Experimental Study of Radon Content in Networked Natural Gas under the Conditions of Yakutsk

V E Stepanov, K A Naumova

1Department of Electric Power, Institute of the Physical-Technical Problems of the North SB RAS, Republic of Sakha (Yakutia) Oktyabrskaya street 1, Yakutsk 677000, Russian Federation
2Department of Power Supply, Institute of Physics and Technology, M.K. Ammosov North-Eastern Federal University, Kulakovsky street 48, Yakutsk 677000, Russian Federation

E-mail: kristinan_1604@rambler.ru

Abstract. Analyzed the problem of radon safety in residential areas with gas stoves of various companies. Volumetric radon concentrations were obtained and annual dose rates were calculated. Measurements were carried out with two instruments: on the radon gauge Alpha Guard and on the РРА-01М-03 manufactured by NTM Protection. Samples of networked natural gas for measurement were taken using an air sampler [1], [2]. A device and methods for sampling methane from domestic gas cookers in the conditions of the city of Yakutsk have been developed. The sampler consists of a silicone hose with a tubular tip with a solid cap. Silicone hose attached to the standard air sampler with two fittings of the company NTM Protection. The divider and the burner are removed from the tile; the tube with the cap is pressed tightly against the iron gas-conducting pipe. The methane launch valve opens to the stove. A flexible tube is put on the loose fitting and lowered into a bowl of water to control the gas outlet. Experimentally chosen time to achieve the maximum volumetric concentration of radon in the sampler for air. The obtained value of radon volumetric activity is: 116 ± 27 Bq / m³

1. Introduction
It is widely known that radon [3], [4] is emitted when natural gas is burned on domestic gas stoves, but there is no detailed study of radon extraction from network natural gas. Consequently, the study of the problem of radon emanation from natural gas is of fundamental scientific importance, as well as relevant in connection with the implementation of the gasification program in the settlements of Yakutia.

In the present work, radon contents in apartments in the city of Yakutsk and in the village of Maya of the Megino-Kangalassky district are investigated. The results of measuring the radon volumetric concentrations are presented, and the annual limit dose loads in five apartments with different gas cookers are determined. Measurements of the radon volumetric activity were carried out on two devices: the Alpha Guard [6] radon radiometer and the PPA-01М-03 production of the NTM Protection [7]. Calibration experiments were also carried out in a radon chamber [5], comparing the readings of the PPA-01М-03 and Alpha Guard instruments. In Russia, it is customary to calibrate Russian-made radiometers by comparing their readings with the results of measurements on an
AlphaGuard instrument, since it is recognized as the most accurate radar meter in the world. As a result of the calibration, a correction factor was calculated for the readings of the PPA device, on which direct measurement of radon in network natural gas is possible.

2. Measurement of the volumetric activity of radon in networked natural gas
To study of volumetric activity radon in networked natural gas, 2 methods were used. The installation for determining radon OA by direct measurement method (figure 1) consists of an insulating cap 1, a sampling hose with a filter 2 and an instrument 3. Before starting the measurements a cap is placed on the stove and then sealed, then, the air intake tube is passed through the cap and placed in a gas burner slabs. Next, turn on the Alpha Guard and the gas stove. Air is pumped through the sampler hose to the radiometer, then, the measurement results are recorded every 10 minutes.

![Figure 1](image1.png)

**Figure 1.** Method for direct measurement of volumetric activities with the help of an Alpha Guard radon radiometer.

For the method of measuring the volumetric activities of radon in LNG using an air sampler (figure 2.), an insulating cap 1, an air intake tube 2 and a sampler 3 are used. Natural gas is sampled as in the previous method. The pressurized gas passes through the suction tube into the sampler. After sampling, the radon content in LNG is measured using the PPA-01M-03 device.

![Figure 2](image2.png)

**Figure 2.** Method for measuring the volumetric activities of radon in LNG using an Air Sampler.

The results are presented in tables 1-5.
Table 1. The results of measurements of radon volumetric activity using the device PPA-01M-03 for residential premises, where a gas stove of the “Beko” company.

| Month | Volumetric activity of \(^{222}\text{Rn}, \text{Bq} / \text{m}^3\) | Temperature, °C | Air pressure, mbar | Humidity, % | \(N_\alpha\) | Toron |
|-------|-----------------------------------------------|-----------------|-------------------|-------------|-----------|-----|
| March | max 79±21, min <20                            | max 25          | max 744           | max 23      | max 19    | max 1 |
| April | max 47±17, min <20                           | max 28          | max 745           | max 21      | min 3     | min 0 |
| May   | max 79±21, min <20                           | max 28          | max 740           | max 24      | max 19    | max 0 |
| June  | max 41±14, min <20                           | max 24          | max 749           | max 24      | max 10    | max 1 |

Table 2. Results of radon measurements for residential premises with a gas stove of the company “Bosch”.

| Month | Volumetric activity of \(^{222}\text{Rn}, \text{Bq} / \text{m}^3\) | Temperature, °C | Air pressure, mbar | Humidity, % | \(N_\alpha\) | Toron |
|-------|-----------------------------------------------|-----------------|-------------------|-------------|-----------|-----|
| March | max 50±16, min 26±12                         | max 28          | max 753           | max 20      | max 12    | max 1 |
| April | max 45±15, min 33±12                         | max 28          | max 752           | max 19      | max 11    | max 1 |
| May   | max 64±19, min <20                           | max 24          | max 749           | max 28      | max 15    | max 1 |
| June  | max 104±26, min=20±9                         | max 22          | max 747           | max 33      | max 25    | max 1 |

Table 3. The results of measurements of the volumetric activities of radon for residential premises in which the gas stove of the company “Hotpoint-Ariston” is used.

| Month | Volumetric activity of \(^{222}\text{Rn}, \text{Bq} / \text{m}^3\) | Temperature, °C | Air pressure, mbar | Humidity, % | \(N_\alpha\) | Toron |
|-------|-----------------------------------------------|-----------------|-------------------|-------------|-----------|-----|
| March | max 104±26, min <20                         | max 23          | max 744           | max 27      | max 25    | max 0 |
| April | max 90±24, min 38±15                        | max 24          | max 746           | max 24      | max 22    | max 1 |
| May   | max 87±21, min 28±11                        | max 24          | max 747           | max 31      | max 21    | max 1 |
| June  | max 106±27, min 20±9                        | max 23          | max 749           | max 30      | max 25    | max 1 |

Table 4. Radon measurements for residential premises where the gas stove of “Zanussi” company is used.

| Month | Volumetric activity of \(^{222}\text{Rn}, \text{Bq} / \text{m}^3\) | Temperature, °C | Air pressure, mbar | Humidity, % | \(N_\alpha\) | Toron |
|-------|-----------------------------------------------|-----------------|-------------------|-------------|-----------|-----|
| March | max 141±32, min 42±15                        | max 21          | max 737           | max 31      | max 34    | max 1 |
| April | max 84±24, min 37±13                         | max 24          | max 744           | max 31      | max 16    | max 4 |
| May   | max 62±18, min 29±11                         | max 24          | max 744           | max 29      | max 15    | max 1 |
| June  | max 94±26, min 35±14                         | max 24          | max 749           | max 31      | max 23    | max 1 |
Table 5. The results of measurements of the volumetric activities of radon for residential premises where an “Ardo” gas stove is used.

| Month | Volumetric activity of $^{222}\text{Rn}$, Bq / m$^3$ | Temperature, $°\text{C}$ | Air pressure, mbar | Humidity, % | $N_\alpha$ | Toron |
|-------|----------------------------------|-----------------|----------------|----------|---------|--------|
| March | max 62±18                         | max 20          | max 744        | max 41   | max 15  | max 0  |
|       | min 33±12                         | min 20          | min 743        | min 41   | min 8   | min 0  |
| April | max 91±23                         | max 21          | max 746        | max 38   | max 22  | max 0  |
|       | min <20                           | min 21          | min 746        | min 37   | min 4   | min 0  |
| May   | max 54±17                         | max 23          | max 748        | max 32   | max 13  | max 1  |
|       | min <20                           | min 22          | min 747        | min 31   | min 2   | min 0  |
| June  | max 108±27                        | max 24          | max 747        | max 30   | max 26  | max 2  |
|       | min <20                           | min 23          | min 747        | min 30   | min 4   | min 0  |

Tables 1-5 show the results of measurements of radon volumetric activity in houses where household gas stoves of five different firms are installed using the PPA-01M-03 device. The maximum value of radon VA, $141 \pm 32$ Bq / m$^3$, was found in the house where the Zanussi stove is installed. The results of experimental studies show that in all studied residential buildings the effective equilibrium volume activity of radon (1) is at the level of maximum permissible radon concentration for new buildings and below the permissible level for buildings in operation.

3. Determination of radiation dose from radon for the population of Yakutsk

The calculation of the individual annual effective dose of internal exposure of adult residents of a settlement (district, etc.) due to short-lived daughter products of radon isotopes in the air is made according to measurements of equivalent equilibrium volume activity (EEVA) of radon isotopes in indoor air and atmospheric air in the territory of the settlement (district and so on. p.) according to the formula [9]:

$$E_{\text{internal}, \text{Rn}} = 9.5 \cdot 10^{-6} \cdot 8760 \cdot (0.2 \cdot EEVA_{\text{street}} + 0.8 \cdot EEVA_{\text{building}})$$  (1)

where $9.5 \cdot 10^{-6}$ is the dose ratio (in units (mSv/m$^3$) / (hour \cdot Bq)); 8760 - the number of hours per year; 0.2 and 0.8 is the share of time spent by people in the premises and on the street, respectively; if for atmospheric air in the territory of a given locality (district, etc.) there are no data on EEVA$\text{street}$ values, then for calculating population exposure doses due to this factor EEVA$\text{street} = 6.5$ Bq / m$^3$ should be taken in accordance with the data on average world EEVA of radon isotopes in the surface layer of atmospheric air [10].

The radon EEVA for a nonequilibrium mixture of short-lived daughter decay products in air is calculated by the following formula [11]:

$$EEVA_{\text{Rn}} = VA_{\text{Rn}} \cdot F$$  (2)

where, $VA_{\text{Rn}}$ is the radon volume activity, $F$ is the equilibrium coefficient between radon and its decay products, which can take values from 0 to 1. In the absence of experimental data on the average value of this coefficient, take $F = 0.5$.

Table 6 presents the results of calculated dose load indications, depending on the installed gas stove under the conditions of the city of Yakutsk.

Table 6. Radon dose rates.

| Types of gas stoves | $VA^{222}\text{Rn}$, Bq / m$^3$ (max. value) | $EEVA^{222}\text{Rn}$, Bq / m$^3$ | $E_{\text{internal}}$, Rn, mSv / year | The ratio of $E_{\text{internal}}$ to PAED |
|---------------------|-----------------------------------|---------------------------------|----------------------------------|----------------------------------|
| Beko                | 19                               | 9,5                            | 0,74                             | 0,074                            |
| Bosch               | 31                               | 15,5                           | 1,14                             | 0,114                            |
| Hotpoint-Ariston    | 14                               | 7                              | 0,57                             | 0,057                            |
| Zanussi             | 27                               | 13,5                           | 1                                | 0,1                              |
| Ardo                | 30                               | 15                             | 1,1                              | 0,11                             |
In all investigated homes, and the average radiation dose to people less than the permissible annual effective dose (PAED) of 10 mSv/year [12]. In the house where the Beko stove is used, the radon volumetric activity value is 13.5 times smaller than the PAED, in the house where the Bosch stove is installed, the radon volumetric activity value is 87.7 times smaller. In homes where Hotpoint-Ariston, Zanussi, and Ardo slabs are installed, the radon volumetric activity values are less than the allowable annual effective dose of 175.4, 100 and 90.9 times, respectively.

Table 7 presents the results of the measurement of radon OA in gas burners of gas stoves of various firms by the method of direct measurements using the AlphaGUARD instrument. The highest values for radon activity were found in the Hotpoint-Ariston gas stove.

**Table 7.** The results of direct measurements on the device AlphaGUARD.

| Locality       | The name of the gas stove | Radon activity levels                      |
|----------------|---------------------------|--------------------------------------------|
| Yakutsk city   | Bosch                     | Max 66±5.9 Bq/m³                           |
|                |                            | Min 29±2.6 Bq/m³                           |
| Yakutsk city   | Hotpoint-Ariston           | Max 81±7.3 Bq/m³                           |
|                |                            | Min 47±4.2 Bq/m³                           |
| Yakutsk city   | Beko                      | Max 47±4.2 Bq/m³                           |
|                |                            | Min 36±3.2 Bq/m³                           |
| Yakutsk city   | Ardo                      | Max 45±4.1 Bq/m³                           |
|                |                            | Min 36±3.2 Bq/m³                           |
| Yakutsk city   | Indesit                   | Max 48.35±6.43 Bq/m³                       |
|                |                            | Min 6.35±0.84 Bq/m³                        |
| Maya village   | Lada                      | Max 10±0.9 Bq/m³                           |
|                |                            | Min 2±0.2 Bq/m³                            |
| Maya village   | Mechta                    | Max 23±2.1 Bq/m³                           |
|                |                            | Min 6±0.5 Bq/m³                            |
| Maya village   | Omich                     | Max 39±3.5 Bq/m³                           |
|                |                            | Min 8±0.7 Bq/m³                            |
| Maya village   | KSTG                      | Max 8±0.7 Bq/m³                            |
|                |                            | Min 0 Bq/m³                                |

As shown in table 7, the maximum value of the radon activity in bulk, using direct measurements as shown in figure 1, was shown by a Hotpoint-Ariston gas stove 81 ± 7.3 Bq/m³.

Table 8 shows the results of measurements of the method of radon volumetric activity in networked natural gas using an Air Sampler (figure 2.)

**Table 8.** The results of direct measurements of radon volumetric activities for the city of Yakutsk.

| Locality       | The name of the gas stove | Radon activity levels                      |
|----------------|---------------------------|--------------------------------------------|
| Yakutsk city   | Indesit                   | Max 91±23 Bq/m³                            |
|                |                            | Min 41±14 Bq/m³                            |
| Yakutsk city   | Gorenje                   | Max 48±16 Bq/m³                            |
|                |                            | Min 25±11 Bq/m³                            |
| Yakutsk city   | Gefest                    | Max 116±27 Bq/m³                           |
|                |                            | Min 26±12 Bq/m³                            |
| Yakutsk city   | Mechta                    | Max 54±29 Bq/m³                            |
|                |                            | Min 16±7 Bq/m³                             |
| Yakutsk city   | Beko                      | Max 48±16 Bq/m³                            |
|                |                            | Min 21±9 Bq/m³                             |
| Yakutsk city   | Ardo                      | Max 49±17 Bq/m³                            |
|                |                            | Min 28±9 Bq/m³                             |
From table 8, it follows that the maximum volumetric activity that was determined experimentally as shown in figure 2 was obtained in a Gefest slab of 116 ± 27 Bq/m³.

4. Conclusions
In this paper, we analyzed the problem of radon security in residential areas with gas stoves of various companies. In the present paper, we tested various methods for measuring radon VA in networked natural gas.

Radon dose loads for residential premises using gas stoves from five different firms were determined. In the house where Beko's stove is used, the annual actual dose load is 13.5 times less than the annual intake limit (10 mSv/year); 17 times less than annual income limit. For apartments in which Zanussi and Ardo plates are installed, dose loads are 10 and 9 times less than the annual income limit, respectively. In this situation, radon appears in the kitchen when burning natural gas while cooking. In addition, an installation was designed and a method for direct measurement of radon in network gas was developed by direct sampling of methane from kitchen gas stoves.

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