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Indoor radon measurements in residential dwellings in Qom, Iran

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ABSTRACT

Background: Inhalation of radon and its short-lived decay products is one of the most significant sources of exposure to natural radiation. Radon is the second cause of lung cancer in the populations. The present study was carried out under the projects of national radon, with the aim of determining the concentration of indoor in the city of Qom located in the central semi-arid region of Iran. ***Materials and Methods:*** Radon measurements were carried out in 123 dwellings using passive sampling with CR-39 detectors for 90 days. The map of radon concentration distribution was prepared using Arc GIS software and the statistical analysis was performed with SPSS version 20. ***Results:*** Indoor radon concentrations in Qom dwellings ranged from 15–259 Bq m^{-3}. The arithmetic mean of indoor radon concentrations on basement, ground floors, first floors and second and upper floors were ,87.94 ,123.43 63.72and 40.69 Bq m^{-3}, respectively. ***Conclusion:*** A correlation was found between the distances from fault zones and measured indoor radon concentration. In most of cases, radon values were lower in well- ventilated dwellings in comparison with poorly-ventilated ones. Moreover, high radon concentration levels were observed in basements. The results indicated that in 30 places (24.3% of cases), the radon concentrations were higher than the reference levels recommended by the World Health Organization (100 Bq m^{-3}).

Keywords: *Indoor radon, CR-39, dwelling, floor, fault.*

INTRODUCTION

Radon (^{222}Rn) with a half-life of 3.8 days is naturally known as a radioactive gas and it is formed by the decay of Radium (^{226}Ra), in the radioactive series of uranium (^{238}U). ^{238}U is existent naturally in soil and rock in various contents (1-3). Radon gas and its short-lived decay products are the most important factors responsible for a person's exposure to natural sources (4). Radon is heavier than air; when generated in earth's layers, it penetrates the pores in the ground and migrates upward by distribution and convection to the surface. This flow is called exhalation and its amount depends on air pressure and diffusion, thermal gradient and humidity of the soil as well (5). The main sources of indoor radon that enter into the houses are: soil through building materials, water, and basement air. Cracks in floor slabs, floor drains, joints and other pores within the foundations of dwellings can elevate the indoor radon concentration (6). When ^{222}Rn accumulates in closed places, it sometimes reaches the level that is harmful to public health (7). When radon and its short-lived progenies such as ^{218}Po and

^{214}Po are deposited in the lungs, their alpha radiation can hurt the tissues (8). After smoking, radon is the second cause of lung cancer in the community (9). Epidemiological studies have shown obvious evidences of the relationships between indoor radon exposure and lung cancer, even at low radon levels, typically found in dwellings. World Health Organization (WHO) proposes a reference level of 100 Bq m^{-3} to minimize health hazards due to indoor radon exposure. However, if this level cannot be reached, the chosen reference level should not exceed 300 Bq m^{-3} (10, 11).

Each person commonly spends more than 80% of his/her time at home or in closed places (12). Therefore, indoor radiation monitoring is very important for estimating the indoor radiation exposure. The indoor radon accumulation is subject to many factors such as temperature, humidity, pressure, ventilation, geological properties, building materials, type of soils, wind speed, and lifestyle of the people who live in houses. There is a large variation in indoor radon concentrations in different, even in areas of a country because of differences in the anthropogenic factors, soil characteristics, climatic parameters and the characteristics of buildings (13-15).

Indoor radon concentration has been investigated in some areas in Iran. In some cases the average concentration of radon in several dwellings was above 100 Bq m^{-3} (16-22). Before this survey, there were no data available about radon concentrations in Qom region. The present study carried out under the projects of national radon (from Institute for Environmental Research (IER) of Tehran University of Medical Sciences). The main objective of this study was to measure the indoor radon variation in 123 dwellings in the city of Qom. In addition, the spatial radon distribution and the effect of some factors such as distance from the fault lines, height from the ground (floor) and ventilation on indoor radon concentration were also examined.

MATERIALS AND METHODS

Study area

The city of Qom located approximately130 km southwest of Tehran (the capital of Iran) is the capital of Qom province. It is located at 34◦ 44' 37'' N latitude, to 55◦ 33' 27'' E longitude in an arid and semi-arid region of the central part of Iran (23-26). The location of study area has been shown in figure 1. This city has an area of approximately 730 square kilometers. Its population is 1,074,036. Qom has a semi-dry climate with the annual rainfall of 161 mm. The temperature in Qom varies from −2.3 ^0C in January to 40.1 ^0C in June. From a geological viewpoint, the soil structure is a combination of clay, sand and sandstone. Because of the presence of some fault lines in the south of Qom, the city faces the threat of earthquakes.

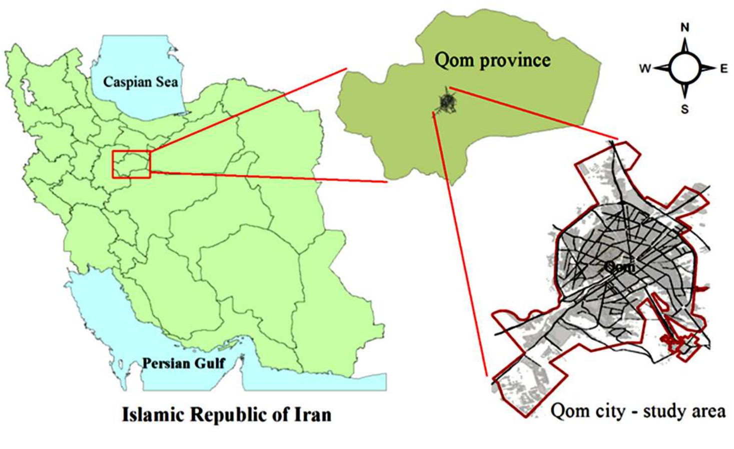

Figure 1. Location of the area under study

Characteristics of dwellings

Measurements of radon concentrations in 123 homes, including 35 basements, 40 ground floors, 21 first floors and 27 second and upper floors, was carried out during the autumn of 2013. Dwellings were randomly selected with an emphasis on coverage of whole investigated area. Information about dwelling characteristics was collected using a questionnaire completed by owners of dwellings. Furthermore, the geographical coordinates of points for mapping radon were recorded using GPS. The radon distribution map was prepared using the Arc GIS application "Arc View 2009".

Experimental details

This investigation was performed with nuclear alpha track detector (ATD) with CR-39 as detector material at dimensions of 30×30×1 mm^3, manufactured by Track Analysis System Co. Ltd. The CR-39 detectors were placed in a plastic container which permits radon to diffuse in [27]. Detectors were numbered and placed in the selected dwellings according to the U.S. EPA protocol, for 90 days to prevent monitoring from being affected by seasonal changes in the area. Detectors were set at least 1.5 m above the floor, at a distance more than 0.5 m from window and at a minimum of 20 cm from any other object [28]. Duplicate measurements were made in 10 percent of the total measurements for validation of our experimental values. The deviation in concentration of the duplicate samples was found to vary from 0.2% to 2.9 % with respect to the original samples.

After exposure time, detectors were wrapped with aluminum foils and delivered to the Reference Radon lab, Central Research Laboratory, Vice Chancellor of Research and Technology, (Mazandaran University of Medical Sciences) In radon laboratory, the detectors were etched in 6.25 N NaOH at 85 °C for 3 hours to magnify the alpha tracks. After removing them from the etching solution, the detectors were washed with distilled water. Detectors were then read by a calibrated semiautomatic system equipped with a camera connected to a personal computer. The number of tracks in a 1 cm^2 area for each film was calculated by an automatic microscope (figure 2). Afterwards, the track density was changed to radon concentration in Bq m^{-3} using calibration factor. *T-test*, ANOVA and Tukey tests (with SPSS software v. 20) were used for data analysis.

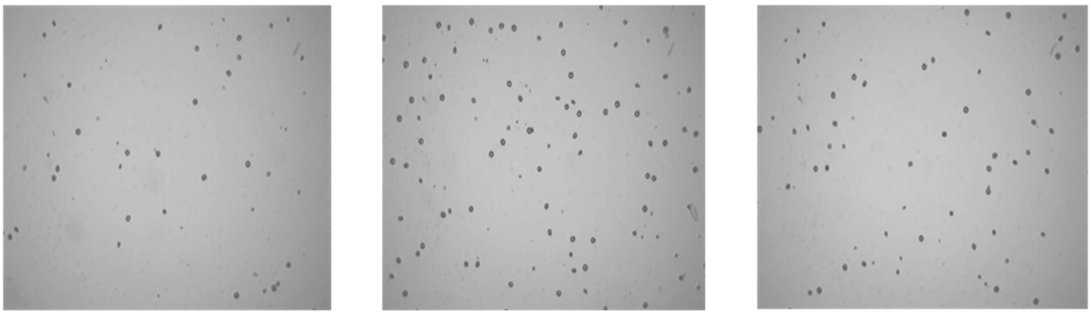

Figure 2. Samples of images taken by electronic microscope (magnification 40); images show the alpha particle track on CR-39.

RESULTS

Table 1 shows the descriptive statistics of the results obtained for dwellings on different floors. The indoor radon concentration in Qom dwellings ranged from 15 to 259 Bq m^{-3}. The arithmetic mean of radon concentration in Qom dwellings (95.83 Bq m^{-3}) was higher than the mean of the world (40 Bq m^{-3}) [29]. The arithmetic means of indoor radon concentration on basement, ground floors, first floors and second and upper floors were 123.43, 87.94, 63.72 and 40.69 Bq m^{-3}, respectively.

The results show the higher mean concentrations on basements and ground floors compared to first and higher floors (figure 3).

Frequency of radon concentration at levels of 50-100 and 100- 150 Bq m^{-3} on ground floors were higher than those in the basements, but radon concentration in 150 -200, 200-250 and 250-300 Bq m^{-3} levels, wereonly observed in basements (figure 4).

In the present study, a major active fault in the south of Qom was identified for evaluating the influence of proximity to a fault on indoor radon concentration. The distance from the fault for each dwelling was estimated and the findings were analyzed. Table 2 show the descriptive statistics of radon concentrations on the ground floors and basements with distances of more than 0.5 km and less than 0.5 km from a fault and the number with the percentage of samples which were above 100 Bq m^{-3} (WHO reference level).

As shown in figure 5 (a & b), the highest values of radon concentration have been observed in dwellings located on or near the fault zones. This figure shows the spatial distribution of indoor radon concentration from basements and ground floors in Qom dwellings in these figures, radon concentrations are classified into 3 ranges. Green zones indicate dwellings which are located in a safe area whose radon concentrations are less than 70 Bq m^{-3}, the yellow zones indicate places where radon concentrations require more attention (70 to 100 Bq m-3).

The measurements of indoor radon concentration were done in dwellings with different ventilation conditions such as HVAC

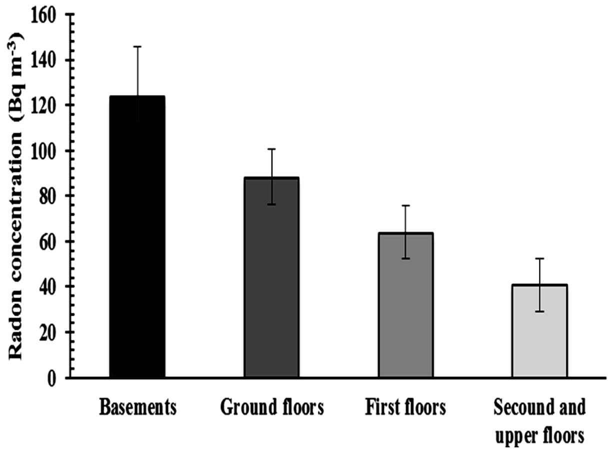

Figure 3. The arithmetic mean of indoor radon concentrations for different floors.

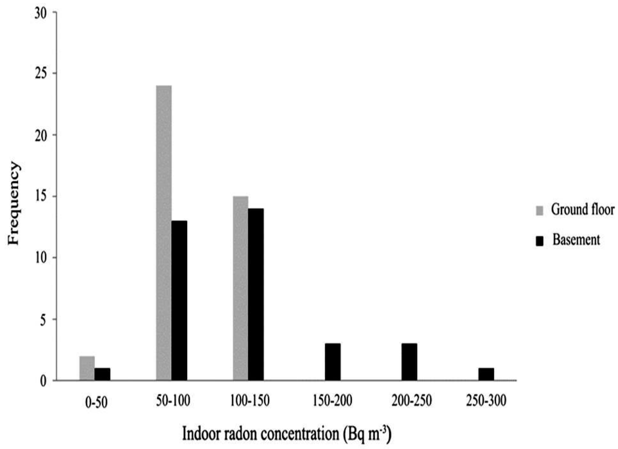

Figure 4. The frequency of indoor radon concentration in basements and ground floors.

Table 1. Descriptive statistics of radon concentrations for different floors.

Floor	No.	AM (Bq m^{-3})	GM (Bq m^{-3})	SD	Max (Bq m^{-3})	Min (Bq m^{-3})
Basement	35	123.43	115.02	50.02	259.00	48.85
Ground floor	40	87.94	83.02	26.40	141.99	43.41
First floor	21	63.72	56.25	24.02	141.00	19.00
Second and upper floors	27	40.69	34.68	23.46	94.00	15.00
Sum	123	95.83	92.76	46.10	259.00	15.00
N: Number of dwelling, AM: Arithmetic mean, SD: Standard deviation, GM: Geometric mean.						

Table 2. Descriptive statistics of radon concentrations with different distances from fault lines.

	Distance to fault	No.	AM (Bq m^{-3})	GM (Bq m^{-3})	SD	Above 100Bq m^{-3} Number (%)
Ground floors	0.5 >km	14	104.57	98.36	44.24	(%64.29)9
	0.5<km	26	78.32	76.25	44.61	(%19.23)5
	Sum	40	87.94	83.02	26.40	(%35.00)14
Basements	0.5 >km	12	134.27	129.36	40.23	(%83.33)10
	0.5<km	23	98,32	86.85	34.01	(%21.74)5
	Sum	35	123,43	115.02	50.20	(%42.86)15
N: Number of dwelling, AM: Arithmetic mean, SD: Standard deviation, GM: Geometric mean.						

(Heating, Ventilating, and Air Conditioning) systems, fans, windows, etc. According to the collected evidence from questionnaires, dwellings were divided into the two groups of "well-ventilated" and "poorly-ventilated" dwellings. The results of radon measurements with different ventilation conditions (on the ground floors) are displayed in table 3. In well-ventilated dwellings concentrations ranged from 43.41 to 141.99Bq m^{-3} and the arithmetic mean of radon concentration was 80.50 Bq m^{-3}. In poorly-ventilated dwellings, the maximum and minimum radon concentrations were 215 and 85.25 Bq m^{-3}, with the arithmetic mean of 94.83 Bq m^{-3}.

Table 4 provides a summary of some of the new studies about the indoor radon investigation in the world with emphasis on surveys conducted in Iran.

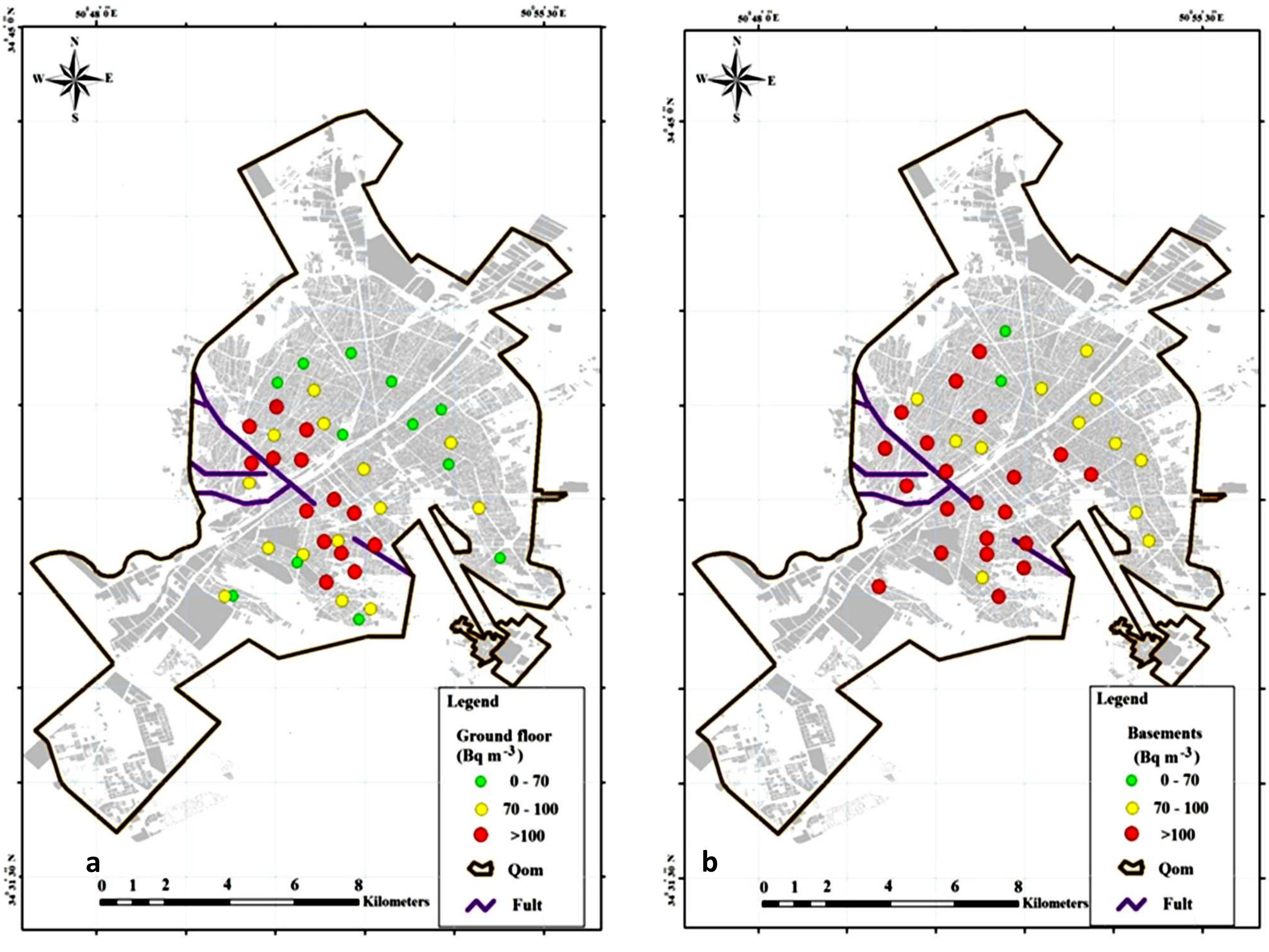

Figure 5. Dwellings radon concentration at ground floors (a) and basements (b).

Table 3. Indoor radon concentrations (Bq m^{-3}) with different ventilation conditions.

Ventilation condition	No.	AM (Bq m^{-3})	GM (Bq m^{-3})	SD	Max (Bq m^{-3})	Min (Bq m^{-3})
Well ventilated	30	80.50	75.25	45.23	141.99	43.41
Poorly ventilated	10	94.83	89.47	44.47	215.39	85.25
Sum	40	87.94	83.50	25.68	215.39	43.41
N: Number of dwelling, AM: Arithmetic mean, SD: Standard deviation, GM: Geometric mean						

Table 4. Summary of the new studies about the indoor radon investigation in the world.

Country	Area	Type of dwelling	Maximum concentration of radon (Bq m^{-3})	Mean concentration of radon (Bq m^{-3})	Minimum concentration of radon (Bq m^{-3})	Reference
Mexico	Mexico City	Family houses	155	87	NR	(30)
Turkey	81 Provinces	Home	1400	81	1	(29)
Pakistan	Hazara	House	254	128	41	(31)
Palestine	Tulkarem	School	210.51	40.42	3.48	(32)
Canada	Quebec	School	663	56	15	(33)
Pakistan	Islamabad Murree	House	181 92	112.5 45.2	45 19	(6)
India	Guwahati	Dwelling	43.16	21.31	9.04	(34)
Romania	Alba county	House & block	624	98	24	(35)
Eastern Sicily	5 Districts	Schools and dwellings	634	90	7	(36)
Cameroon	Poli Lolodorf	Dwellings	2240 4390	294 200	29 24	(1)
Italy	All Italian regions	Underground workplaces	4851	153	27	(37)
Serbia	3 districts in Southern Serbia	Primary schools	607	119	17	(38)
Brazil.	Rio de Janeiro	Modern chapel Old art gallery	166 247	136 146	85 87	(39)
Portugal	Porto	Primary schools	889	197	56	(10)
Iran (Northern cites)	Lahijan Ardabil Sar-Ein Namin	Home	NR NR NR NR	163 240 160 144	NR NR NR NR	(19)
Iran	Mashhad	Apartment	135.2	31.9	12.3	(17)
Iran	Shiraz	Apartment	NR	94	NR	(18)
Iran	Hamedan	Home	364	108	4	(21)
Iran	Yazd province	Old quarters	NR	97.1	NR	(22)
Iran	Yazd	Dwellings underground	747.4	137.36	5.55	(20)
Iran	Gorgan	Bedroom of house	187	48.01	NR	(40)
Iran	Qom	Home	259	95.83	15	This study
NR: Not Reported						

DISCUSSION

The arithmetic mean of radon concentration in Qom dwellings was 95.83 Bq m^{-3}. According to the previous studies, the average amount of radon in Qom dwellings is higher than that in the cities of Gorgan, Shiraz and Mashhad and lower than that in the other cities of Iran mentioned in table 4. The higher amount of radon has been reported in some regions of Cameroon [1], Italy [37], and Portugal [10].

The highest and lowest radon concentrations are observed on basement and second and upper floors (higher than 1st floors) equaling 123.43 and 40.69 Bq m^{-3} respectively. ANOVA tests showed that the average concentrations of various floors are significantly different ($p < 0.001$). In this research indoor radon concentration in 45% of the basements, 35% of the ground floors and 5% (only one sample) of the first floors was above the WHO reference level (100 Bq m^{-3}) and all of the samples from second and upper floors were lower than 100 Bq m^{-3}. Higher concentration of indoor radon in lower floors has been reported by other researchers as well [27, 41, 42] Direct contact with

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soil, plays an important role in increasing indoor radon concentration, because of the exhalation rate of radon from the floors, which depends on subsoil characteristics [43].

The highest values of radon concentration have been observed in dwellings located on or near fault zones. Statistical *t-test* demonstrates that basements and ground floors with less distance (< 0.5 km) from fault, showed significantly ($p<0.001$) higher concentrations of radon than on ground floors and basements with high distance (>0.5 km). The results of current research agree with those of many studies about the effect of fault zone on radon concentration [36, 41, 44]. In fact, radon migration is raised in the vicinity of tectonic disturbances which expand the porosity of the earth's crust. On the other hand, they are passages for radon migration. This has an impression on the indoor exhalation and accumulation.

As shown in figure 5 in some areas (red zone), radon levels are higher than WHO reference level which, imply that appropriate preventive and control actions should be taken in these areas in order to prevent the above-mentioned concentrations reaching the permitted limit [11]. Differences in radon concentration between well-ventilated and poorly-ventilated dwellings are statistically significant ($p < 0.05$). The findings indicate that the average radon concentration is slightly lower for well- ventilated dwellings as compared to poorly ventilated dwellings. The results of this study are consistent with those of many other investigations that have been done on this topic [34, 45-47]. Because indoor radon concentration levels depend on indoor ventilation conditions and in well-ventilated dwellings the radon can easily move out and does not accumulate inside, the indoor radon level goes down in well-ventilated dwellings in comparison to poorly-ventilated ones [46].

CONCLUSION

Based on the results, in 30 places (24.3% of cases) the radon concentrations were higher than the reference levels recommended by the World Health Organization (100 Bq m^{-3}). It could be concluded that the soil characteristics of the dwellings are the most important source of radon for the ground floor and higher concentration of indoor radon observed on lower floors. Most of the high radon concentrations have been reported from places near fault zones; hence the existence of a relation between the exhalation rate from faults and indoor radon concentrations is obvious. The results of the study indicate that the average concentration of radon in dwellings which poor ventilation condition is higher than those that have appropriate ventilation conditions. Finally, it can be noted that, due to the climate of Qom, a large number of dwellings of this city have a basement and hence these basements can concentrate and raise the level of indoor radon in the dwellings.

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Conflict of interest*: *Declared none.

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