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Radiological survey of Coal Seam Gas operations for NORM

Origin Energy Australia Ltd., Queensland

February 2010

Document Record

Title	Radiological survey of Coal Seam Gas Operations for NORM
Client	Origin Energy Australia Ltd., Queensland
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Table of Contents

Index of Tables

Executive Summary

Australian Radiation Services Pty. Ltd. (ARS) conducted a radiological survey of the Origin Coal Seam Gas operations in Queensland for the presence Naturally Occurring Radioactive Material (NORM) between 22nd and 24th February 2010 in the Spring Gully and Talinga regions.

The radiological survey of gas installations, including gas plants, field wells and water treatment faculties indicated the absence of elevated external gamma radiation levels which could be attributable to NORM within the process equipment. Survey measurements (cps) and doses rates recorded for all sites were comparable with the natural background measurements. No radioactive contamination was identified in any of the process items surveyed, which is consistent with the external survey results. Analysis of process waters and scales identified activity concentrations consistent with levels encountered in the natural environment.

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), Australian Radiation Services Pty. Ltd. (ARS) attended the Coal Seam Gas Operations in Queensland to conduct monitoring for Naturally Occurring Radioactive Material (NORM) within its gas producing installations.

Mr. Darren Billingsley, Senior Health Physicist and Mr. Michael Bernardo, Health Physicist with ARS, conducted radiation monitoring between 22nd and 24th February 2010 on facilities in the Spring Gully and Talinga areas in the south-west region of Queensland. This incorporated gas plants, field wells and water treatment facilities.

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

2.0 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. Fifteen (15) representative wells, and water treatment plants at the Spring Gully and Talinga sites were also assessed;
- monitor spool items removed from service 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 coal silt samples collected.

A full scope of works was provided by Origin (Work scope-ARS-feb2210).

3.0 Site details

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 RO water treatment plant
Talinga gas plant, including select field wells
Talinga temporary water treatment plant

4.0 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 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 and closer to 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 and thorium-232 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}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 Naturally Occurring Radioactive Material (NORM) in the conventional gas producing industry is included in Appendix A 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.

5.0 Radiation monitoring equipment

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

Table 1: Radiation monitoring equipment – February 2010.

Monitor	Serial No(s).	Mode/Radiation Type	Measurement units
Exploranium GR-130	9676	Survey mode (gamma)	cps
		Dosemeter mode (gamma)	$nSv{\cdot}h^{-1}$
Thermo 1A with DP2R/4A probe	3512/10650	Alpha	cps
		Beta	cps
HPI Cypher 5000 with 5505 PGM probe	501129/1124	Alpha, Beta and Gamma	cps [a]

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

The Exploranium GR-130 mini-spectrometer (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 NaI scintillation detector. Efficiency tests have identified that the mini-spectrometer can "see" a planar surface of diameter 2 metres from a height of 30 cm from the ground. They can also identify gamma ray emitting radionuclides to a depth of approximately 10 cm to 50 cm in soil depending on the gamma ray energies.

Figure 1: Exploranium GR-130 minispectrometer – February 2010.

The GR-130 instrument has been calibrated in terms of ambient dose equivalent rate and has a resolution of 0.001 $\mu Sv \cdot h^{-1}$. Due to the excellent resolution and fast response to radiation, this instruments is ideal for large scale environmental radiation surveys. GR-130 instrument was used for the external survey of the process equipment.

The Bicron Electra 1A with Model DP2A/4R alpha-beta dual phosphor probe is suitable for measuring alpha and beta radioactive contamination in units of counts per second. The HPI Model 5505 probe contains a geiger-muller pancake detector when connected to the HPI Cypher 5000 is suitable for detecting alpha, beta and gamma radiation in total counts or counts per second.

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).

6.0 Methodology

6.1 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. Billingsley and Mr. Bernardo as required.

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

At all locations, with the exception of the field wells in the Spring Gully region, an Origin representative accompanied ARS to assist with identification of the process equipment.

6.2 Background measurements

Background measurements were performed at each gas plant and field well location prior to conducting the survey with the GR-130 instrument. This included measurements in the survey mode (cps) and the dose rate modes ($nSv \cdot h^{-1}$). The ability of the GR-130 meter to measure very low, background radiation levels means that readings are displayed in $nSv \cdot h^{-1}$. However, for the purpose of this report, all measurements are reported in $\mu Sv \cdot h^{-1}$, 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 GR-130 meter are in the range 50 – 120 cps, and typical dose rates vary between 0.05 and 0.15 $\mu Sv \cdot h^{-1}$.

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.

6.3 Count-rate survey

Using the GR-130 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 were recorded as a range for each process item or section of the plant surveyed (see Appendix B).

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

Figure 2: External survey of field well in Talinga region – February 2010.

6.4 Dose rate survey

Using the GR-130 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. For this survey it was to quantify the count rate survey results, and provide confirmation that there was no external radiation exposure hazard present. The number of dose rate measurements collected was minimal due to the count rate levels encountered during the survey being comparable to background levels.

6.5 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 (Figure 3). 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.

Figure 3: Contamination monitoring of spool – February 2010.

6.6 Sample analysis

Samples were collected for radionuclide analysis by the ARS radionuclide analysis laboratory. Process water samples were collected from the Spring Gully RO Water Treatment Plant (Pond 1) and from the Talinga temporary RO Plant. A sample containing a mixture of sand and coal fines from the Condabri lease was also provide to ARS for radionuclide analysis.

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.

7.0 Results

7.1 External survey

Radiation monitoring results for the external radiological survey of the gas installations, including background measurements are presented in Appendix B.

7.2 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 – February 2010. The results have not been corrected for background radiation levels.

Item	Electra 1A / DP2R/4A alpha (cps)	Electra 1A / DP2R/4A beta (cps)	HPI Cypher / PGM (cps)
Spring Gully Gas plant			
Background	*<0.1*	*1.8 ± 0.1*	*0.6 ± 0.1*
Scrap valve	<0.1	1.2 ± 0.1	0.3 ± 0.1
Talinga site			
Background	*<0.1*	*2.3 ± 0.1*	*0.7 ± 0.1*
Removed spool from tie-in sales gas line	<0.1	2.3 ± 0.1	0.6 ± 0.1
Old Talinga well water line	0.0	1.5 ± 0.4	0.7 ± 0.1
Old Talinga well gas line	<0.1	1.8 ± 0.1	0.5 ± 0.1

7.3 Sample analysis

Gamma ray spectrometry sample analysis results are provided in Appendix C.

Section 10 of the Queensland *Radiation Safety Regulations (1999)* 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 the 'Talinga RO Plant' and the 'Spring Gully RO plant', average activity concentrations are well below prescribed limits for disposal, and consequently exempt from regulation from a radioactivity perspective.

The scale sample 'DM10' and the 'Condabri coal fines' are not considered 'radioactive substances' in Queensland as average activity concentrations are well below the prescribed limits for mineral substances as outlined in Section 5 of the Regulations. In fact, the radionuclide activity concentrations of both samples are consistent with the typical concentrations found normally in uncontaminated soil worldwide. For instance, the radium-226 concentrations identified from both samples (0.021 $Bq \cdot g^{-1}$ and 0.061 $Bq \cdot g^{-1}$) are consistent with this worldwide natural soil radioactivity range of 0.017-0.060 $Bq \cdot g^{-1}$ (UNSCEAR 2000).

8.0 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.

The highest count rates observed during the survey were contributable to natural radioactive material present in the underlying soil. Due to the in-growth period for the formation of radon gas from radium-226, it was expected there may have been notably elevated levels within the vicinity of the equipment temporarily not in use; including gas plant compressors that had been off-line for up to 5 days, or the field wells that had been shut-in. This was shown not to be the case.

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.

No radioactive contamination was identified in any of the process items surveyed, 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 Origin sites.

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 survey provides good baseline data should NORM be identified in the future. Recommendations have been included in this report relating to future assessments.

10.0 Recommendations

- 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 Pb^{210} 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, Rn^{222}), 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.

- Ra^{226} and Ra^{228} concentrations in the produced water and scale samples analysed were at negligible concentrations, suggesting that mobilisation of these key radionuclides is minimal in the existing fields, unlike problems that can be encountered in the conventional gas producing industry (Appendix A). The decision to conduct sample analysis in the future would depend on the outcome of radiation measurements results at the time.

Reference

UNSCEAR 2000. *Sources and Effects of Ionising Radiation*, UNSCEAR, 2000

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 hazard from these 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 – February 2010

Item Description	Exploranium GR-130 survey data (counts per second)	Exploranium GR-130 external dose rate ($\mu Sv h^{-1}$)
Taloona Gas Plant (22/2/10)		
Background (gas plant entrance)	*40 ± 5*	0.024 ± 0.005
Inlet risers	20 - 40	-
Inlet separators	20 - 35	-
Raw water inlet from separators	25 - 45	-
Flare controller	20 – 35	-
Suction header	25 – 45	-
K3 Compressor (online)		
- inside	10 – 25	-
- outside	20 - 40	-
K2 Compressor (offline 5 days)		
- inside	10 – 25	-
- outside	20 – 35	-
K1 Compressor (online)		
- inside	15 – 30	-
- outside	10 – 30	-
Fuel gas skid 2 (online)	25 - 45	-
Fuel gas skid 1 (offline)	20 – 45	-
Glycol skid 1	10 - 25	0.010 – 0.035
Particulate filters from Glycol skids	30 - 45	0.020 – 0.035
Dehydration skid, ground	10 – 20	-
Dehydration skid, upper	15 - 25	-
TEG contactor (base)	15 – 35	-
Sales gas line/skid	30 – 60*	0.030 – 0.045
Strathblane Gas Plant (22/2/10)		
Background (gas plant entrance)	*95 ± 5*	*0.059 ± 0.009*
Inlet risers	40 – 80	-
Inlet separators	30 – 50	-
Raw water inlet from separators	45 – 80	-
Flare controller	35 – 55	-
Suction header	20 – 80*	-
K1 Compressor (online)		
- inside	10 - 30	-
- outside	40 - 70	-
K2 Compressor (online)		
- inside	10 – 30	-
- outside	30 – 80	-
- suction line inlet	25 - 40	-
- soil, beside compressor	110 ± 5*	0.068 ± 0.008
K3 Compressor (offline 1 day)		
- inside	10 – 25	-
- outside	45 – 70	-
- suction line inlet	25 - 30	-
Fuel gas skid 2 (online)		-
Fuel gas skid 1 (offline)		-
Glycol skid (TEG regeneration)	20 - 50	0.017 ± 0.007
Dehydration skid, ground	10 – 35	-
Dehydration skid, upper	25 – 45	-
TEG contactor (base)	25 - 45	-
Degasser drum	25 – 45	-
Produce water pumps skid	25 - 35	-
Sales gas line	40 – 80*	-
Spring Gully Gas Plant (22/2/10)		
Background (gas plant entrance)	*70 ± 10*	*0.040 ± 0.002*

Item Description	Exploranium GR-130 survey data (counts per second)	Exploranium GR-130 external dose rate (μSv h^{-1})
Inlet risers	30 - 60	-
Inlet separators	30 – 45	-
Raw water inlet from separators	40 - 60	-
Flare controller	30 - 45	0.027 ± 0.004
Suction header	35 - 60	-
K4 Compressor (offline)		
- inside	10 – 40	-
- outside	30 – 65	-
K3 Compressor (online)		
- inside	10 – 35	-
- outside	25 – 50	-
- suction line	20 - 35	-
K2 Compressor (online)		
- inside	10 – 20	-
- outside	35 - 55	-
Fuel gas heater skid 1	40 - 60	0.035 ± 0.007
Glycol skid (TEG regeneration)	20 - 40	-
Dehydration skid 2, ground	20 – 35	-
Dehydration skid 2, upper	20 – 35	-
TEG contactor (base)	30 – 45	-
Sales gas line/skid	35 - 60	-
Spring Gully field wells (23/2/10)		
Well SG10 (operating, high gas rate)		
Background	*90 ± 5*	-
Well	40 - 75	-
Well DM3 (operating, high gas rate)		
Background	*80 ± 5*	-
Well	35 - 65	-
Well DM42 (operating, high water rate)		
Background	*70 ± 5*	-
Well	35 - 85	-
Well DM13 (operating, internal scale identified during w/o)		
Background	*60 ± 10*	-
Well	35 - 50	-
Well DM10 (closed, internal scale identified during w/o)		
Background	*85 ± 5*	-
Well	40 - 70	-
Well DM64 (operating)		
Background	*80 ± 5*	-
Well	50 - 75	-
Spring Gully RO Water Treatment Plant (23/2/10)		
Background	*35 ± 5*	-
Arkal filters	20 – 35	-
MF racks	15 – 35	-
Reverse osmosis skid A (online)	20 – 35	-
CIP-to-filtrate tank area	20 – 40	-
RO feed filter	20 - 30	-
Talinga Gas Plant (24/2/10)		
Background (gas plant entrance)	*80 ± 5*	*0.053 ± 0.005*
Inlet risers	55 – 80	-
Silt traps	40 - 70	-
Suction header	45 - 75	-
Screw compressor 7 (online)		
- inlet/outlet	50 – 65	-
- oil and gas scrubbers	20 - 45	-
Screw compressor 4 (offline 2 days)		
- inlet/outlet	45 - 75	-
- oil and gas scrubbers	20 - 40	-

Item Description	Exploranium GR-130 survey data (counts per second)	Exploranium GR-130 external dose rate (μSv/h^{-1})
Screw compressor 1 (online)		
- inlet/outlet	45 – 80*	-
- oil and gas scrubbers	15 - 35	-
We gas line collection point	55 – 85*	-
Reciprocating compressor 1 (offline 1 hour)		
- inlet/outlet	45 - 65	-
- skid	15 - 30	-
Wet gas sales pipeline	55 – 95*	-
Glycol skid, ground	50 - 65	-
Glycol skid, upper	35 - 55	-
TEG filter skid 2, ground	15 – 40	-
TEG filter skid 2, upper	25 - 40	-
Sales gas line/skid	45 – 70	-
Pigging pipeline	55 - 75	-
Talinga field wells (24/2/10)		
Well Talinga 9 (operating)		
Background	*85 ± 10*	*0.076 ± 0.017*
Well	45 - 85	-
Well Talinga 22 (operating)		
Background	*70 ± 5*	-
Well	35 - 75	-
Well Talinga 39 (operating, high flow)		
Background	*75 ± 5*	-
Well	45 - 70	-
Well Talinga 18 (operating, free flowing and minimal gas)		
Background	*80 ± 10*	*0.056 ± 0.008*
Well	55 - 80	-
Well Talinga 13 (shut in)		
Background	*85 ± 10*	-
Well	55 - 70	-
Well Talinga 12 (operating)		
Background	*80 ± 5*	-
Well	55 - 75	-
Well Talinga 10 (shut in)		
Background	*80 ± 5*	-
Well	60 - 80	-
Talinga RO plant (temporary)		
Background	*80 ± 5*	-
Micro filtration system	35 - 50	-
Filtrate water tanks	40 - 70	-
Reverse osmosis	35 - 60	-
Permeate/Service water tanks and waste	45 - 75	-

* elevated levels due to underlying soils only

Appendix C: Radioactivity analysis report – February 2010

To: Origin Energy Resources Ltd.
339 Coronation Drive
Milton QLD 4064

Report No.: 10-1562-R1

Contact: Mr. Oskar Jarvie

Sample description: Water, sludge and scale samples

Number of samples: Four

Submission date: 1st March 2010

Analysis required: Determination of the activity of naturally-occurring radionuclides.

Analytical method: Pretreatment:
A. Solids – samples dried and homogenised, and apportion of each sample was encapsulated in resin in a standard container for measurement.
B. Water – Samples filtered and radiochemical treatment to isolate naturally-occurring radionuclides

Measurement: High resolution gamma ray spectrometry used to determined radionuclide content.

AUSTRALIAN RADIATION SERVICES PTY. LTD.

Report prepared by: Mr. Michael Gilhen
Health Physicist
Signed: Michael Gilhen

Reviewed by: Dr. Malcolm Cooper
Consultant Environmental Scientist
Signed: M.B. Cooper

Date: 10th May 2010

Results:

Radioactivity Concentrations (Solids - $Bq.g^{-1}$; Liquids - $Bq{\bullet}L^{-1}$)

Note:

a) Radioactivity concentrations are expressed in becquerel (Bq) per gram of dry solid or becquerel per litre for water. One becquerel equals one nuclear transformation per second.
b) Less than (<) values indicate the limit of detection for each radionuclide for the measurement system.
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%.

	Client Sample ID (ARS Lab. ID)			
	Talinga RO Plant Water ($Bq{\cdot}L^{-1}$)	Spring Gully RO Plant water ($Bq{\cdot}L^{-1}$)	Condabri coal fines ($Bq{\cdot}g^{-1}$)	DM10 Scale ($Bq{\cdot}g^{-1}$)
Radionuclide	(10-1562-01)	(10-1562-02)	(10-1562-03)	(10-1562-04)
Naturally-occurring uranium (U-238) series				
Thorium-234	<0.14	< 0.13	0.025 ± 0.021	< 0.03
Radium-226	< 0.08	< 0.08	0.021 ± 0.003	0.061 ± 0.006
Lead-210	< 0.15	< 0.14	0.025 ± 0.019	< 0.03
Naturally-occurring thorium (Th-232) series				
Radium-228	< 0.07	< 0.08	0.033 ± 0.006	0.050 ± 0.009
Thorium-228	< 0.07	< 0.06	0.033 ± 0.004	0.052 ± 0.005
Other naturally-occurring radionuclides				
Potassium-40	Not determined	Not determined	0.48 ± 0.05	< 0.04