Radioactivity in hydrocarbon exploration (including fracturing activities)

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Executive summary

Previously overseas, and more recently within New Zealand, questions have been raised around whether radioactivity is associated with hydrocarbon exploration and production. There are two central issues: does the recovery of natural gas and condensate bring with it the potential for release of naturally occurring radioactive materials (NORMs), and secondly, is there a health risk associated with the use or disposal of radioactive isotope tracers that may be used during activities associated with drilling or fracturing?

It should be noted first of all that the use of radioactive materials is a matter under the jurisdiction of the Ministry of Health, and all enquiries or concerns should be directed to that agency in the first instance. The Council has sought or welcomed information provided on radioactivity related to hydrocarbon exploration and production, for the sake of reassurance and public confidence. To the extent that radioactivity might be present in a discharge for which the Council has regulatory control under the Resource Management Act, the Council would also have a degree of statutory function in this regard (but notwithstanding the explicit role of the Ministry of Health) .

The Council has been addressing the issue for close to twenty years, for its own information and to respond to public enquiries made from time to time. More particularly, there has been recently something of a concerted focus on radioactivity through the media, which might be seen as one aspect of a wider conversation on the pros and cons of the introduction of fracturing as a means of enhancing hydrocarbon production.

This report sets out a short summary of the Council's work and findings in this area. It addresses the use of radioactive tracers, the use of radioactive materials within well logging activities, disposal of drilling wastes potentially containing radioactive materials, and the question of naturally occurring radioactive materials (NORMs) that might be released during exploration or production.

Review: a draft of this report has been reviewed by ESR. All ESR comments and proposed emendations have been incorporated in the final version. The Taranaki Regional Council remains responsible for the content of this report.

It should be understood that not all field operators in Taranaki use radioactive tracers, and not all uses of radioactive tracers relate to fracturing. Both chemical and radioactive tracers can be an integral part of a conventional well drilling operation, with a range of applications that encompass, for example, demonstration of well integrity, the accurate placement of down-well equipment, tracking drilling muds during drilling operations, and flow testing.

The Council has been seeking and receiving advice and information from the appropriate specialist and regulatory agencies since 1995 on matters relating to radioactivity and hydrocarbon exploration and production in the Taranaki region. More recently it has undertaken a range of sampling and analytical investigations of its own accord.

A consistent theme runs through all information the Council has accessed. In summary:-

- The Council has sought and received assurances at all points, from the competent statutory authorities and experts, that the use and management of radioactive materials within the hydrocarbon exploration and production sector as established in Taranaki is lawful, and is not harmful to human health;

- The Council has sought and received assurances at all points, from the competent statutory authority and expert body, that the release of any NORMs during hydrocarbon exploration and production as established in Taranaki is not harmful to human health;
- The Council has undertaken its own surveys of produced fluids and soil levels at land remediation sites, to ensure from its own direct measurement that the release of radioactive materials from these sources is not harmful to human health. Measurements have confirmed that this is indeed the case; and indeed neither radioactive tracers as used in hydraulic fracturing nor NORMs that are present in Taranaki fields are 'radioactive' in terms of statutory definitions[1], and indeed they contain levels of radioactivity that are orders of magnitude below those at which controls are required;
- The Council has been repeatedly advised by the appropriate competent authorities and has repeatedly found on its own account, that the levels of radioactivity associated with these activities are comparable to normal, everyday exposure for an average person.
- The determinations made by GNS and the NRL in 1995 are worth re-iterating: '*I find it very difficult to conceive of a credible concern for the health of the general public in the vicinity of a natural gas field'… 'radon levels in New Zealand do not constitute a health risk. The level is lower than the world average and we have no areas of elevated radon concentrations'.*
- In summary, the Council finds no evidence of a health or environmental issue arising from the use of radioactive tracers, the use of radioactive materials within well logging activities, disposal of drilling wastes potentially containing radioactive materials, or the release of naturally occurring radioactive materials (NORMs) during exploration or production.

[1] Radioactive tracers before dilution (i.e. before field use) are regulated quantities of radioactive material

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1. Background

1.1 Statutory responsibilities

The use of radioactive materials in New Zealand and any questions around radioactivity exposure are matters under the jurisdiction of the Ministry of Health, and all enquiries or concerns are appropriately addressed by that agency in the first instance. For its part, the Council has sought or welcomed information provided by the Ministry, for the sake of reassurance and public confidence, and not because of any regulatory or statutory function in this regard. It is not the statutory responsibility of this Council to determine and adjudicate in the use of radioactive materials during hydrocarbon exploration or production, nor to determine the safety of the presence of any radioactivity present in natural gas and hydrocarbon production. Having said that, a discharge of a contaminant in a manner that requires control (by resource consent or by compliance with a Regional Rule) under the Resource Management Act 1991 is a matter for the Council to consider, and there will be times when discharges from an industrial or trade premise into the wider environment may incorporate radioactive materials.

Users of radioactive material are required to obtain a licence (see http://www.legislation.govt.nz/act/public/1965/0023/latest/DLM373117.html), and importers/exporters are required to obtain a consent (see http://www.legislation.govt.nz/act/public/1965/0023/latest/DLM373115.html). These requirements can however be exempted if the material falls below certain thresholds. The criteria for exemption are set out in the Radiation Protection Regulations (see http://www.legislation.govt.nz/regulation/public/1982/0072/latest/DLM81174.html and Section 1.4 below).

The hazard of radioactivity depends on the exposure pathway, the nature of the exposure (intermittent, one-off, or continuous), and the exposed organs. In terms of risk, it is critically important to draw a distinction between the source (its inherent radioactivity, measured in units of becquerels), and the received exposure (how much radioactivity is arriving at the recipient, the consequences of which are measured in units such as 'effective dose equivalent'). Acceptable dose is calculated on the basis of the cumulative exposure across a lifetime, as the mechanism of adverse health effects is generally considered to be progressive (ie the greater the cumulative exposure, the greater the likelihood of an adverse effect occurring).

1.2 Forms of radiation

Radioactive materials are by definition unstable: to achieve stability they release energy in one or more forms of radiation, forming decay products. The most well-known pathways of radioactivity are alpha, beta, and gamma, defined by the nature of the particles or forms of energy they emit, although there are other mechanisms as well (eg electron capture by a nucleus, and proton, neutron, or neutrino ejection). [2]

Gamma radiation almost invariably accompanies any other form of radioactive decay.

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[2] For further information see for example http://en.wikipedia.org/wiki/Radioactive_decay

From the health perspective, gamma and beta radiation present a hazard both internally and externally. Alpha radiation is only an internal hazard. Alpha radiation will not penetrate the dead layer of skin on the body. The primary pathway of human exposure to alpha radiation is obviously ingestion or inhalation (even dermal contact will have limited health consequences insofar as internal organs are concerned); for gamma and beta radiation, ingestion, inhalation, dermal contact or proximity need to be considered.

All living organisms are exposed to radiation from natural sources-

- Cosmic rays from outer space
- External sources such as rocks, soils, and building materials (e.g. uranium, thorium, their radioactive decay products, and any materials containing potassium, as the potassium-40 isotope is universally distributed wherever there is potassium. The human body contains radioactivity of approximately 63Bq/kg potassium-40, 66Bq/kg carbon-14 and 113Bq/kg tritium (H-3.)
- Internal radiation exposure through the consumption of food or water (typically containing relatively higher levels of potassium), and/or air carrying radionuclides. For air, radon-222, which is a gas, is of particular interest where there are high natural levels of uranium or thorium nearby. Radon is a decay product of these elements. Radon releases alpha radiation, and because it is present in significant concentrations in parts of the USA it is there a major cause of lung cancer. Radon gas can be present in some spring water and hot springs. However, radon is not significant in the New Zealand context (see further on this below), and any indiscriminate assumptions about the relevance of issues that have emerged overseas in the New Zealand context are inappropriate.

As noted above, radon (and more widely, all naturally occurring terrestrial radioactive materials, or NORMs) is found where there are significant natural deposits of uranium, radium, thorium, and other mineral deposits of like nature. There are a few very small and isolated (non-commercial) deposits of uranium on the West Coast of the South Island, (described as 'low-grade' at http://www.mineralswestcoast.co.nz/other.aspx), but none in Taranaki.

1.3 Uses and sources of radioactive material in hydrocarbon exploration and flow enhancement activities

Equipment and procedures involving radioactive materials have been used within the hydrocarbon exploration and production industry for many years, as well as in other industries and the public health sector.

Tracers are routinely used in both the drilling and flow enhancement (stimulation by fracturing) of wells. They may be either chemical or radioactive. There are a considerable number of different radioactive materials used, utilising either beta or gamma forms of radiation.

There are several purposes to which tracers are applied. I*n situ* logging is used to detect the location of gamma emitting radioactive tracers (and hence for example the location of the cements, packing, drilling muds, perforating changes, and/or fracturing proppants, or to provide proof of clean-up, depending upon the purpose and means of utilisation), while sampling of return/produced fluids for either beta emitting or chemical tracers is used as a means of evaluating flows and formation clean-up. Matters such as well integrity, the precise placement of equipment or identification of target formations, and extent of fracturing fluid penetration, can be assessed using tracers.

It should be noted that not all field operators in Taranaki use radioactive tracers, and likewise, not all uses of radioactive tracers relate to fracturing. As noted above such tracers can be an integral part of a conventional well drilling operation.

1.4 NZ Radiation Regulations and statutory agencies

Users of ionising radiation must satisfy requirements imposed by the Radiation Protection Act 1965, Radiation Protection Regulations 1982, and Codes of Safe Practice issued by the Office of Radiation Safety.

Regulatory agency
The Office of Radiation Safety's primary role is as the regulatory body administering the Radiation Protection Act 1965 and Radiation Protection Regulations 1982. This involves a wide range of regulatory activities including licensing, issuing consents, and maintenance of codes of safe practice.

Other functions of the Office of Radiation Safety include:
- carrying out responsibilities as New Zealand's competent authority under various international treaties, conventions and regulations, and
- overseeing the provision of authoritative advice to Government and the public regarding all matters associated with radiation.

Until December 2011 the National Radiation Laboratory (NRL) was part of the Ministry of Health and carried out the functions now performed by the Office of Radiation Safety. On 1st December 2011 the scientific staff of the NRL transferred to the Institute of Environmental Science and Research (ESR). The name NRL was also transferred to ESR. The Office of Radiation Safety oversees a contract between the Ministry of Health and ESR for the provision of radiation services. These services include:
- scientific support for regulatory and other functions of the Office of Radiation Safety relating to ionising radiation
- provision of New Zealand's environmental fall out monitoring programme
- scientific advice in respect of non-ionising fields
- support for the Ministry of Health's initiatives relating to emergency reduction, readiness, response and recovery
- scientific advice and support relating to the storage and disposal of spent sealed radioactive material.

Exempt radioactive materials
Some less dangerous irradiating apparatus and radioactive materials are excluded from regulatory control because of the way the Act defines those terms. By definition within the Regulations, '**radioactive material'** (ie any material requiring control under the Regulations) excludes articles containing a radioactive substance giving it a specific radioactivity of less than 100,000 becquerels per kilogram or with a total radioactivity of less than 3,000 becquerels.

There is a partial exemption from regulatory control for any radioactive materials with a level of activity less than those set out in Schedule 1 of the Radiation Protection Regulations. There are controls on disposal and importation. Schedule 1 is reproduced in full in the appendix of this report[3].

1.5 NZ Drinking Water Standards

New Zealand has a radiological standard for drinking water. The context of these standards needs to be understood. There are two separate limits, one for alpha radiation, the other for beta radiation, because of their differing scale of potential effects.

The standard for alpha radiation excludes any radiation from radon-222. There is a separate standard for alpha radiation from radon-222, as pathways from both ingestion and inhalation of radon are taken into account.

The standard for beta-emitting radiation likewise excludes beta radiation emitted from potassium-40, as the body essentially self-regulates its content of potassium-40.

Even taken together, the three standards are very conservative. The Ministry of Health advise that if the level of radioactivity within a drinking water supply was at the limit for each of the three standards, the total dose incurred by a person drinking 2 litres of that water daily would still be less than 5% of the total annual dose the average person was receiving from other natural sources (and far less than recognised thresholds of dangerous exposure, but it should be noted that in general exposure to radioactivity should be minimised).

The particular standards are:

- total alpha concentration in drinking water, excluding any radiation from radon-222, shall not exceed 0.10 becquerel per litre
- total radiation from radon-222 shall not exceed 100 becquerel per litre
- total beta radiation excluding any radiation from potassium-40 shall not exceed 0.50 becquerel per litre.

The response to any excursion of a standard in a drinking water supply is consultation with the National Radiation Laboratory and the region's Medical Officer of Health.

[3] http://www.health.govt.nz/our-work/radiation-safety/role-office-radiation-safety)

2. Discussion

2.1 Sources of information and radioactivity hazard assessment

The Council has always sought advice from and referenced the information provided by the National Radiation Laboratory (ESR), the regional Health Protection Unit, and GNS, in seeking to evaluate whether there has been or is any risk from any radioactive sources associated with hydrocarbon exploration and extraction. These agencies are the appropriate authorities with specific responsibilities in this arena.

2.2 Disposal at land treatment sites

In April 2011, a Council officer took radiation measurements at two different land farming sites, including background (un-used) paddocks, waste stockpiling areas, and land several spread areas that had received wastes from different wellsites. The surveys were undertaken in the presence of a Health Protection officer. None of the measurements at any site exceeded 100 nanoSieverts per hour (nSv/hr- see Glossary). As noted below, this is within the range of normal background radiation levels found in New Zealand.

In December 2011, the Council undertook a further survey of another land farming site. In this case, stockpiles of wastes originating from fracturing activities were measured, as well as a comprehensive site survey including offsite (background) areas. Seventeen sites in all were measured for radiation. None of the readings recorded exceeded 100 nSv/hr, with the maximum, of 86.6 nSv/hr, being detected on a nearby ironsands beach and not on the disposal site.

The full methodology and results were provided to NRL for review and interpretation. NRL responded: *all readings are within the range of normal background radiation…. Anything less than 200 nSv/h is within normal ranges of background. The countrate measured was < 1 cps - that would equate to < 100 nSv/h if a doserate reading had been taken*

(email NRL to Council, 21 December 2011).

2.3 Radioactive tracers

Two companies has advised the Council of their use of radioactive tracers within either drilling or well production enhancement activities, for purposes such as tracking drilling muds within well bores, or to determine the extent of fracturing and to confirm modelled fracturing. The issue raised in the minds of some members of the public is whether this use represents an unacceptable risk to public health.

The Council has noted the following information from the Office of Radiation Safety, Ministry of Health in respect of these tracers:

> *"Further to our telephone conversation this morning I confirm that the proposed arrangements relating to disposal (*of the tracer in question*) are below the exempt activity levels under the Radiation Protection Regulations 1982. Therefore no regulatory issues arise relating to disposal under the Radiation Protection Act."*
>
> *Regards*
> *Stuart Lillie*
> *Office of Radiation Safety*
> *Ministry of Health*
> *(email, 7 June 2012)*

2.4 Naturally occurring radioactive materials (NORMs)

1. The Council first addressed this issue in 1995 and again in 1997, when a submitter to air discharge consent applications repeatedly claimed that natural gas in New Zealand might have high levels of radon-222 (a NORM), and put forward a suggestion that the burning of natural gas in any facility would therefore pose a risk of public exposure to the release of radiation. In response the Council sought information on the level of and risk associated with radon-222 in natural gas, from both GNS and NRL.

The Institute of Geological and Nuclear Sciences advised as follows:

> *"There is an extensive literature on radon gases. It would be expected that radon would be detectable in the well head gases of a natural gas operation. There is New Zealand data on radon in the well head gases from geothermal operations. These data show that the offsite concentrations are not expected to cause health concerns and are generally at normal background levels. Emissions from natural gas operations would be expected to be even less. Our Institute has extremely limited data on radon in natural gas samples. What is available is consistent with the potential hazard being extremely low, and probably negligible.*
>
> *Natural levels vary from place to place as a result in variations in rock and soil type and general meteorological conditions. New Zealand tends to have rather low Radon^{222} levels on a global perspective.*
>
> *Overseas, the potential hazard to the public has been thought sufficient to control Radon levels or undertake remedial action in fairly uncommon circumstances where the Radon^{222} levels are elevated well above background levels. This has happened in a few areas that are particularly high due to abnormally high Uranium concentrations on the underlying rock; to buildings sited on or near old tailings sites from mines; to very well insulated buildings where the basement areas have been so well insulated that ventilation rates are much reduced; or to a combination of such factors.*
>
> *Surveys in New Zealand by the National Radiation Laboratory have shown that there are no areas where people are housed in conditions with high enough Radon levels to cause concern, not even on the West Coast where there are some Uranium deposits of almost commercial significance.*

Dr Whitehead has published several studies of Radon^{222} concentrations resulting from geothermal power producing wells. Radon is indeed measurable in the well head gas (our methods are very sensitive). However the main point to grasp is that the well head acts as a point source. Therefore, the gas is both diluting and decaying radioactively as it disperses from the well head. Measurements and theoretical calculations have shown that there is no elevation in Radon levels in populated areas. I believe his findings are compatible with independent work by the National Radiation Laboratory.

Natural gas wells would also be a source of elevated Radon^{222}. Overseas data suggests that, in general, well head concentrations for natural gas are very much lower than for geothermal steam.

At the request of another commercial client, Dr Whitehead carried out analyses of 4 natural gas samples said to be from various sources in New Zealand. The data are the property of the client. However, as expected, Radon^{222} was detectable but was described by Dr Whitehead as very low. One sample, the highest of the four, was also the hardest to analyse and the result was regarded as 'quite approximate'. Generally the overall data was regarded as among the lowest recorded worldwide.

On the basis of the information available from overseas and a comparison with the geothermal data, I find it very difficult to conceive of a credible concern for the health of the general public in the vicinity of a natural gas field. I would expect Radon concentrations off the site to be well within the bounds of normal variations found in New Zealand.

The National Radiation Laboratory advised as follows:

Radon levels in New Zealand do not constitute a health hazard. The level is lower than the world average and we have no areas of elevated radon concentrations.

We have no experience of Radon concentration in New Zealand natural gas: but radon levels in geothermal steam have been measured and the discharges to the atmosphere do not constitute a health hazard. One wouldn't expect the radon concentrations in natural gas to be any higher than that found in the geothermal steam. Therefore the burning of natural gas in a power station will not constitute a health hazard.

The Taranaki Regional Council also received analytical data on the composition of Kapuni LTS gas (wells KA-1 to KA-11). It was found that Radon^{222} gas was present, at a level of 40.7 Bq/m^3 (1 Bq = 1 disintegration per second).

To put that figure into perspective, the following can be noted:

- World Health Organisation (WHO) reports radioactivity levels of Radon^{222} of 1800 Bq/m^3 in natural gas supplies elsewhere in the world;
- WHO reports the Radon concentrations of 50 000 Bq/m^3 in soil air are 'typical';
- The average Radon concentration in the air inside residential dwellings in Scandinavia is 50 Bq/m^3, in the US and Canada is 27 Bq/m^3, and in Germany is 25 Bq/m^3;
- Most people in Europe are considered to spend their lives exposed to air concentrations lying between 10 Bq/m^3 and several hundred Bq/m^3; and
- WHO recommends no action for any atmosphere of less than 100 Bq/m^3, simple remediation (ventilation) for any building with a concentration of Radon in the

air between 100 and 400 Bq/m^3, and more specific remedial action if the air concentration rises above 400 Bq/m^3.

2. In 2005, further concerns were expressed to the Council over the idea that NORMs might accumulate as a sludge on pipework and other apparatus used within the industry, to levels that were unacceptable for or posed a risk to human health. The Council again sought advice on this speculation, from NRL. NRL responded:-

   In the oil industry where large volumes of oil and gas are moving through pipelines and are being held in large storage tanks, there is a tendency for naturally occurring radioactive materials (NORMs) in the gas and oil to plate out on the internal surfaces of the pipes and the tanks.

   Past experience with sludge in settling tanks and scale in pipework from the Taranaki region would indicate relatively low levels of contamination.

   This material doesn't represent a public health risk[4]
   (letter, NRL-Council 28 February 2005).

3. In late 2010-2011, the Council noted increasing discussion through social media and overseas media concerning release of NORMs in some exploration/development activities overseas. In order to be well-informed and to anticipate what might become an issue for the Council to address in Taranaki, in May 2011 the Council contacted the National Radiation Laboratory (Ministry of Health) to specifically request guidance on this subject.

   I just wanted to follow up on the question of radioactive drilling wastes, as there has been quite a lot of media attention on the subject. You confirmed that there is no risk to drilling cuttings/fluids from radioactive sources used in borehole logging tools. However, I'm wondering about the NORM referred to on the US EPA website http://www.epa.gov/radtown/drilling-waste.html *and how this relates to the geology in Taranaki. Has any work been done in this area by NRL or other organisations eg GNS?* (email Council-NRL 28 May 2011).

   The response was as follows: *Our environmental radioactivity monitoring laboratory headed by Dr Klaus Hermanspahn has conducted some sampling and analysis in the past, such as sludge samples from offshore Taranaki fields on behalf of Shell Todd. The levels were found to be low in comparison to what has been noted in some international fields.* (email NRL-Council 3 June 2011).

The same email exchange covered the issue of the adequacy of the field testing for radioactivity at land remediation sites that the Council had undertaken a month previously.

> *Back in April I borrowed the TDHB geiger counter and walked around a couple of our disposal sites. My understanding is that the meter measures only exposure to gamma and x-rays.*

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[4] ESR subsequently advised that this result does not eliminate the possibility that other samples of scale from elsewhere might have much higher levels of radioactivity.

I didn't get any readings above 100 nSv/hr, so it's safe to assume there is no risk to human health. But should I have also used the external probe to check for alpha/beta/gamma contamination of soil directly, to assess environmental risk?

The NRL response was: *The monitoring you have conducted is sufficient to identify whether or not there is sufficient activity to warrant health concerns. Your readings are essentially normal background measurements.*

The matters covered in the exchange should be noted. This Council has been criticised by some parties for not carrying out testing for alpha radiation at the time it used the geiger counter at the disposal sites. The NRL response makes two things very clear. Firstly, the testing undertaken by the Council had in fact been sufficient to determine whether there was any ground for holding concern over health from radioactivity in general; and secondly, the results showed that there was indeed no elevation of radioactivity above normal background (and no grounds for health concerns).

To put the measurements by the Council into perspective, the International Commission on Radiological Protection recommends doses of artificial radiation should be limited to one million nSv per year[5]. The dosage measured on the land treatment site was equivalent to (for a person remaining on the site for a year continuously) two-thirds of this exposure.

2.5 NORMs- Council sampling

As described above, the Council has undertaken several surveys of radiation at disposal sites. In response to the concern noted above, being expressed by various correspondents that this may be inadequate to put into perspective any supposed risk from alpha radiation emitted from NORMs, the Council has further collected several samples of produced water and sludges from four different producing fields in Taranaki (Pohokura, Kapuni, Waihapa and Cheal), and submitted them to the National Radiation Laboratory (ESR) for comprehensive analysis.

The results are as follows:

Sample 1
Potassium-40: 8.9 +/-1.7 Bq/L
Radium-226 (releases alpha radiation): 0.080 +/- 0.012 Bq/L
Radium-228 (releases alpha radiation): 0.051 +/- 0.021 Bq/L
Total alpha: less than 0.067 Bq/L; total beta: 7.25 Bq/L

Sample 2
Potassium-40: <2.7 Bq/L
Radium-226: 0.241 +/- 0.040 Bq/L
Radium-228: 0.536 +/- 0.078Bq/L
Total alpha: less than 0.039 Bq/L; total beta: less than 0.15 Bq/L

[5] http://en.wikipedia.org/wiki/Sievert

Sample 3
Potassium-40: 50.3 +/-6.6 Bq/L
Radium-226: 0.90 +/- 0.11 Bq/L
Radium-228: 1.91 +/- 0.20 Bq/L
Total alpha: 0.8Bq/L; total beta: 16 Bq/L

Sample 4
Potassium-40: 9.4 +/-2.5 Bq/L
Radium-226: 1.96 +/- 0.13 Bq/L
Radium-228: 1.73 +/- 0.13 Bq/L
Total alpha: 2.7Bq/L; total beta: 3.8 Bq/L

Sample 5 (sludges)
Potassium-40: 353 +/-32 Bq/L
Lead-210: 9.9 +/-2.1 Bq/L
Radium-226: 14.3 +/- 1.2 Bq/L
Radium-228: 14.8 +/- 1.4 Bq/L

All the above results are far below (orders of magnitude below) levels of radioactivity that would require control under the National Radiation Regulations 1982. To put it another way: they are not even considered radioactive, within the terms of the Regulations.

To put these results into perspective, comparisons can be made with natural and everyday sources of radioactivity routinely encountered by the public:-

- The radioactivity of soil due to its potassium-40 content is approximately 400 Bq/kg (ie much higher than the radioactivity of the produced water samples, and higher than the sludge sample)
- The radioactivity of soil due to alpha radiation sources (uranium, thorium, radium) is approximately 110 Bq/kg (ie much higher than the radioactivity of any of the samples)
- The radioactivity of sea water due to its potassium-40 content is 11 Bq/L (ie higher than most of the results for beta radiation from produced water found in the Council samples)
- The radioactivity of bananas is 130 Bq/kg beta and 0.04 Bq/L alpha
- Brazil nuts: 200 Bq/kg beta and 37 Bq/kg alpha
- Carrots: 130 Bq/kg beta and 0.08 Bq/kg alpha
- White potatoes: 130 Bq/kg beta and up to 0.1 Bq/kg alpha
- Beer: 14 Bq/kg beta
- Red meat: 110 Bq/kg beta and 0.02 Bq/kg alpha
- Granite: 1200 Bq/kg beta and 63 Bq/kg alpha
- Cement: 240 Bq/kg beta and 50 Bq/kg alpha
- Wood: 3300 Bq/kg beta
- Bricks: 670 Bq/kg beta and 110 Bq/kg alpha

(source: Idaho State University at www.physics.isu.edu/radinf/natural.htm)

When it is taken into account that there is no exposure pathway for produced water involving human consumption, and that by comparison with the radioactivity of materials in buildings we live and work in daily, and other everyday sources to which we are exposed, the radioactivity of produced water is negligible, the hazard to human health posed by radiation from NORMs in produced water within Taranaki is clearly meaninglessly small. Even should produced water enter freshwater aquifers used for consumptive purposes (ie non-compliance with consent conditions and Freshwater Plan rules), or should a massive discharge of produced water occur into a surface catchment used for consumptive purposes, the low alpha activity present in produced waters in Taranaki, the likely short duration of any such event before detection, and the significant immediate dilution afforded in such circumstances, render the degree of risk negligible in the opinion of Council staff.

2.6 Concerns that have circulated

Allegation 1: *STOS intend to release radioactive americium and thorium as tracers at Kapuni during fracturing activities*

Response: this allegation is false. It appears to be based on a mis-interpretation of information presented by Shell Todd Oil Services within an application for a discharge to land consent, applying the material in the text to an activity to which it did not relate.

The STOS application made it explicit that the Company would use one of three identified tracers, incorporating (respectively) radioactive iridium, radioactive scandium, or radioactive antimony. This information, and information about the levels of radioactivity involved, was set out within the application.

Separately, the application included material safety data sheets for radioactive forms of americium, barium and thorium. There was no suggestion anywhere within the application that these materials were to be used as tracers, or released or discharged into the environment. Such an assumption as has since been circulated, was without foundation in any information presented within the application. The reason the MSDS sheets were included, was because the materials would be present on the fracturing site. These three elements are enclosed within or are used for the calibration of detection equipment used to ensure proper well construction. This information on the intended use of these materials was provided by the Company as part of its disclosure of activities.

STOS have subsequently provided a statement as follows:

Within STOS' AEE accompanying our resource consent applications to undertake HF at four Kapuni wellsites (January 2012) MSDS for 6 radioactive components to be used during tracer operations were included. These were as follows:

***Americium 241** – This substance is used within a Spectrascan Spectral Tool which is temporarily run into the well to record the placement of tracer (and therefore proppant) within the formation at the conclusion of HF[6] operations. At the time of preparing the AEE it was envisaged that the SpectraScan tool to be used on the Tight Gas Pilot Project would utilise Americium 241. However, the SpectraScan tool has recently been upgraded and no long utilises a radioactive source therefore Americium 241 will no longer be used as part of the Tight Gas Pilot Project. It should be noted that if a SpectraScan tool with a radioactive*

[6] HF hydraulic fracturing

source were to be used, any radioactive component of the tool would be contained within a fully sealed unit and would not be discharged to the environment.

***Barium 133** – This substance is used within a Completion Profiler tool which is used in order to determine the type of fluid that is encountered downhole. However, this particular tool is no longer expected to be used as part of the Tight Gas Pilot project. Similarly, as noted above, this substance is contained within a fully sealed unit and is not discharged to the environment.*

***Iridium Oxide, Antimony Oxide & Scandium Oxide -** These three substances comprise the radioactive source within the ZeroWash tracer as described in section 5.8 of the main text of the AEE.*

***Thorium Silicate –** This substance is used within a Thorium Calibration Blanket which contains a small 5uCi source that is required to calibrate the SpectraScan tool just prior to its use within the well. The calibration blanket is only used at the surface and will be stored safely when not in use. This substance is not discharged to the environment.*

As noted above, Americium 241, Barium 133 and Thorium Silicate will not be discharged to the environment. MSDS for these substances were included within the hydraulic fracturing AEE for completeness and to provide full disclosure regarding the overall tracer operation.

Allegation 2: *given the half-lives of americium, thorium and barium are so long, it could be a very long time until levels of radioactivity for these tracers are safe, after their release into the environment*

Response: There is no proposal to release these substances into the environment. But in any case, this view confuses the half-life of an element's radioactivity (a measure of the period over which it remains radioactive) with its level of activity (which indicates the amount of radiation coming off at any one time and hence whether the source is 'safe'). A 'half-life' indicates the length of time required for the radioactivity of an isotope to decline to half the radioactivity present at the start of measurement. It does not indicate whether the level of radioactivity at any time is safe or dangerous.

As noted above, many substances, including everyday substances and also those used in tracer work in drilling and fracturing, can have a very low level of radioactivity; but some of these may well remain radioactive (at a constantly diminishing rate) for some time. This does not mean they are dangerous for any or all of that time. The determinant of risk is how much radiation is coming off a source, not how long it continues to be emitted.

A half life can be very short for some radioactive isotopes, or extend over millions of years in the case of others. Radioactive tracers commonly used in drilling and fracturing operations (either in New Zealand or overseas) include bromine-82, with a half life of 35 hours; iodine-125: half life 59 days; iodine-131: half life 8 days; lanthanum: half life 40 hours; iridium-192: half life 74 days; antimony-124: half life 60 days; and scandium-46: half life 84 days. Radon, the radioactive gas that attracts a lot of attention and concern overseas, has a half life of 3.8 days.

Allegation 3: *the Council should have tested for alpha radiation as well as gamma radiation when monitoring the land treatment sites. Testing only for gamma radioactivity is inadequate.*

Response: as noted above, gamma radiation is almost always present whenever there is radioactivity. The absence of any gamma radiation above natural background levels is a very strong indicator that other forms of radiation are absent also (see section 1.2 above).

This is supported by the advice provided by NRL (see section 2.4 .3 above).

It has subsequently been validated by the results of analyses specifically for both alpha and beta radiation conducted on samples of produced formation water (see section 2.5 above).

Allegation 4: *Council officers asked how to use the [Geiger counter] and read the results… the 'experts' are not up to speed.*

Response: This comment misrepresents the enquiry referred to. It is a matter of established Council practice that it seeks expert peer review to provide an authoritative and independent assurance that the Council's investigations and resultant findings are robust and defensible. This is a basic quality control measure. In the case in question, the Council officer was at pains to seek review of both the mode of measurement, and of the results. Far from this being evidence the '*experts are not up to speed*', the response by the acknowledged authority shows that the work was credible.

3. Summary

In summary:-

- The Council has sought and received assurances at all points, from the competent statutory authorities, that the use and management of radioactive materials within the hydrocarbon exploration and production sector as established in Taranaki is lawful, and is not harmful to human health;
- The Council has sought and received assurances at all points, from the competent statutory authority and expert body, that based on the samples measured to date, the release of any NORMs during hydrocarbon exploration and production as established in Taranaki is not harmful to human health[7];
- The Council has undertaken its own surveys of radioactivity in produced fluids and radiation from soil levels at land remediation sites, to ensure from its own direct measurement that the release of radioactive materials from these sources is not harmful to human health. Measurements have confirmed that this is indeed the case, and indeed neither radioactive tracers as used in fields in Taranaki nor NORMs that are present in Taranaki fields are 'radioactive' in terms of statutory definitions, and contain levels of radioactivity orders of magnitude below those at which controls are required;
- The Council has been repeatedly advised by the competent authority and has repeatedly found on its own account, that the levels of radioactivity associated with these activities would give rise to exposures comparable to normal, everyday exposure for an average person;
- The determinations made by GNS and the NRL in 1995 are worth re-iterating:

  'I find it very difficult to conceive of a credible concern for the health of the general public in the vicinity of a natural gas field'… 'radon levels in New Zealand do not constitute a health risk. The level is lower than the world average and we have no areas of elevated radon concentrations'.

- In summary, the Council finds no evidence of a health or environmental issue arising from the use of radioactive tracers, the use of radioactive materials within well logging activities, disposal of drilling wastes potentially containing radioactive materials, or the release of naturally occurring radioactive materials (NORMs) during exploration or production.

[7] ESR note that they cannot rule out the possibility that an accumulation of radioactive scale within equipment could occur. The Council notes that even if such a possibility were to eventuate, scale build-up would be an issue that would be very specific in terms of occurrence, magnitude, and potential consequences, and would be primarily a workplace rather than wider public health or environmental issue.

Glossary of common terms and abbreviations

The following abbreviations and terms are used within this report:

Alpha radiation	a form of radiation consisting of particles comprising 2 protons and 2 neutrons
Becquerel	a level of radioactivity, of 1 transformation (atomic disintegration) per second.
Beta radiation	a form of radiation consisting of electrons
Gamma radiation	a form of radiation consisting of high energy electromagnetic radiation
Geiger counter	a device for measuring radiation (usually gamma, but it can be adjusted to detect other forms also)
Kilobecquerel	1000 becquerel
Megabecquerel	1,000,000 becquerel
NORMs	Naturally occurring radioactive materials
NRL	National Radiation Laboratory
nSv/h	nanoSieverts per hour. A Seivert is the measure of the effect on biological tissue of a received dose of radiation (effective dose). One nSv is one-thousandth of one millionth of a sievert.

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Appendix 1

Section 4 and Schedule 1 of the National Radiation Regulations 1982

Part 2
Exemptions

4 Partial exemption of certain radioactive materials

- (1) Subject to subclause (2) and regulations 14(2) and 15, nothing in section 12 or section 13(1) of the Act, or in these regulations, shall apply to the manufacture, production, sale, storage, transport, or use, of any radioactive material that contains—
  - (a) either—
    - (i) a quantity of a radionuclide not exceeding in activity the activity set for radionuclides in the group in which it appears in the table in clause 2 of Schedule 1; or
    - (ii) a mixture of radionuclides the sum of the relative activities of which does not exceed 1; or
  - (b) either—
    - (i) a radionuclide at a concentration not exceeding the concentration set for radionuclides in the group in which it appears in the table in clause 3 of Schedule 1; or
    - (ii) a mixture of radionuclides the sum of the relative concentrations of which does not exceed 1.

(2) Subclause (1)(a) shall not apply unless—

- (a) the following conditions exist:
  - (i) the radioactive material, if unpackaged, or the package containing the radioactive material, bears a label as described in clause 2 of Schedule 2; and
  - (ii) the radioactive material is not contained in an article the use of which would require it to be carried by any person, or to be at a distance of less than 300 millimetres from any person; or
- (b) the radioactive material contains a radionuclide, or a mixture of radionuclides, the activity of which does not exceed 0.1 of the activity specified in the said subclause (1)(a) or 3 kilobecquerels, whichever is the greater.

(3) Nothing in section 12 or section 13(1) of the Act, or in these regulations, shall apply to the sale, import, export, storage, transport otherwise than for the purposes of exportation, or use of any article of a kind described in the first column of

Schedule 3 of these regulations if and so long as the article conforms with the conditions set out in the second column of that schedule in relation thereto:

provided that regulation 14(2) shall apply to the articles described in Part 2 of that schedule.

(4) Nothing in section 13(1) of the Act, or in these regulations, shall apply to the use by any person, with the approval of the Director-General and in accordance with any conditions that the Director-General may impose (which may include conditions regarding the attachment of labels and for ensuring safe disposal), of an article of a type specified by the Director-General, which contains a radioactive material, but which, in the opinion of the Director-General, does not constitute a significant hazard to any person.

Schedule 1
Activities and concentrations of radioactive materials

rr 2, 4

1 Interpretation

(1) One becquerel is an activity of 1 transformation per second.

(2) For the purposes of these regulations, when the transformation of the atoms of a radionuclide gives rise to another radionuclide, the activity is measured by the rate of transformation of the first or "parent" radionuclide only.

(3) The classification of any radionuclide may, if it is not shown in clause 2 or clause 3, be obtained on application to the Director of the National Radiation Laboratory.

2 Groups of radionuclides in relation to activities

The groups of radionuclides referred to in paragraph (a) of regulation 4(1), and the corresponding activities are those set out in the following table:

Activity referred to in regulation 4(1)(a)	Radionuclides (listed by symbols)
3 kilobecquerels	Ra–226, Ra–228, Ac–227, Th–228, Th–230, Th–232, Pa–231, U–232, Np–237, Pu–238, Pu–239, Pu–240, Pu–242, Pu–244, Am–241, Am–242m, Am–243, Cm–242, Cm–244, Cf–252
10 kilobecquerels	Nd–144, Sm–147, Pb–210, U–233, U–234, U–235, U–236, U–238, Pu–241
30 kilobecquerels	P–32, Ti–44, Rb–86, Sr–89, Sr–90, Y–91, Ru–106, Cd–115m, In–114m, Sn–125, Te–129m, Ce–144, Po–208, Po–210, Ra–223, Th–227, Th–234, U–230

Activity referred to in regulation 4(1)(a)	Radionuclides (listed by symbols)
100 kilobecquerels	K–40, As–76, Y–90, Sb–122, Sb–124, Te–132, I–129, I–131, Ba–140, Dy–166, Rn–222, Ra–224
300 kilobecquerels	Na–22, Na–24, K–42, Ca–47, Sc–46, V–48, Mn–52, Fe–59, Co–60, Ga–67, As–74, Y–88, Zr–95, Mo–99, Ag–110m, Cd–115, Te–131m, Cs–134, Cs–136, Cs–137, Ba–133, La–140, Ce–143, Eu–152B, Eu–154, Tb–160, Ho–166, Tm–170, Ta–182, Re–188, Os–185, Ir–192, Au–195, Bi–206, Bi–207, Bi–210, Pa–230
1 megabecquerel	Cl–36, Sc–48, Mn–54, Co–56, Co–58, Zn–65, Ga–72, As–73, Se–75 Br–82, Kr–85, Sr–85, Y–87, Nb–95, Tc–96, Ru–103, Ag–105, Ag–111, Sn–113, In–115, Sb–125, Te–127m, I–126, La–138, La–140, Ce–141, Pr–143, Nd–147, Pm–149, Yb–164, Lu–176, Hf–181, W–181, Re–183, Re–186, Os–193, Ir–190, Pt–193m, Pt–193, Au–196, Au–198, Tl–202, Tl–204, Th–231
3 megabecquerels	Ca–45, Sc–47, Cr–51, Mn–56, Co–57, Ge–71, As–77, Rb–87, Zr–93, Tc–97, Tc–97m, Tc–99, Ru–97, Pd–103, Cd–109, In–111, Sn–119m, Te–125m, I–125, Xe–133, Cs–131, Ba–131, Pm–147, Sm–151, Sm–153, Eu–155, Yb–169, Yb–175, Lu–177, W–185, Os–191, Pt–191, Au–199, Hg–197m, Hg–197, Hg–203, Tl–200, Tl–201, Pb–203, Pa–233, Np–239
10 megabecquerels	Be–7, C–14, Fe–55, Ni–63, I–132, Xe–131m, Cs–135, Gd–153, Er–169, Tm–171, Rh–105
30 megabecquerels	F–18, P–33, S–35, Ni–59, Nb–93, I–123, Re–187
100 megabecquerels	Cu–64, Sr–87m, Tc–99m
300 megabecquerels	In–113m
1 gigabecquerel	H–3
300 gigabecquerels	Ar–37

3 Groups of radionuclides in relation to concentration

- The groups of radionuclides referred to in paragraph (b) of regulation 4(1) and the corresponding concentrations, are those set out in the following table:

Concentration referred to in regulation 4(1)(b)	Radionuclides (listed by symbols)
100 kilobecquerels per kilogram	Na–22, Sc–46, Ti–44, V–48, Mn–52, Mn–54, Fe–59, Co–56, Co–58, Co–60, Zn–65, Y–88, Zr–95, Ag–110m, In–111, In–113m, Sb–124, Cs–134, Cs–136, Cs–137, Ba–133, Ba–140, La–138, La–140, Sm–147, Eu–152, Eu–154, Tb–160, Yb–169, Lu–176, Ta–182, Os–185, Ir–192, Pb–210, Bi–206, Bi–207, Po–208, Ra–226, Ra–228, Ac–227,

Concentration referred to in regulation 4(1)(b)	Radionuclides (listed by symbols)
	Th–228, Th–230, Th–232, Pa–231, U–232, U–233, U–234, U–235, U–236, U–238, Np–237, Pu–238, Pu–239, Pu–240, Pu–241, Pu–242, Pu–244, Am–241, Am–242m, Am–243
300 kilobecquerels per kilogram	Na–24, K–40, Ca–47, Sc–48, Co–57, Ga–67, Ga–72, As–74, Se–75, Br–82, Sr–85, Sr–90, Y–87, Nb–95, Tc–96, Ru–106, Ag–105, Sn–113, Te–131m, Te–132, I–126, I–129, Ba–131, Ce–144, Hf–181, Re–183, Ir–190, Pt–193, Au–195, Hg–203, Tl–202, Po–210, Rn–222, Ra–223, Ra–224, Th–227, U–230
1 megabecquerel per kilogram	Mn–56, Rb–86, Y–91, In–114m, Sn–119m, Sb–122, Sb–125, Te–129m, I–131, I–132, Eu–155, Gd–153, Yb–164, W–181, Au–196, Au–198, Tl–200, Tl–204, Pb–203, Th–234, Pa–230
3 megabecquerels per kilogram	Be–7, F–18, P–32, Cl–36, K–42, Sc–47, Cr–51, Cu–64, As–76, Kr–85, Sr–89, Y–90, Mo–99, Ru–97, Ru–103, Cd–109, Cd–115, Cd–115m, Sn–125, Te–125m, Te–127m, I–125, Cs–131, Ce–141, Ce–143, Nd–147, Dy–166, Tm–170, Os–191, Pt–191, Au–199, Tl–201, Bi–210, Np–239
10 megabecquerels per kilogram	Ca–45, As–73, Tc–97, Tc–99, Tc–99m, Rh–105, Ag–111, I–123, Xe–131m, Xe–133, Pr–143, Pm–149, Sm–153, Ho–166, Yb–175, W–185, Re–186, Re–188, Os–193, Hg–197, Hg–197m, Pa–233
30 megabecquerels per kilogram	C–14, P–33, Ni–63, As–77, Zr–93, Nb–93m, Tc–97m, Pd–103, Cs–135, Pm–147, Sm–151, Er–169, Tm–171, Lu–177
100 megabecquerels per kilogram	S–35, Fe–55, Ni–59, Sr–87m, Pt–193m, Th–231
300 megabecquerels per kilogram	Ar–37, Ge–71
3 gigabecquerels per kilogram	H–3