Soil gas radon–thoron monitoring in Dharamsala area of north-west Himalayas, India using solid state nuclear track detectors

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The study described here is based on the measurements of soil gas radon–thoron concentrations performed at Dharamsala region of north-west (NW) Himalayas, India. The study area is tectonically and environmentally significant and shows the features of ductile shear zone due to the presence of distinct thrust planes. Solid state nuclear track detectors (LR-115 films) have been used for the soil gas radon–thoron monitoring. Twenty five radon–thoron discriminators with LR-115 films were installed in the borehole of about 50 cm in the study areas. The recorded radon concentration varies from 1593 to 13570 Bq/m^3 with an average value of 5292 Bq/m^3. The recorded thoron concentration varies from 223 to 2920 Bq/m^3 with an average value of 901 Bq/m^3. The anomalous value of radon–thoron has been observed near to the faults like main boundary thrust (MBT and MBT2) as well as neotectonic lineaments in the region.

1. Introduction

Mapping faults and studying fault zone properties are important for seismic hazard analysis and for understanding earthquake physics. A fault is a fracture or zone of fractures that separates dfferent blocks of crust and accumulates a seismic strain subjected to large stress concentrations. When the energy associated with the accumulated strain is suddenly released, an earthquake occurs on the fault. During most earthquakes, fault motion stays below the earth's surface, but in large earthquakes, fault motion may break through to the surface, offsetting rocks and sediments, as well as anything built on the fault, as much as 10 feet or more. Knowing the location of active faults is important so that planners and developers can avoid building houses or other structures, which would be destroyed when the fault breaks the earth's surface, on the faults. The variations of radon concentrations in the soil gas have been considered as a useful tool for earthquake monitoring and prediction in active fault zones (Liu *et al.* 1985; King 1986; Igarashi *et al.* 1995; Chyi *et al.* 2005; Yang *et al.* 2005, 2011; Kumar *et al.* 2009, 2012; Walia *et al.* 2009, 2013; Pereira *et al.* 2010; Singh *et al.* 2010) as well as for tracing neotectonic faults (Etiope and Lombardi 1995; Ciotoli *et al.* 1998; Guerra and Lombardi 2001; Fu *et al.* 2005; Walia *et al.* 2005, 2010) because of radon noble geochemical

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characteristics. There exists quite a few other isotopes of radon besides ^{222}Rn; the most notable ones are ^{220}Rn that is known as thoron and ^{219}Rn, which is known as actinon.

Radon is a short-lived decay product derived from the ^{238}U decay series, with a half-life of 3.8 days. Thoron is a decay product derived from the ^{232}Th decay series and has a relatively short half-life (55 s) that makes it useful in discriminating sectors with very fast soil-gas transport and/or Th-rich mineral outcrops. Actinon is part of the decay series of ^{235}U and has such a short half-life (4 s) that is neglected in geochemical exploration. However, only a few studies have mentioned thoron (^{220}Rn) for the same applications due to its short half-life (LaBrecque 2002; Yang *et al.* 2005).

For radon–thoron monitoring, various techniques (active as well as passive) have been reported in literature (Eappen and Mayya 2004; Papastefanou 2007; Pereira *et al.* 2010; Kumar *et al.* 2013). Walia *et al.* (2008) have studied soil-gas activity in the vicinity of neotectonic fault zones within the Dharamsala area in the region of the north-west Himalayas, India, by determining enhanced concentration values of radon and helium in the soil, using active detectors, *viz.*, ionization chamber and ASM 100 HDS (Alcatel). However, these instruments available in the market are cost prohibitive. Application of solid state nuclear track detectors (SSNTDs) for radon–thoron measurements is widely accepted (Beck and Gingrich 1976; Gingrich and Fisher 1976) since these detectors are affordable and have the advantage to withstand parametric changes in the atmosphere when deployed in open environments (Tommasino 1990). Various types of SSNTDs are used in different exposure modes for the measurement of radon. Dosimeters of specific designs have been developed using SSNTDs (Eappen and Mayya 2004; Al-Azmi 2009).

In the present study, passive detectors (LR-115 films) has been used in radon–thoron discriminator for the measurement of soil gas radon–thoron in the Dharamsala region of NW Himalayas, India to check the effectiveness of this low cost technique and to know the variations of soil gas radon–thoron concentrations in the tectonically and environmentally significant area.

2. Geology and tectonic setting of the study area

The high seismicity and associated geological phenomena along the Himalayan belt are related to the collision of the Indian and Eurasian converging plates. As a result of this, a series of major thrust planes, the main central thrust (MCT), the main boundary thrust (MBT) and the Himalayan frontal thrust (HFT), have been formed (Gansser 1964). Dharamsala area (32°13′N, 76°19′E, 52 D/SW) of the NW Himalayas lies on the southern slope of the Dhauladhar range (figure 1). The geology of the Dharamsala area which forms a part of lesser and outer Himalayas is characterized by the occurrence of the following formations/group (figure 2) from north to south, *viz.*, Dhauladhar granite, Chail formation, Dharamsala traps, Dharamkot limestone, Sabathus, Dharamsala group and Shivalik group. Diverse lithology (Mahajan *et al.* 1997) within a short span of distance makes the study area tectonically and environmentally significant and shows the features of ductile shear zone due to the presence of distinct thrust planes. From south to north, these are MBT-2 (locally known as Drini Thrust), MBT and MCT (locally known as Chail Thrust). The individual formations and groups are separated from one another by longitudinal thrust systems (Mahajan and Virdi 2000) and the area is cross-cut by transverse faults/lineaments trending northeast–southwest. Kumar and Mahajan (2001) have correlated the Kangra earthquake (1905) and the Dharamsala earthquake (1986) with MBT and its subsidiary Drini thrust in the northeast to southwest direction while the Dharamsala earthquake (1978) is correlated with a transverse fault.

3. Methodology

Radon–thoron discriminator using SSNTDs has been used for the measurement of radon–thoron concentrations in Dharamsala areas of NW Himalayas, India. Radon–thoron discriminator consists of a polyvinyl chloride (PVC) plastic tube of 6 cm diameter and 25 cm length with the top closed. A small rectangular attachment of aluminum (film holder) can be slipped into it. The rectangular attachment has two grooves where SSNTDs can be fixed. The detector consists of 100 μm thick transparent supporting plastic foil with a layer of 12 μm thick red coloured cellulose nitrate (LR-115 type II) which is sensitive to alpha radiation. The upper detector records tracks due to radon alone while lower detector records tracks due to radon and thoron. At the bottom of discriminator, a filter was placed to avoid the contribution from progeny concentrations. Twenty five discriminators along with LR-115 films were kept in the auger hole (about 50 cm depth) for two weeks during dry period, i.e., May–June 2012. After retrieval, the detector films were etched in 2.5 N NaOH solution at a constant temperature of 60°C for 60–90 minutes using the etching bath. For the calculation of track density, optical microscope has been used to scan the chemically etched tracks in the

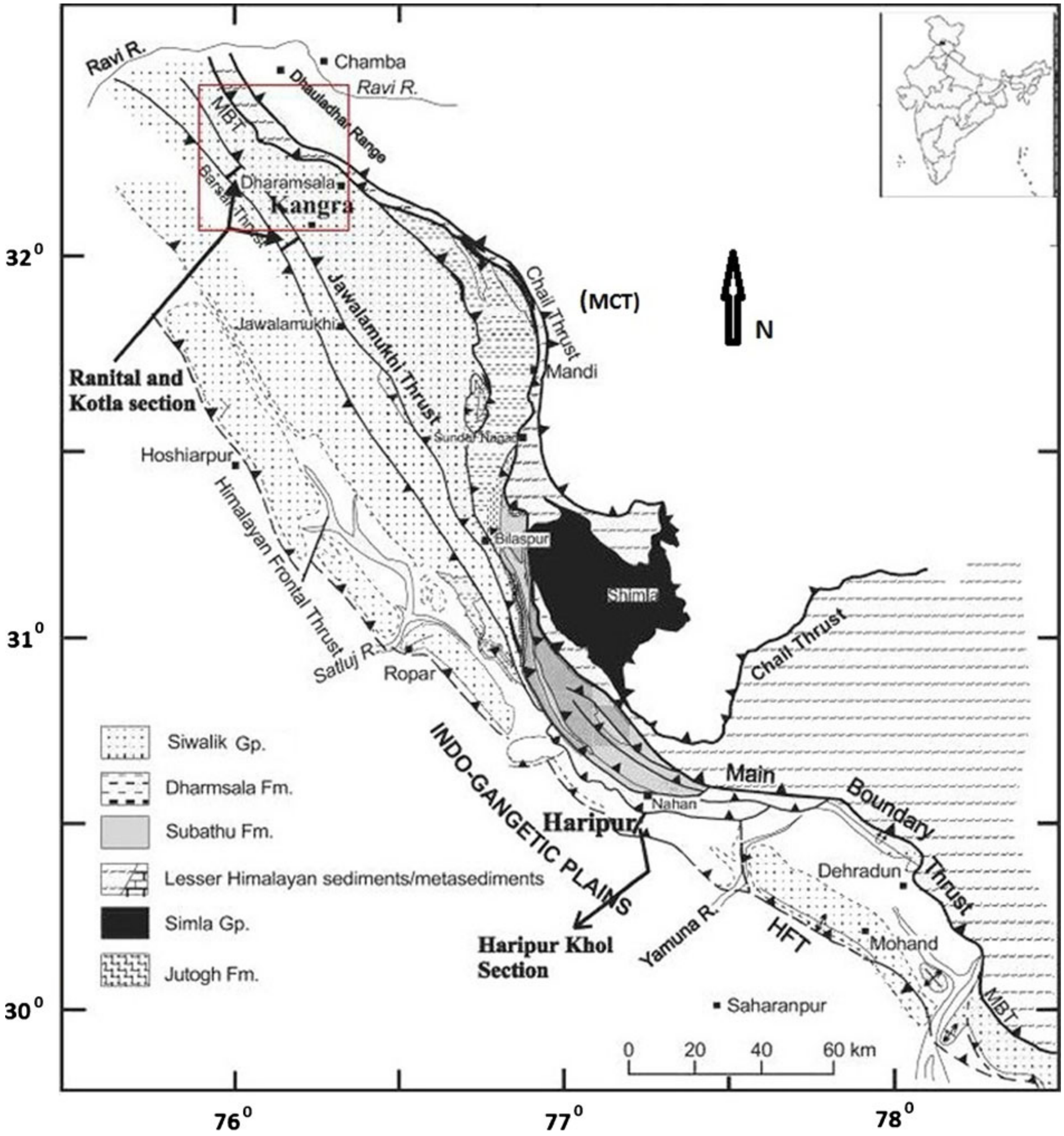

Figure 1. Geological map showing the location of study area.

samples. The measured track density for radon and thoron has converted into Bq/m^3 using the calibration factor described elsewhere (Eappen and Mayya 2004).

4. Results and discussions

Figure 2 shows the 25 sampling locations where LR-115 films have been installed inside radon–thoron discriminators in the Dharamsala area of NW Himalayas. The results of soil gas concentration variations of radon and thoron are shown in table 1. The recorded radon concentration varies from 1593 to 13570 Bq/m^3 with an average value of 5292 Bq/m^3 whereas recorded thoron concentration varies from 23 to 2920 Bq/m^3 with an average value of 901 Bq/m^3. In the present study, radon has shown higher values than of thoron due to short half-life of thoron, it cannot be detected from the greater depth. Further, the effect of moisture on the film at the lower part of discriminator due to its close proximity to the surface, can also be considered as one of the factors in suppressing the thoron signals. The recorded average radon value in the present study is closer to the

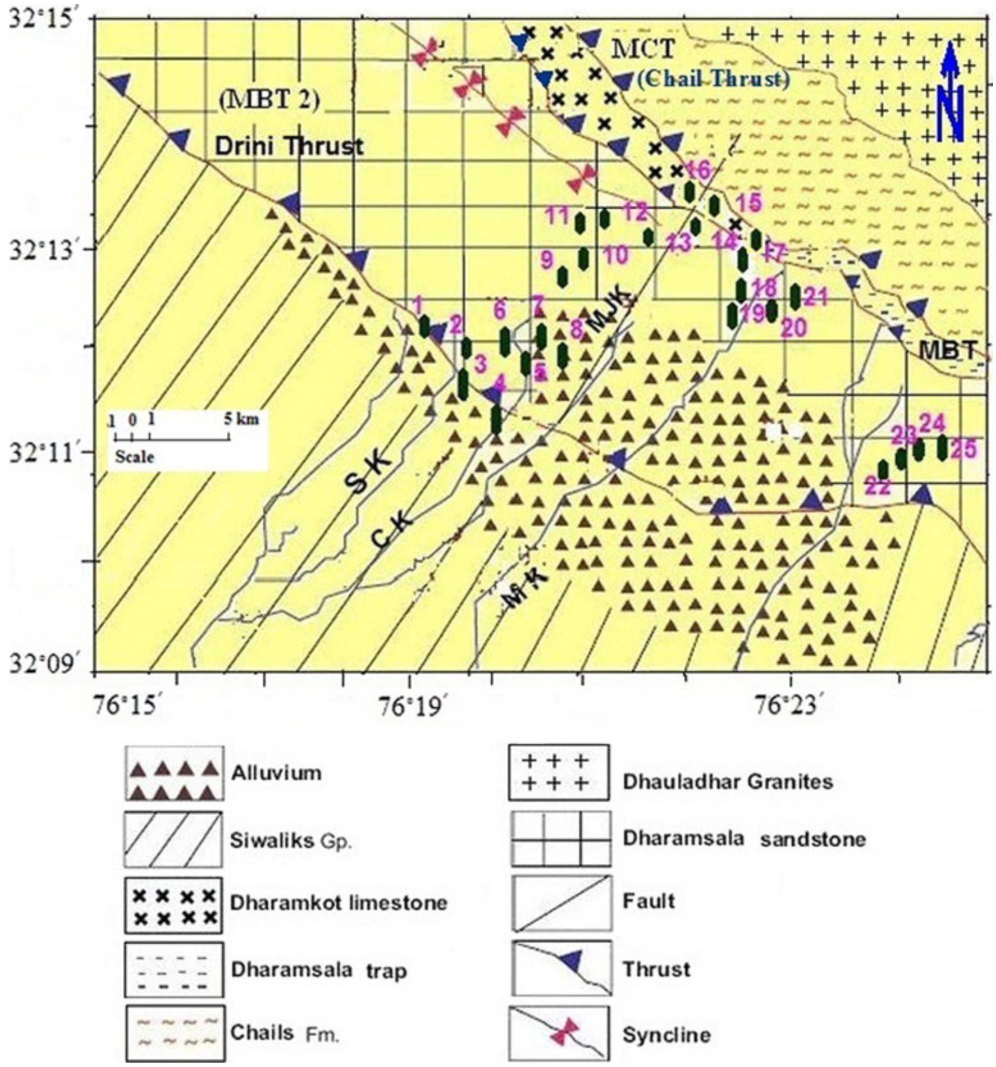

Figure 2. Geological map showing the locations of radon–thoron discriminators installed in the study area and tectonic features (MBT = Main Boundary Thrust, MCT = Main Central Thrust) and drainage systems (SK = Sarah Khad, CK = Churan Khad, MJK = Manjhi Khad, MK = Manuni Khad, DK = Darun Khad) (modified after Mahajan *et al.* 1997).

average values of the radon reported in the Nurpur area of NW Himalayas using SSNTDs (Singh *et al.* 2006) whereas it is less than the average value reported in the Nurpur (Mahajan *et al.* 2010) and the Dharamsala area (Walia *et al.* 2008) of NW Himalayas using active detectors. The difference in the average radon value in the present study with Mahajan *et al.* (2010) and Walia *et al.* (2008) may be due to the different techniques used for radon monitoring.

In order to identify possible threshold values of anomalous soil radon–thoron concentrations, various statistical methods have been used by different authors in the past (Guerra and Lombardi 2001; Fu *et al.* 2005; Walia *et al.* 2005; Pereira *et al.* 2010). In our context, statistical threshold values of radon–thoron gas anomalies are fixed at mean plus one standard deviation and anomalously high values were neglected, which may cause unnecessary high deviation and perturb the real anomalies. Figure 3 shows the high anomalous value of radon–thoron in the study areas. The primary vertical axis in the figure represents radon values and the secondary vertical axis represent thoron values at each sampling location whereas the line drawn (i.e., for X + 1σ) in the figure is for both radon and thoron. The value of radon concentration was found to be anomalous at sampling points 2, 3, 12, 14, 20, 21 and 22 whereas the value of thoron concentration was found to be anomalous at sampling points 3, 8, 12, 17, 20 and 21, respectively. At sampling points 14 and 22, the recorded radon concentrations found to be anomalous whereas thoron concentrations were not. This may be due to the deeper source of gas in the study area as reported by Yang *et al.* (2005). Also at sampling points 8 and

Table 1. *Recorded radon–thoron concentration in the Dharamsala area of NW Himalayas, India.*

Sl. no.	Rn (Bq/m^3)	Th (Bq/m^3)
1	5757	727
2	6583	1243
3	13570	1320
4	3150	963
5	2260	290
6	2557	250
7	5117	507
8	6387	1320
9	1743	593
10	3747	464
11	5507	527
12	12827	2920
13	5080	897
14	6887	1223
15	2380	643
16	1873	223
17	6003	1307
18	5700	710
19	5553	660
20	8187	1704
21	9000	1817
22	6597	997
23	2000	244
24	2263	723
25	1593	253
Average	5292.84	901

17, the recorded values of thoron were anomalous where as radon concentrations were not. It may be due to the shallower gas source in the study area (Yang *et al.* 2005). This gas source can only provide a small amount of radon/thoron gas to the surface due to the microfracture and this small amount of gas may not increase the radon concentration clearly due to its original relative high background level. In contrast, it will significantly enhance the thoron concentration.

At sampling points 3, 12, 20 and 21, both radon and thoron values were found to be anomalous. The sampling point 3, where the recorded values for both radon and thoron were anomalous lying on the Drini thrust (MBT2). The sampling point 14 where the recorded values for radon was anomalous and sampling point 17 where the recorded values for thoron was anomalous, this may be attributed to the presence of MBT nearby or due to probable lineaments which are common features along different drainage systems in the study area as reported by earlier studies (Dhar *et al.* 2002; Walia *et al.* 2008). The sampling point 12 where both radon–thoron values were anomalous lying very close to Syncline. The points 20 and 21, where the recorded values for radon–thoron were anomalous lying very close to Manuni Khud lineament. At sampling point 8 where the recorded thoron value was anomalous lying in between Churan Khad and Manjhi Khad. The low value for radon and thoron has been recorded at sampling points 15 and 16

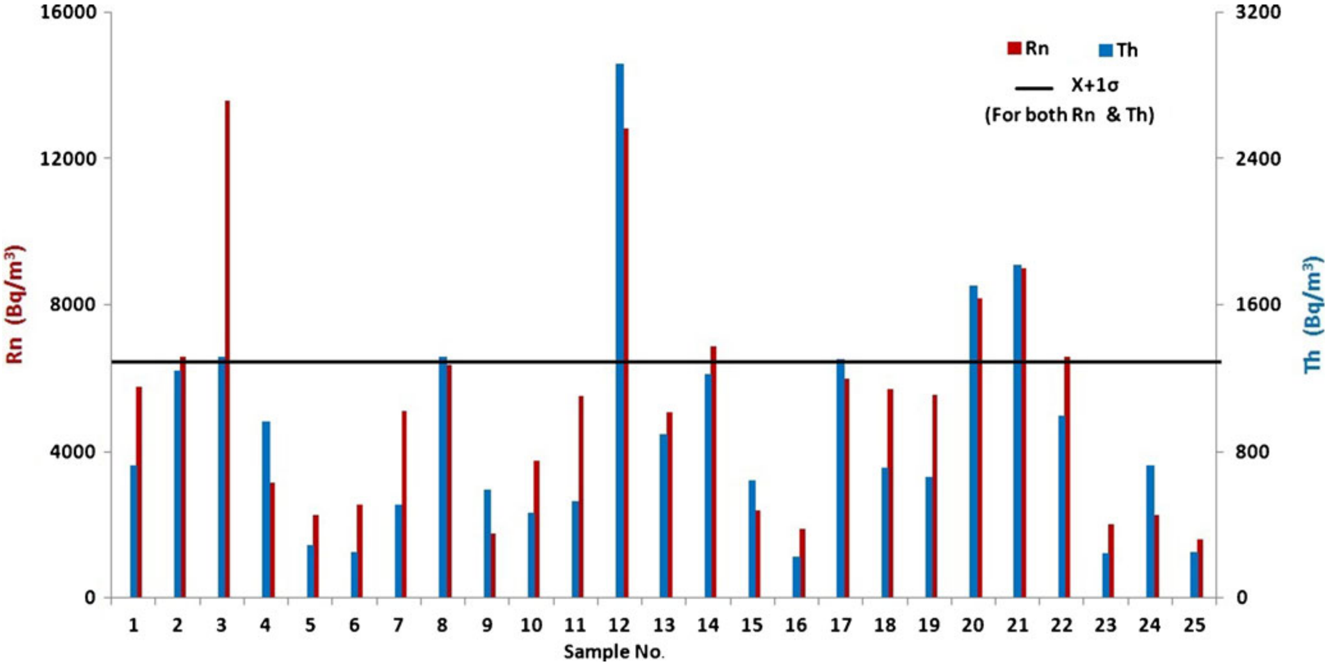

Figure 3. Radon–thoron data as small bar-charts over each location point.

located in fault junction. The possible reason for low values for radon and thoron is that these two points are in the ductile zone in between MBT and MCT, may be having higher porosity, but low permeability. The sampling points 1, 2, 3 and 4 are located around the MBT2. However, only two sampling points, i.e., 2 and 3 have identified anomalous values of radon/thoron. Although, the points 1 and 4 have not shown anomalous values, the value of radon at point 1 and value of thoron at point 4 are found to be higher than the average value, respectively. Overall the anomalous values of radon and thoron were found near to the faults, i.e., main boundary thrust (MBT and MBT2) as well as near Churan Khad (CK), Manuni Khad (MK) and Manji Khad (MJK). These anomalies indicate the presence of lineaments controlling this drainage system. Dhar *et al.* (2002) have already observed intersection pattern of longitudinal thrust and transverse lineaments along Manji Khad (MJK) in the area of Dharamsala.

Walia *et al.* (2008) have also studied soil-gas activity in the vicinity of neotectonic fault zones within the Dharamsala area in the region of the NW Himalayas, India, using active detectors. The authors have also reported anomalous value of radon near to the neotectonic thrust in the regions like main boundary thrust (MBT2) and also along the drainage system in the study area. The similar work is also in progress for soil gas radon–thoron monitoring using SSNTDs in other seismically active zones of NW Himalayas, India and will be reported in the future.

5. Conclusions

An economical and simple method has been evolved to measure soil gas radon–thoron simultaneously using discriminator deploying LR-115 films. In Dharamsala areas, recorded soil gas radon concentration varies from 1593 to 13570 Bq/m^3 with an average value of 5292 Bq/m^3 whereas recorded soil gas thoron concentration varies from 223 to 2920 Bq/m^3 with an average value of 901 Bq/m^3. The anomalous value of radon–thoron has been observed near to the faults in the region, i.e., main boundary thrust (MBT, MBT2) and also along the drainage system in the study area. The presence of neotectonic faults/lineaments in the region has made it tectonically active. Based on the preliminary results of the present study and from the previous studies, it is suggested that the detailed studies of radon–thoron along with other noble gases will be fruitful for such kind of studies.

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