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RESEARCH ARTICLE

Analysis of Radon Gas Variation as a Precursor of Earthquake Prediction Using RAD7.

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Abstract

An earthquake is a natural disaster caused by an unexpected release of seismic energy due to extreme stress within the earth's crust. Such energy is released because of aggressive movements of the tectonic plates in active fault zones. The accumulated energy, containing immense pressure, is transferred from the earth's crust to its surface in the form of seismic waves. An earthquake occurs because the accumulated stresses exceed a certain frictional resistance limit. If for a particular point an accumulation of stresses at the fault is detected, it can be inferred that there is a possibility of earthquake occurrence. Earthquake prediction research aims to detect those variations in a number of physical parameters in a region under study, which may show some anomalous changes prior to an earthquake. These are termed as earthquake precursors. Precursors of various geophysical and geochemical natures are used in earthquake prediction. The most promising precursor is the variation in the rate of upward gas migration. Changes in the rate are most significant in the vicinity of existing faults and fractures. The changes in stresses preceding a major earthquake may either increase or decrease the permeability of faults and fractured zones. Thus, pronounced changes in the rate of migration of gases to the earth's surface in the vicinity of faults and fractured zones can be used as short term precursors of seismic events. During seismic activities, radon gas seeps upward and enters the atmosphere. This radon gas is collected and measured and can be used to predict the arrival of an earthquake. The DURRIDGE RAD7 uses a solid state alpha detector. A solid state detector is a semiconductor material (usually silicon) that converts alpha radiation directly to an electrical signal. It has the ability to electronically determine the energy of each alpha particle. This makes it possible to tell exactly which isotope (polonium-218, polonium-214, etc.) produced the radiation, so that we can immediately distinguish old radon from new radon, radon from thoron and signal from noise. The RAD7 measures radon gas concentration. Radon daughters do not have any effect on the measurement. The RAD7 pulls samples of air through a fine inlet filter, which excludes the progeny, into a chamber for analysis. The radon in the RAD7 chamber decays, producing detectable alpha emitting progeny, particularly the polonium isotopes. Even though the RAD7 detects progeny radiation internally, the only measurement it makes is of radon gas concentration. In other words we can say, the RAD7 does not measure radon daughter concentrations but measures only radon gas concentrations.

Introduction:-

Variations in the environmental energy parameters such as temperature, pressure, relative humidity, conductivity of ionosphere, earth's magnetic field, gravitational field etc either natural or man-made has led to calamities such as tsunamis and earthquakes. The occurrence of an earthquake sends its signature well in advance through Lithosphere, Atmosphere and Ionosphere [5]. Billions of years ago, when the earth was formed, there were many radioactive elements included in the mix of material that became the earth, namely uranium-235, uranium-238, thorium-232 etc. Each has a half life measured in billions of years and each stands at the top of a natural radioactive decay chain. A radioactive element is unstable. At some indeterminate moment, it will change to another element, emitting some form of radiation in the process [3]. While it is impossible to predict exactly when the transformation of an individual atom will take place, we have a very good measure of the probability of decay, within a given time slot. If we started with a very large number of atoms of a radioactive element, we know quite precisely how long it would take before half those atoms had decayed. This time interval is called the half-life of that particular element.

A natural radioactive transformation is accompanied by the emission of one or more of alpha, beta or gamma radiation. An alpha particle is the nucleus of a helium atom. It has two protons and two neutrons. Thus an alpha decay will reduce the atomic number by two and reduce the atomic weight by four. A beta particle is an electron, with its negative charge. Thus beta decay will increase the atomic number by one and leave the atomic weight unchanged. A gamma ray is just a packet of energy, so a gamma decay by itself would leave both the atomic number and atomic weight unchanged. A decay chain is a series of distinct transformations. A uranium-235 nucleus goes through a series of 11 transformations to become stable lead-207. A thorium-232 nucleus goes through 10 transformations to become stable lead-208. Similarly a uranium-238 nucleus goes through 14 transformations to become stable lead-206. All three of these natural decay chains include isotopes of radon. Radon-219 or actinon, is a link in the uranium-235 chain. Radon-220 or thoron, is part of the thorium-232 decay chain. Radon-222 or radon, is part of the uranium-238 decay chain. We will be able to detect radon-222 in indoor air, outdoor air and soil gas. The radon isotope is the first element, in each of the decay chains, that is not a metal. It is in fact, an inert or noble gas. So it can escape any chemical compound its parent (radium) was in and diffuse into the air. To focus on these inert gases, the thoron and radon decay chains, shown below (Fig. 1), are those parts of the thorium-232 and uranium-238 decay chains that include just these radioactive gases and their short-lived progeny.

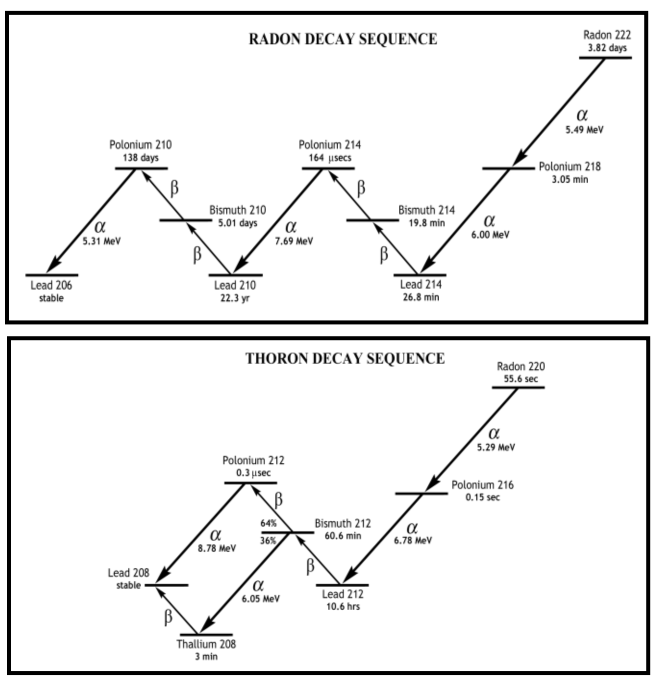

Fig. 1: Radon and Thoron decay sequence

Radon-222 (Radon):-

Every nucleus of radon-222 eventually decays through the sequence polonium-218, lead-214, bismuth-214, polonium-214 and lead-210. With each transformation along this path the nucleus emits characteristic radiations: alpha particles, beta particles or gamma rays or combinations of these. Radon-222 is an inert gaseous alpha-emitter that does not stick to or react with any materials [6]. It has a half-life of 3.82 days. When the radon nucleus decays, it releases an alpha particle with 5.49 MeV of energy and the nucleus transforms to polonium-218. The polonium nucleus can never go back to radon again. Polonium-214 has a half-life of only 164 microseconds (0.000164 seconds) and it emits a 7.69 MeV alpha particle when it decays. When polonium-214 decays, it becomes lead-210, which has a half-life of 22.3 years. This means that an average lead-210 nucleus takes 1.443 times 22.3 years or 32.2 years to decay.

Radon-220 (Thoron):-

Similar to radon-222, every radon-220 (thoron) nucleus eventually decays through a sequence of 5 transformations to Lead-208. Thoron has a half life of only 55.6 seconds [9]. It emits a 6.29 MeV alpha particle and transforms to polonium-216, which in turn has only a 0.15 second half-life before emitting a 6.78 MeV alpha particle and transforming to Lead-212.

The RAD7 measures radon gas concentration. Radon daughters do not have any effect on the measurement. The RAD7 pulls samples of air through a fine inlet filter, which excludes the progeny, into a chamber for analysis. The radon in the RAD7 chamber decays, producing detectable alpha emitting progeny, particularly the polonium isotopes. Though the RAD7 detects progeny radiation internally, the only measurement it makes is of radon gas concentration. Hence the RAD7 does not measure radon daughter concentrations but only the radon gas concentrations.

Instrumentation:-

RAD7 Solid-State Detector:-

The RAD7's internal sample cell is a 0.7 liter hemisphere, coated on the inside with an electrical conductor. A solid-state, Ion-implanted, Planar, Silicon alpha detector is at the center of the hemisphere. The high voltage power circuit charges the inside conductor to a potential of 2000 to 2500V, relative to the detector, creating an electric field throughout the volume of the cell. The electric field propels positively charged particles onto the detector. A radon-222 nucleus that decays within the cell leaves its transformed nucleus, polonium-218, as a positively charged ion. The electric field within the cell drives this positively charged ion to the detector, to which it sticks. Different isotopes have different alpha energies, and produce different strength signals in the detector [3]. The RAD7 amplifies, filters, and sorts the signals according to their strength. In SNIFF mode, the RAD7 uses the polonium-218 signal, to determine radon concentration and the polonium-216 signal, to determine thoron concentration.

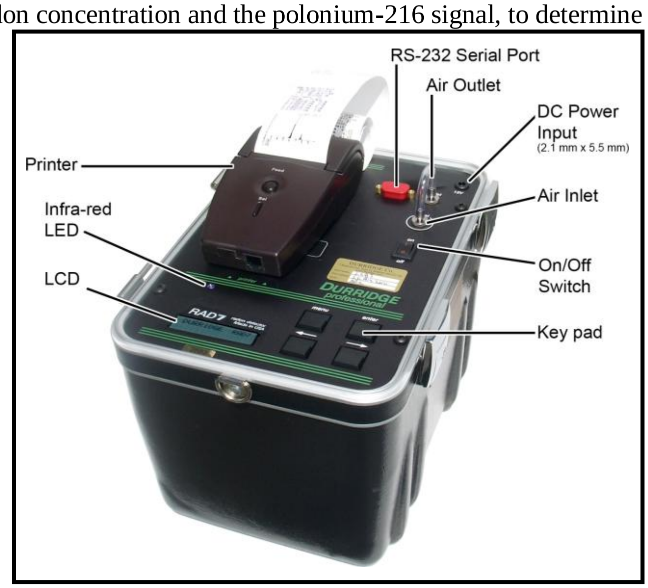

Fig. 2: RAD7: Electronic Radon Detector

RAD7 Spectrum:-

The RAD7 spectrum is a scale of alpha energies from 0 to 10 MeV of particular interest are the radon and thoron daughters that produce alpha particles in the range of 6 to 9 MeV. When the radon and thoron daughters, deposited on the surface of the detector, decay, they emit alpha particles of characteristic energy directly into the solid state detector. The detector produces an electrical signal. Electronic circuits amplify and condition the signal, then convert it to digital form. The RAD7's microprocessor picks up the signal and stores it in a special place in its memory according to the energy of the particle. The accumulations of many signals results in a spectrum. The RAD7 divides the spectrum's 0 to 10 MeV energy scales into a series of 200 individual counters, each representing a 0.05 MeV channel. Whenever the RAD7 detects an alpha particle, it increments one of its 200 counters by one [3]. Every so often, the RAD7 manipulates, condenses, prints out and stores data to long-term memory. Then it resets all 200 counters to zero, and begins the process anew. The idealized spectrum of a 6.00 MeV alpha emitter looks like a single needle-thin spike at exactly 6.00 MeV.

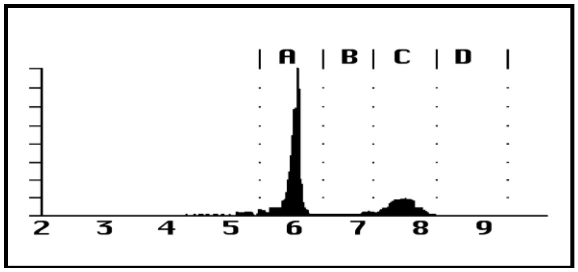

Fig. 3: Operational Radon Spectra

Experimental set up:-

Purging:-

For the RAD7 to be all set to go, ready to start a test, it should be purged for at least five minutes beforehand. Switch on the RAD7, push [MENU], [ENTER], [→] four times, to see >Test Purge on the display, then push [ENTER].

Running the Test:-

When everything is ready, start the test (Test, Start, [ENTER]). The pump will start running and the LCD display will go to the first status window. Although it is difficult to measure one isotope accurately in the presence of the other, but in case with RAD7, it is much less susceptible to radon-thoron interference due to its ability to distinguish the isotopes by their unique alpha particle energies. The RAD7 separates radon and thoron signals and counts the two isotopes at the same time with little interference from one to the other. The RAD7 calculates radon concentration from the count rate in window A (SNIFF mode) or windows A plus C (NORMAL mode). The RAD7 compensates for interference from the long-lived progeny of thoron (10.6 hours) by applying a correction to the radon count rate in both SNIFF and NORMAL modes [3]. The correction is based on a fixed fraction of the count rate in the D window (around the 8.78 MeV peak of Po-212) which predicts the amount of thoron progeny activity in the A window (due to the 6.05 and 6.09 MeV peaks of Bi-212).

Preparation:-

The RAD7 batteries should be fully charged so that, even if there is a power cut, the test will be completed.

Calculating Sample Decay:-

The concentration at the inlet of the RAD7, C_1, can be expressed mathematically as

$$C_1 = C_0 * \exp(-L * V_1 / q) \qquad (1)$$

where C_0 is the original sample concentration,

V_1: volume of the sample tube + drying tube + filter (around 50 mL), q : Flow rate (around 650 mL/min) and L :The decay constant for thoron (.756 /min).

Therefore:

$$C_1/C_0 = \exp (-.756 * 50 / 650) = .943 = 94.3\% \qquad (2)$$

This is the number assumed as the calibration factor.

Design and development:-

The RAD H_2O Accessory:-

The RAD H_2O is an accessory for the RAD7 that enables to measure collected water samples to detect radon with high accuracy over a wide range of concentrations, obtaining the reading within an hour of taking the sample. It is particularly suited for well water testing, where immediate results are often required. The RAD H_2O uses a standard, pre-calibrated degassing system and pre-set protocols, built into the RAD7, which give a direct reading of the radon concentration in the water [3]. Large water samples of up to 2.5L may be sampled using a separate product, the Big Bottle System, in which radon concentrations are calculated using the provided CAPTURE software for Windows and Mac OS X.

Fig. 4: The RAD H_2O Accessory

The WATER PROBE Accessory:-

The Water Probe is used to collect radon from large bodies of water. The probe consists of a semi-permeable membrane tube mounted on an open wire frame. The tube is placed in a closed loop with the RAD7. When the probe is lowered into water, radon passes through the membrane until the radon concentration of the air in the loop is in equilibrium with that of the water. Now the RAD7 data and water temperature data are collected simultaneously and accessed by CAPTURE to determine the final result.

Interpreting the Data:-

As with any Sniff test, the first two 5-minute cycles should be ignored. The next one or two cycles should be averaged, to arrive at the radon concentration of the soil gas.

PC Connectivity:-

The RAD7's built-in serial port allows to transfer radon data to the computer and to communicate with the device remotely in real time. DURRIDGE provides a free software utility for Windows and Macintosh OS X, *CAPTURE*, which makes it easy to perform these actions, as well as to monitor the RAD7's status, graph radon and thoron data, apply corrections to account for environmental factors and export the results for analysis in a spreadsheet program or other software.

Connecting the RAD7 to the Computer:-

On most systems the RAD7 should be connected to the computer using the included USB to Serial adaptor and it will be necessary to install the included adaptor driver software. If the computer has a physical serial port, it is possible to use an RS232 DB9 female to female null modem cable to connect the RAD7 directly to the computer, without the need for adaptors or drivers.

Capture Software:-

CAPTURE is intended to simplify the transfer of data from the RAD7 to a computer. It also provides a wealth of graphing and data analysis options, and offers the ability to export data to other programs for further review [3]. The software is available for Windows and Macintosh OS X. CAPTURE's capabilities fall into three main categories: downloading RAD7 data, graphing and analysis and real-time RAD7 monitoring.

Fig. 5: CAPTURE Software running in Windows 7

Conclusions:-

Radon anomaly is defined as any sudden change in radon concentration crossing the average of that season by $\pm 2\sigma$, where σ represents the standard deviation from the mean value X. Radon anomalies crossing $X+2\sigma$ are called positive anomalies and those crossing $X-2\sigma$ are called negative anomalies [5, 6]. Radon anomalies precede the seismic events and are called pre-seismic or precursory anomalies. The measurement of Radon content can be made accurately and precisely using RAD7 instrumentation. Using the various modes of operation of RAD7, the Radon and Thoron content can be measured simultaneously and independently with high sensitivity. Using the water probe of RAD H_2O, continuous monitoring and analysis of radon can be done for water bodies. With RS-232 port and CAPTURE software we can obtain a direct PC connectivity. The range of the radon concentration provided by RAD7 is from (0 – 20,000 picoCurie/litre (pCi/l)) or (4 – 750,000 Becquerels/cubic meter (Bq/m^3)).

Hence by continual monitoring of the radon content near the tectonic region, well water or seismic sensitive zones, we can predict the occurrence of earthquake well in advance, may be few days or weeks prior to its actual occurrence.

Future scope:-

To predict the occurrence of earthquake well in advance we can study the anomalies of various gases simultaneously like He, CO_2, CH_4 which are also released during the seismic activities and are also the cause for the changes in the meteorological parameters. Variations in the Electric and Magnetic fields can be considered as important earthquake precursors. Changes in ULF, VLF, ELF and RF fields are also observed before a main shock. The hydrological data in existing wells is considered and accepted by many scientists as a crucial precursor of earthquake. The underground well-water level changes are one of the most commonly reported earthquake precursors. Remote sensing from space of surface groundwater levels can be done by measuring the changes in the surface areas of rivers and lakes or by estimating changes in the average depths of rivers and lakes from hydro spectral data.

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