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Swedish Radiation Safety Authority

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2009:04

Radon in DWELLINGS in the Republic of Kalmykia Results from the National Radon Survey 2006-2007

Report number: 2009:04 **ISSN:** 2000-0456
Available at www.stralsakerhetsmyndigheten.se

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Date: Februari 2009

This report concerns a study which has been conducted for the Swedish Radiation Safety Authority, SSM. The conclusions and viewpoints presented in the report are those of the author/authors and do not necessarily coincide with those of the SSM.

Abstract

The National Radon Survey in the Republic of Kalmykia, Russian Federation during 2006 – 2007 was carried out in a cooperation project between the Swedish Radiation Protection Authority (SSI) and the Russian Institute of Radiation Hygiene (RIRH). This work was financed by the Russian Institute of Radiation Hygiene and the Swedish Agency for Development Cooperation (SIDA).

In August 2006 SSI, RIRH, federal and local authorities carried out a field study in Kalmykia when radon daughter measurements (equilibrium equivalent radon concentrations in the air) and gamma radiation measurements were made in 103 buildings. Gamma spectrometry measurements were made at several sites. During the visit the cooperating parties devoted some time to the education of local authorities on radon related issues. During three months in the winter season 2006-2007, long term radon trace measurements were made in 525 randomly chosen dwellings in the Republic of Kalmykia. The radon gas activity varied between 3 and 973 Bq/m^3, with a mean value of 122 Bq/m^3. In 19 of a total of 835 measurement points, the radon activity exceeded the maximum permitted value in Russia of 200 Bq/m^3 of EERC. The year-round radon trace measurement were made in 20 houses in Elista, the capital of the Republic of Kalmykia, for comparison with the three-month measurements. The year-round measurements showed some higher values for the radon activity, and a correction factor of 0.85 was applied. Using data on the number of people living in detached houses and apartments, and applying the radon activities measured, the number of new lung cancer cases caused by radon was calculated to be 20 to 40 of the 100 new cases reported annually.

The methods of construction of the dwellings in Kalmykia is greatly influenced by the history and culture. Most of them were built after World War II and there are only a few that are newly built because of the poor economic situation and the low population growth rate in the Republic. Most people live in detached houses, one-storied with 3-5 rooms, built directly on the ground or on coquina blocks or on a cast concrete footing. The floor is usually made of wooden planks with quite large visible gaps between them, which makes it easy for radon to penetrate into the air of the living space. A 20-30 centimeter high non-ventilated crawl

space is quite usual. Ventilation is provided by the gaps around the windows and doors and the natural draught through the holes. The heating stoves are usually placed in the middle of the houses; coal, wood, sheep and cow dung are used as fuel. The gamma radiation from the building materials is approximately 0.1 μSv/h which indicates that they do not contribute to the radon in the indoor air. The water is stored in cisterns outdoors and this means that it can also be excluded as a source of radon in the indoor air.

The measurements showed very few extreme radon values, but the mean value is relatively high. In order to prevent high radon levels indoors, the radon risks should always be taken into account when constructing a building and to prevent the penetration of radon gas by laying a sheet of plastic over the ground in the crawl space or by sealing the openings and cracks in the floor. It is important that the local authorities are aware of the radon problems so that they can advise on the health risks and their mitigation

Content

1. Introduction 2
Background and objectives 2
Geography and geology 2
Kalmykia's dwelling stock 4
2. Radon and gamma-radiation measurements in Kalmykia in 2001 5
3. The Kalmykian National Radon Survey 2006-2007 8
Field work in Kalmykia, August 2006 8
Radon and gamma-radiation measurements, techniques 8
Measurements and results made and obtained during the field work in August 2006 12
Radon measurements in dwellings during the winter season 2006-2007 and results 13
4. The source of the radon and the cause of indoor radon 17
Building materials 17
Radon from the ground 17
Building construction 18
5. Findings 19
6. Suggestions for measures against radon in Kalmykian buildings 20
For existing buildings: 20
For new buildings: 20
7. Discussion 22
8. Conclusions 27
Appendix 1 29
Ground gamma spectrometry measurements in Kalmykia performed in 2006 29
Appendix 2 31
Short term radon measurements in Kalmykia, performed summer 2006 + description table, examples only 31
Appendix 3 32
Integral radon measurements in randomly chosen buildings in Kalmykia performed winter 2006 – 2007 + description table, examples only 32
Appendix 4 33
20 case-study integral radon measurements in Elista performed 2006-2007 + description table, examples only 33
Appendix 5 34
Radon mitigation methods proposed for Kalmykia 34
Acknowledgements 42
References: 43

1. Introduction

Background and objectives

This report is an account of the results from the National Radon Survey, in the Republic of Kalmykia, Russian Federation, 2006 – 2007. The aim of the National Radon Survey was to provide information on exposure to indoor radon-222 gas in Kalmykian homes, to calculate the radiation dose due to radon to the Kalmykian population and the health risks due to exposure to radon, to determine the sources of the radon and to collect information on the designs of the buildings in order to make it possible to choose best methods for reducing of indoor radon concentrations.

The National Radon Survey was carried out by the Russian Institute of Radiation Hygiene (RIRH) with help from local health authorities – Sanitary Epidemiological Service - and in cooperation with the Swedish Radiation Protection Authority (SSI). The survey formed a part of the cooperation program between RIRH and SSI. The survey was funded by grants from RIHR and the Swedish International Development Agency (SIDA).

Prior to the National Radon Survey, the RIHR had made short term measurements in 2001 of the radon levels indoors as well as integral radon measurements in establishments for children (Table 4). The results of these measurements indicated that the radon concentrations in Kalmykian dwellings were rather high compared to the world average of 40 Becquerel per cubic meter (Bq/m^3) (UNSCEAR 2007). Thus, exposure to indoor radon may be a substantial contributory factor for the lung cancer cases which occur in the population of Kalmykia.

After the planning, the survey started with a fact-fining mission to Kalmykia in August 2006 at which information on the project was given to the Kalmykian Department of the Federal Service for Consumers Protection and Human Well-being and the Sanitary Epidemiological Services. During this mission radon and gamma radiation measurements were carried out in 103 buildings.

During the winter season 20062007, radon measurements were made in 525 randomly chosen dwellings distributed all over the Republic. Measured radon concentrations in indoor air were within the range 3 to 973 Becquerel per cubic meter (Bq/m3), with an average of 122 Bq/m3.

Geography and geology

The Republic of Kalmykia is situated in steppe, semi-desert and desert zones in the south -east of the European part of the Russian Federation. It occupies 75.9 thousand square kilometres and it has a population of about 290,000. The administrative centre of the Republic is Elista.

Within the territory of the Republic of Kalmykia three main types of soils occur. In the west, fertile dark brown (1.5-4.5% humus); in central part, light brown with salty topsoil due to evaporation; in the east, desert-steppe with brown sandy soil with vast areas of salty topsoil.

In the south the territory of Kalmykia borders on the Kuma-Manych depression and the rivers Manych and Kuma; in the south-west it is washed by the Caspian Sea; in the north-west part of Kalmykia's territory are the Yergeninsky Hills. Kalmykia's segment of the Caspian lowlands is called the Sarpa lowlands; its southern part is the Chernie Zemli. Flat country is the dominant type of relief in the Republic.

Kalmykia's natural resources include coal, oil, natural gas, uranium and coquina (a rock type mainly consisting of shell and fragments of calcite organic material. Coquina is widely used as a building material).

The average content of the naturally occurring radioactive materials in the soil on the European part of the Russian Federation is as follows: 238U – 20 Bq/kg, 232Th – 25 Bq/kg and 40K – 430 Bq/kg. Within the territory of the Republic of Kalmykia the average contents of the naturally occurring radionuclides, according to investigations made by the Geological Survey of Russia (vary within the ranges 25 – 50 Bq/kg for 238U, 25 – 40 Bq/kg for 232Th and 615 – 770 Bq /kg for 40K. This it is natural to expect enhanced radon activities in the soil air as a result.

During the fact-finding mission to Kalmykia in August 2006, a number of measurements of the activity concentrations of natural radioactive elements were made in Prijutninsky, Iki-Burulsky and Ketchenerovsky municipalities. These measurements were performed with a portable gamma-spectrometer of type MKC-AT6101D. The following activity concentrations were found for radionuclides in the ground:

- ^{238}U between 12 and 33 Bq/kg with an average of 22 Bq/kg,
- ^{232}Th between 20 and 55 Bq/kg with an average of 34 Bq/kg,
- ^{40}K between 425 and 755 Bq/kg with an average 633 Bq/kg.

These field gamma-spectrometric measurements will be useful for the production of radon prognosis maps for the territory.

Kalmykia’s dwelling stock

Kalmykia’s dwelling stock is influenced by several factors: historical conditions of settlements appearance on the territory, cultural traditions of the population and house owners, economic factors and the availability of building materials. Most of the houses in the republic were built after World War II. Only a small number of new buildings have been built after the Soviet period. This might be explained by the weak economy and the low growth-rate of the population.

The most common building materials in the Republic of Kalmykia are coquina, saman (clay and straw) and red clay bricks. Although there are three towns in Kalmykia, there are few apartment buildings in the Republic and even the housing stock in the towns consists mostly of detached houses.

Type of dwelling	2002		2003		2004	
	%	Number of inhabitants	%	Number of inhabitants	%	Number of inhabi-tants
Totals	100	292,410	100	291,850	100	290,626
Flats in apartment buildings	32	93,571	32	93,392	30	87,188
Room in hostels	3	8,772	4	11,674	4	11,625
Detached houses	46	134,509	47	137,170	47	136,594
Part of detached houses	19	55,558	17	49,614	19	55,219

Table 1: Percentage of different types of living facilities in the Republic of Kalmykia and number of people living in them according to the Kalmykian census 2004 [7]

2. Radon and gamma-radiation measurements in Kalmykia in 2001

The first visit of RIRH experts to the republic of Kalmykia took place in 2001. At that time the objective was to get basic information on the natural radiation exposure situation in the territory and to make contact with the local authorities. During that visit, gamma-radiation measurements were made of the indoor gamma radiation and the radioactivity of the building materials in 246 dwellings/establishments. The results of these measurements are given in Table 2 and Figure 1.

Gamma level µSv/h	Saman	Coquina	Concrete, bricks	All
Average	0.12	0.10	0.10	0.10
Minimum	0.09	0.08	0.07	0.07
Maximum	0.16	0.22	0.16	0.22
Number of measurements	20	25	49	94

Table 2: Overview of the gamma levels found in dwellings built of different materials, 2001

Settlement	EERC, Bq/m^3				
	Average	Minimum	Maximum	Median value	Number of measurements
All	29	0	250	10.6	127
Elista	25	0	207	8.8	119

Table3: Overview of the EERC (equilibrium equivalent radon concentration) measurements, 2001

During the winter period in 2001, 40 integral radon measurements were made in the establishments for children. The average EERC was 40 Bq/m^3 with the range between 10 and 173 Bq/m^3. Totally 80 trace detectors were placed, two in each establishment in the bed room and in the playing room.

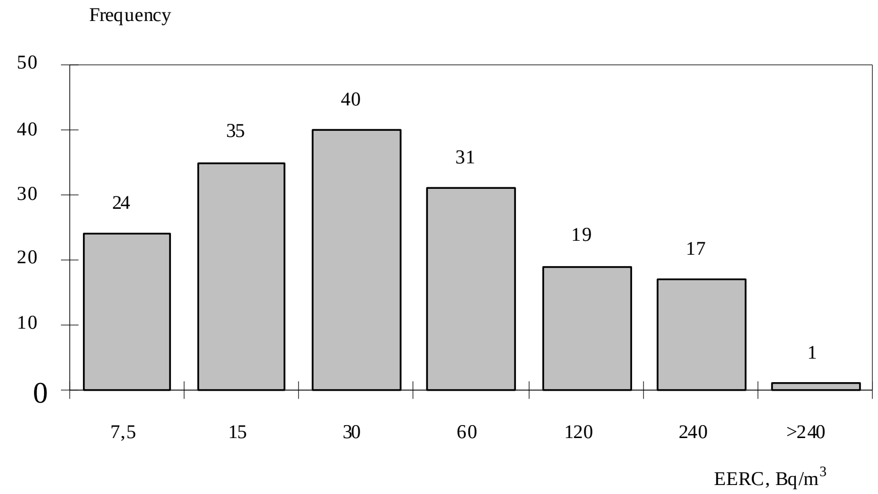
EERC, Bq/m^3				
Average	Median	Minimum	Maximum	Number of measurements
40	20	10	173	40

Table 4: Overview of the results of integral radon measurements in the establishments for children in Elista, 2001

Settlement	Buildings	$EERC_{Rn}$+4,6$EEThC_{Tn}$, Bq/m^3				
		Average	Median	Minimum	Maximum	Number of meas.
Elista	All buildings	41	23	2.5	233	159
	Dwellings	36	12	2.8	233	90
	Medical and children's establishments	48	30	2.5	198	66
All buildings		45	24	2-5	303	167
	Dwellings	43	15	2-8	303	96
	Medical and children's establishments	47	29	2.5	198	68

Table 5: Overview of the integral radon and thoron measurements, 2001

Figure 1: Distribution of the radon and thoron integral measurements, 2001



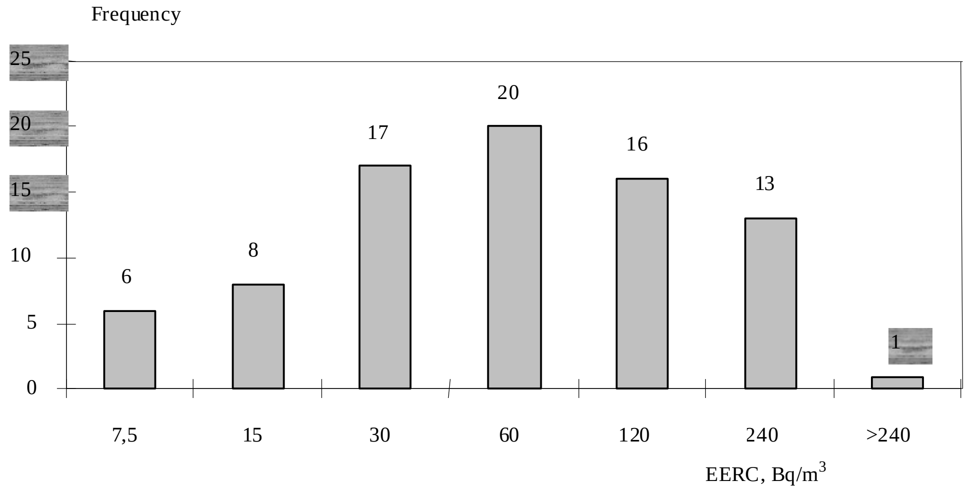
As shown in Table 4 and Table 5, values of EERC in buildings with different functional assignments (dwellings, medical and children kinder-gardens) are rather the similar. That might be explained by the fact that all these buildings are 1 or 2 storied constructions.

When comparing buildings built of different materials, it can be seen that the values of EERC differ significantly (see Table 6). The highest EERC values are characteristic for saman houses.

$EERC_{Rn}$+4,6$EEThC_{Tn}$, Bq/m^3	Saman	Coquina	Concrete, bricks	All
Average	103	49	14	43
Median	90	28	9.2	15
Minimum	7.1	4.5	2.8	2.8
Maximum	303	163	91	303
Total number	21	26	49	96

Table 6: Summation of results of the integral radon and thoron isotopes measurements in dwellings 2001.

Figure 2: Number of buildings per interval measured EERC radon and thoron, 2001.



3. The Kalmykian National Radon Survey 2006-2007

Field work in Kalmykia, August 2006

The survey in 2006 started with a fact-finding mission to the Republic of Kalmykia on 4-13 August. This mission had been organized by RIRH and the Kalmykian Federal Department for Supervision of Consumers Protection and Public Welfare. In that mission there were three radon experts from Sweden and three from RIRH as well as personnel from the local Sanitary Epidemiological Services of the republic. The overall aim of that mission was to gather information on the radon situation in Kalmykia and the causes of the indoor radon concentrations. Thus the team of experts studied the geology, geography, demographic data, construction of buildings and living habits. A number of short-term radon gas measurements were made during the field work, two in each inspected dwelling. The gamma radiation emitted from building materials and the ground was also measured. Where possible, the radon activity was measured in vaults and cellars. The radium-226 concentration in the soils was determined by in-situ gamma spectrometry measurements (Appendix 1).

One day of the mission to Kalmykia was used for giving information to local representatives of the Federal Service for Consumers Protection and Human Wellbeing – Sanitary Epidemiological Services, where the Russian and Swedish experts presented the results from the inspections of the buildings to the representatives of local government. Also, half a day was devoted to education of Local Rospotrebnadzor divisions, called Sanitary Epidemiological Services, from all Kalmykia administrative territories and regions on radon and radon-related health matters.

Radon and gamma-radiation measurements, techniques

During the National Radon Survey in 2006, the following methods for measurements were applied:
Integral measurements of indoor radon-222 activity;
A short-term method to determine the equivalent equilibrium radon activity (EERC);
Gamma spectrometric measurements of the activity concentrations of 226Ra, 232Th and 40K in soil. These measurements were performed with a portable spectrometer equipped with a NaI (Tl) scintillation counter detector.

Figure 6: Radiometer PPA-10

The short-term radon-222 daughter (EERC) measurements were performed with an aerosols radiometer of type PPA-10 of "NTM-Zaschita", Russia (Figure 6). The measurements were made in the following order: air is pumped though the filter at a rate of 15 l/min; a semiconductor detector counts the number of alpha decays in two channels that correspond to RaA (218Po) and RaC' (214Bi); volume activity concentration of radon is calculated. The measurement takes 5 minutes; the uncertainty of the method is lower than 30%; the minimum detectable level is 10 Bq/m3 EERC.

The integral radon measurements were made with cellulose nitrate alpha-track detectors of type LR-115 Type II (produced by Kodak-Pathe, France). The track detector was placed into a cup designed by RIRH (Figure 7).

Figure 7: Alpha-track detector used in the National Radon Survey in the Republic of Kalmykia: 1 – detector holder with alpha-track detectors LR-115 Type II; 2 directing devices of the detector holder with film; 3 – plastic cup; 4 – silicon barrier (membrane); 5 – lid with holes.

During measurement, the plastic cup with its alpha-track detector in its holder is closed. Radon gas seeps into the cup through the lid with holes and silicon barrier. The barrier is thick enough to prevent thoron gas entering the cup.

Etching of the alpha-track detector is done in a 6N solution of distilled water with the help of TRAL facility during 135 minutes and a temperature of 50 ± 1 oC. The etched and dried detectors are placed in a spark counter to be read off. The voltage of 600 V is set on the device and the reading voltage is set for 480 V. Radon activity is calculated using the formula:

$$C_{Rn} = (n - n_O)/(T_{\exp} \cdot \varepsilon) \quad \text{Bq/m3},$$

Where:
n and no = track density of exposed alpha-track detector and its background density (track·cm-2),
T = duration of exposure (days),
ε = alpha-track detector sensitivity (track*m3/(cm2*Bq*days).

Before the National Radon Survey started, the sensitivity of the detectors was calibrated at SSI and RIRH. Etching and analysis of the films was done at RIRH. The detectors were exposed for three months in the winter heating season 2006-2007. Two detectors were placed in each dwelling; usually, one in the bedroom and one in the living room. In two-storey single-family houses, one detector was placed on each level. In multi-apartment buildings measurements were made in flats on the ground floor.

The concentrations of 226Ra, 232Th and 40K in soils and bedrocks were measured with a scintillation gamma-spectrometer, Type MKS-AT6101D, designed by ATOMTEH, Republic of Belarus (Figure 8). The gamma-spectrometer MKS-AT6101D was first placed on the ground and then in a pit dug to a depth of on meter. Measurements were made at each 20 cm level. The measurement time was 20-25 minutes. The measurements give the activity concentrations of 226Ra, 232Th and 40K in the soil at the different levels. For measurements at 1 meter depth, in 4π configuration, a correction factor of 0.6 was applied.

Figure 8: Gamma-spectrometer MKS-AT6101D.

Measurements and results made and obtained during the field work in August 2006

During the field work in August 2006, 103 dwellings in villages and settlements were visited and inspected by the Russian and Swedish experts. For the inspections and measurements, personnel from the local Health Authorities (Sanitary Epidemiological Services) participated and helped in carrying out the measurements and contacting house-owners. For the inspection short-term radon gas measurements were performed in one or two rooms. We also used scintillometers and Geiger-Müller rate meters to measure the gamma radioactivity of the building material of the houses and the ground surrounding the buildings. For some houses we also were able to check the gamma radiation under the buildings, and whenever a house had a cellar below the house or in the garden, measurements were made of the radon gas and gamma radiation in the cellar. During the inspections, descriptions were made of the type of building, building materials, heating system, "ventilation" and the water source (Appendix 2).

Altogether, during the field work, 148 radon daughter measurements were made in 103 buildings in 6 settlements. Of these measurements, 110 were made in dwellings, 21 in cellars and vaults, 17 in kinder gardens or schools. Of the measurements in dwellings, 70% were made in detached houses and 11% in apartment houses. The highest measured radon activity concentrations were 1025 Bq/m3 in a vault, and 200 Bq/m3 in the living part of the house. In 93 % of the houses the radon concentration was below 100 Bq/m3. This high proportion of houses with a radon activity lower than 100 Bq/m3 is explained by the fact that the measurements were carried out in the summer period when the air ventilation due to open windows and doors was good. The results from the field work in 2006 are reported in Appendix 2.

Settlement	**Kinder-gardens or schools**	**Detached houses**	**Apartment houses**	**Cellar, vault**
	Number of measurements			
Narta	4	12	2	2
Vorobjevka	-	23	-	3
Cholun-Homur	3	23	1	8
Iki-Burul	-	5	-	4
Shatta	8	26	4	4
Bair	2	14	-	-
Total	148			
	17/11%	103/70%	7/5%	21/14%

Table 7 Number of measurements per settlement in different buildings

Settlement	Kinder-gardens or schools	Detached houses	Apartment houses	Cellar, vault
	Maximum Rn activity measured, Bq/m3			
Narta	45	125	40	760
Vorobjevka	-	150	-	1025
Cholun-Homur	80	100	60	1360
Iki-Burul	-	<30	-	940
Shatta	50	200	60	810
Bair	40	120	-	-

Table 8 Maximum measured radon activity per settlement in different buildings.

Radon measurements in dwellings during the winter season 2006-2007 and results

In order to have records of the radon concentration in a large enough number of dwellings evenly distributed all over Kalmykia, to evaluate the radon exposure and radiation dose to the Kalmykian population, the National Survey was designed to include radon measurements in 500 randomly chosen dwellings. These dwellings had to be distributed all over the territory of the republic. During the winter season 2006-2007, measurements with alpha-track detectors were performed for three months in 525 dwellings. The number of measured dwellings in each region was proportional to the number of inhabitants in it; further choice of dwellings to be measured within the settlements was done in the same way – proportionally to the number of inhabitants and evenly distributed within the settlement. Representatives of the Institute of Radiation Hygiene in St. Petersburg visited the Republic of Kalmykia in November 2006 to inform the personnel of the local Sanitary Epidemiological Services on the aims of the National Kalmykian Radon Survey, to give instructions on the placement of track detectors, on how they should be gathered and what information on households should be collected. A form used for collecting information on the household was developed by IRH.

Personnel from the local Sanitary Epidemiological Services visited each dwelling to place out and collect the radon-track detectors. During these visits the home owners were informed about the risks of smoking and inhaling radon gas.

Altogether in the 525 dwellings, 834 measurement measurements were made: in 330 detached houses – 551 measurements (63%), in 195 apartment houses – 283 measurements (37%) Appendix 3.

Volume activity of Radon concentrations					
	Average 222Rn, Bq/m3	Median 222Rn, Bq/m3	Minimum 222Rn, Bq/m3	Maximum 222Rn, Bq/m3	Number of measurements
Detached houses	131	103	10	973	726
Apartment houses	59	46	10	452	106
All buildings	122	94	10	973	832

Table 9 Overview of the results of integral radon measurements in the republic of Kalmykia during the winter season 2006-2007

As expected, the radon concentration varies much both in detached houses as well as in apartment houses (Table 9). The average measured values for the whole group of houses is close to that for detached houses since the majority of the measurements were made in these.

The distribution of radon activity values measured during the period 2006 and 2007 is shown in Figure 3. According to Russian legislation the maximum allowable radon activity EERC for existing dwellings is 200 Bq/m3, which corresponds approximately to 400 Bq/m3 of radon gas activity. Only 19 points of a total of 835 exceed the value of 400 Bq/m3, which corresponds to 2.7 %.

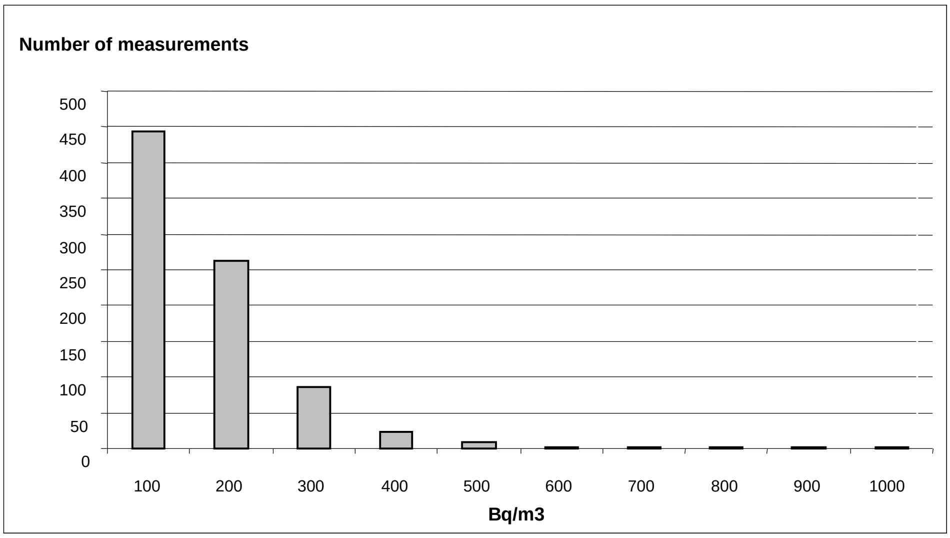


Figure 3 Distribution of the radon concentration in 525 randomly chosen buildings. Results of three-month measurements during the winter season 2006-2007.

Furthermore, 20 buildings where higher-than-average radon activity concentrations were expected, were chosen in Elista to represent the case-study measurements. The purpose with these case-study measurements was to follow the variation of radon activity concentration during the whole year. To see the variation it is advantageous if the radon activity is enhanced and detectable. Thus the houses chosen were situated on hills and on soil which was judged to have good permeability. Most of the selected buildings were new constructions. In these 20 buildings, 480 measurements were made: Of the measured buildings, 16 were detached houses – 384 measurements, 2 were apartment buildings – 48 measurements, and 2 were schools – 48 measurements. See Appendix 4.

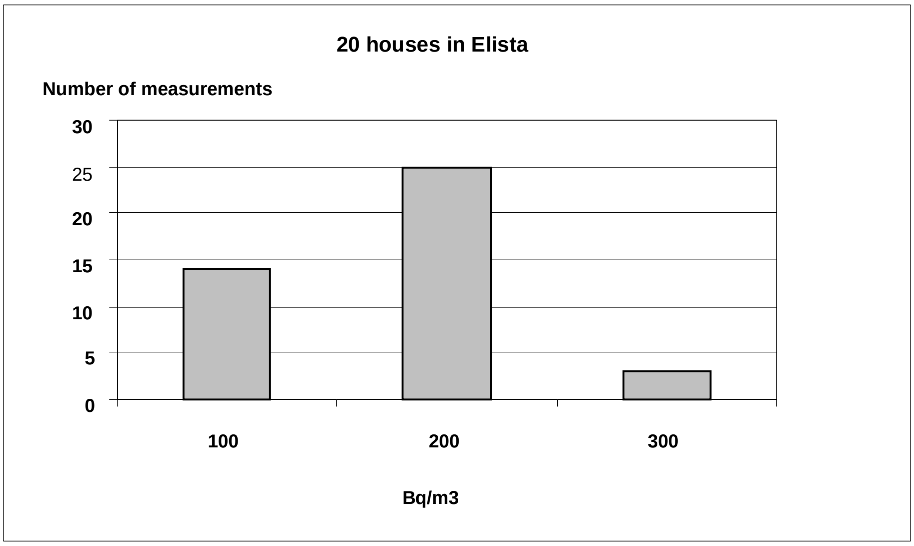


Figure 4 Distribution of radon activity in 20 buildings in Elista, case-study. Results of 12-month measurements, 2006 - 2007.

In the 20 dwellings in Elista, measurements were made all the year around, changing the detectors every month. Only detached houses with one or two stories were chosen for these measurements. The average annual radon activity was found to be 127 Bq/m3, and the average value of radon activity for the period November 2006 to March 2007 was approximately 150 Bq/m3 (Figure 5). These results are applied for calculating a correction coefficient to be used for the calculation of the average indoor radon concentration during the whole year from the results of the measurements during the winter season. Thus a correction coefficient of 0.85 has been used for the results given in Table 9.

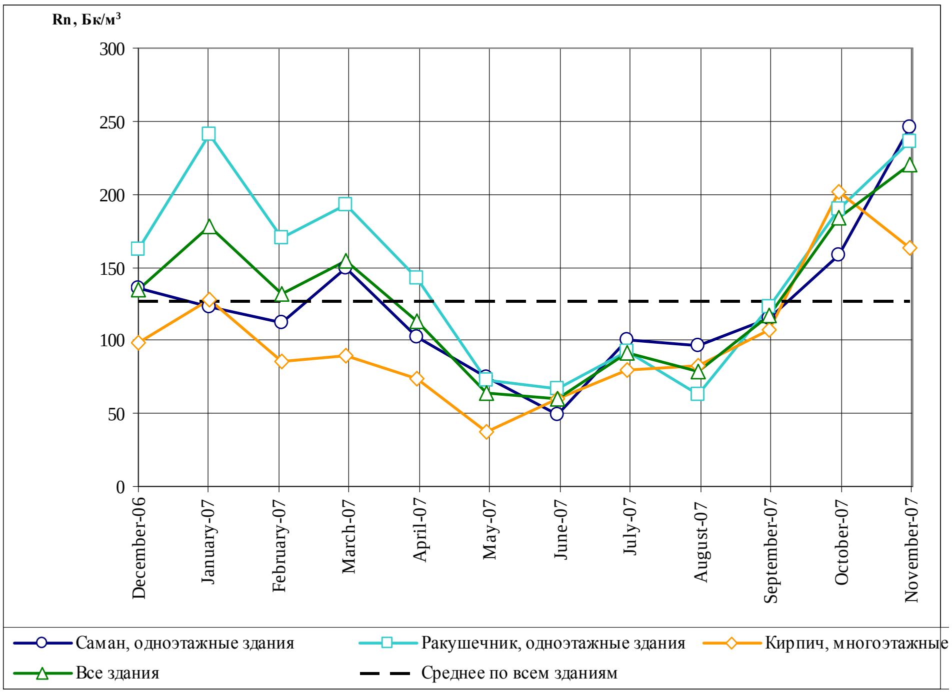


Figure 5 Seasonal changes of radon activity in 20 buildings in Elista, December 2006 to the end of November 2007

The results from the year-round measurements in Elista show that the radon concentration in the dwellings can be 40-55 % lower than the average during the summer months April – September than during the winter month October – April. The temperature indoors and outdoors during the warm period is almost the same, thus no stack effect, and intensive ventilation by opening doors and windows dilutes radon concentration. During the cold period doors and windows are kept closed and ventilation is held at a minimum, but also the heating of the dwellings increases the stack effect with the result that radon gas is transported from the ground into the building.

4. The source of the radon and the cause of indoor radon

Building materials

During the field work August 2006 we inspected dwellings 103 in detached houses, 7 apartments in multifamily buildings and 17 schools. The majority of the detached houses in the visited settlements have outer and inner walls of either shell bricks (coquina), saman (clay mixed with straw), prefabricated wooden-walls or sometimes walls of red clay bricks. Many houses have white facing bricks of sand and lime. The building material in all the inspected buildings has low radioactivity, which was proved by the gamma measurements. Since the radioactivity of the building material is low (average 0.10 µSv/h), the building materials may only contribute a small part of the radon gas found in the dwellings. Thus the main reason of the indoor radon gas is the passive exhalation of radon from the ground surface or active transport of radon gas mixed with the soil air, originating from the ground under the houses and transported into the building by pressure driven convection.

Even if the gamma radiation from the building materials was only checked in 103 of the dwellings inspected in August 2006, and the national radon survey did not include any such measurements, we conclude it to be unlikely that any building material with enhanced radioactivity exists in the republic since the uranium concentration in the bedrock and soil is low.

Radon from the ground

In order to check the "radon potential" of the soil on which the houses were built, at each visited settlement gamma spectrometric measurement were performed in pits dug in the soil. The pits were dug down to a depth of one meter. Measurements were made at each 20 cm level. The ground gamma spectrometric measurements showed that the radium concentration in the soil is normally 20 to 40 Bq 226Ra/kg (range 11.7 to 44.6 Bq 226Ra/kg) (Appendix 1).

No measurement of the radon gas concentration in the soil was made, but using the following formula the radon concentration in the soil air may be calculated:

Cmax = A· e · б · (1 – p) p-1   (Clavensjö, Åkerblom, 1994),

Where:
Cmax = Rn maximum activity concentration of Rn, (kBq/m3)
A = activity concentration of 226Ra, (Bq/kg)

e = 222Rn emanation factor; 0.00755, (h-1)
б = compact volume weight, for soils normally 2650 kg/m3, (kg/m3)
p = porosity.

This formula is used to give an approximate calculation of the maximum radon concentration in the soil air. From the results from measurements performed, the calculated maximum radon gas concentration in the soil air was found to be within the range 30,000 to 60,000 Bq/m3. (Assumed soil porosity 40%, emanation factor 0.4). Normally the actual radon concentration is lower than that calculated, due to the radon flux from the ground surface.

Building construction

Of the inspected buildings, the majority of the detached houses were one storey houses with 3-5 rooms, built directly on the ground foundations of shell blocks, concrete blocks or a cast concrete footing. The floors were made of wooden planks on wooden beams above a 20-30 cm high “crawl space”. Some few houses had a real crawl space. The “crawl spaces” were rarely provided with ventilation openings, and if such openings existed they were often clogged with old rugs to prevent any excess ventilation of the space between the soil and the planks above. The planks of the floor usually had slits between them, and there was no sealing between them. Sometimes it was possible to see the ground through the slits. In some houses the boards were covered by linoleum. Our observation was that no especial care had been taken to make the floors airtight to prevent the inflow of air from the “crawl spaces”.

The houses were ventilated by opening windows and doors and by natural draught through unsealed openings in the building construction.

Heating was usually provided by a stove in the centre of the house. The fuels used were coal, wood, and sheep or cow dung. More rarely natural gas was used.

None of the detached houses in the settlements had access to tap water from a well. Water was transported to the house or group of houses and stored in a cistern from which it was delivered to the house by pipes or by buckets. Thus the water was stored for a sufficiently long time so that if there had been radon in the water from the beginning, the radon would have decayed when the water was used in the household.

The apartment buildings inspected have walls of concrete or bricks. The basement part is constructed of bricks, concrete blocks or cast concrete. The floor consists either of cast concrete or bare soil. The basement part of the houses appeared to be well ventilated since normally several of the basement windows were broken.

5. Findings

One of the results of our field work in Kalmykia is the finding that the main source of indoor radon gas in the buildings is radon transported from the ground on which the buildings are built. The exhalation of radon from building materials is of minor importance.

Radon gas is transported into buildings in three different ways:

1. By exhalation directly from the surface of the ground. This is the case when the floor of the rooms in the building consists of soil without any covering and radon is exhaled directly into the rooms.

2. By convective transport with air from the crawlspace. In this case the radon is transported via exhalation from the topsoil under the building and in the crawl-space the radon is mixed with air. The mixture of air and radon is further trans-ported though openings in the floors into the rooms. Examples of entry points are slits between floorboards, holes around water pipes and plugholes and leaky junc-tions between floors and walls.

3. By convective transport of soil air mixed with radon. The air is actively sucked up from the soil below the building by the pressure difference between the air in the soil and the air indoors created by the stack effect resulting from temperature differences between the soil and the indoor air. This mode of transport is most pronounced during the heating season. The effect is clearly demonstrated in the results from the year-round measurements in Elista, in which the radon concentra-tions generally 3.7 times lower in summer than in winter (Figure 6).

In our opinion the third cause is the most common. Our findings are of great im-portance for deciding which methods should be used to reduce the radon levels in existing buildings and for the prevention of radon problems when planning build-ing work.

6. Suggestions for measures against radon in Kalmykian buildings

Since the main source of radon in Kalmykian buildings is radon from the ground, the methods for preventing radon entering the buildings are methods which hinder the transport of radon. To achieve this, the following methods may be used (Clavensjö and Åkerblom 1994):

For existing buildings:

- sealing of leakage points, always the first action,
- installing a sub-slab suction system; the best action if the sub-floor is of cast-in-place concrete,
- construction of a radon well; a suitable method if the house is built on ground with a high permeability, e.g. thick layers of sand, gravel or fill,
- or in a building with a crawlspace to lay out a layer of plastic (thicker than 0.4 mm) on the ground in the crawlspace thereby hindering further transport of the radon exhaled from the ground into the air in the crawlspace,
- or to increase the ventilation rate in the crawlspace or in the house, thereby diluting the radon and decreasing the concentration in the air.

For new buildings:

- build the house on a cast concrete slab on which the walls are erected. It is important to seal all openings in the slab (e.g. holes around pipes, electric cables and joints between slabs). Since 10 cm of normal concrete is thick enough to prevent most of the diffusion of radon, it is not necessary to make the slab thicker or to use watertight concrete. However, future cracks the slab must be avoided by use of reinforced concrete. In houses with a basement, the walls must also be made of in-situ-cast concrete. If the basement walls are made of elements or blocks, the outside of the wall must be covered by a suitable sealing material,
- for buildings with a crawlspace, lay out a sheet of plastic (thicker than 0.4 mm) on the ground in the crawlspace to prevent the transport of radon from the soil. To ensure that the radon concentration in the crawlspace is kept low, perforated drain pipes may be laid out under the plastic. These pipes are connected together by unperforated pipes and from a central point under the building air is sucked out through the pipes by a fan placed outside. In this way a lower air pressure is maintained below the foil than in the crawlspace, thereby preventing radon from the soil entering the crawlspace.

A low radon concentration indoors can also be attained by laying out a plastic sheet under or in the lowest floor. However, is it important that there are no holes in the plastic, either made during the construction of the building or later, since radon-rich air could be transported through these into the building.

In Kalmykia, the radon concentration in the soil air is rather low (as far as we can judge), and the main reason for the enhanced radon concentrations in the buildings is that the buildings have not been sealed to prent the inflow of radon-rich soil air or radon gas exhaled from the ground below the house. In our opinion, the application of such simple methods as covering the ground in the crawlspace with a plastic sheet and the sealing of holes and slits will in most cases considerably reduce the indoor radon concentration.

For detailed descriptions of methods for radon mitigation and prevention, see the “Radon Book, Existing Buildings” by Bertil Clavensjö and Gustav Åkerblom [5].

7. Discussion

The majority of the dwelling stock (47+19 %) in the republic of Kalmykia consists of detached houses. The population number in Kalmykia is 290,626 according to the annual republican report on the level of life in Kalmykia [7]. Altogether, 191,813 people live in detached houses of which most are single storey buildings. 34 % of the population lives in apartment houses or in hostels (a hostel is a type of building, where people have 1-2 room flats; the sanitary rooms and kitchen are common for all people on the floor) which makes 98,813 people (Table 1). In our calculation we assume that the average number of stories in apartment buildings and hostels is 4.5. This assumption allows us to calculate the number of people living on the first floor, which makes 21,958. Thus, according to our assumptions, 76,855 people live in apartments situated above the first floor.

It should be emphasized that the houses measured in each county were completely randomly chosen in proportion to the number inhabitants in the county, and that the measurements were not especially directed to known radon risk areas.

In all, integral radon measurements were made in 525 dwellings: 330 in detached houses and 195 in apartment buildings.

There was no intention to study the time spent indoors and outdoors in the republic of Kalmykia. Probably some difference might exist when it comes to living habits of the urban and rural populations in Kalmykia. A suggested distribution of time spent indoors and outdoors was 50%. The International Commission on Radiation Protection in its Publication 65, assumes that the average time spent indoors is 7000 hours per year [11] For the calculation of radiation doses caused by exposure to radon, both assumptions are applied when judging the risk of radon-induced lung cancer for different living patterns.

From statistic information presented by Rosmedtehnologii, the average number of new lung cancer cases annually in the Republic of Kalmykia is approximately 100 [1, 2, 3, 4]. No gender distribution is given in the statistics; neither was the number of smokers was available.
The exposure of the Kalmykian population due to indoor radon
The indoor radon concentrations (arithmetic mean and maximum values shown by municipality, type of dwelling) are given in Table 10. In this table the results are compiled from the 843 integral radon measurements that were made during the National Radon Survey, 2006-2007.

City and villages	Number of residents	Number of dwell-ings measured	Am, Bq/m3	Max, Bq/m3
Elista	102700	105	98	452
Яшалтинский район				
Яшалта	5100	14	136	391

Весёлое	579	4	153	359
Октябрьский	971	6	120	265
Красный партизан	360	4	108	212
Красное Михайловское	1188	5	186	360
Матросово	402	5	233	351
Лаганский район				
г. Лагань	14300	25	72	251
с. Улан-Хол	2654	9	105	241
с. Джалыково	1560	5	196	545
Приютненский район				
п. Первомайский	846	4	233	410
Воробьевское СМО	1154	5	293	391
п. Ульдючины	777	8	295	800
п. Нарта	333	8	106	191
Сарпинский район				
с. Садовое	6579	16	111	296
с. Обильное	1251	5	132	208
п. Аршан-Зельмень	668	5	197	354
п. Догзмакин		4	133	169
Черноземльский район				
п. Комсомольский	4600	8	134	354
п. Артезиан	3590	18	78	183
п. Прикумский	1090	5	90	130
п. Ачинеры	970	2	58	81
п. Сарул	488	3	127	248
п. Нарын-Худук	590	2	263	458
п. Адык	970	3	124	151
Юстинский район				
п. Цаган-Аман	6479	8	94	184
Эрдниевское СМО	918	5	80	143
Татальское СМО	839	4	89	120
п. Белозерное		8	79	153
Целинный район				
с. Троицкое	10300	10	109	490

п. Ики-Чонос	980	5	445	973
с. Вознесеновка	2900	6	93	216
п. Хар-Булук		5	98	256
п. Яшкуль (Верхний?)	900	4	104	125
п. Овата	860	5	110	214
Кетченеровский район				
п. Кетченеры	4110	4	158	311
п. Ергенинский	839	4	147	216
п. Чкаловский	865	4	185	409
п. Шата	677	4	148	293
п. Алцын-Хута	817	4	243	325
п. Годжурский		5	248	397
Яшкульский район				
с. Яшкуль	7400	16	116	240
п. Привольный	1059	6	122	263
СПК «Чилгир-1»	1039	5	125	206
«Улан-Эргэ»	1093	4	104	175
Ики-Бурульский район				
п. Ики-Бурул	3800	5	93	160
п. Приманыч	880	6	139	369
п. Оргакин		6	115	264
п. Шатта		4	141	224
п. Магна		5	251	731
Малодербетовский район				
с. Малые Дербеты	6000	15	62	225
п. Ханата		5	77	139
Плодовитинское СМО		4	123	240
Хончнуровское СМО		4	89	118
Октябрьский район				
п. Б. Царын	5100	24	137	393
п. Джангар		4	47	62
п. Цаган-Нур		5	103	190
п. Хошеут		4	146	315
Городовиковский район				

г. Городовиковск	10000	17	148	815
п. Большой Гок		5	213	363
п. Бага-Бурул		5	125	187
п. Шин-Бедл		4	75	97
п. Амур-Санан		5	168	491
с. Виноградное		5	183	357

Table 10 Results of all integral radon measurementsmade in the republic of Kalmykia during the National Radon Survey, December 2006 to December2007

For radon gas the arithmetic mean in detached houses was 131 Bq/m3. All measurements in apartment buildings in this survey were made on the first level, that regardless of whether the building had a basement or not. The radon concentrations in apartment buildings are thus only representative for the flats on the first level. In those dwellings, the average arithmetic mean value was 59 Bq/m3. No radon measurements where made in flats above the first floor, but for our calculations of the radon dose, we assume that the average radon concentration above the first floor is 20 Bq/m3. Figure 3 shows the activity concentration distribution in dwellings.

The results from the measurements made during the National Radon Survey were used for calculation of the radiation dose to the Kalmykian population due to exposure to radon. The number of residents living in detached houses is 191,813 and in flats on the first floor in apartment buildings 21958. The conversion factor given by the International Commission on Radiation Protection in ICRP Publication 65 [11] is 0.021 mSv per year per Bq/m3 (average over 8,760 hours, equilibrium factor 0.4). Applying this conversion factor the average dose due to exposure to radon indoors is calculated for the parts of the population living in detached houses, in apartments and hostels as well as for the whole of the population (Table 1). Depending on the time spent indoors the calculated average dose to the population is 1 mSv/year for 50 % spent indoors, 1.6 mSv/year for 80 % indoors and 2 mSv/year for 100 % indoors.

Type of dwelling	Number of exposed persons	Average 222Rn concentration, Bq/m3	Time spent indoors 50 % (4380 h/year), mean dose, mSv/year	Time spent indoors 80 % (7008 h/year), mean dose, mSv/year	Time spent indoors 100 % (8760 h/year), mean dose, mSv/year
Detached house	191,813	131	1.4	2.2	2.8
Apartment on the first floor	21,958	59	0.6	1.0	1.2
Apartment above the	76,855	20*	0.2	0.3	0.4

first floor					
The whole population	290,626	96	1.0	1.6	2.0

*** assumed indoor concentration of radon-222**

Table 11 Annual radiation dose due to exposure to radon-222 indoors

Using the detriment factor 7.3·10-5 per mSv given by the ICRP for the general public [11], the results of the National Radon Survey indicate that in Kalmykia, depending on the actual time spent indoors, annually about 20-40 Kalmykians (smokers and non-smokers) may be expected to develop lung cancer due to exposure of radon in their homes.

According to the statistical information published by the State Medical Oncology Scientific Research Institute named after Gertsen, "Rosmedtehnologii" in 2003-2007 annualy100 new lung cancer cases are recorded in the republic of Kalmykia (Table 12). As in Kalmykia the total number of induced lung cancer cases per year is about 100 cases, possibly 20-40 % of these cases are caused by exposure to radon in dwellings. Of these radon related lung cancer cases about 89 % would live in detached houses and 11 % in apartment houses.

The ICRP detriment value is based on epidemiological case-control studies on miners which are exposed to radon gas in mines. Their exposure situation is in some ways different from the situation in homes and thus the results from the miners may not be fully applicable to that in homes. However, during the last 15 years several large case-control studies on effects of exposure to radon in homes have been performed and the detriment factor in these are in good agreement with ICRP's for miners [9, 10]. In several studies the synergetic relation between smoking and radon is apparent [9]. In a large European pooling study published by Darby et al. [10] is shown that there exists a multiplicative synergetic effect of exposure to radon and smoking. The risk of lung cancer is up to 25 times higher for a lifelong smoker compared to a lifelong non-smoker. Applied to the average radon concentration in Kalmykia, 96 Bq/m3, the average dose to a non-smoker is calculated to be approximately 0.3 mSv/year, while the average dose to smokers is about 6 mSv/year.

	2003	2004	2005	2006
Number of lungs, bronchial and tracheal oncology diseases diagnosis made for the first time	116	91	85	105
Lethal cases during the first year after diagnosis	78.8%	81.9%	81.3%	5.,6%
Total number of patients under medical supervision by the end of the year	148	137	132	145
Lethal cases (to be discussed)	38.6%	40.2%	38.9%	39.%

Table 12 Number of oncology patients (lungs, bronchia and trachea) [1, 2, 3, 4]

8. Conclusions

1. The National Radon Survey has shown that the indoor radon concentration for the population of Kalmykia compared to the world average is rather high, 122 Bq/m3 compared to the world of average 30-40 Bq/m3 [6]. The radiation dose due to radon exposure at home to an average Kalmykian inhabitant is 1 mSv/year for an assumed 50 % of the day spent indoors. In the Republic of Kalmykia, exposure to radon indoors can be expected to cause 20-40 deaths from lung cancer per year.

2. In Kalmykia, the source of indoor radon is radon gas formed at the decay of radium-226 in the ground and transported from the ground into the buildings through leaks in the floor immediately above the ground. The concentration of radium-226 in the Kalmykian soils varies from low to normal and the radon-222 concentration in the soil air is not high and in normal circumstances it would not cause such a high average indoor radon levels as it does in Kalmykian homes. However, the houses have insufficient protection against influx of radon gas due to the form of construction with concrete slabs, floors and basement walls which are normally not constructed to prevent the influx of air and radon gas from the ground below the slab or through the floor above the crawlspace.

3. In Kalmykia there are relatively few dwellings with high indoor radon concentrations. However, the average radon concentration is rather high. The best way to eliminate the problem with indoor radon is through remedial measures in existing buildings and radon preventive measures in the construction of new buildings.

For existing buildings, indoor radon concentrations can be eliminated in most cases by the use of simple measures. We recommend that when the house has been built with a space below the lowest floor, the bare soil is covered by a sheet of plastic and that gaps and holes in the floor are made airtight.

In cases where the building has a concrete slab on the ground, cracks and holes in the concrete slabs should be sealed. In some cases it might be necessary to install a sub-slab suction system.

For new buildings, precautions should be taken to hinder the transport of radon-rich soil air into the building. In a building with a slab on ground, this can be achieved by good casting of the slab which should be reinforced. Any holes in the slab should be sealed.

If the building has a crawlspace, the bare soil should be covered with a sheet of plastic which must be joined to the foundation walls so there are no gaps between them and the plastic. It is also possible to apply a protective sheet in or directly under the floor above the crawlspace. The crawl space should have good ventilation.

4. To reduce the average radon concentrations, it is important that the local heath and building authorities are given proper training on radon issues. They should in

their turn inform the house-owners on the risks caused by radon exposure and on the methods used to reduce these risks

Appendix 1

Ground gamma spectrometry measurements in Kalmykia performed in 2006

Radionuclide	Specific activity values for natural radionuclides at the given depths (m) from the surface, Bq/kg	
	0.0	**1.0**
Settlement Narta, Prijutinsky district: Lenina street; location: 40 meters from Local Administration Building in the direction of destroyed buildings		
^{238}U (^{226}Ra)	24.4	22.1
^{232}Th	43.5	36.7
^{40}K	699	666
Settlement Narta, Prijutinsky district: Lenina street; location: 30 meters from Local Administration Building (the wall of partly destroyed building, wall material – shell rock)		
^{238}U (^{226}Ra)	23.0	
^{232}Th	15.0	
^{40}K	200	
Settlement Vorobjovka. Prijutinsky district: eastern outskirts of the settlement; location: last street, at a distance of 100 meters from the entrance to the settlement		
^{238}U (^{226}Ra)	18,6	26,8
^{232}Th	38,6	38,6
^{40}K	672	690
Settlement Vorobjovka, Prijutinsky district: western outskirts of the settlement; location: at a distance of 100 meters from the last houses		
^{238}U (^{226}Ra)	17,1	
^{232}Th	43,7	
^{40}K	710	
Settlement Vorobjovka, Prijutinsky district; location: at a distance of 100 meters to the sought from the Recreation Centre		
^{238}U (^{226}Ra)	18,0	
^{232}Th	35,2	
^{40}K	634	
Settlement Vorobjovka, Prijutinsky district; location: at a distance of 100 meters to the north from the Recreation Centre (in the low place)		
^{238}U (^{226}Ra)	19,6	
^{232}Th	32,5	
^{40}K	512	
Settlement Vorobjovka, Prijutinsky district; location: at a distance of 70 meters to the north from the Recreation Centre (on the eminence)		
^{238}U (^{226}Ra)	17.7	
^{232}Th	38.4	
^{40}K	741	
Settlement Cholun-Khamur, Iki-Burulsky district; location: at the distance of 70 meters from the last houses to the north of the settlement		
^{238}U (^{226}Ra)	25.7	21.5
^{232}Th	21.1	32.3
^{40}K	425	606
Settlement Cholun-Khamur, Iki-Burulsky district; location: at a distance of 60 meters from the last house in the sought of the settlement		
^{238}U (^{226}Ra)	31,8	23,9
^{232}Th	28,9	34,0
^{40}K	603	666
Settlement Cholun-Khamur, Iki-Burulsky district; location: basement of kinder-garden (on the soil floor)		
^{238}U (^{226}Ra)	25,0	
^{232}Th	30,0	
^{40}K	510	
Settlement Cholun-Khamur, Iki-Burulsky district; location: basement of the house (on the soil floor)		
^{238}U (^{226}Ra)	30,1	
^{232}Th	53,5	
^{40}K	751	
Settlement Cholun-Khamur, Iki-Burulsky district; location: on the opposite side of the first house of the Shkolnaya street		
^{238}U (^{226}Ra)	23,0	

Radionuclide	Specific activity values for natural radionuclides at the given depths (m) from the surface, Bq/kg	
	0.0	1.0
^{232}Th	40,0	
^{40}K	630	
Settlement Cholun-Khamur, Iki-Burulsky district; location: bottom of the foundation fit for the construction of multi-stored school building (depth 3 meters from the soil surface)		
^{238}U (^{226}Ra)	22,1	
^{232}Th	33,9	
^{40}K	669	
Settlement Cholun-Khamur, Iki-Burulsky district; location: between the foundation fit for the construction of multi-stored school building and 2 stored dwelling houses		
^{238}U (^{226}Ra)	22.0	
^{232}Th	29.8	
^{40}K	521	
Settlement Shatta, Ketchenerovsky district; location: at a distance of 40 meters from the school building in the direction of the sports ground		
^{238}U (^{226}Ra)	27.8	
^{232}Th	32.7	
^{40}K	680	
Settlement Shatta, Ketchenerovsky district; location: at a distance of 5 meters from the school building in the direction of the sports ground		
^{238}U (^{226}Ra)	33.2	
^{232}Th	36.1	
^{40}K	684	
Settlement Shatta, Ketchenerovsky district; location: in the garden behind secondary school		
^{238}U (^{226}Ra)	17.3	22.7
^{232}Th	35.6	35.4
^{40}K	753	696
Settlement Shatta, Ketchenerovsky district; location: bottom of the foundation fit between secondary school and stadium		
^{238}U (^{226}Ra)	16.9	
^{232}Th	39.7	
^{40}K	750	
Settlement Bair, Ketchenerovsky district; location: in the street near the last house on the western side of the settlement		
^{238}U (^{226}Ra)	19.6	
^{232}Th	21.1	
^{40}K	510	
Settlement Bair, Ketchenerovsky district; location: in the kitchen-garden of the last house on the western side of the settlement		
^{238}U (^{226}Ra)	11.7	15.4
^{232}Th	27.5	17.6
^{40}K	597	442

Appendix 2

Short term radon measurements in Kalmykia, performed summer 2006 + description table, examples only

№ п/п	Address	Building	floor	flat	Date	EERC, Bq/m³ $C_{Rn} \pm \Delta_{Rn}$	$C_{Tn} \pm \Delta_{Tn}$	C_{Rn}+ +4.6* C_{Tn}
				Village Name				
1	**Street name**	70	1	Sleeping room	08.08.	10 ± 3	<1.0	15
2	**Steet name**	70	0	Vault	08.08.	275 ± 82	<1.0	280
3	**Street name**	75	1	Sleeping room	08.08.	30 ± 9	<1.0	35
4	**Street name**	75	1	Childrens' room	08.08.	58 ± 17	<1.0	63

№	Type of building	Rooms	Heat-ing	Founda-tion	Soil type/ Ra-226 and Ra-228, Bq/kg, at 1 m depth	Ventilation at the time of measure-ment	Cellar	Comments
1	detached 1 floor Coquina + white facing bricks	2	Gas	Crawl space	Greyish brown silt	Measured in room in which doors and windows were closed	No	Wooden planks on wooden beams. No vents in the crawl space walls
2	Detached 1 floor Coquina + white facing bricks	3	Gas	Crawl space	Greyish brown silt	Measured in room in which doors and windows were open	No	Wooden planks on wooden beams. No vents in the crawl space walls
3	Detached 1 floor Coquina + white facing bricks	3	Gas	Crawl space	Greyish brown silt	Measured in room in which doors and windows were closed	No	Wooden planks on wooden beams. No vents in the crawl space walls. Krysalite as fill in the crawl space

Appendix 3

Integral radon measurements in randomly chosen buildings in Kalmykia performed winter 2006 – 2007 + description table, examples only

№ п/п	Address: Street	Building	Floor	Flat.	Measurement period			OARn ±Δ Rn Bq/m3
	Street X	19	1	23	24.11.06	-	26.02.07	44 ± 13
	Street X, sitting room	19	1	44	22.11.06	-	26.02.07	29 ± 9
	" – " sleeping room							29 ± 9
	Street Y, sitting room	36	1	41	23.11.06	-	01.03.07	52 ± 16
	" – " sleeping room							22 ± 7

№ п/п	Address	Number of rooms	Walls	Foundation	Distance between ground and floor, cm	Cellar or vault	Heating
Village Name (wattere supply – mineshaft «Odjur», at a distance of 15km North from the village). Rubble blocks are produced in Aigursk quarry, vil.Divnoe Stavrapol Region							
1	Street X, 1	4	straw brick	filled	-	-	-
2	Street X, 17	4	Shell brick + lime-and-sand brick	rubble, ventilated	-	-	-
3	Street Y, 29	3	shell brick	Shell bricks, filled	-	-	-
4	Street Z, 26	4	straw brick	rubble	40	-	-
5	Street Z, 28	4	straw brick	straw brick	40	-	-
6	Street Z, 27	5	straw brick	-	-	-	-

Appendix 4

20 case-study integral radon measurements in Elista performed 2006-2007 + description table, examples only

№	Address	Placement	VA, Bq/m^3	VA, Bq/m^3	VA, Bq/m^3	VA, Bq/m^3
			20.11.06-20.12.06	20.12.06-19.01.07	19.01.07-21.02.07	21.02.07-20.03.07
1	Street X, 18	Sitting room	-	621	214	334
		Sleeping room	-	448	184	399
2	Street Z, 96	Children's room	309	545	330	590
		Sitting room	295	277	230	240
3	Street Y, 81A	Sitting room	186	132	178	179
		Children's room	116	190	137	107
4	Street C, 29	Sleeping room	132	183	169	84
		Sitting room	79	136	201	55
5	Street B, 52A	Sleeping room	98	132	30	71

№ п/п	Address	Stores	Cellar	Building material	Number of flats
1	School X	2	No	Straw bricks	-
2	School Y	3	No	White bricks	-
3	Street X	1	No	Straw bricks	1
4	Street Y	1	Yes	Shell bricks and white bricks	1
5	Street Z	2	No	Red clay bricks	1

Appendix 5

Radon mitigation methods proposed for Kalmykia

The present situation
In the inspection of buildings used as dwellings it was apparent that the cause of the indoor radon concentrations was radon transported from the soil on which the buildings stood. But this was not the only cause. In most of the houses - if not all - the construction of the lowest floors and concrete slabs was such that there was no protection against the inflow of radon gas or the transport of radon-rich soil air. Most of the detached single-family houses inspected were constructed with a floor of wooden planks on wooden beams built directly above a 20-40 cm high space on bare ground. In some houses the floor was laid out directly on the ground surface.

When the space was high enough to act as a proper crawlspace it usually had no openings for ventilation with outdoor air, or if it had openings these had been clogged with old rugs. No precautions had been taken to prevent transport of air through the floor into the rooms. In most of the houses there were open gaps between the planks and often also larger holes in the floor. Thus there was nothing that hindered the transport of air from the space below the floor into the rooms above (Figure 1). Transportation of radon gas occurs from the soil into the space below the floor, either by passive diffusion, or actively by a convective flow of soil air containing radon. Air from the space is then transported through gaps and holes into the building by a convective flow created by the difference in temperature between the space and the rooms above, the so-called stack effect. Since the temperature difference between outdoor and indoor air is most pronounced in winter time, normally the radon concentrations indoors are highest during the winter, but low during summer. In houses with a crawlspace, the radon gas in the crawlspace is diluted by fresh air entering through any openings. In this way the radon concentration in the crawlspace is reduced. However, in Kalmykia the openings are often closed. Thus no extra ventilation of the crawlspace occurs.

A relevant point is that the normal porosity in the soil is 30-50 % - and the pores are filled with air or water or a combination of air and water. Thus in a dry soil there is plenty of air available for transport once an air stream is created. Based on the results from measurements of the concentration of radium-226 in soils in Kalmykia, the expected normal radon concentration in the soil air would be 10,000-60,000 Bq/m3.

In some cases the apartment buildings and schools inspected had been built with a concrete slab on the ground. However, the concrete slabs were usually poor quality and they were full of cracks and often holes. Thus the slab did not prevent the flow of radon-rich air from the ground. In several cases, in the basement, part of a slab was missing (Figure 2).

Remedial radon methods for houses with a space/crawlspace below the lowest floor

The indoor radon level in most Kalmykian houses is not especially high. Thus, in most houses, application of simple radon remedial methods will be suitable for reduction of the radon concentration. Since the main reason for the indoor radon in the houses is, that the lowest floor is not sufficiently airtight, and the space below this floor is not ventilated, remedial methods should aim to change this situation. However, increasing the ventilation of the space by making openings in the foundation walls will result in colder floors in the winter and as most floors now lack heat insulation, this is not possible without improving the floors. To seal the existing floors against the inflow of air from the underlying space is not feasible in many cases. To achieve airtight floors, the existing floors would have to be removed and new floors put in.

A reduction of the radon concentration in the space below the lowest floor can be achieved by laying a layer of plastic on the ground surface (Figure 3). In this way the radon flux from the ground is prevented from reaching the air in the crawlspace. However, since in most houses the height of the crawlspace is so low, in most houses it is not possible to lay out the plastic without removing the floor. The layer of plastic laid out must be of good quality and at least 0.4 mm thick, because radon can diffuse through thin plastic and if the plastic is not strong enough, holes easily occur and radon would then be transported through these. When laying out the plastic it is important to ensure that it extends all the way to the foundation walls, where it should be bent downwards to allow condensation water to run off. To prevent condensation water accumulating on the plastic, the ground below should be highest in the middle of the space, as shown in Figure 3.

Another possible method is to place the plastic in, or directly under, the floor. With this method too, the plastic must be laid out so it joins with the outer walls so that there is no gap between the plastic and the wall. However, laying out a layer of plastic on the ground has another advantage in that it prevents moisture from the ground entering into the space below the lowest floor.

Our recommendation is therefore that when renovations are made in an existing house, if the house has a space below the lowest floor, a layer of plastic should always be laid out on the ground and the floor should be fully heat-insulated to enable the underlying space to be ventilated through openings in the foundation walls.

Remedial radon methods for buildings constructed with a concrete slab on the ground

Buildings constructed with a concrete slab on the ground are of two different main types:

1. The slab is cast after the foundation walls have been built, or

2. The slab is cast before the foundation walls are built and these are erected on the slab.

Of course, there exist several variants of foundation constructions for example: when there is no slab on the ground in part of the house or when the house is built on two or more levels.

A normal concrete slab with a thickness of 10 cm is thick enough to prevent nearly all diffusion driven transport of radon gas since during the diffusion the radon atoms have time to decay to radon daughters which are particles. However, if there are holes or cracks in the slab, radon-rich soil air can be transported from the soil into the building. Thus the first remedial action is always to inspect the building to locate holes, gaps and cracks. If such leakage points are found they should be sealed.

However, it can be difficult to locate these leakage paths for radon because the inflow of air can be diffuse and it can be very difficult and time-consuming to seal cracks and gaps. In buildings in which the slab was cast after the foundation walls were erected. There will always be gaps between the walls and the slab because the concrete slab shrinks when the concrete hardens. These gap are difficult to seal.

The most common method for the improvement of radon-afflicted buildings is to install a radon suction system (Figure 4). This is an method in which an air pressure lower than in the building is created and maintained below the slab. In this manner, air from the ground is prevented from entering into the building. A radon suction system consists of a pipe which has one end connected to a suction fan and the other end passing through a hole in the slab so that the end of the pipe is under the slab. The fan sucks air from the ground below the building. To maintain a lower air pressure below the slab it is not necessary to use a powerful fan. It should be noted that the purpose of the fan is not to ventilate the ground below the slab but to create a lower air pressure below the slab than in the rooms above the slab. Normally a 75 W duct-type fan is sufficient. The suction effect of the fan can be adjusted so that it does not suck more air than is necessary. This is achieved by connecting the fan to a speed control.

In order to distribute the suction force as much as possible underneath the slab and to avoid canalization of the flow of air under the slab, a pit must be dug out below the slab. The radius of this pit should be about 30 cm. The suction hole is normally put as close to the building's centre as possible, this to create a suction effect underneath the whole of the slab. Placing the hole close to an outer wall should avoided since the result could be that in winter cold air could be sucked from outdoors, which could damage the building's foundation by freezing.

When the building is a hillside house the fan should be placed some meters from the foundation wall on the hillside. Often one suction point is not enough to provide the desired reduction of the indoor radon concentration. Then suction at more suction points may be necessary. However, one fan is usually enough to maintain sufficient suction power at more the one suction point.

In some cases the transport routes for the radon-rich soil air are through holes in walls situated under the ground surface or through the wall itself, if this is made of a material which is not airtight, e.g. expanded clay blocks or poor quality concrete. Holes can be sealed but radon transport through a wall which is not airtight is more difficult to deal with. In this case it will often be necessary to lay the wall bare in order to be able to apply some type of material that prevents transport of soil air. Such material may be asphalt or a layer of plastic that is glued to the wall.

Radon preventive methods for new constructions

In order in the future to reduce exposure to radon gas, new homes, apartment houses, day care homes, schools, offices and other indoor workplaces should be built in such a way that a low radon indoor level is maintained. We recommend that for all new constructions a "radon protective" design is used.

For a building with crawlspace a "radon protective" design is achieved if the ground in the crawlspace is covered by a layer of plastic and if this plastic is laid out as described above. The foundation walls should have openings for ventilation of the crawlspace and the openings must be kept open even during the winter. The openings must be large enough to provide good ventilation of the space. Since ventilation of the crawlspace cools the air there, the floor above the crawlspace, a layer providing heat-insulation should installed in the floor. There should be no holes in the floor and holes around pipes and cables should be sealed.

For buildings built on a cast concrete slab on the ground, the concrete should be of good quality and be reinforced. It is not necessary to make the slab extra thick, but it is important that there are no open holes in the slab. Holes around pipes and cables should be sealed. We recommend that the slab is made first and that the walls rest on the slab. If prefabricated spandrel beams are used make sure that the joints between them and the slabs are airtight. If the spandrel beams are constructed of lightweight-aggregate, make sure that no air can pass through the beams into the walls above or into the rooms.

Walls below the ground surface should be cast or constructed so that no air can pass through them. Special attention should be paid to ensuring that no air can enter through the joint between the slab and the wall. If the slab has to be cast in more than one section, the joints between the sections must be airtight.

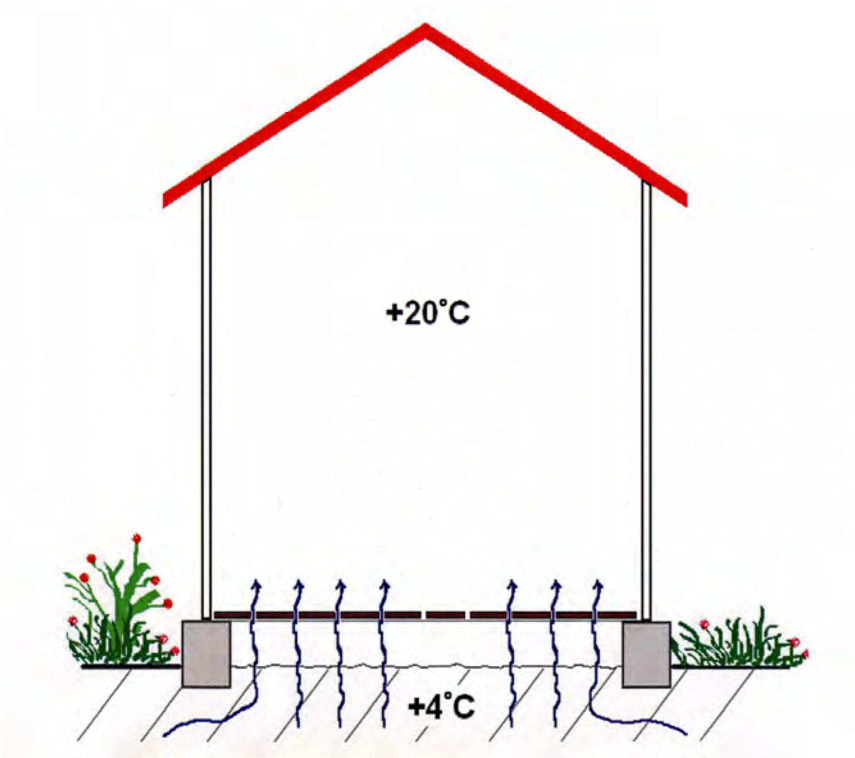


Figure 1 House with a space below the lowest floor. This space is not ventilated. In the winter, radon-rich air is drawn by the stack effect from the space into the house through gaps between the planks and holes in the floor.

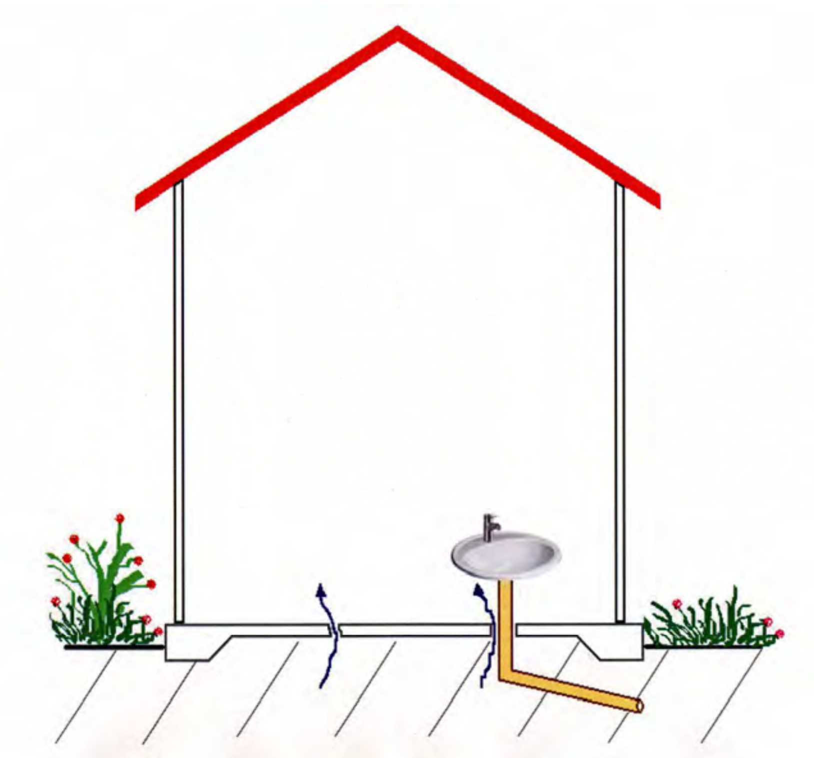


Figure 2 House built on a concrete slab on the ground. Radon-rich soil air passes into the house through cracks and holes in the slab

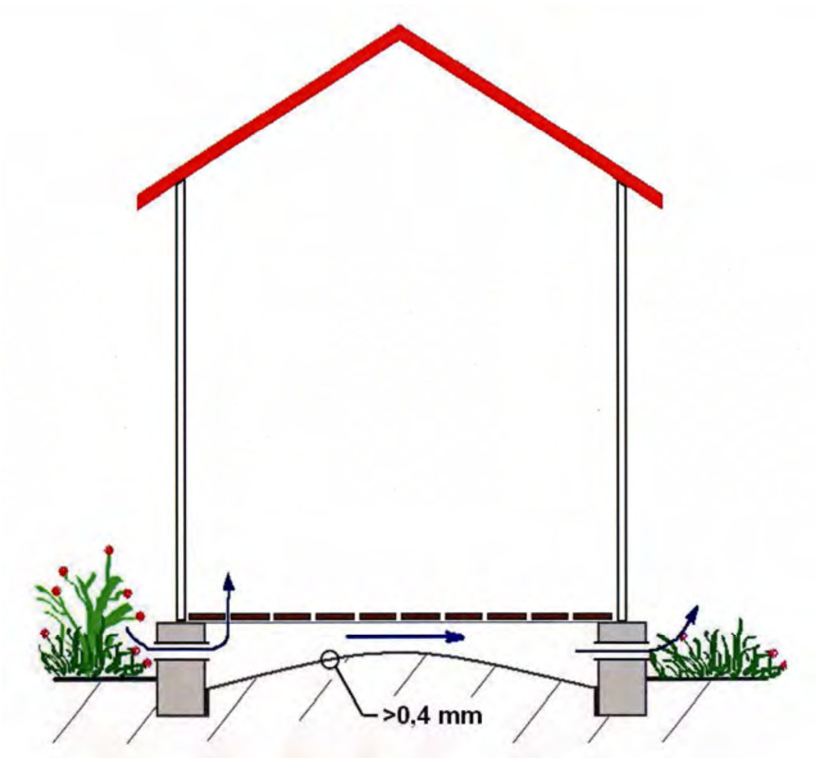


Figure 3 House with a sheet of plastic laid out on the soil in the crawlspace. The plastic prevents radon gas and moisture from entering into the crawlspace. The plastic should be laid out so its highest point is in the middle of the crawlspace and so that it joins tightly with the foundation walls. The crawlspace is well ventilated by outdoor air

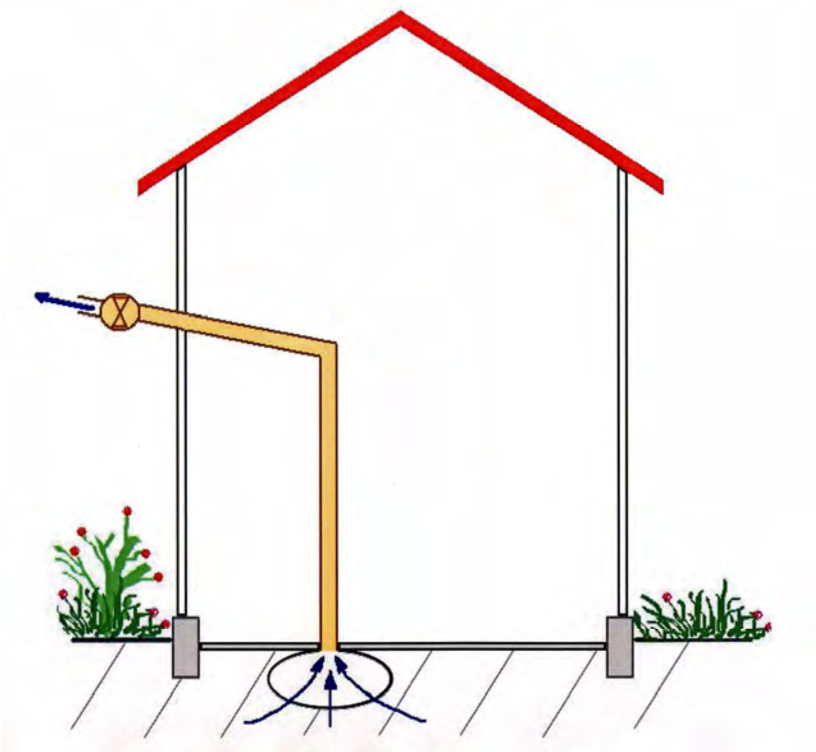


Figure 4 House with a slab on the ground and a radon suction system. The fan creates a lower air pressure below the slab, thereby preventing radon-rich soil air entering into the house. The suction point should be placed in the centre of the house. A suction pit is dug below the slab to create a lower air pressure over an area as large as possible and to prevent canalisation of the flow of air from a point outside the foundations to the suction pipe

Acknowledgements

Авторы настоящего отчета выражают искреннюю благодарность руководителю Управления Федеральной службы по надзору в сфере защиты прав потребителей и благополучия человека по Республике Калмыкия Константину Яшкулову, специалистам Управления Нине Коджиевой, Татьяне Басанговой, руководителю международного сотрудничества РИРГ – Марине Кадуке.

The authors of the report are grateful for the support given by the Head of the Kalmykian Department of the Federal Service for Consumers Protection and Human Well-being Konstantin Yashkulov, representatives of the Sanitary Epidemiological Services in the Republic of Kalmykia Nina Kodjieva, Tatyana Basangova, as well as the Head of International cooperation department at RIRH Marina Kaduka.

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