15th International Congress of the Geological Society of Greece
Athens, 22-24 May, 2019 | Harokopio University of Athens, Greece
Bulletin of the Geological Society of Greece, Sp. Pub. **7** Ext. Abs. GSG2019-072

Radionuclides in Rocks and Associated Health Hazards: Examples from Norway and India

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Introduction

After 1960 the association between radiation and adverse health effects has come to the foreground. Epidemiological research indicates that even low doses of radiation over an appreciable amount of time are distinctly connected to a quantifiable increase in cancer incidence rate. Such low and constant doses of radiation often come from natural sources, namely from the rocks exposed on the surface of the area, or from the drinking water of the aquifers contained within radioactive rocks. Here cancer incidence data from areas with high background radiation and radioactive water sources in India and Norway is examined, so as to demonstrate the correlation between geology and public health hazards.

Radiation and Associated Induced Damage on DNA

In nature, uranium, thorium, radium and radon are the most common sources of ionizing radiation. These radioactive elements tend to concentrate in highly fractionated magmas, so they are commonly found in acidic rocks, such as granites. Uranium exists in three naturally occurring isotopes, $^{234}_{92}\mathrm{U}$, $^{235}_{92}\mathrm{U}$, $^{238}_{92}\mathrm{U}$, of which the latter is the most abundant in nature and has a half life of $4.51 \cdot 10^9$ years. Thorium can be found in nature in 30 different isotopes, but the most stable one is $^{232}_{90}\mathrm{Th}$ with a half life of $13.9 \cdot 10^9$ years. As far as radon ($^{222}_{86}\mathrm{Rn}$) is concerned, it is derived from the parent radionuclide $^{226}_{88}\mathrm{Ra}$, which has a half life of 1620 years, and is a member of the $^{238}_{92}\mathrm{U}$ decay series (Banks *et al.*, 1995). While radon is chemically inert, being a noble gas, it accumulates in groundwaters and more importantly becomes airborne, thus being quite a potent radiation source. Based on the half life values mentioned it becomes evident that even rocks of Precambrian age, containing sizeable amounts of uranium or thorium will be significantly radioactive. All of these radioactive elements emit alpha, beta and gamma radiation during their decay series, which is potentially hazardous to humans, depending on the dose, the dose rate and the time span of exposure.

It is a general axiom that the rate of mutagenesis depends upon the dose rate and the total absorbed dose of ionising radiation. For a given dose and dose rate, the biological effects also depend upon the linear energy transfer (LET), a quantity used to describe the «quality» of radiation (Hall, 1991). As far as radiation protection is concerned, and regarding low LET radiations, experimental results indicate that the same dose delivered in a protracted period of time results in reduced biological effects. This is known as the dose rate effect or DRE, which however only applies to low and intermediate LET radiations (Hall, 1991). Even so, for some types of cells, at different ranges of low dose rates, an inverse DRE is observed, meaning that even low background radiation doses may be quite more dangerous than originally thought, in some cases. Low and intermediate LET radiations, such as electrons, positrons and photons, cause a small number of ionizations per unit of distance traversed into matter. Gamma radiation, i.e. photons, causes mostly indirect effects in cells. Indirect effects are those associated with the molecules produced during water radiolysis. Such molecules are the hydroxyl radicals and other free radicals, which interact with and damage DNA and other biomolecules. However, newer data (Goodhead, 1994) indicate that even low LET radiations cause some degree of focused damage on DNA, creating small clusters of double strand breaks (DSB) which may not always be repaired by the cell, thus leading either to cellular death or to proliferation of potentially cancerous cells. High LET radiations, like alpha radiation, i.e. helium nuclei, deposit a high amount of energy in fewer cells, leading to significant DNA damage, and cellular death. In contrast to photons or electrons, where most irradiated cells survive, alpha radiation leads to a higher percentage of cellular death, albeit surviving cells may have a higher carcinogenic potential, due to more significant DNA damage (Hall, 1991). The consequences are understandably more far reaching if the mutations happen, and are not repaired, in germ line cells, instead of somatic ones. The continued exposure of individuals to even low LET radiations and dose rates not only is hazardous for inducing more and more damage, but for hindering DNA repair by N-glycosylases, endonucleases and purine imidazole-ring cyclases (Téoule, 1987).

Cancer Incidence and Background Radiation in India and Norway

Looking at the annual cancer incidence rate map in the states of India, for the last 26 years (Dhillon *et al.*, 2018) it can be observed that there are significant differences between the rates of different regions. If such a map is correlated with the geology of India, it can be observed that areas, which comprise carbonatites, are also characterised by relatively elevated cancer incidence rates. Interestingly, if the cancer incidence map of India (Dhillon *et al.*, 2018) is overlaid upon the isodose map of India (Sankaran *et al.*, 1986) it can be observed that areas characterised by elevated background radiation levels roughly correspond to areas with elevated cancer incidence rates. Recent research on the carbonatites of Tamil Nadu indicates background radiation well in excess of the safe background radiation exposure levels. One other relative example is the region of Kerala, where much of the soil contains almost 10 wt. % thorium and uranium oxides (Chougaonkar *et al.*, 2004), exhibits the highest cancer incidence rate in India. It is reported that the maximum outdoor dose in this region is 39.1 mSv/a, which is higher than the maximum allowed for a radiation worker, where the limit is 20 mSv/a, and around 13 times the mean human background radiation exposure, which is about 3 mSv/a (Brenner *et al.*, 2003). Another study in the region of Kerala (Forster *et al.*, 2002) proved that the background radiation of the area accelerates point mutations in mitochondrial DNA. By implication, the amount of radiation absorbed could lead also to mutagenesis in the nuclear DNA of the cells, potentially leading to changes in gene expression, in protein structure and functionality and higher risk of cancer incidence.

Norway is an example comparable to India, due to the existence of rocks of comparable age and also of carbonatites of comparable geochemical characteristics. Looking at the cancer incidence rate map of Norway (Patama *et al.*, 2014), it can be deduced that higher cancer incidence rate correspond roughly with locations where there are outcrops of the Precambrian basement, which are mainly granites and gneisses, containing relatively high amounts of radionuclides, leading to elevated levels of background radiation. In addition, Cambrian shales in some areas of Norway are characterised by elevated uranium levels. The potential for adverse health effects has been studied in the Fen carbonatite complex in Telemark (Sundal & Strand, 2004). There are about 350 dwellings in the area which according to measurements are characterised by increased radiation emission. The carbonatites in the area contain the highest amounts of Th ever recorded in a bedrock in Norway. Both the indoor and outdoor radiation values are higher in the areas where the carbonatite is exposed. Another acute problem in Norway is the concentration of radon in groundwater. According to extensive sampling by Banks *et al.* (1995) groundwaters in gneissic and porphyry rocks have radon levels exceeding the maximum acceptable threshold of 100 Bq/lt, with some samples approaching 1000 Bq/lt. Samples from the granite in Iddefjord have a radon concentration of 8500 Bq/lt. Already radon exposure has been estimated to account for around 10 to 20 % of lung cancer cases in Norway (Banks et al., 1995). Samples from the same area also exceed the safe thorium and uranium concentrations.

Discussion and Conclusions

The association between background radiation and health effects has long been established. However, there is no large scale research correlating cancer incidence with background radiation attributable to geological factors at a national or even continental level. How the soil formed by such radioactive rocks contributes to the introduction of radionuclides in the food chain has not been examined here, but this is surely another contributing factor to the dose received by the locals, which has to be studied extensively. In any case it is demonstrated how cancer incidence rates in a national level do exist, at least partially, as a function of background radiation and by implication of regional geological setting.

There is still a lot of research to be undertaken on how exactly different radioactive rocks affect public health, and how governmental public health policies should be formulated taking notice of the petrological and geochemical characteristics of each particular area. In these last decades the effects of radiation on nucleic acids have been thoroughly studied, although there are still many questions and uncertainties, regarding cell sensitivity in particular cell cycle phases and radiation-induced cell signalling and its ramifications for the survival of complex cellular systems. Finally, it would be useful to assess how prolonged relatively small doses of radiations inhibit the function of DNA repair enzymes. By combining such research data it will hopefully be possible to quantify the effects of background radiation at different levels in multicellular organisms in general and humans in particular.

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