

# Radon Concentration in Soil and Radon Exhalation Rate at Al-Dora Refinery and Surrounding Area in Baghdad

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## Abstract

Radon gas concentrations in soil samples were determined from depths (surface, 15, and 30) cm for nine locations in Al-Dora refinery and surrounding area using “sealed can technique” and CR-39 solid state nuclear track detectors. The radon concentration in surface samples ranged from 810.08 to 1380.08 Bq/m<sup>3</sup> with an average 1137.71 Bq/m<sup>3</sup>. The radon concentration in soil at the depth 15 cm was ranged from 490.5 to 1197.52 Bq/m<sup>3</sup> with an average 732.78 Bq/m<sup>3</sup> and at the depth 30 cm was ranged from 362.07 to 889.53 Bq/m<sup>3</sup> with an average 529.41 Bq/m<sup>3</sup>. The surface exhalation rate in surface soil samples ranged from 0.44, to 0.99 Bq·m<sup>-2</sup>·h<sup>-1</sup> with average 0.61 Bq·m<sup>-2</sup>·h<sup>-1</sup>. The surface exhalation rate in soil samples at the depth 15 cm was ranged from 0.22 to 0.64 Bq·m<sup>-2</sup>·h<sup>-1</sup> with average 0.39 Bq·m<sup>-2</sup>·h<sup>-1</sup>. The surface exhalation rate in soil samples at the depth 15 cm was ranged from 0.22 to 0.64 Bq·m<sup>-2</sup>·h<sup>-1</sup> with average 0.39 Bq·m<sup>-2</sup>·h<sup>-1</sup>. The surface exhalation rate and the mass exhalation rate in soil samples at the depth 30 cm ranged from 0.19, to 0.48 Bq·m<sup>-2</sup>·h<sup>-1</sup> with average 0.28 Bq·m<sup>-2</sup>·h<sup>-1</sup>. The mass exhalation rate in surface soil samples ranged from 0.09 to 0.21 Bq·kg<sup>-1</sup>·h<sup>-1</sup> with average 0.12 Bq·kg<sup>-1</sup>·h<sup>-1</sup>. The mass exhalation rate in soil samples from depth 15 cm was ranged from 0.046 to 0.14 Bq·kg<sup>-1</sup>·h<sup>-1</sup> with average 0.08 Bq·kg<sup>-1</sup>·h<sup>-1</sup>. The mass exhalation rate in soil samples at the depth 30 cm was ranged from 0.042 to 0.1 Bq·kg<sup>-1</sup>·h<sup>-1</sup> with average 0.06 Bq·kg<sup>-1</sup>·h<sup>-1</sup>.

## Keywords

Radon Concentration, Soil Sample, CR-39 Track Detector, Radon Exhalation Rate

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## 1. Introduction

The knowledge on radioactivity contents of the various radio-nuclides in soil and rocks plays an important role

in health physics. The naturally occurring radionuclides  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  are the main sources of radiation in soils and rocks.

The gaseous radioactive radon ( $^{222}\text{Rn}$ ), decay product of the radium isotope  $^{226}\text{Ra}$  is present in all types of soil and rock. Radium atoms decays in soil particles, the resulting atoms of radon entering to air filled pores and then transported by diffusion and advection through this space in order to exhale into the atmosphere [1].

The half-life of  $^{222}\text{Rn}$  3.8 days is long enough for part of it to diffuse from the indoor radon sources to the inside of the room. Therefore  $^{222}\text{Rn}$  is the most dominant hazardous radionuclide among the radon isotopes. Both radon and its progeny attached to aerosols are present in the ambient air.  $^{222}\text{Rn}$  gas can enter the house from the soil. When it penetrates into closed rooms and become concentrated, it sometimes reaches harmful levels for public health [2].

So the radon from soil gas is the main cause of radon problem. Based on the National Academy of Science 1998 BEIR VI Report, the US Environmental Protection Agency estimates that about 21,000 annual lung cancer deaths are radon related. EPA also concluded that the effects of radon and cigarette smoking are synergistic, so that smokers are at higher risk from radon, from which it can be concluded that radon is the second leading cause of lung cancer after smoking [3]. The factors which influence the diffusion of radon from the soil into the air are: 1) The uranium and radium concentration in soil and rocks; 2) The emanation capacity of the ground; 3) The porosity of the rock and soil; Barometric pressure gradient between the interfaces; 4) Soil moisture and water saturation grade of the medium; 5) Other variables [4].

The radon and its progeny enter into human's body mainly through ingestion and inhalation [5]. Exposure of person to high concentration of radon and its short-lived progeny for a long period leads to health problems, particularly lung cancer [6].

The determination of radon entry rates into pore spaces, also called emanation rate, and its exhalation to the atmosphere depends on the radon concentrations in soil, on the distribution and concentrations of the radium radionuclide in the bedrock and on the permeability of the soil as well [4].

Although geological substrates potentially fertile to the release of radon should have a basic feature, enriched in uranium and thorium and fractured, these are not, however, enough conditions, especially in areas with hot and humid climate, where important bio genetics residuals cover the rocks. Other crucial properties of the ground for secondary porosity are: type and thickness of soils and their distribution space, water regime and geometry of the aquifer table. In this context, rocks with the same levels in normal radionuclide uranium and thorium can be transformed into an appreciable radon supplier's material [7].

Radon exhalation from soil depends not only on the radium concentration, but also on factors such as:

- The fraction of radon produced which is released from the soil's grain to its interstitial space, also known as the emanation power of fraction;
- The porosity of the material;
- The surface preparation and soil covering [8].

Thus, this paper aims is to measure radon concentration, surface exhalation rate and mass exhalation rate in Al-Dora refinery and surrounding area soil samples to know about the existence of high levels of radon gas.

## 2. Materials and Methods

### 2.1. Measurement of Radon Gas Concentrations

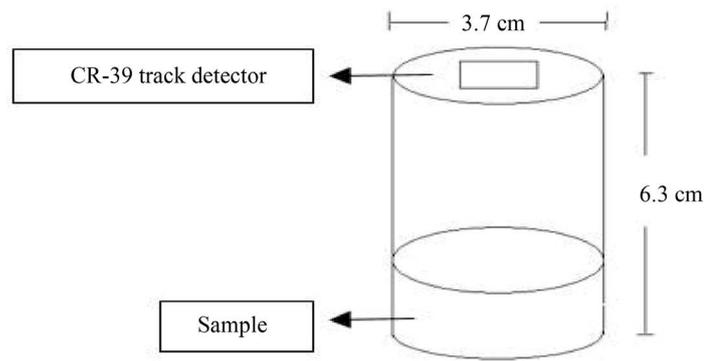
The radon and its daughters were detected by using CR-39 nuclear track detector of thickness (250  $\mu\text{m}$ ) and "sealed can technique" [9].

AL-Dora refinery is located in Baghdad-Iraq. A total of 27 soil samples were collected from Al-Dora refinery and surrounding area from surface, 15 cm and 30 cm depth as shown in **Table 1**. The dust samples were collected from five locations around Al-Dora refinery. These samples were crushed to fine powder by using electrical mill, the fine soil powder will convert to the grain size of (300  $\mu\text{m}$ ), (5 g) of each sample which was placed inside a plastic cylindrical container facing CR-39 track detector into a diffusion chamber **Figure 1**.

The container was then sealed for two months; during that time,  $\alpha$  particles emitted by radon and their daughters bombarded the CR-39 track detectors. After the irradiation, the detectors were developed in NaOH solution 6.25 N at 60°C for 6 hours; after chemical etching,  $\alpha$  particle track densities were determined by an optical microscope 400 $\times$ . The radon concentration  $C_{\text{Rn}}$  in  $\text{Bq}/\text{m}^3$  was determined by the following equation:

**Table 1.** Soil samples locations.

Locations	Symbols
Baghdad AL-Jadida	S1
Dora refinery near crude oil tanks	S2
Dora refinery near diesel tanks	S3
Dora refinery near white oil tanks	S4
Dora refinery (garden)	S5
Dora refinery near oil pipes	S6
Dora	S7
Karada	S8
Zafraniya	S9

**Figure 1.** The apparatus used to study the radon concentration of soil samples.

$$C_{\text{Rn}} = \frac{\rho_x}{KT} \quad (1)$$

where  $\rho_x$  is the track density in ( $\text{tracks}\cdot\text{mm}^{-2}$ ),  $T$  is the exposure time in (days) and  $K$  is the calibration factor of ( $0.42 \pm 0.02$  ( $\text{tracks}\cdot\text{mm}^{-2}$ )  $\text{Bq}^{-1}\cdot\text{m}\cdot\text{h}^{-1}$ ) (Figure 2).

## 2.2. Calculation of Radon Exhalation Rate in Soil Samples

The radon exhalation rate in terms of area  $E_x$  in ( $\text{Bq}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ ) was calculated as follows [10] [11]:

$$E_x = \frac{CV\lambda}{A[T + \lambda^{-1}(e^{-\lambda T} - 1)]} \quad (2)$$

where  $C$  is the integrated radon exposure measured by the CR-39 SSNTD ( $\text{Bq}\cdot\text{m}^{-3}\cdot\text{h}$ ),  $V$  is the effective volume of the container ( $\text{m}^3$ ),  $\lambda$  is the decay constant of radon ( $\text{h}^{-1}$ ),  $T$  is the exposure time (h), and  $A$  is the area covered by the container ( $\text{m}^2$ ).

The radon exhalation rate in terms of mass  $E_m$  in ( $\text{Bq}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ ) was calculated as:

$$E_m = \frac{CV\lambda}{M[T + \lambda^{-1}(e^{-\lambda T} - 1)]} \quad (3)$$

where  $M$  is the mass of the sample (kg).

## 3. Results and Discussion

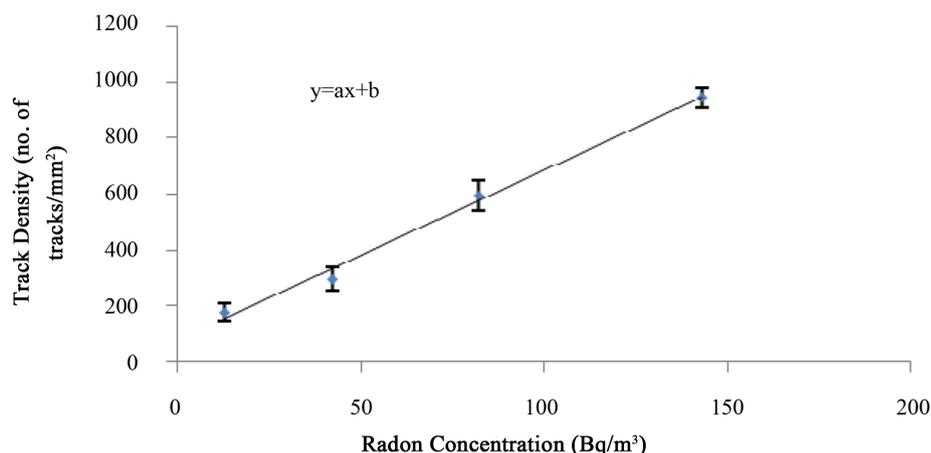
In the present work Radon concentrations were measured for soil samples (surface and from depth 15, 30 cm) in

9 different locations in Al-Dora refinery and surrounding. The dust samples were collected from five locations around Al-Dora refinery **Table 1**. These regions were chose to measure the natural occurring radioactive material which comes from Al-Dora refinery at this region.

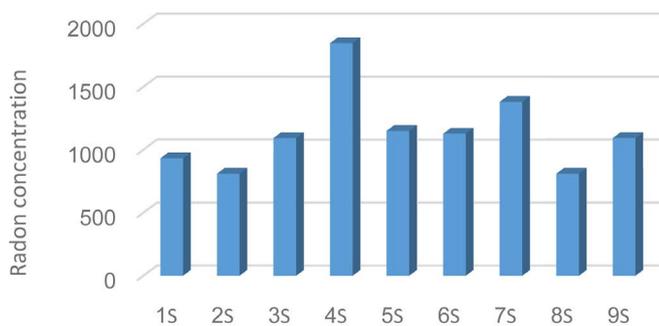
**Tables 2-4** and **Figures 3-5** summarize the results obtained in the present work for radon gas concentrations, the surface exhalation rate and the mass exhalation rate in (surface, 15, 30 cm depth) soil samples.

It can be noticed that the radon concentration values in surface samples were at the range from 810.08 to 1380.08 Bq/m<sup>3</sup> with an average 1137.71 Bq/m<sup>3</sup>. The highest value was in Dora refinery near white oil tanks and the lowest in AL-Karada region as shown in **Figure 3**.

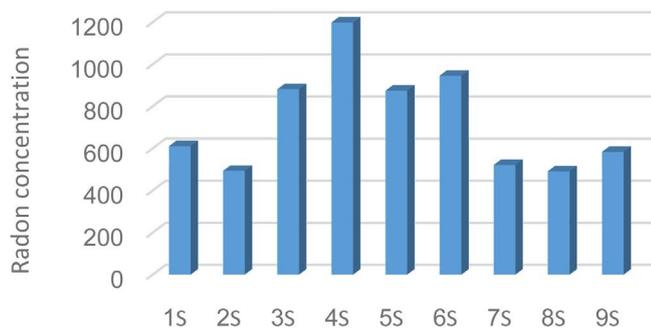
The radon concentrations in soil from depth 15 cm were at the range 490.5 to 1197.52 Bq/m<sup>3</sup> with an average 732.78 Bq/m<sup>3</sup>. The highest value was in AL-Dora refinery near white oil tanks and the lowest in AL-Karada region as shown in **Figure 4**.



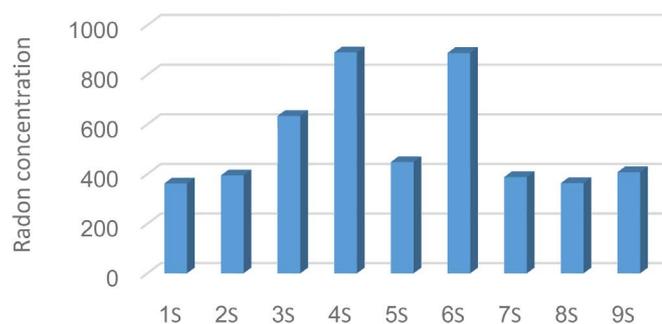
**Figure 2.** Radon concentration (Bq/m<sup>3</sup>) and track density for standard samples [9].



**Figure 3.** Radon concentrations for surface soil samples.



**Figure 4.** Radon concentrations for soil samples at depth 15 cm.



**Figure 5.** Radon concentrations for soil samples at the depth 30 cm.

**Table 2.** Radon concentration, surface exhalation rate, mass exhalation rate for surface soils samples.

Symbols	Radon Concentration Bq/m <sup>3</sup>	$E_s$ (Bq·m <sup>-2</sup> ·h <sup>-1</sup> )	$E_m$ (Bq·kg <sup>-1</sup> ·h <sup>-1</sup> )
S1	932.66	0.5	0.11
S2	810.08	0.44	0.09
S3	1091.62	0.59	0.13
S4	1845.6	0.99	0.21
S5	1149.62	0.62	0.13
S6	1127.08	0.61	0.13
S7	1380.08	0.74	0.16
S8	810.08	0.44	0.09
S9	1091.85	0.59	0.13
Average	1137.71	0.61	0.131

**Table 3.** Radon concentration, surface exhalation rate, mass exhalation rate for soils samples at depth 15 cm.

Symbols	Radon Concentration Bq/m <sup>3</sup>	$E_s$ (Bq·m <sup>-2</sup> ·h <sup>-1</sup> )	$E_m$ (Bq·kg <sup>-1</sup> ·h <sup>-1</sup> )
S1	610.03	0.33	0.07
S2	493.1	0.27	0.057
S3	880.53	0.47	0.10
S4	1197.52	0.64	0.14
S5	873.49	0.47	0.10
S6	945.34	0.51	0.11
S7	521.27	0.28	0.06
S8	490.5	0.26	0.056
S9	583.26	0.31	0.067
Average	732.78	0.39	0.084

The radon concentration in soil from depth 30 cm ranged from 362.07 to 889.53 Bq/m<sup>3</sup> with an average 530.41 Bq/m<sup>3</sup>, the highest concentration was in AL-Dora refinery near white oil tanks as shown in **Figure 5**.

The average of radon concentration for surface, 15 and 30 cm soil samples were 1137.71, 732.78 and 530.41 Bq/m<sup>3</sup> as shown in **Figure 6**.

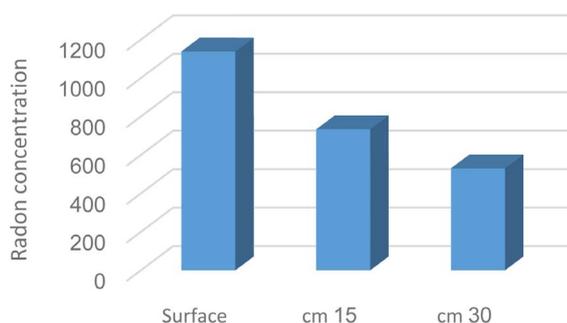
The radon concentration in dust samples were at the range 281.77 to 1620.17 Bq/m<sup>3</sup> with an average 2496.3347 Bq/m<sup>3</sup> as shown in **Table 5** and **Figure 6**. The surface exhalation rate were at the range 0.15 Bq·m<sup>-2</sup>·h<sup>-1</sup> to 2.16 Bq·m<sup>-2</sup>·h<sup>-1</sup> with average 1.34 Bq·m<sup>-2</sup>·h<sup>-1</sup>. While the mass exhalation rate were at the range

**Table 4.** Radon concentration, surface exhalation rate, mass exhalation rate for soils samples at depth 30 cm.

Symbols	Radon Concentration Bq/m <sup>3</sup>	$E_x$ (Bq·m <sup>-2</sup> ·h <sup>-1</sup> )	$E_m$ (Bq·kg <sup>-1</sup> ·h <sup>-1</sup> )
S1	362.07	0.19	0.042
S2	394.48	0.21	0.045
S3	633.98	0.34	0.073
S4	889.53	0.48	0.11
S5	448.01	0.24	0.05
S6	887.57	0.48	0.10
S7	387.43	0.21	0.04
S8	363.48	0.19	0.042
S9	407.16	0.22	0.047
Average	530.41	0.28	0.06

**Table 5.** Radon concentration, surface exhalation rate, mass exhalation rate in dust samples.

Location	Radon Concentration Bq/m <sup>3</sup>	$E_x$ (Bq·m <sup>-2</sup> ·h <sup>-1</sup> )	$E_m$ (Bq·kg <sup>-1</sup> ·h <sup>-1</sup> )
Dora dust	1620.17	0.87	0.19
Karada dust	4015.21	2.16	0.46
Zaafraanjh dust	281.77	0.15	0.032
new Baghdad dust	3268.52	1.75	0.377
Dora refinery dust	3296.7	1.77	0.38
average	2496.3347	1.34	0.29



**Figure 6.** Average radon concentration at surface, 15 cm and 30 cm soil samples.

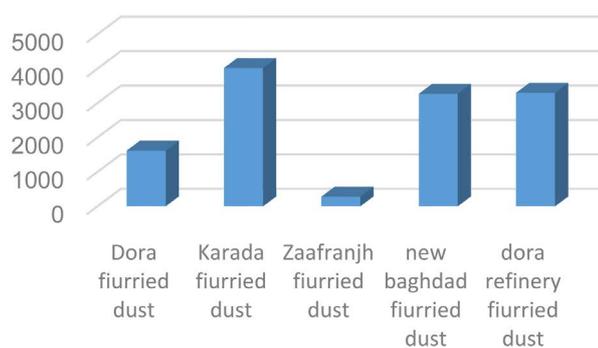
0.032 to 0.46 Bq·kg<sup>-1</sup>·h<sup>-1</sup> with an average 0.29 Bq·kg<sup>-1</sup>·h<sup>-1</sup> as shown in **Table 5** and **Figure 7**.

The radon exhalation rate in term of area in surface soil ranged from 0.44 to 0.99 Bq·m<sup>-2</sup>·h<sup>-1</sup> with average 0.61 Bq·m<sup>-2</sup>·h<sup>-1</sup> as shown in **Table 2**.

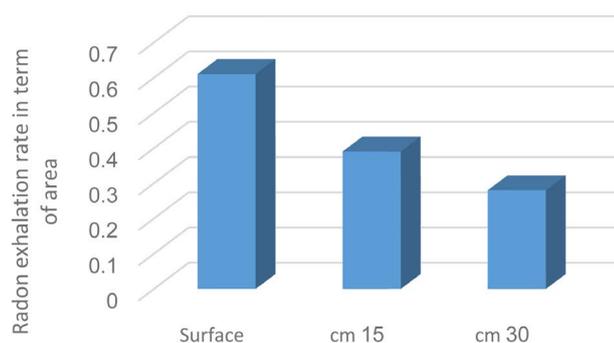
The radon exhalation rate in terms of area in soil samples at the depth 15 cm were at the range 0.22 to 0.64 Bq·m<sup>-2</sup>·h<sup>-1</sup> with average 0.39 Bq·m<sup>-2</sup>·h<sup>-1</sup>.

The radon exhalation rate in terms of area in soil samples from depth 30 cm were at the range 0.19 to 0.48 Bq·m<sup>-2</sup>·h<sup>-1</sup> with average 0.28 Bq·m<sup>-2</sup>·h<sup>-1</sup>. **Figure 8** shows the average surface exhalation rate for surface, 15 cm and 30 cm in Al Dora soil samples.

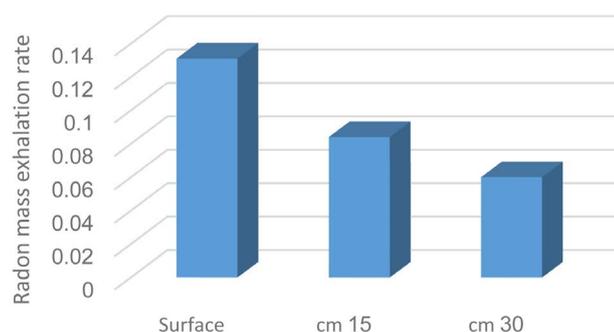
Mass exhalation rate in surface soil were at the range 0.09 to 0.21 Bq·kg<sup>-1</sup>·h<sup>-1</sup> with average 0.12 Bq·kg<sup>-1</sup>·h<sup>-1</sup>. Mass exhalation rate in soil samples from depth 15 cm were at the range 0.046 to 0.14 Bq·kg<sup>-1</sup>·h<sup>-1</sup> with average 0.08 Bq·kg<sup>-1</sup>·h<sup>-1</sup>. Mass exhalation rate in soil samples from depth 30 cm were at the range 0.042 to 0.1 Bq·kg<sup>-1</sup>·h<sup>-1</sup> with average 0.06 Bq·kg<sup>-1</sup>·h<sup>-1</sup>. **Figure 9** shows the average mass exhalation rate for surface, 15 cm



**Figure 7.** Radon concentration for dust samples.



**Figure 8.** Average surface exhalation rate for surface, 15 cm and 30 cm Al Dora soil samples.



**Figure 9.** Average mass exhalation rate for surface, 15 cm and 30 cm in Al Dora soil samples.

and 30 cm in Al Dora soil samples.

It can be noticed that the highest radon concentration in soil samples from different depth were in AL-Dora refinery near white oil tanks which indicate that these region contaminated with natural occurring radioactive material-NORM comes from whit oil tanks.

The present results show that the radon concentration in soil samples (surface, 15 cm and 30 cm depth) and dust samples was higher than the global permissibility limit of exposure to radon inside building for the population ( $200 \text{ Bq}\cdot\text{m}^{-3}$ ) [12]. This concentrations comes from-NORM which are the main sources of radiation in soils and rocks.

#### 4. Conclusions

The results of the present work provide an additional database on radon concentration in AL-Dora refinery soil samples (surface, 15 cm and 30 cm) depth.

The higher concentration in soil samples was found in AL-Dora refinery near white oil tanks at different depths.

The radon concentration in dust samples was found higher than the global permissibility limit of exposure to radon inside buildings for the population ( $200 \text{ Bq}\cdot\text{m}^{-3}$ ). The reason of this concentration comes from the chimney of AL-Dora refinery which release this dust.

The average radon concentration in surface soil samples was found higher than the radon concentrations in soil from depth 15 cm and 30 cm.

The average radon exhalation rate in terms of area and mass in the surface soil samples was higher than radon exhalation rate in terms of area and mass in soil samples from depth 15 cm and 30 cm.

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