RADON MONITORING FOR EARTHQUAKE PREDICTION USING HYBRID UV LIDAR-PHOSWICH SYSTEM

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ABSTRACT

In this work, a technique is proposed based on UV laser based DIAL coupled with Phoswich array detectors for real time remote monitoring of the radon gas in a wide region for mapping the distribution of radon concentration to enhance the accuracy of earthquake prediction.

1. INTRODUCTION

Radon, the 86th element of the periodic system, is produced by the alpha disintegration of ^{226}Ra in the decay series of ^{238}U [1,2]. It is the heaviest noble gas and highly radioactive. Its natural abundance is so low that could not be identified when the researchers discovered other inert elements. Only applications of the radiometric method using alpha detectors, made the radon discovery possible. Radon is a colourless, odourless gas, which is available naturally in the underground reservoirs. It can be diffused through the soil and the rocks into the atmosphere. Radon is known to be an α emitter, which its normal concentration in the atmosphere is measured to be in ppm level.

The total uranium content of the earth crust is about 3-4 ppm which is significant in terms of total mass and its radiological contribution to our atmosphere. One can visualize that earth as a whole, and uranium mines in particular, are sources of radon gas and its various radioactive daughters. It is believed that radon is the main source of radioactivity in the earth's atmosphere. For instance, annual radon emission from some active uranium mines varies from 10-250 TBq, while the normalized radon emission changes from 0.2-3.4 GBq/ton. It indicates that background level of radon drastically differs from one region to another one [3]. The predominant gaseous effluent from active uranium mine is also radon gas in the ventilation air from the underground mines or released into pit from surface mines, where this anomalous concentration of radon denotes as a local background level. In addition, particulates in airborne dust contain ^{238}U and sometimes ^{232}Th and their daughters to be taken into account as the other sources of radioactivity in air [3].

Radon and its daughters have been found to be mainly responsible for lung cancer not only among the uranium miners but also among the general public. According to health physics regulatory, exposure limited to 30 pCi/lit for radiation workers and the annual exposure of less than 4 pCi/lit in any livable area as public threshold level [3]. In addition to the serious health hazards related to radon, it owns a unique property by which one may predict the arrival of earthquake [4,5]. This is because radon gas can be traced by detecting alpha particles emitted during the decay of radon and its daughters. It can be achieved by using rather inexpensive alpha sensitive solid state nuclear track detectors (SSNTD). Moreover, for the earthquake prediction, anomalous changes in radon concentration of ground water and the surrounding atmosphere has been observed prior to large earthquakes, in Russia [6] and China [7]. Radon is determined either in grab samples of air and water or it is measured continuously. Radon itself or its decay products are also detected by ionization chambers, alpha scintillation cells, alpha track detectors, silicon solid state detectors, gamma spectroscopy or by liquid scintillation counting. In addition to radon, seismic data and meteorological parameters, sometimes also thoron (^{220}Rn), gases like CH_4, CO_2, or other chemical constituents are systematically measured. For the selection of reliable sampling sites and the frequency of sampling and analysis, a thorough knowledge of the geology, hydrology and tectonics of the area is needed. As known from the literature, the radon monitoring in soil, water and gas has been shown to be a method for the prediction of earthquake [4-7]. Radon level trapped in the earth crust before the arrival of a physical jolt of an earthquake is correlated with the meteorological and hydrological data as well as with seismic activity. The abrupt changes in radon levels often appear as precursors of earthquakes, based on the microseism and the underground anomalous movements. This change takes place because of the physical stresses which are built up within the earth crust to trigger an earthquake. Work so far done, has indicated the existence of a relationship between earthquake producing processes and the instantaneous radon emanations. The conventional detection of radon using point detectors are labor-intensive and time consuming. It is necessary to establish many detection sites throughout the seismic area. Those passive techniques are sluggish to collect data to predict earthquake on time. We introduce a technique based on the optical remote sensing of radon. Despite, radon does not have infrared bands, however it must be measured by non infrared means in the near UV spectral range, where the absorption line are located. It enables us to investigate the relationship between the variation of radon levels and the intensity of an approaching earthquake.

2. THEORY

Table 1 illustrates several properties of radon. The other uranium chain elements, similar to radon, are often alpha emitters. Thus the remote tracing of those elements is extremely difficult because of short range alpha particles. However, remote sensing by DIAL or fluorescence lidar is possible, accordingly.

An interactive remote sensing system is suggested to achieve this purpose [4,5]. It consists of two main parts: a Phoswich detector to trace 510 keV characteristic gamma emission of radon as shown in Fig.1 and a DIAL coupled with a 2^{nd} harmonic Nd:YAG pumped second harmonic Ti:Sa laser. It serves as a tunable UV coherent source for the rapid identification of the radon effluent concentration as well as its exact location.

Table 1. Some properties of ^{222}Rn.

Parameter	Value
Half-life ($T_{1/2}$)	3.82 d
Abundance (air)	ppm
Abundance (Earth's crust)	4×10^{-13} mg/kg
Density at 293 K	9.73 mg/cm^3
Atomic absorption line	351.7 nm
Strong atomic emission lines	745 & 705.5 nm

A Phoswich (Phosphor sandwich) detector is a combination of two dissimilar scintillators optically coupled to a single PM tube, employing pulse shape discrimination to suppress background in the counting X-ray. It consists of a typical thin NaI(Tl) and a thick CsI(Tl) within different decay times, 0.25 μs and 1 μs respectively, so that, the shape of the output pulse from the PM tube is dependent on the relative contribution of scintillation light from the two scintillators. Lightly penetrating radiations in the order of keV, are stopped fully in the first scintillator, but more penetrating MeV photons may generate light in the thick sintillator. The events generating light in both scintillators are denied to suppress the noise.

When the X-rays, from the source being observed, enter the detector through a mechanical collimator, it will generally interact with an Iodine atom in the NaI crystal. This interaction occurs at a single point in the crystal and causes an electron to be ejected from the atom. This electron then excites the light-generating modes of the crystal to create a scintillation in the form of a pulse of light, whose intensity is proportional to the energy of the original X- (or γ) rays, to be viewed through a photomultiplier tube. This tube converts the pulse of light into an amplified electrical charge pulse. Thus, the amplifier and the subsequent electronics deal with a peak voltage of the pulse that is, again, proportional to the X-ray's initial energy. By calibrating the exact relation between incident X-ray energy loss and the digitized value of the voltage pulse height, the inferred incident energy of the X-ray is revealed.

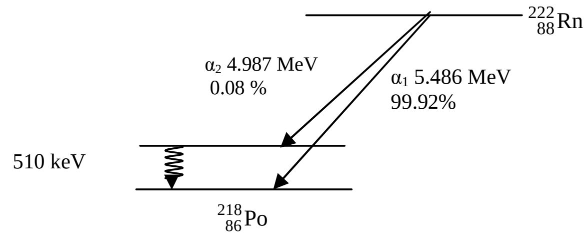

Fig.1. Typical ^{222}Rn decay scheme including the corresponding α decay associated with γ emission.

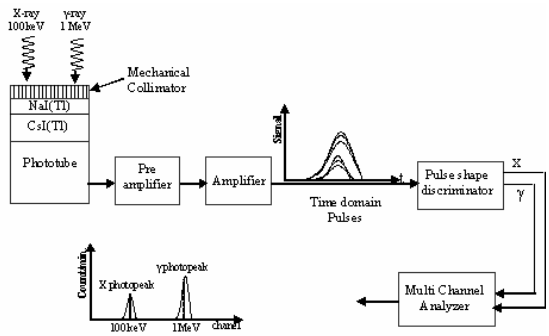

Fig.2. Performance of Phoswich dual energy analyzer as the X-ray/gamma discrimination system.

Fig.2 shows a typical Phoswich detector performance using pulse height spectrum with an external pulse shape unit in order to discriminate X- and γ-photopeaks respectively. Events resulting in scintillations from both volumes can be recognized by their pulse shape and can thus be rejected for X-ray detection.

Minimum activity detected by Phoswich is about 10 μCi/m^3 for 100 sec signal collecting time at 100 m far from the gaseous source. That value reduces for closer or larger source at longer integration time.

In fact, it may be an X-ray emitted from a far field dense plume or a near field dilute one. Therefore it is necessary to quantify the radon release by a differential absorption lidar. DIAL tunes the UV laser on the typical absorption line of radon to determine the relative concentration using the logarithmic derivatives of the backscattered signal at the tuned line λ_{on}, the atomic absorption peak, and the detuned wavelength λ_{off} at non absorptive line [8,9]. The differential absorption lidar (DIAL) technique has proven to be a useful technique for the remote sensing of various trace gases in the atmosphere [8-11]. In the DIAL technique, the average gas concentration at selected lines, over scanning area, is determined by analyzing the lidar backscattered signals. Using the assumption in atomic species monitoring due to remarkably narrow absorption bandwidth of atomic transition at which λ_{on} is chosen to be close to λ_{off} , the concentration at range R, N(R), is given as below:

$$N(R)=\frac{1}{2[\sigma_{abs}(\lambda_{on})-\sigma_{abs}(\lambda_{off})]}\frac{d}{dR}[\mathrm{Ln}\frac{P_s(\lambda_{off},R)}{P_s(\lambda_{on},R)}] \qquad (1)$$

where $\sigma_{abs}(\lambda_i)$ is absorption cross section of radon at λ_i and $P_s(\lambda_i,R)$ is backscatter signal at λ_i.

Therefore, the local concentration of radon gas is proportional to the derivative of logarithmic signal. When a couple of subsequent laser pulses, one at λ_{on} and the other at λ_{off} , are sent to the atmosphere, then the backscattered signal at λ_{on} experiences a drop in P_s–R plot, the graph of the logarithmic signal versus distance R, shows that N(R) is proportional to the slope of broken line. The break point indicates the distance where radon gas diffuses to atmosphere.

On the other hand, the rate of radionuclide transformation, namely the activity A, of a source is equal to the number of identical radioactive atoms, N, present in the source, multiplied by their characteristic radioactive decay constant λ, thus A=Nλ. The numerical value of λ expresses the statistical probability of decay of each radioactive atom and is equal to $\lambda=\ln(2)/T_{1/2}$, where $T_{1/2}$ denotes the nuclear half-life.

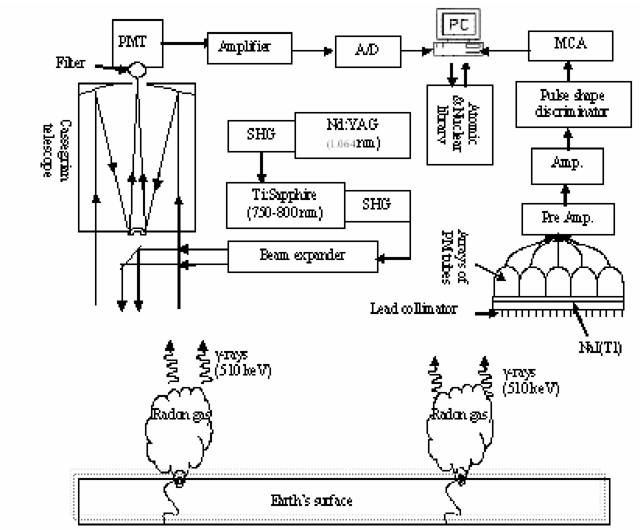

Fig.3. Performance of the hybrid Poswich-DIAL.

DIAL, itself consists of a transmitter, a receiver and an analyzer. For example, the transmitter utilizes a couple of UV lasers with ~10 ns duration, average power 3-10 W, tunable in range of 300-400 nm. The laser beam is conducted to the middle of a Casegraian telescope and sent to the environment atmosphere. In receiver section, we need to employ very sensitive detectors with high S/N ratio to detect backscattered signals. PMT converts the optical signal to electrical one that in turn is amplified via electronic circuits to analyze the data. The received backscattered photons as an analogue signal are then converted to digital by means of an A/D converter. The backscattered signal is detected, sampled, preamplified and then sent to the amplifier with low and high gain stages. Low gain amplifier detects backscatter signals at short distances and high gain one is responsible to reveal backscatter signals at long distances. The analyser is connected to the atomic library and the tuning device laser resonator accordingly.

3. HYBRID SYSTEM PERFORMANCE

The interactive performance of the hybrid system is shown in Fig. 3. The setup includes Phoswich detector and DIAL, which interact with each other through a processor for the simultaneous operation of the individual units. At first, DIAL telescope, mounted on a vehicle, sweeps the direction of motion to receive the backscattered signals of the radon effluent. According to TOF, the location and the concentration of radon will be identified. The processor commands to Phoswich detector to integrate the signals in the definite time interval, as to the vehicle stops at location during the collection time. The field of view of Phoswich detector is automatically aligned to the effluent direction in order to determine the photopeaks of γ photons of radon at 510 keV. Moreover, the other possible radioactive species having characteristic X-photopeaks are detected, such as ^{238}U , ^{241}Am and ^{238}Pu attached to aerosols at 113.5 keV, 17 keV and 43 keV respectively. The signals due to the other trace elements could be integrated during the collection time. Those X–ray photons are stopped within the thin NaI(Tl) scintillator, while high energetic γ-rays due to the γ-emitter radionuclides may generate light in the thick scintillator accordingly. It will identify the source species afterwards, using the nuclear library data. Similarly, if the disciminator distinguishes a single signal from NaI thin detector, then the X-ray library is used to identify the transuranuim or uranium chain elements [5]. The corresponding UV absorption lines (λ_{on}) of ^{238}U are 351.5, 356.7, 358.5 nm, which lie on the SHG spectrum of $Ti:Al_2O_3$ laser as well. The remote sensing of ^{232}Th is performed at 324.6 nm using THG of the laser. Moreover ^{234}Pa and ^{233}Tl from Uranium chain may be traced using the corresponding absorptive lines at 363.4 and 377.5 nm, respectively. Therefore, during the Phoswich integration time, the characteristic X-ray or γ emission of the other radionuclides may be identified, to search the corresponding absorption lines through the atomic library. Then, the processor commands to DIAL to tune the appropriate UV line of laser probe.

The received area of detector with an array PMT of the coupled Phoswich detectors is designed to be equivalent to the telescope area of the lidar system with the same solid angle such that the lidar telescope and the Phoswich detector own the same photon acceptance.

The radon monitoring could be static or mobile. In static monitoring, laser probe is more powerful. For the mobile scanning using a vehicle (van or helicopter), table 2 illustrates some properties of the typical UV laser i.e. a second harmonic generation of the Ti:Al_2O_3 laser pumped by SHG Nd:YAG. A UV differential absorption lidar system for the measurement of radon is proposed to fulfil all requirements for the operation on broad of a small helicopter.

Table 2: Some properties of typical tunable UV laser for radon monitoring.

Property	Value
Laser wavelength (nm)	300-400
Average power (W)	3-10
Pulse energy (mj/pulse)	30-100
Laser bandwidth (GHz)	10-100
Target distance (m)	100-300
Pulse duration (ns)	10-30
Pulse repetition rate (Hz)	100-300
Vehicle velocity (km/hr)	10-100

4. CONCLUSION

The concentration of radon gas in the atmosphere has a correlation with the earthquake occurrence. It was found that there is a proportionality between a surge in emission of radon gas within a particular area and high probability of earthquake occurring in that area. In fact, the monitoring has revealed that tectonic movement that produces earthquake, very often induces significant radon emission a few days before the quake. Though, the researchers have so far detected no solid correlation between the amounts of the radon emission and the strength of the quake. They have also been unable to determine exactly how long after an emission, a quake will happen. ^{222}Rn is known as an alpha emitter which is usually detected by several in situ conventional techniques. Those methods are far from being able to predict either time or place of earthquake. On the other hand, alpha is a short range particle in air, therefore radon remote sensing sounds to be impossible. The hybrid system of detection employs the characteristic γ-ray emission as a nuclear foot print of radon as well as its unique UV absorption line as its atomic foot-print as well as the corresponding fluorescence emission lines. The alpha emission of radon is associated with its 510 keV gamma emission, which could be detected by the Phoswich, unfortunately, this emission has a little probability to require a long integration time [8,9]. Moreover, it does not discern a far dense radon effluent from a dilute plume nearby. Atomic absorption line of radon at 351.7 nm in UV spectral range, enable us to tune a suitable UV laser probe to determine local concentration of Radon. In summary, the abrupt changes in the subsequent profiles of radon abundance in the atmosphere is taken into account as a significant parameter for the onset of earthquake. Here, we have proposed a radon monitoring technique based on tunable UV laser based DIAL coupled with the Phoswich array, for instantaneous mapping of background radon emission. It leads to analyze those abrupt changes to assure us the forthcoming event by double checking of the precursor radon.

5. RFERENCES

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