frequency seismic waves originating from the foreshocks carry substantial amount of energy through the earth and are responsible for instantaneous stress changes and diffusive processes at depths of the earth's interior. Dilatation and compression effects of these waves are likely to cause perturbation in the thermodynamic state of the geothermal reservoirs located at different distances resulting in disruption of the physico-chemical balance and fluid composition. Consequently the changed pore pressures coupled with micro fracturing, increases the permeability of the host rocks, enthalpy of the reservoir increases leading to enhancement of gas concentration.

Currently attempts are being made to initiate activities in the measurement of the elevated $^{4}$He / $^{3}$He ratio in the helium isotopic composition of terrestrial gases in geothermal areas and fault zones, which reflect geo-pressurised fluid flows through the deep earth to the surface. These fluids play a major role in earthquake mechanics especially in deformation zones, collision boundaries and subduction areas. The increasing value of the index R(R = $^{4}$He/$^{3}$He) in such areas indicate a quantitative measure of earthquake preparation rate. Because helium is a non-fractionating element, a gradient in R is a function of and a clear indication of the intruding magmatic fluids that eventually lead to an earthquake.

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These activities have been funded by the Department of Science and Technology (DST) and the Department of Atomic Energy (DAE), Government of India.

Cover photograph shows aftermath of an earthquake
Research in earthquake prediction has drawn serious attention of geophysicists as well as investigators in different branches of natural science in many countries across the globe for over several decades. Although no reliable method to accurately foretell the time, place and magnitude of an impending earthquake has as yet been established, it has been reported that several earthquakes are heralded by the occurrence of foreshocks that can be detected by various dense local monitoring networks. A seismic event might start with a pre-slip stage, hours to days before the earthquake. This pre-slip nucleation phase would be silent, and too slow to be picked up with conventional seismic instrumentation. There are other instruments that can measure seismic induced deviations such as changes in the levels of radon and helium gas, electrical and magnetic properties, velocity changes of seismic waves, high energy charged particle flux variations in space and even abnormal animal behaviour. We do not have a direct access to observing deep earth phenomena; especially those relating to the curious behaviour of heterogeneous rock structure during the buildup of an earthquake. However, the crustal changes that occur during the process finds expression in changes in gas geochemical features in spring emissions and hydrothermal activity. Changes in the concentration of subsurface volatile components discharged from spring vents across time may be exploited to extract useful information related with deep earth phenomena that results in changes in the contour and content of gas emission at surface level.

A strong earthquake or large scale disturbance of the ocean floor, such as land slides or volcanic eruption can generate a potentially dangerous sea wave called Tsunami. Its threat lies in the great speed at which it travels (as much as 950 km/h), its long wavelength (up to 200 km), its low observable height in the open ocean and its ability to pile up rapidly to heights of 30 m or more as it moves into shallow water along an exposed coast. The suddenness of the Tsunami's arrival and consequence lack of warning time results in numerous casualties and catastrophic devastation when Tsunamis move into populated areas as we have recently seen in South Eastern Asian countries.

A distinctive feature of the earth is to emit gaseous volatiles from depth to the surrounding atmosphere. The release of sub-surface gas principally takes place from fractured and faulted tracts and the other natural openings such as geothermal and hydrothermal outlets. In an attempt to improve the basic understanding of the process of deep earth gas emission and their relation to seismic occurrences, a research project has been undertaken at Bakreswar (23°52'30"N; 87°02'30"E), in the district of Birbhum, West Bengal, India (see Figure 1). This spring is known to be tectonically sensitive. We report here the recent observations of anomalous large scale radon emission, striking high gamma dose rate and the significant increase in the He/CH4 ratio in the thermal spring emanations at Bakreswar prior to the devastating earth quake of about 9.1 in the Richter scale near the island of Sumatra, Indonesia on December 26, 2004 and followed by unprecedented Tsunami.

**Experimental Methods**

The experimental set up at the spring site, Bakreswar, contains a computer assisted gas measurement system, helium in particular, a radon and gamma dose monitoring instrument and a radon progeny-measuring device. All the equipments are directly integrated with the spring vent as shown in Figure 2. Escaping bubbles from the spring vents are trapped underwater beneath an inverted SS funnel, F, and flows through 6.2 mm OD SS tubing through a series of moisture traps, MT, containing anhydrous CaCl2, for drying the gas. The gas concentration changes are monitored by a gas chromatograph GC, consisting of a micro thermal conductivity detector (µ-TCD), capillary column and an auto-sampling valve as injector. The sampling interval and data acquisition of the chromatograph is done through a C2000 Windows based data station. Ultra pure hydrogen gas is used as the carrier gas. A radon monitor, RM, type PQ2000 PRO Alpha Guard
provided with Data-Expert professional software registers changes in spring gas radon concentrations. The instrument can determine Rn-222 concentrations from 2 Bq/m³ to 2 × 10⁴ Bq/m³ with a resolution of 1 Bq/m³. It is also equipped with a GM tube to measure gamma dose rate. The gamma measuring range is from 20 nSv/h to 10 mSv/h with a resolution of 1 nSv/h.

Continuous and simultaneous data collection have been in progress for some time with a sampling interval of one hour for helium, ten minutes for radon and gamma dose. An UPS that can over ride prolonged normal power failure assures uninterrupted power. Adequate precautionary measures have been taken to ensure that the observed anomalous changes in the data are not caused by meteorological factors but can indeed be caused by changes in tectonic stress field or structure. The test site is composed of a cluster of small openings with gas flow rate of 3.5 slpm at a temperature of 67-70°C. Radon is carried by the escaping thermal spring gas primarily consisting of nitrogen (92.2 vol %) besides methane, oxygen + argon and helium with 3.4, 3.0 and 1.4 vol %, respectively. The gases are released from the spring vents at an absolute pressure of about 1.6 bar. Thus atmospheric pressure changes have little effect, if any, on variations in spring gas concentrations or in the gas flow rate. Geochemical parameters that are most affected by tectonic changes are helium, radon and gamma dose. They therefore appear to be promising factors in a monitoring programme seeking linkage with seismic events of varying magnitudes.

Results and Discussions

The time series data derived from in situ measurements of radon, gamma dose and He/CH₄, taken at spring site are plotted in figure 3, 4 and 5 respectively. It is seen that during seismically quiescent periods the variations of all the three monitored parameters are of pulsed nature with a average concentrations of 841.59 ± 19.43 kBq/m³ for radon, 165.70 ± 49.72 nSv/hr for gamma dose rate and 0.096 ± 0.016 for He/CH₄ ratio.

On December 17 and 18, 2004 amplitude of variation of radon concentration sharply increased to around 913.61 kBq/m³ as shown in figure 3 which is greater than 3σ. The gamma dose rate increased steeply to 380.0 nSv/hr as shown in figure 4, and this fluctuation is more than 4σ on December 14 and 15, 2004. The observed gamma signal is the composite gamma emission due to the decay of radon and its short-lived daughters 218Po, 214Po, 214Bi and 214Pb. While gamma is associated in all the transitions, the observed gamma is principally due to 214Pb (t₁/₂ = 26.8m). The sudden
spurt of the gamma dose, most likely, has a bearing on the deep earth activity, particularly, in the mechanically weak tracts of the solid earth. We find the ratio He/CH₄ to be a better index of seismic variations than either He or CH₄, taken separately.

The remarkable increase in the He/CH₄ to a value of 0.18 between December 20 and 22, 2004, is recorded and the amplitude swing in He/CH₄ was more than 3σ as shown in figure 5. The earthquake initiation mechanism brings about the change in thermodynamical

![He/CH₄ ratio chart](image)

**Figure 5**: Variations of He/CH₄ ratio during December 14 to 28, 2004

state of the fluid reservoir and affects the distribution of the stress field. This, in turn, leads to enhanced permeation of deep earth volatiles and helium in particular.

Our findings of large scale anomalous fluctuations in spring gas composition at Bakreswar a few days prior to the major earthquake on December 26, 2004, is quite compatible with similar observations reported earlier by other investigators studying earthquake precursory phenomena worldwide.

The anomalous fluctuation of radon, gamma dose and helium emanating from thermal spring may have resulted from (i) relative increase in heat flow (ii) stress-induced pore collapse and (iii) stress-induced micro fracturing. The observed effect could be attributed to any one of the three or a possible combination thereof. There have been several attempts in the past to correlate the event, earthquake, with laboratory observable as a precursory phenomenon. The weighted average of all the literature-based data favours a partial success towards such an attempt.

We report here the recent (March 1, 2005) startling observation of an explosive burst of helium from the thermal spring emanations at Bakreswar. We believe that this observation is related to the major earthquake, reported as 8.7 on the Richter scale, which occurred off the coast of Sumatra in Indonesia on March 28, 2005. The nature and magnitude of the helium burst is the first of its kind and indicates undispersed high density and high velocity fluid transport accompanied by helium degassing.

Figure 6 shows the isometric plot of the GC observation made over the period March 1-2, 2005. It shows a very unusual helium burst along with a new peak to the left of the helium peak. This has been identified, using a reference deuterium gas in the GC, as the deuterium peak. The origin of the deuterium peak remains unexplored at present, although there does exist the possibility of a deep-seated volatile emission.

Sudden alterations in deep-earth equilibrium conditions generated by processes leading to an earthquake of magnitude above the threshold would produce physio-chemical anomalies in hydrothermal aquifers, fault intersections and in gas-magma mix leading to excessive helium, hydrogen bubbling and fluid dispersal, chemical reactions and cracking of crystalloids. The explosive sudden increase as well as subsidence in the helium concentration indicates sharp changes in the deep-earth geochemical equilibrium conditions brought about by alterations in lithostatic pressure during an earthquake formation process. The expelled mass of volatiles containing excess helium resembles a pressure pulse escaping through the hot spring vent with minimum dilution and transmission loss.

The occurrence of foreshocks is mostly random and they precede the main shocks with an intensity which is a function of depth, epicentral distance, distribution of the stress field across the earthquake precursory zone and the main shock-slip orientation. The observed fluctuation may well tentatively be explained as follows. High