Radon Precursory Anomalies for Some Earthquakes in N-W Himalaya, India

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<table>
<thead>
<tr>
<th>DATE</th>
<th>EPICENTRE</th>
<th>LOCATION</th>
<th>MAGNITUDE</th>
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<tbody>
<tr>
<td>1869 JAN 10</td>
<td>25 93</td>
<td>NEAR CACHAR, ASSAM</td>
<td>7.5</td>
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<tr>
<td>1885 MAY 30</td>
<td>34.1 74.6</td>
<td>SOPOR, J&amp;K</td>
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<td>1897 JUN 12</td>
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<td>7.6</td>
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<td>1930 JUL 02</td>
<td>25.8 90.2</td>
<td>DHUBRI, ASSAM</td>
<td>7.1</td>
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<td>1934 JAN 15</td>
<td>26.6 86.8</td>
<td>BIHAR-NEPAL BORDER</td>
<td>8.3</td>
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<tr>
<td>1941 JUN 26</td>
<td>12.4 92.5</td>
<td>ANDAMAN ISLANDS</td>
<td>8.1</td>
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<td>1943 OCT 23</td>
<td>26.8 94.0</td>
<td>ASSAM</td>
<td>7.2</td>
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<td>1950 AUG 15</td>
<td>28.5 96.7</td>
<td>ARUNACHAL PRADESH-CHINA BORDER</td>
<td>8.5</td>
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<td>1956 JUL 21</td>
<td>23.3 70.0</td>
<td>ANJAR, GUJARAT</td>
<td>7.0</td>
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<td>1967 DEC 10</td>
<td>17.37 73.75</td>
<td>KOYNA, MAHARASHTRA</td>
<td>6.5</td>
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<td>1975 JAN 19</td>
<td>32.38 78.49</td>
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<td>1988 AUG 06</td>
<td>25.13 95.15</td>
<td>MANIPUR-MYANMAR BORDER</td>
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<td>1988 AUG 21</td>
<td>26.72 86.63</td>
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<td>6.4</td>
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<td>1991 OCT 20</td>
<td>30.75 78.86</td>
<td>UTTARKASHI, UP HILLS</td>
<td>6.6</td>
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<td>1993 SEP 30</td>
<td>18.07 76.62</td>
<td>LATUR-OSMANABAD, MAHARASHTRA</td>
<td>6.3</td>
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<td>1997 MAY 22</td>
<td>23.08 80.06</td>
<td>JABALPUR, MP</td>
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<tr>
<td>1999 MAR 29</td>
<td>30.41 79.42</td>
<td>CHAMOLI DIST, UP</td>
<td>6.8</td>
</tr>
<tr>
<td>2001 JAN 26</td>
<td>23.40 70.28</td>
<td>BHUJ, GUJARAT</td>
<td>6.9</td>
</tr>
</tbody>
</table>

**List of Significant Earthquakes in India and its Neighbourhood**

**Date**: Day, Month and Year

**Epicentre**: Latitude and Longitude

**Location**: Name of the area affected

**Magnitude**: Intensity of the earthquake measured on the Richter scale
PLOT OF EARTHQUAKES (M >= 5.0) FROM IMD CATALOGUE FOR THE PERIOD FROM 1800 TO SEPT. 2001

Total events: 3383
Selected events: 3383

Magnitudes:
M = 5  
M = 6  
M = 7  
M = 8  

[Map of India showing earthquake distribution with magnitudes highlighted]
Seismicity of Southern Asia (above magnitude 3.0 Ms)
NOTE: Towns falling at the boundary of zones demarcation line between two zones shall be considered in High Zone.
TECTONIC MAP OF INDIA
Faults active since the Quaternary period (See References)

WWW.ASC-INDIA.ORG

- Subduction Boundary
- Thrust Boundary
- Fault or Fault Zone
- Spreading Centre
- Fracture Zone
- Active Volcano
Subsurface Soil Gases

- Radon ($^{222}\text{Rn}$)
- Helium ($^4\text{He}$)
- Carbon-di-oxide ($\text{CO}_2$)
- Methane ($\text{CH}_4$)
What is Radon?

- A radioactive & inert gas
- 7.5 times heavier than air
- 100 times heavier than hydrogen
- Three isotopes:
  - Radon (Rn^{222}) 3.83 days
  - Thoron (Rn^{220}) 54.5 sec
  - Actinon (Rn^{219}) 3.92 sec
What is Helium (He⁴)?

• Generated during the radioactive decay of isotopes of uranium and thorium in rocks and soil
• Highly diffusive and inert gas
• Shows the value 5.24 ppm in air
Factors controlling emanation

- Transmission Characteristics of Bedrock
- Mineralogical Effects
- Uranium/Thorium Concentration
- Carrier Fluids
- Weather and Soil Types
• Gases measured in soils can be strongly disturbed by environmental variables like atmospheric pressure, soil temperature, rainfall, soil moisture etc.
Emanometry Technique

Diagram:

- Soil Gas/Water Probe
- Air Pump
- Detector Scintillation Unit
- Electronic Counter
- Power Supply
Soil-Gas Emanometry

Radon Emanometer used for radon sampling

Soil-gas probe used for radon sampling
Groundwater radon sampling methodology
Correlation coefficient of radon concentration in soil-gas with different meteorological parameters at Palampur

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average (Avg)</th>
<th>Standard Deviation (Std)</th>
<th>% Variation Coefficient (Std/Avg)</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radon (Bq/L)</td>
<td>22</td>
<td>12.7</td>
<td>58</td>
<td>___</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>23.9</td>
<td>5.4</td>
<td>23</td>
<td>0.18</td>
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<tr>
<td>Relative Humidity (%)</td>
<td>64.3</td>
<td>18.1</td>
<td>28</td>
<td>0.31</td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td>5.5</td>
<td>14.8</td>
<td>267</td>
<td>0.19</td>
</tr>
<tr>
<td>Wind Velocity (km/hr)</td>
<td>4.5</td>
<td>1.4</td>
<td>32</td>
<td>-0.27</td>
</tr>
</tbody>
</table>
Radon Anomaly

• Radon anomaly is defined as any sudden change in radon concentration crossing the average of that season by $\pm 2\sigma$.

• Radon anomalies followed by seismic event is Pre-seismic

• Anomaly occur simultaneously (same day) with seismic event is called Co-seismic

• Anomaly after the seismic event is Post-seismic
Dalhousie

Time Window (March 1995)

(Virk et al., 1995)
Radon Conc. (Bq/L)

- **Groundwater**
  - $\bar{X} + 2\sigma = 46.63$
  - $\bar{X} = 56.69$
  - $\bar{X} + 2\sigma = 69.66$

- **Soil-gas**
  - $\bar{X} = 24.31$

Chamoli Eq
M = 6.8

Palampur

(Virk et al. 2001)
Palampur

Time window (March 99)

Helium Conc. (ppm)

(Virk et al. 2001)
A-B : He/Rn ratio under normal condition
B-C : Rise in He/Rn ratio as stresses accumulate at depth
C-D : Drop in He/Rn ratio prior to triggering of the shock
D-E : Drop back in He/Rn ratio after the shock

Fig. 3. A conceptual He/Rn ratio model as a predictive tool for earthquakes.
Chamoli Eq

He/Rn (Walia et al. 2005)

Time window (March 1999)

(Walia et al. 2005)
• The total number of microseismic events correlated are 63.
<table>
<thead>
<tr>
<th>Station</th>
<th>I. Soil-gas</th>
<th>II. Water</th>
<th>I. Soil-gas</th>
<th>II. Water</th>
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</thead>
<tbody>
<tr>
<td>Palampur</td>
<td>36</td>
<td>26</td>
<td>21/27</td>
<td>18/23</td>
</tr>
<tr>
<td>Dalhousie</td>
<td>29</td>
<td>25</td>
<td>19/24</td>
<td>14/15</td>
</tr>
<tr>
<td></td>
<td>Correlated</td>
<td>Not</td>
<td>Correlated</td>
<td>Not</td>
</tr>
<tr>
<td></td>
<td>with events</td>
<td>correlated</td>
<td>with events</td>
<td>correlated</td>
</tr>
<tr>
<td></td>
<td>(b)</td>
<td>(c)</td>
<td>(b/a)</td>
<td>(c/a)</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>8</td>
<td>58</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>31</td>
<td>42</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>1.38</td>
<td>2.23</td>
<td>1.94</td>
<td>1.28</td>
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</table>
Palampur station is found to be relatively more sensitive than the Dalhousie station as a total number of 40 seismic events correlated with radon anomalies are observed at Palampur as compared to 36 events at Dalhousie in both the media.

A total of 116 radon anomalies were observed in the whole grid during the given time window and out of it 74 are correlated with seismic events.

Most of the anomalies are pre-seismic 76% whereas only 14% are co-seismic and 10% are post-seismic.
Variation of Radon Conc. with Microseismicity in the region

- **Seismic Events/year**: 27, 19, 20, 40, 83, 70, 80, 79
- **Avg. Rn conc./year**: Line graph showing an increasing trend from 1992 to 1999.
• About 142 cases of radon anomalies in soil-gas and groundwater correlated with earthquakes of magnitude range between 2.1 to 4.8 and having epicentral distances less than 200 kms during time period 1992-1999.

• Whereas single earthquake of magnitude 4.7, 4.8, 5.1 and 6.8 were correlated with radon anomalies during the period.

• The radon behaviour observed in soil-gas and groundwater indicate that the transport phenomenon entirely different.
• The behaviour of Palampur and Dalhousie stations across the MBF is almost reciprocal. This may be due to relative motion of crustal blocks producing compressional strain on one side and dilatational strain on the other.

• Radon measurements carried out for earthquake precursory study seem to be one of the promising technique.
Thank You !!!