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Scottish Universities Research & Reactor Centre

AN AERIAL GAMMA RAY SURVEY OF HUNTERSTON NUCLEAR POWER STATION IN 14-15 APRIL AND 4 MAY 1994

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EXECUTIVE SUMMARY

An aerial gamma-ray survey of the environment of Hunterston Nuclear Power Station was commissioned by Scottish Nuclear Limited, and conducted by the Scottish Universities Research and Reactor Centre. The area enclosed a 31km square, with Hunterston Nuclear Power Station at the centre, and was flown with a flight line spacing of 500m. A secondary area, in closer proximity to the nuclear site, was flown with 250m spacing.

Over 6300 separate spectra were recorded with a high volume spectrometer operated from a helicopter from 14-15th April and on 4th May 1994. Spectral data were recorded together with satellite navigation (GPS) and radar altimetry data, and have been analysed for ^{137}Cs, ^{60}Co, ^{40}K, ^{214}Bi and ^{208}Tl and gamma dose rate. The results provide a comprehensive record of the radiation environment around Hunterston and have been used to map the distribution of natural and man-made radionuclides, forming a baseline from which future environmental changes may be assessed.

The natural radionuclides ^{40}K, ^{214}Bi and ^{208}Tl are highly correlated with each other and show a distribution which reflects both the underlying geological and geomorphological features of the area. The main structural boundaries on Bute, Cumbrae and the mainland can be discerned in the maps, as can some igneous intrusions. Areas with peat or alluvium cover appear as negative features in the radiometric maps.

The distribution of ^{137}Cs, mainly derived from Chernobyl and weapons testing fallout has been mapped with greater detail than hitherto available in this area. Local enhancements immediately to the south of the Hunterston "A" station and on a salt marsh near Irvine were noted in an earlier survey conducted for the District Council in 1990. The feature near the site has reduced by approximately one order of magnitude since the previous survey, but is still detectable. An enhancement to the ^{60}Co map was also observed at this location. Other ^{60}Co variations in the survey are close to detection limits and show a slight correlation with signals from natural sources. Therefore they are more probably due to residuals remaining after separation of spectral interferences than to low level ^{60}Co contamination.

Gamma ray dose rates range from approximately 0.1 to 0.6 mGy a^{-1} with a mean value of 0.22 mGy a^{-1}, and are derived mainly from natural sources. Ground level measurements were taken at twelve district monitoring points within the area using a 3x3" NaI spectrometer and a survey meter (Series 6/80) used routinely by SNL. Both ground based data sets were in good agreement with each other and with the aerial survey after accounting for instrumental and cosmic ray background contributions.

The longer term impact of the site can be assessed by future surveys. Moreover under emergency conditions it would be possible to utilise this method for rapid mapping of the area on a timescale which cannot be matched using alternative approaches.

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The survey was commissioned from SURRC by Scottish Nuclear Limited (Safety and Quality Division: Emergency Planning Department).

1. INTRODUCTION

An airborne gamma ray survey of the area surrounding Hunterston Nuclear Power Station was conducted between 14th-15th April and 4th May 1994, to define the present radiation background for emergency reference purposes. This provides a comprehensive data set which will allow future changes in the radiation environment of Hunterston to be assessed. The method also provides a means of rapid response to any future incident leading to the release of radioactivity to the environment.

Aerial radiation survey methods are well suited to large scale environmental surveys. By operating suitable spectrometers from low flying aircraft, in this case a helicopter, it is possible to map the distribution of gamma-ray emitting radionuclides at ground level. This has a number of benefits in comparison with conventional methods. The aircraft can carry high sensitivity detectors capable of making environmental radioactivity measurements every few seconds. This provides a sampling rate some 10^2-10^3 times greater than other approaches. The high mobility of the aircraft is advantageous, as is it's ability to operate over varied terrain, unimpeded by ground level obstacles or natural boundaries. The remote sensing nature of the measurements minimises exposure of survey teams to contamination or radiation hazards. The radiation detector averages signals over fields of view of several hundred metre dimensions[1,2,3], resulting in an area sampling rate some 10^6-10^7 times greater than ground based methods. This results in the only practical means of conducting surveys with total effective coverage, which can be used for rapid location of point sources or areas of radioactive contamination. This has important applications to environmental radioactivity studies, particularly under time-constrained conditions, and has a unique significance to emergency response.

The ability to work in a complementary manner with ground based teams is also important. Ground based in-situ spectrometry can provide a high level of spatial resolution and sensitivity, and links effectively to sampling for radiochemical analysis, allowing alpha and beta emitters to be determined. However these methods are costly and time consuming, and have a low sampling density. They are not well suited to rapid and representative location of environmental contamination. The combination of aerial and ground based observations however overcomes the limitations of both methods, allowing efficient and representative focusing of ground based resources.

Airborne gamma spectrometry has been used following the 1957 Windscale accident[4], to locate fragments of a nuclear powered satellite which landed in Canada in 1978[5,6], and for rapid national mapping of Sweden in 1986[7]. The United States has had a series of fully equipped aircraft on emergency standby for over 20 years[8]. The environmental applications and capabilities have been recently extended in the UK [9-14] through a programme of surveys and developments conducted by SURRC. This has included searches for lost sources[15,16], detailed post-Chernobyl mapping and baseline studies of upland areas[17-21], studies of the variations in natural radioactivity for epidemiology[22] and detailed mapping of the environment of nuclear sites[23-25].

Modern systems such as those developed at SURRC over the last few years are capable of recording and analysing gamma spectrometry automatically during flight, and of producing computer generated colour maps extremely rapidly after landing. These considerations lead to important emergency response potential, for production of detailed maps of deposition within hours or days, rather than weeks, months or even years. The systems can be rapidly installed into aircraft or other vehicles, and can be maintained in a state of readiness for use in the laboratory. This provides an alternative approach to maintaining an emergency response capability to that of fixed permanent installations, with both economic and operational benefits.

The incorporation of an airborne component to emergency response plans for Scottish Nuclear sites is under preparation. This baseline survey complements and extends the regular ground based environmental monitoring programme conducted by Scottish Nuclear for operational and emergency response purposes, while providing reference data for future use.

2. SURVEY DETAILS

The main survey area comprised a 31km square, bounded by OS coordinates of NS030670, NS340670, NS030360 and NS340360, with Hunterston Nuclear Power Station at the centre. This area was surveyed with a flight line spacing of 500m. In addition, a subgrid bounded by OS coordinates NS160490, NS160540, NS210490 and NS210540 was defined for the purposes of surveying with a flight line spacing of 250m. In both cases flight lines were extended out to sea by at least 1km to define marine background levels beyond the influence of terrestrial radiation; otherwise the area over the sea was not surveyed.

The main survey was conducted on 14th and 15th April 1994 using an Aerospatiale twin engine AS355 Squirrel helicopter operated from Cumbernauld Airport, and refuelled at Prestwick International Airport during each day's survey. Transit times between Cumbernauld and Hunterston were approximately 30 minutes; each sortie lasted between 120 and 180 minutes. An additional flight was made on 4th May to supplement the data set on little Cumbrae and on the eastern edge of the survey zone. Some observations were also made at the start and end of the Torness Survey in March to enable cross calibration of both surveys.

The spectrometer comprised a 16 litre NaI(Tl) detector and an SURRC airborne survey instrumentation rack. The equipment incorporates uninterruptible power supplies, instrumentation power supplies, a spectrometer facility with dual pulse height analyser, GPS satellite navigation, ADC's, and a data logging system based on a 486 computer. Both detector and spectrometer were mounted on CAA approved baseplates in the aircraft which can be rapidly installed if required. The equipment records a sequence of full gamma ray spectra during flights, interleaved with latitude and longitude data, and ground clearance measurements by radar altimetry.

Immediately following installation the radar altimeter was calibrated at Cumbernauld relative to barometric altitude, and the background rates, due to the equipment and aircraft were recorded and compared with normal values. A flight test was conducted between Cumbernauld and Lochwinnoch, and reference measurements were made over a calibration site defined in the Raithburn Valley during an aerial survey commissioned by three Ayrshire Districts in 1990[20]. A 12-15% difference in sensitivity between the installation used on 14-15th April and those used for the Torness survey and the supplementary flight was noted, and taken into account in data analysis. This is attributed to differences in the attenuation of gamma radiation passing through the individual aircraft.

The survey was conducted with a ground clearance of 50-75 metres and ground speed of approximately 120 kph. Waypoints defining the start and end of each flight line within the survey zone were calculated and programmed in to the GPS equipment. This was then used to guide the pilot through the survey. The spectrometer resolution, energy calibration, and sensitivity were tested each day, using a reference ^{137}Cs source at Cumbernauld. Continuous gain monitoring was conducted during the survey using natural ^{40}K to maintain better than 1% gain stability during flight. More than 6300 gamma ray spectra with associated positional data were recorded from the area during the survey period, following standard SURRC procedures.

The SURRC recording technique and data nomenclature have been designed to make checks of spectrometer operation possible during flight, and to enable rapid checks on all data during reduction and analysis. The data reduction stages are all self-recording, and the archive is so structured that primary data can be examined where any unusual features have been located. The archive for each survey is fully retrievable, doubly backed up, and use has been made of ASCII text only files for all data storage in accordance with quality assurance procedures developed over many surveys. These procedures have been designed to ensure a demonstrably high level of data integrity, and are periodically reviewed to take account of system developments.

The data reduction procedures[12] follow a sequence of isolation and quantification of signals corresponding to individual nuclides, and estimation of ground level dose rate. Initial processing comprises extraction of count rate data from selected energy regions corresponding to the full-energy peaks for individual nuclides. This takes place in real time during the flight, for predefined nuclides, and can be supplemented by full spectral analysis afterwards if required. The resulting summary records of the flight and its series of individual count rates are then calibrated in four stages. Firstly net count rates are obtained by subtraction of background values from recorded gross count rates. Secondly spectral interferences between nuclides are separated using a matrix stripping procedure. The data are then standardised to remove the effects of altitude variations, and finally converted to calibrated activity per unit area, activity concentrations or dose rate values as appropriate. Data can be mapped rapidly at any stage of this procedure.

For this survey, spectral windows corresponding to ^{137}Cs (661 keV), ^{60}Co (1172 keV), ^{40}K (1461 keV), ^{214}Bi (1764 keV), ^{208}Tl (2615 keV) and total count rate above 450 keV (for estimation of ground level dose rate) were predefined. Stripping coefficients were checked at SURRC, using calibration pads[13,14,28], prior to installation of the equipment and noted to be consistent with previous measurements. Background rates were checked at the start of survey, and periodically throughout, using data recorded over sea. Coefficients for altitude correction and calibration were taken from previous aerial surveys[18,19,20,24,25], where they had been validated by extensive ground sampling, with the exception of ^{60}Co. For this radionuclide stripped count rates standardised to 100m clearance were evaluated and mapped. For other nuclides results were calibrated in terms of activity per unit area, integrated to a soil depth of 0.3m.

During the survey period in April a series of ground based dose rate estimates was made, at twelve district monitoring points to enable comparison between ground based and airborne estimates for these locations. Ground based observations were made using a series 6/80 Mini Instruments survey meter and a 3x3" NaI spectrometer.

3. RESULTS AND DISCUSSION

3.1 Aerial Survey

Baseline maps were produced for ^{137}Cs, ^{60}Co, ^{40}K, ^{214}Bi, ^{208}Tl and estimated gamma dose rate. They are shown in figures 3.2 to 3.7, for the overall survey area, and in figures 3.8 to 3.11 for the inner area close to the power station. No flights occurred directly over the nuclear site, and therefore the maps refer to the periphery of the station and it's environment.

When interpreting these maps it is important to consider the effects of spatial smoothing and detector field of view, especially if comparisons with ground based readings are contemplated. For example, a point source on the ground surface will appear to be spread over larger lateral dimensions, to an extent which is a function of detector angular response and the measurement height. Distributed sources are spatially averaged over distances which are defined by a combination of detector field of view and flight line spacing. The spatial response and line spacing also determines the proportion of the land area which has been effectively surveyed. At 500m line spacing and 75m altitude more than 75% effective area coverage is achieved; at 250m line spacing, total coverage is obtained. The radiometric maps have been interpolated between flight lines, taking care to avoid excessive spatial smoothing, and reflect radiometric variations over spatial dimensions comparable to the line spacing. Therefore figures 3.8-3.11 show additional detail in comparison with figures 3.2-3.7

^{137}Cs is widely distributed at low levels in the environment as a result of nuclear weapons testing, the Chernobyl reactor accident, and discharges from the nuclear fuel cycle. The aerial survey data from this area have a mean and standard deviation of 7.9±4.5 kBq m^{-2}, showing similar levels to those observed near Torness[29], but with a higher coefficient of variation. The mean value is biassed downwards in this data set by the higher proportion of observations taken over sea than in other surveys. Figure 3.2 shows the distribution of ^{137}Cs in the area. Part of this area was surveyed at 1 km line spacing in 1990 for the District Councils[20]. This data set shows a similar pattern in many respects but adds additional spatial details. General levels of ^{137}Cs in the upland areas of the mainland tend to be higher than in coastal or island locations reaching values of over 16 kBq m^{-2} in places. The features reported in 1990 close to the Hunterston "A" station, at Bogside Flats (NS311387), alongside the River Irvine, and on Great Cumbrae were observed once more. The first of these was associated with a precipitator tower at the "A" station, and it was noted that the signal strengths for ^{137}Cs over Goldenberry Hill had reduced considerably in comparison with the 1990 data set, as a result of activities associated with the on-going decommissioning programme. A ground based investigation was conducted on the Island of Great Cumbrae, in conjunction with SNL, Cunninghame District Council and the Strathclyde Regional Chemist's Laboratory. This has confirmed the presence of ^{137}Cs in both coastal and inland locations in Cumbrae, at levels which are similar or lower than to those observed in many mainland locations, as indicated by the aerial survey.

^{60}Co is an activation product which released at very low levels from reactor sites. The distribution of ^{60}Co count rates after stripping natural interferences is shown in figure 3.3.

From just beyond the perimeter fence at Hunterston, a small signal within the ^{60}Co window can be observed. This is also associated with the feature discussed above. Once again the signal levels are lower than observed in 1990, reflecting remedial action on site, but the feature has not been entirely removed. Other than this feature the remaining signals are at a level consistent with residuals remaining after spectral stripping of the spectrometer background from natural radionuclides. There is evidence for a spatial correlation between these residual counts and the distribution of natural potassium. It has been estimated that a plane surface source of 1 kBq m^{-2} ^{60}Co measured by a 16 litre detector at 100m height would give approximately 14 cps. The limits of detection of aerial survey measurements are dependent principally upon detector sensitivity and counting period. It has been estimated that for the radionuclides reported here, a level of approximately 1 kBq m^{-2} represents the minimum limit of detection. In view of this, it would appear that the ^{60}Co results are below or close to the minimum level of detection.

The ^{40}K (figure 3.4), ^{214}Bi (figure 3.5), and ^{208}Tl (figure 3.6) maps convey information mainly about the geological and geomorphological background to the area. There are some striking correlations with geological boundaries. For example the NW and southern parts of Bute show considerable contrast on either side of the fault system separating Dalradian and Upper Devonian rocks; an area of enhanced ^{40}K activity in the SW of Bute correlates with known geological faults; and there is evidence of features associated with the Dusk Water Fault and Paisley Ruck on the Mainland. A series of fine grained acidic intrusions on the Western parts of the mainland forms a ring like feature which is clearly visible on the ^{40}K map. The spectrum from one of these areas, marked as a quarry site on the OS map (NS209515) is shown in figure 3.1.

The ^{214}Bi and ^{208}Tl maps (figures 3.5 and 3.6) show complementary patterns to ^{40}K. ^{214}Bi shows enhanced levels to the south and east of the major mainland faults, a feature also observed in the 1990 survey. The ^{208}Tl pattern shows similar features, but also reflects the same boundaries as the ^{40}K map. Again the results are spatially consistent with those obtained previously.

Estimated gamma dose rates at ground level are shown in figure 3.7, varying by approximately 5 times within the area, as a result of geological and soil cover variations. The pattern is predominantly influenced by the natural sources of radioactivity, the contribution of ^{137}Cs to the gamma ray dose rate being small. For example the areas of the eastern parts of the mainland which show the highest ^{137}Cs levels, show both the lowest and highest gamma dose rates correlated with the geological boundaries which determine ^{40}K, ^{208}Tl and to a lesser extent ^{214}Bi. Similar influences can be seen on Cumbrae and Bute.

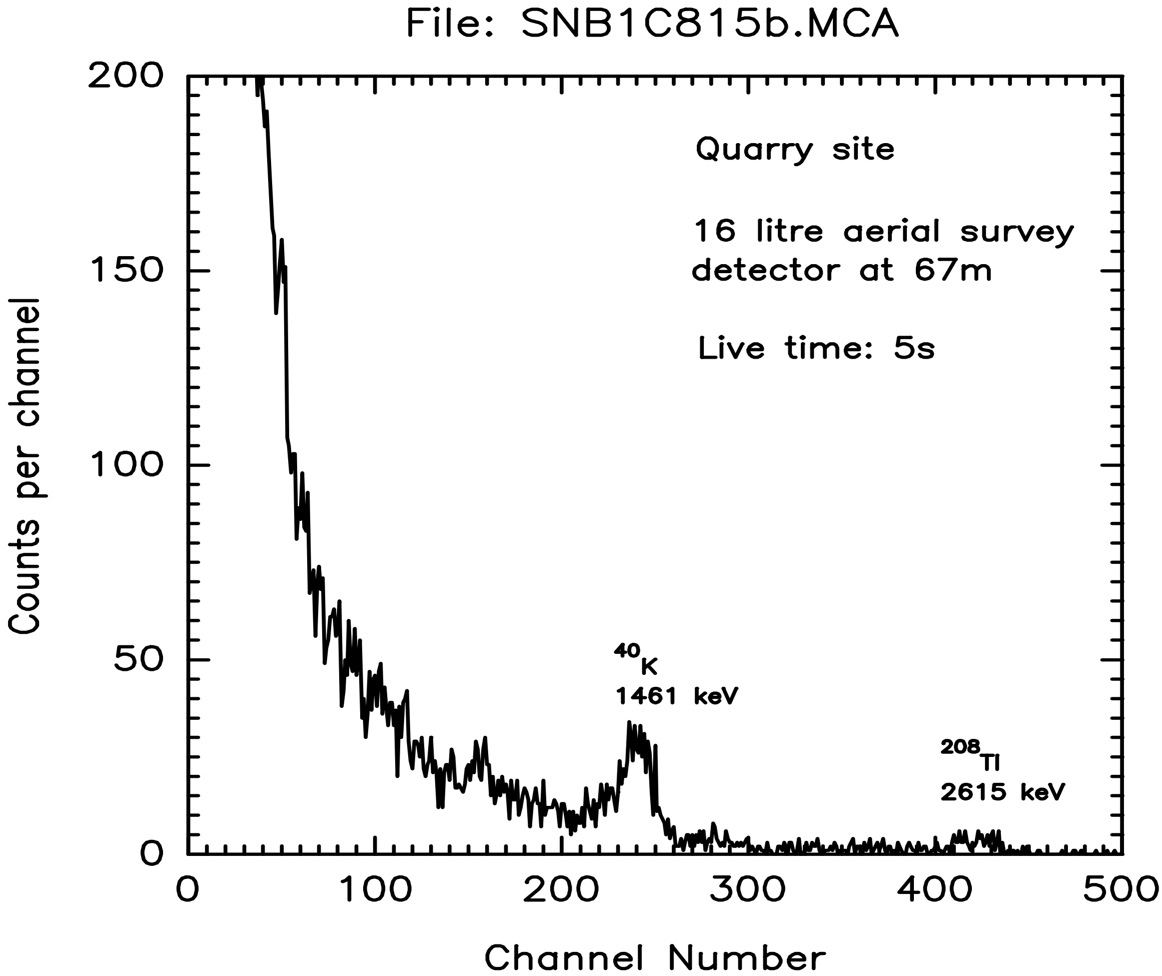


Figure 3.1 Spectrum taken near Biglies Farm.

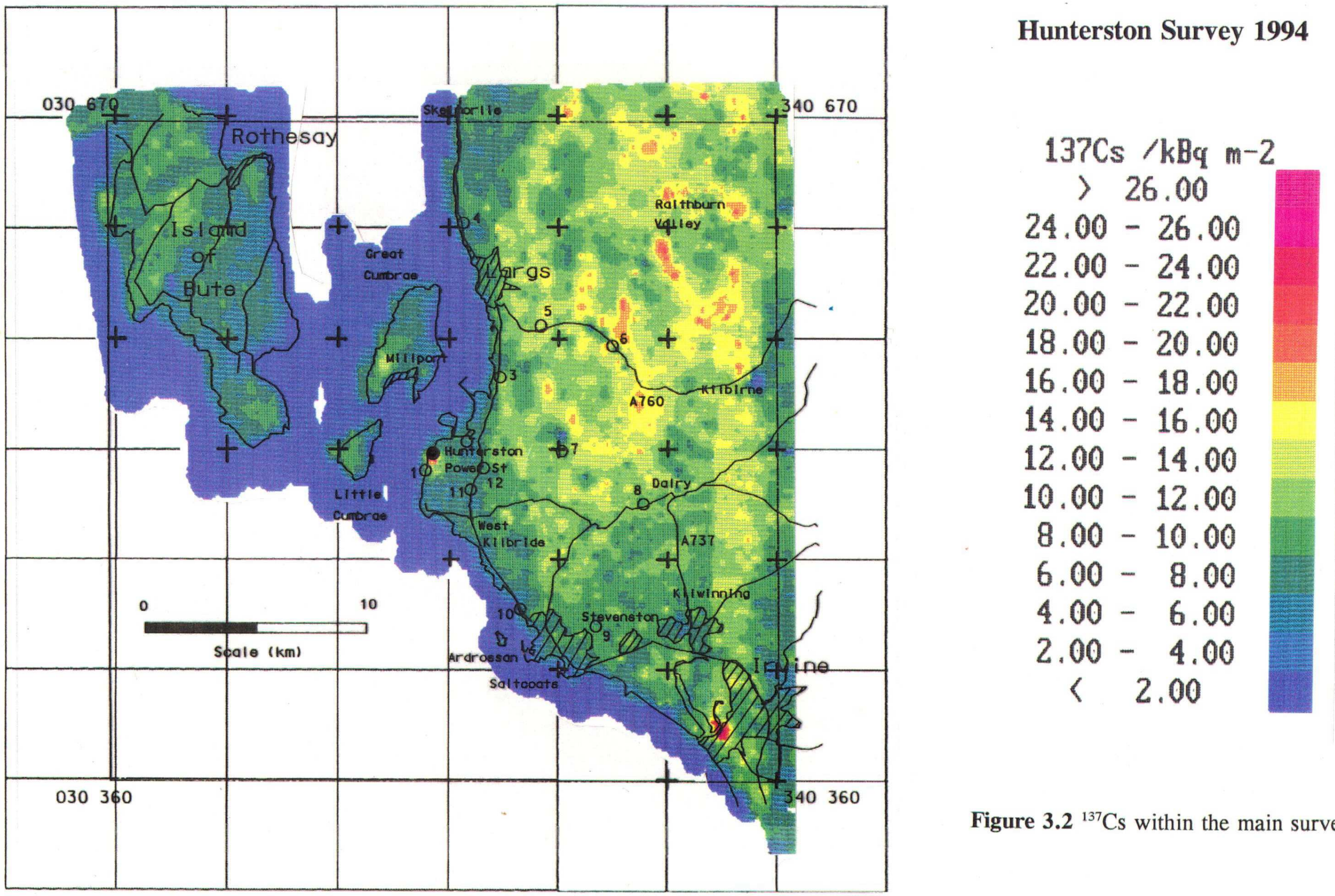


Figure 3.2 ^{137}Cs within the main survey area

Hunterston Survey 1994

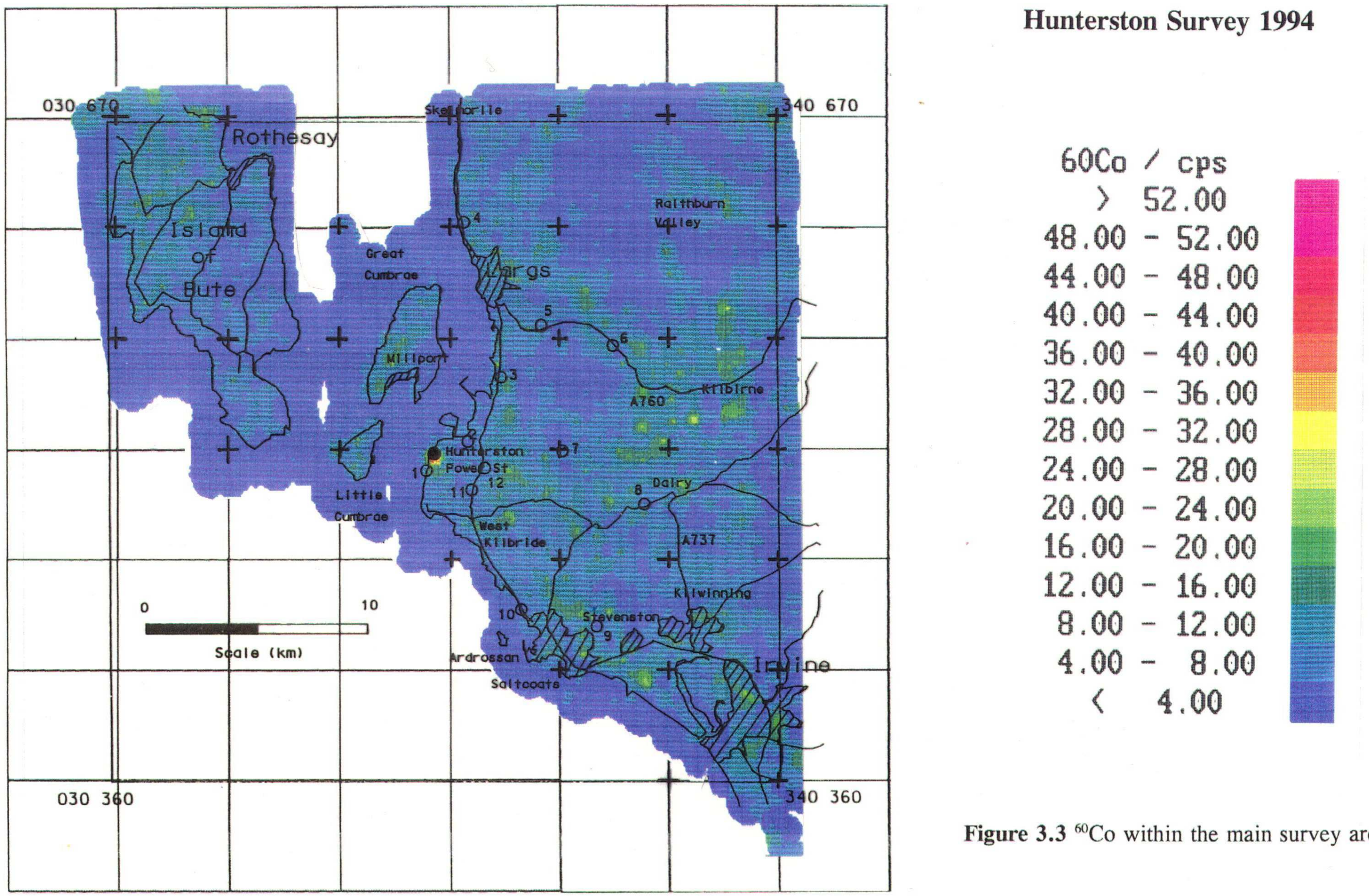


Figure 3.3 ^{60}Co within the main survey area

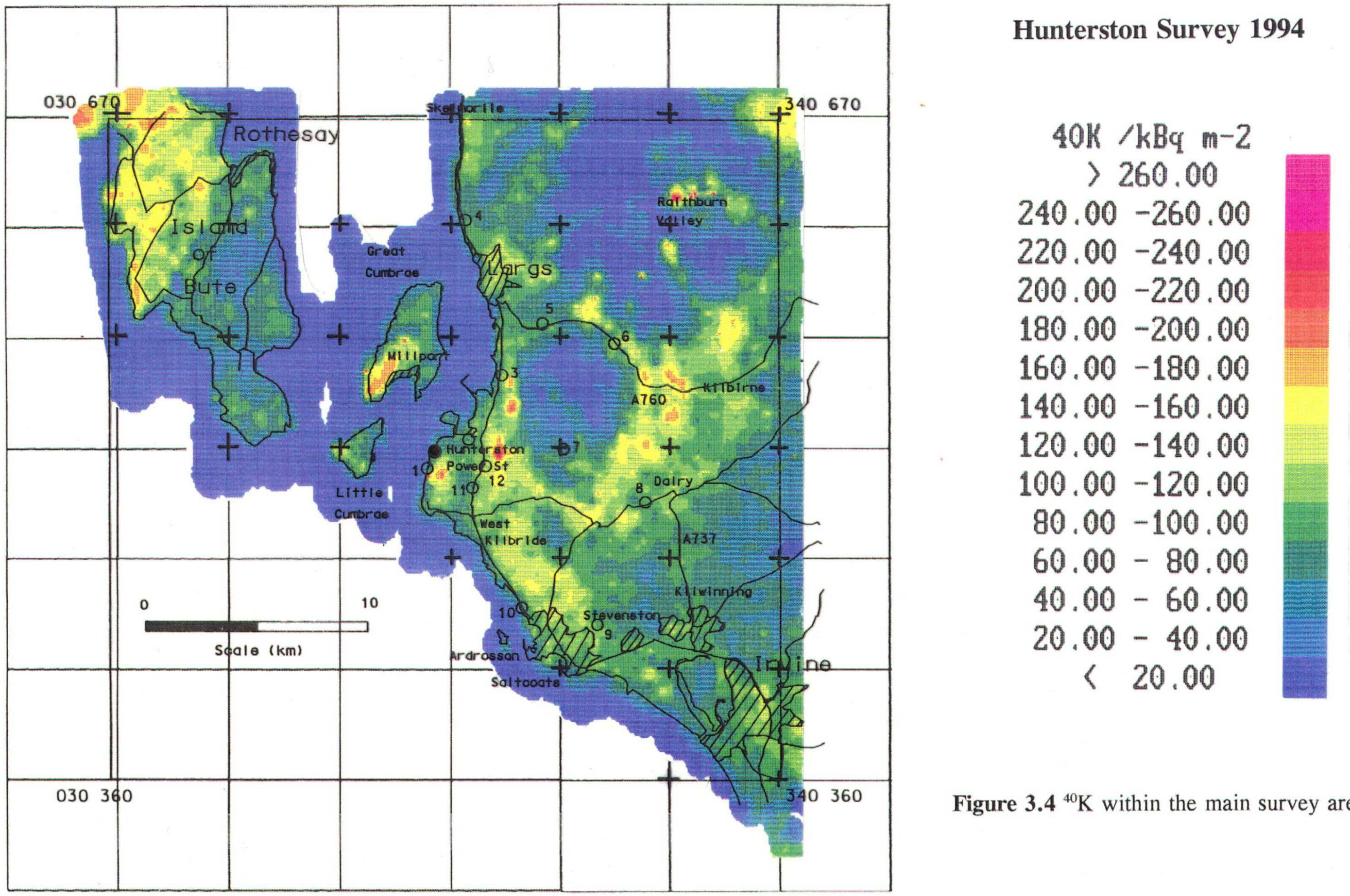


Figure 3.4 ^{40}K within the main survey area

Hunterston Survey 1994

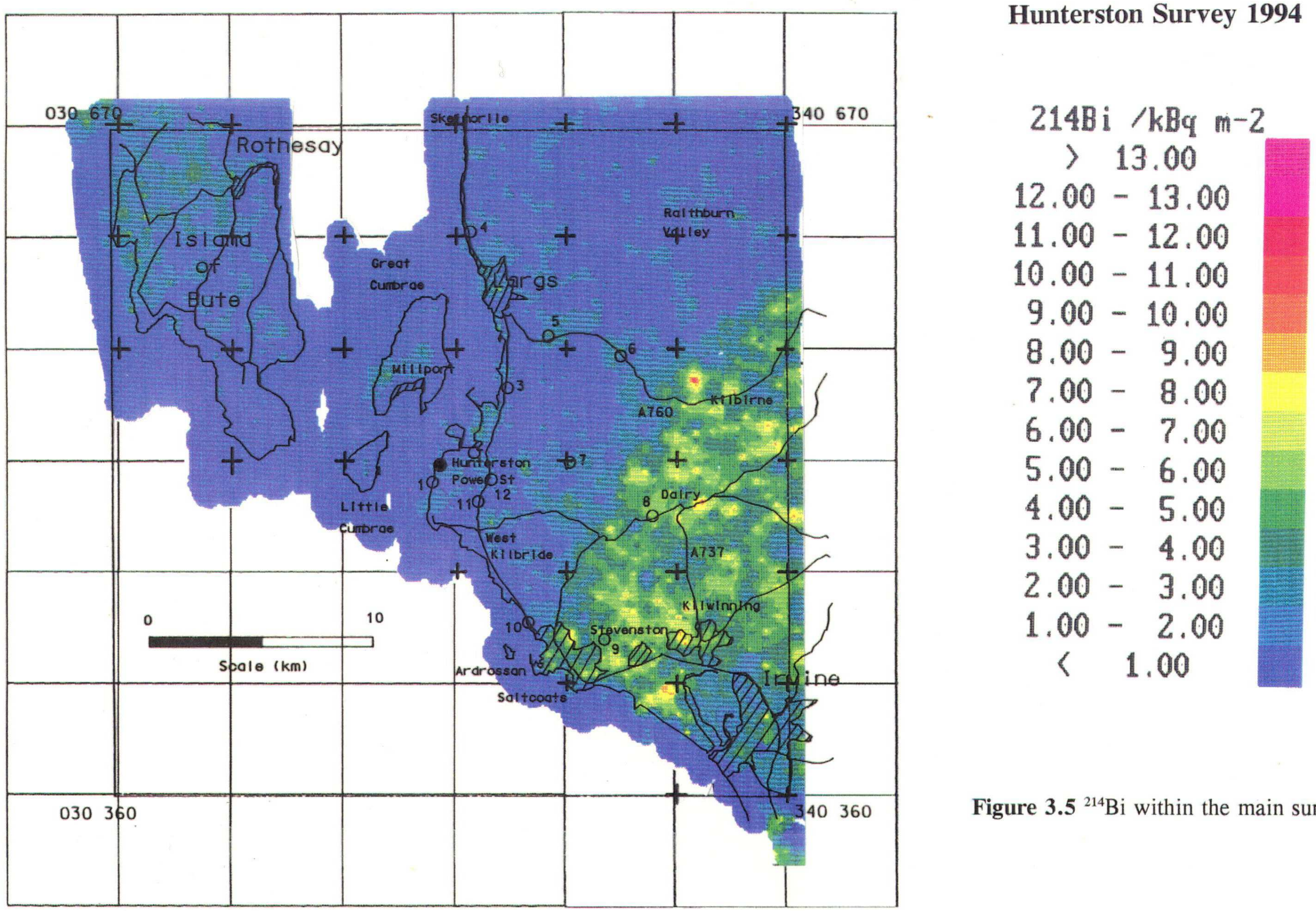
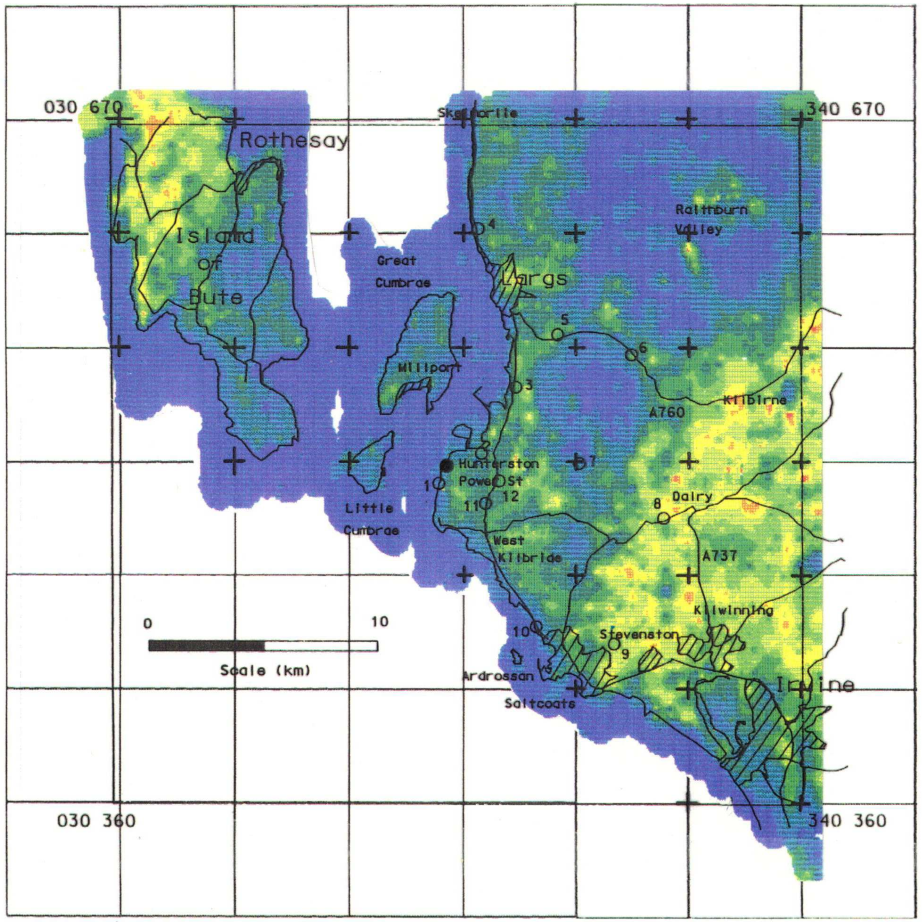


Figure 3.5 ^{214}Bi within the main survey area



Hunterston Survey 1994

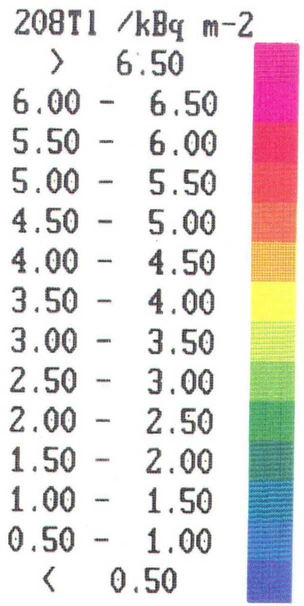


Figure 3.6 ^{208}Tl within the main survey area

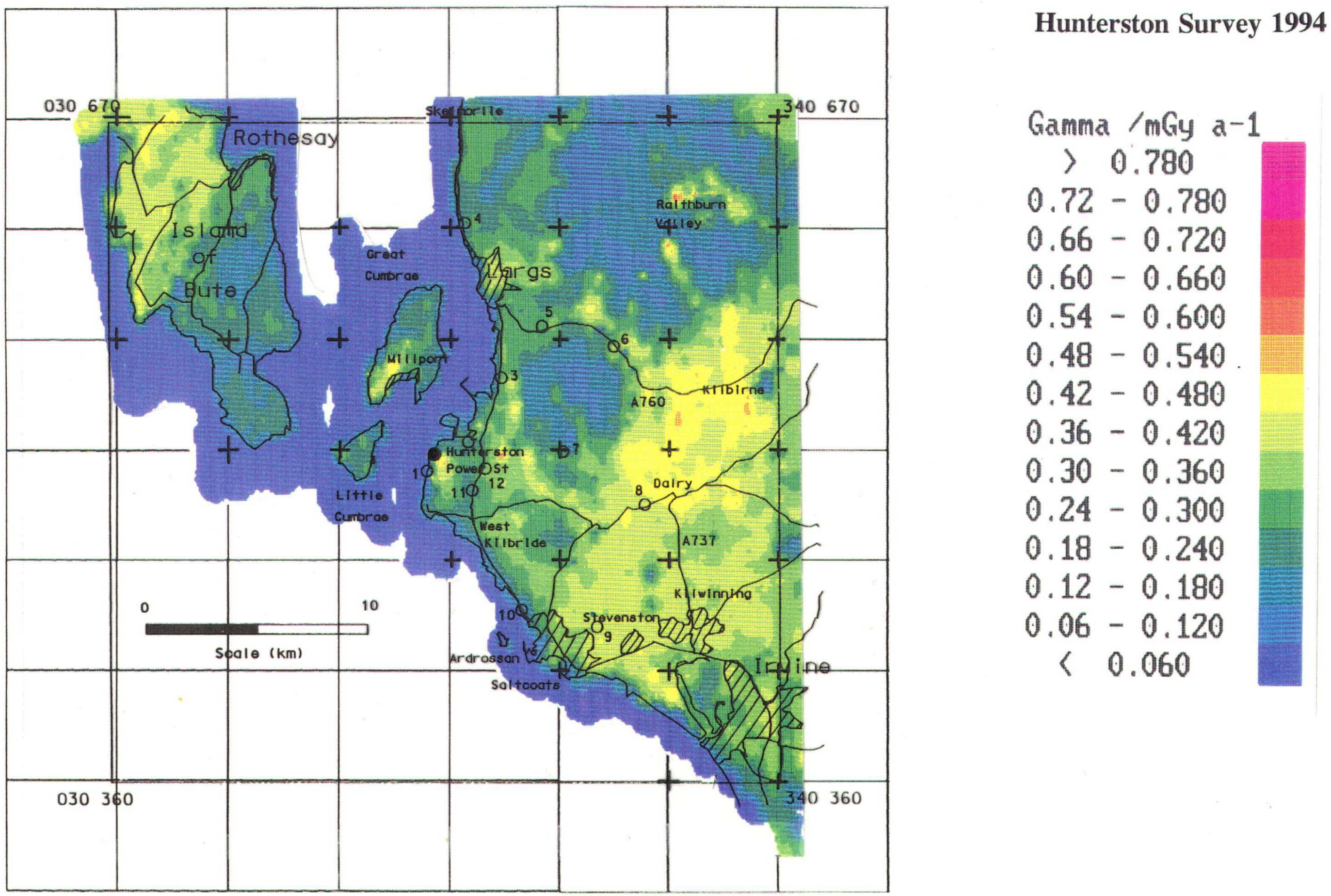


Figure 3.7 Estimated gamma dose-rate within main survey area

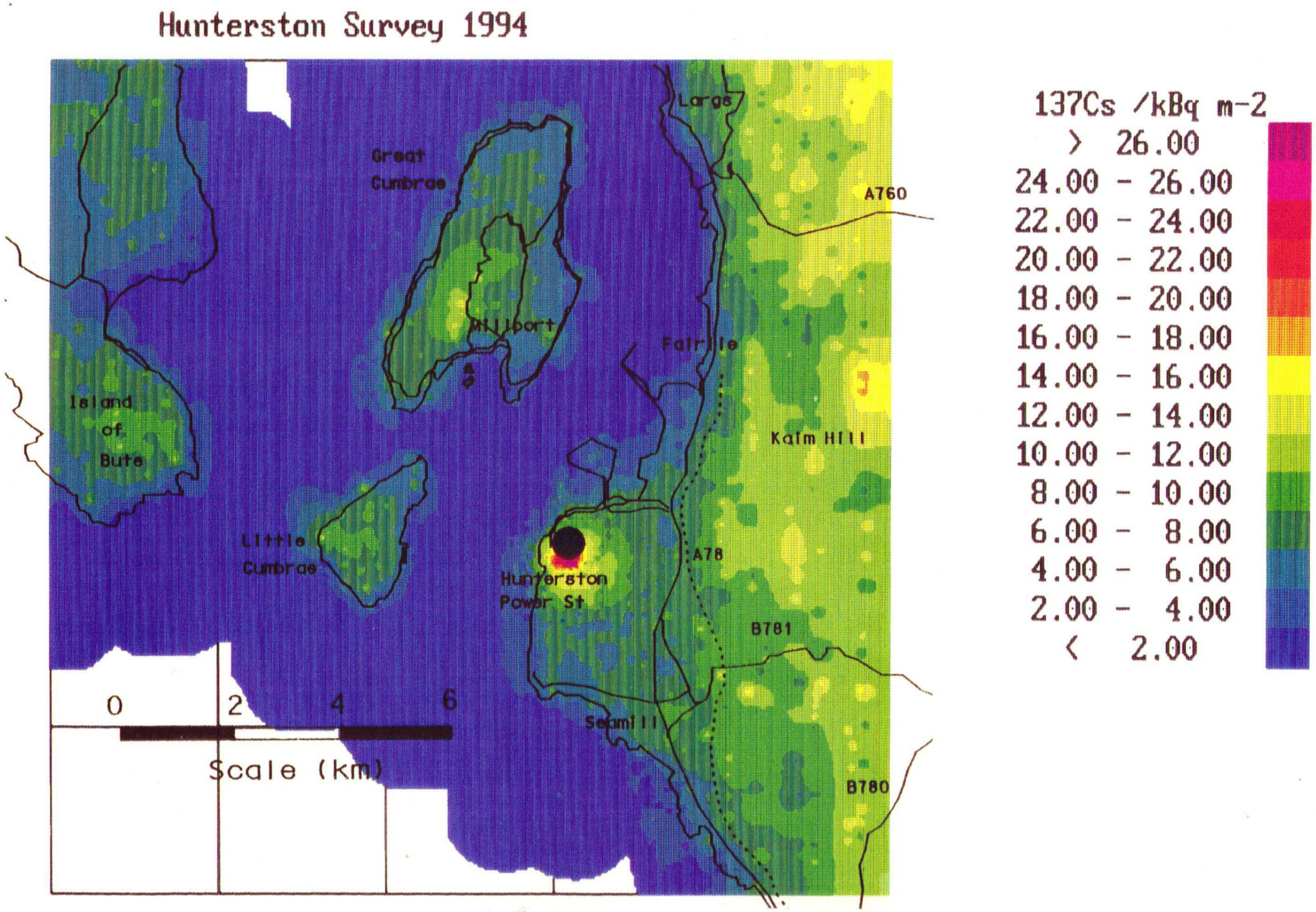


Figure 3.8 ^{137}Cs in the near environment of Hunterston Nuclear Power Station

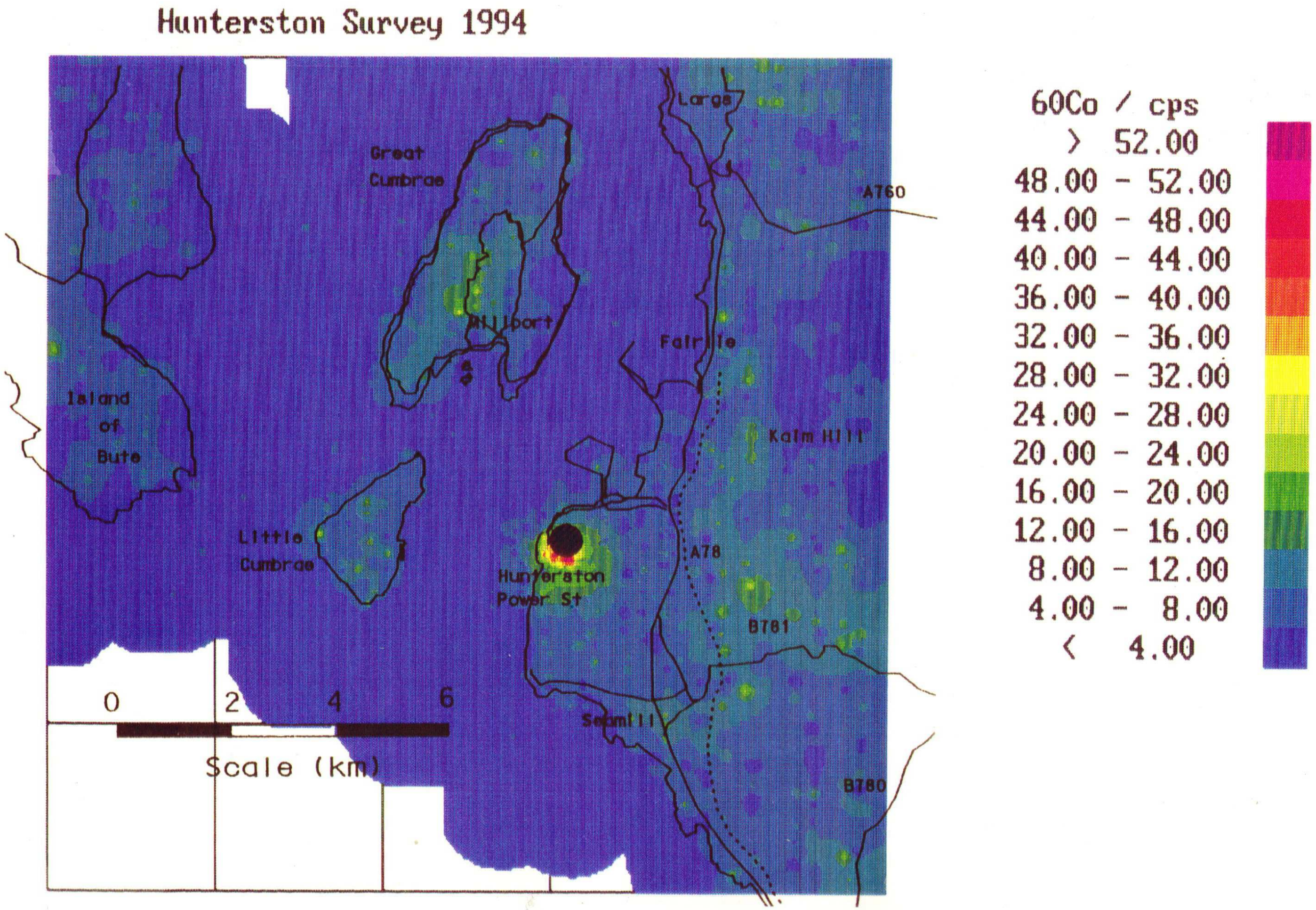


Figure 3.9 ^{60}Co in the near environment of Hunterston Nuclear Power Station

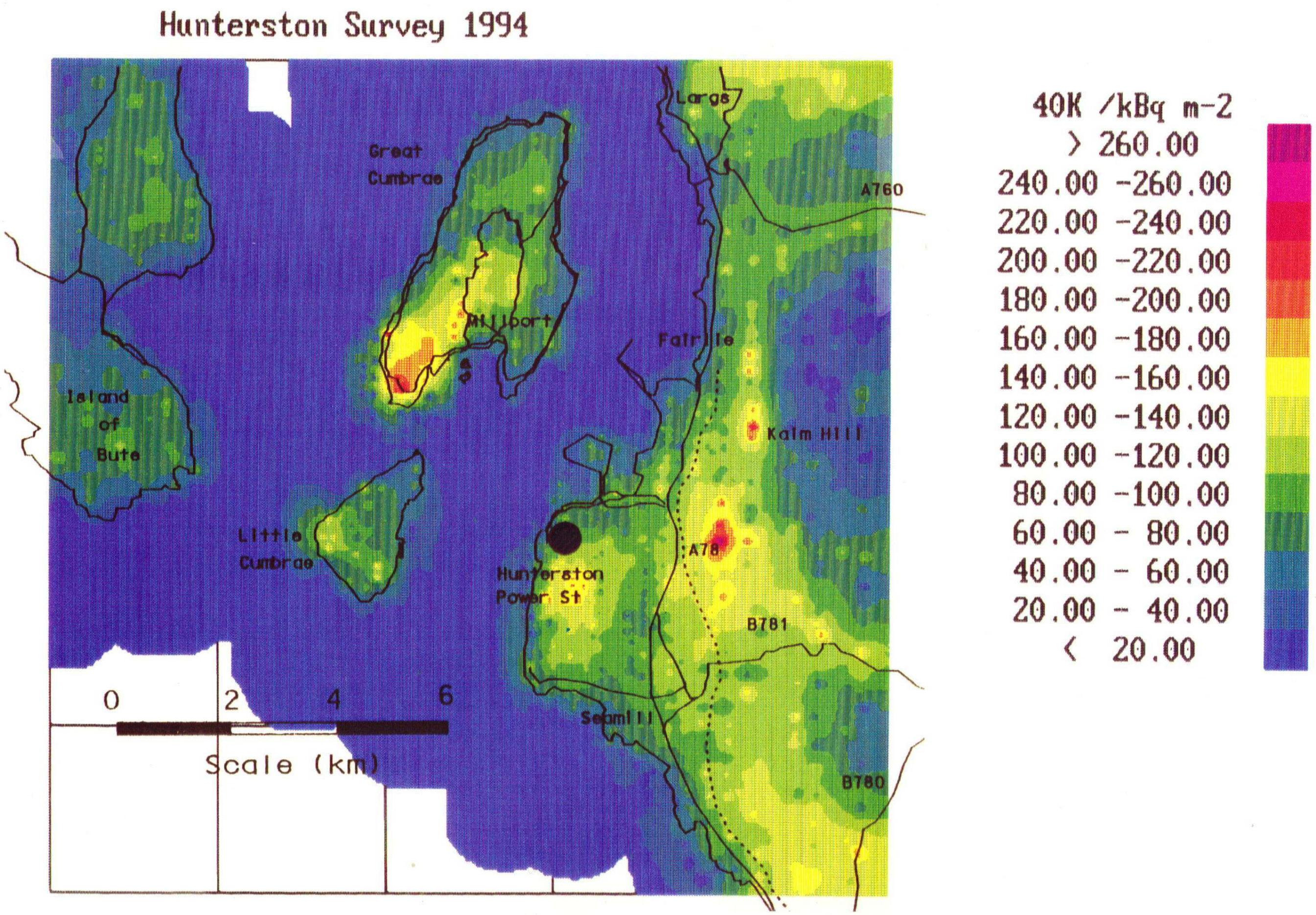


Figure 3.10 ^{40}K in the near environment of Hunterston Nuclear Power Station

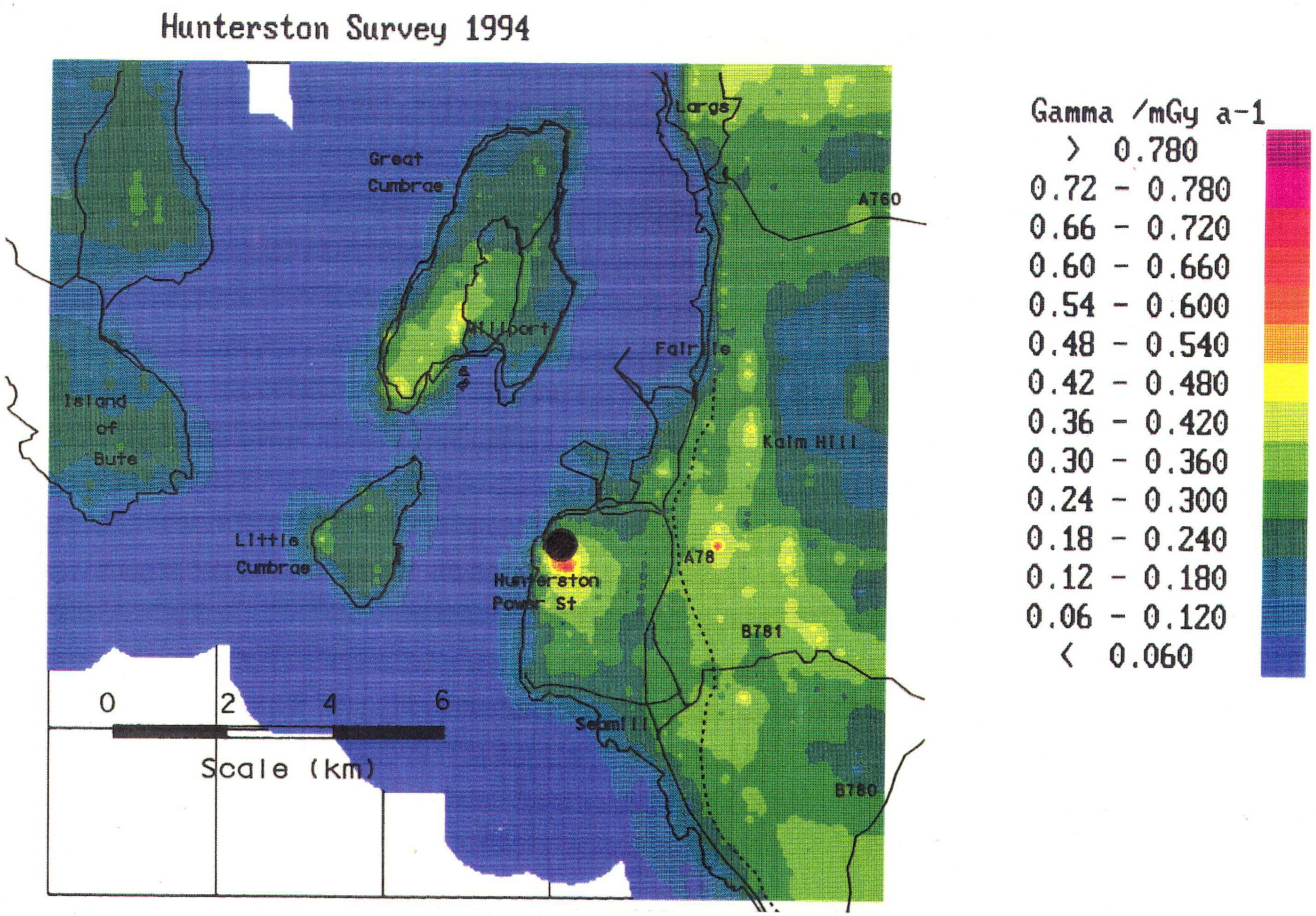


Figure 3.11 Estimated gamma dose-rate in the near environment of Hunterston Nuclear Power Station

3.2. Ground Based Measurements

Ground based 3x3" NaI(Tl) scintillation detector (SURRC) and 6/80 geiger dose-rate meter (Scottish Nuclear) measurements were made for the purposes of investigating the relationship between the two devices, and a cross comparison of estimated dose-rates. A total of twelve sites were visited on the 20th and 21st April 1994.

The results were converted to dose rate estimates as follows. For the 3x3" NaI(Tl) detector, the spectrum was integrated from 450-3000 keV, a background rate of 2.2 cps was subtracted, and the result multiplied by a calibration factor of 6.963×10^{-4} μGy/hr per cps. The use of a 450 keV threshold for scintillation detectors is well documented, as are other higher energy levels, that transform the energy dependent response into an estimated dose.

For the series 6/80 instrument a conversion from count rate to dose rate based on a calibration factor of 0.053 μGy/hr per cps was initially applied without background subtraction. However this resulted in readings with an inherent contribution from cosmic radiation and the intrinsic instrument background in additional to the external gamma ray dose rate. Work was undertaken near Torness to determine the cosmic and intrinsic combined components, based on measurements taken over Whiteadder Reservoir from a polymer boat, and observations in a 10 cm lead shield at SURRC. This led to the conclusion that a combined cosmic and intrinsic background rate of 1.02 cps should be subtracted for the Torness 6/80 series measurements before application of the dose rate conversion factor. This value has also been used to correct the Hunterston readings. Green et al [30] subtracted these components from 6/80 series observations when assessing national gamma ray dose rates. They represent a significant proportion of the total dose rate originally estimated from the 6/80.

The results from twelve district monitoring sites are listed in table 3.1. Both ground level detectors have a slightly different field of view owing to their distinct angular responses. Furthermore the aerial survey estimates of ground level gamma-dose rate are calculated from 100m normalised altitude. Therefore, the field of view of the detector is quite different to ground level measurements and much larger (400-500m in diameter, compared with 10-30m). The effect of this is to average radiation response, and level out local enhancements within the cone from which radiation is received by each detector. For these reasons slight differences between individual observations are most likely to be partly due to the different dose rates being observed by each system. Examples of this can be seen at points 1, 6 and 7, where the aerial survey system shows lower readings in locations with bodies of water (low activity) or waterlogged peat within the field of view of the airborne system, but having less influence on the ground based readings.

The mean values across all sampling points for the 6/80 and scintillation detector are 0.033 ± 0.008 μGy/hr and 0.027 ± 0.008 μGy/hr respectively. The mean gamma-dose rate across all nine sites for the aerial survey detector is 0.027 ± 0.012 μGy/hr. Given the environmental variability of gamma dose rates within the aerial survey zone, these results are in acceptable agreement with each other.

Table 3.1

Site	6/80 Geiger Dose-Rate Meter µGy/hr (Corrected)	3x3" NaI(Tl) µGy/hr >450 keV	Aerial Survey µGy/hr >450 keV
1.	0.039	0.035	0.013
2.	0.022	0.013	0.020
3.	0.034	0.030	0.035
4.	0.024	0.019	0.028
5.	0.038	0.026	0.029
6.	0.047	0.042	0.014
7.	0.037	0.029	0.016
8.	0.039	0.030	0.049
9.	0.036	0.029	0.045
10.	0.025	0.019	0.024
11.	0.026	0.021	0.021
12.	0.028	0.025	0.032
Mean Values:	0.033 ±0.008	0.027±0.008	0.027 ±0.012

4. CONCLUSIONS

A gamma-ray survey of Hunterston Nuclear Power Station and surrounding environment, up to 31km square, has been successfully conducted using a large volume scintillation detector operated in a helicopter. The results have been archived and establish a reference set from which future environmental changes can be assessed. A total number of over 6300 separate spectra were collected during the period 14-15 April and 4 May 1994. Colour maps indicating the radionuclide concentrations of ^{137}Cs, ^{40}K, ^{214}Bi and ^{208}Tl have been produced. In addition, maps of the distribution of count rate within a ^{60}Co spectral window (normalised to 100m altitude) as measured from a 16 litre NaI(Tl) scintillation detector, and estimated gamma dose rate at ground level are shown.

The main survey area shows ^{137}Cs arising from weapons and Chernobyl fallout. The deposition pattern within this survey area has been mapped to a greater level of detail than previously available through national ground based results [26,27] and from the 1990 aerial survey[20]. Fallout concentrations on the Island of Great Cumbrae are similar to those found on the mainland. There is evidence of ^{137}Cs signals to the south of the Hunterston "A" Station and at Bogside Flats marsh near Irvine. The first of these, at Hunterston, was also observed in 1990 and shown to be associated with activity contained on the site. The signal levels are lower than observed in 1990, as a result of site actions. The second signal, from activity on a salt marsh near Irvine, is likely to have been derived from past discharges from Sellafield. Further ground sampling would be needed to determine the concentration and vertical distribution of this source, given the possibility of a buried profile as observed in other parts of SW Scotland [21].

The distribution of count rate in the ^{60}Co window is also enhanced to the south of the "A" station in the same location as above. Once again signal levels are significantly lower than observed in 1990. Outside this area the variation of ^{60}Co count rate is attributed to residuals remaining after stripping natural interferences, and not to low-level contamination. The range of count rates is close to minimum detectable levels, and shows a slight correlation with natural nuclides.

The maps of the natural radionuclides show patterns which correspond to the underlying geology. The total gamma dose rate is mainly driven by the presence of high levels of ^{40}K, ^{214}Bi and ^{208}Tl.

Finally having defined the existing distribution of gamma ray emitters in the environment of Hunterston, it will be possible to examine future changes due to the long term operation of the plant, or in the event of an incident leading to the release of radioactivity from the site. This provides an important contribution to the positive environmental quality assurance, and to emergency response capabilities for the site.

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