AUSTRALIAN RADIATION SERVICES

Radiological survey of Coal Seam Gas operations for NORM

Origin Energy Australia Ltd., Queensland

August 2013

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Executive Summary

SGS Australian Radiation Services (SGS ARS) conducted a radiological survey of the Origin Coal Seam Gas operations in Queensland for the presence Naturally Occurring Radioactive Material (NORM) between 20th and 22nd August 2013 in the Spring Gully and Talinga regions.

The radiological survey of gas installations, including gas plants, field wells and water treatment facilities (WTF) indicated the absence of elevated external gamma radiation levels which could be attributable to NORM within the process equipment. The exception was two vessels in the Spring Gully WTF which showed elevated levels of NORM, no radioactive contamination was identified in any of the process items surveyed.

Analysis of process waters and scales identified activity concentrations consistent with levels encountered in the natural environment with the exception of slightly elevated Ra-226 and Ra-228 activity concentrations found in the sample taken from the SG WTF Pond A crust.

Consequently there is currently a negligible external radiation hazard to personnel working in any areas of those facilities assessed, when compared with an individual's exposure to natural background radiation levels, and there is no reason to suggest there is any internal ingestion/or inhalation hazard from a radiation exposure perspective as a result of handling process equipment from any of the Origin sites.

Unlike conventional gas production, the potential for NORM to accumulate in a coal seam gas installation over an extended period of time is relatively unknown. It may depend on several factors including local geology and the extraction and processing techniques utilised. Several recommendations have been made to regulate any potential accumulation of radioactive scale in the gas facilities over the coming years.

1.0 Introduction

Following a request from Oskar Jarvie, Chemist with Origin Energy Australia Ltd. (Origin), SGS Australian Radiation Services (SGS ARS) attended the Coal Seam Gas Operations located in Queensland to conduct radiation monitoring for Naturally Occurring Radioactive Material (NORM) within its gas producing installations.

Mr. Glenn Riley, Senior Health Physicist and Mr. Daniel Kim, Health Physicist at SGS ARS, conducted radiation monitoring between 20th and 22nd August 2013 on facilities in the Spring Gully and Talinga areas in the south-west region of Queensland. This incorporated the gas plants located at Spring Gully, Strathblane, Taloona and Talinga, water treatment facilities located at Spring Gully and Talinga and also a selection of field wells.

This report presents the findings and associated recommendations from the site visit.

2.0 Background

SGS ARS previously conducted a radiological survey of the facilities described in 4.0 (*refer ARS report 10-1562 Radiological survey of Coal Seam Gas operations for NORM, February 2010).* A follow up visit formed part of the recommendations in this report.

3.0 Scope of work

Scope of work for the visit was to:

- Conduct a radiological survey for external gamma radiation of the Spring Gully, Strathblane, Taloona and Talinga gas plant installations where NORM could potentially be present. Seven (7) representative wells were included in this survey along with the water treatment facility (WTF) at the Spring Gully and the Talinga sites;
- Monitor spool items internally for radioactive contamination, where possible, thus identifying the internal inhalation/ingestion hazard present; and
- Collect and conduct gamma ray spectrometry analysis of production water and sludge samples.

4.0 Site details

During the site visit, a combination of gas plants and field wells were selected for monitoring. Samples of were taken from each of the selected field wells.

Sites: Spring Gully Gas Plant, including select field wells
Strathblane Gas Plant, including select field wells
Taloona Gas Plant, including select field wells
Spring Gully WTF
Talinga Gas Plant, including select field wells
Talinga WTF

5.0 Natural background radiation levels in Australia

Humans are exposed to natural radiation to a greater or lesser extent, from a number of sources. For example, cosmic radiation from outer space; the presence of uranium, thorium and potassium-40 (^{40}K) in the Earth's crust; and radon gas released from the decay of uranium.

The total average dose to an individual from natural background radiation is about 2.4 millisievert (mSv) per year, but varies widely throughout the world depending on altitude at which people live, the local geology, the type of housing lived in, and the food consumed. In some countries the average annual dose received from natural background radiation is in excess of 10 mSv. Due to the local geology and our mode of living, average annual doses in Australia are generally below the worldwide average estimated to be 1.7 mSv. The natural background radiation level from external gamma radiation sources only in Australia is approximately 0.9 mSv per person per year primarily from cosmic and terrestrial sources, which equates to ~0.10 $\mu Sv \cdot h^{-1}$ averaged over the year. Typical background dose rates can vary from ~0.05 to ~0.15 $\mu Sv \cdot h^{-1}$ depending on the above mentioned factors and may be even higher in some instances.

Uranium and thorium are dispersed throughout rocks and soils in low concentrations of a few parts per million (ppm). Naturally-occurring uranium-238 (^{238}U) and thorium-232 (^{232}Th) are parents of separate long-lived series of radionuclides of several elements, which decay in succession until stable lead is formed. In addition, radioactive potassium, ^{40}K, is present with stable potassium, which is a common element in the Earth's crust. A number of radionuclides in both natural decay series emit gamma radiation, as does ^{40}K, and this leads to external and internal irradiation of people. The incorporation of these elements into building materials also leads to exposure indoors. Radioactive elements of the uranium and thorium natural series also can be incorporated into food and drinking water, which results in internal exposures to radiation from the consumption of foodstuffs.

Radon and thoron gas are a particularly significant source of exposure to natural radiation, especially radon-222 (^{222}Rn) from the decay of ^{226}Ra from the ^{238}U series. Build-up of radon gas inside houses can lead to an accumulation of radon indoors if a dwelling is not well ventilated. Exposure to radon gas can contribute to more than half the overall dose to individuals from natural sources in some countries.

Uranium and thorium are present in some minerals and ores at higher concentrations than are found in soil, but not necessarily at levels that could be exploited for the elements themselves. The processing of these ores can lead to additional radiation exposure of workers and the public during operations or from management of waste materials.

The presence of NORM in the conventional gas producing industry is included in Appendix A: NORM in the 'conventional' gas industry as additional background information. The potential for the presence of NORM in the extraction of the natural gas from underground coal beds is relatively unknown and not widely recognised or reported within the radiation safety industry.

6.0 Radiation monitoring equipment

The radiation monitoring equipment used during the site visit is listed in Table 1.

Table 1: Radiation monitoring equipment – August 2013.

Monitor	Serial No(s).	Mode/Radiation Type	Measurement units
RS220	1710	Survey mode (gamma)	cps
		Dosemeter mode (gamma)	$nSv \cdot h^{-1}$
Ludlum Model 2360 with 43-93	267508 / PR286541	Alpha	cps
		Beta	cps

a. Integrated 'counts' over a 30-second period are displayed and converted to a cps equivalent.

The Radiation Solutions RS220 (see Figure 1) is used to search, locate and identify gamma ray emitting radionuclides. This instrument is suitable for a 'search and locate' exercise as it contains a highly sensitive Sodium Iodide (NaI) scintillation detector.

Figure 1: Radiation Solutions RS220 Superspec – October 2013.

The RS220 instrument has been calibrated in terms of ambient dose equivalent rate and has a resolution of 0.001 µSv·h^{-1}. Due to the excellent resolution and fast response to radiation, this instrument is ideal for large scale environmental radiation surveys. The RS220 instrument was used for the external survey of the process equipment.

The Ludlum Model 2360 and 43-93 alpha-beta dual phosphor probe is suitable for measuring alpha and beta radioactive contamination in units of counts per second. Radiation counts for alpha and beta radiation can be individually measured or summed as a total count result.

All radiation monitoring equipment has been calibrated within the past twelve (12) months to a Cs-137 source whose output is traceable to the Australian Primary Standard of Exposure maintained by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).

7.0 Methodology

7.1 Testing protocol

Prior to commencing any survey work, discussions were held with Origin management and process personnel to identify key equipment to be included in the survey. Site specific inductions were completed by Mr. Riley and Mr. Kim as required.

The radiation monitoring equipment used is not intrinsically safe and hence a 'low voltage' permit and gas detector were required before any survey work could be conducted at any of the monitoring sites.

During the site visit, Mr Kim Burette, Field Support Chemist at Origin, accompanied Mr. Riley and Mr. Kim to assist with the identification of process equipments and sampling at the selected field wells.

7.2 Background measurements

Background measurements were performed at each survey site prior to conducting the survey with the RS220 instrument. This included measurements in the survey mode (cps) and the dose rate modes (nSv·h^{-1}). The ability of the RS220 meter to measure very low, background radiation levels means that readings are displayed in nSv·h^{-1}. However, for the purpose of this report, all measurements are reported in µSv·h^{-1}, the standard unit for reporting occupational dose rates (1000 nSv = 1 µSv).

Background levels recorded at each site are presented with the survey results in Appendix B. The stated uncertainties are one standard deviation calculated from a data set of a minimum of five measurements.

Background levels varied considerably between sites and are dependant on several factors most notably the presence of naturally occurring radionuclide present in the soils and/or cover material (e.g. natural soil, gravel road base, concrete, or an elevated walkway). Generally, background count rates measured on land with the RS220 meter are in the range 50 – 110 cps, and typical dose rates vary between 0.03 and 0.06 µSv·h^{-1}.

Background measurements were also conducted for the contamination monitoring equipment used. A pass/fail criterion value was developed for each radiation monitoring instrument used based upon the sum of the mean background count rate and three standard deviations of this mean. Items which record radiation count rates in excess of a criterion value are considered to contain detectable radioactive contamination.

7.3 Count-rate survey

Using the RS220 meter in 'survey' mode, key process items and spool identified were checked for the presence of NORM. Sweeping measurements were conducted with the instrument in direct contact or close proximity to the outside surfaces of the process equipment (Figure 2). The instrument display current and historical count rates enabling a 'spike' in gamma radiation levels to be readily observed. Counts rates observed for each process item or section of the plant surveyed (see Appendix B) were compared with background readings for the area and recorded either on site drawings supplied by Mr. Burette or in separate field notes where drawings were not available.

Particular consideration was given to sections of the process where NORM scale could potentially accumulate including pumps, valves and sharp bends in spool.

Figure 2: External survey of field well in Talinga region – August 2013.

7.4 Dose rate survey

Using the RS220 instrument, limited dose rate measurements were also performed in close proximity to the process equipment.

The number of dose rate measurements conducted is dependent on the levels identified during the count rate survey.

The purpose of obtaining dose rates is to quantify the dose an individual would receive as a result of any external radiation exposure or to demonstrate that no external radiation exposure risk is present. The number of dose rate measurements collected was minimal due to the count rate levels encountered during the survey being consistently within background levels.

7.5 Contamination measurements

Direct measurements for the less penetrating alpha and beta contamination on internal surfaces of process equipment was limited to items that had been removed from service previously. Internal monitoring of in-line spools and equipment was not possible as all plants and equipment were sealed or in operation at the time of the survey. An additional consideration was that external survey results provided no indication that internal contamination would be present and consequently extensive contamination monitoring was not considered warranted at the time of the survey.

7.6 Sample analysis

Samples were collected and submitted to the SGS ARS Analytical Services Group for radionuclide analysis. Water and sludge samples were collected from various wells across all sites and sludge samples were collected from Pond A at the SG WTF. For a full list of samples see Appendix C: Radioactivity analysis report – November 2013.

The solid sample was prepared for analysis by drying, grinding and homogenising, and a portion transferred to a standard plastic container and analysed by high-resolution gamma ray spectrometry. Water samples were subject to preliminary radiochemical treatment to isolate specific radionuclides and then analysed by gamma ray spectrometry for their soluble and insoluble components. Radionuclide concentrations were determined for key radionuclides from the uranium and thorium radioactive decay series including uranium-238 (as thorium-234), radium-226, lead-210, radium-228 and thorium-228, and other detectable natural radionuclides.

8.0 Results

8.1 External survey

Radiation monitoring results for the external radiological survey of the gas installations, including background measurements are presented in Appendix B:External radiological survey results – August 2013. With the exception of two vessels in the Spring Gully WTF, no elevated levels were detected on any of the items surveyed.

8.2 Internal contamination measurements

Results from the internal assessment of process equipment removed form service is provided in Table 2.

Table 2: Results from the NORM monitoring of the internal surface of process items removed from services – August 2013. The results have not been corrected for background radiation levels.

Item	Ludlum 2360/43-93 alpha (cps)	Ludlum 2360/43-93 beta (cps)
SG016 lay-down area		
Background	*<0.1*	*5.3 ± 0.1*
Process item 1	<0.1	2.6
Process item 2	<0.1	3.4
Process item 3	<0.1	2.4
Process item 4	<0.1	2.3

8.3 Spring Gully WTF Vessels containing activated alumina

Elevated external radiation levels were detected on Vessel V-8221-20103 and V-8221-20203. A photograph of one of these vessels is shown in Figure 3.

Figure 3: Activated alumina vessel in SG WTF – August 2013.

SGS ARS were advised that the activated aluminas are being used to extract impurities such as elemental barium and strontium from process however these are not naturally radioactive and are therefore not expected to cause elevated background levels. In order to determine the source of the elevated readings, a spectrum was collected using the RS220 in surface contact with the outside of the vessel. An 1800 second count time was used. Following collection of the spectrum, the results were downloaded and analysed using the RSanalyst software supplied with the RS220. Both Ra-226 and Th-232 were identified in the collected spectrum, indicating that the vessels are in some way removing naturally radioactive materials from the water in addition to other elements such as barium and strontium.

8.4 Sample analysis

Gamma ray spectrometry sample analysis results are provided in Appendix C: Radioactivity analysis report – November 2013

Schedule 3 of the Queensland *Radiation Safety Regulations (2010)* prescribes limits for the disposal of radioactive material in water. Considering total activity concentration of radionuclides in the naturally occurring radium and thorium identified in samples collected at wells at across all sites, average activity concentrations are well below prescribed limits for disposal, and consequently exempt from regulation from a radioactivity perspective.

All samples are not considered 'radioactive substances' in Queensland as average activity concentrations are well below the prescribed limits for mineral substances as outlined in the Regulations. In fact, the radionuclide activity concentrations of both samples are consistent with the typical concentrations found normally in uncontaminated soil worldwide.

It should be noted however, that there were slightly elevated levels of both Ra-226 and Ra-228 in sample 13-2366-09 taken off the crust of Pond A (the pond was dry at the time of sampling). Analysis showed that Ra-226 was not in equilibrium with Pb-210 and Ra-228 was not in equilibrium with Th-228 for this sample. This result indicates that a production process is favouring the transport of Ra-226 and Ra-228 into Pond A.

8.5 Discussion

The radiological survey of the gas installations, including gas plants, field wells and water treatment plants indicated the absence of elevated external gamma radiation levels attributable to NORM. Survey measurements (cps) and doses rates recorded for all sites were comparable with the natural background measurements.

Consequently there is a negligible external radiation hazard to personnel working in any areas of those facilities assessed, when compared with an individual's exposure to natural background radiation levels. All ambient dose rate measurements are comparable or less than those levels normally encountered as a result of other sources of natural background radiation.

The highest count rates observed during the survey were found in vessels using activated alumina in the SG WTF. Elevated count rate of 210 s^{-1} for V-8221-20103 and 200 s^{-1} for V-8221-20203 was measured which corresponded to an external dose rate of 0.100 µGy.h^{-1} and 0.075 µGy.h^{-1}. Ra-226 and Th-232 were identified in the spectrum collected on the exterior surface of one of the vessels. These radiation levels do not currently present an external radiation hazard to staff occupying the area around the vessel however samples of the alumina should be analysed prior to any disposal of the alumina or cleaning of the vessel to ensure any regulatory requirements for personal monitoring and disposal are met.

Slightly elevated levels of Ra-226 and Ra-228 were detected in samples collected from Pond A. Due to the relatively high solubility of radium in water, this result can be expected and is typical in the oil and gas industry. The levels currently found are significantly below the level where regulatory control is enforced; however future monitoring of the pond crust is recommended.

No radioactive contamination was identified in any of the process items surveyed in the lay down yard, which is consistent with the external survey results. Consequently there is no reason to suggest there is any internal ingestion/or inhalation hazard from a radiation exposure perspective as a result of handling process equipment from any of the sites surveyed.

The reasons for the presence of NORM in the extracted gas or produced water can be due to several factors including the geophysical nature of the reservoir, extraction techniques, etc. In conventional gas production, newly operational plants may have insignificant levels of NORM during initial stages of commissioning, but can accumulate NORM over a period of time, sometimes within a few years. The rate of accumulation can depend on many factors. However, the potential for NORM to accumulate in a coal seam gas installation over an extended period of time is unknown.

9.0 Conclusions

The results obtained during the radiological survey of gas installations in the Spring Gully and Talinga regions indicate that the levels of NORM at the time of assessment were negligible comparable to natural background radiation levels. The measurements collected from this follow-up survey will continue to provide good baseline data should NORM be identified in the future. Recommendations have been included in this report relating to future assessments.

10.0 Recommendations

- Future monitoring programs should include any ponds used for process water to check for elevated ^{226}Ra and ^{228}Ra concentrations.
- A sample of the activated alumina from SG WTF Vessel 8221-20103 and 8221-20103 should be analysed prior to any disposal or cleaning taking place in this equipment.
- Based on the monitoring results, a repeat survey of the gas plants and installations assessed during this visit is not warranted for a period of at least 2 years. This survey should include a repeat external survey of identical plant equipment and wells assessed during this survey.
- If new Origin gas plants are established, a baseline external survey should be conducted within the first 3-months of operation similar to the surveys conducted during this visit.
- Origin could consider scheduling the survey during a major maintenance shutdown. This would enable potential NORM contamination levels on internal surfaces of operational process equipment to be assessed. The key radionuclides targeted would be ^{210}Pb and the associated progeny which cannot be identified externally due the low penetrating power of the associated radiation, and are prevalent in conventional gas producing facilities (Appendix 1). The likelihood of these radionuclides being present is low (considering the external survey failed to identify its parent, ^{222}Rn), internal measurements

inside key process equipment would provide confirmation of this. This could be conducted in the next 1-2 years depending on the Origin shutdown schedule.

Appendix A: NORM in the 'conventional' gas industry

Formation water present within oil and gas reservoirs contains cations of calcium, strontium, barium and radium which are dissolved from the reservoir rock. As a consequence, under certain temperature, pressure and chemical conditions, formation water contains the radium radioisotopes Radium-226 (^{226}Ra) and Radium-228 (^{228}Ra).

Radon gas (^{222}Rn) is generated in the reservoir rock through the decay of ^{226}Ra. Mixed gas / water streams extracted from the reservoir blend with the produced radon gas. When radon decays, short-lived decay products (radon progeny) are generated which plate out on the internal surfaces of process pipes and vessels. These short-lived radionuclides emit high-energy gamma radiation which can be readily identified on external surfaces of equipment.

In gas processing product streams, radon generally follows the dry gas stream. De-ethanisors, fractionators, condensers and storage tanks are all considered items where radon gas may accumulate. Radon has a boiling point between that of propane and ethane and consequently can also be expected to be more concentrated in propane and ethane circuits.

Due to the short half-life of radon and its progeny, 99% of these radionuclides will have decayed to the longer-lived metal lead-210 (^{210}Pb) within 25 days. ^{210}Pb undergoes further decay to the other short-lived radionuclides Bismuth-210 (^{210}Bi) and Polonium-210 (^{210}Po). Concentrations of ^{210}Pb and its decay products can be expected to increase over time in gas producing facilities. None of these radionuclides have strong gamma radiation emissions and cannot be identified externally. The main radiation hazards from the deposits are generally due to the inhalation of internal radioactive contamination removed or disturbed during maintenance works. The opening of process equipment whilst the plant is shutdown provides a unique opportunity to identify if ^{210}Pb is present on the internal surfaces.

The extent of mobilisation of ^{226}Ra and ^{228}Ra from gas reservoirs and its appearance in produced water can vary considerably. Generally speaking, lower concentrations are expected in scales and sands extracted during gas processing, in comparison with oil producing installations where concentrations are generally higher.

Appendix B: External radiological survey results – August 2013

Item Description	RS220 survey data (counts per second)	RS220 external dose rate ($\mu Sv \cdot h^{-1}$)
Taloona Gas Plant (20/8/13)		
Background (gas plant entrance)	*52 ± 4*	0.019 ± 0.003
X8500-09	Within background	-
PL8500-01	Within background	
X8500-06 Glycol cooler, regeneration skid and contactor	Within background	-
X8500-08 Glycol cooler, regeneration skid and contactor **(running)**	Within background	-
Major pipeline linking compressors	Within background	-
Compressor X8500-04	Within background	-
Strathblane Gas Plant (20/8/13)		
Background (gas plant entrance)	*101 ± 3*	*0.041 ± 0.002*
X8300-07	Within background	-
PL8300-01	Within background	
X8300-05 Glycol cooler, regeneration skid and contactor	Within background	-
X8500-07 Glycol cooler, regeneration skid and contactor	Within background	-
X8300-08 Oily water treatment unit	Within background	-
X8300-09 Oily water treatment unit	Within background	-
F8300-700	Within background	-
S8300-01A and 02A Inlet separators and surrounding pipeline	Within background	-
K8300-06 compressor	Within background	-
Spring Gully Gas Plant (20/8/13)		
Background (gas plant entrance)	*80 ± 8*	*0.033 ± 0.002*
X8400-07 Sales gas metering skid and associated pipework	Within background	-
X8400-05 Glycol dehyder	Within background	-
X8400-06	Within background	-
Major pipeline linking compressors	Within background	-
X8400-04 compressor	Within background	-
S8400-01 inlet separator	Within background	
S8400-02 inlet separator	Within background	
S8400-03 inlet separator	Within background	
Spring Gully field wells (20/2/10)		
Well SG95 (Sample taken)		
Background	*104 ± 5*	*0.037 ± 0.002*
Well	Within background	-
Well SG29 (Sample taken)		
Background	*91 ± 8*	*0.039 ± 0.003*
Well	Within background	-
Well DM83 (Sample taken)		
Background	*94 ± 9*	*0.035 ± 0.003*
Well	Within background	-
Spring Gully Water Treatment Facility (20/8/13)		
Background	*41 ± 4*	*0.017 ± 0.004*
Various filters and pipework throughout WTF	Within background	-
Vessel V-8221-20103 (activated alumina)	**210**	***0.100***
Vessel V-8221-20203 (activated alumina)	**200**	***0.075***
Pond A Cell 1 (22/8/13)	Within background	-
Talinga Gas Plant (20/8/13)		
Background (gas plant entrance)	*84 ± 6*	*0.035 ± 0.004*
K4404-1 Screw compressor	Within background	-
S4403-01 inlet separator	Within background	
S4403-02 inlet separator	Within background	
S4403-03 inlet separator	Within background	

Item Description	RS220 survey data (counts per second)	RS220 external dose rate (µSv·h^{-1})
S4403-04 inlet separator	Within background	-
V4414 compressed air receiver	Within background	-
X4414 compressed air dryer	Within background	-
K4414-1 air compressor	Within background	-
K4414-2 air compressor	Within background	-
K4414-3 air compressor	Within background	-
4410 oil talk area including skimmers, filters, pumps and tanks	Within background	-
Main pipe rack	Within background	-
X4405-01 Glycol dehydration unit	Within background	-
X4405-01 Gas filter/ Coalescer skid	Within background	-
X4405-01 Glycol dehydration unit	Within background	-
C4405-01 Contactor	Within background	-
E4405-01 Glycol cooler	Within background	-
X4405-02 Glycol dehydration unit	Within background	-
X4405-02 Gas filter/ Coalescer skid	Within background	-
X4405-02 Glycol dehydration unit	Within background	-
C4405-02 Contactor	Within background	-
E4405-02 Glycol cooler	Within background	-
X4400- Sales gas meter skid	Within background	-
X4405-02 Glycol dehydration unit	Within background	-
X4405-02 Gas filter/ Coalescer skid	Within background	-
X4405-02 Glycol dehydration unit	Within background	-
C4405-02 Contactor	Within background	-
E4405-02 Glycol cooler	Within background	-
K4406-05 Sales compressor	Within background	-
Talinga field wells (24/2/10)		
Well Talinga 15B (Sample taken)		
Background	*82 ± 7*	*0.031 ± 0.002*
Well pipe work and process equipment	Within background	-
Well Talinga 18 (Sample taken)		
Background	*94 ± 8*	*0.041 ± 0.005*
Well pipe work and process equipment	Within background	-
Well Talinga 37 (Sample taken)		
Background	*86 ± 7*	*0.034 ± 0.003*
Well pipework and process equipment	Within background	-
Well Talinga 69 (Sample taken)		
Background	*59 ± 4*	*0.026 ± 0.004*
Well pipe work and process equipment	Within background	-
Talinga Water Treatment Facility (21/08/13)		
Background	*80 ± 5*	-
Various filters and pipe work throughout WTF	Within background	-
Tank farm outside of main WTF building	Within background	-

Appendix C: Radioactivity analysis report – November 2013

REPORT №: **13-2366-R1**

Issue date: **14th November 2013**

Client: **Origin Energy Australia Ltd.**

Contact: Mr. Kim Burette

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E-mail: kim.burette@originenergy.com.au

Client reference: CoC dated 23rd September 2013 (G.R) and Purchase Order № 16138266

SAMPLE DETAILS

Sample description or type: Water and sludge

Number of samples received: Nine:
- 7 x water samples; and
- 2 x sludge samples

Date received: 23rd September 2013

Analysis required: Naturally occurring radionuclides; solid and liquid components of water samples analysed individually after separation where possible.

SGS AUSTRALIAN RADIATION SERVICES

Authorised signatory: [signature]

Name: **Mr. Ben Milne**

Position: Radiochemist/Health Physicist

Accreditation No. 16987
Accredited for compliance with ISO/IEC 17025

Important Note:

a. This report supersedes any previous reports with this reference number.
b. The results in this report apply to the sample(s) as received by SGS Australian Radiation Services
c. This report has been prepared and issued in accordance with NATA's accreditation requirements.

RESULTS:

Notes:

a) Radionuclide or gross radioactivity concentrations are expressed in becquerel per kilogram of dried solid sample or becquerel per litre of water sample unless otherwise specified. The becquerel (Bq) is the SI unit for activity and equals one nuclear transformation per second.
b) Less than (<) values indicate the detection limit for each radionuclide or parameter for the measurement system used. The respective detection limits have been calculated in accordance with ISO 11929.
c) The reported uncertainty in each result is the expanded uncertainty calculated using a coverage factor of 2, providing a level of confidence of approximately 95%.
d) Not reported as mass of solid component insufficient for analysis.

Test method: a. Preparation – ARS-SOP-AS303 – Preparation of solid samples for measurement by HPGe.
ARS-SOP-AS301 – Preparation of water samples for measurement by HPGe.
b. Measurement – ARS-SOP-AS406 – High resolution gamma ray spectrometry.

		Radionuclide Concentration					
		Naturally-occurring uranium (U-238) series			***Naturally-occurring thorium (Th-232) series***		***Other***
Client Sample ID (ARS Lab. ID)	**Units**	**Thorium-234**	**Radium-226**	**Lead-210**	**Radium-228**	**Thorium-228**	**Potassium-40**
Talinga 15B (Liquid component) (13-2366-W1)	$Bq \cdot L^{-1}$	0.31 ± 0.27	< 0.1	0.29 ± 0.24	0.211 ± 0.098	0.080 ± 0.040	-
Talinga 15B (Solid component) (13-2366-01)	$Bq \cdot kg^{-1}$	48 ± 26	20.2 ± 6.1	37 ± 21	38 ± 11	35.5 ± 3.7	493 ± 57
Talinga 69 (Liquid component) (13-2366-W2)	$Bq \cdot L^{-1}$	0.39 ± 0.40	0.504 ± 0.068	0.67 ± 0.32	1.35 ± 0.17	< 0.1	-
Talinga 69 (Solid component) (13-2366-02)	$Bq \cdot kg^{-1}$	45 ± 18	27.1 ± 3.0	40 ± 18	37.3 ± 4.4	35.5 ± 3.0	467 ± 49
Talinga 18 (Liquid component) (13-2366-W3)	$Bq \cdot L^{-1}$	0.40 ± 0.40	0.150 ± 0.064	0.48 ± 0.33	0.64 ± 0.16	0.104 ± 0.037	-
Talinga 18 (Solid component) (13-2366-03)	$Bq \cdot kg^{-1}$	32 ± 16	20.5 ± 2.3	41 ± 14	33.6 ± 4.3	26.8 ± 2.2	406 ± 43

Client Sample ID (ARS Lab. ID)	Units	Radionuclide Concentration: Naturally-occurring uranium (U-238) series			Naturally-occurring thorium (Th-232) series		Other
		Thorium-234	Radium-226	Lead-210	Radium-228	Thorium-228	Potassium-40
Talinga 37 (Liquid component) (13-2366-W4)	$Bq \cdot L^{-1}$	< 0.3	1.165 ± 0.094	0.37 ± 0.13	1.56 ± 0.15	0.143 ± 0.022	-
Talinga 37 (Solid component) (13-2366-04)	$Bq \cdot kg^{-1}$	22.8 ± 6.6	23.4 ± 2.0	22.9 ± 4.3	27.6 ± 3.2	25.1 ± 2.1	391 ± 42
DM 83 (Liquid component) (13-2366-W5)	$Bq \cdot L^{-1}$	< 0.7	< 0.2	< 0.6	0.20 ± 0.11	< 0.2	-
DM 83 (Solid component) (13-2366-05)	$Bq \cdot kg^{-1}$	N/A[d]	N/A[d]	N/A[d]	N/A[d]	N/A[d]	N/A[d]
SG 29 (Liquid component) (13-2366-W6)	$Bq \cdot L^{-1}$	0.19 ± 0.13	0.365 ± 0.053	0.207 ± 0.094	0.315 ± 0.077	0.056 ± 0.021	-
SG 29 (Solid component) (13-2366-06)	$Bq \cdot kg^{-1}$	16 ± 11	19.1 ± 2.0	< 20	23.6 ± 3.0	12.9 ± 1.5	< 10
SG 95 (Liquid component) (13-2366-W7)	$Bq \cdot L^{-1}$	< 0.2	0.101 ± 0.026	< 0.2	0.098 ± 0.045	< 0.03	-
SG 95 (Solid component) (13-2366-07)	$Bq \cdot kg^{-1}$	N/A[d]	N/A[d]	N/A[d]	N/A[d]	N/A[d]	N/A[d]
SG WTF Pond A Cell 1 (13-2366-08)	$Bq \cdot kg^{-1}$	< 20	82.9 ± 6.0	58.8 ± 8.8	79.9 ± 7.2	58.0 ± 4.5	216 ± 28
SG WTF Pond A sludge sub surface (13-2366-09)	$Bq \cdot kg^{-1}$	42 ± 14	132 ± 10	98 ± 16	121 ± 12	108.5 ± 8.5	283 ± 45