA/LL Liquid Scintillation Counter System • 1995-present: Berthold Low-Level Planchet Counter LB770-2
Plutonium-239	Airborne particulate Deposition Land soil Suspended particulate Seafood Seaweed Sediment	Ashing, precipitation, ion chromatography and electroplating	Alpha spectrometry	• BRMP-1993: Terminal multi-channel analyzer (Nuclear Data Model ND76) • 1994: Multi-channel buffer (EG & G Ortec Model 920-8) • 1995-present: EG & G Ortec OCTETE PC Alpha Spectrometry System
Carbon-14	Airborne particulate Carbon dioxide Terrestrial foodstuff Seafood	Benzene synthesis or CO_2 production and graphitisation	Liquid scintillation counting (AEA Technology and Harwell Scientifics Ltd.) or Accelerator mass spectrometry technique (Rafter Radiocarbon Laboratory)	• BRMP and 1993-1998: Contracted out to AEA Technology, Harwell, U.K. for measurement • 1999-2000: Contracted out to Rafter Radiocarbon Laboratory, New Zealand for measurement • 2001: Contracted out to Harwell Scientifics Ltd., Harwell, U.K. for measurement • 2002: Contracted out to Rafter Radiocarbon Laboratory, New Zealand for measurement

Remarks:

(1) Since underground water normally has lower tritium concentration, electrolytic enrichment is required. In addition, in 1998, a joint project was conducted with Government Laboratory to optimize the electrolysis time. Results indicated that the electrolysis time could be shortened by half.

(2) Strontium-90 measurement was changed from liquid scintillation counting technique to gas flow counting technique in 1995. Chemical treatment of seaweed and mineral samples had to be revised accordingly.

Table 5.1 Summary of ambient gamma dose rate obtained from the TLD network and the RMN

TLD Network:

Period	Total number of sampling locations	Range (μGy/h)	Average dose rate (μGy/h)	Standard deviation (μGy/h)
BRMP	49[(1)]	0.08 – 0.18	0.12	0.02
ERMP-II	27[(2)]	0.08 – 0.19	0.12	0.02

RMN:

Period	Total number of sampling locations	Range (μGy/h)	Average dose rate (μGy/h)	Standard deviation (μGy/h)
BRMP	4[(1)]	0.10 – 0.17	0.13	0.03
ERMP-II	10[(2)]	0.09 – 0.14	0.11	0.02

Remarks:

(1) There were 49 TLD stations and 4 RMN stations in the BRMP.

(2) There were 27 TLD stations and 10 RMN stations in the ERMP-II.

Table 5.2 Summary of typical minimum detectable activity

Measurement type		**BRMP * Detection limit**		**ERMP-II * Detection limit [period is specified]**	
Gamma emitting radionuclides		I-131	Cs-137	I-131	Cs-137
	Airborne particulate	10 μBq m^{-3}	10 μBq m^{-3}	10 μBq m^{-3}	10 μBq m^{-3}
	Airborne radioiodine [a]	0.0006 Bq m^{-3}	-	0.0001 Bq m^{-3}	-
	Wet deposition	0.1 Bq L^{-1}	0.1 Bq L^{-1}	0.1 Bq L^{-1}	0.1 Bq L^{-1}
	Rice	0.1 Bq kg^{-1}	0.2 Bq kg^{-1}	0.1 Bq kg^{-1}	0.2 Bq kg^{-1}
	Milk	0.2 Bq L^{-1}	0.3 Bq L^{-1}	0.2 Bq L^{-1}	0.3 Bq L^{-1}
	Vegetable	0.3 Bq kg^{-1}	0.4 Bq kg^{-1}	0.3 Bq kg^{-1}	0.4 Bq kg^{-1}
	Fruit	0.2 Bq kg^{-1}	0.3 Bq kg^{-1}	0.2 Bq kg^{-1}	0.3 Bq kg^{-1}
	Poultry	0.1 Bq kg^{-1}	0.2 Bq kg^{-1}	0.1 Bq kg^{-1}	0.2 Bq kg^{-1}
	Meat	0.3 Bq kg^{-1}	0.4 Bq kg^{-1}	0.3 Bq kg^{-1}	0.4 Bq kg^{-1}
	Land soil	2 Bq kg^{-1}	2 Bq kg^{-1}	2 Bq kg^{-1}	2 Bq kg^{-1}
	Water samples	0.1 Bq L^{-1}	0.1 Bq L^{-1}	0.1 Bq L^{-1}	0.1 Bq L^{-1}
	Suspended particulate	0.01 Bq L^{-1}	0.02 Bq L^{-1}	0.01 Bq L^{-1}	0.02 Bq L^{-1}
	Seafood [b]	0.1 Bq kg^{-1}	0.2 Bq kg^{-1}	0.1[92-00], 0.03[01-02] Bq kg^{-1}	0.2[92-00], 0.06[01-02] Bq kg^{-1}
	Seaweed	1 Bq kg^{-1}	2 Bq kg^{-1}	1 Bq kg^{-1}	2 Bq kg^{-1}
	Sediment	0.4 Bq kg^{-1}	0.5 Bq kg^{-1}	0.4 Bq kg^{-1}	0.5 Bq kg^{-1}
Tritium	Wet deposition [c]	8 Bq L^{-1}		8[92-96], 6[97-02] Bq L^{-1}	
	Water vapour [c, d]	70 Bq m^{-3}		70 Bq m^{-3}	
	Rice [c]	1 Bq kg^{-1}		1 Bq kg^{-1}	
	Milk [c]	6 Bq L^{-1}		6 Bq L^{-1}	
	Vegetable [c]	6 Bq kg^{-1}		6[92-96], 5[97-02] Bq kg^{-1}	
	Fruit [c]	4 Bq kg^{-1}		4 Bq kg^{-1}	
	Poultry [c]	2 Bq kg^{-1}		2[92-96], 4[97-02] Bq kg^{-1}	
	Meat [c]	5 Bq kg^{-1}		5[92-96], 4[97-02] Bq kg^{-1}	
	Water samples [c]	6 Bq L^{-1}		6 Bq L^{-1}	
	Underground water [c]	0.4 Bq L^{-1}		0.4 Bq L^{-1}	
	Seafood [c]	3 Bq kg^{-1}		3[92-96] 4[97-02] Bq kg^{-1}	
	Seaweed [c]	5 Bq kg^{-1}		5[92-96], 2[97-02] Bq kg^{-1}	

Table 5.3 Summary of iodine-131 activity concentrations in the BRMP and ERMP-II samples

Type	Sub-type	Unit	**BRMP - all**		**BRMP - measurable***				**ERMP-II - all**		**ERMP-II - measurable***			
			Total no. of samples	**Range****	**No. of samples with measurable activity**	**% of measurable samples**	**Mean concentration*****	**Standard deviation*****	**Total no. of samples**	**Range****	**No. of samples with measurable activity**	**% of measurable samples**	**Mean concentration*****	**Standard deviation*****
<u>Atmospheric</u>														
Airborne particulate	Airborne particulate	uBq/m3	138	<10 - 328	2	1	183	205	373	<10	0	0	--	--
Airborne radioiodine	Airborne radioiodine	mBq/m3	52	<0.6	1	2	2	--	407	<0.1	0	0	--	--
Wet deposition	Wet deposition	Bq/L	142	<0.1	0	0	--	--	342	<0.1	0	0	--	--
Pencentage of samples with measurable activity concentration in the atmospheric pathway						0.9						0		
<u>Terrestrial</u>														
Rice	Rice	Bq/kg	17	<0.1	0	0	--	--	42	<0.1	0	0	--	--
Pasteurized milk	Pasteurized milk	Bq/L	53	<0.2	0	0	--	--	108	<0.2	0	0	--	--
Vegetable	Vegetable	Bq/kg	59	<0.3	0	0	--	--	152	<0.3	0	0	--	--
Fruit														
	Banana	Bq/kg	13	<0.2	0	0	--	--	36	<0.2	0	0	--	--
	Lychee	Bq/kg	4	<0.2	0	0	--	--	9	<0.2	0	0	--	--
	Mandarin	Bq/kg	7	<0.2	0	0	--	--	16	<0.2	0	0	--	--
	Sugar cane	Bq/kg	4	<0.1	0	0	--	--	11	<0.2	0	0	--	--
Poultry														
	Chicken	Bq/kg	30	<0.1	0	0	--	--	82	<0.1	0	0	--	--
	Duck	Bq/kg	30	<0.1	0	0	--	--	78	<0.1	0	0	--	--
Meat														
	Beef	Bq/kg	14	<0.3	0	0	--	--	43	<0.3	0	0	--	--
	Pork	Bq/kg	28	<0.3	0	0	--	--	82	<0.3	0	0	--	--
	Pig's liver	Bq/kg	28	<0.3	0	0	--	--	81	<0.3	0	0	--	--
Land soil	Land soil	Bq/kg	78	<2	0	0	--	--	122	<2	0	0	--	--
Pencentage of samples with measurable activity concentration in the terrestrial pathway						0						0		
<u>Aquatic</u>														
Water samples														
	Seawater (upper)	Bq/L	35	<0.1	0	0	--	--	44	<0.1	0	0	--	--
	Seawater (middle)	Bq/L	34	<0.1	0	0	--	--	44	<0.1	0	0	--	--
	Seawater (lower)	Bq/L	33	<0.1	0	0	--	--	44	<0.1	0	0	--	--
	Drinking water (untreated)	Bq/L	55	<0.1	0	0	--	--	260	<0.1	0	0	--	--
	Drinking water (treated)	Bq/L	68	<0.1	0	0	--	--	219	<0.1	0	0	--	--
	Underground water	Bq/L	77	<0.1	0	0	--	--	51	<0.1	0	0	--	--
Suspended														
particulate	Upper level	Bq/L	32	<0.01	0	0	--	--	32	<0.01	0	0	--	--
	Middle level	Bq/L	32	<0.01	0	0	--	--	32	<0.01	0	0	--	--
	Lower level	Bq/L	32	<0.01	0	0	--	--	33	<0.01	0	0	--	--
Seafood														
	Aristichthys nobilis	Bq/kg	28	<0.1	0	0	--	--	84	<0.1	0	0	--	--
	Nemipterus japonicus	Bq/kg	12	<0.1	0	0	--	--	21	<0.1	0	0	--	--
	Trichiurus haumela	Bq/kg	10	<0.1	0	0	--	--	34	<0.1	0	0	--	--
	Platycephalus indicus	Bq/kg	26	<0.1	0	0	--	--	27	<0.1	0	0	--	--
	Crab	Bq/kg	31	<0.1	0	0	--	--	33	<0.1	0	0	--	--
	Shrimp	Bq/kg	26	<0.1	0	0	--	--	24	<0.1	0	0	--	--
	Squid	Bq/kg	23	<0.2	0	0	--	--	33	<0.1	0	0	--	--
	Shellfish (Tapes philippinaru)	Bq/kg	34	<0.1	0	0	--	--	23	<0.1	0	0	--	--
	Shellfish (Perna viridis)	Bq/kg	46	<0.1	0	0	--	--	68	<0.1	0	0	--	--
	Shellfish (Babylonia formosae)	Bq/kg	13	<0.1	0	0	--	--	15	<0.1	0	0	--	--

Table 5.3 cont'd

Type	Sub-type	Unit	BRMP - all		BRMP - measurable*				ERMP-II - all		ERMP-II - measurable*			
			Total no. of samples	Range**	No. of samples with measur-able activity	% of measur-able samples	Mean concen-tration***	Standard deviat-ion***	Total no. of samples	Range**	No. of samples with measur-able activity	% of measur-able samples	Mean concen-tration***	Standard deviat-ion***
Seaweed	Seaweed	Bq/kg	19	<1	2	11	0.5	0.1	62	<1	1	2	0.2	--
Sediment	Sediment	Bq/kg	78	<0.4	0	0	--	--	300	<0.4	0	0	--	--
Pencentage of samples with measurable activity concentration in the aquatic pathway						0.3						0.07		

Remarks:

* Measurable means the activity concentration of the sample is above the MDA.

** Range is the activity concentration of all samples from minimum to maximum. The lower level is the MDA except for sample type with 100% measurable activity concentration.

*** Mean and standard derivation are calculated only for samples with measurable activity.

Table 5.4 Summary of caesium-137 activity concentrations in the BRMP and ERMP-II samples

			BRMP - all		BRMP - measurable*				ERMP-II - all		ERMP-II - measurable*			
Type	**Sub-type**	**Unit**	**Total no. of samples**	**Range****	**No. of samples with measurable activity**	**% of measurable samples**	**Mean concentration*****	**Standard deviation*****	**Total no. of samples**	**Range****	**No. of samples with measurable activity**	**% of measurable samples**	**Mean concentration*****	**Standard deviation*****
Atmospheric														
Airborne particulate	Airborne particulate	uBq/m3	138	<10	0	0	--	--	373	<10	0	0	--	--
Wet deposition	Wet deposition	Bq/L	142	<0.1	0	0	--	--	342	<0.1	0	0	--	--
Pencentage of samples with measurable activity concentration in the atmospheric pathway						0						0		
Terrestrial														
Rice	Rice	Bq/kg	17	<0.2 - 0.9	9	53	0.4	0.3	42	<0.2 - 0.3	21	50	0.15	0.06
Pasteurized milk	Pasteurized milk	Bq/L	53	<0.3 - 0.3	1	2	0.3	--	108	<0.3 - 0.3	1	1	0.3	--
Vegetable	Vegetable	Bq/kg	59	<0.4	0	0	--	--	152	<0.4	0	0	--	--
Fruit														
	Banana	Bq/kg	13	<0.2	0	0	--	--	36	<0.3	0	0	--	--
	Lychee	Bq/kg	4	<0.3	0	0	--	--	9	<0.3	0	0	--	--
	Mandarin	Bq/kg	7	<0.3	0	0	--	--	16	<0.3	0	0	--	--
	Sugar cane	Bq/kg	4	<0.1	0	0	--	--	11	<0.3	0	0	--	--
Poultry														
	Chicken	Bq/kg	30	<0.2	0	0	--	--	82	<0.2	0	0	--	--
	Duck	Bq/kg	30	<0.2	0	0	--	--	78	<0.2	0	0	--	--
Meat														
	Beef	Bq/kg	14	<0.4	3	21	0.2	--	43	<0.4	0	0	--	--
	Pork	Bq/kg	28	<0.4 - 0.9	11	39	0.4	0.2	82	<0.4 - 1.1 #	22	27	0.3	0.2
	Pig's liver	Bq/kg	28	<0.4	0	0	--	--	81	<0.4 - 0.4	2	2	0.3	0.2
Land soil	Land soil	Bq/kg	78	<2 - 10	43	55	3.1	1.7	122	<2 - 6.1	66	54	2.1	1.3
Pencentage of samples with measurable activity concentration in the terrestrial pathway						18						13		
Aquatic														
Water samples														
	Seawater (upper)	Bq/L	35	<0.1	0	0	--	--	44	<0.1	0	0	--	--
	Seawater (middle)	Bq/L	34	<0.1	0	0	--	--	44	<0.1	0	0	--	--
	Seawater (lower)	Bq/L	33	<0.1	0	0	--	--	44	<0.1	0	0	--	--
	Drinking water (untreated)	Bq/L	55	<0.1	0	0	--	--	260	<0.1	0	0	--	--
	Drinking water (treated)	Bq/L	68	<0.1	0	0	--	--	219	<0.1	0	0	--	--
	Underground water	Bq/L	77	<0.1	0	0	--	--	51	<0.1	0	0	--	--
Suspended particulate														
	Upper level	Bq/L	32	<0.02	0	0	--	--	32	<0.02	0	0	--	--
	Middle level	Bq/L	32	<0.02	0	0	--	--	32	<0.02	0	0	--	--
	Lower level	Bq/L	32	<0.02	0	0	--	--	33	<0.02	0	0	--	--
Seafood														
	Aristichthys nobilis	Bq/kg	28	<0.1	0	0	--	--	84	<0.2	0	0	--	--
	Nemipterus japonicus	Bq/kg	12	<0.2	3	25	0.1	--	21	<0.2	1	5	0.1	--
	Trichiurus haumela	Bq/kg	10	<0.2 - 0.2	8	80	0.2	0.1	34	<0.2 - 0.2	18	53	0.13	0.05
	Platycephalus indicus	Bq/kg	26	<0.2 - 0.2	14	54	0.1	0.1	27	<0.2	4	15	0.1	0.0
	Crab	Bq/kg	31	<0.1	0	0	--	--	33	<0.2	0	0	--	--
	Shrimp	Bq/kg	26	<0.2	1	4	0.1	--	24	<0.2	0	0	--	--
	Squid	Bq/kg	23	<0.2	0	0	--	--	33	<0.2	0	0	--	--
	Shellfish (Tapes philippinaru)	Bq/kg	34	<0.1	0	0	--	--	23	<0.2	0	0	--	--
	Shellfish (Perna viridis)	Bq/kg	46	<0.1	0	0	--	--	68	<0.2	0	0	--	--
	Shellfish (Babylonia formosae)	Bq/kg	13	<0.1	0	0	--	--	15	<0.2	0	0	--	--

Table 5.4 cont'd

Type	Sub-type	Unit	BRMP - all: Total no. of samples	BRMP - all: Range**	BRMP - measurable*: No. of samples with measur-able activity	BRMP - measurable*: % of measur-able samples	BRMP - measurable*: Mean concen-tration***	BRMP - measurable*: Standard deviat-ion***	ERMP-II - all: Total no. of samples	ERMP-II - all: Range**	ERMP-II - measurable*: No. of samples with measur-able activity	ERMP-II - measurable*: % of measur-able samples	ERMP-II - measurable*: Mean concen-tration***	ERMP-II - measurable*: Standard deviat-ion***
Seaweed	Seaweed	Bq/kg	19	<2	1	5	1.0	--	62	<2	0	0	--	--
Sediment	Sediment	Bq/kg	78	<0.5 - 3.1	75	96	1.0	0.6	300	<0.5 - 1.9	291	97	0.8	0.3
Pencentage of samples with measurable activity concentration in the aquatic pathway						14						21		

Remarks:

* Measurable means the activity concentration of the sample is above the MDA.

** Range is the activity concentration of all samples from minimum to maximum. The lower level is the MDA except for sample type with 100% measurable activity concentration.

*** Mean and standard derivation are calculated only for samples with measurable activity.

\# Activity concentration with 2 sigma measurement uncertainty at the 95% confidence level is 1.1±

Table 5.5 Summary of tritium activity concentrations in the BRMP and ERMP-II samples

Type	Sub-type	Unit	BRMP - all		BRMP - measurable*				ERMP-II - all		ERMP-II - measurable*			
			Total no. of samples	Range**	No. of samples with measurable activity	% of measurable samples	Mean concentration***	Standard deviation***	Total no. of samples	Range**	No. of samples with measurable activity	% of measurable samples	Mean concentration***	Standard deviation***
Atmospheric														
Wet deposition	Wet deposition	Bq/L	135	<8 - 12	81	60	2	2	338	<8	174	51	2	2
Water vapour	Water vapour	Bq/m3	44	<70 - 242	42	95	71	69	102	<70 - 174	65	64	27	34
Percentage of samples with measurable activity concentration in the atmospheric pathway						69						54		
Terrestrial														
Rice	Rice	Bq/kg	16	<1	9	56	0.2	0.2	42	<1 - 1.1 #	21	50	0.3	0.2
Pasteurized milk	Pasteurized milk	Bg/L	49	<6	33	67	1.3	1.2	105	<6	59	56	2.0	1.3
Vegetable	Vegetable	Bq/kg	58	<6 - 7.4	41	71	2.5	2.0	149	<6 - 7.7 ##	98	66	2.6	2.0
Fruit														
	Banana	Bq/kg	12	<3	8	67	0.9	0.6	36	<4	19	53	0.9	0.7
	Lychee	Bq/kg	4	<4	3	75	1.3	0.8	11	<4	8	73	1.5	1.2
	Mandarin	Bq/kg	6	<4	5	83	1.0	0.8	16	<4	9	56	1.4	0.9
	Sugar cane	Bq/kg	4	<2	4	100	1.5	0.8	11	<4	6	55	1.6	1.1
Poultry														
	Chicken	Bq/kg	30	<2 - 2.2	26	87	0.7	0.5	80	<4	48	60	0.7	0.5
	Duck	Bq/kg	30	<2 - 3.5	19	63	0.8	0.8	79	<4	46	58	0.6	0.5
Meat														
	Beef	Bq/kg	13	<5 - 5.3	11	85	1.9	1.4	42	<5 - 5.5	31	74	1.7	1.4
	Pork	Bq/kg	26	<4	20	77	1.6	1	82	<5	51	62	1.8	1.1
	Pig's liver	Bq/kg	26	<4	25	96	1.6	0.9	79	<5	51	65	1.7	1.1
Percentage of samples with measurable activity concentration in the terrestrial pathway						74						61		
Aquatic														
Water samples														
	Seawater (upper)	Bq/L	28	<6	14	50	1.6	1.5	32	<6	19	59	2.0	1.2
	Seawater (middle)	Bq/L	28	<6	14	50	1.7	1.6	31	<6	19	61	2.2	1.5
	Seawater (lower)	Bq/L	28	<6	15	54	1.9	1.3	32	<6	19	59	1.7	1.1
	Drinking water (untreated)	Bq/L	52	<6	32	62	1.9	1.5	262	<6 - 6.7 ###	167	64	2.0	1.5
	Drinking water (treated)	Bq/L	67	<6	44	66	1.6	1.2	219	<6	129	59	1.9	1.3
	Underground water	Bq/L	71	<0.4 - 2.8	71	100	0.5	0.4	51	<0.4 - 1.6	43	84	0.4	0.3
Seafood														
	Aristichthys nobilis	Bq/kg	28	<2	18	64	0.3	0.3	83	<4	46	55	0.6	0.4
	Nemipterus japonicus	Bq/kg	12	<2	11	92	0.7	0.3	22	<4	12	55	0.5	0.4
	Trichiurus haumela	Bq/kg	10	<2	6	60	0.9	0.5	33	<4	14	42	0.8	0.5
	Platycephalus indicus	Bq/kg	24	<2	12	50	0.8	0.6	28	<4	18	64	0.7	0.4
	Crab	Bq/kg	29	<2	21	72	0.7	0.5	33	<4	18	55	0.7	0.4
	Shrimp	Bq/kg	23	<2 - 4.9	18	78	1.1	1.1	24	<4 - 4.0	9	38	1.1	1.2
	Squid	Bq/kg	23	<3	19	83	1.5	0.8	33	<4	13	39	1.0	0.6
	Shellfish (Tapes philippinaru)	Bq/kg	34	<2	13	38	0.3	0.2	23	<4	11	48	0.5	0.3
	Shellfish (Perna viridis)	Bq/kg	46	<2	25	54	0.7	0.4	67	<4	40	60	0.7	0.6
	Shellfish (Babylonia formosae)	Bq/kg	13	<1	10	77	0.3	0.2	15	<4	10	67	0.5	0.4
Seaweed	Seaweed	Bq/kg	19	<5	12	63	0.6	1.2	62	<5	42	68	0.8	0.7
Percentage of samples with measurable activity concentration in the aquatic pathway						66						60		

Remarks:

* Measurable means the activity concentration of the sample is above the MDA.

** Range is the activity concentration of all samples from minimum to maximum. The lower level is the MDA except for sample type with 100% measurable activity concentration.

*** Mean and standard derivation are calculated only for samples with measurable activity.

\# Activity concentration with 2 sigma measurement uncertainty at the 95% confidence level is 1.1±

\## Activity concentration with 2 sigma measurement uncertainty at the 95% confidence level is 7.7±

\### Activity concentration with 2 sigma measurement uncertainty at the 95% confidence level is 6.7±

Table 5.5 Summary of tritium activity concentrations in the BRMP and ERMP-II samples

			BRMP - all		**BRMP - measurable***				**ERMP-II - all**		**ERMP-II - measurable***			
Type	**Sub-type**	**Unit**	**Total no. of samples**	**Range****	**No. of samples with measur-able activity**	**% of measur-able samples**	**Mean concen-tration*** **	**Standard deviat-ion*****	**Total no. of samples**	**Range****	**No. of samples with measur-able activity**	**% of measur-able samples**	**Mean concen-tration*****	**Standard deviat-ion*****
Atmospheric														
Wet deposition	Wet deposition	Bq/L	135	<8 - 12	81	60	2	2	338	<8	174	51	2	2
Water vapour	Water vapour	Bq/m3	44	<70 - 242	42	95	71	69	102	<70 - 174	65	64	27	34
Percentage of samples with measurable activity concentration in the atmospheric pathway						69						54		
Terrestrial														
Rice	Rice	Bq/kg	16	<1	9	56	0.2	0.2	42	<1 - 1.1 #	21	50	0.3	0.2
Pasteurized milk	Pasteurized milk	Bg/L	49	<6	33	67	1.3	1.2	105	<6	59	56	2.0	1.3
Vegetable	Vegetable	Bq/kg	58	<6 - 7.4	41	71	2.5	2.0	149	<6 - 7.7 ##	98	66	2.6	2.0
Fruit														
	Banana	Bq/kg	12	<3	8	67	0.9	0.6	36	<4	19	53	0.9	0.7
	Lychee	Bq/kg	4	<4	3	75	1.3	0.8	11	<4	8	73	1.5	1.2
	Mandarin	Bq/kg	6	<4	5	83	1.0	0.8	16	<4	9	56	1.4	0.9
	Sugar cane	Bq/kg	4	<2	4	100	1.5	0.8	11	<4	6	55	1.6	1.1
Poultry														
	Chicken	Bq/kg	30	<2 - 2.2	26	87	0.7	0.5	80	<4	48	60	0.7	0.5
	Duck	Bq/kg	30	<2 - 3.5	19	63	0.8	0.8	79	<4	46	58	0.6	0.5
Meat														
	Beef	Bq/kg	13	<5 - 5.3	11	85	1.9	1.4	42	<5 - 5.5	31	74	1.7	1.4
	Pork	Bq/kg	26	<4	20	77	1.6	1	82	<5	51	62	1.8	1.1
	Pig's liver	Bq/kg	26	<4	25	96	1.6	0.9	79	<5	51	65	1.7	1.1
Percentage of samples with measurable activity concentration in the terrestrial pathway						74						61		
Aquatic														
Water samples														
	Seawater (upper)	Bq/L	28	<6	14	50	1.6	1.5	32	<6	19	59	2.0	1.2
	Seawater (middle)	Bq/L	28	<6	14	50	1.7	1.6	31	<6	19	61	2.2	1.5
	Seawater (lower)	Bq/L	28	<6	15	54	1.9	1.3	32	<6	19	59	1.7	1.1
	Drinking water (untreated)	Bq/L	52	<6	32	62	1.9	1.5	262	<6 - 6.7 ###	167	64	2.0	1.5
	Drinking water (treated)	Bq/L	67	<6	44	66	1.6	1.2	219	<6	129	59	1.9	1.3
	Underground water	Bq/L	71	<0.4 - 2.8	71	100	0.5	0.4	51	<0.4 - 1.6	43	84	0.4	0.3
Seafood														
	Aristichthys nobilis	Bq/kg	28	<2	18	64	0.3	0.3	83	<4	46	55	0.6	0.4
	Nemipterus japonicus	Bq/kg	12	<2	11	92	0.7	0.3	22	<4	12	55	0.5	0.4
	Trichiurus haumela	Bq/kg	10	<2	6	60	0.9	0.5	33	<4	14	42	0.8	0.5
	Platycephalus indicus	Bq/kg	24	<2	12	50	0.8	0.6	28	<4	18	64	0.7	0.4
	Crab	Bq/kg	29	<2	21	72	0.7	0.5	33	<4	18	55	0.7	0.4
	Shrimp	Bq/kg	23	<2 - 4.9	18	78	1.1	1.1	24	<4 - 4.0	9	38	1.1	1.2
	Squid	Bq/kg	23	<3	19	83	1.5	0.8	33	<4	13	39	1.0	0.6
	Shellfish (Tapes philippinaru)	Bq/kg	34	<2	13	38	0.3	0.2	23	<4	11	48	0.5	0.3
	Shellfish (Perna viridis)	Bq/kg	46	<2	25	54	0.7	0.4	67	<4	40	60	0.7	0.6
	Shellfish (Babylonia formosae)	Bq/kg	13	<1	10	77	0.3	0.2	15	<4	10	67	0.5	0.4
Seaweed	Seaweed	Bq/kg	19	<5	12	63	0.6	1.2	62	<5	42	68	0.8	0.7
Percentage of samples with measurable activity concentration in the aquatic pathway						66						60		

Remarks:

* Measurable means the activity concentration of the sample is above the MDA.

** Range is the activity concentration of all samples from minimum to maximum. The lower level is the MDA except for sample type with 100% measurable activity concentration.

*** Mean and standard derivation are calculated only for samples with measurable activity.

\# Activity concentration with 2 sigma measurement uncertainty at the 95% confidence level is 1.1±

\## Activity concentration with 2 sigma measurement uncertainty at the 95% confidence level is 7.7±

\### Activity concentration with 2 sigma measurement uncertainty at the 95% confidence level is 6.7±

Table 5.6 Summary of strontium-90 activity concentrations in the BRMP and ERMP-II samples

			BRMP - all		**BRMP - measurable***				**ERMP-II - all**		**ERMP-II - measurable***			
Type	**Sub-type**	**Unit**	**Total no. of samples**	**Range****	**No. of samples with measur-able activity**	**% of measur-able samples**	**Mean concen-tration*****	**Standard deviat-ion*****	**Total no. of samples**	**Range****	**No. of samples with measur-able activity**	**% of measur-able samples**	**Mean concen-tration*****	**Standard deviat-ion*****
<u>Atmospheric</u>														
Airborne particulate	Airborne particulate	uBq/m3	35	<3 - 5	16	46	1	1	206	<1 - 6 #	39	19	3	1
Wet deposition	Wet deposition	mBq/L	111	<2 - 39	52	47	4	8	321	<2 - 31	108	34	5	6
Percentage of samples with measurable activity concentration in the atmospheric pathway						47						28		
<u>Terrestrial</u>														
Rice	Rice	mBq/kg	14	<5 - 56	13	93	22	17	36	<5 - 26	32	89	9	7
Pasteurized milk	Pasteurized milk	mBq/L	42	8 - 81	42	100	27	17	89	<7 - 69	83	93	22	14
Vegetable	Vegetable	mBq/kg	54	<11 - 570	54	100	128	102	129	<11 - 372	123	95	104	75
Fruit														
	Banana	mBq/kg	10	<6 - 27	10	100	12	9	33	<6 - 22	20	61	11	6
	Lychee	mBq/kg	3	5 - 14	3	100	8	5	9	<6 - 13	7	78	6	4
	Mandarin	mBq/kg	5	10 - 84	5	100	34	32	11	14 - 82	11	100	45	20
	Sugar cane	mBq/kg	4	2 - 14	4	100	7	5	10	<6 - 12	8	80	4	4
Poultry														
	Chicken	mBq/kg	28	<4 - 37	24	86	5	8	68	<4 - 19	33	49	5	4
	Duck	mBq/kg	28	<3 - 53	23	82	6	12	70	<4 - 13	35	50	3	2
Meat														
	Beef	mBq/kg	12	<9 - 35	10	83	11	12	39	<12 - 23	12	31	8	7
	Pork	mBq/kg	23	<10 - 36	19	83	7	9	71	<12 - 26	21	30	11	5
	Pig's liver	mBq/kg	23	<12 - 43	15	65	12	14	72	<12 - 23	17	24	12	7
Land soil	Land soil	Bq/kg	78	<1.5 - 27.3	73	94	4.8	5.2	87	<1.5 - 3.8	12	14	2.4	0.8
Percentage of samples with measurable activity concentration in the terrestrial pathway						91						57		
<u>Aquatic</u>														
Suspended particulate														
	Upper level	mBq/L	4	<7	2	50	5	1	28	<7	8	29	4	2
	Middle level	mBq/L	4	--	0	0	--	--	27	<7	3	11	4	1
	Lower level	mBq/L	4	<7	1	25	0.2	--	28	<7 - 7	7	25	5	2
Seafood														
	Aristichthys nobilis	mBq/kg	26	<4 - 94	26	100	16	19	77	<10 - 17	66	86	7	4
	Nemipterus japonicus	mBq/kg	11	<6 - 21	9	82	5	8	22	<10 - 24 ##	12	55	7	6
	Trichiurus haumela	mBq/kg	9	<6 - 49	2	22	25	34	33	<10 - 25	13	39	8	7
	Platycephalus indicus	mBq/kg	23	<6 - 25	15	65	7	7	21	<10 - 18	12	57	7	4
	Crab	mBq/kg	28	<8 - 105	27	96	38	30	27	<10 - 60	11	41	19	16
	Shrimp	mBq/kg	25	<9 - 66	21	84	24	18	21	<10 - 23	11	52	12	7
	Squid	mBq/kg	21	<10 - 43	13	62	10	12	33	<10 - 34	10	30	14	12
	Shellfish (Tapes philippinaru)	mBq/kg	32	<7 - 32	20	63	11	10	21	<10 - 11	9	43	6	3
	Shellfish (Perna viridis)	mBq/kg	41	<7 - 47	32	78	12	12	59	<10 - 29	24	41	8	7
	Shellfish (Babylonia formosae)	mBq/kg	12	<9 - 31	10	83	13	13	12	<10 - 10	5	42	6	3
Seaweed	Seaweed	mBq/kg	16	<600 - 1440	15	94	434	180	59	<600 - 1712 ###	52	88	353	377
Percentage of samples with measurable activity concentration in the aquatic pathway						75						52		

Remarks:

* Measurable means the activity concentration of the sample is above the MDA.

** Range is the activity concentration of all samples from minimum to maximum. The lower level is the MDA except for sample type with 100% measurable activity concentration.

*** Mean and standard derivation are calculated only for samples with measurable activity.

\# Activity concentration with 2 sigma measurement uncertainty at the 95% confidence level is 6±

\## Activity concentration with 2 sigma measurement uncertainty at the 95% confidence level is 24±

\### Activity concentration with 2 sigma measurement uncertainty at the 95% confidence level is 1712±

Table 5.7 Summary of carbon-14 activity concentrations in the BRMP and ERMP-II samples

Type	Sub-type	Unit	BRMP - all		BRMP - measurable*				ERMP-II - all		ERMP-II - measurable*			
			Total no. of samples	Range**	No. of samples with measurable activity	% of measurable samples	Mean concentration***	Standard deviation***	Total no. of samples	Range**	No. of samples with measurable activity	% of measurable samples	Mean concentration***	Standard deviation***
Atmospheric														
Airborne particulate	Airborne particulate	Bq/kg C	31	138 - 298	31	100	279	27	9	242 - 277	9	100	267	10
Carbon dioxide in air	Carbon dioxide in air	Bq/kg C	7	184 - 297	7	100	258	36	10	238 - 259	10	100	248	6
Pencentage of samples with measurable activity concentration in the atmospheric pathway						100						100		
Terrestrial														
Rice	Rice	Bq/kg C	2	259 - 264	2	100	262	4	10	242 - 259	10	100	251	6
Pasteurized milk	Pasteurized milk	Bq/kg C	5	271 - 291	5	100	281	9	10	244 - 260	10	100	253	6
Vegetable	Vegetable	Bq/kg C	8	223 - 292	8	100	253	25	10	238 - 257	10	100	248	6
Fruit														
	Banana	Bq/kg C	4	259 - 283	4	100	271	11	8	237 - 256	8	100	246	9
	Lychee	Bq/kg C	3	261 - 280	3	100	268	11	1	--	1	100	249	--
	Mandarin	Bq/kg C	2	252 - 263	2	100	258	8	--	--	--	--	--	--
	Sugar cane	Bq/kg C	2	263 - 290	2	100	277	19	--	--	--	--	--	--
Poultry														
	Chicken	Bq/kg C	6	255 - 278	6	100	267	8	9	247 - 261	9	100	254	5
	Duck	Bq/kg C	7	263 - 282	7	100	274	7	1	--	1	100	267	--
Meat														
	Beef	Bq/kg C	4	256 - 288	4	100	271	13	1	--	1	100	262	--
	Pork	Bq/kg C	8	255 - 275	8	100	267	7	8	246 - 263	8	100	254	5
	Pig's liver	Bq/kg C	8	258 - 381	8	100	281	41	1	--	1	100	252	--
Pencentage of samples with measurable activity concentration in the terrestrial pathway						100						100		
Aquatic														
Seafood														
	Aristichthys nobilis	Bq/kg C	7	263 - 273	7	100	267	3	10	239 - 257	10	100	247	6
	Nemipterus japonicus	Bq/kg C	10	227 - 267	10	100	256	11	1	--	1	100	251	--
	Trichiurus haumela	Bq/kg C	10	248 - 274	10	100	257	7	7	244 - 257	7	100	249	5
	Platycephalus indicus	Bq/kg C	11	235 - 273	11	100	257	11	--	--	--	--	--	--
	Crab	Bq/kg C	9	224 - 266	9	100	247	17	1	--	1	100	255	--
	Shrimp	Bq/kg C	12	221 - 279	12	100	254	18	7	243 - 255	7	100	248	4
	Squid	Bq/kg C	13	223 - 296	13	100	255	20	7	244 - 253	7	100	248	5
	Shellfish (Tapes philippinaru)	Bq/kg C	11	175 - 267	11	100	248	25	6	240 - 251	6	100	246	4
	Shellfish (Perna viridis)	Bq/kg C	12	223 - 274	12	100	255	16	1	--	1	100	249	--
	Shellfish (Babylonia formosae)	Bq/kg C	6	255 - 263	6	100	257	3	--	--	--	--	--	--
Pencentage of samples with measurable activity concentration in the aquatic pathway						100						100		

Remarks:

* Measurable means the activity concentration of the sample is above the MDA.

** Range is the activity concentration of all samples from minimum to maximum. The lower level is the MDA except for sample type with 100% measurable activity concentration.

*** Mean and standard derivation are calculated only for samples with measurable activity.

Table 5.8 Summary of plutonium-239 activity concentrations in the BRMP and ERMP-II samples

			BRMP - all		**BRMP - measurable***				**ERMP-II - all**		**ERMP-II - measurable***			
Type	**Sub-type**	**Unit**	**Total no. of samples**	**Range****	**No. of samples with measur-able activity**	**% of measur-able samples**	**Mean concen-tration*****	**Standard deviat-ion*****	**Total no. of samples**	**Range****	**No. of samples with measur-able activity**	**% of measur-able samples**	**Mean concen-tration*****	**Standard deviat-ion*****
Atmospheric														
Airborne particulate	Airborne particulate	uBq/m3	41	<0.2	0	0	--	--	201	<0.2	0	0	--	--
Wet deposition	Wet deposition	mBq/L	58	<0.2	0	0	--	--	291	<0.2	0	0	--	--
Pencentage of samples with measurable activity concentration in the atmospheric pathway						0						0		
Terrestrial														
Land soil	Land soil	mBq/kg	25	<200	5	20	93	4	123	<200 - 418 #	18	15	223	94
Pencentage of samples with measurable activity concentration in the terrestrial pathway						20						15		
Aquatic														
Suspended particulate	Upper level	mBq/L	32	<0.3	0	0	--	--	28	<0.3	0	0	--	--
	Middle level	mBq/L	32	<0.3	0	0	--	--	28	<0.3	0	0	--	--
	Lower level	mBq/L	32	<0.3	0	0	--	--	28	<0.3	0	0	--	--
Seafood	Aristichthys nobilis	mBq/kg	21	<2	0	0	--	--	78	<2	0	0	--	--
	Nemipterus japonicus	mBq/kg	9	<2	0	0	--	--	22	<2	0	0	--	--
	Trichiurus haumela	mBq/kg	8	<2	0	0	--	--	32	<2	0	0	--	--
	Platycephalus indicus	mBq/kg	18	<2	0	0	--	--	20	<2	0	0	--	--
	Crab	mBq/kg	20	<2	0	0	--	--	29	<2	0	0	--	--
	Shrimp	mBq/kg	16	<2	5	31	0.9	0.3	22	<2	0	0	--	--
	Squid	mBq/kg	14	<2	2	14	0.8	0.1	33	<2	0	0	--	--
	Shellfish (Tapes philippinaru)	mBq/kg	16	<2	3	19	0.7	0.2	22	<2	0	0	--	--
	Shellfish (Perna viridis)	mBq/kg	19	<2	3	16	0.7	0.3	58	<2	0	0	--	--
	Shellfish (Babylonia formosae)	mBq/kg	8	<2	2	25	0.7	0.2	13	<2	0	0	--	--
Seaweed	Seaweed	mBq/kg	15	<10 - 101	7	47	56	27	57	<10 - 90	20	35	42	21
Sediment	Sediment	mBq/kg	28	<200 - 567	25	89	195	94	263	<200 - 660 ##	136	52	191	119
Pencentage of samples with measurable activity concentration in the aquatic pathway						16						21		

Remarks:

* Measurable means the activity concentration of the sample is above the MDA.

** Range is the activity concentration of all samples from minimum to maximum. The lower level is the MDA except for samplem type with 100% measurable activity concentration.

*** Mean and standard derivation are calculated only for samples with measurable activity.

\# Direct comparison between the BRMP and ERMP(92-02) measurement results could not be made as the sampling sites are different.

\#\# Activity concentration with 2 sigma measurement uncertainty at the 95% confidence level is 660±

Table 6.1 Hypothesis testing of ambient gamma dose rate obtained from the TLD network and the RMN

Period	Total number of sampling locations	Range (μGy/h)	Average dose rate (μGy/h)	Standard deviation (μGy/h)	t-test[1]	
					1% level of significance	5% level of significance
BRMP	53[2]	0.08 - 0.18	0.12	0.02	Accepted	Accepted
ERMP-II	37[3]	0.08 - 0.19	0.12	0.02		

Remarks:

(1) Test hypothesis: BRMP and ERMP-II samples are drawn from the same population.

(2) There were 47 TLD stations and 4 RMN stations in the BRMP.

(3) There were 27 TLD stations and 10 RMN stations in the ERMP-II.

Table 6.2 Hypothesis testing of carbon-14 activity concentrations in foodstuffs after decay correction

Period	**Number of samples**	**Mean concentration (Bq/kg C)**	**Standard deviation (Bq/kg C)**	**t-test(2)**	
				1% level of significance	**5% level of significance**
BRMP	59	269	20	Accepted	Accepted
ERMP-II (1)	59	267	8		

Remarks:

(1) ERMP-II measurement results are decay corrected to the BRMP period using the halving time of 13 years.

(2) Test hypothesis: BRMP and ERMP-II samples are drawn from the same population.

Table 6.3 Hypothesis testing of strontium-90 activity concentrations in rice, milk and vegetable samples after decay correction

Sample type	Unit	BRMP			ERMP-II(1)			t-test(2)	
		No. of samples	Mean concentration	Standard deviation	No. of samples	Mean concentration	Standard deviation	1% level of significance	5% level of significance
Rice	mBq/kg	13	22	17	32	15	10	Accepted	Accepted
Milk	mBq/L	42	27	17	83	35	19	Accepted	Rejected
Vegetable	mBq/kg	54	128	102	123	175	122	Accepted	Rejected

Remarks:

(1) ERMP-II measurement results are decay corrected to the BRMP period using the halving time of 11.6 years.

(2) Test hypothesis: BRMP and ERMP-II samples are drawn from the same population.

APPENDIX A

DETAILS OF THE QUALITY ASSURANCE PROGRAMME

Based on "The Procedures Manual of the Environmental Measurements Laboratory, HASL-300" (U.S. Department of Energy, 1997), HKO has drawn up a QA programme. This appendix reviews the QA programme in the areas of: staff qualifications, sampling techniques, preparation and storage of samples, coding and record keeping, quality control samples, instrument calibrations and stability, background evaluations, data storage, intra-laboratory comparisons and inter-laboratory comparisons.

A.1 Staff Qualifications

When technical personnel perform a procedure in which they are not experienced, they have to be first trained, then tested in order to demonstrate that they can perform the procedure with an acceptable level of uncertainty.

HKO has arranged training, both in-house and to established laboratories and institutes, including the IAEA Marine Environmental Laboratory and the China Institute for Radiation Protection for its technical personnel to ensure that the personnel understand the nature of the physical and chemical properties that affect the measurement procedures that they perform, so that they may recognize and interpret any deviations from the expected behaviour.

A.2 Sampling Techniques

Sample collection must be representative of the parameter or material to be analysed. Before sampling, the analyst must define clearly the material that is to be sampled to ascertain that the sample is representative.

One of the major components of the ERMP is to detect artificial radioactive materials in the environment of Hong Kong arising from the operation of the NPS. Three major exposure pathways are monitored, namely the atmospheric pathway, the terrestrial pathway and the aquatic pathway. To ensure the representativeness of the samples collected, the sampling locations and types of sample to be collected are reviewed periodically. Details of the review can be found in the ERMP Annual Reports (Hong Kong Observatory, 1992 - 2003).

A.3 Preparation and Storage of Samples

A variety of environmental media samples, including food, vegetation, water and atmospheric particulates, are collected and returned to the laboratory for analysis. Some of these samples may require pretreatment before analysis. Pretreatment normally alters the physical state of the sample, and sometimes alters its chemical state as well. In planning the pretreatment, the analyst considers the nature of the measurement and the appropriate state of the sample for measurement. After the measurement, the portions of samples that are to be stored should be properly recorded in an archival system.

With the exception of carbon-14 measurements, all radioactivity measurements of environmental samples collected are carried out at the Radiation Laboratory at King's Park. After the samples are collected and delivered to the Radiation Laboratory at King's Park, they are subjected to sample treatment processes using various physical and chemical methods, followed by radioactivity measurement.

All collected samples are stored under preset conditions to avoid degradation, spoiling, decomposition, and contamination. All food samples are kept in refrigeration at King's Park for a short period of time before analysis. After the completion of all required measurements or analyses, the food samples are recorded and transferred to a cold storage warehouse for storage of at least two years. Other environmental samples are stored at King's Park for a period of at least two years.

A.4 Coding and Record Keeping

At the time of sample collection, samples are normally given code numbers that serve to identify them during subsequent analytical, calculation and reporting stages. There is an advantage in keeping the codes as simple as possible to minimise the probability that errors will be made in transferring data. However, the code should be distinctive enough to distinguish each set of samples and data passing through the laboratory. It is desirable to use codes that contain information on the site and/or time of sampling, or upon the nature of the sample.

A simple and effective coding system has been adopted by HKO since the beginning of the ERMP. The coding system contains information on the type of the sample, sampling location and date of sampling. Each sample has a unique sample code and all corresponding analysed results are kept under the same code.

Since the beginning of the ERMP, a computer database system has been established for recording the analysed results for each sample. In 1999, the database system has been enhanced to include more information. These are sample weight, measurement time, name of analyst, measurement equipment used, counting time, spectrum reference and date of analysis, for the ease of reference.

A.5 Quality Control Samples

Whenever possible, quality control (QC) samples should be submitted to the analyst along with routine samples in such a way that the analyst does not know which of the samples are the QC samples. These QC samples, which usually include duplicate and blank samples, should be adopted for testing the precision of sample analysis.

Duplicate samples are obtained by repeating the sample collection. Since the beginning of the ERMP, one out of ten samples submitted for analysis is selected as a QC sample for duplicate analysis. These QC samples are chosen from various matrices included in the ERMP. More than a thousand analyses had been conducted for the QC samples. Over 99.5% of the results obtained from the QC samples agreed with those from the routine samples. For cases that the routine and QA measurements disagreed with each other, the measurements will be repeated to identify the faulty steps. However, there are cases in which the sample material had been depleted so the repeated measurement cannot be conducted. A summary of the results is shown in Table A1.

Blank samples are also analysed on a regular basis to give a measure of any contamination of the sample that might occur during the course of sample preparation or analysis. In addition to the blank samples, HKO has also made use of samples which are spiked with known amount of radioactivity for routine monitoring of the analyst skills and measurement system performance. A schedule of analysing the blank and spiked samples is shown in Table A2.

A.6 Instrument Calibrations and Stability

For efficient performance of the measurement systems, preventive maintenance should be conducted in accordance with an appropriate schedule. A record of instrument performance has to be maintained, and any modifications made in the instruments, whether permanently or for a particular project, should be documented.

All the measurement instruments employed at King's Park Radiation Laboratories are calibrated periodically. The calibration frequency depends on the type of instrument. The calibration schedule for different measurement instruments is shown in Table A3.

Each measurement instrument has its own performance check(s) to ensure normal operation of the instrument. Since the beginning of the ERMP, depending on the type of instrument one or more of the following factors have been monitored in the performance checks: energy spectrum, system efficiency, system resolution. Results of the performance check are recorded for comparison and future reference.

A.7 Background Evaluation

Commonly, instruments will provide a background signal that may be the result of minor fluctuations. It is necessary to measure this background signal so that the data from routine measurements may be corrected for its presence. Even when the signal from the measured samples is high relative to the background, the background signal should be measured regularly to be sure that it has not changed and the instrument has not become defective or contaminated. Background level for each type of measurement instrument is measured on a regular basis. A schedule of conducting background level measurement is shown in Table A4.

A.8 Data Storage

Whenever data are transferred or stored, an appropriate control procedure should be established to minimise the danger that human error will compromise the quality of the data. When data are stored electronically, backup files must be prepared to eliminate the possibility that the data may inadvertently be lost.

Since the beginning of the ERMP, HKO has stored all the analysed data in a computer database system. The database system has been enhanced in 1999 so as to achieve Year 2000 compliance. In order to prevent run down of hard disk space of the database system, backup of data is conducted daily.

A.9 Intra-laboratory Comparisons

Whenever it is possible, attempts are made to verify that no systematic error is introduced into the results of analytical procedures because of differences in techniques among analysts, or because of differences in performance between supposedly equivalent instruments. Analyses of selected samples are repeated using different analysts, and the results are compared to insure that variations are within the expected range.

In 2000, HKO formed two independent teams of laboratory analysts. Randomly selected samples are analyzed by the independent analysts, and the precision of the results are checked with those obtained during routine analyses.

In order to further monitor the quality of the ERMP sample preparation and measurement, HKO and Government Laboratory began a series of quality assurance procedures in 2000 using IAEA reference materials on a half yearly basis. In the past three years, all results of the measurements were within IAEA confidence limits. A summary of the measurement results is given in Table A5.

A.10 Inter-laboratory Comparisons

Since ERMP began, the HKO had participated in 13 inter-laboratory comparison exercises held by the International Atomic Energy Agency (IAEA). The 13 comparison samples include clover sample, tuna fish flesh sample, Pacific Ocean sediment sample, soil sample, marine cockle flesh sample, Irish Sea sediment sample, Baltic Sea sediment sample, Arabian Sea sediment sample, Irish Sea water sample, black soil sample, podsolic soil sample, Fangataufa sediment sample and Irish and North Sea fish sample. A summary of the measurement results reported by HKO is shown in Table A6.

Over 90% of the measurement results made by HKO were within the range of accepted values reported by IAEA except for americium-241 and potassium-40 in the cockle flesh sample, lead-214 in the Arabian Sea water sample and strontium-90 in the Irish Sea water sample.

The outliers of the americium-241, potassium-40 and lead-214 were due to the low energy peak of americium-241, and the use of an outdated background value in the latter two cases respectively.

The discrepancy of the reported value for strontium-90 in the Irish Sea water sample was the result of the presence of strontium at elevated levels in the sea water samples, which interfered with the determination of the chemical yield. To overcome the problem observed, the Government Laboratory introduced the use of strontium-85, a gamma-emitting isotope, as a tracer to improve the determination of the yield.

In 1999, strontium-90 analyses of the land soil samples collected in the second round of sampling between 1994 and 1996 were completed. Results of the measurements could not meet the established quality control requirement. HKO therefore participated in a proficiency exercise organized by the IAEA in 1999 on the determination of strontium-90 in a mineral matrix. Based on the advice given by IAEA, the Government Laboratory revised the chemical separation procedure to give a sample smaller suited for the gas flow counting instrument. With the revised sample preparation technique, re-measurement of the 1994-1996 land soil samples has been conducted.

In addition to the IAEA inter-comparison exercises and proficiency exercises, HKO also participated in the inter-laboratory comparison exercises organized by the World Health Organization and counterpart laboratories in the mainland. In 1995, HKO participated in an inter-laboratory comparison exercises organized by the World Health Organization (WHO). In 1998, HKO participated in an inter-laboratory comparison exercise on field measurement of ambient gamma absorbed dose rate organised by the China Institute for Radiation Protection (CIRP). The values reported by HKO in agreed with the reference values published by the WHO and CIRP. A summary of the measurement results reported is shown in Table A7.

Table A1 Summary of analysis results for quality control samples (1992 – 2002)

Sample matrix	**Radionuclide analysed**	**No. of measurement for QC samples analysis**	**No. of measurements on QC samples that are outside the uncertainty of the routine analysis**
Airborne Particulate	I-131	14	0
	Cs-137	14	0
	Sr-90	1	0
	Pu-239	1	1*
Radioiodine	I-131	30	0
Water Vapour	H-3	10	0
Wet Deposition	I-131	23	0
	Cs-137	23	0
	H-3	23	0
	Sr-90	23	0
	Pu-239	23	0
Total Deposition	I-131	18	0
	Cs-137	18	0
	H-3	12	0
	Sr-90	12	1*
	Pu-239	12	0
Rice	I-131	13	0
	Cs-137	13	0
	H-3	13	0
	Sr-90	13	0
Milk	I-131	7	0
	Cs-137	7	0
	H-3	7	0
	Sr-90	7	0
Vegetable	I-131	22	0
	Cs-137	22	0
	H-3	22	0
	Sr-90	22	0
Fruit	I-131	31	0
	Cs-137	31	0
	H-3	31	0
	Sr-90	31	0
Poultry	I-131	16	0
	Cs-137	16	0
	H-3	16	0
	Sr-90	16	0

Table A1 cont'd

Sample matrix	Radionuclide analysed	No. of measurement for QC samples analysis	No. of measurements on QC samples that are outside the uncertainty of the routine analysis
Meat	I-131	21	0
	Cs-137	21	0
	H-3	21	0
	Sr-90	21	1*
Land Soil	I-131	3	0
	Cs-137	3	0
	Sr-90	3	0
	Pu-239	3	0
Water Samples	I-131	26	0
	H-3	26	0
Suspended Particulate	I-131	4	0
	Cs-137	4	0
	Sr-90	4	1*
	Pu-239	4	0
Seafood	I-131	41	0
	Cs-137	41	0
	H-3	41	0
	Sr-90	41	0
	Pu-239	41	0
Seaweed	I-131	17	0
	Cs-137	17	0
	H-3	17	0
	Sr-90	17	0
	Pu-239	17	0
Sediment	I-131	36	0
	Cs-137	36	0
	Pu-239	36	0
	Total:	1175	4**

Remarks:

* Discrepancy might occur in the course of sample treatment or measurement. No further samples were available for re-processing.

** 99.7% of the QC samples analysis agreed with the results from the routine analysis.

Table A2 Schedule of analyzing blank and spiked samples

Measurement Instrument	Frequency of analyzing blank samples	Frequency of analyzing spiked samples
Gamma Spectrometry System	N/A	Daily
Liquid Scintillation Counting System	Monthly	Monthly
Low-level Counting System	Monthly	Monthly
Alpha Spectrometry System	Monthly	Monthly

Table A3 Calibration schedule of the measuring equipment

Measurement Instrument	**Type of calibration**	**Calibration frequency**
Gamma Spectrometry System	Efficiency	Annually
	Energy	Daily
Liquid Scintillation Counting System	Efficiency	Annually
Low-level Counting System	Efficiency	Annually
Alpha Spectrometry System	Efficiency	Annually
	Energy	Monthly

Table A4 Schedule of measuring background level

Measurement Instrument	Background measurement time	Frequency
Gamma Spectrometry System	150000 sec	Weekly
Liquid Scintillation Counting System	36000 sec	Once in every set of samples
Low-level Counting System	30000 sec	Weekly
Alpha Spectrometry System	220000 sec	Monthly

Table A5 Measurement results of IAEA reference materials IAEA-375 (Soil Matrix) and IAEA-134 (Flesh Matrix) in 2000, IAEA-381 (Irish Sea Water) and IAEA-368 (Pacific Ocean Sediment) in 2001, IAEA-Soil-6 (Soil), IAEA-152 (Milk Powder) and IAEA-368 (Pacific Ocean Sediment) in 2002

IAEA-375 (Soil Matrix)

Pu-239/240 measurement results (reference date: 31 December 1991, unit: Bg kg^{-1})			
Measurement date	**Measurement result**	**Reference value**	**95% confidence interval from IAEA**
3 Feb 2000	0.34 ± 0.17	0.3	0.26 – 0.34
8 Feb 2000	0.34 ± 0.17	0.3	0.26 – 0.34

Sr-90 measurement results (reference date: 31 December 1991, unit: Bg kg^{-1})			
Measurement date	**Measurement result**	**Reference value**	**95% confidence interval from IAEA**
15 Apr 2000	104.0 ± 30.1	108	101 – 114
15 Apr 2000	104.0 ± 30.2	108	101 – 114
15 Apr 2000	101.5 ± 30.1	108	101 – 114

IAEA-134 (Flesh Matrix)

Pu-239/240 measurement results (reference date: 1 January 1992, unit: Bg kg^{-1})			
Measurement date	**Measurement result**	**Reference value**	**95% confidence interval from IAEA**
26 Sep 2000	15.6 ± 4.7	15	13.8 – 16.2
26 Sep 2000	15.1 ± 4.5	15	13.8 – 16.2

Sr-90 measurement results (reference date: 1 January 1992, unit: Bg kg^{-1})			
Measurement date	**Measurement result**	**Reference value**	**95% confidence interval from IAEA**
5 Sep 2000	4.20 ± 1.30	4.8	4.1 – 6
5 Sep 2000	4.29 ± 1.33	4.8	4.1 – 6
6 Sep 2000	4.29 ± 1.33	4.8	4.1 – 6

Table A5 cont'd

IAEA-381 (Irish Sea Water)

Pu-239/240 measurement results (reference date: 7 September 1993, unit: mBg kg^{-1})			
Measurement date	**Measurement result**	**Reference value**	**95% confidence interval from IAEA**
28 Apr 2001	13.8 ± 2.2	13.2	13.0 – 14.0
28 Apr 2001	12.9 ± 2.3	13.2	13.0 – 14.0
15 May 2001	12.6 ± 2.0	13.2	13.0 – 14.0
19 May 2001	12.8 ± 2.1	13.2	13.0 – 14.0

Sr-90 measurement results (reference date: 7 September 1993, unit: mBg kg^{-1})			
Measurement date	**Measurement result**	**Reference value**	**95% confidence interval from IAEA**
19 Mar 2001	144 ± 44	141	132 – 150
12 May 2001	146 ± 44	141	132 – 150
12 May 2001	148 ± 45	141	132 – 150

IAEA-368 (Pacific Ocean Sediment)

Pu-239/240 measurement results (reference date: 1 January 1990, unit: Bg kg^{-1})			
Measurement date	**Measurement result**	**Reference value**	**95% confidence interval from IAEA**
13 Jul 2001	32.8 ± 1.2	31.0	29.0 – 34.0
21 Jul 2001	32.1 ± 1.2	31.0	29.0 – 34.0
21 Jul 2001	32.2 ± 1.2	31.0	29.0 – 34.0
24 Jul 2001	33.3 ± 1.2	31.0	29.0 – 34.0

Sr-90 measurement results (reference date: 1 January 1990, unit: Bg kg^{-1})			
Measurement date	**Measurement result**	**Reference value**	**95% confidence interval from IAEA**
13 Dec 2001	0.75 ± 1.09	1.8	0.45 – 6.90
27 Dec 2001	0.75 ± 1.02	1.8	0.45 – 6.90

Table A5 cont'd

IAEA-Soil-6 (Soil)

Pu-239/240 measurement results (reference date: 30 January 1983, unit: Bq kg^{-1})			
Measurement date	**Measurement result**	**Reference value**	**95% confidence interval from IAEA**
3 May 2002	1.11 ± 0.23	1.04	0.96 – 1.11
22 May 2002	1.01 ± 0.22	1.04	0.96 – 1.11
22 May 2002	1.18 ± 0.28	1.04	0.96 – 1.11

Sr-90 measurement results (reference date: 30 January 1983, unit: Bq kg^{-1})			
Measurement date	**Measurement result**	**Reference value**	**95% confidence interval from IAEA**
18 Jun 2002	28.26 ± 8.53	30.34	24.20 – 31.67
19 Jun 2002	26.72 ± 8.07	30.34	24.20 – 31.67
20 Jun 2002	26.72 ± 8.07	30.34	24.20 – 31.67

IAEA-152 (Milk Powder)

Sr-90 measurement results (reference date: 31 August 1987, unit Bq kg^{-1})			
Measurement date	**Measurement result**	**Reference value**	**95% confidence interval from IAEA**
10 Dec 2002	7.8 ± 2.3	7.7	7.0 – 8.3
10 Dec 2002	7.7 ± 2.3	7.7	7.0 – 8.3
11 Dec 2002	7.5 ± 2.3	7.7	7.0 – 8.3

IAEA-368 (Pacific Ocean Sediment)

Pu-239/240 measurement results (reference date: 1 January 1990, unit Bq kg^{-1})			
Measurement date	**Measurement result**	**Reference value**	**95% confidence interval from IAEA**
24 Dec 2002	29.4 ± 1.2	31.0	29.0 – 34.0
31 Dec 2002	30.9 ± 1.2	31.0	29.0 – 34.0
31 Dec 2002	29.2 ± 1.4	31.0	29.0 – 34.0

Table A6 Results of the IAEA inter-laboratory comparison exercises

Measurement year	Reference date of sample	Sample	Radionuclide analysed	IAEA Results (Bq/kg)		HKO reported value (Bq/kg)
				Reference value (median)	Range of accepted values	
1989	1 August 1986	Clover (IAEA-156)	Potassium-40	657	503-780	759±36
			Caesium-134	132	79-173	149±11
			Caesium-137	264	190-349	297±3
			Strontium-90	14.8	8.3-20.0	10.3±0.9
1989	1 January 1989	Tuna Fish Flesh (IAEA-352)	Potassium-40	391	300-470	425±15
			Caesium-137	2.7	1.9-3.5	3.2±0.5
			Polonium-210[(1)]	2.2	--	1.9±0.3
1990	1 January 1990	Pacific Ocean Sediment (IAEA-367)	Caesium-137	195	162-230	194±8
			Plutonium-239/240	38	24-51	42±6
1991	31 December 1991	Soil (IAEA-375)	Potassium-40	424	351-520	399±32
			Ruthenium-106	56	44.3-71.1	49.75±10
			Antimony-125	77	64.7-90.1	67.5±5.2
			Caesium-134	463	363-569	433±19
			Caesium-137	5280	4310-6368	4758±180
			Strontium-90	108	51-160	106.2±5
			Plutonium-239/240	0.3	0.19-0.47	0.243-0.06

Table A6 cont'd

Measurement year	Reference date of sample	Sample	Radionuclide analysed	IAEA Results (Bq/kg)		HKO reported value (Bq/kg)
				Reference value (median)	Range of accepted values	
1992	1 January 1992	Cockle Flesh (IAEA-134)	Potassium-40[2]	212	160.5-269	290±14
			Cobalt-60	4.5	3.3-6.3	5.0±0.6
			Caesium-137	49.8	39.6-60	50.0±2.5
			Uranium-235	0.49	0.12-5.2	4.9±0.6
			Americium-241[3]	38.15	32-44.6	46±5
1992	1 January 1992	Irish Sea Sediment (IAEA-135)	Potassium-40	560	420.6-702	532±19
			Cobalt-60	4.8	3.04-6.5	4.9±0.5
			Caesium-134	5.2	2.7-8.2	5.5±0.5
			Caesium-137	1108	897-1374	1010±41
			Europium-154	6.8	5.8-8.3	6.4±0.6
			Europium-155	5.5	4.5-7	5.5±0.7
			Americium-241	318	250-400	346±33
1993	1 January 1993	Baltic Sea Sediment (IAEA-300)	Potassium-40	1059	820-1327.6	1172±43
			Caesium-134	66.6	49.7-81.6	74±2
			Caesium-137	1066.6	813-1291	1171±34
			Plutonium-239/240	3.55	3.09-4	3.7±0.3
			Strontium-90	10.8	1.7-16	13±1

Table A6 cont'd

Measurement year	Reference date of sample	Sample	Radionuclide analysed	IAEA Results (Bq/kg)		HKO reported value (Bq/kg)
				Reference value (median)	Range of accepted values	
1993	1 January 1993	Arabian Sea Sediment (IAEA-315)	Potassium-40	297	210-387	294±22
			Cobalt-60	144	104-186	137±2
			Strontium-90	51.0	27-82.3	45±1
			Caesium-134	12.0	8-15.4	13±1
			Caesium-137	541	356-755	504±23
			Thallium-208	11	6.8-42.1	8±1
			Bismuth-212	27	14-32	21±5
			Lead-212	26.4	21.1-32	26±4
			Bismuth-214	12.9	6-19	15±2
			Lead-214[(4)]	13.0	8-17.2	20±2
			Radium-226	14.2	8-23	<40
			Actinium-228	26.5	17.5-33	32±3
			Plutonium-239/240	70.0	50.7-86.5	68±2
			Americium-241	20.0	10.6-28.6	24±8
1994	31 December 1994	Black Soil (IAEA-326)	Potassium-40	578.9	417.4-751	597±21.5
			Plutonium-239/240	0.494	0.405-0.600	0.53±0.29
			Strontium-90	9.93	7.2-13.67	10.37±0.65

Table A6 cont’d

Measurement year	Reference date of sample	Sample	Radionuclide analysed	IAEA Results (Bq/kg)		HKO reported value (Bq/kg)
				Reference value (median)	Range of accepted values	
1994	31 December 1994	Podsolic Soil (IAEA-327)	Potassium-40	620.9	460-780	631.5±24.6
			Caesium-137	24.8	20.64-29.39	24.5±1.7
			Plutonium-239/240	0.576	0.443-0.710	0.512±0.140
			Strontium-90	2.36	1.61-3.12	1.77±0.58
1996	7 September 1993	Irish Sea Water (IAEA-381)	Caesium-137	0.482	0.420-0.530	0.480±0.070
			Plutonium-239/240	0.0132	0.0100-0.0156	0.0130±0.0020
			Tritium	74.7	63-88	63±7
			Strontium-90(5)	0.141	0.120-0.175	0.068±0.027
1998	1 August 1996	Fangataufa Sediment (IAEA-384)	Cobalt-60	2.50	1.68-3.30	2.5±0.3
			Plutonium-239/240	108	89-124	110±17.2
			Plutonium-238	39.0	31.21-46	42.5±8.0
			Strontium-90	1.5	0.82-3.20	3.2±0.3
2000	1 January 1997(6)	Irish and North Sea Fish (IAEA-414)	Potassium-40	--	368.50 – 609.25	516.85 ± 58.12
			Caesium-137	--	4.22 – 6.25	6.25 ± 1.05
			Plutonium-239/240	--	0.103 – 0.154	0.11 ± 0.02
			Strontium-90	--	0.103 – 1.250	<0.16; <0.15

Table A6 cont'd

Remarks:

(1) Range of accepted values of polonium-210 was not provided in the IAEA report. However, the HKO reported value was within the confidence interval of 1.7-2.7 Bq/kg.

(2) The reported value of potassium-40 lay outside the range of accepted values because a wrong background potassium-40 value was used in one of the 5 measurements to perform background subtraction.

(3) The reported value of americium-241 lay slightly outside the range of accepted values because the lowest energy gamma peak used for efficiency calibration of the gamma spectrometry system was 88 keV which was higher than energy peak of americium-241 (59.5 keV). The system efficiencies below 88 keV were therefore estimated by extrapolation which might have caused a small error in the reported activity concentration.

(4) The discrepancy between the reported value of lead-214 and the accepted range is likely due to the use of a non-updated and high uncertainty background value in background subtraction.

(5) The discrepancy between the reported value for strontium-90 and the IAEA range of accepted value is the result of the presence of strontium at elevated levels in the soil samples, which interferes with the determination of the chemical yield. The Government Laboratory is investigating into the use of strontium-85 as a tracer with a view obtaining more accurate determination of the chemical yield.

(6) IAEA results are based on the preliminary report released by the IAEA in 2001. Reference values are not yet available.

Table A7 Results of the inter-laboratory comparison exercises organized by the World Health Organization and the China Institute for Radiation Protection

World Health Organization

Measurement year	Reference date	Sample	Radionuclide	WHO reference (Bq/kg)	HKO reported value (Bq/kg)
1995	1 January 1995	Milk Power A (WHO 95/01)	Potassium-40	436	464±24
			Caesium-134	96.9	97.0±5.0
			Caesium-137	2629	2665±155
		Milk Power B (WHO 95/01)	Potassium-40	548	600±30
			Caesium-134	20.56	21.0±1.0
			Caesium-137	603	609±136

China Institute for Radiation Protection

Measurement year	Field measurement site	Survey point	CIRP reference value (nGy/h)	HKO reported value (nGy/h)
1998	Lawn of Sun Yat-sen Memorial Hall, Guangzhou	1	129±4	128±3
		2	124±5	117±6
		3	145±5	145±3
	King's Park Meteorological Station, Hong Kong	A	170±5	168±3
		B	174±4	171±2
		C	166±4	166±3