ANSTO MINERALS

The Uranium Processing and Radioactivity Specialists

TECHNICAL MEMORANDUM: AM_TN_2009_03_06

SUBMITTED TO: Ash Development Association of Australia (ADAA)

SUBJECT: Assessment of Naturally Occurring Radionuclides in Australian Coal Combustion Products (CCPs)

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Commercial-in-Confidence

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1. Introduction

The charter of the Ash Development Association of Australia (ADAA) is to increase users, stakeholders and regulators awareness of the benefits arising from the effective use of coal combustion products (CCPs), which are mineral resources. The Association undertakes research into the use of CCPs, more commonly known as coal ash, and supports studies aimed at increasing the technical information available for their on-use.

A suite of fifty five (55) CCP samples were collected by ADAA from .across Australia and submitted to ANSTO Minerals to determine the concentration of naturally occurring radionuclides present in each sample.

The sample collection methodology involved the collection of fine fly ash, medium fly ash and run-of-station bottom ash samples from ADAA members throughout Australia. The geographic distribution of members is illustrated in **Figure 1**.

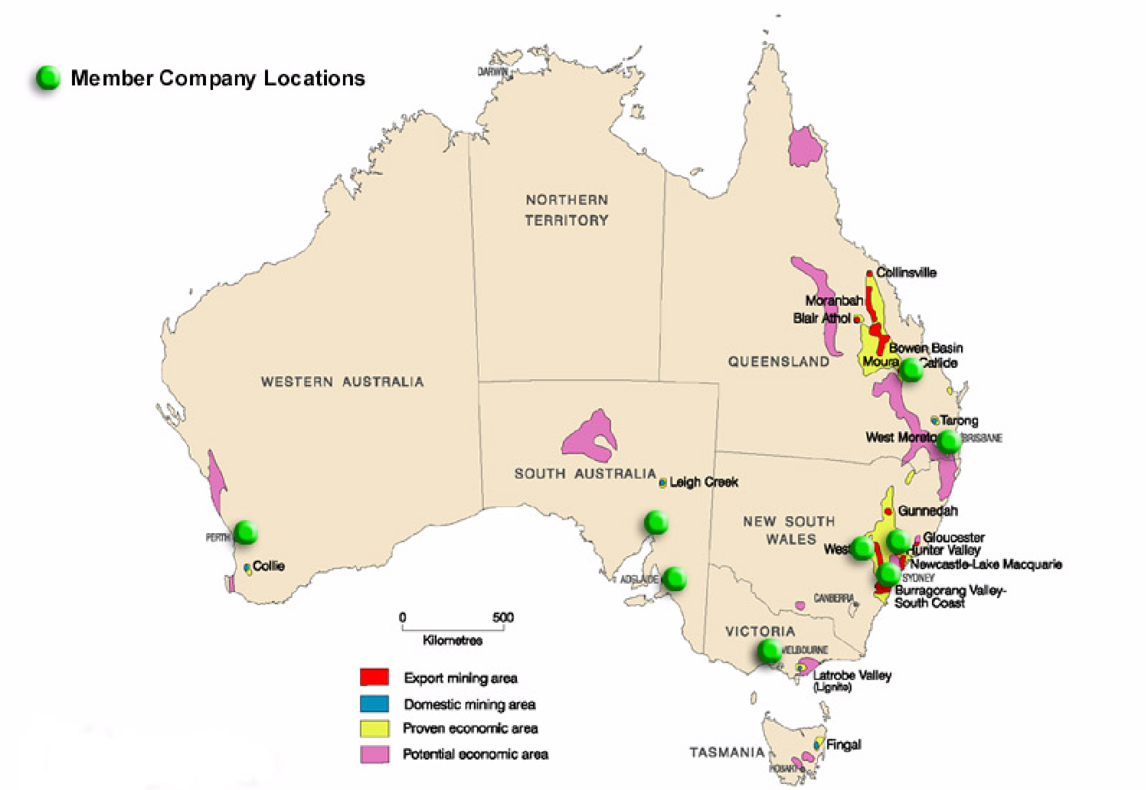

Figure 1- Distribution of Members

An objective of this study is to update the current knowledge of ADAA and its members on the available data for CCPs, as they relate to naturally occurring radioactive material or NORM. Accordingly, this assessment seeks to update current published data on:

- low radionuclide concentrations present in CCPs;
- any consistencies/inconsistencies with the results from previous studies; and
- comparison with background radionuclide concentrations in soils.

Documentation provided by the ADAA indicated the samples to be fine fly ash (FA), medium fly ash (FA) and run of station (ROS) bottom ash (BA) from various companies and areas in Australia.

A copy of this documentation is given in **Appendix A**.

2. Sampling Collection and Data Treatment

Samples were received in 500 mL plastic containers. Most samples were analysed in the "as received" condition. Some samples required drying and were then pulverised prior to analysis. This information, together with the sample description, is given in **Appendix B**.

All sample data has been treated confidentially and no published results identify individual participants. Participating members are provided with a unique identifier (member code) to assist with distinguishing their respective materials and results for internal assessment purposes and for comparison against other CCP sources from throughout Australia. The participants in the 2008/9 sampling program are listed below:

CCP Generator	CCP Marketer/Processors
•CS Energy (QLD)	•Blue Circle Ash
•Delta Electricity (NSW)	•Cement Australia
•Eraring Energy (NSW)	•Flyash Australia
•Flinders Power (SA)	•Independent Fly Ash Brokers
•Intergen (QLD)	•Pozzolanic Enterprises
•International Power (VIC)	
•Loy Yang Power (VIC)	
•Macquarie Generation (NSW)	
•Stanwell Corporation (QLD	
•Tarong Energy (QLD)	
•Tarong North (QLD	
•TRUenergy (VIC)	
•Verve Energy (WA)	

Table 1 – Environmental Testing Program 2008/9 – Participants

3. Analysis by ANSTO Minerals

The ash samples were analysed using the following techniques:

- Gamma spectrometry;
- Delayed Neutron Activation (DNA) counting .for uranium;

- Neutron Activation Analysis (NAA) for thorium;
- Alpha spectrometry for ^{210}Po; and
- Beta counting for ^{210}Pb.

The results are summarised in **Table 1**. The radium equivalent[1] values (see **Section 5.2**) have also been included in this table.

The U and Th decay series radionuclides were determined by gamma spectrometry. For gamma spectrometry, solid samples were packed into 45 mm plastic Petri dishes and left for 3 weeks to allow for the ingrowth of radium daughters. Samples were then counted using high-purity germanium (HPGe) N-type gamma detectors.

The samples were microwave digested for radiochemical analysis for ^{210}Po and ^{210}Pb.

XRF analysis was carried out for density correction in gamma spectrometry. These results have been provided in **Appendix C**.

[1] Radium equivalent – see **Section 5.2**.

4. General Information

Uranium and thorium are found in trace amounts in virtually all materials in the surface layers of the earth's crust[2]. The ^{238}U decay chain (**Figure 1**) is made up of the parent, ^{238}U, and its 13 daughter radionuclides or progeny. Similarly, the ^{232}Th decay chain (**Figure 2**) is made up of the parent, ^{232}Th, and its 10 progeny.

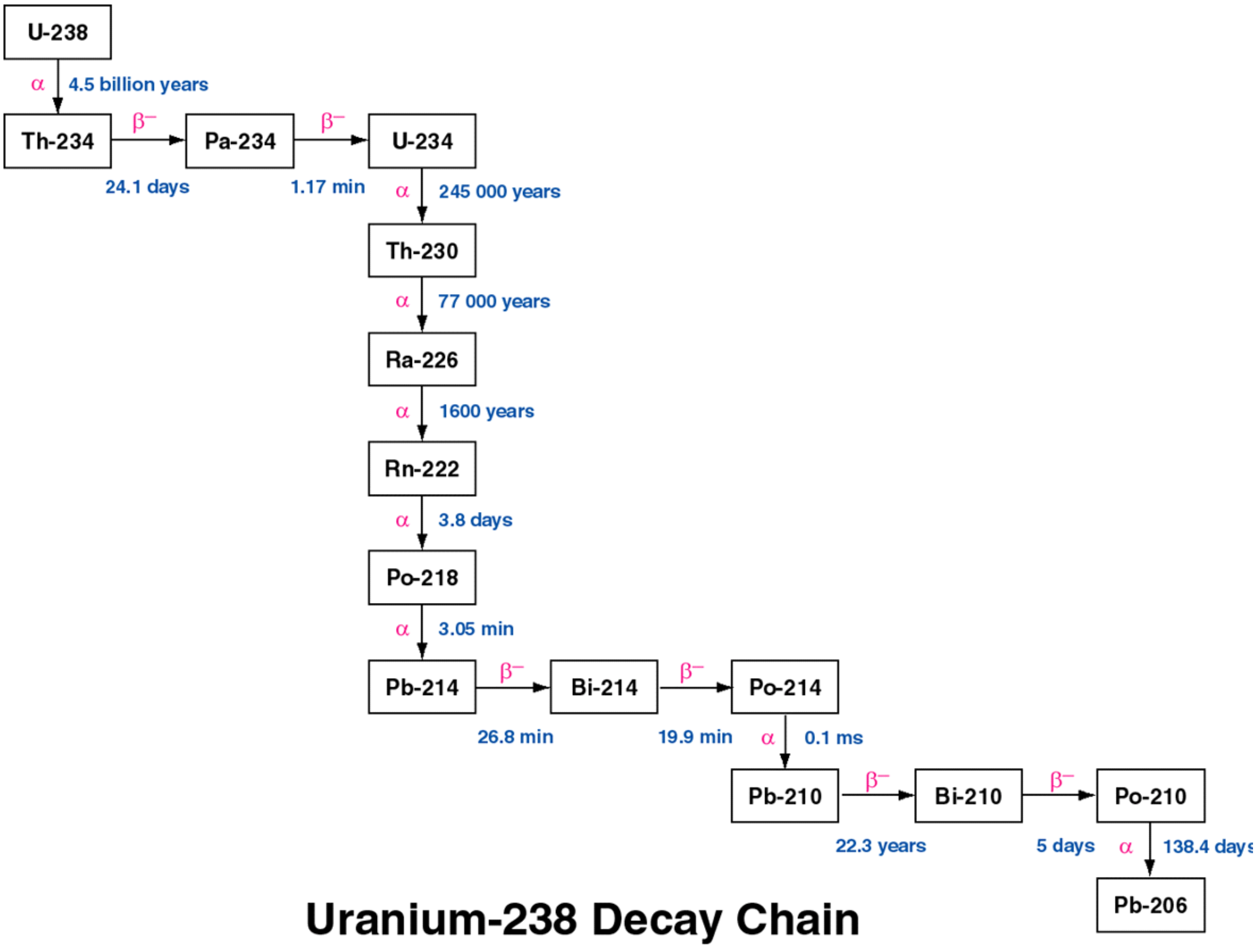

FIGURE 1

[2] www.greenhighways.org - A.L. Torrenueva : Radioactivity in Coal Ash and Ash Products www.greenhighways.org.

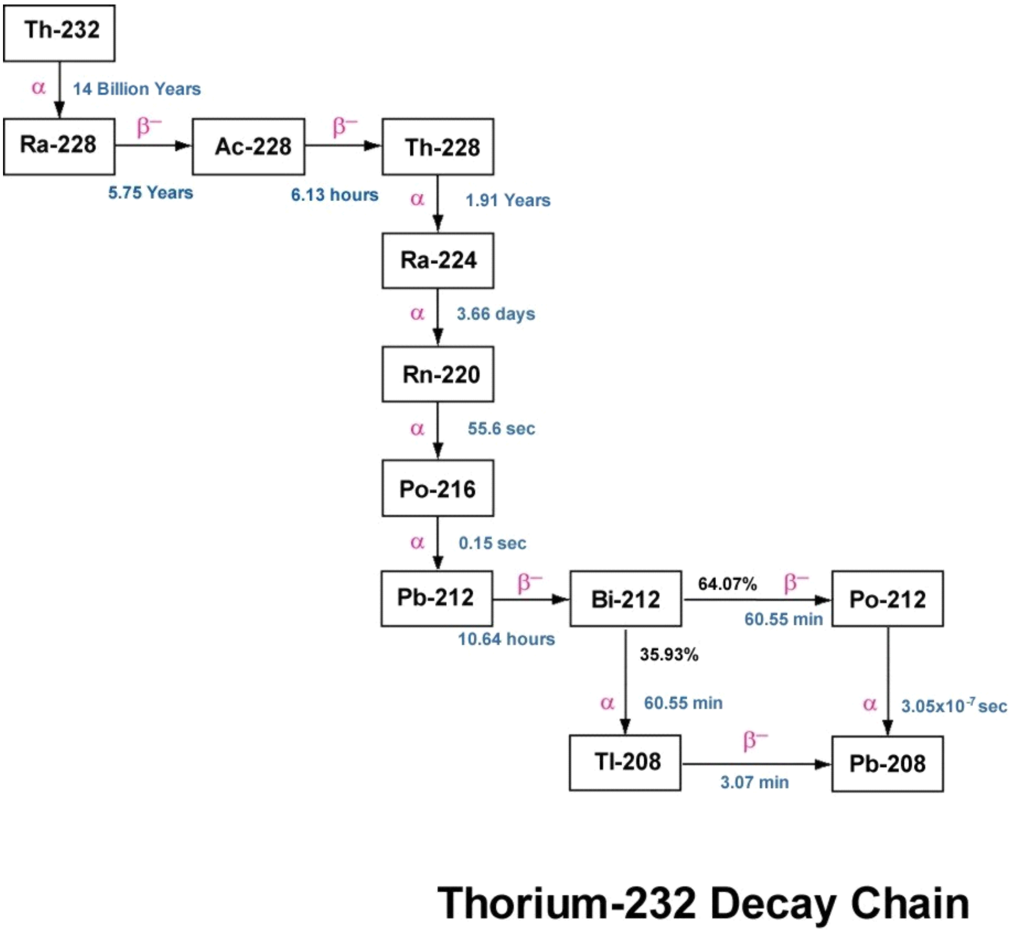

FIGURE 2

Coal contains trace amounts of ^{238}U, ^{235}U and ^{232}Th series radionuclides and ^{40}K. These radionuclides are associated with minerals in the coal, such as sulphides, or occur in the minerals making up the coal formation. Radionuclide concentrations in coal depend on the type of coal and the location of the mine, and are generally lower than those in soils. Most radionuclides in the original coal remain with the ash, with an enhancement factor of approximately 3-20[3]. The various radionuclides partition between the different forms of ash, with the more volatile radionuclides (^{210}Po and ^{210}Pb) accumulating in the fly ash and stack emissions, and the more refractory elements (U and Th) in the bottom ash and slag[3]. Radioactivity released to the atmosphere during combustion consists primarily of gaseous ^{222}Rn.

[3] Safety Guide *Management of Naturally Occurring Radioactive Material (NORM)*, Radiation Protection Series No. 15, ARPANSA, August 2008.

Gamma Spectrometry

The activities of radionuclides in the ^{238}U and ^{232}Th decay chains are determined by gamma spectrometry. A chain is said to be in secular equilibrium if the measured activity concentrations (Bq/kg of solid) of the decay chain radionuclides are statistically the same (± 10%). This is generally the case in older, primary geological deposits. During chemical and thermal processing, however, the radionuclides behave according to their physical and chemical characteristics and hence disequilibrium often results. When this occurs, ^{238}U and ^{232}Th activities must be determined using other techniques (as discussed below).

Not all radionuclides in the respective decay chains emit gamma radiation. The activity of ^{238}U and its progeny (see **Figure 1**) are determined by measuring the gamma-emitting radionuclides ^{234}Th, ^{234m}Pa, ^{230}Th, ^{214}Pb, ^{214}Bi and ^{210}Pb. If the measured activities of the progeny are the same (i.e. secular equilibrium), the activity of ^{238}U can then be inferred from the measured activity of its immediate daughter, ^{234}Th. If the decay chain is not in equilibrium, the sample must be left for 4 months to allow ingrowth[4] of ^{234}Th from its parent ^{238}U, or the ^{238}U concentration determined independently. Polonium-210 is an alpha emitter and is measured using alpha spectrometry (see below).

In a similar manner, ^{232}Th and its progeny (see **Figure 2**) are determined by measuring the gamma-emitting radionuclides ^{228}Ac, ^{228}Th, ^{224}Ra, ^{212}Pb, ^{212}Bi and ^{208}Tl. If the decay chain is in secular equilibrium, the activity of ^{232}Th is inferred from the measured activity of ^{228}Ac, a short-lived daughter[5] (6.13 h) of ^{228}Ra.

DNA and NAA

The most accurate methods for measuring ^{238}U and ^{232}Th are DNA and NAA, respectively. Both are selective, sensitive and rapid nuclear techniques used to determine these elements at ppm levels or lower.

Radiochemistry

In this work, ^{210}Po was determined using alpha spectrometry. Polonium was extracted from 6 M hydrochloric acid using diethyl ammonium diethyl dithiocarbamate (DDTC) in chloroform. After autodeposition onto a silver disc, ^{210}Po was alpha counted.

Lead-210 was determined using beta spectrometry. Lead was extracted from 1.5 M hydrochloric acid using DDTC in chloroform. After precipitation as the chromate, the solid was left for 3 weeks to allow ingrowth of its daughter, ^{210}Bi, which was then counted using beta counting.

Sample size was restricted to 0.1 g for microwave digestion. Because of this, most samples were below the detection limit for ^{210}Pb using beta spectrometry and therefore, only the gamma results for ^{210}Pb have been reported. These values are more reliable because of the larger sample size taken (20-30 g).

5. Discussion of Results

CCPs, more commonly known as fly ash and furnace bottom ash, are widely used in cement and pre-mixed concrete, in clay bricks and blocks, in road making as filler in asphalt and in general civil

[4] The half-life of ^{234}Th is 24.10 days. ^{234}Th will be in equilibrium with its parent, ^{238}U, after 5 half-lives or 120 days.
[5] The half-life of ^{228}Ac is 6.13 hours. ^{228}Ac will be in equilibrium with its parent, ^{228}Ra, after 5 half-lives or 31 hours.

and construction applications across Australia. Based on ADAA reported data[6], some 4.308 Mt or 30 percent of CCPs produced in 2007 were used in various value added products and/or applications.

Radioactivity concentrations in CCPs are generally comparable to those materials used in conventional concrete [cement, sand, basaltic aggregates and additives] and other building materials, such as brick.

The use of fly ash, especially in building materials, may increase the potential risk of exposure to radiation, primarily through the inhalation of gaseous radon (^{222}Rn), a radioactive daughter of ^{226}Ra. However, since the fly ash is mixed with other materials in these products, the low (< 1 Bq/g; see **Section 5.1**) concentration of radioactivity is significantly diluted.

5.1 Radionuclide Concentrations in CCPs

The results of this study have shown that none of the fly ash samples would be considered radioactive from a regulatory perspective, since no single radionuclide is above the limit[7] of 1 Bq/g or 1000 Bq/kg for radionuclides of natural origin or above 10,000 Bq/kg for ^{40}K.

As expected, the fine/medium fly ashes contain higher concentrations of the volatile radionuclides, ^{210}Po and ^{210}Pb, compared to bottom ash. At the time of combustion, ^{210}Po concentrations on the finer particles will be significantly higher than those measured in this study. For example, the concentration of sample 402 (medium FA) was 460 Bq/kg on the counting date of 9 January 2009. This is equivalent to a concentration of 575 Bq/g on the sampling date of 7 November 2008. If this material was produced on, say, 1 January 2008, the concentration would be 2170 Bq/kg. Based on this assumption, the material would be considered radioactive from a regulatory perspective at the time of combustion. It is important, therefore, that factors like this are taken into consideration.

Unsupported[8] ^{210}Po will decay and the concentration of ^{210}Po in any end-use product will ultimately be determined by the parent ^{210}Pb concentration. Polonium-210 has a half-life of 138 days and will be in equilibrium with its parent, ^{210}Pb, after approximately 5 half-lives *i.e*. ~2 years.

5.2 Activity Concentration Indices

For end-use products, the radium equivalent activity is an index commonly used to compare the activity concentrations of building materials that contain varying amounts of Ra, Th and K. It is defined[9] as the weighted sum of the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K and is based on the estimation that 370 Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th and 4810 Bq/kg of ^{40}K produce the same gamma dose rate. A radium equivalent of 370 Bq/kg in building materials can produce an exposure of about 1.5 mSv/y to the inhabitants[9].

The radium equivalent, Ra_{eq}, is defined as:

$$Ra_{eq} = A_{Ra} + (A_{Th} \times 1.43) + (A_K \times 0.077)$$

where A_{Ra}, A_{Th} and A_K are the activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

[6] www.adaa.asn.au/welcome.html (Accessed Feb 2009).
[7] IAEA Safety Guide No. RS-G-1.7, *Table 1, Application of the Concepts of Exclusion, Exemption and Clearance*, 2004.
[8] Unsupported means that the parent radionuclide, in this case ^{210}Pb, has a lower concentration.
[9] UNSCEAR, *Ionising Radiation: Sources and Biological Effects*, United Nations Scientific Committee on the Effects of Atomic Radiation, 1982.

The Ra_{eq} values for the CCPs in this study are given in **Table 1**. The average values (Bq/kg) were:

- All samples - 224
- fine fly ash - 248
- medium fly ash - 263
- ROS bottom ash - 159

Based on these results, if the CCPs in this study were blended for use in, for example, concrete, at a ratio of 5% by weight[10], the contribution of the ash to the total gamma ray dose from the concrete would be well below 1.5 mSv/y.

In their paper on the natural radioactivity and gamma dose from Sri Lankan clay bricks, Hewamanna *et a*l.[11] have extended this formula to use as a criterion to limit the annual radiation dose from building materials and also to calculate dose rates in air from different combinations of these radionuclides in the clay bricks.

The European Commission (guidance report RP 112[12]) describes the radiation protection principles that should be used for the purpose of limiting exposure due to the radioactivity in building materials[13]. They recommend the use of an activity concentration index, I, defined as:

$$I = C_{Ra\text{-}226}/300\ \text{Bq/kg} + C_{Th\text{-}232}/200\ \text{Bq/kg} + C_{K\text{-}40}/3000\ \text{Bq/kg}$$

where $C_{Ra\text{-}226}$, $C_{Th\text{-}232}$ and $C_{K\text{-}40}$ are the activity concentrations, in Bq/kg, of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in the building material. For practical purposes, RP 112 states that the measurement of ^{232}Th can be replaced by that of ^{228}Ra, which is more readily measured by gamma spectrometry.

The activity concentration index must not exceed the following values, depending on the dose criterion and the way the amount of material is used in the building. It should only be used as a screening tool and any decision on restriction of material for use should be based on a separate dose assessment.

Dose criterion:	0.3 mSv/y	1 mSv/y
Materials used in bulk amounts, e.g. concrete	$I \leq 0.5$	$I \leq 1$
Superficial and other materials with restricted use: tiles, boards etc	$I \leq 2$	$I \leq 6$

The average activity concentration index values for the CCPs in this study were:

- All samples - 0.78
- fine fly ash - 0.80
- medium fly ash - 0.92
- ROS bottom ash - 0.56

[10] Beretka, J. and Mathew, P.J., *Natural radioactivity of Australian fly ashes*, 2nd International Conference on Ash Technology and Marketing, London, September 16-21, 1984.
[11] Hewamanna, R., Sumithrarachchi, C.S., Mahawatte, P., Nanayakkara, H.L.C. and Ratnayake, H.C. - *Natural radioactivity and gamma dose from Sri Lankan clay bricks used in building and construction*, Applied Radiation and Isotopes, 54, 2001, 365-369.
[12] European Commission, RP 112, *Radiological protection principles concerning the natural radioactivity of building materials*, 1999.
[13] European Commission, European Commission Services considerations with regard to natural radiation sources in BSS Directive, January 2009.

Again, if this material was blended for use using the above concrete scenario, the dose rates would be well below the stated restricted use values.

5.3 Comparison with Previous Studies

The Australian Radiation Laboratory (now ARPANSA) carried out studies on coal and fly ash from power stations across Australia in the early 1980's. This data has been summarised, together with cited references, in **Appendix C**. The average R_{eq} value for the data obtained in 1981 for NSW power station ash samples, substituting ^{228}Ra values for ^{232}Th values, was 373 Bq/kg.

In their study, Bertetka and Mathew[10] reported radioactivities and radium equivalent values for fly ashes from various power stations across Australia. The types of ash were not given. The data is summarised in **Table 2**.

TABLE 2
Radionuclide Concentrations and Radium Equivalent for Fly Ashes from various Power Stations

Power Station	Concentration (Bq/kg)			Ra_{eq} (Bq/kg)
	^{226}Ra	^{232}Th	^{40}K	
A	110	120	450	320
B	90	130	190	300
C	110	150	570	370
D	30	70	100	140
E	60	90	320	210
F	140	200	210	450
G	7	-	20	10
H	40	7	-	60
I	160	280	70	570
J	150	290	60	570

The results from the current study compare well, and are consistent with, this earlier data.

5.4 Comparison with Background Concentrations in Soil

Uranium is found in all soils and the concentration varies according to the type of rock the soil is derived from. **Table 3** summarises a selection of average natural radionuclide concentrations in soils found in the literature. The average radionuclide values for the fine (FA) and medium (FA) fly ashes and the ROS (BA) from this study have been included for comparison.

The radionuclide concentrations for the fine and medium fly ashes are either within or not significantly higher than the specified ranges for background soil concentrations. The ROS bottom ashes are all within these stated ranges.

5.5 Elemental Makeup of Ash Samples

The XRF results in **Appendix D** were used to determine the elemental makeup of the ash samples. This data is summarised in **Appendix E**. The majority of the fly ashes are produced from the combustion of black coal and contain aluminium silicate with varying amounts of iron and titanium oxides. South Australian ash also contains elevated concentrations of Na, Mg and Ca. The samples from central Queensland and West Australian coast ashes were similar and contain higher concentrations of iron oxide. Ash samples from Stanwell (Rockhampton) had elevated concentrations of iron and calcium oxides. In contrast, brown coal from the Gippsland region in Victoria was sulphidic and varied considerably with respect to the other elements given that the coal sources are in close proximity.

In general, higher Th and U assays were obtained in fly ashes from South Australia and the West Australian coast. Fly ash samples from the Gippsland region contain significantly lower concentrations of these elements.

TABLE 3
Average Radionuclide Concentrations in Soils and CCPs

Reference	Concentration in soil (Bq/kg)			
	^{238}U	^{226}Ra	^{232}Th	^{40}K
Background Concentrations (general)				
Karunakara et al.[14]	-	31 (15 – 61)	26 (11 – 42)	160 (78 – 255)
UNSCEAR[15]	35 (16 – 110)	35 (17 – 60)	30 (11 – 64)	400 (140 – 850)
IAEA[16]	25 (10 – 50)	25 (10 – 50)	25 (7 – 50)	370 (100- 700)
NRC[17]	22	-	-	-
Eisenbud and Gesell[18]	22	-	37	400
Myrick et al.[19] (world)	24 (12 – 49)	29 (18 – 73)	24 (8 – 48)	-
Myrick et al.[20] (USA)	37 (4 – 141)	37 (4 – 141)	36 (4 – 126)	-
Background Concentrations (around U production sites)				
Ramli et al.[21]	59 – 485	-	60 - 1204	-
Tome et al.[22]	93 – 328	191 – 492	14 – 48	-
Read and Pickering[23]	2.3	< 17	-	-
Ibraham and Whicker[24]	50	-	44	-
Average Radionuclide Concentrations for CCPs (in this study)				
Fine (FA)	110	88	100	210
Medium (FA)	93	87	110	250
ROS (BA)	52	58	62	170

[14] Karunakara, N., Somashekarappa, H.M., Avadhani, D.N., Mahesh, H.M., Narayana, Y. and Siddappa, K., Radium-226, ^{232}Th and ^{40}K distribution in the environment of Kaiga of south-west coast of India. *Health Physics*, 80, 470-476, 2001.

[15] UNSCEAR, *Ionising Radiation: Sources and Biological Effects*, United Nations Scientific Committee on the Effects of Atomic Radiation, 2000.

[16] IAEA, *Generic Procedures for Assessment and Response during a Radiological Emergency*, IAEA TECDOC Series No. 1162, 2000.

[17] NRC, *Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials*, 1999.

[18] Eisenbud, M. and Gesell, T., *Environmental Radioactivity from Natural, Industrial and Military Sources*, 4th Edition, 1997.

[19] Myrick, T.E., Bervan, B.A. and Haywood, F.F., *State Background Radiation Levels: Results of Measurements Taken During 1975-1979*. ORNL/TM-7343. Oak Ridge National Laboratory, 1981.

[20] Myrick, T.E., Bervan, B.A. and Haywood, F.F., *State Background Radiation Levels: Results of Measurements Taken During 1975-1979*. ORNL/TM-7343. Oak Ridge National Laboratory, 1981.

[21] Ramli, A.T., Hussein, A.W. and Wood, A.K., Environmental ^{238}U and ^{232}Th concentration measurements in an area of high level natural background radiation at Palong, Johor, Malaysia. *Journal of Environmental Radioactivity*, 80, 287-304, 2005.

[22] Tome, F.V., Rodriguez, P.B. and Lozano, J.C., Distribution and mobilisation of U, Th and ^{226}Ra in the plant-soil compartments of a mineralised uranium area in south-west Spain, *.Journal of Envoronmental Radioactivity*, 59, 41-60, 2002.

[23] Read, J. and Pickering, R., *Ecological and toxicological effects of exposure to an acidic, radioactive tailings storage. Environmental Monitoring and Assessment*, 54, 69-85.

[24] Ibraham, S.A., and Whicker, F.W., Comparative uptake of U and Th by native plants at a U production site. *Health Physics*, 54, 413-419, 1988.

TABLE 1
Gamma Spectrometry, DNA, NAA and Radiochemistry Results

Sample		DNA		Gamma			Radiochemistry		NAA		Gamma			Radium
No.	Type	^{238}U		^{230}Th	^{226}Ra	^{210}Pb	^{210}Po*	Count Date	^{232}Th		^{228}Ra	^{228}Th	^{40}K	Equivalent
		ppm	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg		ppm	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg
201	Fine (FA)	9.9	120	< 130	68	89	120	05-Jan-09	19	77	82	88	56	182
202	Medium (FA)	5.3	66	< 100	34	37	95	05-Jan-09	18	73	45	42	< 31	141
211	ROS (BA)	3.7	46	< 120	57	< 20	45	05-Jan-09	13	53	62	56	96	140
301	Fine (FA)	4.6	57	< 130	58	63	69	05-Jan-09	14	57	72	67	150	151
302	Medium (FA)	3.4	42	< 90	62	66	190	05-Jan-09	17	69	64	62	190	175
311	ROS (BA)	3.0	37	< 90	51	20	< 10	05-Jan-09	13	53	52	60	190	141
401	Fine (FA)	18	220	< 230	120	250	270	09-Jan-09	30	120	140	130	730	348
402	Medium (FA)	8.8	110	< 220	110	150	460	09-Jan-09	25	100	120	110	680	305
411	ROS (BA)	7.3	91	< 130	93	24	< 10	09-Jan-09	24	97	86	93	560	275
601	Fine (FA)	12	150	< 130	140	170	200	09-Jan-09	52	210	220	210	330	466
602	Medium (FA)	10	120	< 140	130	110	100	15-Jan-09	50	200	210	210	330	441
611	ROS (BA)	10	120	< 150	130	64	23	15-Jan-09	49	200	200	200	260	436
701	Fine (FA)	8.8	110	< 140	120	120	120	15-Jan-09	28	110	130	120	350	304
702	Medium (FA)	9.5	120	< 110	110	100	170	15-Jan-09	29	120	110	130	450	316
711	ROS (BA)	6.9	86	< 70	86	24	< 10	15-Jan-09	22	89	< 70	88	400	244
901	Fine (FA)	4.4	55	< 140	57	56	65	29-Jan-09	19	77	67	63	120	176
902	Medium (FA)	4.6	57	< 180	69	70	160	29-Jan-09	17	69	83	74	160	180
911	ROS (BA)	4.9	61	< 150	65	28	26	29-Jan-09	19	77	71	76	130	185

* ^{210}Po activity on count date.

TABLE 1 (continued)
Gamma Spectrometry, DNA, NAA and Radiochemistry Results

Sample		DNA		Gamma			Radiochemistry		NAA		Gamma			Radium
No.	Type	^{238}U		^{230}Th	^{226}Ra	^{210}Pb	^{210}Po*	Count Date	^{232}Th		^{228}Ra	^{228}Th	^{40}K	Equivalent
		ppm	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg		ppm	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg
1001	Fine (FA)	< 0.4	< 5.0	< 140	17	< 22	< 10	29-Jan-09	1.0	4.0	< 9.3	5.7	230	40
1002	Medium (FA)	< 0.4	< 5.0	< 90	6.3	< 12	< 10	29-Jan-09	0.8	3	< 6.7	3.7	130	21
1011	ROS (BA)	< 0.4	< 5.0	< 140	< 3.6	< 16	< 10	02-Mar-09	< 0.4	< 5.0	< 7.3	< 2.3	< 43	14
1101	Fine (FA)	4.7	58	< 120	53	100	86	29-Jan-09	10	40	42	39	98	118
1102	Medium (FA)	4.0	50	< 230	60	81	85	10-Feb-09	10	40	46	41	180	131
1111	ROS (BA)	4.2	52	< 200	66	79	80	10-Feb-09	6.0	20	45	37	130	105
1302	Medium (FA)	3.8	47	< 90	53	52	51	10-Feb-09	15	61	56	57	320	165
1311	ROS (BA)	2.4	30	< 80	60	23	< 10	10-Feb-09	10	40	57	58	340	143
1401	Fine (FA)	5.2	64	< 130	52	82	69	10-Feb-09	12	48	65	56	140	131
1402	Medium (FA)	2.5	31	< 140	39	28	< 10	10-Feb-09	10	40	59	46	160	109
1411	ROS (BA)	2.7	33	< 100	46	17	< 10	16-Feb-09	15	61	57	53	150	145
1501	Fine (FA)	3.8	47	< 100	40	72	35	16-Feb-09	12	48	45	41	59	113
1502	Medium (FA)	2.9	36	< 90	42	61	< 10	16-Feb-09	12	48	47	48	63	115
1511	ROS (BA)	2.1	26	< 120	39	< 12	13	16-Feb-09	11	44	45	45	94	109
1601	Fine (FA)	1.2	15	< 130	14	< 17	31	16-Feb-09	4.0	20	19	12	75	48
1611	ROS (BA)	< 0.4	< 5.0	< 100	9.4	< 12	< 10	16-Feb-09	2.0	8.0	9.2	8.2	< 25	23
1801	Fine (FA)	9.2	110	< 130	78	120	110	20-Feb-09	17	69	70	62	240	195
1802	Medium (FA)	7.2	89	< 160	86	99	68	20-Feb-09	17	69	73	68	230	202
1811	ROS (BA)	6.0	74	< 110	68	< 12	< 10	20-Feb-09	17	69	62	59	200	182

* ^{210}Po activity on count date.

TABLE 1 (continued)
Gamma Spectrometry, DNA, NAA and Radiochemistry Results

Sample		DNA		Gamma			Radiochemistry		NAA		Gamma			Radium
No.	Type	^{238}U		^{230}Th	^{226}Ra	^{210}Pb	^{210}Po*	Count Date	^{232}Th		^{228}Ra	^{228}Th	^{40}K	Equivalent
		ppm	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg		ppm	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg
1911	ROS (BA)	5.0	62	< 100	66	65	60	20-Feb-09	19	77	89	77	170	189
2001	Fine (FA)	9.2	110	< 90	100	120	95	20-Feb-09	22	89	110	100	540	269
2002	Medium (FA)	8.2	100	<120	100	120	44	20-Feb-09	24	97	110	100	500	277
2201	Fine (FA)	14	170	< 190	130	150	140	24-Feb-09	46	190	210	220	330	427
2202	Medium (FA)	12	150	< 250	140	130	97	24-Feb-09	47	190	210	200	340	438
2301	Fine (FA)	12	150	< 230	120	100	110	24-Feb-09	50	200	180	170	230	424
2302	Medium (FA)	11	140	< 190	140	130	100	24-Feb-09	48	190	200	210	280	433
2401	Fine (FA)	12	150	< 160	150	120	130	24-Feb-09	44	180	200	200	160	420
2402	Medium (FA)	18	220	< 200	180	220	180	24-Feb-09	55	220	220	200	130	505
2501	Fine (FA)	17	210	< 160	210	250	230	26-Feb-09	49	200	260	240	170	509
2502	Medium (FA)	16	200	< 290	200	210	200	26-Feb-09	53	210	280	250	140	511
2511	ROS (BA)	5.0	62	< 120	63	24	< 10	26-Feb-09	23	93	82	86	44	199
2901	Fine (FA)	5.2	64	< 130	64	57	36	26-Feb-09	20	81	76	79	130	190
2911	ROS (BA)	2.9	36	< 150	38	< 18	< 10	26-Feb-09	8.0	30	44	40	130	91
3001	Fine (FA)	13	160	< 80	100	190	190	26-Feb-09	25	100	160	150	45	246
3011	ROS (BA)	3.9	48	< 60	44	12	< 10	02-Mar-09	10	40	49	50	38	104
3101	Fine (FA)	5.8	72	< 90	71	74	68	02-Mar-09	23	93	94	95	51	208
3111	ROS (BA)	4.7	58	<160	56	< 18	< 10	02-Mar-09	14	57	71	71	< 27	140

* ^{210}Po activity on count date.

APPENDIX A

Samples Received

ADAA Commercial-in-Confidence

ANALYSIS REQUEST AND CHAIN OF CUSTODY

Ash Development Association of Australia, PO Box 1194, Wollongong NSW 2500, Telephone: +61 2 4228 1389, Facsimile: +61 2 4228 1777, Mobile: 0418 885 290, Email: adaa@adaa.asn.au

Company Name: **Master COC**
Project Name: NORMS
Contact Name: Lauren Robertson
Address: PO Box 1194
Wollongong, NSW 2500
Phone: 02 4228 1389
Email: lrobertson@hbmgroup.com.au
Facsimile: 02 4228 1777

Matrix Codes	Preservative Codes	Container Codes
CW – Clean Water	P1 – Chilled 4°C	C1 – 125LPET
WW – Waste Water	P2 – Frozen	C2 – 500mL PET
GW – Ground Water	P3 – Filtered	C3 – 200mL PET
EF – Effluent	P4 – HNO_3 PH<2	C4 – 100mL PET
BS – Biosolid	P5 – H_2SO_4 PH<2	C5 – 1L Glass
SL – Soil	P6 – HCl PH<2	C6 – Amber Glass
SD – Sediment	P7 – Lugol's Iodine	C7 – Sterile
OT - *Other	P8 – *Other	C8 – *Other

ANALYSES REQUIRED

Client Sample ID	Description	Sample Date	Matrix	No. Of Containers	Container Type + Preservative								ANALYSIS REQUIRED	
													NORM's	
201	Fine (FA	7/11/08	OT	1	C2	P8							Yes	
202	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
211	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
301	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
302	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
311	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
401	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
402	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
411	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
601	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
602	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	

Form : Analysis Request and Chain of Custody 1/05/2007
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611	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
701	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
702	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
711	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
901	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
902	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
911	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
1001	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
1002	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
1011	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
1101	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
1102	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
1111	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
1302	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
1311	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
1401	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
1402	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
1411	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
1501	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
1502	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
1511	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
1601	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
1611	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
1801	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
1802	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
1811	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	

1911	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
2001	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
2002	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
2201	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
2202	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
2301	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
2302	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
2401	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
2402	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
2501	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
2502	Medium (FA)	7/11/08	OT	1	C2	P8							Yes	
2511	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
2901	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
2911	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
3001	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
3011	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	
3101	Fine (FA)	7/11/08	OT	1	C2	P8							Yes	
3111	ROS (BA)	7/11/08	OT	1	C2	P8							Yes	

Samples relinquished by:		Date/Time		Samples received by:		Date/Time:	
Samples received by:		Date/Time		Samples received by:		Date/Time:	

COMMENTS: All samples received from members sites across Australia with last 7 days. Combined onto master COC and delivere to ANSTO testing facilities

Please retain sample until: / /

Ash Development Association of Australia (ADAA) PO Box 1194, Wollongong NSW 2500, Telephone: (02) 4228 1389, Facsimile: (02) 42 1777, Mobile: 0418 885 290, Email: adaa@adaa.asn.

ANALYSIS REQUEST AND CHAIN OF CUSTODY

Commercial in Confidence

Please complete the above form with all requested information and forward all labelled samples to "Ash Development Association of Australia (ADAA)" at the following address:

ADAA (Attention Lauren)

Suite 2/Level 1 – 336 Keira Street (P.O Box 1194)

Wollongong, NSW 2500

<u>Instructions for sampling site</u>

Sampling Procedures

Fly ash samples are to be taken in accordance with the requirements of the following Australian Standards:

- AS 1199 – Sampling procedures and tables for inspection by attributes
- AS 1399 – Guide to AS 1199

TABLE 1

SPECIFIED REQUIREMENTS

Grade	Fineness, by mass passing 45 µm sieve, % minimum	Loss on ignition, % maximum	Moisture content % maximum	SO_3 content, % maximum
Fine	75	4.0	1.0	3.0
Medium	65	5.0	1.0	3.0
Coarse	55	6.0	1.0	3.0
Reference test method	AS 3583.1	AS 3583.3	AS 3583.2	AS 3583.8

Furnace bottom ash samples are to be taken in accordance with the requirements of the following Australian Standard:

- AS 1141.3.1 – Methods for Sampling and Testing Aggregates 1996 (Method 3.1 – Sampling Aggregates: Section 6.9 – Sampling from Stockpiles).

An extract from the Standard is shown below:

Generally samples from the surface of the stockpiles are not representative. Approximately 200mm of surface material should be removed and samples taken from the fresh exposed face. Increment sampling should be carried out in various locations and at various heights on the sides of the perimeter of the stockpile. This approach ensures the whole stockpile is being sampled and not one section only. Samples should then be placed in the supplied jars and labelled accordingly.

Samples of approximately 200 – 500g must be placed in unused clean containers and sealed with screw cap or equivalent to withstand transportation to the laboratory. Each container should be clearly labelled with the required information.

Ash Development Association of Australia.

APPENDIX B

Sample Preparation for Gamma, Radiochemistry and XRF

NO#	Client Sample ID	Dried in Oven	Pulverised	Description
1	201			Grey, Sticks together
2	202			grey, sandy
3	211	YES	YES	black, powder
4	301			dark grey, sandy
5	302			dark grey, sandy
6	311	YES	YES	grey, sticks together
7	401			grey, powder
8	402			Grey, Sticks together
9	411	YES (2 nights)	YES	dark grey, sandy
10	601			light grey powder
11	602			light grey powder
12	611	YES (2 nights)	YES	grey powder
13	701			grey powder
14	702			grey powder
15	711	YES	YES	dark grey, sandy
16	901			grey sandy
17	902			grey powder
18	911	YES (2 nights)	YES	grey powder
19	1001			Brown Powder
20	1002			Brown Powder
21	1011	YES	YES	black, powder
22	1101			grey powder
23	1102			grey/brown powder
24	1111			grey/brown powder
25	1302			grey powder
26	1311	YES	YES	black, powder
27	1401			Grey, Sticks together
28	1402			Grey, Sticks together
29	1411	YES (2 nights)	YES	grey, sandy
30	1501			Grey, Sticks together
31	1502			Grey, Sticks together
32	1511	YES (2 nights)	YES	grey sandy
33	1601			Brown Powder
34	1611	YES (2 nights)	YES	dark grey powder
35	1801			grey powder
36	1802			grey powder
37	1811	YES (2 nights)	YES	dark grey sandy
38	1911			grey powder
39	2001			Grey, Sticks together
40	2002			Grey, Sticks together
41	2201			grey powder
42	2202			Grey, Sticks together
43	2301			Grey, Sticks together
44	2302			Grey, Sticks together
45	2401			Brown Powder
46	2402			grey/brown powder
47	2501			grey/brown powder
48	2502			grey/brown powder
49	2511	YES (2 nights)	YES	dark grey powder
50	2901			light brown powder
51	2911	YES (2 nights)	YES	black, powder
52	3001			light brown/grey sticks together
53	3011	YES (2 nights)	YES	grey sandy
54	3101			light brown/grey sticks together
55	3111	YES (2 nights)	YES	grey sandy

APPENDIX C

Coal and Fly Ash Data

Australian Radiation Laboratory Annual Review of Research Projects 1980, TR41, Part 2 (pp. 55-115), D.W. Kearn (Ed.), Nov. 1981, p. 87-89							
Port Augusta Power Station, South Australia							
	Bq/kg	^{238}U	^{226}Ra	^{210}Pb	^{228}Th	^{228}Ra	^{40}K
	coal	60	41	60	85	87	-
	FA 1	-	150	330	310	290	-
	FA 2	-	160	290	360	340	-
	BA	150	110	80	210	210	-
Western Australia Power Stations							
Location	Bq/kg	^{238}U	^{226}Ra	^{210}Pb	^{228}Th	^{228}Ra	^{40}K
Bunbury	coal	10	12	20	30	32	-
	FA	270	190	430	350	320	-
	BA	50	68	40	190	160	-
Kwinana	coal	30	7	30	15	21	-
	FA	90	125	96	283	268	-
	BA	82	75	30	170	162	-
Queensland Power Stations							
Location	Bq/kg	^{238}U	^{226}Ra	^{210}Pb	^{228}Th	^{228}Ra	^{40}K
Gladstone	coal	14	9	60	18	18	-
	FA	83	76	83	118	138	-
Callide	coal	24	14	38	33	33	-
	FA	92	43	38	81	77	-
Collinsville	coal	27	19	46	21	44	-
	FA	91	77	58	148	151	-
Swanbank	coal	20	13	21	24	25	-
	FA	90	77	60	148	151	-
Australian Radiation Laboratory Annual Review of Research Projects 1981, TR50, Part 3 (pp. 95-150), D.W. Kearn (Ed.), Jan. 1983, p. 142-143							
New South Wales Power Stations Ash Samples							
Location	Bq/kg	^{238}U	^{226}Ra	^{210}Pb	^{228}Th	^{228}Ra	^{40}K
Liddell		94	133	191	210	152	550
Munmorah		101	172	143	261	182	1400
Wangi		140	122	111	120	118	800
Wallerwang	Precip. ash	118	105	132	214	173	810
	BA	83	88	4	98	97	510
Vales Point	Precip. ash	154	142	150	133	136	530
	BA	110	88	6	98	99	530

APPENDIX D

XRF Results

REPORT NUMBER: 082765
Report Date: 17th November 2008

Sample description	**Sum**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**V**	**Cr**
--------------------	%	%	%	%	%	%	%	%	%	%	%	%	%
201	95.7	<0.01	0.288	9.84	33.8	<0.01	0.088	<0.01	0.130	0.232	0.976	0.024	<0.01
202	96.0	<0.01	0.295	10.9	33.1	<0.01	0.079	<0.01	0.126	0.223	0.884	0.022	<0.01
211	76.9	0.112	0.365	10.7	24.1	<0.01	0.102	<0.01	0.292	0.726	0.651	0.010	0.007
301	98.1	0.396	0.815	14.9	27.8	<0.01	0.039	<0.01	0.573	2.28	0.774	0.012	<0.01
302	98.1	0.325	0.802	14.7	27.3	0.010	0.039	<0.01	0.540	2.42	0.827	0.009	<0.01
311	95.0	0.43	0.801	13.6	27.5	0.007	0.026	0.028	0.565	2.07	0.735	0.009	<0.01
401	94.2	<0.01	0.159	13.6	28.0	0.056	0.485	<0.01	2.52	0.318	0.751	0.017	0.013
402	92.4	0.051	0.148	12.7	29.0	0.020	0.080	<0.01	2.35	0.293	0.664	0.012	<0.01
411	91.7	<0.01	0.122	11.4	30.1	<0.01	0.043	<0.01	1.84	0.304	0.602	0.006	0.010
601	98.2	2.08	1.39	16.3	23.3	0.339	0.107	<0.01	0.970	3.4	1.28	0.014	0.018
602	97.6	1.49	1.25	14.8	24.8	0.276	0.041	<0.01	0.868	3.26	1.41	0.014	0.012
611	98.0	2.05	1.41	13.2	24.8	0.240	0.094	1.22	0.658	3.21	1.34	0.015	0.032
701	96.1	0.196	0.282	11.6	30.4	0.075	0.052	<0.01	1.07	1.4	0.587	0.007	<0.01
702	97.3	0.334	0.368	11.9	30.3	0.087	0.063	<0.01	1.40	1.58	0.567	0.009	0.012
711	95.3	0.184	0.524	8.86	28.2	0.042	0.046	<0.01	1.29	2.42	0.444	<0.01	0.015
901	98.6	0.11	0.486	17.1	27.0	<0.01	0.046	<0.01	0.447	1.44	0.975	0.013	<0.01
902	97.7	0.079	0.358	17.2	25.4	<0.01	0.243	<0.01	0.498	1.97	1.18	0.006	<0.01
911	98.9	0.901	0.378	17.0	25.4	0.010	0.037	0.146	0.469	2.38	1.13	0.013	<0.01
1001	90.8	6.75	9.81	0.489	<0.01	<0.01	8.890	1.75	0.680	17.89	0.109	<0.01	<0.01
1002	82.7	3.88	11.1	0.368	0.23	<0.01	4.350	1.95	0.346	20.15	0.101	<0.01	0.010
1011	10.2	0.588	0.879	<0.01	0.56	<0.01	0.366	<0.01	<0.01	1.93	0.027	<0.01	0.014
1101	93.0	5.2	2.95	10.1	17.8	0.028	4.890	0.166	0.468	1.42	1.13	0.016	0.037
1102	92.0	5.17	3.09	10.1	15.6	0.024	5.460	0.046	0.434	1.5	0.984	0.013	0.021
1111	96.0	8.38	3.79	8.69	18.2	0.013	4.800	1.84	0.371	1.47	0.773	0.008	0.017
1302	95.0	0.047	0.785	10.4	25.2	0.487	0.127	<0.01	0.982	4.79	0.647	0.011	0.010
1311	90.9	0.055	1.38	7.47	19.8	0.332	0.056	<0.01	0.736	5.68	0.638	0.009	0.009
1401	96.8	<0.01	0.128	12.5	31.9	0.010	0.048	<0.01	0.317	0.127	0.985	0.020	0.008
1402	98.7	<0.01	0.181	14.0	31.3	<0.01	0.057	<0.01	0.366	0.152	0.89	0.010	<0.01
1411	97.2	<0.01	0.13	12.9	32.1	<0.01	0.086	<0.01	0.367	0.0827	0.99	0.013	0.010

Sample description	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**Sr**	**Y**	**Zr**	**Nb**	**Mo**
--------------------	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
201	0.0142	0.876	<0.01	0.009	<0.01	<0.01	0.025	0.01	0.074	0.01	0.01
202	0.0136	1.18	<0.01	0.010	<0.01	<0.01	0.024	0.01	0.073	<0.01	<0.01
211	0.0150	0.999	<0.01	<0.01	<0.01	<0.01	0.033	0.01	0.051	0.01	<0.01
301	0.0273	2.01	<0.01	<0.01	<0.01	<0.01	0.039	<0.01	0.052	0.01	0.01
302	0.0253	2.00	<0.01	<0.01	<0.01	<0.01	0.040	<0.01	0.048	0.01	<0.01
311	0.0266	2.22	<0.01	<0.01	<0.01	<0.01	0.038	<0.01	0.047	0.01	<0.01
401	0.0304	1.25	<0.01	<0.01	<0.01	0.02	0.023	0.01	0.073	0.02	0.01
402	0.0175	0.832	<0.01	<0.01	<0.01	<0.01	0.023	0.01	0.068	0.01	0.01
411	0.0307	1.05	<0.01	<0.01	<0.01	<0.01	0.018	<0.01	0.061	<0.01	<0.01
601	0.0428	2.03	<0.01	<0.01	<0.01	<0.01	0.024	0.01	0.067	0.02	<0.01
602	0.0528	2.37	<0.01	<0.01	<0.01	<0.01	0.025	<0.01	0.073	0.02	<0.01
611	0.0946	3.36	<0.01	0.009	0.008	<0.01	0.023	<0.01	0.082	0.01	0.01
701	0.0536	2.48	<0.01	<0.01	<0.01	<0.01	0.039	<0.01	0.055	0.01	0.01
702	0.0491	2.29	<0.01	<0.01	<0.01	<0.01	0.043	<0.01	0.056	0.01	0.01
711	0.2440	7.3	<0.01	<0.01	<0.01	<0.01	0.036	0.01	0.050	0.01	0.02
901	0.0260	1.84	<0.01	<0.01	<0.01	0.01	0.029	0.01	0.057	0.01	<0.01
902	0.0414	2.44	<0.01	<0.01	<0.01	0.009	0.026	0.01	0.089	0.23	<0.01
911	0.0709	2.83	<0.01	<0.01	<0.01	<0.01	0.027	<0.01	0.054	0.01	0.01
1001	0.1600	9.21	<0.01	<0.01	<0.01	0.021	0.220	<0.01	0.012	<0.01	0.01
1002	0.1940	10.4	0.008	0.009	<0.01	0.015	0.256	<0.01	0.012	0.01	0.01
1011	0.0275	2.02	<0.01	<0.01	<0.01	<0.01	0.036	<0.01	<0.01	<0.01	0.01
1101	0.0334	4.75	<0.01	0.020	<0.01	0.013	0.045	<0.01	0.036	0.01	0.01
1102	0.0354	6.16	0.009	0.013	<0.01	0.014	0.046	<0.01	0.032	0.01	0.01
1111	0.0196	3.46	<0.01	0.012	<0.01	0.015	0.040	<0.01	0.108	0.01	<0.01
1301	0.0822	6.29	<0.01	<0.01	<0.01	<0.01	0.051	<0.01	0.033	<0.01	<0.01
1311	0.3890	14.2	0.013	<0.01	<0.01	<0.01	0.046	<0.01	0.027	0.01	0.01
1401	0.0226	1.44	<0.01	<0.01	<0.01	0.03	<0.01	0.01	0.059	<0.01	<0.01
1402	0.0325	1.61	<0.01	<0.01	<0.01	0.01	<0.01	0.01	0.045	<0.01	0.01
1411	0.0221	1.03	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.044	0.01	0.01

REPORT NUMBER: 082765
Report Date: 17th November 2008

Sample description	Sum	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr
--------------------	%	%	%	%	%	%	%	%	%	%	%	%	%
1501	99.0	<0.01	0.059	16.4	30.0	0.042	0.025	<0.01	0.132	0.0564	1.32	0.027	<0.01
1502	97.3	0.05	0.097	16.3	29.2	0.022	0.060	<0.01	0.141	0.0593	1.37	0.027	0.032
1511	97.5	<0.01	0.126	13.8	31.1	<0.01	0.045	<0.01	0.278	0.0915	0.856	0.008	0.033
1601	93.7	3.2	8.89	2.05	0.54	0.012	4.700	0.224	0.221	5.18	0.106	<0.01	0.017
1611	85.7	0.491	11.2	1.80	1.21	0.007	2.050	0.042	<0.01	5.72	0.093	<0.01	0.009
1801	97.8	<0.01	0.333	10.2	32.8	0.067	0.109	<0.01	0.869	0.454	0.54	<0.01	<0.01
1802	99.0	<0.01	0.346	11.4	31.8	0.078	0.068	<0.01	0.734	1.3	0.668	0.010	<0.01
1811	97.6	<0.01	0.525	12.3	27.6	0.060	0.024	<0.01	0.721	1.31	0.772	0.011	0.020
1911	99.4	0.222	0.462	17.4	27.2	<0.01	0.041	<0.01	0.437	1.48	0.98	0.015	<0.01
2001	97.4	0.035	0.141	11.5	32.8	0.019	0.036	<0.01	1.57	0.166	0.582	0.008	0.020
2002	97.4	<0.01	0.125	12.6	32.1	0.011	0.033	<0.01	1.58	0.158	0.602	0.010	0.012
2201	97.4	1.96	1.31	16.3	22.8	0.373	0.099	<0.01	1.01	3.25	1.34	0.014	0.014
2202	98.0	1.74	1.28	15.2	24.1	0.312	0.051	<0.01	0.974	2.85	1.30	0.012	0.019
2301	97.5	1.7	1.29	15.5	23.7	0.310	0.051	<0.01	0.894	3.08	1.41	0.013	0.017
2302	98.0	1.77	1.28	15.6	24.0	0.310	0.050	<0.01	0.937	2.91	1.32	0.015	0.021
2401	97.8	0.03	0.708	11.8	23.6	0.273	0.126	<0.01	0.464	1.06	0.892	0.007	0.017
2402	97.4	0.24	0.998	16.8	20.5	0.509	0.153	<0.01	0.449	1.42	1.06	0.009	0.016
2501	96.4	0.161	0.74	16.3	21.9	0.399	0.180	<0.01	0.428	1.09	1.06	0.012	0.017
2502	95.7	0.286	1.01	16.7	19.8	0.530	0.153	<0.01	0.359	1.39	1.06	0.009	0.021
2511	96.0	0.095	0.297	4.3	33.4	0.095	0.065	0.0141	0.024	0.449	0.475	<0.01	0.016
2901	98.5	0.456	0.928	14.6	23.3	0.315	0.097	<0.01	0.431	2.57	0.941	0.014	0.008
2911	85.1	0.609	0.687	10.9	20.8	0.180	0.062	0.281	0.548	2.16	0.749	0.008	0.028
3001	98.2	<0.01	0.766	18.4	22.5	0.074	0.344	<0.01	0.081	1.31	2.08	0.032	0.018
3011	97.9	<0.01	0.239	14.4	27.1	<0.01	0.014	<0.01	0.045	0.433	1.08	0.006	0.008
3101	98.6	<0.01	0.503	16.9	25.2	0.030	0.014	<0.01	0.098	0.795	1.33	0.014	0.009
3111	97.4	<0.01	0.217	16.4	26.5	<0.01	0.012	<0.01	0.048	0.454	1.48	0.011	0.012

Sample description	Mn	Fe	Co	Ni	Cu	Zn	Sr	Y	Zr	Nb	Mo
--------------------	%	%	%	%	%	%	%	%	%	%	%
1501	<0.01	0.395	<0.01	<0.01	<0.01	0.03	0.017	0.01	0.056	0.01	0.01
1502	<0.01	0.47	<0.01	0.027	0.01	0.02	0.013	0.01	0.053	0.01	<0.01
1511	0.0362	1.62	<0.01	0.020	<0.01	<0.01	<0.01	0.01	0.044	0.01	<0.01
1601	0.4540	33.01	0.021	0.030	<0.01	0.02	0.112	<0.01	<0.01	0.01	0.02
1611	0.5360	31.11	0.018	0.020	<0.01	<0.01	0.144	<0.01	<0.01	<0.01	0.02
1801	0.0455	3.05	<0.01	<0.01	<0.01	0.01	0.023	0.01	0.046	0.01	<0.01
1802	0.0345	2.83	<0.01	<0.01	<0.01	<0.01	0.030	<0.01	0.049	0.01	0.01
1811	0.1180	6.87	0.008	0.023	<0.01	<0.01	0.034	0.01	0.061	0.01	0.01
1911	0.0284	1.77	<0.01	<0.01	<0.01	0.01	0.030	0.01	0.055	0.01	0.01
2001	0.0194	1.11	<0.01	0.015	<0.01	<0.01	0.021	0.01	0.069	0.01	0.01
2002	0.0174	0.989	<0.01	0.011	<0.01	<0.01	0.020	0.01	0.068	0.01	0.01
2201	0.0546	2.42	<0.01	0.008	0.01	0.01	0.020	<0.01	0.060	0.02	0.01
2202	0.0730	3.09	<0.01	<0.01	<0.01	<0.01	0.023	<0.01	0.069	0.01	<0.01
2301	0.0667	2.86	<0.01	<0.01	<0.01	<0.01	0.018	0.01	0.071	0.02	0.01
2302	0.0702	2.81	<0.01	0.010	<0.01	<0.01	0.019	<0.01	0.072	0.01	0.01
2401	0.0809	12.78	0.023	0.027	<0.01	0.03	0.133	0.01	0.056	0.01	0.01
2402	0.0671	8.78	0.021	0.031	<0.01	0.06	0.174	0.02	0.056	0.01	0.01
2501	0.0477	7.58	0.024	0.038	<0.01	0.09	0.133	0.02	0.055	0.01	0.01
2502	0.0510	8.95	0.020	0.031	0.009	0.05	0.165	0.02	0.056	0.01	0.02
2511	<0.01	9.41	0.013	0.012	<0.01	<0.01	0.041	0.01	0.048	0.01	0.01
2901	0.1040	8.04	0.009	0.010	<0.01	<0.01	0.099	0.01	0.045	0.01	0.01
2911	0.0992	8.28	<0.01	0.017	<0.01	<0.01	0.067	<0.01	0.037	<0.01	0.01
3001	0.1050	4.85	0.012	0.019	0.01	0.03	0.029	0.01	0.088	0.01	0.01
3011	0.1250	6.59	0.008	0.008	<0.01	<0.01	<0.01	<0.01	0.046	0.01	<0.01
3101	0.1330	5.6	<0.01	0.011	<0.01	0.01	0.03	<0.01	0.057	0.01	<0.01
3111	0.0811	4.22	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.056	<0.01	0.01

APPENDIX E

Elemental Makeup of Fly Ash Samples

Sample	Wt %									ppm	
	Na2O	MgO	Al2O3	SiO2	SO3	K2O	CaO	TiO2	Fe2O3	U	Th
201	< 0.01	0.48	19	72	0.22	0.16	0.32	1.6	1.3	9.9	19
202	< 0.01	0.49	21	71	0.20	0.15	0.31	1.5	1.7	5.3	18
211	0.15	0.61	20	51	0.25	0.35	1.0	1.1	1.4	3.7	13
301	0.53	1.4	28	60	0.098	0.69	3.2	1.3	2.9	4.6	14
302	0.44	1.3	28	58	0.098	0.65	3.4	1.4	2.9	3.4	17
311	0.58	1.3	26	59	0.065	0.68	2.9	1.2	3.2	3.0	13
401	< 0.01	0.26	26	60	1.2	3.0	0.44	1.3	1.8	18	30
402	0.069	0.25	24	62	0.20	2.8	0.41	1.1	1.2	8.8	25
411	< 0.01	0.20	22	64	0.11	2.2	0.43	1.0	1.5	7.3	24
601	2.8	2.3	31	50	0.27	1.2	4.8	2.1	2.9	12	52
602	2.0	2.1	28	53	0.10	1.0	4.6	2.4	3.4	10	50
611	2.8	2.3	25	53	0.24	0.79	4.5	2.2	4.8	10	49
701	0.26	0.47	22	65	0.13	1.3	2.0	0.98	3.546	8.8	28
702	0.45	0.61	23	65	0.16	1.7	2.2	0.95	3.274	9.5	29
711	0.25	0.87	17	60	0.11	1.6	3.4	0.74	10	6.9	22
901	0.15	0.81	32	58	0.11	0.54	2.0	1.6	2.6	4.4	19
902	0.11	0.59	33	54	0.61	0.60	2.8	2.0	3.5	4.6	17
911	1.2	0.63	32	54	0.093	0.56	3.3	1.9	4.0	4.9	19
1001	9.1	16	0.92	< 0.01	22	0.82	25	0.18	13	< 0.4	1.0
1002	5.2	18	0.70	0.50	11	0.42	28	0.17	15	< 0.4	0.8
1011	0.79	1.5	< 0.01	1.2	0.91	< 0.01	2.7	0.045	2.9	< 0.4	< 0.4
1101	7.0	4.9	19	38	12	0.56	2.0	1.9	6.8	4.7	10
1102	7.0	5.1	19	33	14	0.52	2.1	1.6	8.8	4.0	10
1111	11	6.3	16	39	12	0.45	2.1	1.3	4.9	4.2	6.0
1302	0.063	1.3	20	54	0.32	1.2	6.7	1.1	9.0	3.8	15
1311	0.074	2.3	14	42	0.14	0.89	7.9	1.1	20	2.4	10
1401	< 0.01	0.21	24	68	0.12	0.38	0.18	1.6	2.1	5.2	12
1402	< 0.01	0.30	26	67	0.14	0.44	0.21	1.5	2.3	2.5	10
1411	< 0.01	0.22	24	69	0.21	0.44	0.12	1.7	1.5	2.7	15
1501	< 0.01	0.098	31	64	0.062	0.16	0.079	2.2	0.56	3.8	12
1502	0.067	0.16	31	63	0.15	0.17	0.083	2.3	0.67	2.9	12
1511	< 0.01	0.21	26	66	0.11	0.33	0.13	1.4	2.3	2.1	11
1601	4.3	15	3.9	1.2	12	0.27	7.2	0.18	47	1.2	4.0
1611	0.66	19	3.4	2.6	5.1	< 0.01	8.0	0.16	44	< 0.4	2.0
1801	< 0.01	0.55	19	70	0.27	1.0	0.64	0.90	4.4	9.2	17
1802	< 0.01	0.57	22	68	0.17	0.88	1.8	1.1	4.0	7.2	17
1811	< 0.01	0.87	23	59	0.061	0.87	1.8	1.3	9.8	6.0	17
1911	0.30	0.77	33	58	0.10	0.53	2.1	1.6	2.5	5.0	19
2001	0.047	0.23	22	70	0.090	1.9	0.23	0.97	1.6	9.2	22
2002	< 0.01	0.21	24	69	0.083	1.9	0.22	1.0	1.4	8.2	24
2201	2.6	2.2	31	49	0.25	1.2	4.5	2.2	3.5	14	46
2202	2.3	2.1	29	52	0.13	1.2	4.0	2.2	4.4	12	47
2301	2.3	2.1	29	51	0.13	1.1	4.3	2.4	4.1	12	50
2302	2.4	2.1	29	51	0.12	1.1	4.1	2.2	4.0	11	48
2401	0.040	1.2	22	50	0.31	0.56	1.5	1.5	18	12	44
2402	0.32	1.7	32	44	0.38	0.54	2.0	1.8	13	18	55
2501	0.22	1.2	31	47	0.45	0.52	1.5	1.8	11	17	49
2502	0.39	1.7	31	42	0.38	0.43	1.9	1.8	13	16	53
2511	0.13	0.49	8.1	72	0.16	0.029	0.63	0.79	13	5.0	23
2901	0.61	1.5	28	50	0.24	0.52	3.6	1.6	11	5.2	20
2911	0.82	1.1	21	45	0.16	0.66	3.0	1.2	12	2.9	8.0
3001	< 0.01	1.3	35	48	0.86	0.097	1.8	3.5	6.9	13	25
3011	< 0.01	0.40	27	58	0.034	0.054	0.61	1.8	9.4	3.9	10
3101	< 0.01	0.83	32	54	0.035	0.12	1.1	2.2	8.0	5.8	23
3111	< 0.01	0.36	31	57	0.029	0.058	0.64	2.5	6.0	4.7	14

- aluminium silicate
- aluminium silicate with minor Na,Mg,Ca oxides
- quartz with aluminium/iron oxides
- sulphates
- high C content at start
- aluminium silicate with major Na,Mg,Ca oxides
- aluminium/iron silicate with major Ca oxide
- iron/magnesium sulphate
- aluminium/iron silicate
- quartz with aluminium/iron oxides
- aluminium/iron silicate with titanium oxide