

### **Estimation of Radionuclide Contents**

As shown in Table 1 that the radionuclide contents are various in accordance with its geology of area. Although the sampled values from Hong Kong are most relevant in term of geological aspect, the data may be outdated as the coal import origin have changed from South Africa mainly to Indonesia recently. It is noticed that coal import origin for coal-fire power plant in Philippines is also from China and Indonesia, which is same as Hong Kong, and hence the radionuclide content in PFA is assumed to similar to Tsang Tsui's Ash Lagoon. In addition, the worldwide average value from UNSCEAR as shown in item 8 in Table1 indicate a higher values than the Philippine's sample. The values from UNSCEAR 200Bq/kg for Ra, Th and K are therefore adopted as a conservative approach and more representatives in further estimation.

**Table 1 Radionuclide Contents**

PFA Locations	Acs (Bq/Kg)			Reference	Coal Origin
	C <sub>Ra</sub>	C <sub>Th</sub>	C <sub>K</sub>		
1 Hong Kong	100-180	99-211	98-258	Tso, M-Y W. and Leung, J. K. C. ,1996	China, South Africa <sup>(1)</sup>
2 Philippines	131	140	414	Vangeline K. Parami et al, 2010	China, Indonesia
3 Baoji, China	112.2	147.5	385.6	Lu X. et al. (2006)	Unknown
4 Poland	119.3	91.5	758		Unknown
5 India	151	177.7	840.1		Unknown
6 Shanghai, China	189.8	202.4	278.6		Unknown
7 Beijing, China	160	162	699		Unknown
8 World Average	200	200	200	Table 27 Typical concentrations of radionuclides in raw and produced materials and in wastes of the mineral processing industry, ANNEX B of UNSEAR 2000 Vol 1	Worldwide
9 United Kingdom	180	100	650	United Kingdom Quality Ash Association (UKQAA) website <a href="http://www.ukqaa.org.uk">www.ukqaa.org.uk</a> . See also UKQAA Technical Datasheet 8.5, Radiation and Fly Ash	Unknown
10 Hungary	200-2000	20-300	300-800	Naturally-Occurring Radioactive Materials (NORM) (updated June 2014), <a href="http://www.world-nuclear.org/info/Safety-and-Security/Radiation-and-Health/Naturally-Occurring-Radioactive-Materials-NORM/">http://www.world-nuclear.org/info/Safety-and-Security/Radiation-and-Health/Naturally-Occurring-Radioactive-Materials-NORM/</a>	Unknown
11 USA	100-600	30-300	100-1200		Unknown
12 Germany ash	6-166	3-120	125-742		Unknown

Note (1) : In accordance with Hong Kong Energy Statistics Annual Report, Coal import origin have changed from South Africa mainly to Indonesia. Please refer to Annex A

**Gamma Rate**

The absorbed dose gamma rate at 1m above the ash lagoon is estimated by equation suggested by Tso & Leung, 1995 as shown in below.

$$\dot{D} = (3.01C_{Ra} + 4.19C_{Th} + 0.308C_K)\rho \times 10^{-13} \text{ Gy h}^{-1}$$

(Source: Tso & Leung, 1995)

The density  $\rho$  is assumed to be 2760kg/m<sup>3</sup> in accordance with the CLP PFA testing sample in 2012 (Refer to Annex B). By adopting value of 200Bg/kg for Ra, Th and K as a conservative approach, the estimated absorbed dose gamma rate at 1m above the ash lagoon would be 0.414  $\mu\text{Gy/h}$ .

**Table 2 Absorbed Dose Rate**

	D ( $\mu\text{Gy/h}$ )	Ra <sub>eq</sub>
Hong Kong 1995 min	0.206	249
Hong Kong 1995 Max	0.415	502
Hong Kong 1995	0.311	375
Philippines	0.306	363
Baoji, China	0.297	353
Poland	0.269	309
India	0.402	470
Shanghai, China	0.415	501
Beijing, China	0.380	445
<b>UNSEAR 2000</b>	<b>0.414</b>	<b>501</b>
UK Typical Value 2010	0.320	373

### **Radon Concentration**

The radon concentration exhaled from the dry ash lagoon is estimated by equations as suggested by Tso & Leung, 1995.

The  $^{222}\text{Rn}$  exhalation rate,  $J \text{ Bq m}^{-2} \text{ s}^{-1}$  is given by

$$J = A\rho\eta\sqrt{\frac{\lambda K}{\varepsilon}} \tanh\left(\sqrt{\frac{\lambda\varepsilon}{K}} d\right) \quad (2)$$

where  $A$  = activity concentration of  $^{226}\text{Ra}$  in  $\text{Bq kg}^{-1}$ ,  $\rho$  = density in  $\text{kg m}^{-3}$ ,  $\eta$  = emanating fraction,  $\lambda$  = decay constant of  $^{222}\text{Rn}$  ( $2.10 \times 10^{-6} \text{ s}^{-1}$ ),  $K$  = effective diffusion coefficient of  $^{222}\text{Rn}$  in  $\text{m}^2 \text{ s}^{-1}$ ,  $\varepsilon$  = porosity of material, and  $d$  = half of the thickness of material in m.

(Source: Tso& Leung, 1995)

Moreover, the concentration of  $^{222}\text{Rn}$ ,  $C \text{ Bq m}^{-3}$  inside the model room is given by (when all other  $^{222}\text{Rn}$  sources, except outdoor  $^{222}\text{Rn}$ , are neglected)

$$C = \frac{\left(\frac{JS}{V}\right) + \lambda_v C_o}{\lambda_v + \lambda} \quad (3)$$

where  $S$  = exhalation surface area in  $\text{m}^2$ ,  $V$  = volume of room in  $\text{m}^3$ ,  $\lambda_v$  = ventilation rate in  $\text{s}^{-1}$ , and  $C_o$  = outdoor  $^{222}\text{Rn}$  concentration

(Source: Tso& Leung, 1995)

As suggested by WHO and ICRP, the estimations would be affected by various environmental factors, including depth of PFA, changes in the radionuclide contents in the PFA, changes in the routes available for the passage of radon, changes in the rate of air exchange, variation in the geology of the area, changes in the pressure differential, and changes in meteorological conditions, etc. In this connection, the latest site specific parameters will be adopted in the estimation, whereas the more conservative assumptions would be adopted, if the site specific values are not available.

**Table 3 Potential Variation**

Potential Variation	Value Adoption and Justification
Depth of PFA	20m, conservative assumption, as value deeper than 20 would have no additional effect to the Rn estimation
Changes in the radionuclide contents in the PFA	The worldwide average value of 200Bg/Kg from UNSCEAR 2000 is adopted as a conservative approach and more representatives
Changes in the routes available for the passage of radon	No change, since the radon gas is emitted from an uncovered PFA platform
Changes in the rate of air exchange	As the PFA lagoon located in the open field nearby sea area, the frequency that wind speed below 0.5m/s is considered as very low and hence 0.5m/s is adopted as conservative approach.
Variation in the geology of the area	No change, since the radon gas is emitted from an uncovered PFA platform
Changes in the pressure differential	It is considered in term of wind speed.
Changes in meteorological conditions	It is considered in term of wind speed.

**Table 4 Estimation of Rn Concentration**

Parameter	Abbreviation	Unit	Value	Remark
Activity of $^{226}\text{Ra}$	$A_{\text{Ra}}$	$\text{BqKg}^{-1}$	200	UNSCEAR 2000
Density	$\rho$	$\text{kgm}^{-3}$	2760	Highest value among the testing results from CLP 2012 samples (refer to Annex B)
Emanating Fraction	$\eta$		5.1%	Average value of PFA Samples (Tso & Leung, 1995)
Rn Decay constant	$\lambda$		2.10E-06	
Porosity	$\varepsilon$		0.27	Average value of PFA Samples (Tso & Leung, 1995)
Half of the thickness of the material	d	m	20.00	Most Conservative assumptions as value deeper than 20 would have no effect to the Rn estimation
Effective Diffusion Coefficient	K	$\text{m}^2\text{s}^{-1}$	1.00E-06	Green, 1986
$^{222}\text{Rn}$ Exhalation Rate	J	$\text{Bqm}^{-2}\text{s}^{-1}$	<b>0.0785</b>	Calculated
Wind Speed	$V_w$	$\text{ms}^{-1}$	0.5	As the PFA lagoon located in the open field nearby sea area, the frequency that wind speed below 0.5m/s is considered as very low, and hence 0.5m/s is adopted as conservative approach.
Length of Lagoon	L	m	145	The longest lengths in its north and south sides
Width of Lagoon	W	m	239	The longest lengths in its west and east sides
Height of Vertical Colume	H	m	10	Assume the mixing column to be 10m
Flow Rate	F	$\text{m}^3\text{s}^{-1}$	1195	Calculated
Exhalation Surface	S		34655	Calculated
Ventilation Rate	$\lambda_v$	$\text{s}^{-1}$	0.000478	Calculated
Volume	V		2500000	Calculated
Outdoor Radon Concentration	$C_0$		0	Assumed to be zero
$^{222}\text{Rn}$ Concentration	C	$\text{Bqm}^{-3}$	<b>2.3</b>	Calculated

**3.4(A) 一九九零年按供應地劃分的煤產品進口貨量及按目的地劃分的轉口貨量**  
**Quantity of imports of coal products by supplier and**  
**quantity of re-exports of coal products by destination for 1990**

	蒸餾煤與其他煤產品 Steam coal and other coal	木炭 Wood charcoal	無煙煤 Anthracite	公噸 tonne 焦煤與半焦煤 Coke and semi-coke
<b>A. 進口供應地</b> Imports by supplier				
南非 South Africa, Republic of	3 216 557 (36)	0	0	0
澳洲 Australia	3 002 928 (34)	0	316 (15)	0
中國內地 The mainland of China	1 707 577 (19)	1 244 (7)	420 (20)	19 (1)
印度尼西亞 Indonesia	659 540 (7)	503 (3)	0	0
哥倫比亞 Columbia	233 792 (3)	0	0	0
美國 U.S.A.	108 220 (1)	149 (1)	0	0
新加坡 Singapore, Republic of	0	15 483 (84)	0	0
其他 Others	0	1 068 (6)	1 317 (64)	1 494 (99)
整體進口 Total imports	8 928 614	18 447	2 053	1 513
<b>B. 轉口目的地</b> Re-exports by destination				
中國內地 The mainland of China	0	921 (42)	0	53 (49)
澳門 Macau	0	693 (32)	0	0
台灣 Taiwan	0	307 (14)	0	19 (17)
其他 Others	0	274 (12)	0	37 (34)
整體轉口 Total re-exports	0	2 195	0	109
<b>C. 進口留用</b> Retained imports	8 928 614	16 252	2 053	1 404

註釋： 括號內數字表示佔整體數字的百分比。

Note: Figures in brackets denote percentage shares against the corresponding total.

**3.4(B) 一九九五年按供應地劃分的煤產品進口貨量及按目的地劃分的轉口貨量**  
**Quantity of imports of coal products by supplier and**  
**quantity of re-exports of coal products by destination for 1995**

	蒸餾煤與其他煤產品 Steam coal and other coal	木炭 Wood charcoal	無煙煤 Anthracite	公噸 tonne 焦煤與半焦煤 Coke and semi-coke
<b>A. 進口供應地</b> Imports by supplier				
南非 South Africa, Republic of	2 770 020 (30)	0	0	0
澳洲 Australia	2 567 730 (28)	22 (#)	0	0
印度尼西亞 Indonesia	2 192 384 (24)	1 824 (11)	0	0
中國內地 The mainland of China	1 233 511 (14)	913 (6)	0	1 187 (95)
新加坡 Singapore, Republic of	0	12 874 (81)	0	0
其他 Others	345 498 (4)	264 (2)	0	60 (5)
整體進口 Total imports	9 109 143	15 897	0	1 247
<b>B. 轉口目的地</b> Re-exports by destination				
澳門 Macau	0	1 028 (52)	0	0
中國內地 The mainland of China	111 (74)	317 (16)	0	0
台灣 Taiwan	38 (26)	107 (5)	0	50 (27)
大韓民國 Korea, Republic of	0	0	0	80 (43)
肯尼亞 Kenya	0	0	0	54 (29)
其他 Others	0	525 (27)	0	0
整體轉口 Total re-exports	149	1 977	0	184
<b>C. 進口留用</b> Retained imports	9 108 994	13 920	0	1 063

註釋：括號內數字表示佔整體數字的百分比。

Notes: Figures in brackets denote percentage shares against the corresponding total.

# 少於百分之零點五。

# Less than 0.5%.

**3.4(C) 二零零零年按供應地劃分的煤產品進口貨量及按目的地劃分的轉口貨量**  
**Quantity of imports of coal products by supplier and**  
**quantity of re-exports of coal products by destination for 2000**

	蒸餾煤與其他煤產品 Steam coal and other coal	木炭 Wood charcoal	無煙煤 Anthracite	公噸 tonne 焦煤與半焦煤 Coke and semi-coke
<b>A. 進口供應地</b> Imports by supplier				
印度尼西亞 Indonesia	2 846 309 (47)	1 314 (14)	0	0
中國內地 The mainland of China	2 303 877 (38)	2 536 (28)	610 (46)	33 106 (100)
南非 South Africa	568 930 (9)	0	0	0
澳洲 Australia	276 005 (5)	20 (#)	0	0
俄羅斯聯邦 Russian Federation, The	61 371 (1)		0	0
新加坡 Singapore, Republic of	0	5 075 (55)	0	0
其他 Others	1 915 (#)	252 (3)	717 (54)	0
整體進口 Total imports	6 058 407	9 197	1 327	33 106
<b>B. 轉口目的地</b> Re-exports by destination				
台灣 Taiwan	0	24 (1)	17 (100)	33 106 (100)
中國內地 The mainland of China	590 (98)	2 956 (94)	0	0
沙地阿拉伯 Saudi Arabia	0	144 (5)	0	0
其他 Others	15 (2)	23 (1)	0	0
整體轉口 Total re-exports	605	3 147	17	33 106
<b>C. 進口留用</b> Retained imports	6 057 802	6 050	1 310	0

註釋：括號內數字表示佔整體數字的百分比。

Notes: Figures in brackets denote percentage shares against the corresponding total.

# 少於百分之零點五。

# Less than 0.5%.

**3.4(A) 2003年按供應地劃分的煤產品進口貨量及按目的地劃分的轉口貨量**  
**Quantity of imports of coal products by supplier and**  
**quantity of re-exports of coal products by destination for 2003**

	蒸餾煤與其他煤產品 Steam coal and other coal	木炭 Wood charcoal	無煙煤 Anthracite	焦煤與半焦煤 Coke and semi-coke	公噸 tonne
<b>A. 進口供應地</b> Imports by supplier					
印度尼西亞 Indonesia	7 481 235 (70.0)	1 408 (14.0)	0	0	0
中國內地 The mainland of China	2 374 147 (22.2)	4 523 (45.0)	576 (85.1)	0	0
澳大利亞 Australia	831 793 (7.8)	16 (0.2)	0	0	0
新加坡 Singapore	0	2 693 (26.8)	0	0	0
德國 Germany	524 ##	0	0	0	0
斯里蘭卡 Sri Lanka	598 ##	0	0	0	0
美國 United States of America	2 ##	361 (3.6)	1 (0.1)	0	0
其他 Others	571 ##	1 048 (10.4)	100 (14.8)	0	0
整體進口 Total imports	10 688 870	10 049	677	0	0
<b>B. 轉口目的地</b> Re-exports by destination					
中國內地 The mainland of China	12 981 (99.9)	1 077 (62.0)	0	0	0
美國 United States of America	0	355 (20.4)	0	0	0
其他 Others	8 (0.1)	304 (17.5)	0	0	0
整體轉口 Total re-exports	12 989	1 736	0	0	0
<b>C. 進口留用</b> Retained imports	10 675 881	8 313	677	0	0

註釋： 括號內數字表示佔整體數字的百分比。

Notes : Figures in brackets denote percentage shares against the corresponding total.

## 少於整體數字的 0.05%。

## Less than 0.05% of the corresponding total.



### 3.4(B) 2008年按供應地劃分的煤產品進口貨量及按目的地劃分的轉口貨量 Quantity of imports of coal products by supplier and quantity of re-exports of coal products by destination for 2008

	蒸餾煤與其他煤產品 Steam coal and other coal	木炭 Wood charcoal	無煙煤 Anthracite	焦煤與半焦煤 Coke and semi-coke	公噸 tonne
<b>A. 進口供應地</b> Imports by supplier					
印度尼西亞 Indonesia	10 721 675 (94.5)	3 874 (46.4)	0	0	0
中國內地 The mainland of China	475 845 (4.2)	314 (3.8)	0	0	0
澳大利亞 Australia	146 436 (1.3)	0	0	0	0
新加坡 Singapore	0	2 316 (27.8)	0	0	0
馬來西亞 Malaysia	0	847 (10.2)	0	0	0
菲律賓 Philippines	0	769 (9.2)	0	0	0
德國 Germany	563 (##)	0	0	0	0
越南 Vietnam	0	195 (2.3)	160 (97.6)	0	0
其他 Others	463 (##)	26 (0.3)	4 (2.4)	0	0
整體進口 Total imports	11 344 982	8 341	164	0	0
<b>B. 轉口目的地</b> Re-exports by destination					
澳門 Macao	0	857 (88.6)	0	0	0
美國 United States of America	0	85 (8.8)	0	0	0
其他 Others	21 (100.0)	25 (2.6)	2 (100.0)	0	0
整體轉口 Total re-exports	21	967	2	0	0
<b>C. 進口留用</b> Retained imports	11 344 961	7 374	162	0	0

註釋： 括號內數字表示佔整體數字的百分比。

## 少於整體數字的0.05%。

Notes : Figures in brackets denote percentage shares against the corresponding total.

## Less than 0.05% of the corresponding total.

### 3.4(C) 2013年按供應地劃分的煤產品進口貨量及按目的地劃分的轉口貨量 Quantity of imports of coal products by supplier and quantity of re-exports of coal products by destination for 2013

	蒸餾煤與其他煤產品 Steam coal and other coal	木炭 Wood charcoal	無煙煤 Anthracite	焦煤與半焦煤 Coke and semi-coke
公噸 tonne				
<b>A. 進口供應地</b> Imports by supplier				
印度尼西亞 Indonesia	12 298 798 (94.8)	2 981 (36.4)	0	0
澳大利亞 Australia	527 435 (4.1)	8 (0.1)	0	0
俄羅斯 Russia	145 142 (1.1)	0	0	0
中國內地 The mainland of China	221 ##	2 005 (24.5)	2 (100.0)	0
泰國 Thailand	0	1 447 (17.7)	0	0
德國 Germany	893 ##	0	0	0
馬來西亞 Malaysia	0	661 (8.1)	0	0
荷蘭 Netherlands	617 ##	0	0	0
越南 Vietnam	0	513 (6.3)	0	0
其他 Others	564 ##	578 (7.1)	0	0
整體進口 Total imports	12 973 670	8 193	2	0
<b>B. 轉口目的地</b> Re-exports by destination				
韓國 Korea	0	4 892 (86.3)	0	0
澳門 Macao	2 166 (100.0)	418 (7.4)	0	0
日本 Japan	0	277 (4.9)	0	0
其他 Others	0	82 (1.4)	0	0
整體轉口 Total re-exports	2 166	5 669	0	0
<b>C. 進口留用</b> Retained imports	12 971 504	2 524	2	0

註釋： 括號內數字表示佔整體數字的百分比。

Notes : Figures in brackets denote percentage shares against the corresponding total.

## 少於整體數字的0.05%。

## Less than 0.05% of the corresponding total.

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5	Golden Eagle 金鷹	PC	5
6	Onoda	PC	6
7	Skyscraper	PC	7
8	Green Island Hong Kong - Special 青洲牌	PC	8
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10	China Resources Cement 華潤水泥	PC	10
11	Gold Carp 金鯉	PC	11
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For cementitious materials not included in the Cement Circular, ER may request PWCL to carry out test.

The above test results were uploaded to our web-site of [www.cedd.gov.hk/eng/forms/doc/cement\\_cir.pdf](http://www.cedd.gov.hk/eng/forms/doc/cement_cir.pdf)

Should you have any question regarding to this Circular, please contact PTO/Lab2, Mr. Y.W. Yim, at telephone number 2305 1275, or in writing to the Public Works Central Laboratory Building, 2B Cheung Yip Street, Kowloon Bay, Kowloon, Hong Kong.

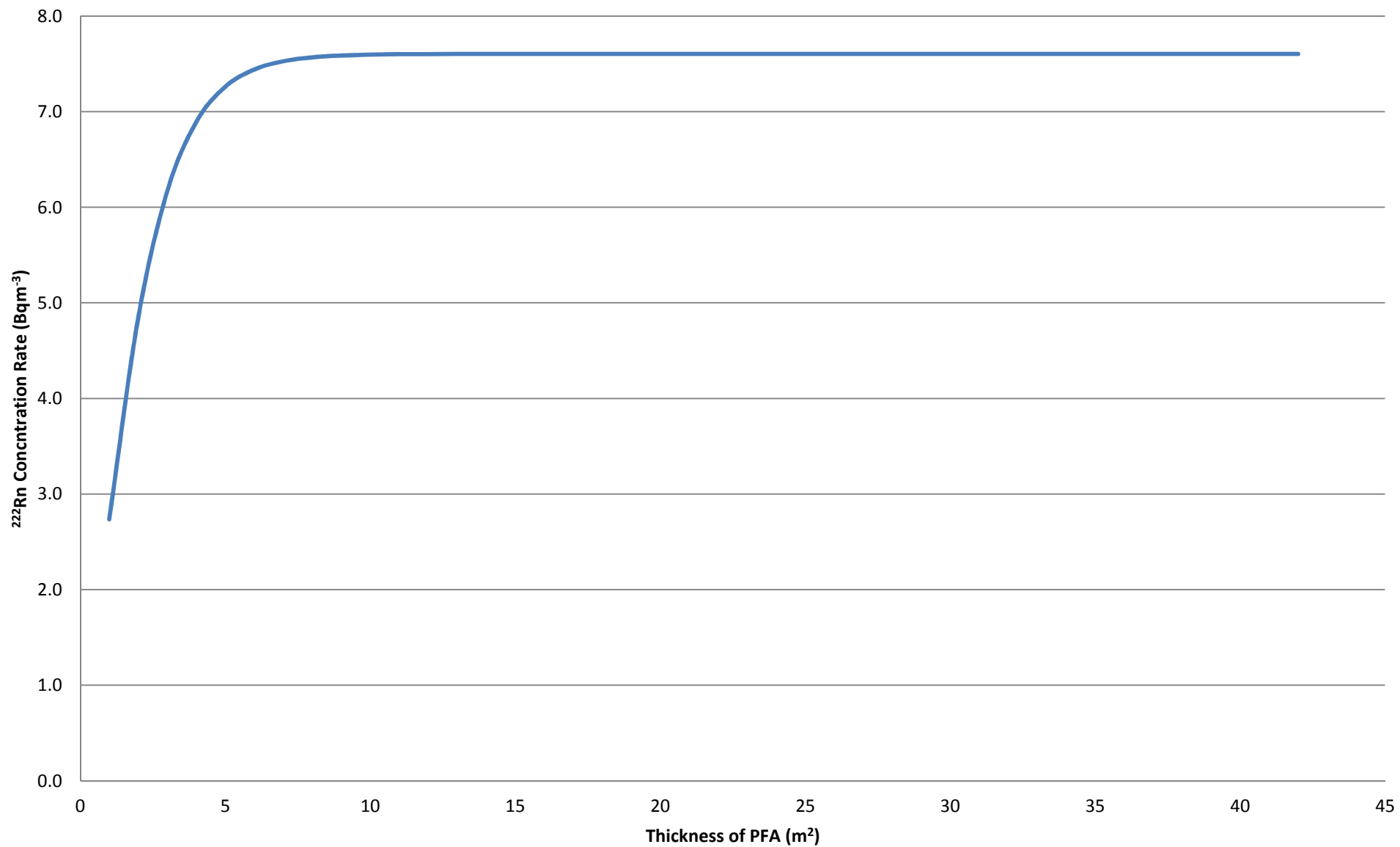
**12 CLP Power Hong Kong Ltd.  
(Pulverised-fuel Ash)**

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<b>Laboratory Reference</b>	1100071	1100091	1100107	1200016	1200034	1200056	1200076	BS3892:Part 1: 1997 Specification
Date Sample Received	26/08/2011	26/10/2011	21/12/2011	22/02/2012	25/04/2012	22/06/2012	22/08/2012	
Country of Origin Stated By Client	Hong Kong	Hong Kong	Hong Kong	Hong Kong	Hong Kong	Hong Kong	Hong Kong	
<b>Physical Properties</b>								
Fineness (%)	6.6	9.9	5.6	7.3	8.3	5.8	4.9	Not more than 12%
Particle Density (kg/m <sup>3</sup> )	2710	2430	2610	2550	2470	2570	2760	Not less than 2000 kg/m <sup>3</sup>
Water Requirement (%)	90	96	94	93	93	87	93	See Note
Strength Factor ---	1.00	0.84	0.96	0.85	0.91	1.00	0.85	See Note
Standard Consistententce (%)	24.0	25.0	24.5	24.5	25.0	23.0	24.0	---
Initial Setting Time (min)	210	200	145	155	170	170	185	Not less than the initial setting time of the Portland cement used
Soundness (mm)	0.5	0.5	0.0	0.0	0.5	0.0	0.0	Not more than 10 mm
<b>Portland Cement used</b>								
Brand	Onoda	Emerald	Golden Eagle	Champion	Onoda	Onoda	Onoda	
Lab. Reference. No.	1100065	1100082	1100100	1200006	1200027	1200027	1200049	
Initial Setting Time	140	150	120	130	140	140	150	
<b>Chemical Composition</b>								
Moisture Content (%)	0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1	Not more than 0.5%
Loss-on-ignition (%)	1.0	2.4	1.4	2.0	2.5	2.6	1.8	Not more than 7%
Sulphate content (%)	1.5	0.8	1.9	1.0	1.0	1.1	1.4	Not more than 2.0%
Chloride content (%)	0.01	<0.01	0.01	0.01	<0.01	0.03	<0.01	Not more than 0.1%
Calcium Oxide content (%)	14.3	6.5	10.8	7.8	5.7	9.5	13.2	Not more than 10.0%
K <sub>2</sub> O (%)	1.55	1.81	1.31	1.61	0.82	1.59	1.48	---
Na <sub>2</sub> O (%)	2.42	1.56	4.45	1.12	1.25	5.57	1.21	---
Total Alkali ( Na <sub>2</sub> O Eq.) (%)	3.44	2.75	5.32	2.18	1.79	6.62	2.19	---

Note: In accordance with GS16.07(b), the criteria for water requirement and strength factor at 28 days shall not apply, but the values of water requirement and strength factor at 28 days shall be reported.

### Sensitivity Test for Thickness of the PFA



### Sensitivity Test For Wind Speed

