Scottish Universities Research & Reactor Centre

AN AERIAL GAMMA RAY SURVEY OF TORNESS NUCLEAR POWER STATION IN 27-30 MARCH 1994

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EXECUTIVE SUMMARY

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

Over 6000 gamma ray spectra were recorded with a high volume spectrometer operated from a helicopter over a three day period in March 1994. Spectral data were recorded together with satellite navigation (GPS) and radar altimetry data. The results provide a comprehensive record of the radiation environment around Torness and have been used to map the distribution of natural and man-made radionuclides, forming a baseline to enable 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 of the Dunbar-Gifford and Lammermuir faults can be partly discerned in the maps, as can some igneous intrusions. Areas with peat or alluvium cover appear as negative features in the radiometric maps.

Radiocaesium ^{137}Cs levels range from below 4 kBq m^{-2} to over 20 kBq m^{-2}. Upland areas near Coldingham Common, Black Castle Hill and Dunbar Common show the highest values, similar in deposition pattern and level to Chernobyl activity observed in the West of Scotland and elsewhere. Published national maps derived from meteorological and ground sampling data predicted much lower levels for these locations. However core samples taken after the survey have confirmed the presence of the activity, and the attribution to Chernobyl. This finding demonstrates both the effectiveness of the method for rapid location of radioactive deposition, and the need for baseline studies to determine present levels. Count rates from a spectral window corresponding to ^{60}Co were also mapped. The results are close to detection limits and show a slight correlation with 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 0.34 mGy a^{-1}, and are derived mainly from natural sources. Ground level measurements were taken at nine 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.

There is no evidence that Torness Power Station has affected the surrounding radiation environment, within the operational and sensitivity limits of the aerial survey.

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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Acknowledgements

We would like to acknowledge the contribution to this work of Captain Paul Heathcote and the support staff of Dollar Helicopters in providing a rapid and effective survey. We are also grateful to Gerry Hartley, Tim Watkins, Scott Craig and colleagues at Torness for their assistance in accommodating the survey and it's ground support.

We also thank Mr. Bill Harrison for access to his land, Mr Thompson (Area Manager) of the Lothian Regional Council Water and Drainage Department and Mr & Mrs McKinley for providing access to Whiteadder Reservoir for background measurements.

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 Torness Nuclear Power Station was conducted, between 27-30 March 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 Torness 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 NT590600, NT590900, NT900600 and NT900900, with Torness 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 NT715720, NT715780, NT775720 and NT775780 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 survey was conducted between 27th and 30st March 1994 using an AS350 Squirrel helicopter operated from Cumbernauld Airport, and re-fuelled at the Torness helipad during each day's survey. Transit times between Cumbernauld and Torness were approximately 30 minutes; each sortie lasted between 120 and 180 minutes.

The spectrometer was installed in the aircraft on 26th March. It 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].

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 6000 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 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 March a series of ground based dose rate estimates was made, at nine 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.

An additional field trip was conducted on 2nd of September to collect soil cores from three locations where the aerial survey had identified ^{137}Cs, and to measure cosmic ray and intrinsic background count rates from the SNL series 6/80 instrument over a body of water, in this case Whiteadder reservoir.

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 3.3 to 3.8, for the overall survey area, and in figures 3.9 to 3.12 for the inner area close to the power station, which also encompasses the Blue Circle Cement Works about 5km further west. No flights occurred directly over the nuclear site, and therefore the maps refer to it's environment, rather than the station itself. However the absence of any detected signal at the closest points of measurement, above the perimeter fence does reflect the effective shielding of all major radiation sources on-site during the survey.

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 3.9-3.12 show additional detail in comparison with figures 3.3-3.8

^{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 7.2±2.8 kBq m^{-2}. The ^{137}Cs map (figure 3.3) shows a number of interesting features. The lowest levels, of 2-4 kBq m^{-2}, are observed for example in the areas NW of Dunbar, and between Abbey St. Bathans and Grantshouse. By contrast locations such as Coldingham Common (15-24 kBq m^{-2}), the area between Black Castle Hill and Abbey St. Bathans (8-15 kBq m^{-2}) and Dunbar Common (8-15 kBq m^{-2}) show ^{137}Cs levels which are similar to the Chernobyl deposition observed in Western parts of Scotland, and are higher than had been expected in this area. Weapons' testing fallout is expected to contribute less than 2 kBq m^{-2} to these environments, published national maps of Chernobyl deposition in Scotland[27], had indicated levels of approximately 0.5-1 kBq m^{-2} for this part of Scotland. Figure 3.1 shows a single aerial survey spectrum near Coldingham Common, which clearly indicates the presence of the 662 keV ^{137}Cs peak. There is no history of discharge of fission products from Torness, and therefore a ground based field trip was conducted in September 1994 to collect soil cores for ^{134}Cs/^{137}Cs analysis. These results, which have confirmed the original attribution to the Chernobyl accident, are presented in section 3.2.2.

^{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 3.4. The range of count rates close to the Torness site is comparable and indistinguishable from elsewhere within the survey area, and is at a level which is consistent with the expected

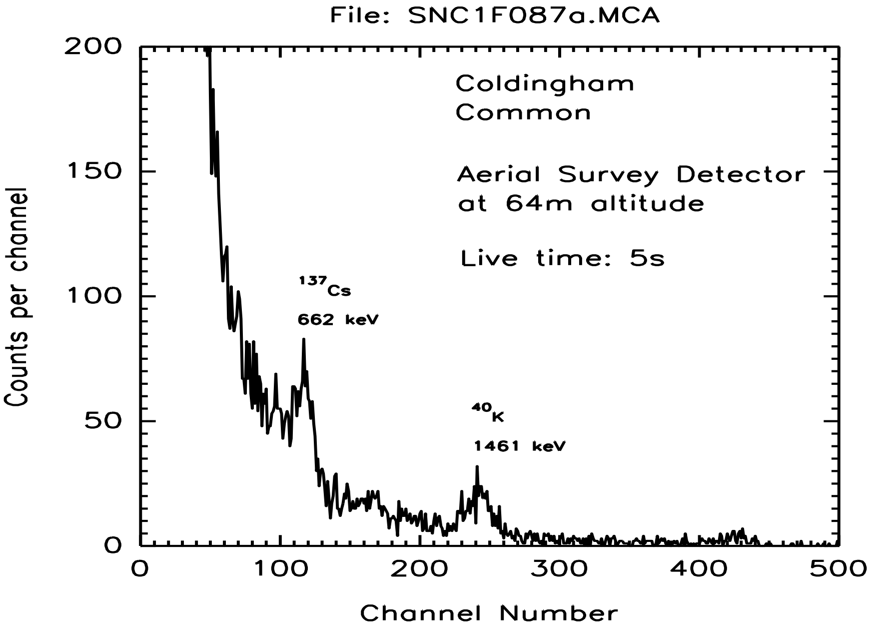

Figure 3.1 Spectrum near Coldingham Common

residuals remaining after the spectral stripping of the spectrometer background from natural radionuclides. There is slight evidence for a spatial correlation between the 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 3.5), ^{214}Bi (figure 3.6), and ^{208}Tl (figure 3.7) maps convey information mainly about the geological and geomorphological background to the area. Within the ^{214}Bi map there are small local enhancements at the Cement Works near Dunbar. This is mainly due the exposure of rock surfaces in these areas, which have a lower water content than the soil and vegetation overburden which covers the rest of the survey area, leading to slightly enhanced concentrations of natural radionuclides. Quarry sites are indicated on the OS map at these locations. Figure 3.2 shows a spectrum recorded in the vicinity of a quarry site, near the cement works SE of Dunbar. At this location, there are enhanced concentrations of ^{214}Bi (1764 keV) and ^{208}Tl (2615 keV), deriving from the decay series of uranium and thorium. There are also naturally occurring features, for example between Monynut Edge and Abbey St. Bathans, which are the main contributors to the local gamma dose rates.

The estimated annual gamma dose rate at ground level is shown in figure 3.8. Gamma rays dose rates vary by approximately 5 times within the area, as a result of geological and soil cover variations. Figure 3.12 shows the area immediately surrounding Torness Nuclear Power Station, which has a lower gamma dose rate than other locations in the vicinity. There is no evidence that activities on the site have raised the general environmental dose levels.

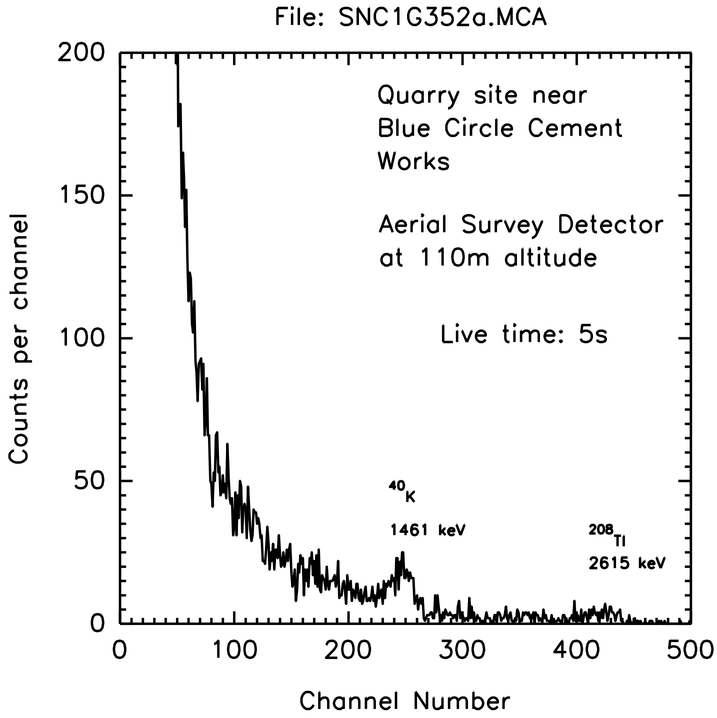

Figure 3.2 Spectrum near Cement Works

The overall gamma ray dose rate estimates show a pattern predominantly influenced by the natural sources of radioactivity. The contribution of ^{137}Cs to the gamma ray dose rate is also small, for example the area around Coldingham Common which has the highest levels of ^{137}Cs recorded in the survey area does not show a higher gamma ray dose rate compared with it's surroundings. Dose rates have been estimated from the integrated count rate above 450 keV. The conversion constant used is appropriate to natural sources and those with a similar energy distribution. For post accident surveys, where sources with complex and varying energy distributions other approaches to dose rate evaluation might be appropriate. However previous studies have shown that the present method gives similar results to ground based instruments on sites with considerable anthropogenic deposits of ^{137}Cs[25]. It would in any case be sensible to validate dose rate conversion procedures by ground to air comparison under circumstances where the photon energy distribution departs significantly from natural conditions.

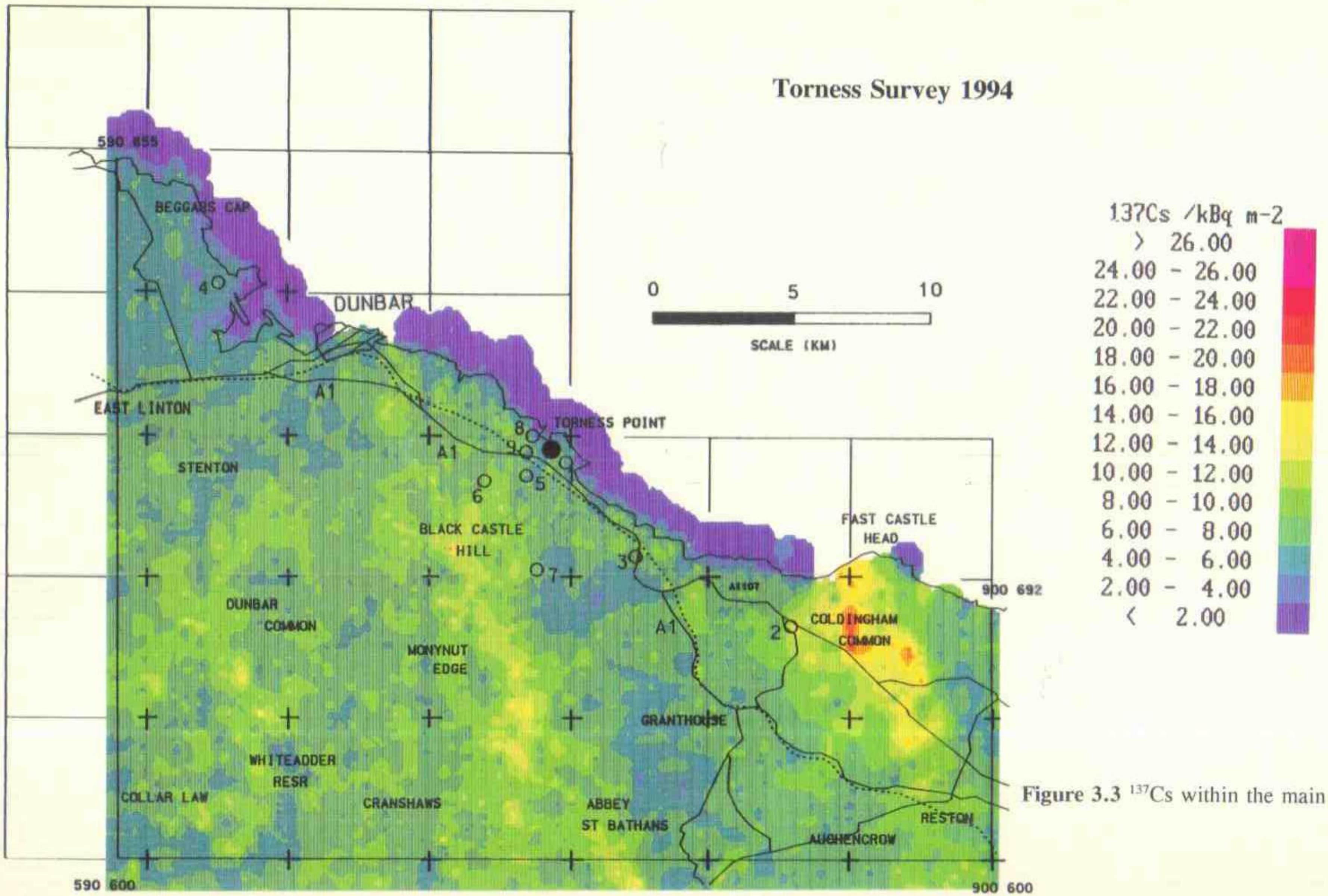

Figure 3.3 ^{137}Cs within the main survey area

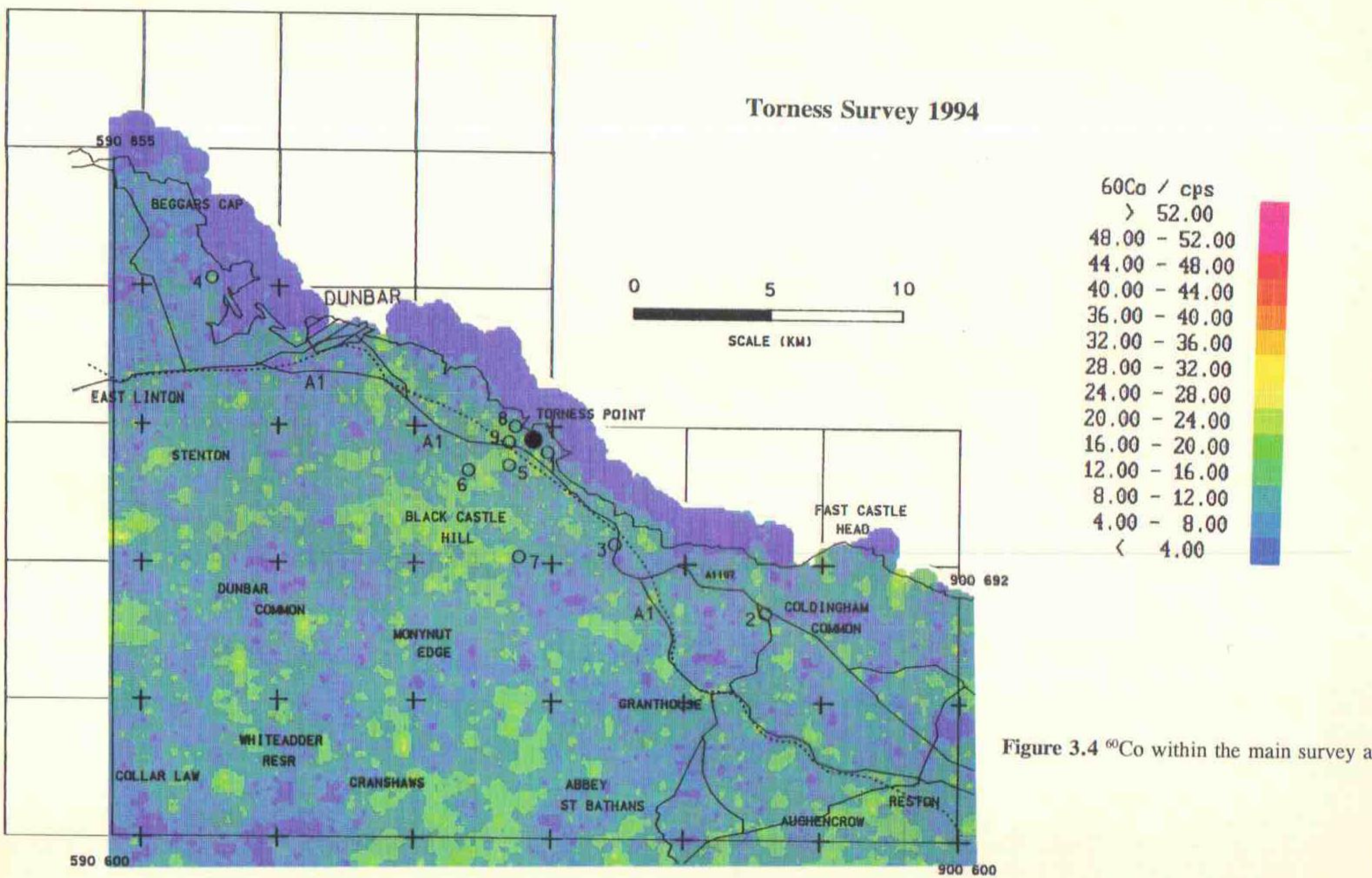

Figure 3.4 ^{60}Co within the main survey area

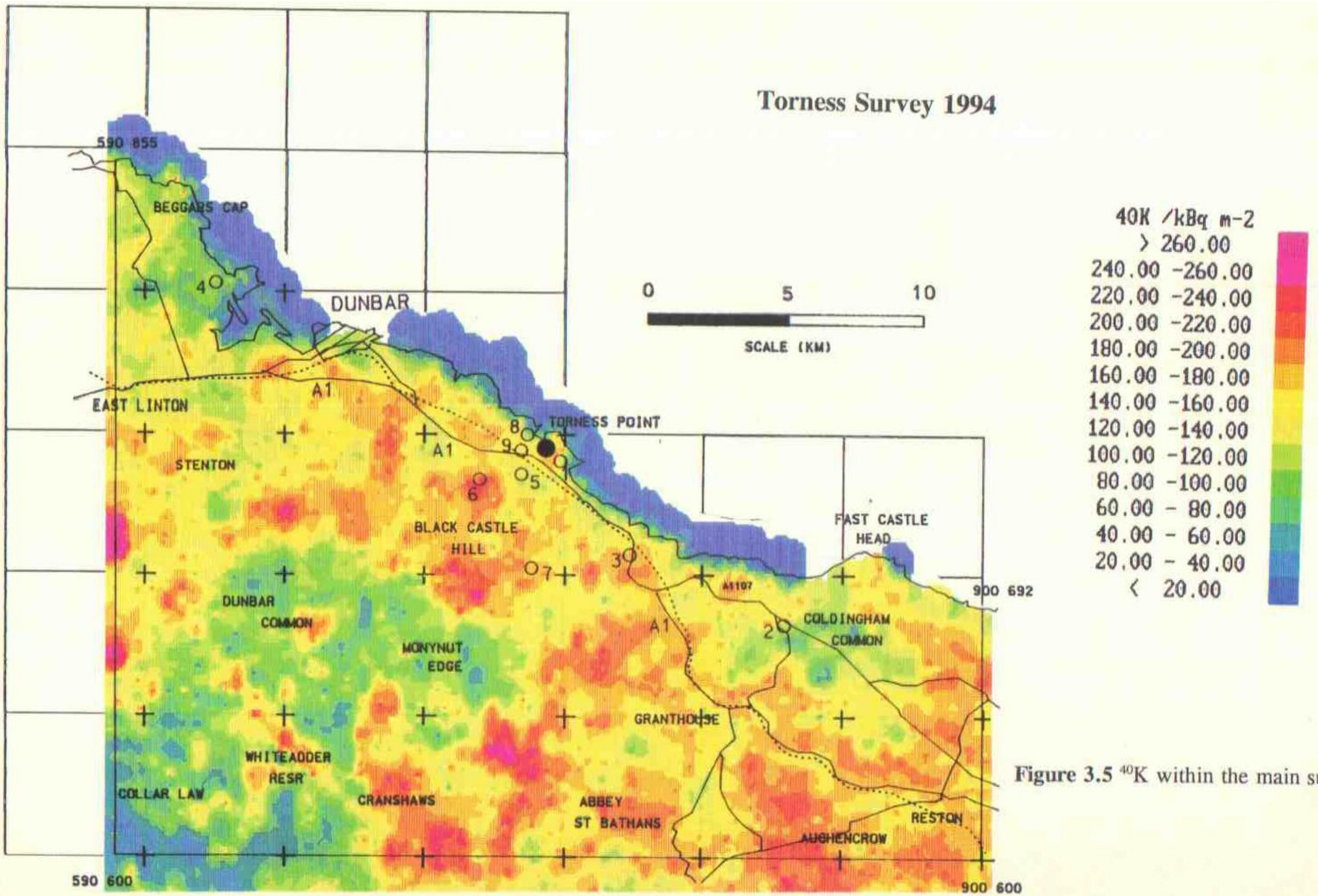

Figure 3.5 ^{40}K within the main survey area

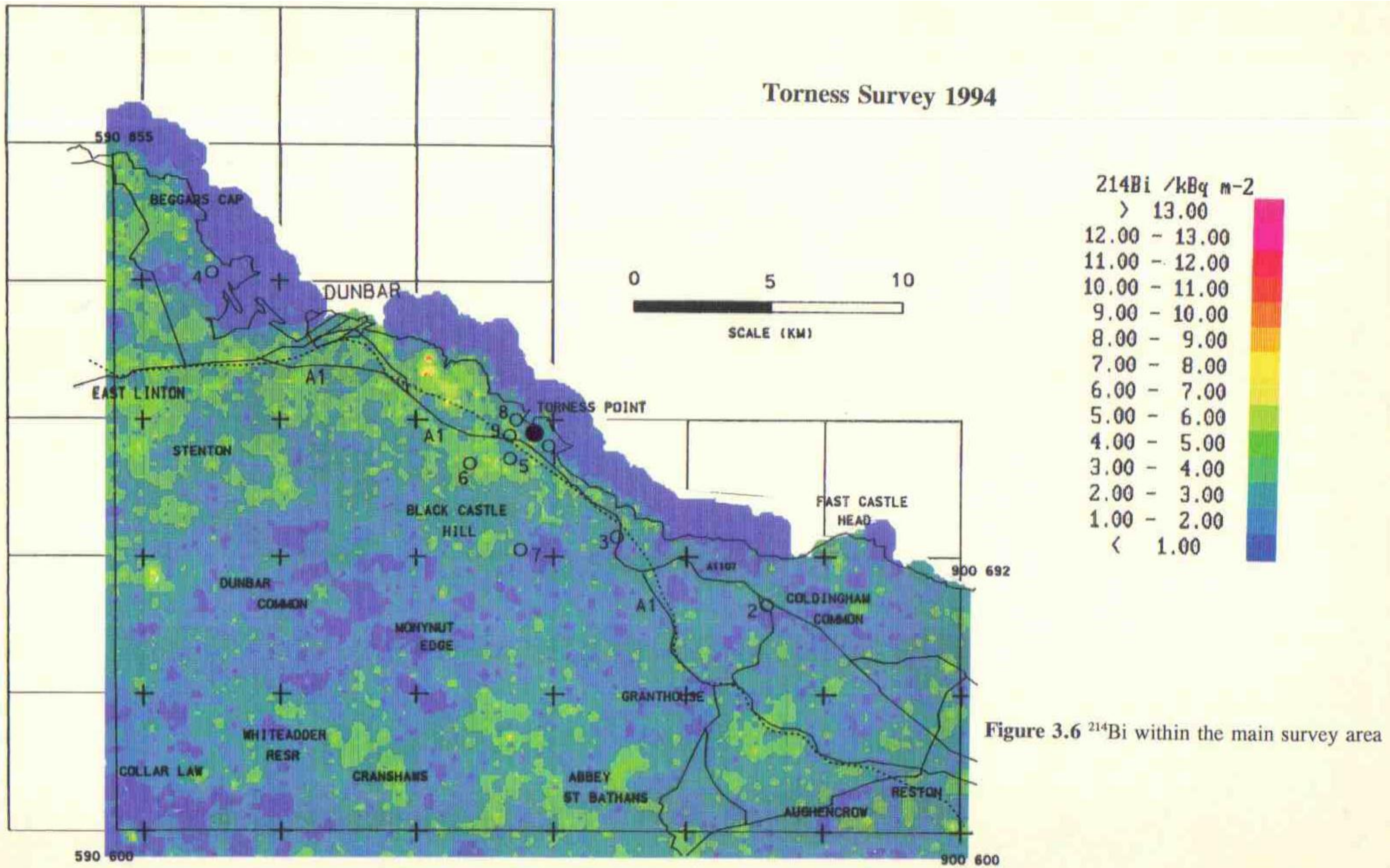

Figure 3.6 ^{214}Bi within the main survey area

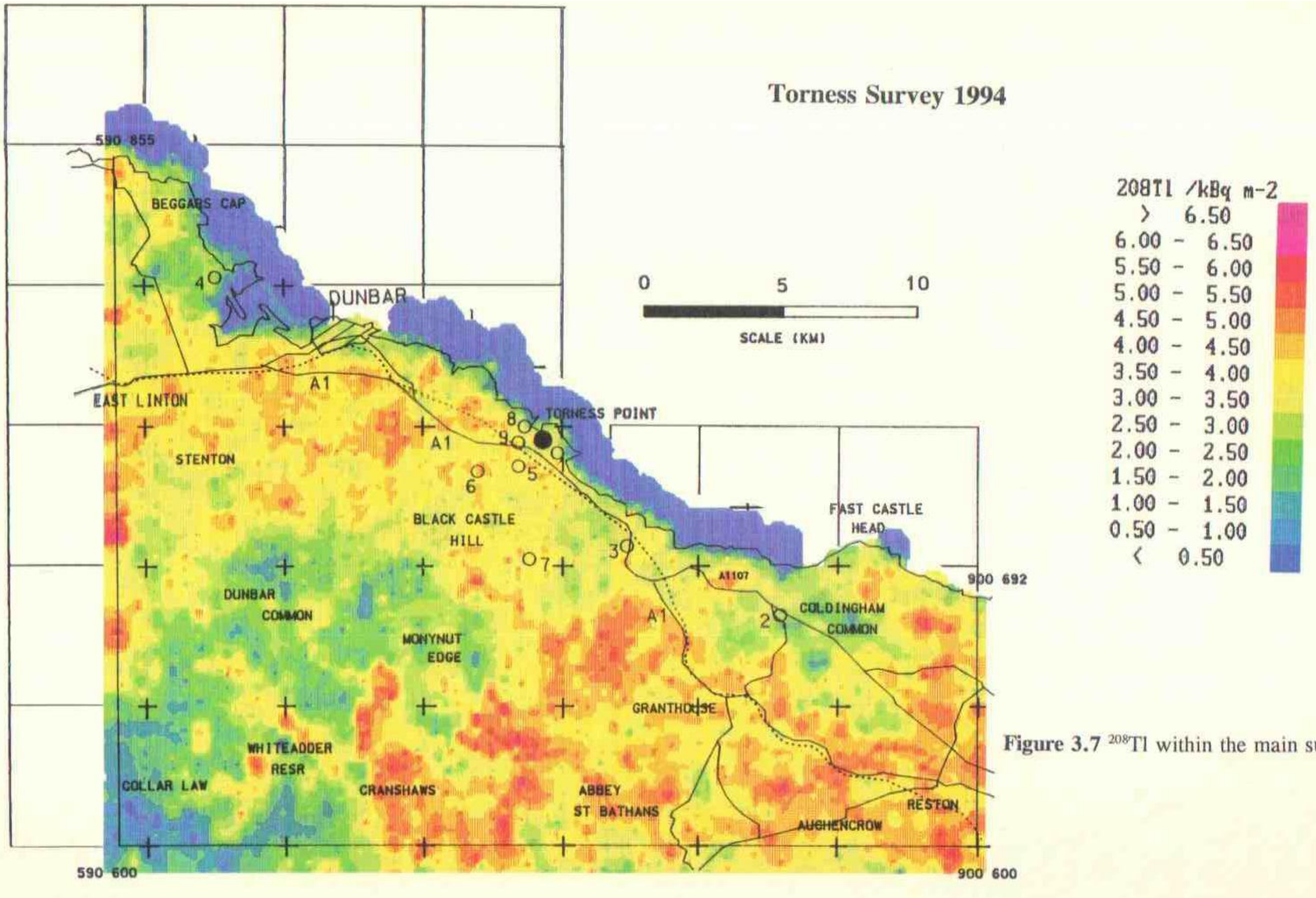

Figure 3.7 ^{208}Tl within the main survey area

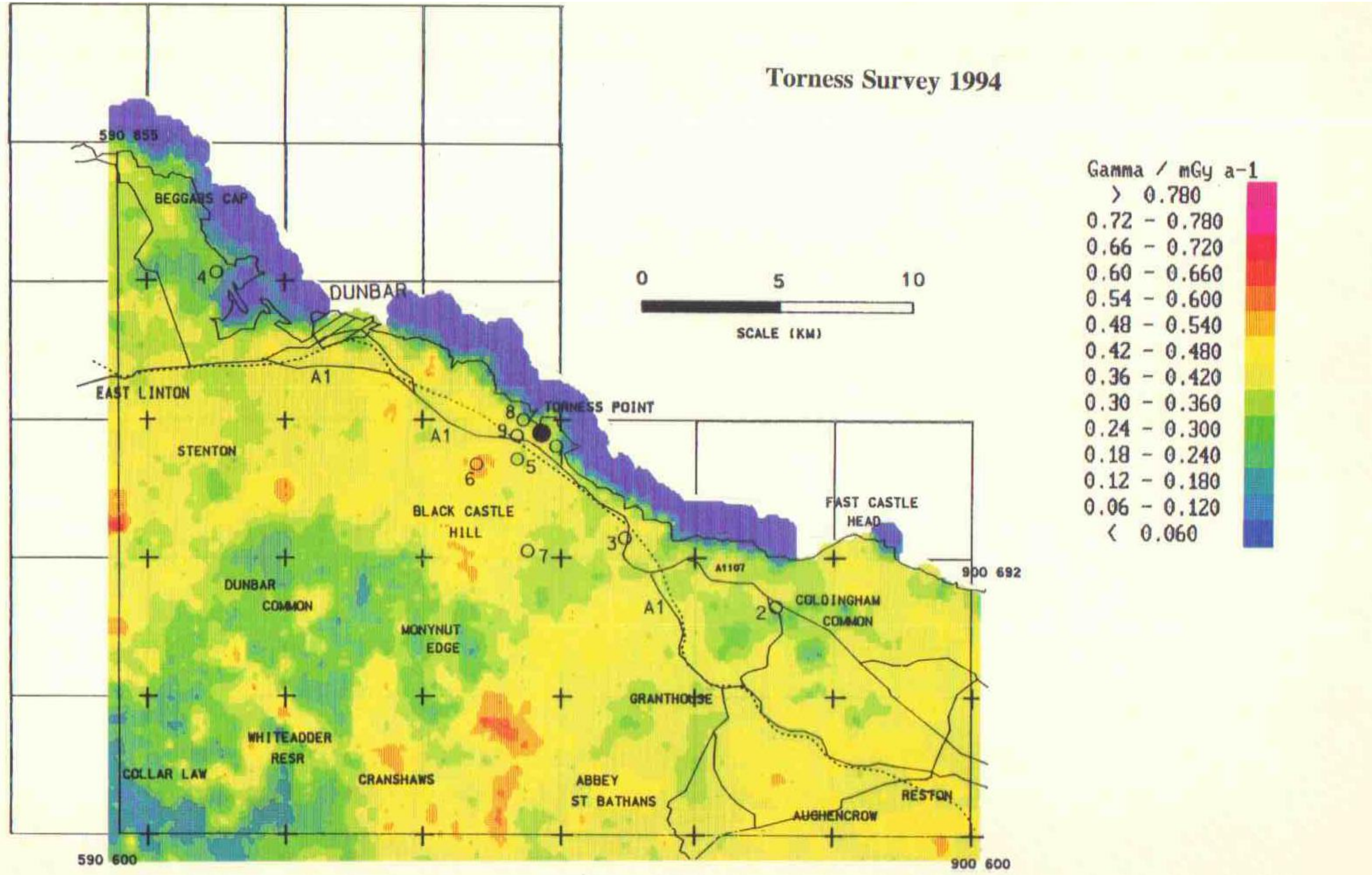

Figure 3.8 Estimated gamma dose-rate within main survey area

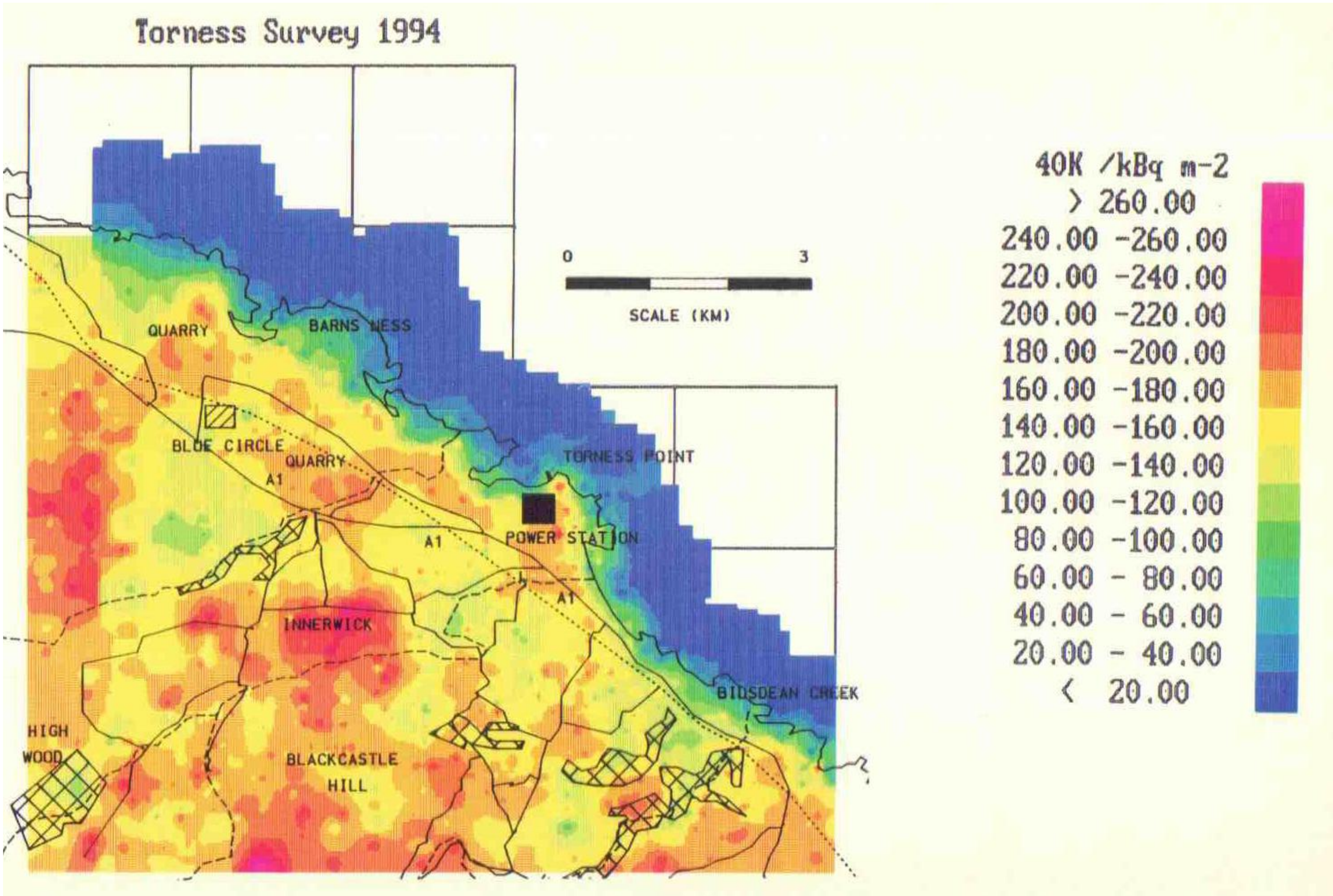

Figure 3.9 ^{40}K in the near environment of Torness Nuclear Power Station

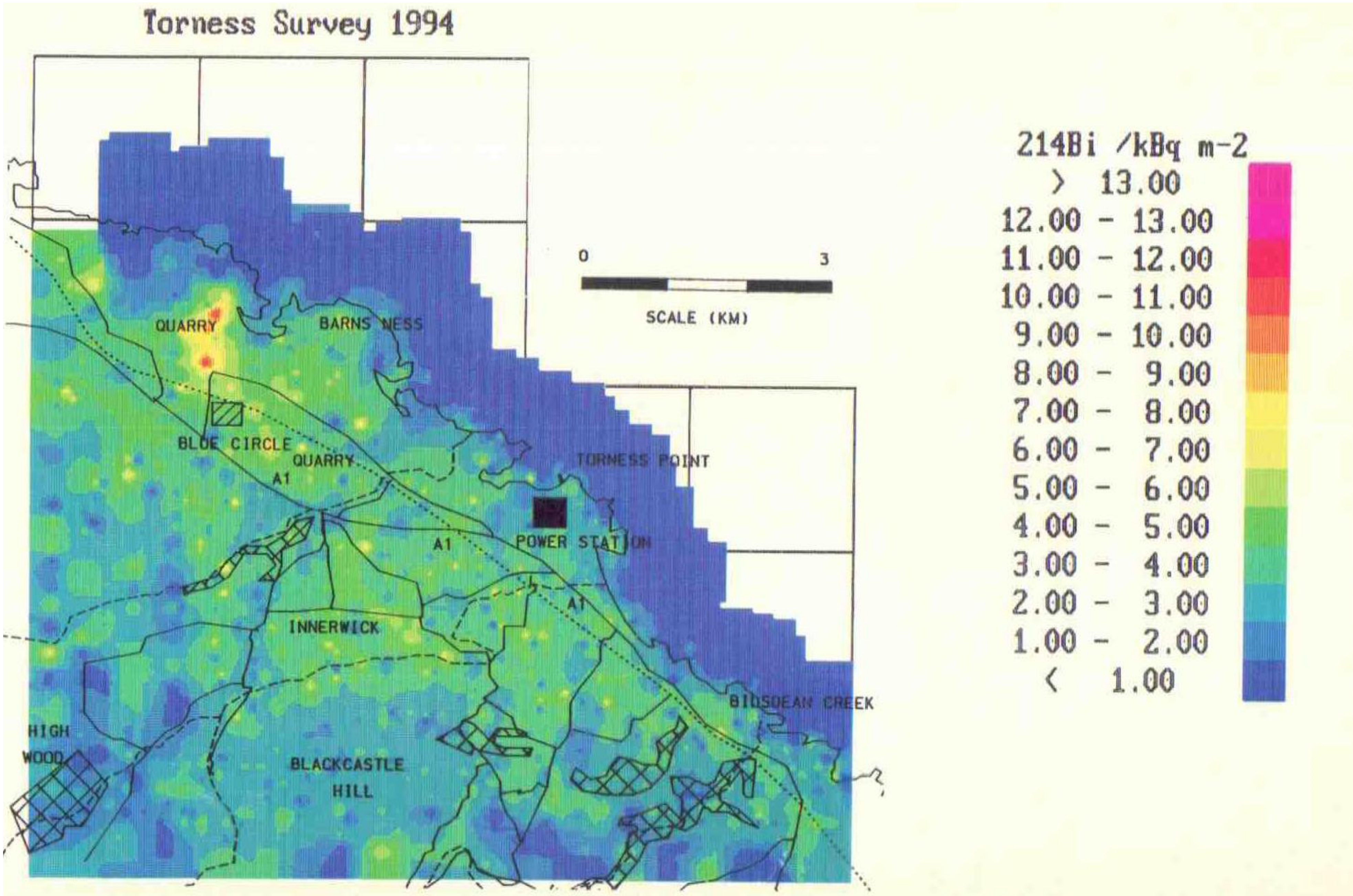

Figure 3.10 ^{214}Bi in the near environment of Torness Nuclear Power Station

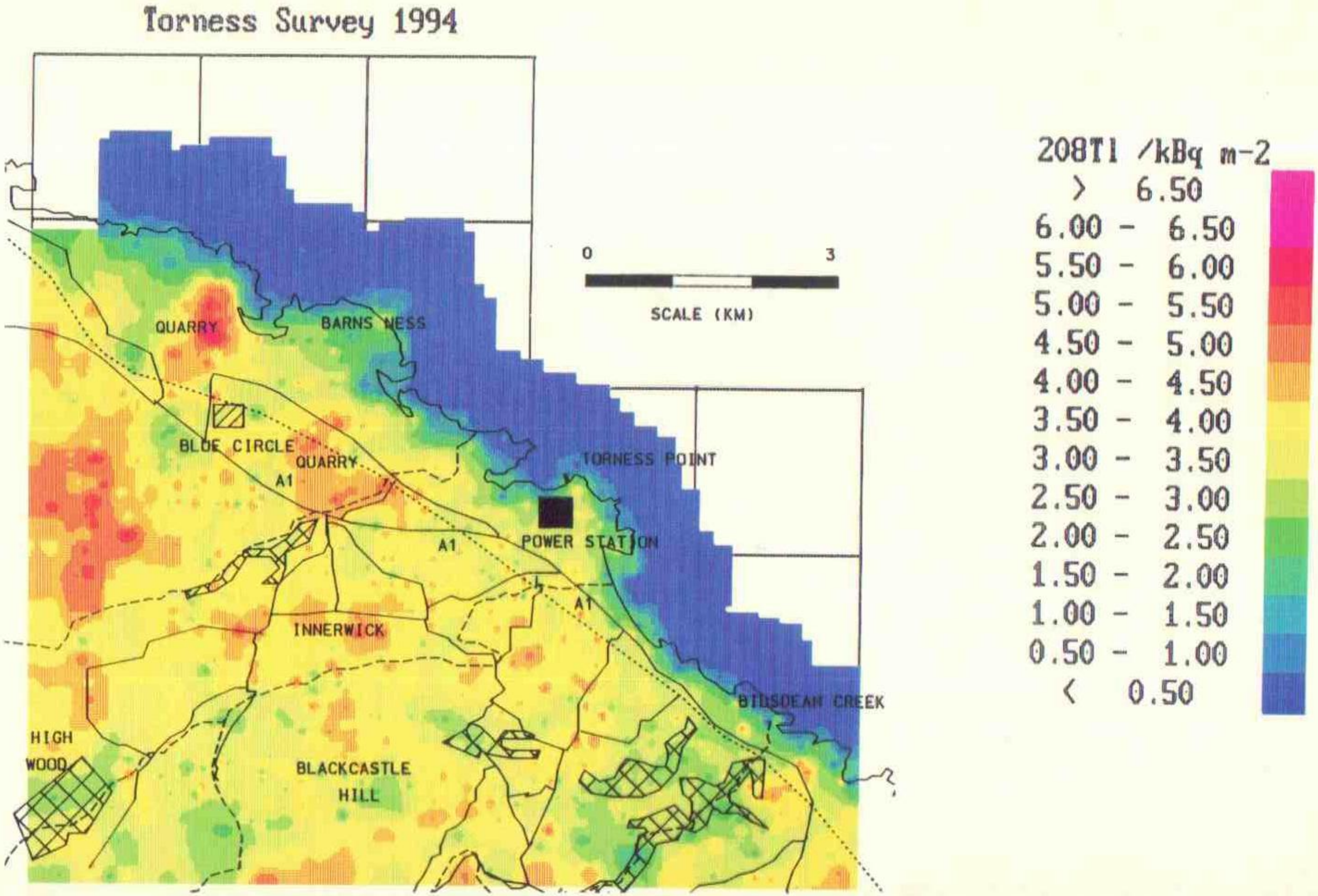

Figure 3.11 ^{208}Tl in the near environment of Torness Nuclear Power Station

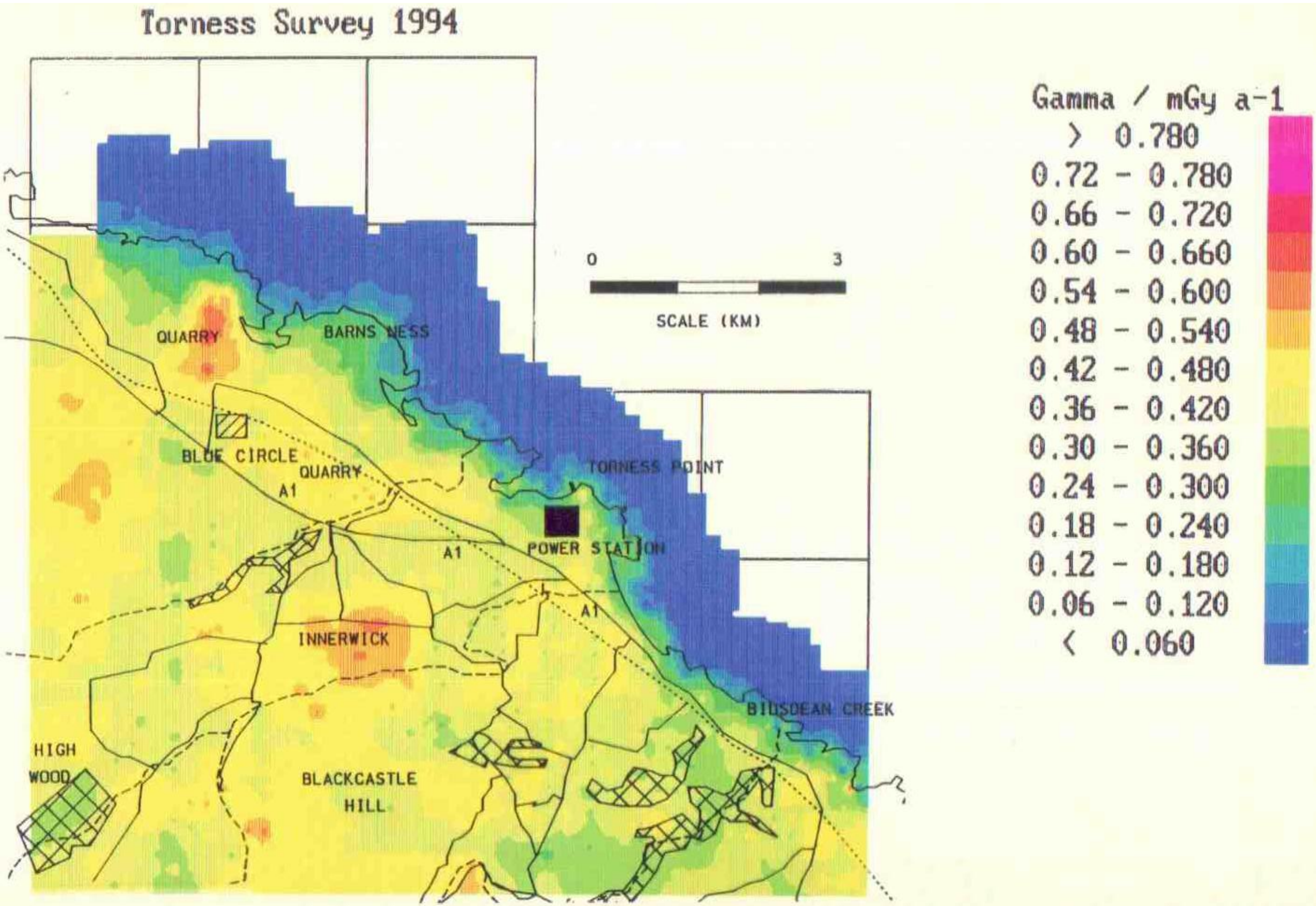

Figure 3.12 Estimated gamma dose-rate in the near environment of Torness Nuclear Power Station

3.2 Ground Based Measurements

Ground based measurements were undertaken during the survey to compare dose rate estimates at district monitoring points with the aerial survey results, and also to investigate the ^{137}Cs deposits discovered by the aerial survey.

3.2.1 Gamma Dose Rate measurements

Ground based 3x3" NaI(Tl) scintillation detector (SURRC) and series 6/80 Mini-Instruments (Scottish Nuclear) measurements were made at 9 nine sites, visited during the 29 March 1994 as listed in table 3.1.

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 0.049 µGy/hr per cps was initially applied without background subtraction. However this resulted in readings which contained an inherent contribution from cosmic radiation and the intrinsic instrument background in additional to the external gamma ray dose rate. Additional work was undertaken to determine the cosmic and intrinsic combined components, based on a series of measurements taken over the centre of the Whiteadder Reservoir from a polymer boat, and further 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 from the 6/80 series measurements before application of the dose rate conversion factor of 0.049 µGy hr^{-1} cps^{-1}. Green et al [30] also subtracted these components from 6/80 series observations when assessing national gamma ray dose rates. These components represent a significant proportion of the total dose rate originally estimated from the 6/80.

Both ground level detectors will 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.

The mean values across all sampling points for the 6/80 and scintillation detector are 0.038±0.004 µGy/hr and 0.034±0.004 µGy/hr respectively. The mean gamma-dose rate across all nine sites for the aerial survey detector is 0.042±0.011 µGy/hr. Given the environmental variability of gamma dose rates within the aerial survey zone, which spans a factor of five, 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.	0.045	0.039	0.034
2.	0.037	0.035	0.045
3.	0.034	0.031	0.046
4.	0.038	0.037	0.024
5.	0.040	0.033	0.029
6.	0.040	0.037	0.060
7.	0.041	0.030	0.044
8.	0.030	0.029	0.047
9.	0.038	0.031	0.047
Mean Values:	0.038 ±0.004	0.034 ±0.004	0.042 ±0.011

3.2.2 Further Ground Based Investigations

On the 2nd September further fieldwork was conducted in collaboration with SNL to confirm levels and origin of ^{137}Cs on Coldingham Common (55° 54.74'N 2° 13.93'W), and two other areas nearby, Corse Law (55° 53.298'N 2° 25.317'W) and Moss Law (55° 52.55'N 2° 37.62'W). These locations were identified from the aerial survey map by using a hand-held GPS receiver.

On heather moorland of Coldingham Common two cores taken to 20 and 30cm were taken, and an in-situ 3x3" NaI measurement. Each core was split vertically to allow SNL to take a subsample for comparison. In addition, Scott Craig from SNL Torness recorded a Ge spectrum at ground level over 1800s which positively showed both 661 and 795 keV peaks corresponding to ^{137}Cs and ^{134}Cs respectively, in a ratio consistent with Chernobyl fallout. After subsequent laboratory preparation and analysis of the cores 21.2±0.6 kBq m^{-2} (0-20cm depth) ^{137}Cs was found to be present. A $^{134}Cs/^{137}Cs$ ratio of 0.030±0.005 was determined and compares extremely well with 0.036 expected from Chernobyl (to August 1994). Over the 0-30cm depth, 8.4±0.3 kBq m^{-2} was found. The discrepancy may be due to splitting the cores and non-uniform activity inventory. NaI in-situ measurements found ^{137}Cs inventory to be 23 kBq m^{-2}. Aerial survey measurements estimated ^{137}Cs to be present in the range 15-18 kBq m^{-2}.

On Corse Law, an area of wide grassland, two cores were taken to 30cm each and again split vertically. In-situ readings by NaI were taken. The activity levels were expected to be lower here and was not clear from SNL in-situ measurements if ^{134}Cs was present. Core analysis revealed ^{137}Cs to be present to 7.5 kBq m^{-2}. NaI in-situ measurements found ^{137}Cs to 14 kBq m^{-2}. Aerial survey readings near this site showed 8-12 kBq m^{-2}.

The final site visited was an exposed area of peat land from which four cores (to 30cm depth) were taken. A single NaI measurement was recorded here. Core analysis revealed ^{137}Cs at the 7.1±0.1 kBq m^{-2} level. NaI in-situ measurements showed ^{137}Cs to 5 kBq m^{-2} and aerial survey readings near this site found 4-8 kBq m^{-2}.

4. CONCLUSIONS

A baseline survey of Torness Nuclear Power Station and surrounding area has been successfully flown by using aerial survey techniques. A total number of over 6000 spectra were collected in a three day period between 27-30 March 1994. Maps indicating radionuclide concentration of ^{137}Cs, ^{40}K, ^{214}Bi and ^{208}Tl have been produced over a 31km square survey area. In addition, a map of the distribution of count rate in a ^{60}Co spectral window measured from a 16 litre NaI(Tl) detector (normalised to 100m altitude) is shown, together with estimated gamma dose rates at ground level. This data will form an archive which any future changes can be compared.

The ^{137}Cs map shows features, attributable to Chernobyl, which have hitherto been underestimated. Clark and Smith [26] estimated total deposition, on the basis of rainfall data, to be in the region of 0.1-1 kBq m^{-2}. Similar estimates have been published by the Scottish Office [27] following a program of ground based sampling. This work has identified locations near Coldingham Common have been identified to have depositions of approximately 20 kBq m^{-2}. Dunbar Common and the area between Abbey St. Bathans and Black Castle Hill have levels between 10-15 kBq m^{-2}. These features were confirmed by examination of individual spectra from the aerial survey data set, and by later ground based investigations. It is not clear whether this is a reflection of higher rainfall in these areas during May 1986 than previously realised, or potentially a result of dry deposition mechanisms operating in this area. However it is clear that the results justify the baseline investigation, in that they have added appreciably to knowledge of the present levels of anthropogenic radioactivity in the vicinity of the Torness station.

Results from a spectral window corresponding to ^{60}Co show a variation across the whole survey area at levels close to minimum detection limits, and with a slight residual correlation with natural sources. There is no reason to associate operations at Torness with these results.

The maps of the natural radionuclides show the underlying surface geology, although some features are outside the spatial resolution of the detector. Of interest are apparently quarry workings in the vicinity of the Cement Works near Dunbar, which show generally higher levels of ^{214}Bi and ^{208}Tl, from the uranium and thorium decay series. In other locations of the survey area, ^{40}K is the dominant radionuclide that contributes significantly to the total gamma dose-rate.

Overall within the sensitivity and operational limits of the aerial survey, there is no evidence that Torness Power Station has had a significant effect on it's surrounding radiation environment.

Having defined the existing distribution of gamma ray emitters in the environment of Torness, it will be possible to examine future changes due to long term operations, 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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