Radiological Protection Institute of Ireland
An Instituúid Éireannach um Chosaint Raideolaíoch

Radioactivity in Bottled Water Produced in Ireland

RADIATION UNITS

Radioactivity is measured in units called becquerels (Bq). One becquerel corresponds to one radioactive disintegration per second.

When measuring radioactive discharges to the environment or referring to the content of radioactive sources used in medicine, industry and education, it is more usual to talk in terms of kilobecquerels (kBq), megabecquerels (MBq), gigabecquerels (GBq) or terabecquerels (TBq)

1 kBq = 1000 Bq

1 MBq = 1,000,000 Bq

1 GBq = 1,000,000,000 Bq

1 TBq = 1,000,000,000,000 Bq

Much lower concentrations of radioactivity are normally found in the environment and so the measurement is often reported in units of millibecquerels (mBq). There are one thousand millibecquerels in a becquerel.

1 Bq = 1000 mBq

Radiation Dose When radiation interacts with body tissues and organs, the radiation dose received is a function of factors such as the type of radiation, the part of the body affected, the exposure pathway, etc. This means that one becquerel of radioactivity will not always deliver the same radiation dose. A unit called 'effective dose' has been developed to take account of the differences between different types of radiation so that their biological impact can be compared directly. Effective dose is measured in units called sieverts (Sv).

The sievert is a large unit, and in practice it is more usual to measure radiation doses received by individuals in terms of fractions of a sievert.

1 sievert = 1000 millisievert (mSv)

= 1,000,000 microsievert (μSv)

= 1,000,000,000 nanosievert (nSv)

In RPII reports the term 'effective dose' is often referred to as 'radiation dose' or simply 'dose'.

Collective dose is the sum of the radiation doses received by each individual in the population. This allows comparison of the total radiation dose received from different sources. Collective dose is reported in units of man sieverts (man Sv) or man millisieverts (man mSv).

Per caput dose is the collective dose divided by the total population. Per caput dose is reported in units of sieverts, or fractions of a sievert.

RPII 13/05

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Executive Summary

All water contains trace amounts of naturally occuring radioactivity. With this in mind the RPII has completed a survey of levels of natural radioactivity in 21 samples of bottled water produced in Ireland.

All of the 21 bottled water samples complied with the radiological quality requirements of Statutory Instrument (S.I) 225 of 2007,the World Health Organisation(WHO) recommendations and the new Euratom Drinking Water directive.

The samples which give rise to the highest doses of radioactivity would not add significantly to the average annual dose received by people living in Ireland.

Introduction

The World Health Organisation(WHO) recommended daily fluid intake, including moisture from food, for an average adult is approximately two litres (WHO, 1993). For many people bottled water offers a convenient choice to stay hydrated. Naturally sourced bottled waters are by far the most popular choice across the European Union: natural mineral water and spring waters together represent 97 % of the market volume.

Per capita consumption of bottled water in the European Union varies enormously from one country to another with the average consumption at 104 litres a year. Ireland has a relatively low consumption level compared to other European countries, Figure 1 (European Federation of Bottled Waters, 2013).

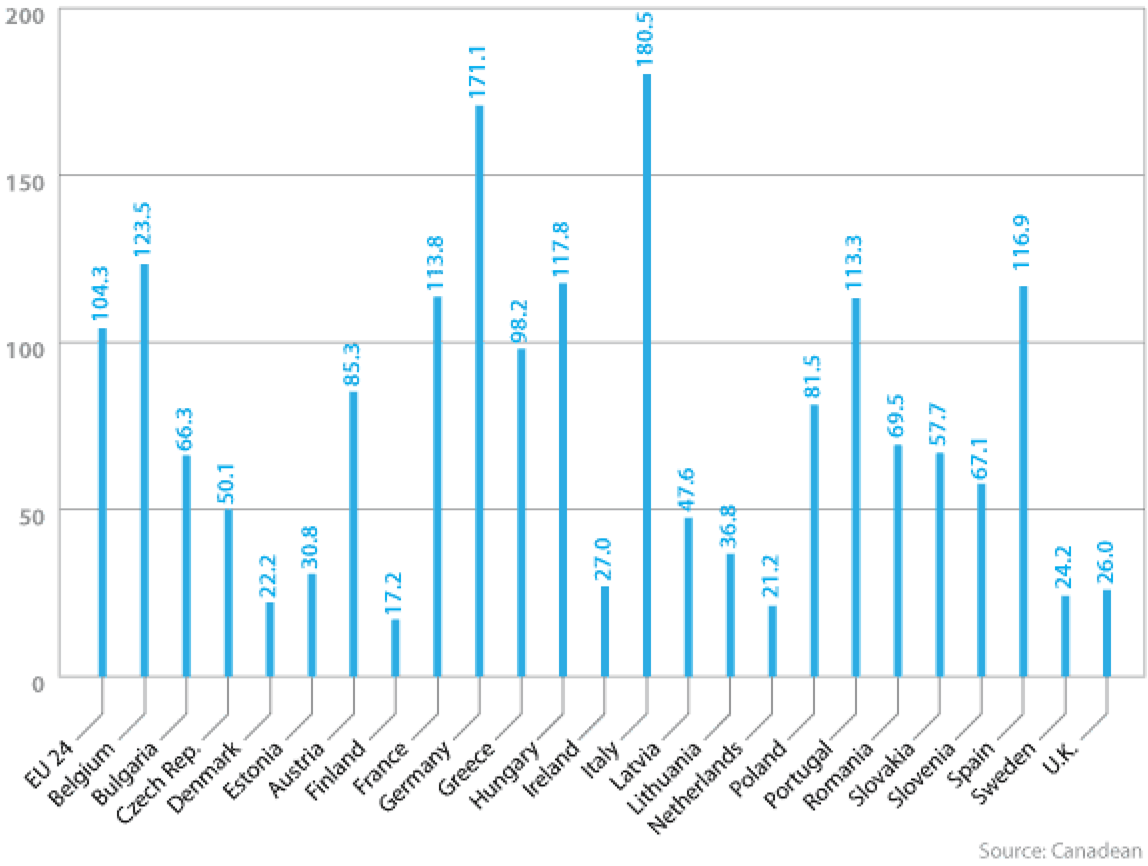
Radionuclides from the natural decay series are ubiquitous in the earth's crust and they infiltrate natural water and enter the drinking water cycle. The contribution of drinking water from all sources to total exposure to radionuclides is typically very small and is due largely to naturally occurring radionuclides in the uranium and thorium decay series. Under the Radiological Protection Act, 1991, the RPII is required to monitor radioactivity in drinking water (Ireland, 1991).

The RPII's annual drinking water monitoring programme is focussed on public supplies serving large population centres which comprise mainly of surface water supplies or large aquifers (McGinnity P., Currivan L., Dowdall A., Hanley O., Kelleher K., McKittrick L., Somerville S., Wong J., Pollard D., McMahon C., 2012). In addition a comprehensive study of natural radioactivty in groundwater sources in Ireland has recently been completed (Dowdall A., et al, 2012). As a consequence the current state of knowledge concerning radioactivity in these supplies is comprehensive.

Although Irish people typically consume 27 lires of bottled water per year no comprehensive picture of radioactivity from this source existed prior to this study. Furthermore, levels of naturally occurring radioactivity in bottled water may be high as it is often sourced from groundwater which comes into contact with bedrock and soil containing elements such as those in the uranium and thorium decay series (WHO, 2006).

To address this knowledge gap, a survey of natural radioactivty in bottled water produced in Ireland was undertaken by the RPII. The study comprised sampling and analysis of 21 bottled waters. The main drivers of this study were to establish levels of natural radioactivity in bottled water produced in Ireland and to assess compliance of these products with the Drinking Water Directive (DWD) (European Communities, 1998) .

Figure 1 EU and individual country per capita consumption of bottled water in 2012 (litres)



Regulations governing radioactivity in bottled water and assessment of compliance

Radioactivity requirements of the Drinking Water Directive

The European Communities Drinking Water Directive (DWD) (European Communities, 1998) on the quality of water intended for human consumption sets out standards for drinking water.

In Ireland bottled water is covered by European Communities (Natural mineral waters, spring waters and other waters in bottles or containers) Regulations, 2007 (S.I. No. 225 of 2007) (Ireland, 2007b). This legislation covers the definition of natural mineral water, spring water and 'other water', their exploitation, treatment, microbiological criteria, chemical contaminants, sales description, labelling and packaging. In addition spring waters and 'other waters' must also comply with European Communities (Drinking water)(No. 2) Regulations, 2007, S.I. No. 278 of 2007 (Ireland, 2007a).

With regard to radioactivity, the Directive, and Statutory Instruments, set parametric standards for tritium and total indicative dose (TID) as set out in Table 1.

Table 1: Parametric values for radioactivity from S.I. 225 of 2007

Parameter	Parametric Value
Tritium	100 Bq/l
Total indicative dose[a]	0.10 mSv/y

[a]Excluding tritium, potassium-40, radon and radon decay products.

WHO recommendations on drinking water

Current WHO guidelines recommend that any water which could lead to an annual exposure to radiation of more than 0.1 mSv per year should be investigated further. This is known as the reference dose level. The Total Indicative Dose (TID) is the committed effective dose for one year of intake resulting from all the radionuclides whose presence in a water supply has been detected, of both natural and artificial origin, excluding tritium[1], potassium–40[2], radon[3] and radon decay products. In Ireland, the annual dose from natural background radiation is estimated to be 3.4 mSv/y (Colgan P.A., Organo C., Hone C., Fenton D., 2008) and a TID of 0.1 mSv/y therefore represents less than 3% of this dose.

The TID is calculated using measured radionuclide concentrations, dose coefficients for adults laid down by the International Commission on Radiological Protection (ICRP) in its Publication 72 (ICRP, 1996) and consumption rates.

In assessing compliance of water supplies with the TID parametric value the RPII applies the World Health Organisation recommendations on drinking water (WHO, 1993). This approach is

[1] Tritium is excluded as a parametric value of 100 Bq/l for this radionuclide is set out separately in the DWD.
[2] Potassium-40, a naturally occurring radionuclide, is a key element in regulating many bodily functions such as digestion, heart rate and the water content of cells. Levels in the body are naturally regulated by metabolic processes and not significantly influenced by intake levels. Therefore, potassium-40 is excluded from TID.
[3] Radon and radon decay products are also excluded because radon is volatile and will not be detected by the gross alpha and beta screening procedure.

consistent with that set out in the recently adopted Euratom drinking water directive (European Commission, 2013).

In practical terms, the process of identifying individual radionuclides in drinking water and determining their concentrations is time consuming and expensive. In most circumstances, the concentrations are low, and such detailed analysis is normally not justified for routine monitoring. A more practical approach is to use a screening procedure, where the total radioactivity present in the form of alpha and beta radiation is first determined, without regard to the identity of specific radionuclides. These measurements are suitable as a preliminary screening procedure to determine whether further radioisotope-specific analysis is necessary (WHO, 2011).

The methodology described by the WHO (1993) for controlling radiological hazards in drinking water has two stages:

- initial screening for gross alpha and/or beta activity to determine whether the activity concentrations are below levels at which no further action is required; and
- if these screening levels are exceeded, investigation of the concentrations of individual radionuclides

The recommended screening levels for gross alpha and gross beta activity are 100 and 1,000 mBq/l, respectively. If the radioactivity concentrations in the drinking water is below these screening values, then the water source is considered to be in compliance with DWD, i.e. the dose arising from one year's consumption of drinking water does not exceed 0.1 mSv. Such drinking water is considered acceptable for human consumption from a radiological perspective and no action to reduce radioactivity is necessary.

Where a screening level is exceeded, then further analysis to identify the radionuclide(s) contributing to the elevated activity is required in order to calculate the resulting radiation dose to consumers. In this study the concentrations of the uranium isotopes, Ra-226 and Po-210 and their contribution to gross alpha activity were assessed. The thorium isotopes were not considered as thorium is relatively insoluble in water at neutral pH values (Beyermann, M., Bünger, Schmidt, K. And Obrikat, D., 2010). The dose arising from each radionuclide was calculated assuming a consumption rate of two litres per day, the standard WHO drinking water consumption rate (WHO, 2011). The WHO guidelines also note that the dose of 0.1 mSv would be exceeded only if the exposure to the measured concentrations were to continue for a full year.

Tritium, a radioactive isotope of hydrogen exists in the atmosphere principally in the form of water vapour and precipitates in rain and snow (Eisenbud, 1997). Previous routine monitoring by the RPII has established that levels of tritium are well below the parametric value specified in the DWD (RPII, 2010). There are currently no tritium discharges in the water catchment areas in Ireland. For these reasons, analysis for tritium was not carried out as part of this study.

It is important to emphasise that the above requirements apply to existing or new water supplies that are intended to be placed on the market in a bottle. They are not intended to apply to a water source temporarily contaminated as a result of an emergency involving the release of radionuclides into the environment.

Contribution of naturally occurring radionuclides to gross alpha activity

The ICRP ingestion dose coefficients used to calculate indicative doses for naturally occurring alpha emitting radionuclides are presented in Table 2. Of the naturally occurring radionuclides, the uranium isotopes have the lowest ingestion dose coefficients. They are approximately 25 times lower than that of Po-210, which has the highest ingestion dose coefficient of the radionuclides of relevance. The WHO (WHO, 1993) gross alpha screening level of 100 mBq/l is based on the conservative assumption that all of the alpha activity is due to Po-210.

Assuming an intake of two litres of water per day, a concentration 117 mBq/l of Po-210 in a water source would give rise to a radiation dose of 0.1 mSv/y, whereas a concentration of 3000 mBq/l of uranium would be required to give the same radiation dose.

Table 2: Radiological data used to calculate indicative doses for drinking water

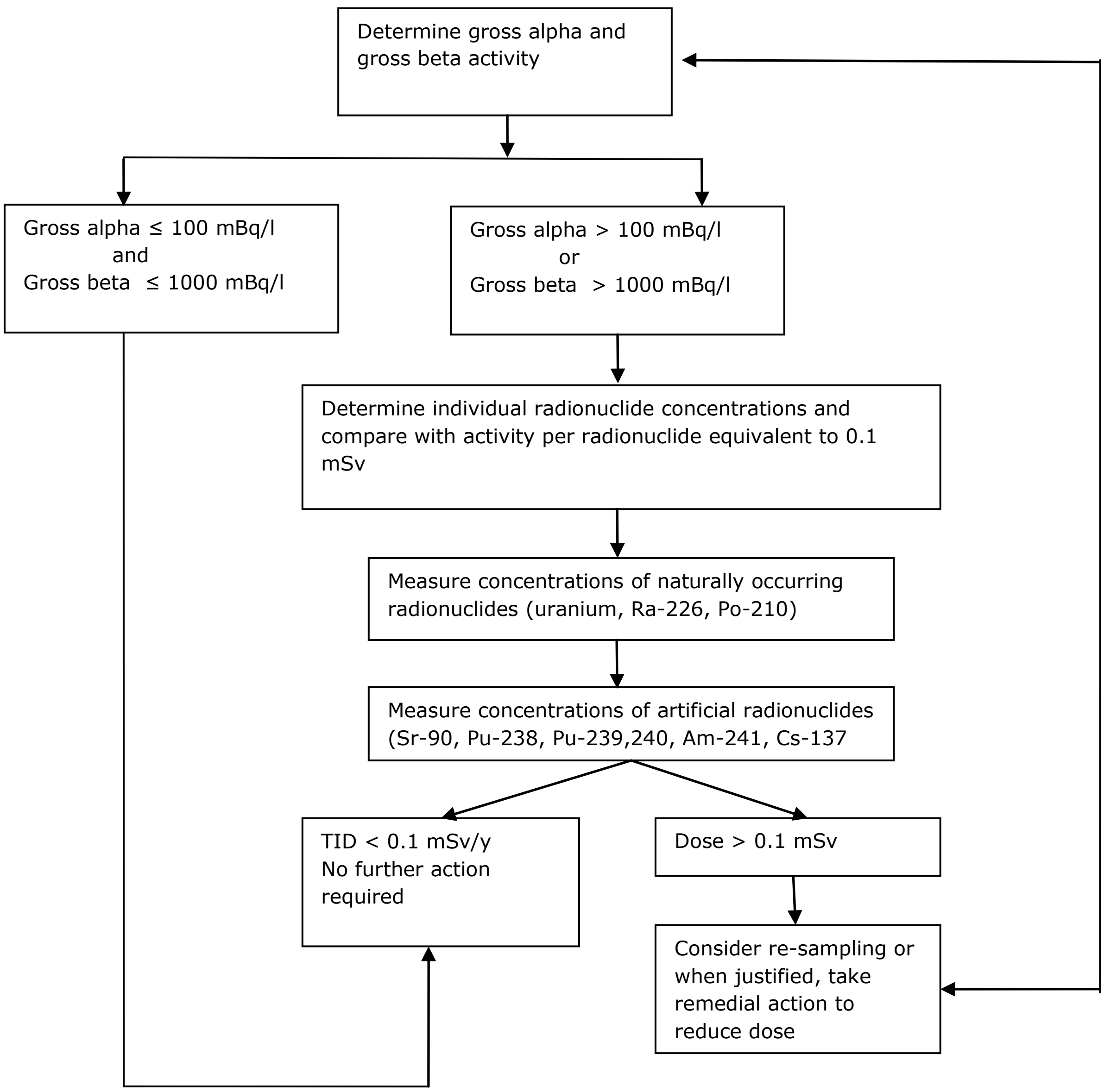
<table>
<tr><th>Radionuclide</th><th>Ingested Dose Coefficient for Adults (Sv/Bq)[a]</th><th>Activity per radionuclide (mBq/l) equivalent to 0.1 mSv</th></tr>
<tr><td>Po-210</td><td>1.2×10^{-6}</td><td>117</td></tr>
<tr><td>Ra-226</td><td>2.8×10^{-7}</td><td>500</td></tr>
<tr><td>Thorium-232</td><td>2.3×10^{-7}</td><td>600</td></tr>
<tr><td>Uranium-234</td><td>4.9×10^{-8}</td><td rowspan="3">3000</td></tr>
<tr><td>Uranium-235</td><td>4.7×10^{-8}</td></tr>
<tr><td>Uranium-238</td><td>4.5×10^{-8}</td></tr>
</table>

Note [a] Source: (ICRP, 1996)

Assessment of compliance

In this study, to assess compliance with S.I. 225 of 2007, samples were screened initially for their gross alpha and gross beta activity using the screening levels of 100 mBq/l and 1,000 mBq/l, respectively, as per Figure 2. Where the gross alpha activity exceeded 100 mBq/l, in the first instance, the uranium activity concentration was calculated from the uranium concentration measured chemically by the Irish Environmental Protection Agency, EPA.

Figure 2 Application of screening for radionuclides in drinking water



In a previous study carried out by Sequeira (Sequeira, S., Pollard, D., Smith, V., Howett, D., Hayden, E., Fegan, M., Dowdall, A., Brogan, C., O'Colmáin, M., Cunningham, J.D., 1999), it was demonstrated that despite its low ingestion dose coefficient, uranium typically contributes significantly to gross alpha activity in Irish drinking waters. On the assumption that uranium isotopes are present in their natural isotopic abundances, uranium activity concentrations were calculated using the method detailed in the appendix of this report. The uranium activity concentration thus calculated could then be subtracted from the gross alpha activity concentration.

Where the residual alpha activity was less than 100 mBq/l, it can be assumed that no other naturally occurring alpha emitting radionuclide or combination of alpha emitting radionuclides could result in a TID greater than 0.1 mSv/y. This is based on a worst case scenario that all remaining activity is attributable to Po-210 where an activity of 117 mBq/l would be required to give a TID of 0.1 mSv/y, Table 3. Thus, the water source is deemed to be in compliance with the WHO guidelines (WHO, 1993), the requirements for TID in S. I. 225 of 2007 and the new Euratom Drinking Water Directive (European Commission, 2013).

It should be noted when assessing gross alpha activity for compliance with the 100 mBq/l screening limit, a conservative approach was taken. Where the sum of gross alpha activity, including the combined standard uncertainty, was approximately 100 mBq/l or greater, then the water source was flagged as requiring further analysis. Where it could be shown on the basis of the uranium measurements that the gross alpha activity minus the contribution from uranium is still approximately 100 mBq/l or greater, then the individual concentrations of Ra-226 and Po-210 were determined and the dose arising from each component was assessed.

Summary of assessment criteria for bottled water produced in Ireland.

A summary of the assessment criteria used for bottled water produced in Ireland over the course of this study is presented in Table 3.

Table 3: Summary of assessment criteria for bottled water produced in Ireland

Analysis Type	Assessment Criteria
Gross Alpha	Screening limit of 100 mBq/l, above which further analysis required (WHO, 1993)]
Gross Beta	Screening limit of 1000 mBq/l above which further analysis required (WHO, 1993)
Uranium	3000 mBq/l (ICRP, 1996)
Ra-226	500 mBq/l (ICRP, 1996)
Po-210	117 mBq/l (ICRP, 1996)

Analytical Methods

Sampling

21 samples of bottled water were collected in plastic bottles by Environmental Health Officers from the Health Service Executive on behalf of RPII at wide range of bottled water producers in Ireland. Samples were acidified upon receipt to minimise adsorption of radioactivity onto the walls of the sample container.

All samples provided were uncarbonated (still) water. Each sample consisted of five litres of water from the same batch.

Analysis

A summary of the analytical techniques used for the determination of gross alpha and beta analysis, Ra-226, and Po-210 over the course of this work is presented in Table 4.

Table 4: Analytical techniques used in the assessment

Measurements	Analytical Techniques	Method Reference	Typical Minimum Detectable Activities	Typical Counting Uncertainties (k=1)
Gross alpha Gross beta	Evaporation and gas flow proportional counting	ISO/DIS 10704: Water quality—Measurement of gross alpha and gross beta activity in non-saline water—Thin source deposit method (ISO, 2008)	5 mBq/l (24 h count)	40% or better 30% or better
Ra-226	Gamma spectroscopy from activities of short-lived radon progenies (Pb-214 and Bi-214)	In-house method	50 mBq/l	40 % or better
Po-210	Evaporation and electrodeposition onto silver disc followed by alpha spectrometry	ISO standard 13161, Water quality - Measurement of Po 210 activity concentration in water by alpha spectrometry (ISO, 2011)	<0.5 mBq/l (4 day count)	30% or better

Gross Alpha and Beta Analysis

Gross alpha and beta determination is not an absolute determination of the sample alpha and beta radioactive content, but a relative determination referred to specific alpha and beta emitters that constitute the standard calibration sources (ISO, 2008).

An aliquot of the water sample was taken and evaporated to a deposit at a controlled temperature. The alpha and beta activity of the deposit was measured by counting in a gas flow proportional counter calibrated using Po-209 (alpha) and Sr-90/Y-90 (beta).

Uranium Calculations

The RPII carried out gross alpha and beta screening for all samples collected. Where the screening level of 100 mBq/l gross alpha was exceeded total uranium concentration (uranium-234, 235 and 238) for each sample was determined by the EPA, Ireland. These measurements were carried out using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) .The total uranium measurements were then used by RPII to calculate the activity concentration of uranium in mBq/l for each source and the consequent radiation dose (see Appendix). As shown in the calculation in the appendix a water source with a uranium concentration of 1 μg/l gives rise to a dose of less than 1% of the 0.1 mSv/y dose specified S.I. 225 of 2007.

Polonium-210

After sampling, the test sample undergoes a treatment which leads to an extremely thin deposit of the Po on a metal disc, for measurement by alpha spectrometry. As Po-210 has a half-life of 138.376days the sample was analysed as soon as possible to give an activity concentration on the sampling date.

The main steps of the sample treatment are:

- filtration if necessary
- acidification with concentrated nitric acid and addition of a Po tracer Po-209 solution
- addition of a reducing agent, ascorbic acid
- spontaneous deposition of a thin layer on to a metal disc.

The activity concentration measurement as well as the determination of the total yield is carried out by alpha spectrometry (ISO, 2011)

Radium-226

The water sample is evaporated to a dry residue. The residue was counted using high resolution gamma spectrometry. Ra-226 was determined by the 351 keV and 609 keV gamma rays of its Pb-214 and Bi-214 progeny. The equilibrium factor between radium and the radon progeny was determined from the exhalation rate of radon from the sample and the time interval between sample preparation and measurement.

Quality Assurance and Results

The RPII places a strong emphasis on quality assurance and reliability of data. Best laboratory practice is ensured by accreditation of test procedures, through the Irish National Accreditation Board, to International Standard ISO/IEC 17025 (INAB, 2012). For this study, ISO methods or methods based on ISO standards were used where possible. Details regarding the analytical techniques used by RPII are given in Table 4. Analytical techniques are validated both through exchange of samples with other laboratories and through analysis of certified reference materials for proficiency testing.

Results and Conclusions

Gross alpha and beta activity

Table 5 shows the gross alpha and beta activity concentrations and associated uncertainties for all analysed samples. Gross alpha activity in the samples ranged from below the limit of detection to 125 ± 19 mBq/l. Gross beta activity in the samples ranged from below the limit of detection to 658 ± 68 mBq/l.

Table 5: Gross alpha and beta activity concentration for bottled water produced in Ireland

RPII Sample Code	County	Alpha Activity (mBq/l)	Uncertainty (k=1)	Beta Activity (mBq/l)	Uncertainty (k=1)	Further Analysis Required
ES1200369	Cavan	< 34		45	12	No
ES1200320	Clare	< 28		< 47		No
ES1200319	Clare	< 23		40	11	No
ES1200310	Galway	48	12	90	15	No
ES1200326	Kerry	70	13	122	17	No
ES1200351	Kilkenny	125	18	150	19	Yes
ES1200367	Limerick	59	13	110	16	No
ES1200323	Limerick	55	15	130	27	No
ES1200364	Mayo	< 28		528	56	No
ES1200368	Meath	10	2	88	9	No
ES1200336	Monaghan	< 33		88	14	No
ES1200306	Monaghan	38	11	85	14	No
ES1200335	Monaghan	89	19	94	25	Yes
ES1200337	Monaghan	68	13	102	15	No
ES1200311	Sligo	< 22		52	10	No
ES1200321	Tipperary	< 30		263	29	No
ES1200362	Tipperary	46	13	116	19	No
ES1200363	Tipperary	70	14	87	17	No
ES1200322	Tipperary	< 37		386	41	No
ES1200324	Tipperary	65	12	658	68	No

Of the sources screened, all gross beta activity concentrations were below the WHO gross beta screening level of 1,000 mBq/l. Consequently no further action was required for these sources.

For 19 of the 21 samples, the gross alpha activity was below the WHO screening limit of 100 mBq/l and no further action was required for these sources. Initially, one of the bottled waters from Monaghan, was also found to have the gross alpha activity concentrations that may have exceeded 100 mBq/l when the sum of gross alpha activity and combined standard uncertainty was considered. Following a number of repeat measurements this sample was cleared (Table 6).

Table 6: Replicate analyses - Monaghan sample

RPII Sample Code	County	Alpha Activity (mBq/l)	Activity Uncertainty (k=1)	Beta Activity (mBq/l)	Activity Uncertainty (k=1)
ES1200335_1	Monaghan	89	20	94	26
ES1200335_2	Monaghan	< 53		105	27
ES1200335_3	Monaghan	< 53		118	22

The bottled water from Kilkenny was also found to have gross alpha activity concentrations that exceeded the 100 mBq/l screening level. Subsequent replicate analyses of the sample also indicated that the gross alpha activity was higher than 100 mBq/l with a mean gross alpha activity of 126 mBq/l (Table 7). Thus the Kilkenny sample was deemed to meet the criteria for requiring assessment of individual radionuclides.

Table 7: Replicate analyses - Kilkenny sample

RPII Sample Code	County	Alpha Activity (mBq/l)	Activity Uncertainty (k=1)	Beta Activity (mBq/l)	Activity Uncertainty (k=1)
ES1200351_1	Kilkenny	125	18	150	19
ES1200351_2	Kilkenny	111	18	148	19
ES1200351_3	Kilkenny	142	21	152	19

Uranium Activity Concentration

Analysis for uranium was carried out by the Irish Environmental Protection Agency, EPA. In the first instance, the contribution of uranium to gross alpha activity was estimated for the water source using the EPA's uranium measurements. The uranium activity concentration was calculated using equations (1) and (2) (see Appendix) and then compared with the gross alpha activity measured for the sample taken on the same date.

The concentration of uranium detected for the water sample was found to be 2.4 ug/l. When these concentrations were converted to activity concentrations in mBq/l, the uranium activity concentration was found to be 29.28 mBq/l.

It can be seen that uranium accounts for approximately 24% of the gross alpha activity. When the contribution of uranium activity concentration is subtracted from the gross alpha activity, the remaining gross alpha activity concentration (including the combined standard uncertainty) could still have exceeded the WHO screening level of 100 mBq/l and further investigation was required. Analysis for Ra-226 and Po-210 was carried out and the contribution of these radionuclides to alpha activity and to radiation dose was estimated.

Polonium-210 and Radium-226 activity concentrations

Ra-226 analysis was carried out for the Kilkenny sample. A Po-210 activity of 3 mBq/l was measured accounting for approximately 2.5% of the gross alpha activity. A Ra-226 activity concentration of 310 ± 30 mBq/l was measured[4]. A summary of activity concentrations for this sample is shown in Table 8.

Table 8: Summary of results for Kilkenny sample

Analysis Type	Activity Concentration mBq/l	Assessment Criteria (Table 2)
Mean Gross Alpha	126	100
Mean Gross Beta	150	1000
Uranium-238	29.28	3000
Ra-226	310	500
Po-210	3	117

Dose Assessment

The TID parametric value of 0.1mSv/y represents a very low level of risk that is not expected to give rise to any detectable adverse health effect. A conservative assessment of the radiation dose arising from consumption of the Kilkenny water sample was made using the following three scenarios:

1. Assuming an intake of two litres per day or 730 litres per year, the radiation dose for each radionuclide was calculated by multiplying the measured activity concentration by the relevant dose co-efficient. The Kilkenny sample from this survey could lead to an ingested dose of 0.07 mSv (Table 9). This is a conservative estimate as it assumes that an individual consumes two litres of this particular bottled water each day for a year.

[4] The Kilkenny sample was analysed for gross alpha and beta activity shortly after (24 hours) preparation, therefore, not allowing time for ingrowth of Ra-226 daughter products. This may account for the difference between the gross alpha activity and the Ra-226 activity.

Table 9: Calculated Dose for an Adult using WHO guidance

Radionuclide	ICRP adult ingestion dose coefficient (Sv/Bq)	Activity Concentration (mBq/l)	Annual Consumption rate (l)	Activity ingested per annum (Bq)	Dose to adult per annum (mSv)
U-238	4.50E-08	29.28	730	21.37	9.62E-04
Ra-226	2.80E-07	310	730	226.30	6.34E-02
Po-210	1.20E-06	3	730	2.26	2.72E-03
				Total	0.07

2. A survey undertaken by the European Federation of Bottled Waters (European Federation of Bottled Waters, 2013). in 2012 found that Irish people consume 27 litres of bottled water per year. Using this intake value, consumption of the Kilkenny bottled water would result in a total dose arising from ingestion of the water of 0.0025mSv (Table 10).

Table 10: Calculated Dose for an Adult using European Federation of Bottled Waters data

Radionuclide	ICRP adult ingestion dose coefficient (Sv/Bq)	Activity Concentration (mBq/l)	Annual Consumption rate (l)	Activity ingested per annum (Bq)	Dose to adult per annum (mSv)
U-238	4.50E-08	29.28	27	0.79	3.56E-05
Ra-226	2.80E-07	310	27	8.37	2.34E-03
Po-210	1.20E-06	3	27	0.08	1.00E-04
				Total	0.0025

3. Additional information supplied by the bottled water producer indicated that this spring water has been used as an ingredient in infant juice drinks. An upper bound of the dose that could be received by an infant through consumption of the juice drink mentioned above was estimated based on the following assumptions:

- The infant consumes one standard bottle of the juice drink per day i.e. 150 ml per day or 150 x 365 = 55 litres per annum.
- The spring water constitutes 93% of the final product e.g. the Ra-226 activity in the finished product is 310 x 0.93 = 288 mBq/l. The estimated dose is then 0.017 mSv, Table 11.

Table 11: Calculated Dose to an Infant of prepared infant juice

Radionuclide	ICRP adult ingestion dose coefficient (Sv/Bq)	Activity (mBq/l)	Annual Consumption rate (l)	Activity ingested per annum (Bq)	Dose to infant per annum (mSv)
U-238	1.20E-07	27	55	1.49	1.78E-04
Ra-226	9.60E-07	288	55	15.84	1.52E-02
Po-210	8.80E-06	3	55	0.17	1.45E-03
				Total	0.017

Further analysis of the Kilkenny sample for individual radionuclides demonstrated that the activity contributions of uranium, Po-210 and Ra-226 were found to be below those activity concentrations which would give rise to a dose of 0.1 mSv/y. Thus even taking very conservative assumptions this bottled water was shown to comply with the radiological requirements set out in legislation.

In conclusion all sources tested as part of this study were found to comply with the requirements for TID set out in S.I. 225 of 2007 and are fit for consumption with regard to radiological quality

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Appendix

Method to determine Uranium activity

Assuming that uranium isotopes are present in equilibrium and that therefore their natural isotopic abundances apply, the concentration of each isotope can be calculated using equation (1):

> *uranium isotope concentration (µg/l) = uranium concentration (µg/l) x natural isotopic abundance for each uranium isotope*

Then, using their respective specific activities (Table A1), the uranium activity concentrations (mBq/l) can be calculated using equation (2):

> *uranium isotope activity concentration (Bq/l) = uranium isotope concentration (µg/l) x specific activity of uranium isotope (Bq/ µg).*

For example, using the natural isotopic abundances and the specific activity of uranium isotopes, a concentration of 1 µg/l of total uranium is found to have an activity concentration of 25.8 mBq/l of alpha activity using equations (1) and (2):

> *1 µg/l of uranium = (1 x 0.000057 U-234) + (1 x 0.0072 U-235) + (1 x 0.9927 U-238)*
>
> *0.0258 Bq/l = (0.000057 x 2.30E+02) + (0.0072 x 8.00E-02) + (0.9927 x 1.22E-02)*

Finally, the dose due to uranium is calculated from the total activity concentration and the specific activity of uranium using equation (3):

> *Dose (Sv/year) = total activity concentration (Bq/l) x ingestion dose co-efficient (Sv/Bq) x intake of water per year (l)*

Again, using the example above and converting to millisieverts, using equation (3), the dose is calculated to be:

> *8.9E-04 Sv/year= (0.0258 Bq/l x 4.70E-08 Sv/Bq) x 1000*

Radionuclide	Ingested Dose Coefficient for Adults (Sv/Bq)[1]	Specific Activity (Bq/µg)	Natural Isotopic Abundance
U-234	4.90E-8	2.30E+02	0.000057
U-235	4.50E-8	8.00E-02	0.0072
U-238	4.70E-08	1.22E-02	0.9927
		Total	0.999957

Table A1 Ingested dose co-efficient for adults, natural isotropic abundances and specific activities for uranium isotopes

Note [1] Source: ICRP, 1996

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To ensure that people in Ireland are protected from the harmful effects of radiation

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