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The detection of underground nuclear explosions by natural signatures

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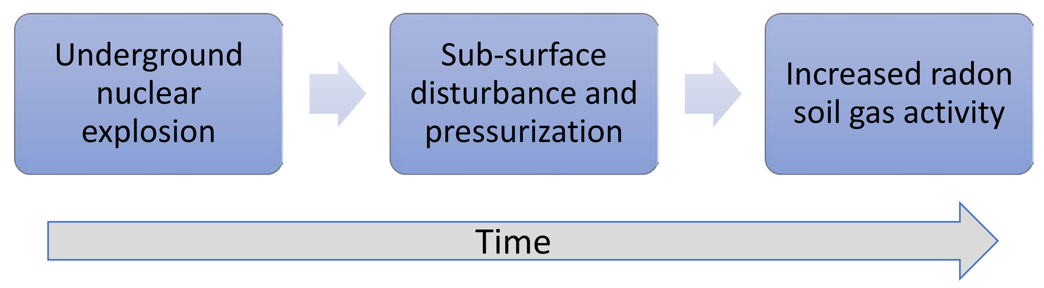
Abstract

The detection of underground nuclear explosions (UNEs) is challenging due to containment measures undertaken to prevent escape of radioactive signatures. These signatures include fission and activation products generated from the explosion. Measures may also be undertaken to restrict generation of seismic and infrasound signatures. A new approach is proposed to detect such tests using natural signatures produced from the increased release of radon gas isotopes (^{222}Rn and ^{220}Rn) from the disturbance and pressurization of the sub-surface flow regime caused by a UNE. Whilst physical barriers can be constructed to ensure containment, measures are not typically implemented to restrict radon escaping from beyond the containment cage around the cavity. It is envisaged such soils, rock and pore waters are placed under significant stress and agitation by the explosion, and would be subject to increased radon release. The resulting anomalous radon concentrations (and progeny) could be useful for UNE detection.

Hypothesis

That disturbance and pressurization of the sub-surface flow regime associated with a UNE produces displacement of natural ^{222}Rn and ^{220}Rn soil gas activity. Such radon anomalies (and their associated progeny) could be used for UNE detection.

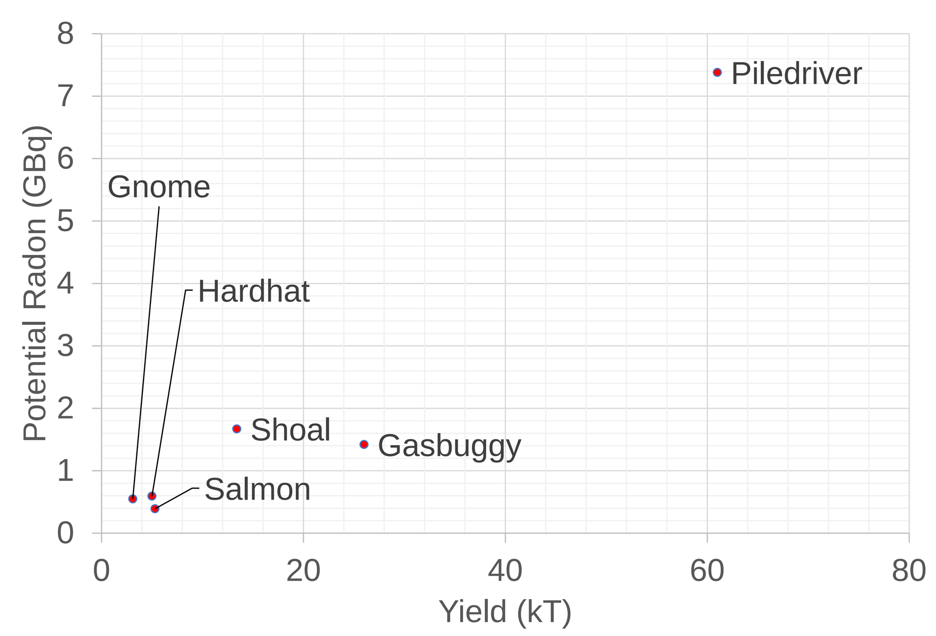


Radon

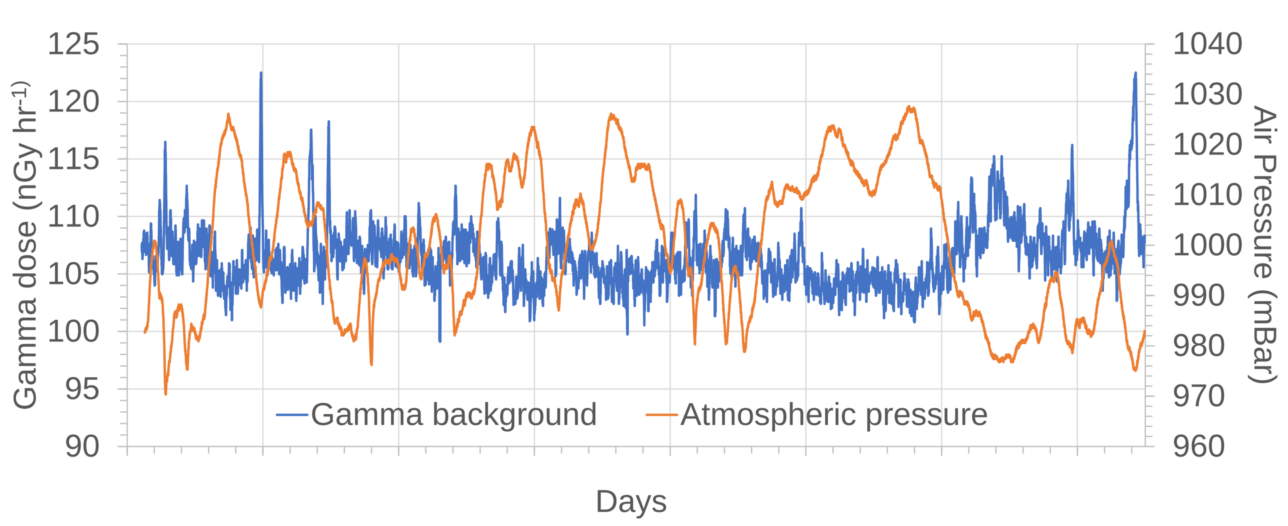
Radon is a naturally occurring noble gas with two main isotopes of environmental interest (^{222}Rn, "radon", $t_{½}$ = 3.83 d, ^{238}U chain; ^{220}Rn, "thoron", $t_{½}$ = 55.6 s, ^{232}Th chain). All of the radon isotopes are chemically inert and have difficulty forming chemical compounds. The natural isotopes ^{222}Rn and ^{220}Rn originate from the ^{238}U and ^{232}Th decay series, the progenitors of which are present in almost all rocks and soils at a concentration of 0.5 – 4.7 ppm and 1.6 – 20 ppm. Although ^{232}Th concentrations are typically four times that of ^{238}U, the contribution to background radioactivity is similar on account of the lower specific activity of ^{232}Th (4.07 Bq g^{-1}) relative to ^{238}U (12.22 Bq g^{-1}). This results in similar production rates for both ^{222}Rn and ^{220}Rn. A typical soil that contains ~ 25 Bq kg^{-1} of ^{232}Th would be expected to have a deep soil pore air ^{220}Rn concentration of ~20,000 Bq m^{-3}. Similar concentrations would be expected for ^{222}Rn, which would be in the range of 4,000 – 40,000 Bq m^{-3}.

Increased radon soil gas activity

Following the explosion, it is hypothesised that the ^{222}Rn and ^{220}Rn soil gas activity shall become elevated as the sub-surface flow regime becomes disturbed and pressurised. This shall facilitate the movement of radon from the depth of the UNE towards the surface. Assuming a typical ^{222}Rn and ^{220}Rn soil concentration of 20,000 Bq m^{-3}, and using published UNE cavity measurements for different yield tests, it is possible to estimate a potential radon signature. Assuming total radon displacement within the cavity (the vaporized region produced by a UNE), and ignoring the failed region beyond (where permanent distortion occurs), the potential radon release activity can be calculated. This assumes that this cavity fraction escapes, and there are no contributions from beyond the cavity. In reality, the distortion of the failed region beyond the cavity could result in additional radon displacement.

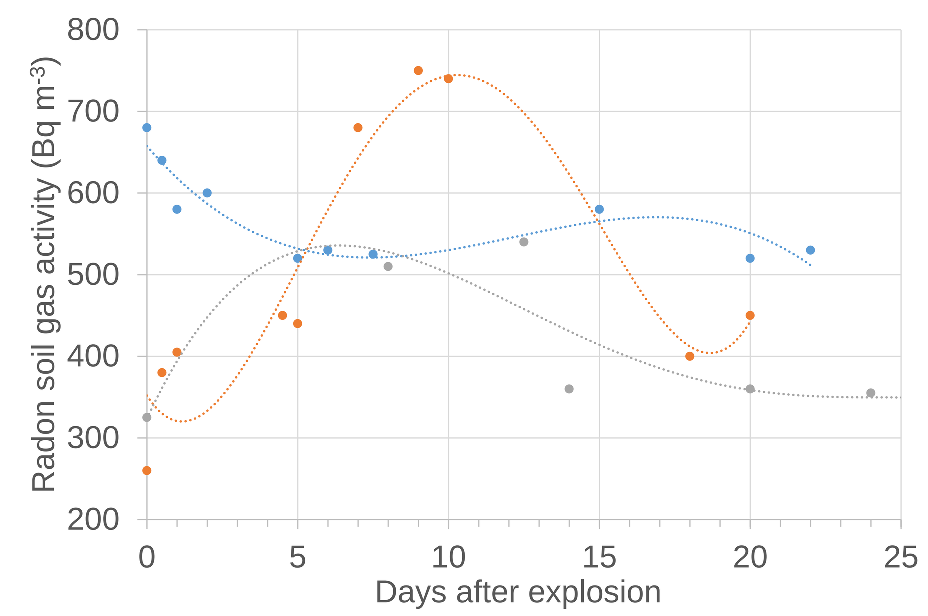


Estimates of potential radon release using published cavity data from Rogers (1970).



Correlations between gross gamma background activity and atmospheric pressure

This hypothesis is supported by studies by Carrigan et al. (2016) that observed highly responsive background radon signals with chimney pressurization (~40 mbar), and increases in soil gas radon concentrations by a factor 10 – 15 during the pressurization period. The process is essentially reverse barometric pumping whereby radon concentrations are inversely correlated to air pressure. The phenomena is frequently observed for environmental monitoring.



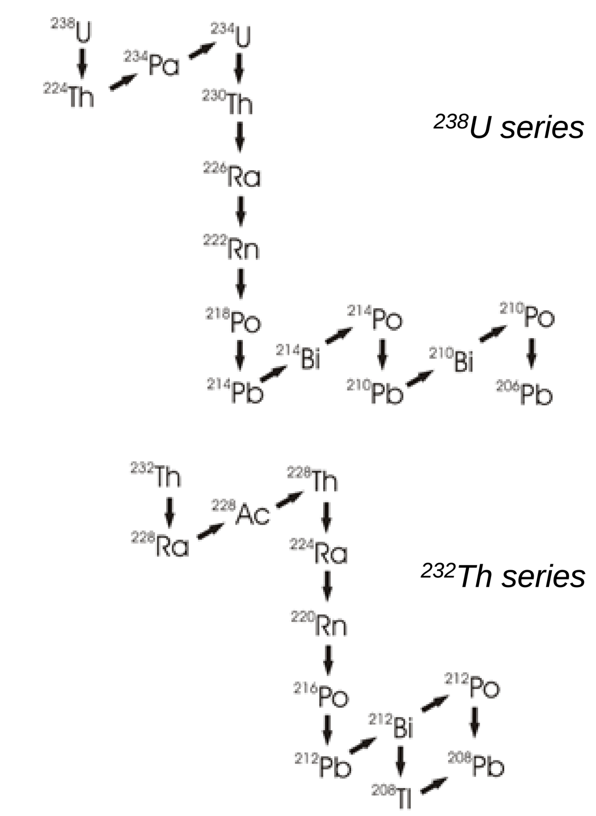
Historical observations

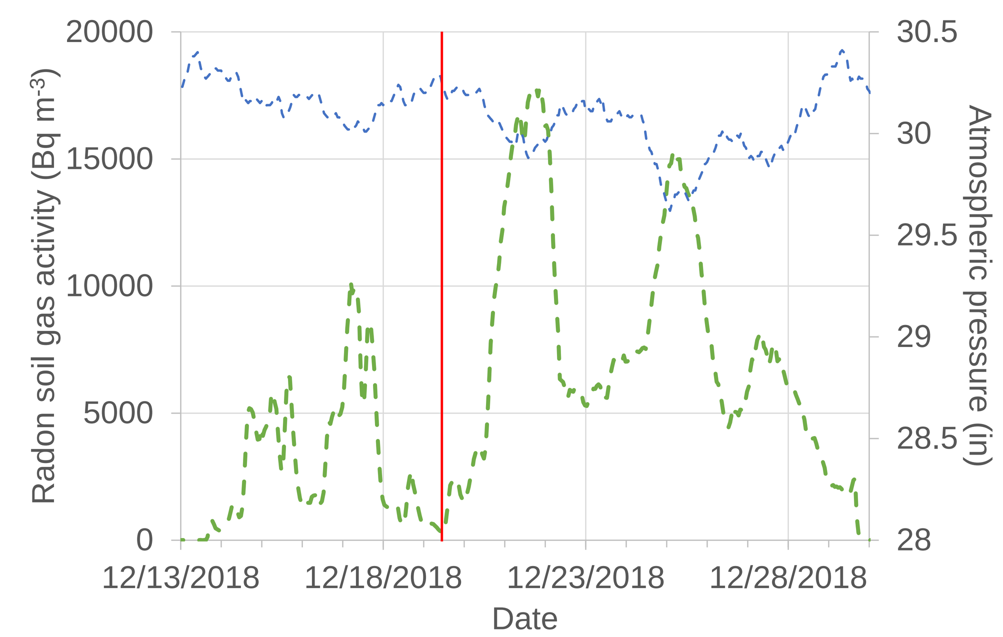
Previous research has investigated radon anomalies during the US Nuclear Explosive Test Program at the Nevada National Security Site (NNSS, USA). Evans et al. (1962) studied 10 nuclear explosive tests (including low yield < 10 kT) with statistically significant anomalies detected for 9. Wollenberg et al. (1977) studied 7 nuclear explosive tests (20 – 1000 kT) with some correlations in soil gas activity observed.

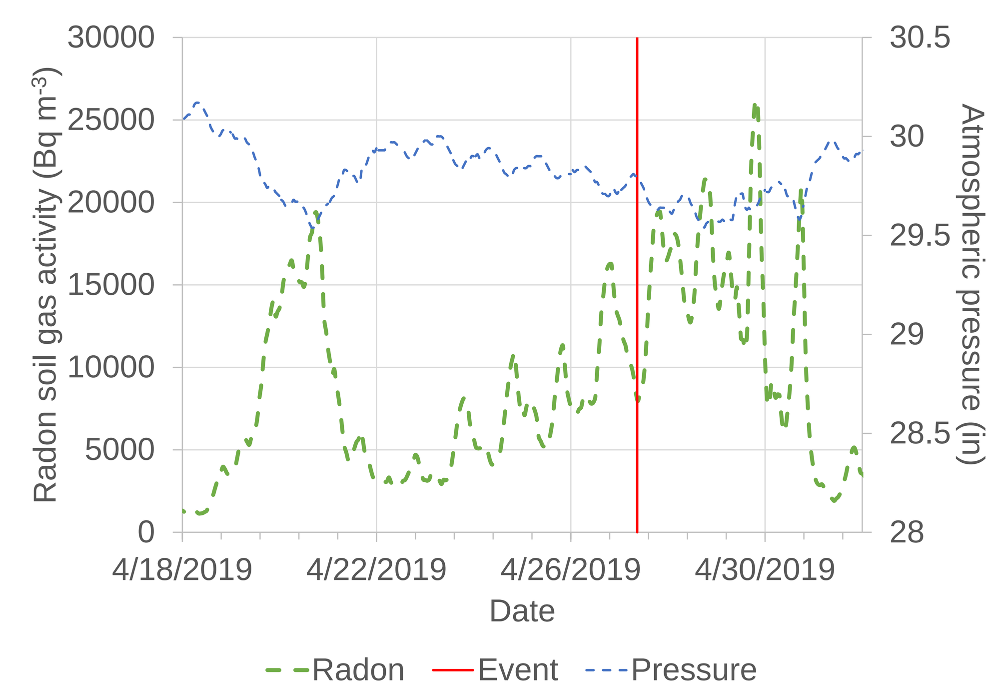
Measurements of radon soil gas activity following US nuclear explosive tests (denoted by different colors). After Evans et al (1962).

Signal magnification

The radioactive decay of ^{222}Rn and ^{220}Rn produces a variety of short-lived isotopes (^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, ^{208}Tl) with half-lives up to 10.64 hours, that readily oxidise and attach to surfaces such as soil particles or aerosols. The progeny could act to increase the detectability of a radon anomaly. In particular, the lead, bismuth and thallium isotopes have relatively strong gamma-emissions and are well-suited for detection by gamma-spectrometry. Elevations in background gamma radioactivity due to the short-lived radon progeny are often observed for environmental monitoring programs (Burnett et al., 2010).







Measurements of radon soil gas (green) and atmospheric pressure (blue) at the SGZ during DAG-2 and DAG-3. The red line denotes the explosion time.

Hypothesis validation

Radon detection instrumentation was deployed at the Dry Alluvium Geology (DAG) experiments as part of the Source Physics Experiment (SPE) Phase II. As part of the DAG series, different yield explosions were undertaken at various depths, to obtain seismic data useful for earthquake and nuclear explosion monitoring applications. Radon measurements were undertaken at three DAG shots (1000 kg at 350 m; 50,000 kg at 300 m; and 1,000 kg at 150 m) with the objective of detecting fluctuations in the radon soil gas activity after the explosion.

In all instances a significant increase in the soil gas activity was detected 1 – 2 days after the explosion, supporting the hypothesis that an initial radon increase would occur following a UNE. However, it is problematic to conclude such increases are solely attributable to the disturbance and pressurization of the sub-surface flow regime. This is because the atmospheric pressure also falls during the observed increases in radon soil gas activity, such that barometric pumping could be a contributing factor. The radon soil gas activity is also subject to background fluctuations that require further characterization. Thus, while the DAG series has provided supporting data, further study is required to robustly prove the proposed hypothesis.

References

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