Executive summary

This is the final report for the Defra-funded project to 'Understand the Implications of the European Commission's (EC's) Proposals Relating to Radon in Drinking Water for the UK'. Ricardo-AEA led the 14 month study in collaboration with Public Health England (PHE) and the British Geological Survey (BGS). The aim of this project was to provide risk-based information to Defra and the UK Drinking Water Regulators to help them understand the implications for the UK of adoption of the new Directive under the Euratom Treaty (Council Directive 2013/51/Euratom).

The new Directive lays down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption. A parametric value of 100 Bq L^{-1} of radon has been introduced. However, Member States may set a level higher than 100 Bq L^{-1} but lower than 1,000 Bq L^{-1} which is judged 'inappropriate to be exceeded'. In addition, the new Directive specifies that the limit of detection of the method of analysis for radon should 10 Bq L^{-1}.

The project focussed on six objectives. These were:

1. Review existing knowledge on exposure to radon and its decay products, via air and drinking water, and any associated health implications, with particular regard to whether a value between 100 and 1,000 Bq L^{-1} can be established, which is judged 'inappropriate to exceed'.
2. Collate and review any data from water companies and from a selection of local authorities on the presence of radon in water supplies.
3. Review any data from the published and grey literature on the occurrence of radon in water supplies.
4. Review the understanding of how geological factors affect radon concentrations in water and create a map of drinking water risk areas.
5. Plot locations of public and private groundwater supplies on the risk map and report the number of supplies that fall in different risk areas.
6. Consider the availability and costs of methods of analysis for radon that can meet the specified performance requirements of the new Directive.

This final report combines two interim reports and includes additional data that had been obtained after the issue of those reports. This final conclusion to the project makes clear recommendations to DWI on how to take the findings forward, and areas for further study.

During objective 1 we carried out a literature review to gather data on exposure to radon following exposure via air and drinking water and the associated health implications (i.e. the hazard). An exposure assessment in terms of how the public would be exposed was also addressed as well proposing levels that would be 'inappropriate to exceed'. Exposure data obtained from objective 2 and 3 was compared with the proposed parametric value to gain an understanding of the implication of the use of such values, either in terms of potential health risk or in terms of potential remediation/treatment of water sources. In proposing a level of radon in water that should not be exceeded, various factors were reflected:

- The main route of exposure to radon from water is via inhalation, although oral exposure should also be considered. The dose from ingestion is small compared to the inhalation dose.
- Radon from ground and water sources both contribute to indoor air concentrations
- Radon from drinking water should be considered as an 'existing exposure situation' and managed using radiological criteria broadly consistent with those used for radon in air.

The main conclusion of objective 1 was that 1,000 Bq L^{-1} may be considered to be a level of radon in water that is 'inappropriate to exceed'. It corresponds to an indoor air concentration of radon that is similar to, but not much lower than, that used to manage radon in indoor air in the UK. It is also consistent with the new Directive that identifies this concentration as being that point above which remedial action is justified on radiological grounds without further consideration. Proposals are made for optimisation of protection below this level, as required in the new Directive.

Objectives 2 and 3 focussed on the exposure assessment in terms of the levels of radon in water supplies in the UK, by gathering data from water companies and local authorities (objective 2) and from a literature review of published and 'grey literature' (objective 3). Reported data obtained in objectives 2 and 3 suggested that the concentration of radon in the majority of water samples tested is below the suggested limit of 1,000 Bq L^{-1}, with the exception of some supplies in known radon-affected areas. Radon levels in public (treated) supplies were lower than levels in private supplies.

Objectives 4 and 5 focussed on creating a hazard identification map for radon in drinking water, based on an assessment of geological factors and aquifers and plotting the locations of water supplies on the map. If drinking water is derived from groundwater, the concentration of radon in the water will depend on the concentration of radon in the source aquifer, which in turn is controlled by uranium distribution, and to a limited extent by the aquifer's physical properties, especially pore size. The pathway from aquifer to consumer, and especially the extent to which water is stored and aerated, will affect the ultimate radon concentration.

Available data, collected in objectives 2 and 3, were combined with hydrogeological mapping to assess radon hazard. The relatively small number of samples available meant that it was necessary to supplement the radon in water data with information from radon in air potential mapping. Areas with Low Hazard were identified, in which waters are unlikely to reach the range of radon concentration (at least 100 to 1,000 Bq L^{-1}) above which monitoring and other action may be needed. Areas of High Hazard with elevated radon values are plausible and were, in some cases, identified. Moderate Hazard areas, between these extremes, may well not breach the parametric value, but there is little evidence to demonstrate this.

Only 2% of groundwater derived public supplies in England and Wales lie on High Hazard rock units. In Scotland this is 3%. Northern Ireland only has one groundwater-derived public supply, consisting of two co-located boreholes, and this is on an area of Low Hazard. A higher percentage of private supplies lie on High Hazard rock units; 28% of groundwater sources in England and Wales and 6% of sources in Scotland. Only 1% of sources in Northern Ireland are on High Hazard aquifers, but this is taken from a limited dataset and may be an underestimate.

For objective 6, we reviewed a number of analytical methods that exist for the determination of the activity concentration of radon in drinking water. All these methods are capable of meeting the performance characteristic described in the new Directive of 10 Bq L^{-1}.

The preferred analytical methodology selected by a laboratory will depend on its current testing capability and resources. Regardless of which method is selected, all collection and measurement systems must be included within an ISO 17025 accredited system which also conforms to the Drinking Water Testing Specification. Whilst these requirements are already well known to most laboratories, there are problems in applying it to the determination of radon in water due to the lack of suitable reference standards, particularly for field based methods.

Radon is present in UK drinking water supplies but generally at low concentrations. The lowest concentrations are generally observed in large volume public water supplies especially those derived from surface sources and where indoor radon levels in air are unlikely to be high. The highest concentrations of radon in water tend to occur in smaller, mainly private water supplies obtained from ground sources in areas where high levels of radon in air are most likely.

Key Recommendations

1*)* A concentration of 1,000 Bq L^{-1} of radon in a drinking water supply represents a level that should be considered 'inappropriate to exceed and below which optimisation of protection should be continued'. To meet the conditions permitted in the new Directive, it is proposed that this criterion should be expressed in the form: "concentrations at or above 1,000 Bq L^{-1} are considered inappropriate". This concentration yields an indoor concentration of air similar to that which is already used to manage radon entering buildings from the ground.

2) The parametric value should be retained at its default value of 100 Bq L^{-1} to support investigation and optimisation. Optimisation of protection should include consideration of intervention to reduce radon concentrations in the range 100 to 1,000 Bq L^{-1}, especially where they occur in water supplies serving multiple premises. Intervention to reduce radon concentrations in water supplies serving multiple premises may allow costs to be averaged over multiple properties to avoid exposures of the occupants of each property.

3) A scheme should be adopted, for public and private water supplies that uses hydrogeological and radon-related geological information together with evidence from existing measurements of radon in water, to identify geographical areas where the hazard of significantly elevated concentrations is assessed to be Low, Moderate or High. The Hazard Identification Scheme would enable effort to be focussed in areas where high concentrations are most likely to occur and would provide a basis for providing advice and making decisions about whether specific water supplies should be tested for radon. A preliminary Hazard Identification Scheme has been prepared for use and is described in detail elsewhere in this report.

4) In High Hazard areas, appropriate monitoring should be undertaken to identify where significant elevated concentrations of radon occur in water supplies that might require action to reduce concentrations. High Hazard areas are those where existing measurements of radon in water and supporting scientific evidence suggest that elevated concentrations are more likely to occur.

5) In Low Hazard areas, monitoring of radon in drinking water sources is considered not to be necessary for the purposes of identifying water sources that might require action. Low Hazard areas are those where evidence suggests that significantly elevated concentrations of radon in water are not expected.

6) In Moderate Hazard areas, appropriate monitoring should be undertaken to identify where significant elevated concentrations of radon occur in water supplies that might require action to reduce concentrations. Moderate Hazard areas are those where there is some evidence to suggest that significantly elevated radon levels may occur in water sources, but the prevalence and distribution of concentrations is expected to be lower than areas of High Hazard but there is insufficient evidence to support assignment to other hazard categories.

7) In each hazard band further measurements of radon in a range of water sources should be made to develop the evidence base and support future review and update of the Hazard Identification Scheme and the assignment of areas to the various hazard bands. The overall reported number of measurements of radon in water is limited and is less than 1% of the number available for radon in air. The measurements themselves are less standardised, they often represent spot samples at various points in the water network and some have poor quality location data. Improvements to the form and structure of the Hazard Identification Scheme could be achieved if the evidence base were improved.

8) Surface water sources that have any of the following characteristics (primarily fed from rainfall or a substantial river, long residence time (>few days) in a volume that is open to air, presence in sustained open air turbulent flow or agitation) are unlikely to have significantly elevated radon concentrations, irrespective of the local hazard band, and monitoring of radon in such sources is considered not to be necessary for the purposes of identifying water sources that might require action. Water sources that fall clearly into this category would be: rivers, reservoirs and lakes. The situation is less clear-cut for some surface sources, such as springs or streams with a nearby upstream spring source, that are likely to have had significant contact with radon emanating ground material. Once a water source has no or minimal contact with a solid matrix that emanates radon, the concentration of radon will reduce according to the radioactive half-life. An open water body that undergoes significant turbulence (e.g. flowing rivers) will lose a significant proportion of its radon content to atmosphere.

9) Further investigations should be made to clarify those types of water source that can be characterised as being 'surface water' with the aim of identifying the tangible characteristics that lead to low radon concentrations (e.g. one or more of the following: not directly derived from the ground (e.g. rainfall), long residence time, significant turbulence, significant open air boundary) and those that should be treated as having characteristics of ground water (e.g. derived from the ground with one or more of the following attributes: short residence time, low turbulence, limited open air boundary). The current database of radon measurements in water does not always clearly identify water sources (e.g. springs) that may have been sampled at a location where the water has the characteristics of 'ground water'.

10) The most relevant criterion for householders with a private non-shared water supply is 1,000 Bq L^{-1} since this protects at a level comparable with control of ground derived radon. The possible presence of such a level of radon can be indicated with a standard radon-in-air measurement. Most of the homes with such a water supply in High and Moderate Hazard areas, where the highest levels of radon in water are expected, are in the 1 km grid squares that contain radon affected areas. Radon testing is already advised in radon affected areas. Therefore existing advice to test for radon in air can also support the identification of homes that might have high indoor radon levels arising from a private water supply in these areas. For householders with private water supplies it may be appropriate to extend this advice, for the purpose of assessing risk from radon in water only, to include those homes lying anywhere in the 1 km grid squares that include radon affected areas. Online resources, including the radon indicative atlases and an interactive map, identifying these areas are already available on the Gov.uk and UKradon.org websites.

11) Some areas with identified private water supplies are classified as being at Moderate or High Hazard for radon in water but lie outside the 1 km grid squares that contain radon affected areas. In these areas there is presently no advice to test for radon and no published means of identifying them. Further investigations of levels of radon arising from private water supplies in these areas would identify whether the hazard map could be refined and/or further advice is needed.

12) A range of analytical testing methods are available, both laboratory based and in-situ, that can be used to determine radon concentrations in water within relevant concentration ranges, including a Minimum Detectable Concentration (MDC) of 10 Bq L^{-1}. A range of techniques were identified in the study, all capable of yielding reliable results and meeting the MDC criterion. Each of the analytical methods identified is considered acceptable for use in determining radon concentrations in water as long as it is undertaken by suitably trained staff and applied with appropriate quality controls.

13) A national database of measurements of radon in water should be established and maintained to provide the evidence base to support the future review of the Hazard Identification Scheme. Such a database would need to capture appropriate information (e.g. location, type of water source, sample date, method used) as well as providing appropriate privacy and information security controls.

14) The Hazard Identification Scheme should be reviewed in the light of additional measurements of radon in water made in a range of areas. The monitoring data should encompass measurements made to support risk assessment in areas of Moderate and High Hazard as well as a wider programme to enhance the evidence base across the range of hazard areas and types of water source.