

## Preface

# “IGCP Project 571: Radon, Health and Natural Hazards”

G. K. Gillmore<sup>1</sup>, R. G. M. Crockett<sup>2</sup>, and T. A. Przylibski<sup>3</sup>

<sup>1</sup>Centre for Earth and Environmental Sciences Research (CEESR), School of Geography, Geology, and the Environment, Kingston University, Kingston upon Thames, UK

<sup>2</sup>Radon Research Group, School of Science & Technology, University of Northampton, Northampton, UK

<sup>3</sup>Division of Geology and Mineral Waters, Institute of Mining, Faculty of Geoengineering, Mining and Geology, Wrocław University of Technology, Wrocław, Poland

\*Email addresses: g.gillmore@kingston.ac.uk, robin.crockett@northampton.ac.uk, tadeusz.przylibski@pwr.wroc.pl

## 1 Introduction

It is important to understand radon migration through and between the Earth’s “spheres”, e.g. atmosphere, hydrosphere, lithosphere and biosphere – for two main reasons. Firstly, this knowledge enables effective protection of people from the direct health hazard arising from the decay of radon and its daughter products. Secondly, as well as this direct hazard, this knowledge adds to our understanding of the mechanisms involved with other natural hazards such as earthquakes and volcanic eruptions.

The papers in this special issue of Natural Hazards and Earth Systems Sciences represent a cross-section of the presentations made in the NH9.5 session *Radon, Health and Natural Hazards* at the 2009 European Geosciences Union (EGU) General Assembly, at which the International Geoscience Programme (IGCP) Project 571, *Radon, Health and Natural Hazards* was launched. This project has enjoyed a successful first year, culminating in a second session (NH8.3) at the 2010 EGU General Assembly, which drew a significantly higher number of presentations. We are grateful to everyone who has contributed, whatever the manner, to that success and look forward to the future.

### 1.1 IGCP Project 571 outline statement

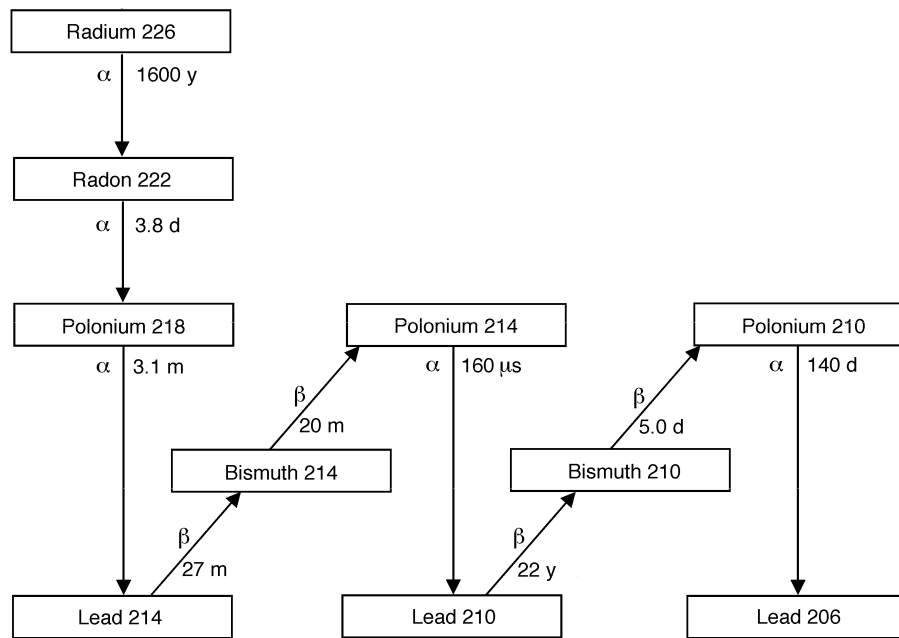
This project focuses on a variety of impacts and hazard-associated manifestations of radon gas. This colourless, odourless, radioactive gas together with its radioactive daughter isotopes has been linked to lung cancer (and other cancers); the basic decay chain is shown in Fig. 1. In the UK it has been suggested by government bodies (e.g. the Health Protection Agency; and also see Darby et al., 2005) that between 1000 and 2000 people die each year

from radon induced lung cancer. This is not simply a UK problem: for example, the corresponding figure for the USA is 15 000–22 000. Recent European-wide research has demonstrated that there is no “safe” lower limit for radon exposure (e.g. Darby et al., 2005), which throws into question limits set in the UK (200 Bq/m<sup>3</sup>, domestic (but with an additional newly-specified 100 Bq/m<sup>3</sup> “target” in 2010); 400 Bq/m<sup>3</sup>, workplace) and corresponding limits set elsewhere in Europe and the USA. Raised radon levels have been noted in work environments (in particular water treatment plants, tunnels, caves and mines) throughout the world and links have been made between radon levels in mines and the incidence of lung cancer in mine workers, for example. Other recent research has clearly demonstrated a link between ocean and earth tides and indoor radon levels in some locations. This work is a step towards understanding the drivers behind indoor atmospheric radon concentrations, but much is still unknown. Similarly, radon is being increasingly used in the monitoring of earthquake activity: a good example are the Anatolian Faults monitoring networks recently established in Turkey (e.g. Baykara et al., 2009; Inan et al., 2008) but there are networks being planned/established in Nepal and Tibet. Radon in groundwater wells has been used to monitor such activity in Japan (e.g. Igarashi et al., 1995) and Iran (e.g. Mokhtari, 2010). Understanding the behaviour and drivers of radon gas will greatly help hazard planners – both concerning radon itself and using it as an earthquake/landslide/volcanic hazard monitor and precursor.

Radon hazard assessment is a multi-/inter-disciplinary subject as it requires inputs from geologists, geographers (e.g. Geographic Information Systems), mathematicians, physicists, epidemiologists, medical researchers and planners. This hazard has significant socio-economic impact in the developed world and in the developing world, in terms of both indoor radon and radon-associated hazards such as earthquake activity. Short-term and long-term benefits of the programme would be to better inform decision makers as to



Correspondence to: G. K. Gillmore  
(g.gillmore@kingston.ac.uk)



**Fig. 1.** The Basic Radon ( $^{222}\text{Rn}$ ) Decay Chain. The isotopes and their atomic masses are shown within the boxes; the main decay processes are indicated by arrows, with type of decay and half-life indicated.

where and when to employ resources to minimise societal risk – both directly from radon gas and its radioactive daughter isotopes and indirectly from radon-sensitive hazards.

## 2 EGU2009 Session NH9.5 Radon, Health and Natural Hazards

The abstracts submitted to the EGU2009 NH9.5 session encompassed a large part of the proposed activity for IGCP Project 571 *Radon, Health and Natural Hazards*, ranging from soil gas monitoring for seismicity to mathematical-analytical techniques to radon in the built environment to spatial anomalies and mapping to health hazards and evaluations. All session presenters were invited to contribute to this special issue and, whilst the coverage is not as even as would be possible from a larger session, the eight peer-reviewed papers resulting from this invitation represent the scope of the presentations and the perspective for the IGCP Project. The authors present and discuss their findings separately in the contexts of their research: in this short introductory article we briefly summarise the key issues raised by the authors which link the papers in the context of the IGCP Project and the EGU session.

### 2.1 Radon as a hazard and hazard diagnostic

Historically, it has been the health-hazards aspects of radon, and radium and uranium (its radioactive precursors), which have driven research. Indeed, comparing and disseminating

information and best practice in this regard was one of the main drivers for the IGCP Project and the initial EGU-based meeting.

A range of studies, mostly with miners, have shown that the main health effect of radon is the induction of respiratory tract cancers (e.g. Härting and Hesse, 1879). Both radon and its progeny emit  $\alpha$ -particles, which are a high radiological hazard (see Fig. 1). These, often attached to airborne particles (e.g. dust), provide the majority of dose to the respiratory system, which is the main entry for radon and progeny into the body. Radioactive decay here means that very sensitive tissues are exposed to a hazardous dose of radioactivity: the potential consequences of such doses are respiratory tract cancers.

The main health risk for the majority of populations arises from radon's tendency to accumulate in the built environment, noting that there are well defined risks associated with exposures encountered by specialised groups such as mineworkers. In general, radon enters buildings from the ground, i.e. the rocks and soils on which buildings are sited. Owing to its density, radon is approximately 7.6 times denser than air, it tends to accumulate where ventilation is inadequate. This is considered by Gillmore and Jabarivasal (2010), in a region where there are still limited data on indoor radon concentrations. They undertook a study of radon concentrations in Hamadan City, Iran, using CR-39 SSNTDs. This is a region where the underlying geology has radon generation and accumulation potential: this comprises a mixture of granites in the surrounding mountain chain, with metamorphic and sedimentary materials in the form of

younger karstic limestones and alluvial fans. The widespread presence of qanats and the significance of the alluvial fan sediments in terms of radon distribution are discussed. The average indoor radon concentration recorded was 2.5 times the average global population weighted indoor radon level.

Another source of radon, and a significant radon vector in some conditions, is groundwater. This can manifest as a direct health-hazard in water drawn from wells and boreholes in uranium-bearing rocks and soils, and this is considered by Smetanova et al. (2010). They investigated boreholes in the Little Carpathian Mountains near Bratislava and looked at temporal and spatial variations. They noted significant short-term radon variations in the water in some boreholes linked, they suggest, to water level changes in those boreholes arising from significant well-defined rainfall events. They also note that where such water is used for a drinking water supply, there is a potential health hazard if the water is consumed before enough time has elapsed to allow the radioactivity to decay to a “safe” level (noting, as above, that no level is strictly safe).

In order to assess the health risks posed by radon, it is necessary to measure radon concentrations and calculate or estimate resultant (annual) exposures and doses experienced by people (and animals). The papers by Wertheim et al. (2010) and Groves-Kirkby et al. (2010) consider aspects of measurement and exposure/dose estimation. Wertheim et al. (2010) report advances in the optical reading of SSNTDs using a cutting-edge laser confocal microscope system in a new way, i.e. 3-D imaging/reconstruction, to image and measure the detector surface and immediate sub-surface. This work demonstrates that 2-D analysis of surface images, the conventional track analysis for CR-39 based detectors, may not account fully for oblique and/or overlapping impacts and has potential implications regarding the assumed linearities of observed track-density with radon concentrations and exposure durations. Groves-Kirkby et al. (2010) consider seasonal variations and the reliability and appropriateness of applying seasonal correction to sub-annual measurements for regional domestic settings. These authors quantify considerable spatial variations in seasonal variations across European countries and report greater seasonal variation on underlying lithologies such as karstic limestones, whereas radon levels tend to be higher but less seasonally-variable above igneous lithologies.

As well as monitoring radon concentrations for the purposes of exposure and dose estimation, variation in radon concentrations can provide evidence of crustal geophysical processes. Mahajan et al. (2010) and Vaupotic et al. (2010) consider radon in soils in seismically active and fault containing regions. Mahajan et al. (2010) examined radon and helium ( $^4\text{He}$ ) in soils associated with recently developed fractures/faults in the Himalayas. They undertook traverse surveys which demonstrated raised levels along the Dehar lineament compared with other thrust zones. They also noted raised radon and helium in soil gases near the

Himalayan Frontal Fault (HFF) which they suggest indicates a buried/blind fault or thrust zone running parallel to the HFF. Vaupotic et al. (2010) examined the Ravne Fault, an active fault in Slovenia, by setting up measurement profiles both perpendicular and parallel to it, to assess variations in soil gas radon and exhalation rates for example. Radon soil gas concentration was noted to vary from 0.9 to 32.9 kBq/m<sup>3</sup>, with significant variations along deformation zones both perpendicular and parallel to the fault. This is work that is ongoing.

To conclude the material in this special issue, there are two papers which consider radon as an indicator of crustal processes and geophysical hazards, e.g. location and behaviour of faults, response to tidal forces and changes in stresses associated with earthquakes, as revealed by cyclic and anomalous features of radon time-series. Analysing radon (or other soil gas) time-series for the presence of such features has the potential to reveal important information but the analysis is complicated by the stochastic nature of radon emissions and the range of natural and anthropogenic influences to which these are susceptible (e.g. Crockett et al., 2006; Neves et al., 2009).

Tidal forces vary cyclically (with time) and so will influence radon concentrations cyclically (e.g. Aumento, 2002). Depending on location, the actual influence will be a combination of (direct) earth-tidal and (indirect) tidal-loading influences (e.g. Yong and Wei, 1995; Barnet et al., 1997) but, in essence, the result will be a basic 12.4-h lunar-tidal cycle modulated with luni-solar bi-weekly and lunar monthly cycles. Another influence on radon concentrations in and emissions from rocks, soils and groundwater are changes in seismic stresses before, during and after earthquakes (e.g. Khan et al., 1990; Planinic et al., 2000). The underlying mechanisms are the same as for tidal influences but instead of cyclic variations, seismic variations are essentially anomalous (with time). Crockett et al. (2010) report the use of Empirical Mode Decomposition (EMD) and Singular Spectrum Analysis (SSA) to identify cyclic variations otherwise obscured by the stochastic nature of radon time-series. Crockett and Gillmore (2010) report the use of EMD to improve the identification of simultaneous similar anomalies temporally associated with earthquakes in paired radon time-series. Both EMD and SSA have wider potential applications in the investigation of geophysical and other time-series, and development of these techniques and their applications is ongoing work.

### 3 The future?

It is clear that these papers bring valuable new data and methods that are of considerable interest to scientists working on radon behaviour in the environment. The IGCP 571 Project is now into its second year with a second successful set of sessions at the 2010 EGU General

Assembly and proposed 2011 sessions, building on the momentum from the 2009 sessions. The 2010 sessions saw 6 oral and 22 poster presentations and it is anticipated that these will form the next stage, e.g. a second set of peer-reviewed papers, in reporting on the progress of the IGCP Project with its objectives of disseminating information, research results and good practice.

*Acknowledgements.* We, the guest editors of this special edition, would like to thank our three IGCP Project co-leaders, namely F. Perrier, V. Walia and B. S. Bajwa for their assistance in encouraging and reviewing submissions. All of us would like to thank the International Union of Geological Sciences (IUGS) (<http://www.iugs.org>) and UNESCO (<http://www.unesco.org>) for funding IGCP ([http://portal.unesco.org/science/en/ev.php-URL\\_ID=6304&URL\\_DO=DO\\_TOPIC&URL\\_SECTION=201.html](http://portal.unesco.org/science/en/ev.php-URL_ID=6304&URL_DO=DO_TOPIC&URL_SECTION=201.html)) Project 571 to raise the awareness of radon as a hazard and hazard indicator.

We would also like to thank the journal editor, Fausto Guzzetti, for his support and encouragement together with the editorial staff at Copernicus.

## References

- Aumento, F.: Radon Tides on an Active Volcanic Island: Terceira, Azores, *Geofisica International*, 41, 499–505, 2002.
- Barnet, I., Procházka, J., and Skalský, L.: Do the Earth tides have an influence on short-term variations in radon concentration?, *Radiat. Prot. Dosim.*, 69(1), 51–60, 1997.
- Baykara, O., Inceöz, M., Dođru, M., Aksoy, E., and Kuülahci, F.: Soil radon monitoring and anomalies in East Anatolian Fault System (Turkey), *J. Radioanal. Nucl. Ch.*, 279(1), 159–164, doi:10.1007/s10967-007-7211-2, 2009.
- Crockett, R. G. M., Gillmore, G. K., Phillips, P. S., Denman, A. R., and Groves-Kirkby, C. J.: Tidal Synchronicity of Built-Environment Radon Levels in the UK, *Geophys. Res. Lett.*, 33, L05308, doi:10.1029/2005GL024950, 2006.
- Crockett, R. G. M. and Gillmore, G. K.: Spectral-decomposition techniques for the identification of radon anomalies temporally associated with earthquakes occurring in the UK in 2002 and 2008, *Nat. Hazards Earth Syst. Sci.*, 10, 1079–1084, doi:10.5194/nhess-10-1079-2010, 2010.
- Crockett, R. G. M., Perrier, F., and Richon, P.: Spectral-decomposition techniques for the identification of periodic and anomalous phenomena in radon time-series, *Nat. Hazards Earth Syst. Sci.*, 10, 559–564, doi:10.5194/nhess-10-559-2010, 2010.
- Darby, S., Hill, D., Auvinen, A., Barros-Dios, J. M., Baysson, H., Bochicchio, F., Deo, H., Falk, R., Forastiere, F., Hakama, M., Heid, I., Kreienbrock, L., Kreuzer, M., Lagarde, F., Mäkeläinen, I., Muirhead, C., Oberaigner, W., Pershagen, G., Ruano-Ravina, A., Ruosteenoja, E., Schaffrath Rosario, A., Tirmarche, M., Tomásek, L., Whitley, E., Wichmann, H.-E., and Doll, R.: Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies, *BMJ*, 330(7485), 223–226, doi:10.1136/bmj.38308.477650.63, 2005.
- Gillmore, G. K. and Jabarivasal, N.: A reconnaissance study of radon concentrations in Hamadan city, Iran, *Nat. Hazards Earth Syst. Sci.*, 10, 857–863, doi:10.5194/nhess-10-857-2010, 2010.
- Groves-Kirkby, C. J., Denman, A. R., Phillips, P. S., Crockett, R. G. M., and Sinclair, J. M.: Comparison of seasonal variability in European domestic radon measurements, *Nat. Hazards Earth Syst. Sci.*, 10, 565–569, doi:10.5194/nhess-10-565-2010, 2010.
- Härting, F. H. and Hesse, W.: Der Lungenkrebs, die Bergkrankheit in den Schneeberger Gruben, *Vierteljahrsschrift für gerichtliche Medicin und öffentliches Sanitswesen*, 30, 296–309, 31, 102–132 and 313–337, 1879 (in German).
- Igarashi, G., Saeki, S., Takahata, N., Sumikawa, K., Tasaka, S., Sasaki, Y., Takahashi, M., and Sano, Y.: Ground-Water Radon Anomaly Before the Kobe Earthquake in Japan, *Science*, 269(5220), 60–61, doi:10.1126/science.269.5220.60, 1995.
- Inan, S., Akgul, T., Seyis, C., Saatçılar, R., Baykut, S., Ergintav, S., and Baş, M.: Geochemical monitoring in the Marmara region (NW Turkey): A search for precursors of seismic activity, *J. Geophys. Res.*, 113, B03401, doi:10.1029/2007JB005206, 2008.
- Khan, H. A., Tufail, M., and Qureshi, A. A.: Radon signals for earthquake prediction and geological prospection, *J. Islamic Academy of Sciences*, 3(3), 229–231, 1990.
- Mahajan, S., Walia, V., Bajwa, B. S., Kumar, A., Singh, S., Seth, N., Dhar, S., Gill, G. S., and Yang, T. F.: Soil-gas radon/helium surveys in some neotectonic areas of NW Himalayan foothills, India, *Nat. Hazards Earth Syst. Sci.*, 10, 1221–1227, doi:10.5194/nhess-10-1221-2010, 2010.
- Mokhtari, M.: Earthquake prediction activities and Damavand earthquake precursor test site in Iran, *Nat. Hazards*, 52(2), 351–368, 2010.
- Neves, L. J. P. F., Barbosa, S. M., and Pereira, A. J. S. C.: Indoor Radon Periodicities and their Physical Constraints: a study in the Coimbra region (Central Portugal), *J. Environ. Radioactiv.*, 100, 896–904, doi:10.1016/j.jenvrad.2009.06.017, 2009.
- Planinic, J., Radolic, V., and Culo, D.: Searching for an earthquake pre-cursor: temporal variations of radon in soil and water, *Fizika B*, 9(2), 75–82, 2000.
- Smetanová, I., Holá, K., Müllerová, M., Polášková, A., and Túnyi, I.: Temporal and spatial changes of radon concentration in borehole water (Little Carpathians Mts., Slovakia), *Nat. Hazards Earth Syst. Sci.*, 10, 1373–1377, doi:10.5194/nhess-10-1373-2010, 2010.
- Vaupotič, J., Gregorič, A., Kobal, I., Žvab, P., Kozak, K., Mazur, J., Kochowska, E., and Grządziel, D.: Radon concentration in soil gas and radon exhalation rate at the Ravne Fault in NW Slovenia, *Nat. Hazards Earth Syst. Sci.*, 10, 895–899, doi:10.5194/nhess-10-895-2010, 2010.
- Wertheim, D., Gillmore, G., Brown, L., and Petford, N.: 3-D imaging of particle tracks in solid state nuclear track detectors, *Nat. Hazards Earth Syst. Sci.*, 10, 1033–1036, doi:10.5194/nhess-10-1033-2010, 2010.
- Yong, S. and Wei, Z.: The correlation between Radon Variation and Earth Solid Tide Change in Rock-Groundwater System – the Mechanical Foundation for using Radon change to predict earthquake, *Journal of Earthquake Prediction Research*, 4, 423–430, 1995.