Guidelines on compliance with the requirements of the Drinking Water Ordinance in the testing and evaluation of radioactive substances in drinking water

Recommendation of the BMUB, BMG, BfS, UBA, responsible state authorities, the DVGW and the BDEW

Imprint

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1 Introduction

On 22 October 2013, the Council of the European Union adopted Council Directive 2013/51/Euratom laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption [Euratom 2013]. The Third Ordinance amending the Drinking Water Ordinance, which came into force on 26 November 2015, implemented this Directive into national law [BMG 2015a]. Although the Drinking Water Ordinance, like the EC Drinking Water Directive, already contained requirements with regard to radioactive substances (for tritium an activity concentration of 100 becquerels per litre and for all other radionuclides – with the exception of tritium, potassium-40, radon and radon decay products – a total reference dose of 0.1 millisieverts per year), the necessary specifications that were needed to determine this, however, have so far been lacking.

Drinking water can contain increased amounts of natural radioactive substances, depending on the geology of the subsoil. Anthropogenic radionuclides (artificial radionuclides) in drinking water are only conceivable through uncontrolled releases from the handling of such radionuclides, e.g. from the handling of radioactive substances in medicine, research, technology and the use of nuclear energy.

On behalf of the then Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), the Federal Office for Radiation Protection (BfS) carried out an extensive research programme from 2003 to 2008 to determine data on the content of natural radionuclides in drinking water and the resulting radiation exposure [BfS 2009]. These studies have shown that there is a significant natural occurrence of radioactivity in drinking water in certain regions of Germany, especially in central and southern Germany. Radiation exposure to radionuclides in drinking water is very low on average and health hazards can generally be ruled out. Nevertheless, the BfS testing programme showed that the fluctuation range of the concentrations of natural radionuclides in drinking water is very wide, and that in individual cases precautionary measures to reduce these concentrations would be appropriate.

Based on these findings, Guidelines [BMU 2012] were drafted in 2012, at the instigation of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and under the auspices of the Federal Office for Radiation Protection (BfS) in cooperation with experts from various federal states and associations. The Guidelines formulated the missing requirements and criteria for testing and evaluating the quality of drinking water regarding radioactive ingredients and outlined ways of practical application. These Guidelines illustrated the state of professional and appropriate health care in the drinking water sector. They were based on the approaches outlined for this purpose in the recommendations of the World Health Organization [WHO 1993, 2004, 2011], in the EC Drinking Water Directive (including the drafts of the relevant implementing regulations) [EC 1998], in the recommendations of the European Commission and the German Commission on Radiological Protection (SSK) for radon-222 and its decay products in drinking water [EC 2001, SSK 2004], and in the results and conclusions from the drinking water measuring programme of the BfS [2009].

The above-mentioned recommendations [WHO 2011, EC 1998, SSK 2004] and the findings of the BfS drinking water measuring programme [BfS 2009] were the basis for Directive 2013/51/Euratom [Euratom 2013] adopted by the EU Council of Ministers in November 2013 and its national implementation in the framework of the amended Drinking Water Ordinance of 18 November 2015 (effective 26 November 2015) (BMG 2015a). Due to the now legally binding requirements, the 2012 Guidelines required revision – and this current version replaces it. These new Guidelines aim to contribute to a uniform understanding and to facilitate the implementation of the new regulations on the monitoring of radioactive substances in drinking water in the Drinking Water Ordinance [BMG 2016].

At their meeting on 28 September 2016, the state authorities responsible for drinking water monitoring in the States' Working Group on Environmental Health Protection (LAUG) welcomed the revised draft and recommended its implementation, following the adoption of individual amendments. At its meeting on 8 and 9 November 2016, the Technical Committee on Radiation Protection (FAS) noted with approval the revision of the Guidelines and welcomed their use in the harmonised implementation of the regulations on radioactive substances in the Drinking Water Ordinance.

The Federal Ministry for the Environment, Nature Conservation, Construction and Nuclear Safety (BMUB), the Federal Office for Radiation Protection (BfS), the Federal Ministry of Health (BMG), the Federal Environment Agency (UBA), the responsible state authorities as well as the German Technical and Scientific Association for Gas and Water e.V. (DVGW) and the Federal Association of the Energy and Water Industry (BDEW) thus recommend the application of the Guidelines – within the framework of testing and evaluating the drinking water quality – in their present form, which corresponds to the state-of-the-art of science.

2 Legal foundations

The Third Ordinance amending the Drinking Water Ordinance [BMG 2015a] lays down requirements for the measurement and monitoring of the drinking water quality regarding artificial and natural radioactive substances. Parameter values are specified for radon-222 (Rn-222), for tritium (H-3) and for the reference dose. With a view to determining the reference dose, measurable reference concentrations in drinking water of the dose-relevant natural radionuclides (uranium-238 (U-238), uranium-234 (U-234), radium-226 (Ra-226), radium-228 (Ra-228), lead-210 (Pb-210), polonium-210 (Po-210)) and the artificial radioactive nuclides (carbon-14 (C-14), strontium-90 (Sr-90), plutonium-239/240 (Pu-239/240), americium-241 (Am-241), cobalt-60 (Co-60), caesium-134 (Cs-134), caesium-137 (Cs-137), iodine-131 (I-131)) are specified. To verify and monitor compliance with the parameter values, requirements are formulated for sampling and the testing strategy, test sites and testing procedures, as well as specifications for the frequency of testing and the evaluation of the test results. Additional explanations can also be found in the Special Section (B) of the explanatory statement on the Drinking Water Ordinance [BMG 2015b]. These regulations are the basis for measures to reduce radioactive substances in drinking water in individual cases and for ensuring the quality of drinking water with regard to radioactive substances.

The operators and other owners of a water supply system are generally obliged to carry out testing of the drinking water with regard to radionuclides of natural origin. Since regular official monitoring of artificial radioactivity in the environment already takes place in Germany [BMU 1986, 2006a], further testing of the drinking water for 'artificial radionuclides' is usually not necessary.

In principle, the obligation to carry out tests only affects 'central waterworks' ('a-plants) pursuant to §3 (2)(a) of the Drinking Water Ordinance [BMG 2016] in order to avoid disproportionate expenditure for small business operations. Testing procedures in 'decentralised small waterworks' ('b plants', §3 (2)(b) of the Drinking Water Ordinance) may be ordered accordingly if higher concentrations of radioactive substances are to be expected. An obligation to test self-sufficiency plants (c-plants pursuant to §3 (2)(c) of the Drinking Water Ordinance) is not specified, but an obligation for the responsible authority to provide comprehensive information to the operators of such plants, if necessary, does exist [BMG 2015b].

If parameter values for radioactive substances are exceeded, the responsible authority checks whether there is a risk to human health from the point of view of radiation protection and whether measures to reduce the radionuclide content must be ordered [BMG 2016].

3 Terms, symbols and units

The following terms are defined in accordance with the glossary of the BMUB's 'Procedure manuals for monitoring radioactive substances in the environment and external radiation' [see Annex A-2, RADIZ 2009].

3.1 Activity

Activity is the number of nuclear transformations of a radionuclide or mixture of radionuclides occurring in a time interval, divided by the length of the time interval. The unit of activity is the becquerel (Bq) corresponding to one nuclear transformation per second or the millibecquerel (mBq, 1 mBq = 10^{-3} Bq).

3.2 Dose (radiation dose)

A measure of the biological effect of the absorbed ionising radiation, where one dose per unit of time is referred to as the dose rate. The unit of the dose is the gray (Gy) or milligray (mGy, 1 mGy = 10^{-3} Gy).

3.3 Effective dose

The effective dose is the sum of the organ doses in relevant organs and tissues multiplied by the corresponding tissue weighting factors. The unit of the effective dose is the sievert (Sv) or millisievert (mSv, 1 mSv = 10^{-3} Sv). The effective dose is a measure of the health risk associated with exposure to radiation.

3.4 Ingestion dose

An ingestion dose is the organ dose or effective dose resulting from the intake of radioactive substances with food and drinking water (ingestion). The effective dose through ingestion of drinking water is the sum of the products of the nuclide-specific activity concentrations with the respective nuclide-specific, committed dose coefficients [BMU 2001a] and the annual drinking water consumption.

3.5 Ionising radiation

Term for any particle radiation or electromagnetic radiation which is able to liberate electrons from atoms or molecules so that ions or residual molecules with a positive charge remain (ionisation), which are then able to trigger other ionisation or radical formation processes.

- Alpha radiation: particle radiation consisting of alpha particles (helium atom nuclei)
- Beta radiation: particle radiation consisting of beta particles (electrons)
- Gamma radiation: high-energy electromagnetic radiation (photon radiation).

3.6 Parameter value

For the purposes of the Drinking Water Ordinance (§3 (9)a), 'parameter values' are values *(note: activity concentration or reference dose)* for radioactive substances in drinking water. When these values are exceeded, the competent authority checks whether the presence of radioactive substances in drinking water poses a risk to human health that requires immediate action [BMG 2016]. Parameter values are given as activity concentrations in the Bq/l unit of measurement and as a reference dose per calendar year in the mSv/a unit of measurement.

3.7 Radioactivity

Characteristic of atoms (more precisely: atomic nuclei) to transform themselves without external influence (to decay) and to emit a characteristic ionising radiation while doing so.

3.8 Radionuclides

Unstable atomic nuclei that spontaneously decay while emitting ionising radiation are called radionuclides or radioactive nuclides.

3.9 Reference dose

The reference dose is an effective ingestion dose, which is a convention specific to the drinking water sector. It is defined in §3 (9)b of the Drinking Water Ordinance and should be understood as the effective ingestion-committed dose for one adult reference person (>17 years), as a result of the ingestion of all the radionuclides of both natural and artificial origin detected in drinking water for one year (except for tritium, Rn-222 and its short-lived decay products as well as potassium-40 (K-40)) [BMG 2016]. In the case of an adult reference person, drinking water consumption of 730 l per year should be assumed for the calculation of the reference dose (see Chapter 5.4).

3.10 Screening measurement, screening procedure

Screening is generally understood to be the implementation of a gradual selection process. In the context of the Drinking Water Ordinance [BMG 2016], screening procedures generally include the determination of sum parameters in the form of total activities of alpha or beta radiation-emitting radionuclides, in order to be able to estimate compliance with the reference dose.

3.11 Radiation exposure

Radiation exposure is generally defined as the effect of radiation on the human body.

4 Radioactivity in drinking water and radiation exposure

This chapter describes basic facts about radioactivity in drinking water and the resulting radiation exposure. For a more detailed description of the occurrence of radioactive substances in the water cycle (inter alia), please refer to the Technical Bulletin DVGW W 253 [DVGW 2008a].

4.1 Artificial radioactivity in drinking water

Artificial radionuclides derive mainly from the global fallout of above-ground nuclear tests in the years from 1950-1980 and from contamination as a result of the Chernobyl reactor disaster in 1986. In contrast, the Fukushima reactor disaster in 2011 did not have any demonstrable effects on drinking water in Germany. Artificial radionuclides are not currently being detected in drinking water in Germany (or are present only in extremely low concentrations).

In accordance with §47 and §48 of the Radiation Protection Ordinance (StrlSchV) [BMU 2001b], the emission of radioactive substances, e.g. from nuclear power plants or nuclear medical facilities, is subject to strict requirements and controls in order to avoid their discharge into the environment (and thus into drinking water) to the fullest extent.

It is practically impossible for artificial radionuclides to get into drinking water in normal operation, due to the limitations of the discharge of radioactive material through the waste water from nuclear facilities. The contribution of radionuclides of artificial origin to human radiation exposure through drinking water consumption is very low [BMUB 2015].

In accordance with the Euratom Treaty (Articles 35 and 36), the Federal Republic of Germany has been carrying out regular official monitoring of radioactivity in the environment since the 1950s (including in the environmental areas of surface water, groundwater, drinking water and waste water that are relevant for these Guidelines). The results are published on a regular basis (e.g. in annual 'Environmental Radioactivity and Radiation Exposure' reports published by the Federal Ministry for the Environment [BMUB 2015]).

On the one hand, monitoring is carried out by the official measuring stations of the federal states within the framework of the general monitoring of environmental radioactivity on the basis of the Precautionary Radiation Protection Act (StrVG) [BMU 1986, BMU 2006a]; on the other hand, it is carried out by the operators themselves and by independent experts through a contract for the monitoring of nuclear installations. In this case, monitoring is installation-related and based on §48 of the Radiation Protection Ordinance (StrlSchV) in accordance with the Guidelines for Emission and Immission Monitoring of Nuclear Installations (REI) [BMU 2006b].

Based on these legal foundations, groundwater, untreated water and drinking water samples are regularly taken at around 400 sampling points and tested for artificial radionuclides such as Cs-137, tritium and Sr-90. The sampling points are selected with the aim of detecting the occurrence of artificial radionuclides in drinking water at an early stage and taking any necessary measures.

If there are indications that the parameter values specified in Annex 3a Part I of the Drinking Water Ordinance [BMG 2016] may be exceeded, e.g. because radioactive substances have been released as a result of a nuclear accident or other event, the competent authority may order tests for artificial radionuclides.

If an event occurs that has a significant impact on the radiation exposure of the population and the contamination of the environment, monitoring will be intensified on the basis of the StrVG. If necessary, the BMUB sets dose and contamination levels which may not be exceeded and recommends appropriate measures to be taken by the competent federal state authorities where required.

4.2 Natural radioactivity in drinking water

Depending on the individual geological conditions, all rocks and soils contain natural radionuclides, especially those of the three decay series originating from uranium-238 (U-238), uranium-235 (U-235) and thorium-232 (Th-232), as well as the radionuclide K-40. These radionuclides can enter surface water and groundwater (including bank filtrate, fissure and tunnel water) to varying extents through complex solution and transport processes. The activity concentrations of the natural radionuclides in these waters and the relative activity proportions of the single nuclides can vary within wide limits and are (inter alia) dependent on:

- the (hydro)geological conditions on site,
- the uranium and thorium content of aquifer rocks,
- the half-life of the radionuclide,
- the element-specific chemical-physical properties of the radionuclide (e.g. solubility, sorption, complexing behaviour, oxidation levels).

On average, radiation exposure due to drinking water in Germany is low compared with the total natural and man-made radiation exposure of the population. The mean effective dose from drinking water consumption for the adult age group is approximately 0.01 mSv/a [BfS 2009]. The total natural radiation exposure, on the other hand, averages 2.1 mSv/a (see Table 1). It varies locally from 1 mSv/a to 6 mSv/a; this broad range is mainly determined by the inhalation of Rn-222 and its short-lived decay products.

Table 1 - Effective annual dose of a person through ionising radiation in 2014 averaged over the population of Germany and broken down by radiation origin, according to BMUB [2016]

	1. Natural radiation exposure	**Average effective dose in millisieverts per year**	
1.1	through cosmic radiation (at sea level)	approx. 0.3	
1.2	through external terrestrial radiation when outdoors (5 hrs/day)[1] when in buildings (19 hrs/day)	approx. 0.4	 approx. 0.1 approx. 0.3
1.3	through inhalation of radon decay products when outdoors (5 hrs/day) when in buildings (19 hrs/day)	approx. 1.1	 approx. 0.2 approx. 0.9
1.4	through ingestion of naturally-radioactive substances	approx. 0.3	
	Sum of natural radiation exposure	**approx. 2.1**	
2.	**Man-made radiation exposure**		
2.1	through fallout from nuclear weapons tests	< 0.01	
2.2	radiation exposure caused by the accident at the Chernobyl nuclear power plant	< 0.011	
2.3	through nuclear facilities	< 0.01	
2.4	through the use of radioactive substances and ionising radiation in medicine* (without therapy) of which through nuclear medicine examinations	approx. 1.9	 approx. 0.1
	Sum of man-made radiation exposure	**approx. 1.9**	

* Data from 2012, evaluations from 2014; estimation with population based on the new census of 2011

Depending on local geological and hydrogeological conditions, the fluctuation range of concentrations of natural radionuclides in drinking water can be so great that the consumption of drinking water extracted from groundwater aquifers can, in individual cases, lead to radiation exposure, which should not be tolerated for health reasons (cf. Chapter 7.4). Such markedly increased concentrations of natural radionuclides are more frequently found in waters of the German low mountain range, such as in the Erzgebirge, Vogtland, Fichtelgebirge, Bayerischer Wald, Oberpfälzer Wald, in the Harz and in the Black Forest.

The radionuclide K-40 occupies a special position. With a half-life of about 1.3 billion years, it is as durable as the starting nuclides of the three above-mentioned natural decay series. Natural potassium contains approximately 0.012% of K-40. Like the stable potassium isotopes, it enters the human body with food and

[1] The stated times are fixed, plausible values for radiation protection purposes.

accounts for about half of the total human exposure to radiation through food consumption. The potassium content of the body, which is necessary for life functions, is constant and is not affected by human activity, so the K-40 content in drinking water is generally excluded from the regulatory monitoring. However, the value of 0.3 mSv/a in row 1.4 of Table 1 also includes the contribution of K-40.

5 Requirements for drinking water with regard to radioactive substances

The requirements for drinking water with regard to radioactive substances are listed in the Drinking Water Ordinance, Annex 3a, Part I [BMG 2016]. The functional basics of the individual parameters are summarised in this chapter.

5.1 Preliminary remark

The parameter values for Rn-222, tritium and the reference dose given in Table 2 correspond to Annex 3a Part I of the Drinking Water Ordinance [BMG 2016]. For Rn-222, the value provided for in Directive 2013/51/Euratom [Euratom 2013] has been adopted. However, the option provided for in the above-mentioned Directive [Euratom 2013] to set a higher value as a parameter has not been adopted. This decision was based mainly on corresponding recommendations of the Commission on Radiological Protection in Germany [SSK 2004] as well as on the evaluation of scientific studies on the content of Rn-222 in drinking water in Germany [BfS 2009].

Table 2 – Parameter values for Rn-222, tritium and reference dose according to the Drinking Water Ordinance [BMG 2016].

Consecutive number	Parameter	Parameter value	Unit
1	Radon-222	100	Bq/l
2	Tritium	100	Bq/l
3	Reference dose*	0.10	mSv/a

* Explanation: per calendar year

5.2 Radon-222

Radon-222 is a radioactive noble gas with a half-life of 3.8 days. It is freely soluble in water. Increased concentrations of Rn-222 in groundwater are found primarily in the crystalline basement, especially in granite. The BfS [2009] study presented in Chapter 4.2 has shown that Rn-222 in drinking water can make a relevant contribution to radiation exposure.

In its report "Radiation exposure by radon-222, lead-210 and polonium-210 in drinking water" [SSK 2004], the Commission on Radiological Protection recommended in 2004 that a reference value of 100 Bq/l for the Rn-222 activity concentration be established for drinking water in Germany. The report showed that at this Rn-222 activity concentration in drinking water, an average radiation exposure of approx. 0.4 mSv/a is expected for all age groups of the population, consisting of approx. 0.05 mSv/a due to the ingestion of drinking water and approx. 0.35 mSv/a due to the inhalation of short-lived Rn-222 decay products through the release of Rn-222 into the air in typical domestic use (e.g. during showering). In view of this, the Commission on Radiological Protection considers that the establishment of a reference value above 100 Bq/l cannot be justified.

5.3 Tritium

Tritium, a low-energy beta radiator with a half-life of 12.3 years, is one of the radionuclides that are continuously reproduced in the atmosphere due to the influence of cosmic radiation (cosmogenic radionuclides) and reach the water cycle with precipitation. However, tritium is also produced in large quantities during the operation of nuclear reactors and is discharged into the waste water from nuclear facilities under official control. Chemically, tritium is present as water (HTO) and thus possesses a very high degree of mobility in the environment and in the aquatic system. Increased tritium activity concentrations in surface water or groundwater are therefore considered as an indicator of influence through anthropogenic sources.

The tritium content in water is continuously monitored in Germany on the basis of the aforementioned legal regulations [BMU 1986, 2006a, b]. The measured activity concentrations are generally well below the tritium parameter value of 100 Bq/l [BMUB 2015].

5.4 Reference dose

Unlike the concentrations of radionuclides in water, the effective committed dose (*E*) defined as the reference dose per year cannot be measured but is a calculated quantity and represents a measure of the health risk from exposure to ionising radiation. It is the sum of the products of the nuclide-specific activity concentration of the radionuclides to be taken into account in accordance with the Drinking Water Ordinance [BMG 2016] with the respective dose coefficient and the average annual drinking water consumption of 730 l for the adult reference person, in accordance with the WHO [WHO 1993, 2004, 2011] and the EU [EC 1998]. The resulting calculation is as follows:

$$E = \sum_r E_r$$

$$E_r = C_r \cdot g_r \cdot U$$

with the variables

E_r = committed effective dose for the radionuclide *r*
C_r = activity concentration of the radionuclide *r* in drinking water in Bq/l
g_r = ingestion-committed dose coefficients for the radionuclide *r* in Sv/Bq corresponding to the age group > 17 years
U = consumed amount of drinking water of 730 l for the age group > 17 years

The dose coefficients describe the dose produced in the body as a function of the absorbed activity (becquerel). They are specified as nuclide and age-specific in Federal Gazette No. 160a and b, Part II of 28 August 2001 [BMU 2001a]. For the relevant natural radionuclides, the ingestion-committed dose coefficients g_r for the age group > 17 years are given in Table 3. Changes of dose coefficients due to new scientific knowledge will also be officially announced.

Table 3 – Dose coefficients for the calculation of the effective dose for radionuclide uptake by ingestion in mSv/Bq for the age group > 17 years according to BMU [2001a]

Ra-226	Ra-228	U-238	U-234	Pb-210	Po-210
2.8E-4	6.9E-4	4.5E-5	4.9E-5	6.9E-4	1.2E-3

The evaluation approach adopted in the Council Directive 2013/51/Euratom [Euratom 2013], which considers adults as reference persons, assumes that the entire population, including infants and young children, is adequately protected. Here it is taken into account that the reference dose is only a parameter value (with indicator function), which when exceeded initially triggers testing and decision-making processes with a view to the continuation of drinking water monitoring and, if necessary, the treatment of the drinking water. The adequacy of any measures that may be required must be weighed against the decision. This means that the protection concept also provides for the acceptance of exceedances. As a precautionary measure, the reference dose was set rather low at 0.1 mSv/a. It represents only a fraction of the population's total exposure, and the annual consumption of drinking water is also very conservative, with a volume of 730 litres.

Instead of the above calculation method, proof that the reference dose parameter value is not exceeded can also be provided by other methods. The procedures as well as the respective test conditions and test values required to assess compliance with the reference dose within the meaning of the Drinking Water Ordinance [BMG 2016] are presented in Chapter 7.2.

6 Principles of the analysis concept in accordance with the Drinking Water Ordinance

6.1 Analysis of artificial radionuclides and tritium

In principle, analyses of drinking water with regard to radionuclides of artificial origin are not necessary. In Germany – as already described in Chapter 4.1 – with regard to tritium and other artificial radionuclides, regular official monitoring is carried out on the basis of the StrVG, or installation-related monitoring is performed on the basis of Section 48 of the StrlSchV in accordance with the Directive on Emission and Immission Monitoring of Nuclear Facilities (REI) [BMU 2006b] by the operators of these facilities themselves.

Tests are only necessary if there are concrete indications that artificial radionuclides (including tritium) could occur, e.g. as a result of uncontrolled releases in the catchment area of a water supply system to an extent that is relevant for drinking water. The competent authority may order tests where there is evidence of increased activity levels in this respect. If the parameter value for tritium is exceeded in drinking water, the water must be tested for other artificial radionuclides, since tritium is regarded as being an indicator nuclide for the presence of artificial radioactive substances [BMG 2016].

The methods for determining the activity concentration of artificial radioactive substances in drinking water are described, inter alia, in the Federal Government's Procedure manuals for monitoring radioactive substances in the environment, published by the BMUB (see Annex A-2). Please refer to these Procedure manuals for further information.

6.2 Scope and frequency of testing for natural radionuclides, information requirement

According to §14a, para 1 of the Drinking Water Ordinance [BMG 2016], there is an obligation to inspect drinking water for radionuclides of natural origin. However, §14a, para 4 [BMG 2016] specifies cases in which the competent authority may release the water supplier from the obligation to inspect individual or all parameters for a certain period of time.

The reason for this is the assessment that the vast majority of water supply areas in Germany will not have significant radiation exposure due to radioactivity in drinking water and that unnecessary expenditure for the water supply companies is to be avoided.

The testing concept distinguishes between initial testing and regular testing.

Initial tests for existing installations, i.e. water supply plants that were already in operation at the time of the entry into force of the amending regulation (26.11.2015), must be completed within a period of 4 years after the entry into force of the amending regulation. The prescribed tests can be distributed over the entire transitional period [BMG 2015b]. If a new water supply system is put into operation, initial tests must be carried out within a period of twelve months, provided that none of the exceptions pursuant to §14a, para 4 [BMG 2016] as mentioned above apply. In the same way, initial tests will have to be carried out within twelve months if a water supply system undergoes significant changes in water extraction or water treatment that may have a negative effect on the content of radionuclides [BMG 2015b, 2016]. This is the case, for example, if local (hydro-)geological conditions suggest that changes in the hydraulic and/or hydro-chemical conditions, e.g. due to the commissioning of new wells (also within well galleries) or modifications in the pumping characteristics of wells, may be associated with higher levels of radionuclides.

During the initial test, at least 4 separate tests must be carried out during different quarters of the year in order to address possible seasonal or operational fluctuations in the radionuclide content. Such fluctuations can be attributed, e.g. to weather-related influences, changing mixture ratios of waters of different origins or to other different operating conditions of water extraction, treatment and distribution installations. If water from different extraction areas is frequently used as drinking water in varying mixture ratios and increased activity concentrations of natural radionuclides cannot be excluded due to the (hydro-)geological conditions, it is recommended to include the relevant untreated waters in the test procedures.

After the initial test has been completed, consumers must be informed of the results within the scope of the annual information requirement pursuant to §21, para 1 of the Drinking Water Ordinance [BMG 2016].

An initial test is not required if the competent authority has made an assessment in accordance with §14a, para 4, sentence 2, item 1 [BMG 2016]. This exemption allows the water supply company to demonstrate compliance with the radioactivity parameters by means of existing representative data (obtained from survey and monitoring measurements or from other reliable sources of information). To what extent the results of previous tests serve as reliable information that the specified parameter values for radioactive substances are not exceeded (and if an initial test is not necessary) is decided by the competent authority at the request of the operator or other owner of a water supply installation on a case-by-case basis. Measurement results can be regarded as reliable analysis values if the tests were carried out in accordance with the 'Guidelines for the Testing and Evaluation of Radioactivity in Drinking Water' [BMU 2012] and the requirements listed therein for test laboratories (including working according to the generally accepted rules of technology, a system of quality assurance, successful participation in external quality assurance programmes and adequately qualified personnel).

If the results of the initial test indicate that parameter values have been exceeded, ***regular tests*** must be carried out (cf. Chapter 7.4). The number of samples per year shall in principle be determined in accordance with the 'Minimum Frequency of Testing' table in Annex 3a, Part III [BMG 2016].

In the case of naturally occurring radionuclides, where prior testing has indicated a stable activity concentration (deviation of the individual values from quarterly measurements by no more than 20% from the annual mean value of the nuclide to be considered individually), the competent authority may, depending on local conditions, specify fewer tests and adjust the scope of the tests correspondingly.

Regular tests are not necessary if the initial test results comply with the parameter values or indicate only a minor excess which is negligible from the point of view of radiation protection (cf. Chapter 7.4). The competent authority shall determine this in accordance with §14a, para 4, sentence 2, item 2 [BMG 2016] at the request of the operator or other owner of a water supply installation.

If the competent authority orders treatment measures to reduce the content of radionuclides in drinking water pursuant to §9 para 5a [BMG 2016], regular tests must be carried out in order to check the continuing effectiveness of the treatment.

6.3 Conducting the tests

In contrast to the radon-222 and tritium parameters, which are directly determined by activity measurements, the reference dose parameter is not a directly measurable parameter (as described in Chapter 5.4).

According to the Drinking Water Ordinance and in accordance with the recommendations of the WHO [1993, 2004, 2011] and the Euratom Directive [Euratom 2013], a step-by-step testing procedure is possible to verify compliance with the reference dose. The aim of this procedure is to reduce the effort involved in the analysis. Following this procedure, the first step of the tests begins with screening measurements (determination of sum parameters), for the evaluation of which test conditions and test values are specified in Annex 3a, Part III of the Drinking Water Ordinance [BMG 2016]. The determination of a total beta activity concentration is not necessary, since the determination of artificial radionuclides can generally be dispensed with (as explained above).

The test conditions of the screening procedures are conservative, so that an underestimation of the actual reference dose (false negative result) is largely avoided during the initial test. Conversely, this does not mean that if the test conditions are exceeded, the parameter value of the reference dose must also be assumed to be exceeded. Further tests must be carried out to clarify this situation.

Single nuclide determinations must be carried out in a second step (usually when the test values of the screening procedures are exceeded). For the relevant radionuclides, Annex 3a Part II of the Drinking Water Ordinance [BMG 2016] specifies reference activity concentrations which are to be used in comparison with the measured activity concentrations to check compliance with the parameter value of the reference dose.

A step-by-step procedure can be dispensed with if, for example, increased activity concentrations of natural radionuclides (and thus the need for nuclide-specific measurements) are to be expected on the basis of previous test results, or if nuclide-specific data appear desirable or necessary for other reasons. In such cases, screening procedures are dispensed with and testing begins with the determination of the single nuclides (cf. Annex A-1).

If regular tests of the drinking water are to be carried out on the basis of the results of the initial test with regard to the reference dose, the competent authority may decide how these tests are to be carried out (specification of the radionuclides in question which in the specific case make a significant contribution to the dose as well as the determination of the extent and frequency of the tests to be carried out). Without separate stipulations, the minimum frequencies according to the Drinking Water Ordinance Annex 3a Part III of the 'Minimum Frequency of Testing' table apply.

Table 4 shows the reference activity concentrations listed in the Drinking Water Ordinance [BMG 2016].

Table 4 – Reference activity concentrations for radioactive substances in drinking water [BMG 2016].

Sequential number	Radionuclide	Reference activity concentration
	Radionuclides of natural origin	
1	U-238	3.0 Bq/l
2	U-234	2.8 Bq/l
3	Ra-226	0.5 Bq/l
4	Ra-228	0.2 Bq/l
5	Pb-210	0.2 Bq/l
6	Po-210	0.1 Bq/l
	Artificial radionuclides	
7	C-14	240 Bq/l
8	Sr-90	4.9 Bq/l
9	Pu-239/Pu-240	0.6 Bq/l
10	Am-241	0.7 Bq/l
11	Co-60	40 Bq/l
12	Cs-134	7.2 Bq/l
13	Cs-137	11 Bq/l
14	I-131	6.2 Bq/l

The reference activity concentrations given are values calculated for a dose of 0.1 mSv/a, taking into account the ingestion dose coefficients for adults and a consumption rate of 730 litres of drinking water per year.

In the case of the uranium isotopes U-238 and U-234, the reference activity concentrations listed in Table 4 only address the radiotoxic properties of uranium. Uranium occupies a special position, since the Drinking Water Ordinance has stipulated a limit value for the mass concentration of 10 micrograms per litre (µg/l) in Annex 2, Part I (sequential number 15) since 2011 due to uranium's *chemical* toxicity [BMG 2011]. This mass concentration of uranium, caused almost exclusively by isotope U-238, corresponds to a U-238 activity concentration which is only a fraction (1/24) of the nuclide-specific reference activity concentration (10 µg/l uranium corresponds to a U-238 activity concentration of 0.124 Bq/l). However, adherence to the limit value for the chemical parameter uranium does not mean that the U-234 activity concentration is also negligibly low reference dose-wise. In the drinking water measurement programme of the BfS [2009], U-234/U-238 activity ratios were determined up to a value of 10. At this value and at a uranium concentration of 10 µg/l, the resulting U-234 activity concentration is 1.24 Bq/l, which already corresponds to 45% of the nuclide-specific reference activity concentration.

Information on the practical implementation of the test concept is contained in Chapter 7 and in the explanations on the flowchart in Annex A-1.

6.4 Addressing fluctuations in the radionuclide content

The activity concentrations of natural radionuclides in drinking water can be subject to considerable fluctuations, e.g. due to weather-related influences or to different operating conditions of the water extraction, treatment and distribution installations. Test results on factors influencing the Rn-222 activity concentration in drinking water are included in the 2011 'Radon and Radon Decay Products in Drinking Water in Bavaria' report by the Federal Bavarian State Ministry for the Environment [LfU 2011].

For health assessment, however, it is not individual values but averages over longer periods of time that are of interest. See Chapter 7.1 for information on calculating mean values.

Four measurements in the different quarters of a year should be performed in the initial testing of radioactivity-related parameters. When planning the four quarterly measurements, possible seasonal variations in radionuclide levels and changing operating conditions in the water supply facilities should be taken into account in order to obtain an arithmetic mean value that is representative of the system to be considered. The scope and frequency of the tests are independent of the chosen procedure (cf. Annex A-1) for checking compliance with the reference dose.

7 Practical application of the testing concept

This chapter explains the practical implementation of the test to determine the radon-222 parameters and (in particular) the reference dose as well as the evaluation of the measured quantities. In addition to the screening procedures of the Drinking Water Ordinance for the determination of the reference dose [BMG 2016], Chapter 7.2.5 recommends a procedure that facilitates further simplification of nuclide-specific measurements and thus limits the analytical effort to the extent necessary. This procedure does not contradict the requirements of the Drinking Water Ordinance: Plausibility considerations for the assessment of compliance with the parameter value of the reference dose are also not excluded in this case. It is not necessary to calculate the reference dose in the mSv/a unit of measurement as a result of single nuclide determinations.

7.1 Overview of the parameters and measurands to be determined

Table 5 summarises the parameters for testing for natural radioactivity in drinking water with the respective test values of Annex 3a of the Drinking Water Ordinance [BMG 2016], as explained in the following chapters.

Table 5 – Testing of drinking water

Sequential number	Parameters/ Measured quantities	Unit	Test values/ Requirements	Comments
1	Reference dose*	mSv/year	0.1	Ra-228, Ra-226, U-238, U-234, Pb-210 and Po-210
1a	Gross alpha activity	Bq/l	0.05	Screening measurement to check compliance with the reference dose
1b	Gross alpha activity and Pb-210, Ra-228	Bq/l	0.1 each 0.2	Extended screening measurement to check compliance with the reference dose
1c	Activity concentrations of the radionuclides referred to in line 1	Bq/l	see Table 4	Determination of the single nuclides and application of the summation formula (Chapter 7.2.4)
2	Radon-222	Bq/l	100	

* Explanation: per calendar year

For the calculation of annual mean values, a uniform procedure is recommended for addressing measured values below the limits of detection (LOD). The mean value $\bar{C}_{r,\mathrm{mess}}$ is calculated as follows: If only measured values below the LOD are present, the absolute value of the highest detection limit is indicated as an average value. In all other cases, the respective measured values (above the LOD) and the absolute values of the achieved detection limits are used for averaging.

7.2 Reference dose

In accordance with the test concept of the Drinking Water Ordinance [BMG 2016], three methods can be used for testing compliance with the reference dose; these methods differ in their complexity and in the information they provide:

- a simple screening procedure (Drinking Water Ordinance, Annex 3a, Part III, item 2, letter c, double letter bb),
- an extended screening procedure (Drinking Water Ordinance Annex 3a, Part III, item 2, letter c, double letter aa) and
- the determination of single nuclides (Drinking Water Ordinance Annex 3a, Part III, item 2, letter c, double letter cc).

The use of screening methods and the introduction of the summation parameter of the gross alpha activity concentration as a test value are aimed at both simplifying the test procedures and reducing their scope. The conceptual distinction made in these Guidelines between ‘simple’ and ‘extended’ screening corresponds to the procedures described in the Drinking Water Ordinance, which are characterised by the indication ‘with test value $C_{\text{alpha-ges}} \leq 0.05$ becquerel per litre’ or ‘with test value $C_{\text{alpha-ges}} \leq 0.1$ becquerel per litre’ (Annex 3a, Part III, item 2, letter c, double letter bb or aa [BMG 2016]). In addition to the different test values of the gross alpha activity concentration, the methods for determining the gross alpha activity concentration (Tables 5 and 8) are also characterised by different test conditions and diverging performance characteristics (limits of detection).

Each of the three above-mentioned procedures is suitable for determining whether the requirements of the Drinking Water Ordinance [BMG 2016] with regard to the reference dose have been met or whether further testing is necessary. However, a calculation of the reference dose based on the measured activity concentrations – and thus a quantitative comparison with the parameter value of 0.1 mSv/a (Table 5) – is only possible when the latter procedure is used. The three procedures are explained in more detail below.

An overview of measures to check compliance with the reference dose requirements is given in Annex A-1. Annex A-3 contains forms which make it easier to evaluate the measurement results in each individual step of the testing procedure.

The procedure shown schematically in Annex A-1 largely reflects the monitoring strategy with regard to the reference dose, as outlined in the Drinking Water Ordinance [BMG 2016]. Suitable measures to reduce the effort involved in analysis are also recommended from a radiation protection perspective.

The forms shown in Annex A-3 can be used with the Microsoft® Excel spreadsheet programme. Instructions for using the forms are also given in Annex A-3.

7.2.1 Gross alpha activity

The aim of the measurement of the gross alpha activity concentration is the summarised determination of the activity concentrations of the natural alpha emitters U-238, U-234, Ra-226 and Po-210. Contributions of other natural (also alpha-emitting) radionuclides, in particular Rn-222 and Ra-224, should be largely excluded, since these are not taken into consideration in the determination of the dose[1].

In contrast to the above-mentioned dose-relevant alpha emitters, the radionuclides Pb-210 and Ra-228, which emit beta radiation, are not included in the measurement of the gross alpha activity concentration.

7.2.2 Simple screening procedure

For the procedure described as 'simple screening' in these Guidelines, the Drinking Water Ordinance specifies a test value of the gross alpha activity concentration of 0.05 Bq/l [BMG 2016].

The value, which is 2 times lower than that in the Euratom Directive [Euratom 2013] is justified by the results of the extensive measurement programme carried out by the BfS [2009]. Taking into account the determined activity concentrations and the varying activity ratios of the natural alpha and beta radiation-emitting radionuclides, the check for compliance with the reference dose can be carried out by means of a very simple procedure, in which only the value for the gross alpha activity is measured and the presence of the natural beta emitters Ra-228 and Pb-210, which are also dose-relevant, is deduced. In order to particularly address Po-210, for which the lowest reference activity concentration was derived, and the above-mentioned natural beta emitters without nuclide-specific determination when estimating the reference dose, the test value of 0.05 Bq/l for the gross alpha activity was specified in this case. The statistical evaluation of the measurement data from the study [BfS 2009] showed that adherence to this test value also demonstrates compliance with the reference dose of 0.1 mSv/year.

Further nuclide-specific tests of the drinking water are therefore not necessary if the test condition shown in the following equation is fulfilled:

$$\bar{C}_{\text{alpha-ges}} \leq 0.05 \text{ Bq/l.}$$

$\bar{C}_{\text{alpha-ges}}$ symbolises the arithmetic mean value of four quarterly measurements. To use this simple screening procedure, an analytical method that enables the detection of a summary alpha activity of 0.025 Bq/l [BMG 2016] should be selected.

If the arithmetic mean value of the gross alpha activity concentration determined from four quarterly measurements exceeds 0.05 Bq/l, further tests are required (cf. Chapter 7.2.4, 7.2.5 and Annex A-1). However, even if the above test value for the gross alpha activity concentration is exceeded, only in very few cases will this mean that the parameter value of the reference dose of 0.1 mSv/a is also exceeded, since the gross alpha activity concentration is often dominated by the uranium nuclides, which, from a radiological perspective, are comparatively less significant[2].

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[1] Special analytical conditions can have the effect that Rn-222 and Ra-224 only make a negligible contribution to the measuring effect in the determination of the gross alpha activity concentration. These conditions are documented in the relevant procedure manuals in Annex A-2.

[2] An indication of this is provided by converting the known uranium concentration of the drinking water into the U-238 activity concentration, multiplying this value by a factor of 2 (for an assumed U-234/U-238 activity ratio of 1) and comparing the resulting product with the measured value of the gross alpha activity concentration.

7.2.3 Extended screening procedure

In the extended screening procedure, the gross alpha activity concentration described in Chapter 7.2.1 is also determined as one of three measured variables. However, test methods with performance characteristics that include comparatively higher limits of detection can be used here. A detection limit of 0.04 Bq/l (Table 8) is required for these determination methods.

In addition to the gross alpha activity, the beta-emitting radionuclides Pb-210 and Ra-228 must also be measured. The test condition is shown in the equation below. It includes the comparison of the sum of the quotients of the arithmetic mean values of the three measured variables, which in turn are summarised from four quarterly measurements, and the respective test or reference values with the value 1.

$$\frac{\overline{C}_{\text{alpha-ges(mess)}}}{0.1\,\text{Bq/l}} + \frac{\overline{C}_{\text{Ra-228(mess)}}}{0.2\,\text{Bq/l}} + \frac{\overline{C}_{\text{Pb-210(mess)}}}{0.2\,\text{Bq/l}} \leq 1$$

If the test condition is met, no further reference dose tests are required; the parameter value of 0.1 mSv/a is thus considered to be complied with. If the test condition is exceeded, further tests are required, which may be limited to the determination of the radionuclide Ra-226 in a first step under certain conditions (see Chapter 7.2.5 and Annex A-1).

7.2.4 Determination of single nuclides

If the test conditions for the screening procedures are exceeded, nuclide-specific tests must be carried out in accordance with Annex 3a, Part III, item 2, letter c, double letter cc [BMG 2016].

Four measurements in different annual quarters are required for nuclide-specific tests. The arithmetic mean values $\overline{C}_{r,\text{mess}}$ from each of the four measurement results are used as a basis for the evaluation. The operator and other owners of an existing installation must note that the prescribed tests (including screening procedures and the determination of single nuclides) must be completed by 26 November 2019.

The reference dose may be calculated in accordance with the relationship for determining the effective dose through the ingestion of radionuclides as explained in Chapter 3.4. For practical reasons, however, it is recommended to preferably check compliance with the reference dose by means of the following derived test condition into which the respective mean activity concentrations $\overline{C}_{r,\text{mess}}$ from the results of the quarterly radionuclide measurements are inserted:

$$\sum_r \frac{\overline{C}_{r,\text{mess}}}{C_{r,\text{ref}}} \leq 1$$

$C_{r,\text{ref}}$ represents the reference activity concentrations of the individual radionuclides to be taken into account here (listed in Table 6).

Table 6 – Reference activity concentrations $C_{r,\text{ref}}$ of natural radionuclides [BMG 2016]

Nuclide	U-238	U-234	Ra-226	Ra-228	Pb-210	Po-210
Bq/l	3.0	2.8	0.5	0.2	0.2	0.1

In the exclusive consideration of the relevant radionuclides of natural origin in accordance with this recommendation, the complete above relationship is as follows:

$$\frac{\overline{C}_{\text{U}-238}}{C_{\text{U}-238\text{ref}}}+\frac{\overline{C}_{\text{U}-234}}{C_{\text{U}-234\text{ref}}}+\frac{\overline{C}_{\text{Ra}-226}}{C_{\text{Ra}-226\text{ref}}}+\frac{\overline{C}_{\text{Ra}-228}}{C_{\text{Ra}-228\text{ref}}}+\frac{\overline{C}_{\text{Pb}-210}}{C_{\text{Pb}-210\text{ref}}}+\frac{\overline{C}_{\text{Po}-210}}{C_{\text{Po}-210\text{ref}}}\leq 1$$

If the inequality is satisfied, no further tests are required; the parameter value of the reference dose (0.1 mSv/a) is complied with. Please refer to Chapter 7.4 for the procedure when the test condition is exceeded. The result of the summation divided by 10 shows the dose in mSv/a and can be directly compared with the reference dose parameter value of 0.1 mSv/a or with the dose ranges shown in Table 7.

7.2.5 Simplifying nuclide-specific measurements

The procedure explained below is a recommendation from the point of view of radiation protection; it serves to clarify the regulations for the carrying out of the determination procedure for single nuclides in Annex 3a of the Drinking Water Ordinance [BMG 2016]. In accordance with Part II of Annex 3a, the radionuclides listed in Table 4 must be taken into account. With regard to radionuclides of artificial origin, tests pursuant to §14a, para 1 are generally not required. This general exemption from the obligation to carry out tests (an exemption which is not differentiated according to single nuclides) does not apply in the case of radionuclides of natural origin. However, the inclusion of the 6 natural radionuclides mentioned above in the dose estimation is not equivalent to a metrological proof of each single nuclide, i.e. even if not all the listed radionuclides are measured, they are nevertheless taken into account. The recommended procedure is legally compliant with the requirements of Directive 2013/51/Euratom [Euratom 2013] and the Drinking Water Ordinance with regard to the implementation and scope of test procedures.

The results from the BfS Drinking Water Testing Programme [BfS 2009] show that the contributions of the Pb-210 and Po-210 radionuclides to the reference dose for all the tested waters in which the Rn-222 activity concentration does not exceed 100 Bq/l are clearly below the reference dose. The combined contribution of these radionuclides to the dose was below 0.05 mSv/a for the 460 drinking waters for which complete nuclide information is available and in the majority of cases even significantly lower. In addition, the dosage contribution of the two uranium isotopes U-234 and U-238 at values of the gross alpha activity concentration of less than 0.25 Bq/l cannot exceed approximately 0.01 mSv/a.

Based on these scientific findings, the requirement in accordance with Annex 3a, Part III, item 2, letter c, double letter cc of the Drinking Water Ordinance [BMG 2016] is specified in concrete terms, i.e. for individual radionuclides or radionuclide groups. Accordingly, proof of compliance with the reference dose parameter value is given if the values of the mean Rn-222 and gross alpha activity concentrations are not more than 100 Bq/l or 0.25 Bq/l and the dose contribution induced by the two radium isotopes Ra-226 and Ra-228 is less than 0.05 mSv/a.

Under the conditions: $\overline{C}_{\mathbf{Rn\text{-}222}} \leq \mathbf{100\ Bq/l}$ and $\overline{C}_{\mathbf{alpha\text{-}ges}} \leq \mathbf{0.25\ Bq/l,}$ the test condition specified in Chapter 7.2.4 for the single nuclide determination procedure is modified as follows:

$$\frac{\overline{C}_{\text{Ra}-226}}{C_{\text{Ra}-226\text{ref}}}+\frac{\overline{C}_{\text{Ra}-228}}{C_{\text{Ra}-228\text{ref}}}\leq 0.5$$

If this test condition and the aforementioned requirements for its application are met, further nuclide-specific analyses can be dispensed with. This recommendation is included in the flowchart in Annex A-1. If the test condition is exceeded, complete nuclide-specific analyses are required in all cases (see Chapter 7.2.4).

With the simplified proof of compliance with the reference dose described here, the dose contributions of the 6 radionuclides are taken into account and, at the same time, the analytical effort at this test stage is limited to the actually necessary level. In contrast to the measurement of 6 radionuclides mentioned in Chapter 7.2.4, only the activity concentrations of the 2 radium isotopes must be determined. However, it is not possible to calculate the dose using this procedure. Comparable to the screening procedures, the adherence to the parameter value of the reference dose is estimated on the basis of the model described above.

If it is not possible to prove compliance with the reference dose (as radioactivity parameter) in the last stage of testing, it must be checked whether and within what timeframe measures to reduce the radionuclide content in drinking water should be taken. See Chapter 7.4 for information on the evaluation of test results above the parameter values for the reference dose and/or the Rn-222 activity concentration.

A flowchart of the described test steps for checking compliance with the reference dose parameter can be found in Annex A-1.

7.3 Radon-222

An initial test should be carried out in order to determine the extent of any possible exposure to Rn-222 in drinking water. Pursuant to §14a, para 4 of the Drinking Water Ordinance [BMG 2016], an exemption from the obligation to carry out tests can be applied for from the competent authority (cf. Chapter 6.2).

In order to determine the annual average Rn-222 activity concentration in drinking water, four measurements are carried out in different quarters as part of the initial test. When planning the four quarterly measurements, possible changes due to seasonal fluctuations and changing operating sequences in the water extraction, treatment and distribution installations must be taken into account. The collection and analysis of representative samples is particularly important in the case of strongly fluctuating Rn-222 activity concentrations.

After completion of the four quarterly measurements, the mean value shall be calculated from the individual measurement results and compared with the parameter value of the Rn-222 activity concentration of 100 Bq/l.

If this value is complied with, a waiver of regular tests may be applied for from the competent authority in accordance with §14a, para 4, sentence 2, item 2 of the Drinking Water Ordinance [BMG 2016]. If the value is exceeded, a check must be performed to ascertain whether and within what timeframe measures should be taken to reduce the Rn-222 content in the drinking water. Please refer to Table 7 in Chapter 7.4 for recommendations. The evaluation of the Rn-222 activity concentration in drinking water is carried out independently of the reference dose by directly comparing the measured values with the parameter value of 100 Bq/l.

7.4 Procedure when the reference dose and/or the Rn-222 activity concentration parameter values are exceeded

Drinking water should be safe to use for a lifetime, so its consumption should not significantly contribute to the total radiation exposure of the population from natural sources. This precautionary approach is reflected in the radiological quality parameters for drinking water.

If the parameter values of the reference dose and/or the Rn-222 activity concentration are exceeded, measures to reduce the radionuclide content (Drinking Water Ordinance §9, para 5a [BMG 2016]) must be examined for health reasons. In terms of proportionality, however, countermeasures are not always mandatory. The following aspects should be taken into consideration:

- The specified parameter value for the reference dose of 0.1 mSv per calendar year is only a fraction of the total natural radiation exposure of the population (on average 2.1 mSv per calendar year). Depending on the degree to which the parameter values are exceeded, on the number of persons affected and on the technical effort required to reduce the radionuclide content in question, it is therefore possible from a radiological point of view to accept exceedances for transitional periods or, if necessary, permanently. Specific recommendations can be found below in this section.

- Any disruption of the drinking water supply can result in serious disadvantages for the consumer (e.g. occurrence of hygiene shortcomings, interruption of the flushing sewer system, lack of extinguishing water) [DVGW 2008b].

Dose values or Rn-222 activity concentrations which are only slightly above the parameter values can be tolerated – even permanently – if a reduction cannot be achieved by the simplest means (e.g. by changes in the operating regime). In this context, it can be assumed that the exceedance is insignificant if the values determined are not higher than 1.2 times the respective parameter values. Retesting (repeat measurement) to check the annual average value of the critical parameters is recommended after no later than 5 years, provided that the competent authority permits testing that deviates from the prescribed minimum frequency (see Chapter 6.2). This test should preferably be carried out in the same way as the initial test, i.e. quarterly measurements are carried out and annual average values are calculated. Table 7 provides recommendations for the evaluation and the procedure when the reference dose and/or the Rn-222 activity concentration parameters are exceeded.

Table 7 – Recommendations when the reference dose and/or Rn-222 activity concentration parameters are exceeded

Reference dose *E*	**Rn-222 activity concentration (annual average value)**	**Recommendations/Notes**
E<= 0.1 mSv/a	$\bar{C}_{Rn\text{-}222}$<= 100 Bq/l	Parameter values are adhered to, no measures required Repeat measurements in the case of significant changes (see Chapter 6.2)
0.1 mSv/a <*E*<= 0.12 mSv/a	100 Bq/l <$\bar{C}_{Rn\text{-}222}$<= 120 Bq/l	Exceeding the parameter values of the reference dose and/or Rn-222 activity concentration can be tolerated permanently if a reduction cannot be achieved with the simplest means. Repeat measurements after 5 years at the latest
0.12 mSv/a <*E*<= 0.2 mSv/a	120 Bq/l <$\bar{C}_{Rn\text{-}222}$<= 300 Bq/l	Carry out and verify reduction measures within a period of **10 years**, taking proportionality into account. Check the sustainability of the measures by means of repeat measurements after 5 years at the latest
0.2 mSv/a <*E*<= 0.3 mSv/a	300 Bq/l <$\bar{C}_{Rn\text{-}222}$<= 1000 Bq/l	Carry out and verify reduction measures within a period of **3 years**, taking proportionality into account. Check the sustainability of the measures by means of repeat measurements after 5 years at the latest
E>0.3 mSv/a	$\bar{C}_{Rn\text{-}222}$> 1000 Bq/l	Carry out and verify short-term measures to reduce the reference dose and/or the Rn222 activity concentration. Check the sustainability of the measures by means of repeat measurements after 5 years at the latest

In the event that the values determined are not only slightly higher than the parameter values, they can nevertheless be accepted from a radiation protection point of view for a period of around 3 to 10 years, depending on the amount exceeded. If the conditions specified in Table 7, lines 3 and 4 are complied with, this represents only a small, tolerable increase in relation to the total natural radiation exposure. With regard to Rn-222 activity concentrations, the underlying approach is compatible with the range of values provided for in the EU Radon Recommendation [EC 2001].

If the dose determined is increased by more than 3 times or the Rn-222 activity concentration is increased by more than 10 times compared to the respective parameter values, reduction measures should be taken as soon as possible for reasons of radiation protection precaution and a subsequent test of the effectiveness of these measures should be carried out.

Where measures to reduce radionuclide concentrations are carried out, provision should be made for repeat measurements to verify the sustainability of the measures after a period of no more than 5 years. The type and extent of these measurements shall be determined by the competent authority, which shall take the circumstances of the individual case into account (Drinking Water Ordinance §9, para 5a [BMG 2016]).

Table 7 summarises the recommendations when the reference dose and/or Rn-222 activity concentration parameters are exceeded.

The following measures can be taken to bring the values down to below the parameter values:

- Change of operating regime,
- Blending of waters from different wells,
- Treatment of the water (such as aeration of the water, use of ion exchangers, further examples are found in e.g. DVGW [2003]).

Possible effects on other water-chemical, physical and bacteriological parameters must be taken into account in order to comply with the requirements of the Drinking Water Ordinance. The generally accepted rules of technology (e.g. DVGW rules and regulations) should be observed during treatment. The measures required in individual cases are ordered by the competent authority (Drinking Water Ordinance §9, para 5a [BMG 2016]).

8 Analytical determination of radioactivity-related parameters

8.1 Requirements for sampling and test laboratories

The tests, including sampling, which are required by §15, para 4 of the Drinking Water Ordinance may only be carried out by approved testing and examination bodies (test laboratories) [BMG 2016]. The competent and highest federal state authority or a body designated by this authority shall, on request, grant approval to a testing and examination body (test laboratory) which operates in the federal state concerned and is not already approved by another federal state, provided that the test laboratory

1. complies with the requirements of the Drinking Water Ordinance, Annex 3a, Part III, item 3 [BMG 2016] with regard to radioactive substances,

2. works according to the generally accepted rules of technology,

3. has a system of internal quality assurance,

4. successfully participates in external quality assurance programmes at least once a year,

5. has personnel with sufficient qualifications for the relevant activities; and

6. is accredited by a national accreditation body of a member state of the European Union for appropriate drinking water tests.

In line with the requirements of §15 of the Drinking Water Ordinance [BMG 2016], sampling for radioactivity tests shall be carried out by an expert sampler. Sampling is carried out according to the BMUB's procedure manuals (Annex A-2) or in accordance with equivalent procedures. For the taking of samples for the determination of activity, the procedures shall be communicated to the sampler in the form of work instructions by the authorised testing and examination body (also referred to as the test laboratory or measuring station).

When documenting the sampling, the requirements of §15, para 3 of the Drinking Water Ordinance [BMG 2016] shall be taken into account. In particular, care must be taken to ensure that the exact date and time of sampling, the sampling procedure itself and any special occurrences are documented in addition to accurate information about the location. Furthermore, it must be possible to determine when the sample was handed over (transmitted) to the test laboratory. Samples must be handed over to the test laboratories in a timely manner. Drinking water samples for the determination of Rn-222 must be handed over to the laboratory immediately (usually within 24 hours), due to the low half-life of Rn-222.

As with all other tests carried out in accordance with the Drinking Water Ordinance, sampling must be included in the accreditation of the test laboratory concerned and the personnel must be specifically and regularly trained as part of their further training and education. The competence of other personnel should also be ensured by appropriate training and further education.

8.2 Sampling points in the water supply system

Compliance with the quality requirements for drinking water must be ensured for taps that are installed in a drinking water installation and are used to extract drinking water, i.e. for the consumer's taps. Since the concentration of radionuclides usually does not increase further in the distribution network (including the drinking water installation), compliance with the quality requirements can also be proven by testing after completion of the water treatment, i.e. at the waterworks outlet. It is recommended that the tests should be carried out at this point, at which the parameters not related to radioactivity are also examined. If the test conditions are complied with at this point, no further tests in the distribution network or on consumers' premises are necessary.

The Rn-222 activity concentration usually decreases during the distribution procedure between the end of the water treatment and the consumer's tap, due to the short half-life of Rn-222 (3.82 days) and outgassing in pressureless water storage facilities (particularly in turbulent water intakes in water tanks, e.g. in elevated tanks). In individual cases in which the Rn-222 activity concentration parameter value of 100 Bq/l is exceeded at the end of the treatment process, it may therefore be useful to check compliance with this activity concentration in the public water supply system or at the outlet of elevated tanks or other water storage facilities.

8.3 Test methods and performance characteristics

Sampling and test procedures for the parameter values for radioactive substances are based on generally accepted rules of technology. Suitable methods for the determination of artificial and natural radionuclides in drinking water are described in the procedure manuals of the Coordinating Office for monitoring environmental radioactivity in drinking water, groundwater, waste water, sewage sludge and waste water from nuclear facilities. The Coordinating Office is part of the BfS pursuant to §11 of the StrVG [BMU 1986]. The measuring instructions can be found in the 'Procedure manuals for monitoring radioactive substances in the environment and external radiation', published by the BMUB. Applicable DIN and ISO standards can also be used. The suitability of the methods should be tested on the basis of the achievable detection limits (Table 8) and the reliability of the results should be demonstrated by e.g. participation in inter-laboratory tests.

The detection limits are specified in Annex 3a, Part III of the Drinking Water Ordinance as performance characteristics for the determination of the parameters tritium and Rn-222, the gross alpha activity concentration, the gross beta activity concentration and for individual radionuclides [BMG 2016].

Table 8 – Performance characteristics [BMG 2016]

Sequential number	Parameters, gross activity concentrations and radionuclides	Detection limit (Notes 1 and 2)
1	Tritium	10 Bq/l
2	Radon-222	10 Bq/l
3	Gross alpha activity concentration Gross beta activity concentration	0.04 Bq/l (Note 3) 0.4 Bq/l
4	U-238	0.02 Bq/l
5	U-234	0.02 Bq/l
6	Ra-226	0.04 Bq/l
7	Ra-228	0.02 Bq/l (Note 4)
8	Pb-210	0.02 Bq/l
9	Po-210	0.01 Bq/l
10	C-14	20 Bq/l
11	Sr-90	0.4 Bq/l
12	Pu-239/Pu-240	0.04 Bq/l
13	Am-241	0.06 Bq/l
14	Co-60	0.5 Bq/l
15	Cs-134	0.5 Bq/l
16	Cs-137	0.5 Bq/l
17	I-131	0.5 Bq/l

Note 1: The detection limit shall be calculated in compliance with DIN ISO 11929 [2011], with probabilities of the first or second type of error of 5 percent each.

Note 2: Measurement uncertainties must be calculated and documented. The confidence interval can also be indicated; in this case, the interval is to be determined with the probability 1 - γ of 95 percent.

Note 3: This detection limit applies only to the use of the test value of 0.1 becquerel per litre, taking into account the activity concentrations of Pb-210 and Ra-228. When using the test value of 0.05 becquerel per litre without any further nuclide-specific testing (if only natural radionuclides are to be taken into account), a detection limit of 0.025 becquerel per litre applies.

Note 4: This detection limit applies only to the initial test with regard to the reference dose for a new water resource. If the initial test shows no plausible reason for Ra-228 to exceed 20 percent of the derived concentration, a test method with a detection limit of up to 0.08 becquerel per litre for Ra-228 can be used for regular tests.

The detection limit for tritium and Rn-222 is 10 percent of the parameter value of 100 Bq/l. For the gross alpha activity concentration of 0.1 Bq/l, the detection limit is 0.04 Bq/l (= 40 percent); with a test value of 0.05 Bq/l, it is 0.025 Bq/l (= 50 percent). The detection limit for the gross beta activity concentration is also 40 percent of the 1.0 Bq/l value.

8.4 Requirements for analytical procedures

8.4.1 Sampling and sample treatment

For the sampling and sample treatment of drinking water for determining the radioactivity-related parameters, please refer to the BMUB procedure manuals H-VORBEMERK-TWASS-01, H-VORBEMERK-TWASS-02 and, where applicable, H-γ-SPEKT-TWASS-01. Special instructions for the sampling and treatment of samples during testing for Rn-222 and Pb-210 in drinking water are also provided for in the corresponding procedure manuals (see Annex A-2).

The degassing of Rn-222 is only carried out in case that a Pb-210 test is required. It is performed on the freshly-taken sample, either on site or in the test laboratory. If the Rn-222 activity concentration is known to be below 50 Bq/l, it is not necessary to degas the sample, since the maximum Pb-210 activity concentration that can be reproduced within approx. 7 days does not exceed 10% of the reference activity concentration (200 mBq/l).

As considerable differences in radionuclide concentrations can occur even at short distances between individual wells, it is important to ensure that representative operating conditions exist for the supply when taking samples. This must be taken into account in the quarterly sampling procedures performed in installations with changing operating conditions (e.g. different flow rates of individual wells). Technological processes in drinking water treatment (e.g. filter rinsing, filtrations) are also subject to a certain time regime and may influence the measured values of the radioactivity-related parameters.

8.4.2 Procedure manuals of the Coordinating Offices

Suitable sampling and analysis methods for monitoring activity concentrations or the specific activities of radioactive substances in the environment were developed in the past by the Coordinating Offices for monitoring radioactivity in the environment that are part of different federal authorities. These procedures were published in a loose-leaf collection by the then Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), until 2006 in paper form [BMU 2006c]. Since 2010, the manuals have been published under the title ‘Procedure manuals for monitoring radioactive substances in the environment and external radiation’ [Annex A-2] and are available on the BMUB’s website at:

www.bmub.bund.de/P384/

They consist of a general part describing properties for alpha, beta and gamma-emitting radionuclides and giving an overview of analytical methods for these substances, and a part with instructions on the procedures of the Coordinating Offices responsible for the various environmental areas (pursuant to §3 StrVG [BMU 1986]).

The BMUB’s procedure manuals have been the standard for radioactivity testing in the environmental sector in Germany for decades now and are therefore generally accepted rules of technology. We therefore recommend to use methods for testing radioactivity in drinking water that meet the specifications of the procedure manuals or at least comply with DIN or DIN ISO standards.

8.4.3 Other measurement procedures

In addition to the BMUB's procedure manuals, a number of proven and documented measuring procedures exist in Germany for the determination of radionuclides in environmental media, including those for ground, surface and drinking water. These include the procedures documented in the loose-leaf collection 'Recommendations for Monitoring Environmental Radioactivity' of the Working Group for Environmental Monitoring (AKU) of the German Radiation Protection Association (FS). These recommendations are not primarily based on the environmental areas to be monitored, but on analysis and detection procedures. They can be downloaded from the FS website at:

http://www.fs-ev.org/arbeitskreise/umweltueberwachung/loseblattsammlung/

Numerous DIN and ISO standards are also available (see Annex A-2).

8.4.4 Compulsory detection limits

As described above, qualified sampling, sample treatment and analysis procedures are available for monitoring radioactivity-related parameters. In order to ensure the practical applicability of an analytical procedure, it must at least be capable of complying with the detection limits specified in Table 8.

To comply with these detection limits, necessary sample volumes, the type of sample containers, sample preparation, measuring times, start of measurements, etc. must be individually adapted to the specific conditions of the laboratory concerned, e.g. with regard to the existing measuring technology, the premises and the background radiation (zero-effect counting rates) and the chemical yields achieved in practice. To this end, appropriate laboratory regulations must be drawn up by the measuring station (the test laboratory) and the procedures to be applied in practice must be validated.

8.4.5 Calculating the decision thresholds, detection limits and measurement uncertainties

- Decision threshold and detection limit:

Table 8 shows the minimum detection limits (in becquerel per litre) to be complied with for the relevant radionuclides and summation parameters during testing for activity concentrations. These values can be found in the Drinking Water Ordinance, Annex 3a, Part III [BMG 2016].

In the field of nuclear radiation measurement, a special set of standards has been developed for determining the decision threshold, the detection limit and the degree of measurement uncertainty; in particular, DIN 1319-4 [1999] defines these parameters and DIN ISO 11929 [2011] specifies the methods for determining them. These definitions and methods, which differ substantially from the definitions for the chemical parameters, have become established in the entire field of nuclear radiation and radiation protection measurements. They must also be used as a basis for the measurement of radioactivity-related parameters in drinking water for reasons of consistency.

The decision threshold is the value of the measurement variable, above which it is decided that the physical effect actually exists. According to DIN ISO 11929 [2011], the decision threshold is defined in such a way that the probability for making the wrong decision, viz. that the true value of the measurand is zero, is less than a given value α; the decision threshold is therefore used to assess whether a measuring effect exists or not. The definition of the term "decision threshold" according to DIN ISO 11929 [2011] thus corresponds to the term "decision limit" as defined for chemical analysis in DIN 32465 [2008] and as used for the chemical parameters in drinking water (cf. Drinking Water Ordinance, Annex 5, Part II, Note 2 [BMG 2001]).

The meaning of the term “detection limit” for radioactivity measurements in drinking water according to DIN ISO 11929 [2011] is as follows: The detection limit is the smallest concentration of a radionuclide in a drinking water sample which, taking into account the selected procedure’s uncertainties, leads with sufficient certainty (> 95%) to a measurement result which is recognised as a real concentration of the radionuclide in the relevant drinking water sample, as it differs sufficiently from the unavoidable contribution of underground radiation. The detection limit thus enables a decision to be taken whether or not a measurement method is suitable for the specified measurement purpose. The detection limit obtained differs from measurement to measurement within certain limits. For each measurement, it is compared with the detection limit to be complied with (Table 8) in order to decide whether the measurement purpose has been fulfilled or if the measurement procedure must be repeated.

For chemical analyses, this definition of the detection limit is commensurate with the limit described as identification limit (*Erfassungsgrenze*) in DIN 32465 [2008]. Within the framework of the Drinking Water Ordinance [BMG 2015a], the specification of the identification limit for determining chemical parameters is not required. Due to the different calculation bases for radioactivity measurements and chemical analysis, the detection limits specified in Annex 3a, Part III, item 3, note 1 and in Annex 5, Part II, note 2 of the Drinking Water Ordinance [BMG 2001, 2016] are approximately the same, although they have a different meaning.

The following procedure is obligatory for the measurement of radioactivity-related parameters in drinking water (using the above definitions):

1) Comparison of the experimentally-determined detection limit and the detection limit to be complied with (see Table 8) → determination of the **suitability** of the measurement procedure prior to routine application

2) Comparison of the primary measurement result (experimental value of the measured variable) with the decision threshold

   a) If the decision threshold is exceeded, the best estimated value and its uncertainty are given as the measurement result.

   b) If the decision threshold is not exceeded, the result shall be indicated as “< detection limit”, together with the detection limit itself. The term “< decision threshold” is not factually incorrect. However, the probability of error here is approximately 50%, so that including this information is not useful.

- Measurement uncertainties:

According to general practice in the area of the implementation of the Drinking Water Ordinance [BMG 2016], an inclusion of the measurement uncertainties assigned to the concrete measured values in the test report is not required. In the area of nuclear radiation measurement technology, however, the so-called complete measurement result, which includes the measurement uncertainty in addition to the actual measured value, is mandatory. It is therefore recommended to include the respective measurement uncertainties in the test report.

The measurement uncertainties are not taken into account when checking compliance with the parameter values and test conditions. At the same time, however, it makes sense to establish minimum requirements for the measurement uncertainties for the determinants, in order to limit the extent of incorrect assessments caused by metrological errors and to enable an appropriate assessment of the measurement results.

When using the currently available standard measurement methods, relative measurement uncertainties in the range of the detection limits of max. 25% for the measurand to be determined can be achieved. (Below the detection limits to be observed and especially below the detection limits achieved, the relative measurement uncertainties are increasingly dominated by the count-statistical uncertainty and can reach significantly higher values than 25%.) Since the detection limits to be achieved in most cases amount to 10% of the respective reference activity concentrations, the measurement uncertainty of these small and very uncertain values above the decision threshold and below the achieved detection limit does not have a major influence on the assessment of compliance with the reference values.

One exception to this rule is the summation parameter “Gross alpha activity concentration”, the determination of which involves relative measurement uncertainties of up to 50%. These uncertainties also correlate with the results of inter-laboratory tests carried out to date. However, this summation parameter is not used to calculate the reference dose, but only to assess whether further measurements are necessary.

Measured values below detection limits cannot be used for the assessment of test results. When calculating the mean values or quotients of measured and derived activity concentrations, the absolute amounts of detection limits are taken into account as the lowest values.

8.5 Test report

In accordance with the requirements of DIN EN ISO/IEC 17025 [2005] for accredited laboratories, all results must be documented in a test report. Each test report should at least contain the following information:

- name and address of the laboratory (if applicable, an additional location is required if the laboratory has multiple addresses),
- unambiguous identification (e.g. the order or serial number) and an identification on each page and at the end of the test report, including page numbering,
- name and address of the client or initiator,
- date of receipt of the tested samples in the laboratory,
- information on the analytical methods used,
- details of the analysis results with units of measurement.

More information is also required to interpret the test results:

- date of sampling,
- clear sample designation,
- information on the place of sampling and the sampling procedure (analogous to the requirements of the Drinking Water Ordinance §15, para 3 [BMG 2016]).
- details of the ambient conditions during sampling – these can influence the interpretation of test results (cf. procedure manual on sampling).
- information on the annual quarter (1st, 2nd, 3rd or 4th quarter) during which the sampling was carried out,
- all individual values for the necessary tests for compliance with the reference dose or parameter value of the Rn-222 activity concentration.

If a test report contains results of tests carried out by sub-contractors or by outsourced parties, these results must be clearly marked in accordance with DIN EN ISO/IEC 17025 [2005]. Even in the case of sampling not being carried out in-house, it must be possible to identify the person(s) who carried out the work and whether it was carried out under accreditation conditions.

For the radioactivity parameters, the determined measurement results with measurement uncertainties must be reported in accordance with the specifications of DIN ISO 11929 [2011].

In addition to the test reports, the forms compiled in Annex A-3 "Test for Compliance with Radioactivity-Related Parameters" can be used to document the measurements carried out and to compare them with the corresponding test conditions in each test step. The calculations required for this are carried out automatically with the forms designed as Microsoft® Excel spreadsheets; explanations are also given in the form of instructions in Annex A-3. These forms are not a substitute for a test report but are instead intended to assist in facilitating the assessment of drinking water requirements with regard to radioactivity. Documentation of the automatically-performed calculations can be requested for each form from the Coordinating Office at the email address 'leitstelle-h@bfs.de'.

The forms are analogous with the individual test steps, which are usually carried out one after the other (cf. Chapters 7.2.2 to 7.2.5, Annex A-1). They are assigned to the respective measurement and testing tasks as explained below:

- **Testing for compliance with the reference dose and Rn-222 activity concentration parameters (simple and extended screening procedures)**

  Form I: Check for compliance with the test value of the gross alpha activity concentration in the simple screening procedure and the parameter value of the Rn-222 activity concentration in accordance with Chapters 7.2.2 and 7.3.

  – I.1: Results of an individual sample

  – I.2: Summary and evaluation of 4 quarterly measurements

  Form II: Check for compliance with the test value of the gross alpha activity concentration in the extended screening procedure and the parameter value of the Rn-222 activity concentration according to Chapters 7.2.3 and 7.3.

  – II.1: Results of an individual sample

  – II.2: Summary and evaluation of 4 quarterly measurements

- **Testing for compliance with the reference dose parameter value by determining the activity concentration of gross alpha, Rn-222 and radium isotopes** (simplification of nuclide-specific measurements)

  Form III: Check for compliance with the reference dose parameter value by determining the activity concentration of gross alpha, Rn-222 and radium isotopes in accordance with Chapters 7.2.5 and Annex A-1.

  – III.1: Results of an individual sample

  – III.2: Summary and evaluation of 4 quarterly measurements

- **Testing for compliance with the reference dose parameter value by determining the activity concentration of single nuclides (determination of the single nuclides)**

  Form IV: Check for compliance with the reference dose parameter value by determining the activity concentration of the single nuclides in accordance with Chapter 7.2.4.

  – IV.1: Results of an individual sample

  – IV.2: Summary and evaluation of 4 quarterly measurements

8.6 Quality assurance

According to §15 of the Drinking Water Ordinance [BMG 2001], test laboratories must have an internal quality assurance system and participate successfully in external quality assurance programmes at least once a year. These requirements also apply to the methods for determining radioactivity-related parameters.

Inter-laboratory comparison tests are the most important instrument of external quality assurance – this is why regular and successful participation is absolutely necessary in order to prove the competence of a test laboratory. With regard to the determination of radioactivity in drinking water, BfS conducts relevant inter-laboratory comparison tests in its role as the Coordinating Office for 'Monitoring of Environmental Radioactivity in Drinking Water, Groundwater, Waste water, Sewage Sludge and Waste' pursuant to §11, para 4 (6) of the StrVG [BMU 1986].

From 2010 on, inter-laboratory comparison tests for drinking water will be offered at regular intervals for the external quality assurance of the laboratories involved in drinking water monitoring – however, not all parameters or measurement variables are taken into account in every such test.

If no inter-laboratory tests are carried out for a certain parameter or measurand, laboratory comparative tests with certified reference materials or other suitable samples can also be carried out after consultation with the Coordinating Office.

List of Literature

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BMG (2011) Erste Verordnung zur Änderung der Trinkwasserverordnung vom 3. Mai 2011. Federal Law Gazette. part I no. 21: p. 748–774

BMG (2015a) Dritte Verordnung zur Änderung der Trinkwasserverordnung vom 18. November 2015. Federal Law Gazette part I no. 46 p. 2076-2083

BMG (2015b) 456/15 Bundesrat Drucksache vom 02.10.2015. Dritte Verordnung zur Änderung der Trinkwasserverordnung. Bundesrat: 45 p.

BMG (2016) Trinkwasserverordnung in der Fassung der Bekanntmachung vom 10. März 2016. Federal Law Gazette part I no. 12 p. 459-491

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BMU (2006b) Richtlinie zur Emissions- und Immissionsüberwachung kerntechnischer Anlagen (REI) vom 7. Dezember 2005. GMBl. Nr. 14–17: 254 p.

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BMUB (2016) Jahresbericht 2014 „Umweltradioaktivität und Strahlenbelastung“ (und Vorläufer seit 1968). Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (editor), Bonn: 369 p. Available at: http://nbn-resolving.de/urn:nbn:de:0221-2016091514109

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DIN EN ISO/IEC 17025 (2005) Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien (ISO/IEC 17025: 2005): 68 p.

DIN 32645 (2008) Chemische Analytik – Nachweis-, Erfassungs- und Bestimmungsgrenze unter Wiederholbedingungen – Begriffe, Verfahren, Auswertung: 29 p.

DIN ISO 11929 (2011) Bestimmung der charakteristischen Grenzen (Erkennungsgrenze, Nachweisgrenze und Grenzen des Vertrauensbereichs) bei Messungen ionisierender Strahlung – Grundlagen und Anwendungen (ISO 11929: 2010): 82 p.

DVGW (2003) Wasseraufbereitung – Grundlagen und Verfahren. Lehr- und Handbuch Wasserversorgung. Band 6. Jekel, M., Gimbel, R., Ließfeld, R., Oldenbourg Industrieverlag, Munich: 468 p.

DVGW (2008a) Trinkwasserversorgung und Radioaktivität. Technische Mitteilung – Hinweis W 253. DVGW-Deutscher Verein des Gas- und Wasserfachs e.V. (editor), Bonn: 44 p.

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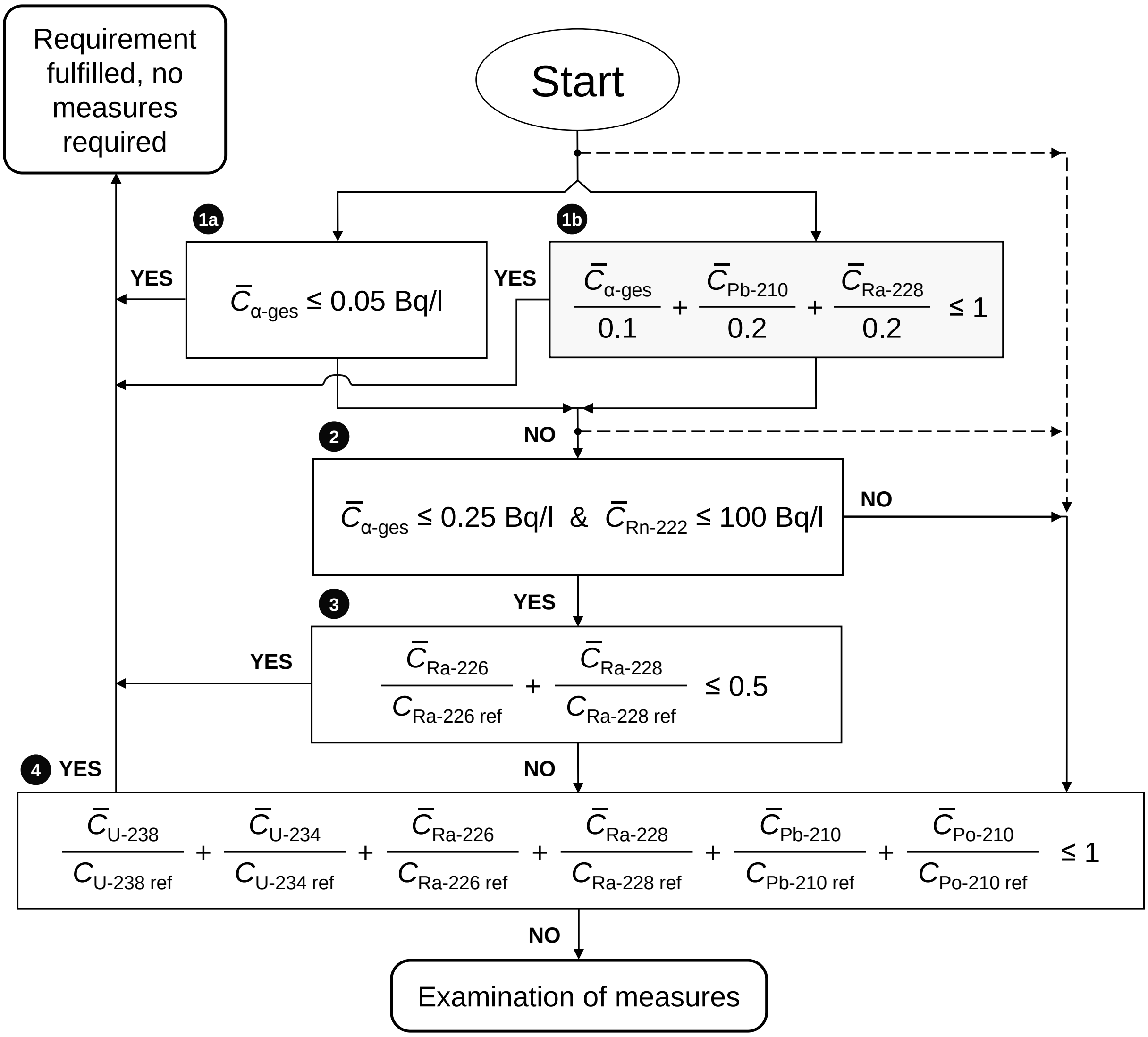
WHO (2011) 9. Radiological aspects. In: Guidelines for Drinking-Water Quality. 4th edition. World Health Organization (editor), Geneva: p. 203–217.

Annex A-1: Flowchart for the recommended tests for compliance with the reference dose parameter value



(1) The activity concentrations indicated for the relevant screening procedures (1a or 1b) are determined in four different annual quarters. Calculate the mean values from the results of the quarterly measurements (cf. Chapter 6.4) and check for compliance with the relevant test condition (1a or 1b) (cf. Chapter 7.2.2 or 7.2.3). The specified timeframe also applies in case that you choose not to determine the gross alpha activity concentration but to directly establish the activity concentration of the six relevant individual nuclides according to 4.

(2) This test serves to define how to carry out the nuclide-specific tests with the aim of reducing the effort involved in the analysis (cf. Chapter 7.2.5). If both criteria stated in 2 are met, it is only necessary to determine the activity concentrations of both radium isotopes in four different annual quarters. If the Ra-228 concentrations are known, e.g. as a result of screening measurements according to procedure 1b, there is no need to repeat the Ra-228 measurements. Alternatively, you may determine all relevant radionuclides according to 4.

(3) The requirement stated in 3 serves to check if further nuclide-specific tests are necessary. If the indicated condition is not complied with in exceptional cases, the activity concentrations of the radionuclides U-238,

U-234, Pb-210 and Po-210, which have not been taken into account so far, must be determined in the following year (in four different annual quarters).

(4) This is the most comprehensive step of the test and it involves the activity concentrations of all relevant radionuclides. In contrast to the test criteria indicated in ❶ to ❸, the results from the determination of the individual nuclides according to ❹ can be used to calculate the reference dose (cf. Chapter 7.2.4). The further course of action depends on the compliance with or exceedance of the test condition or on the result of the comparison with the parameter value (0.1 mSv/a) of the reference dose (cf. Chapter 7.4).

Annex A-2: List of the applicable standards (BMUB procedure manuals, ISO, DIN) and standards under revision (as of January 2016)

BMUB – Procedure manuals for monitoring radioactive substances in the environment and external radiation (www.bmub.bund.de/P384/)

BMUB procedure manuals relevant for radioactivity tests according to the Drinking Water Ordinance

Standard / procedure	Title
BMUB procedure manuals	
H-VORBEMERK-TWASS-01	Preface
H-VORBEMERK-TWASS-02	Vorbemerkung hinsichtlich der Anforderungen bei der Probeentnahme aus Trink- und Grundwasser [Preliminary remarks regarding the requirements for sampling from drinking water and ground water]
H-Rn-222-TWASS-01 (1994)	Rapid procedure for determining radon-222 in drinking water
H-α-Gesamt-TWASS-01 (2006)	Procedure for determining the gross alpha activity concentration in drinking water and ground water
H-α-Gesamt-TWASS-02 (2009)	Rapid procedure for determining the gross alpha activity concentration in drinking water
H-α-SPEKT-TWASS-01 (1992)	Procedure for determining uranium isotopes in drinking water and ground water by alpha spectrometry
H-Ra-226-TWASS-01 (1992)	Procedure for determining radium-226 in drinking water and ground water
H-Ra-228-TWASS-01 (2004)	Procedure for determining the activity concentration of radium-228 in drinking water and ground water
H-Ra-228-TWASS-02 (2004)	Procedure for determining the activity concentration of radium-228 in drinking water and ground water

Standard / procedure	Title
H-Po-210-TWASS-01 (1998)	Procedure for determining polonium-210 in drinking water
H-Pb-210/Po-210-TWASS-01 (2009)	Procedure for determining the activity concentrations of lead-210 and polonium-210 in drinking water and ground water
H-Pb-210-AWASS-01 (1993)	Procedure for determining lead-210 in wastewater
H-H-3-AWASS-01 (2000)	Procedure for determining tritium in wastewater
H-β-Gesamt-TWASS-01 (2008)	Procedure for determining the gross beta activity concentration in drinking water and ground water
H-C-14-AWASS-01 (1992)	Procedure for determining carbon-14 in wastewater
H-Sr-90-TWASS-01 (1992)	Procedure for determining strontium-90 in drinking water and ground water
H-γ-SPEKT-TWASS-01 (1992)	Procedure for determining radionuclides in drinking water and ground water by gamma spectrometry
H-α-SPEKT-TWASS-03 (1992)	Procedure for determining plutonium isotopes in drinking water and ground water by alpha spectrometry
H-U/Pu/Am-AWASS-01 (2000)	Procedure for determining uranium, plutonium and americium by extraction-chromatographic procedures
Allgemeine Kapitel (2014)	Formelzeichen für Größen und Einheiten [Symbols for quantities and units]
Allgemeine Kapitel (2009)	Gammaspektrometrie [Gamma-spectrometry]
Allgemeine Kapitel (2009)	Betaspektrometrie und integrale Messung [Beta-spectrometry and integral measurement]

Standard / procedure	Title
Allgemeine Kapitel (2009)	Alphaspektrometrie [Alpha-spectrometry]
Allgemeine Kapitel (2013)	Massenbezogene Aktivitäten und Äquivalente [Mass-related activities and equivalents]
Allgemeine Kapitel (2013)	Nachweis- und Erkennungsgrenze [Decision threshold and detection limit]
Allgemeine Kapitel (2009)	Dokumentation von Messwerten [Documentation of measured values]
Allgemeine Kapitel (2009)	Qualitätskontrolle [Quality assurance]
Allgemeine Kapitel (2014)	Kernphysikalische Daten [Nuclear data]
Allgemeine Kapitel (2015)	Berechnungsverfahren [Calculation methods]
In preparation	
Allgemeine Kapitel	Messunsicherheiten [Measurement uncertainties]
Allgemeine Kapitel	Zerfallskorrektion bei mehrgliedrigen Zerfallsreihen [Decay correction for multi-step decay chains]

DIN and ISO standards and standards under revision

The list also includes new work projects, indicated as DRAFTS.

Standard / procedure	Title
ISO 80000-10: 2009	Quantities and units -- Part 10: Atomic and nuclear physics
ISO 5667-1: 2006	Water quality -- Sampling -- Part 1: Guidance on the design of sampling programmes and sampling techniques
ISO 5667-3: 2012	Water quality -- Sampling -- Part 3: Guidance on the preservation and handling of water samples
ISO 5667-5: 2006	Water quality -- Sampling -- Part 5: Guidance on sampling of drinking water from treatment works and piped distribution systems
ISO 9696: 2007	Water quality -- Measurement of gross alpha activity in non-saline water -- Thick source method
ISO 9697: 2015	Water quality -- Gross beta activity in non-saline water -- Test method using thick source
ISO 9698: 2010	Water quality -- Determination of tritium activity concentration -- Liquid scintillation counting method
ISO 10703: 2007	Water quality -- Determination of the activity concentration of radionuclides -- Method by high resolution gamma-ray spectrometry
ISO 10704: 2009	Water quality -- Measurement of gross alpha and gross beta activity in non-saline water -- Thin source deposit method
ISO 15839:2003	Water quality -- On-line sensors/analysing equipment for water -- Specifications and performance tests.

Standard / procedure	Title
ISO 17381:2003	Water quality -- Selection and application of ready-to-use test kit methods in water analysis.
ISO 11704: 2010	Water quality -- Measurement of gross alpha and beta activity concentration in non-saline water -- Liquid scintillation counting method
ISO 13160: 2012	Water quality -- Strontium 90 and strontium 89 -- Test methods using liquid scintillation or proportional counting
ISO 13161: 2011	Water quality -- Measurement of polonium 210 activity concentration in water by alpha spectrometry
ISO 13162: 2011	Water quality -- Determination of carbon 14 activity -- Liquid scintillation counting method
ISO 13163: 2013	Water quality -- Lead-210 -- Test method using liquid scintillation counting
ISO 13164-1: 2013	Water quality -- Radon-222 -- Part 1: General principles
ISO 13164-2: 2013	Water quality -- Radon-222 -- Part 2: Test method using gamma spectrometry
ISO 13164-3: 2013	Water quality -- Radon-222 -- Part 3: Test method using emanometry
ISO 13164-4: 2015	Water quality -- Radon-222 -- Part 4: Test method using two-phase liquid scintillation counting
ISO 13165-1: 2013	Water quality -- Radium-226 -- Part 1: Test method using liquid scintillation counting
ISO 13165-2: 2014	Water quality -- Radium-226 -- Part 2: Test method using emanometry
ISO 13167: 2015	Water quality -- Plutonium, americium, curium and neptunium -- Test method using alpha spectrometry

Standard / procedure	Title
ENTWÜRFE	
ISO/DIS 9696: 2015-12	Water quality -- Measurement of gross alpha activity in non-saline water -- Thick source method
ISO/FDIS 13165-3: 2015-11	Water quality -- Radium-226 -- Part 3: Test method using coprecipitation and gamma-spectrometry
ISO/CD 13169: 2015-11	Water quality -- Uranium -- Test method using alpha liquid scintillation counting
ISO/FDIS 17294-2: 2015-12	Water quality -- Application of inductively coupled plasma mass spectrometry (ICP-MS) -- Part 2: Determination of selected elements including uranium isotopes
DIN	
DIN EN ISO 5667-1: 2007-04	Water quality – Sampling – Part 1: Guidance on the design of sampling programmes and sampling techniques (ISO 5667-1: 2006)
DIN EN ISO 5667-3: 2013-03	Water quality – Sampling – Part 3: Preservation and handling of water samples (ISO 5667-3: 2012)
DIN ISO 5667-5: 2011-02	Water quality – Sampling – Part 5: Guidance on sampling of drinking water from treatment works and piped distribution systems (ISO 5667-5: 2006)
DIN EN ISO 9698: 2015-12	Water quality – Determination of tritium activity concentration – Liquid scintillation counting method (ISO 9698: 2010)
DIN 38404-14: 1987-06	German standard methods for the examination of water, waste water and sludge; physical and physico-chemical parameters (group C); determination of gross alpha activity concentration A_α in potable water, ground water and surface water (C 14)

Standard / procedure	Title
DIN 38404-15: 1987-09	German standard methods for the examination of water, waste water and sludge; physical and physico-chemical parameters (group C); determination of residual beta activity in drinking water, ground water, surface water and waste water (C 15)
DIN 38404-18: 1994-03	German standard methods for the examination of water, waste water and sludge; physical and physico-chemical parameters (group C); determination of Radium-226 concentration in potable water, ground water, surface water and waste water (C 18)
DIN 38406-17: 2009-10	German standard methods for the examination of water, waste water and sludge - Cations (group E) - Part 17: Determination of uranium - Method using adsorptive stripping voltammetry in surface water, raw water and drinking water (E 17)
DIN EN ISO 10703: 2015-12	Water quality – Determination of the activity concentration of radionuclides – Method by high resolution gamma-ray spectrometry (ISO 10703: 2007)
DIN EN ISO 10704:2015-11	Water quality – Measurement of gross alpha and gross beta activity in non-saline water – Thin source deposit method (ISO 10704: 2009)
DIN EN ISO 11704: 2015-11	Water quality – Measurement of gross alpha and beta activity concentration in non-saline water – Liquid scintillation counting method (ISO 11704: 2010)
DIN ISO 11929: 2011-01	Determination of the characteristic limits (decision threshold, detection limit and limits of the confidence interval) for measurements of ionizing radiation – Fundamentals and application (ISO 11929: 2010)
DIN EN ISO 13161: 2016-01	Water quality – Measurement of polonium 210 activity concentration in water by alpha spectrometry (ISO 13161: 2011)
DIN ISO 13165-1: 2015-11	Water quality – Radium-226 – Part 1: Test method using liquid scintillation counting (ISO 13165-1: 2013)

Standard / procedure	Title
DIN EN ISO 17294-2: 2005-02	Water quality – Application of inductively coupled plasma mass spectrometry (ICP-MS) – Part 2: Determination of 62 elements (ISO 17294-2: 2003)
DRAFTS	
DIN EN ISO 9696: 2016-01	Water quality – Measurement of gross alpha activity in non-saline water – Thick source method (ISO/DIS 9696: 2015)
DIN EN ISO 9697: 2016-01	Water quality – Gross beta activity in non-saline water – Test method using thick source (ISO 9697: 2015)
E DIN EN ISO 17294-2: 2014-12	Water quality – Application of inductively coupled plasma mass spectrometry (ICP-MS) – Part 2: Determination of selected elements including uranium isotopes (ISO/FDIS 17294-2: 2014)
E DIN EN ISO 13160: 2015-04	Water quality – Strontium 90 and strontium 89 – Test methods using liquid scintillation counting or proportional counting (ISO 13160: 2012)

Annex A-3: "Test for Compliance with Radioactivity-Related Parameters" forms

Form I.1: Check for compliance with the test value of the gross alpha activity concentration in the simple screening procedure and the parameter value of the Rn-222 activity concentration in accordance with Chapters 7.2.2 and 7.3 (results of an individual sample)

Requirements for drinking water with respect to radioactivity

I.1: Check for compliance with the test value of the gross alpha activity concentration in the simple screening procedure and the parameter value of the Rn-222 activity concentration in accordance with Chapters 7.2.2 and 7.3 (results of an individual sample)

1. General information

Initiator (name, address): ______________________________

____

Contact person (name, phone): ______________________________

2. Sampling point details

Name of sampling point: ______________________________

Place of sampling: ______________________________

Postcode: ________ Town or city: ______________________________

Street, number: ______________________________

Type of sampling point: ☐ Water tap ☐ Pump outlet

☐ ______________________________

☐ Sampling immediately after first outflow

☐ Sampling after outflow time of ________ min (equalling ________ L)

Outflow volume: ________ L Outflow time: ________ sec Outflow rate: ________ L/sec

3. Sampling details

Date: ________________ Start time: ________________

4. Check for compliance with the test value of the gross alpha activity concentration and the parameter value of the Rn-222 activity concentration

Quarter no. [1]: 1 of 4

Measurand/ parameter	Unit	Procedure	Limit of detection[2]	$C_{r,\text{prüf}}$ [2] / $C_{r,\text{para}}$ [3]	$C_{r,\text{mess}}$
$C_{\alpha\text{-ges}}$	mBq/l		25	50	
$C_{\text{Rn-222}}$	Bq/l		10	100	

[1] According to Chapter 6.4: 1st, 2nd, 3rd or 4th quarterly measurement

[2] Limit of detection and test value ($C_{r,\text{prüf}}$) according to Drinking Water Ordinance, Annex 3a Part III [BMG 2015a]

[3] Parameter value ($C_{r,\text{para}}$) according to Drinking Water Ordinance, Annex 3a Part I [BMG 2015a]

Form I.2: Check for compliance with the test value of the gross alpha activity concentration in the simple screening procedure and the parameter value of the Rn-222 activity concentration in accordance with Chapters 7.2.2 and 7.3 (summary and evaluation of 4 quarterly measurements)

Requirements for drinking water with respect to radioactivity

I.2: Check for compliance with the test value of the gross alpha activity concentration in the simple screening procedure and the parameter value of the Rn-222 activity concentration in accordance with Chapters 7.2.2 and 7.3 (summary and evaluation of 4 quarterly measurements)

1. General information

Initiator (name, address): ____________________

____

Contact person (name, phone): ____________________

2. Sampling point details

Name of sampling point: ____________________

Place of sampling: ____________________

Postcode: __________ Town or city: ____________________

Street, number: ____________________

3. Check for compliance with the test value of the gross alpha activity concentration and the parameter value of the Rn-222 activity concentration

Measurement		1	2	3	4	**Mean value**
Sampling date						
Measurand	**Unit**	$C_{r,mess}$	$C_{r,mess}$	$C_{r,mess}$	$C_{r,mess}$	$\bar{C}_{r,mess}$ 1)
$C_{\alpha\text{-ges}}$	mBq/l					
$C_{Rn\text{-}222}$	Bq/l					

$\bar{C}_{\alpha\text{-ges}} \leq 50$ mBq/l 2) ☐ yes ☐ no

$\bar{C}_{Rn\text{-}222} \leq 100$ Bq/l 3) ☐ yes ☐ no

$\bar{C}_{\alpha\text{-ges}} \leq 250$ mBq/l and $\bar{C}_{Rn\text{-}222} \leq 100$ Bq/l 4) ☐ yes ☐ no

1) The arithmetic mean value of the individual measured values $C_{r,mess}$ (obtained from measurements in 4 different annual quarters) is determined.

2) If "**yes**", the reference dose parameter value is considered to be complied with and no further tests will be required. If "**no**", nuclide-specific measurements are required. Under the condition described in footnote 4), these measurements can be limited to the nuclides Ra-226 and Ra-228. In all other cases, the nuclide-specific measurements described in Chapter 7.2.4 have to be performed (form IV.1).

3) If "**yes**", the parameter value for the Rn-222 activity concentration is considered to be complied with. If "**no**", reduction measures for drinking water may have to be taken (cf. Chapter 7.4).

4) If "**yes**", the radium isotopes Ra-226 and Ra-228 need to be determined in four different annual quarters (cf. Annex A-1). Please use form III.1 in this case for the determination of the reference dose. If "**no**", more detailed nuclide-specific measurements according to Chapter 7.2.4 will be required (form IV.1).

Form II.1: Check for compliance with the test value of the gross alpha activity concentration in the extended screening procedure and the parameter value of the Rn-222 activity concentration according to Chapters 7.2.3 and 7.3 (results of an individual sample)

Requirements for drinking water with respect to radioactivity

II.1: Check for compliance with the test value of the gross alpha activity concentration in the extended screening procedure and the parameter value of the Rn-222 activity concentration according to Chapters 7.2.3 and 7.3 (results of an individual sample)

1. General information

Initiator (name, address): ______________________________

____

Contact person (name, phone): ______________________________

2. Sampling point details

Name of sampling point: ______________________________

Place of sampling: ______________________________

Postcode: ________ Town or city: ______________________________

Street, number: ______________________________

Type of sampling point: ☐ Water tap ☐ Pump outlet

☐ ______________________________

☐ Sampling immediately after first outflow

☐ Sampling after outflow time of ________ min (equalling ________ L)

Outflow volume: ________ L Outflow time: ________ sec Outflow rate: ________ L/sec

3. Sampling details

Date: ________________ Start time: ________________

4. Check for compliance with the test condition of the extended screening procedure and the parameter value of the Rn-222 activity concentration

Quarter no. 1): <u>1</u> of 4

Measurand/ parameter	Unit	Procedure	Limit of detection 2)	$C_{r,\text{prüf}}$ 2) / $C_{r,\text{ref}}$ 3) / $C_{r,\text{para}}$ 4)	$C_{r,\text{mess}}$
$C_{\alpha\text{-ges}}$	mBq/l		40	100	
$C_{\text{Pb-210}}$	mBq/l		20	200	
$C_{\text{Ra-228}}$	mBq/l		20 (80 5))	200	
$C_{\text{Rn-222}}$	Bq/l		10	100	

1) According to Chapter 6.4: 1st, 2nd, 3rd or 4th quarterly measurement

2) Limit of detection and test value ($C_{r,\text{prüf}}$) according to Drinking Water Ordinance, Annex 3a Part III [BMG 2015a]

3) Reference activity concentration ($C_{r,\text{ref}}$) according to Drinking Water Ordinance, Annex 3a Part II

4) Parameter value ($C_{r,\text{para}}$) according to Drinking Water Ordinance, Annex 3a Part I [BMG 2015a]

5) In the case of regular tests if $C_{\text{Ra-228}} \leq 40$ mBq/l

Form II.2: Check for compliance with the test value of the gross alpha activity concentration in the extended screening procedure and the parameter value of the Rn-222 activity concentration according to Chapters 7.2.3 and 7.3 (summary and evaluation of 4 quarterly measurements)

Requirements for drinking water with respect to radioactivity

II.2: Check for compliance with the test value of the gross alpha activity concentration in the extended screening procedure and the parameter value of the Rn-222 activity concentration according to Chapters 7.2.3 and 7.3 (summary and evaluation of 4 quarterly measurements)

1. General information

Initiator (name, address): ______________________________

____

Contact person (name, phone): ______________________________

2. Sampling point details

Name of sampling point: ______________________________

Place of sampling: ______________________________

Postcode: __________ Town or city: ______________________________

Street, number: ______________________________

3. Check for compliance with the test condition of the extended screening procedure and the parameter value of the Rn-222 activity concentration

Measurement		1	2	3	4	**Mean value**
Sampling date						
Measurand	**Unit**	$C_{r,\mathrm{mess}}$	$C_{r,\mathrm{mess}}$	$C_{r,\mathrm{mess}}$	$C_{r,\mathrm{mess}}$	$C_{r,\mathrm{mess}}$ [1)]
$C_{\alpha\text{-ges}}$	mBq/l					
$C_{\text{Pb-210}}$	mBq/l					
$C_{\text{Ra-228}}$	mBq/l					
$C_{\text{Rn-222}}$	Bq/l					

$$\frac{\bar{C}_{\alpha\text{-ges}}}{100\ \text{mBq/l}} + \frac{\bar{C}_{\text{Pb-210}}}{200\ \text{mBq/l}} + \frac{\bar{C}_{\text{Ra-228}}}{200\ \text{mBq/l}} \leq 1\ ^{2)}$$ ☐ yes ☐ no

$\bar{C}_{\text{Rn-222}} \leq 100$ Bq/l [3)] ☐ yes ☐ no

$\bar{C}_{\alpha\text{-ges}} \leq 250$ mBq/l <u>and</u> $\bar{C}_{\text{Rn-222}} \leq 100$ Bq/l [4)] ☐ yes ☐ no

1) The arithmetic mean value of the individual measured values $C_{r,\mathrm{mess}}$ (obtained from measurements in 4 different annual quarters) is determined.

2) If "**yes**", the reference dose parameter value is considered to be complied with and no further tests will be required. If "**no**", further testing can be limited to the nuclide Ra-226 under the condition described in footnote 4). In all other cases, nuclide-specific measurements will be required (cf. footnote 4).

3) If "**yes**", the parameter value for the Rn-222 activity concentration is considered to be complied with. If "**no**", reduction measures for drinking water may have to be taken (cf. Chapter 7.4).

4) If "**yes**", only the radium isotope Ra-226 has to be determined in four different annual quarters (cf. Chapter 7.2.5). Please use form III.1 for the determination of the reference dose; current measured values for Ra-228 can be transferred from form II.1. If "**no**", more detailed nuclide-specific measurements according to Chapter 7.2.4 will be required (form IV.1).

Form III.1: Check for compliance with the reference dose parameter value by determining the activity concentration of gross alpha, Rn-222 and radium isotopes in accordance with Chapters 7.2.5 and Annex A-1 (results of an individual sample)

Requirements for drinking water with respect to radioactivity

III.1: Check for compliance with the reference dose parameter value by determining the activity concentration of gross alpha, Rn-222 and radium isotopes in accordance with Chapters 7.2.5 and Annex A-1 (results of an individual sample)

1. General information

Initiator (name, address): ____________________

____

Contact person (name, phone): ____________________

2. Sampling point details

Name of sampling point: ____________________

Place of sampling: ____________________

Postcode: ________ Town or city: ____________________

Street, number: ____________________

Type of sampling point: ☐ Water tap ☐ Pump outlet

☐ ____________________

☐ Sampling immediately after first outflow

☐ Sampling after outflow time of ________ min (equalling ________ L)

Outflow volume: ________ L Outflow time: ________ sec Outflow rate: ________ L/sec

3. Sampling details

Date: ________________ Start time: ________________

4. Check for compliance with the reference dose parameter value

Quarter no. [1]: 1 of 4

Checking for compliance with the reference dose parameter on the basis of radium isotopes is only possible if the following condition is met:

$$\bar{C}_{\alpha\text{-ges}} \leq 250 \text{ mBq/l } \underline{\text{and}} \ \bar{C}_{Rn\text{-}222} \leq 100 \text{ Bq/l}$$

Measurand	Unit	Procedure	Limit of detection[2]	$C_{r,ref}$ [3]	$C_{r,mess}$
$C_{Ra\text{-}226}$	mBq/l		40	500	
$C_{Ra\text{-}228}$ [4]	mBq/l		20	200	

1) According to Chapter 6.4: 1st, 2nd, 3rd or 4th quarterly measurement

2) Limit of detection according to Drinking Water Ordinance, Annex 3a Part III [BMG 2015a]

3) Reference activity concentration ($C_{r,ref}$) according to Drinking Water Ordinance, Annex 3a Part II

4) May be transferred from form II.1.

Form III.2: Check for compliance with the reference dose parameter value by determining the activity concentration of gross alpha, Rn-222 and radium isotopes in accordance with Chapters 7.2.5 and Annex A-1 (summary and evaluation of 4 quarterly measurements)

Requirements for drinking water with respect to radioactivity

III.2: Check for compliance with the reference dose parameter value by determining the activity concentration of gross alpha, Rn-222 and radium isotopes in accordance with Chapters 7.2.5 and Annex A-1 (summary and evaluation of 4 quarterly measurements)

1. General information

Initiator (name, address): ______________________________

____

Contact person (name, phone): ______________________________

2. Sampling point details

Name of sampling point: ______________________________

Place of sampling: ______________________________

Postcode: __________ Town or city: ______________________________

Street, number: ______________________________

3. Check for compliance with the reference dose parameter value

Checking for compliance with the reference dose parameter on the basis of radium isotopes is only possible if the following condition is met:

$$\bar{C}_{\alpha\text{-ges}} \leq 250 \text{ mBq/l } \underline{\text{and}} \ \bar{C}_{\text{Rn-222}} \leq 100 \text{ Bq/l}$$

Measurement		1	2	3	4	Mean value
Sampling date						
Measurand	Unit	$C_{r,\text{mess}}$	$C_{r,\text{mess}}$	$C_{r,\text{mess}}$	$C_{r,\text{mess}}$	$C_{r,\text{mess}}$ 1)
$C_{\text{Ra-226}}$	mBq/l					
$C_{\text{Ra-228}}$	mBq/l					

$$\frac{\bar{C}_{\text{Ra-226}}}{C_{\text{Ra-226 ref}}} + \frac{\bar{C}_{\text{Ra-228}}}{C_{\text{Ra-228 ref}}} \leq 0.5 \ ^{2,3)}$$

☐ yes ☐ no

1) The arithmetic mean value of the individual measured values $C_{r,\text{mess}}$ (obtained from measurements in 4 different annual quarters) is determined.

2) Reference activity concentrations: Ra-226 500 mBq/l; Ra-228 200 mBq/l.

3) If "**yes**", the reference dose parameter value is considered to be complied with and no further tests will be required. If "**no**", further nuclide-specific measurements according to Chapter 7.2.5 will be required (form IV.1).

Form IV.1: Check for compliance with the reference dose parameter value by determining the activity concentration of the single nuclides in accordance with Chapter 7.2.4 (results of an individual sample)

Requirements for drinking water with respect to radioactivity

IV.1: Check for compliance with the reference dose parameter value by determining the activity concentration of the single nuclides in accordance with Chapter 7.2.4 (results of an individual sample)

1. General information

Initiator (name, address): ______________________________

____

Contact person (name, phone): ______________________________

2. Sampling point details

Name of sampling point: ______________________________

Place of sampling: ______________________________

Postcode: ________ Town or city: ______________________________

Street, number: ______________________________

Type of sampling point: ☐ Water tap ☐ Pump outlet

☐ ______________________________

☐ Sampling immediately after first outflow

☐ Sampling after outflow time of ________ min (equalling ________ L)

Outflow volume: ________ L Outflow time: ________ sec Outflow rate: ________ L/sec

3. Sampling details

Date: ______________ Start time: ______________

4. Check for compliance with the reference dose parameter value

Quarter no. [1]: _1_ of 4

Measurand	Unit	Procedure	Limit of detection[2]	$C_{r,ref}$ [3]	$C_{r,mess}$
$C_{U\text{-}238}$	mBq/l		100	3000	
$C_{U\text{-}234}$	mBq/l		100	2800	
$C_{Ra\text{-}226}$ [4]	mBq/l		40	500	
$C_{Ra\text{-}228}$ [4,5]	mBq/l		20	200	
$C_{Pb\text{-}210}$ [5]	mBq/l		20	200	
$C_{Po\text{-}210}$	mBq/l		10	100	

[1] According to Chapter 6.4: 1st, 2nd, 3rd or 4th quarterly measurement

[2] Limit of detection according to Drinking Water Ordinance, Annex 3a Part III [BMG 2015a]

[3] Reference activity concentration ($C_{r,ref}$) according to Drinking Water Ordinance, Annex 3a Part II

[4] May be transferred from form III.1.

[5] May be transferred from form II.1.

Form IV.2: Check for compliance with the reference dose parameter value by determining the activity concentration of the single nuclides in accordance with Chapter 7.2.4 (summary and evaluation of 4 quarterly measurements)

Requirements for drinking water with respect to radioactivity

IV.2: Check for compliance with the reference dose parameter value by determining the activity concentration of the single nuclides in accordance with Chapter 7.2.4 (summary and evaluation of 4 quarterly measurements)

1. General information

Initiator (name, address): ______________________________

____

Contact person (name, phone): ______________________________

2. Sampling point details

Name of sampling point: ______________________________

Place of sampling: ______________________________

Postcode: ____________ Town or city: ______________________________

Street, number: ______________________________

3. Check for compliance with the reference dose parameter value

Measurement		1	2	3	4	**Mean value**
Sampling date						
Measurand	**Unit**	$C_{r,\text{mess}}$	$C_{r,\text{mess}}$	$C_{r,\text{mess}}$	$C_{r,\text{mess}}$	$\bar{C}_{r,\text{mess}}$ [1)]
$C_{U\text{-}238}$	mBq/l					
$C_{U\text{-}234}$	mBq/l					
$C_{Ra\text{-}226}$	mBq/l					
$C_{Ra\text{-}228}$	mBq/l					
$C_{Pb\text{-}210}$	mBq/l					
$C_{Po\text{-}210}$	mBq/l					

$$\sum_r \frac{\bar{C}_{r,\text{mess}}}{C_{r,\text{ref}}} \leq 1^{\,2,3)}$$

☐ yes ☐ no (E = ... mSv/a)

1) The arithmetic mean value of the individual measured values $C_{r,\text{mess}}$ (obtained from measurements in 4 different annual quarters) is determined.

2) Reference activity concentrations: U-238 3000 mBq/l; U-234 2800 mBq/l; Ra-226 500 mBq/l; Ra-228 200 mBq/l; Pb-210 200 mBq/l; Po-210 100 mBq/l.

3) If “**yes**”, the reference dose parameter value is considered to be complied with and no further tests will be required. If “**no**”, remedial measures may have to be taken (cf. Chapter 7.4).

Instructions for using forms I to IV

These instructions describe the handling of forms I to IV, created with Microsoft® Excel. These forms, saved in Excel-97-2003 format (ending .XLS), are integrated into the pdf file containing these Guidelines and can be extracted with both Adobe Acrobat Reader and other PDF viewers (e.g. Sumatra PDF, Okular). In the case of Acrobat Reader, select the paper clip icon on the left-hand side to show the embedded files. By selecting these files (multiple selection is possible) and pressing the "Save" button above, you can save the files at the specified location.

If you use the free Sumatra PDF viewer, you will find the files in the Bookmarks view below the Table of contents. A "Save as…" window opens on selection of the files.

Apart from the above-mentioned applications you can also use the Mozilla Firefox web browser with its integrated and activated PDF preview. Open the PDF document, for example, via the link on the relevant BMUB webpage or via "File" → "Open file" (if the menu bar is hidden, press the Alt key). Select the square icon on the left ("Toggle Sidebar") and a button with a paper clip icon will appear. Select one of the listed files and a dialogue window will open so that you can save the file.

The available template forms are each divided into five worksheets, four of which are intended for the individual quarterly measurements and one is to be used for the summary of the measuring results and the comparison of the calculated mean value with the relevant test conditions of each step. In order to minimize the effort of entering the data, recurring information is carried over from one worksheet to the next. A validity check is performed on the majority of the input fields.

Description of the worksheets I.1, II.1, III.1 and IV.1 (results of an individual sample)

Section 1 – General information

Enter here the initiator and contact person details. The entries are carried over to the following worksheets. If changes occur during the test procedure, you can overwrite the previous details and the new value will then be carried over to the following worksheets.

Section 2 – Sampling point details

Enter here the sampling point and sampling procedure details. The location data will be carried over to the following worksheets and cannot be changed there. If you enter data into the "Outflow volume" and "Outflow time" fields, the resulting "Outflow rate" is calculated and shown.

Section 3 – Sampling details

Enter here the date and time of sampling. The date will be shown in the relevant fields of the summary.

Section 4 – Measured value data

Enter the measured values and the relevant measuring procedures (e.g. gamma-spectrometry, alpha-spectrometry, LSC measurement) in this section. In order to reduce the effort associated with entering the data, the measuring procedures are carried over to the worksheet for the following quarter. If a different method is used, you can change it there. The measured value fields are each separated into three cells. The one in the middle cannot be edited. Values above the limit of detection (LOD) should be entered into the first cell, then a “±” symbol will appear in the second cell. You can enter the measurement uncertainty in the third cell, using the same unit of measurement that was used for the measured value (see example below). Values below the limit of detection should be entered into the third cell, then a “<” symbol will appear in the second cell (the first cell must be left empty). The content of these cells is copied into the relevant positions on the worksheet “Summary and evaluation”.

Measured value and measurement uncertainty:	12.3 ± 3.4	Measured value below LOD:	< 10

Important note: *The measured values must be entered in the unit of measurement corresponding to the measurand. The unit generally used in these forms is “mBq/l”.*

Description of the worksheets I.2, II.2, III.2 and IV.2 (summary and evaluation)

These worksheets are the last sheet of each form. They summarise the most important data stated in the previous worksheets, calculate a mean value from the individual values and show the status of the test for compliance with the relevant test condition via checks in the corresponding checkboxes.

The mean value $\bar{C}_{r,\text{mess}}$ is calculated as follows: If only measured values below the limit of detection are indicated, the highest limit of detection is shown as the mean value in the form < │LOD│. In all other cases, the relevant measured values or the absolute values of the limits of detection are used to calculate the mean value. The reference dose calculated in form IV.2 is thus indicated in the form of an inequality (E = < value), if the mean value of the activity concentration of at least one radionuclide is < │LOD│, in all other cases it is indicated in the form of an equation (E = value).

Note: The calculated values and not the rounded mean values as indicated are used for the comparison with the relevant test conditions.

The yes/no checkboxes only show the status if all required measured values have been entered. For example, all corresponding values from the annual quarters are needed to check compliance with the test value for the gross alpha activity concentration in form I.2. The same applies to the Rn-222 activity concentration in forms I.2 and II.2. However, compliance with the parameter value of the Rn-222 activity concentration can be checked independently of the reference dose. The comparison with the relevant test condition only requires the complete data for one of the considered parameters (Rn-222 or reference dose on the basis of the screening procedure). The forms can thus also be used separately. Forms III.2 and IV.2 will only show the results of the checks if all values have been entered into the tables.