THORON-SCOUT – first diffusion based active Radon and Thoron monitor

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Abstract. THORON-SCOUT is a stand-alone diffusion based active Radon and Thoron monitor for long term indoor measurements to evaluate the human health risk due to activity concentration in the breathing air. Alpha-particle spectroscopy of Po isotopes, being the progeny of the decay of the radioactive noble gas Radon, is applied to separately monitor activity contributions of $^{222}$Rn and $^{220}$Rn (Thoron) as well. In this work we show that the portion of Thoron (Tn) may locally be remarkable and even dominating and cannot be neglected as often has been assumed up to now. Along with tobacco consumption, Rn radioactivity turned out to be a dangerous cause of lung cancer, especially in older badly vented buildings situated in regions of radioactive geological formations. THORON-SCOUT allows a precise examination of the indoor atmosphere with respect to Rn and Inactivity concentration and, therefore, a realistic evaluation of corresponding health risk.

1. Basic considerations

Two radiologically important isotopes of the noble gas Radon occur in nature: $^{222}$Rn (isotopic ratio $\approx$90%) and $^{220}$Rn ($\approx$9%; called Thoron (Tn)). Together with their short-lived radioactive progeny, they are members of the natural decay series of $^{238}$U and $^{232}$Th, respectively. Migrating from environmental bedrock and soil into buildings, radioactive Rn gas and its aerosol-attached and free progeny, in this way, become health-relevant constituents of the breathing air.

The evaluation of human health risk due to inhalation of radioactive Rn and subsequent damage of lung tissue by energy-rich alpha particles from the decay of absorbed progeny is mainly based on activity concentration measurement of $^{222}$Rn. The risk due to Tn has usually been ignored up to now because of putative less abundance. As shown below, this must not be the case in general but strongly depends on the environmental conditions.

The ratio of the so called potential alpha energy (PAE) per decay for Tn and Rn progeny with short half-life amounts to PAE/Bq ($^{216}$Po $\rightarrow$ Tn) / PAE/Bq ($^{218}$Po $\rightarrow$ Rn) $\approx$8.75%.

Summing up over the entire Tn and Rn decay series, this ratio increases considerably and, consequently, the incorporated equivalent dose due to Tn alpha decay. The precise evaluation of the local health risk, therefore, requires long-term monitoring of both the Rn and Tn activity concentrations in indoor air.

2. THORON-SCOUT

The THORON-SCOUT developed by SARAD GmbH Dresden is the first diffusion based device on the market appropriate for long term active Rn and Tn monitoring[1] (figure 1).
Figure 1. Layout of the THORON-SCOUT.

It applies fast gas diffusion through a special membrane into a measurement volume which is arranged outside of the corpus of the device to guarantee a higher sensitivity. The measurement status and actual results are visualized on a small display.

The ionized decay products from Rn and Tn alpha radioactivity are collected by an electrical field on the surface of a Si semiconductor detector. Alpha-particle spectroscopy within four regions of interest (ROI) is applied to register the decay of $^{218, 216, 214, 212}\text{Po}$ isotopes as well as to distinguish between Rn and Tn progeny (figure 2). This enables the quantitative evaluation of the relevant activity concentrations in the local environment.

Figure 2. Registration of alpha particle spectra within four ROIs calibrated to $^{218}\text{Po}$ (Rn “fast” mode), $^{214}\text{Po}$ (Rn “slow” mode) and $^{216, 212}\text{Po}$ (Tn) decay, respectively.

One of the principal advantages of THORON-SCOUT is its self-sustaining measurement regime without any pump, i.e., without possible vibrations or disturbing noise. Powered by conventional mono-cells, the device works autonomously over about one month. An internal clock controls the user adjusted measurement cycle which may be chosen between 1 min and 4 h. Two measurement modes are possible for Rn detection where the “fast” mode relates to only $^{218}\text{Po}$ decay detection, and the “slow” mode relates to both $^{218}\text{Po}$ and $^{214}\text{Po}$ decay detection. In the “slow” mode, the registration
sensitivity is, therefore, doubled. Simultaneously, the Tn activity concentration measurement is realized by registering $^{216}\text{Po}$ and $^{212}\text{Po}$ decay with a sensitivity of 0.67 cpm per kBq/m$^3$[1].

The alpha spectra shown in figure 2 reveal another problem which had to be solved during the design of THORON-SCOUT. This concerns the optimal assessment of the four ROIs for alpha particle counting from the decay of the corresponding isotopes and the necessary determination of correction factors for the low-energy tails of the alpha spectra which partly fall into neighboring ROIs. Furthermore, the alpha decay branch of the isotope $^{212}\text{Bi}$ (36.2 %), which belongs to the Th decay series and, therefore, is also a Tn progeny, energetically overlaps with the ROI for $^{218}\text{Po}$ decay, which is used for the determination of the Rn activity concentration, especially in the “fast” mode. When the latter problem has been solved by additionally registering the alpha particles from $^{212}\text{Po}$ decay following the $\beta$-decay branch of $^{212}\text{Bi}$ (63.8 %), the former one requires a special calibration procedure of every device in Rn and Tn gas atmosphere, respectively. The absolute sensitivity with respect to Rn and Tn is obtained by comparison with a reference device [1].

The corresponding correction factors as well as all other measurement parameters concerning the duration of a measurement cycle, the measurement mode, etc. can be written into the device using special set-up software. The ROI counting data for every measurement cycle are automatically converted into concentration activity units of Bq/m$^3$ for Rn and Tn, respectively, and stored in the internal memory of volume of 2047 records (2 Gbyte). Additionally, the actual temperature, barometric pressure, and relative air humidity are registered and stored for every cycle. An internal movement sensor registers any position change of the device during the measurement period.

The device set-up and the data read-out are realized via USB or RS232 interface. Wireless data transfer via 2.4 GHz ZigBee is also possible what allows a remote measurement control.

3. Indoor Rn and Tn monitoring using THORON-SCOUT

Exemplarily, some results of Rn / Tn monitoring with THORON-SCOUT carried out in the cellar of an older apartment building during 63 hours are shown in figure 3 [2].

The dotted lines represent the actual measurement data obtained within a cycle of 1 hour. The full lines are obtained by smoothing over 3 h to reduce the statistical data scattering. The right ordinate of figure 3 indicates the difference between indoor and outdoor temperatures. The daily change of this temperature difference is also given in the graph (black line) together with the activity concentration data. In this way, it is rather clearly seen in figure 3 how the indoor Rn gas concentration changes with this temperature difference during the routine of the day. Since the atmospheric pressure as well as the indoor temperature (about ±1 degree) and air humidity (not given in the graph) changed only marginally during the measurement period, one may conclude that the determining factor for the actual indoor Rn / Tn activity concentrations is the outdoor temperature which of course strongly depends on the actual weather. Obviously, at increasing or decreasing temperature difference, the velocity of diffusion of Rn gas through the grounding of the building remarkably changes, and the indoor Ra / Tn activity concentrations change adequately, however, with a delay of several hours. This behavior seems to be plausible from a consideration of the so-called chimney effect where warm air rises upward. The density of warm indoor air is slightly less than that of colder outdoor air. Convection within the building leads to the built up of some suck through the grounding into the building. In other words, Rn gas diffusion into the building is influenced by a gradient of specific pressure which for his part is caused by the mentioned temperature difference.

Figure 3 also reveals that the indoor activity concentrations of Rn and Tn show a similar trend during the routine of the day. Since the source concentrations of Rn and Tn in the environmental bedrock and soil of the building are governed by the natural radioactive decay of $^{238}\text{U}$ and $^{232}\text{Th}$ being constituents of the locally present geological formation, the ratio of the corresponding indoor activity concentrations should, therefore, be nearly constant and characteristic for the location of the building. The more it is important at new building activities that the environmental ground is investigated with respect to geogenic Rn gas sources prior to final decisions. SARAD GmbH offers the necessary technical equipment and corresponding monitors for such measurements [3]. At considerably higher
Rn / Tn concentrations in the environmental, geological formation, special measures have to be planned and carried out to eventually meet national standards of indoor activity concentration.

**Figure 3.** Results of indoor Rn / Tn activity concentration monitoring carried out by means of THORON-SCOUT in the cellar of an older apartment building situated in the hill country near the town Dresden in Germany [2].

The specific result of Rn / Tn monitoring given in figure 3 consists in the fact that in this case, the indoor Tn activity concentration exceeds that of Rn by roughly a factor of two. This impressively proves the statement given above. The realistic evaluation of the health risk due to indoor radioactive Rn gas necessarily requires Rn and Tn monitoring as well. One cannot and must not neglect the locally in no way the negligible contribution of Tn.

**References**

[1] Horak G, Streil T, Oeser V, Sabol J and Duzynski M 2014 8th Int. Conf. on High Levels of Natural Radiation and Radon Areas(Prague, Czech Republic) (priv. comm.)

[2] Streil T, Oeser V, Horak G, Duzynski M and Wagner W 2015 Third Int. Conf. on Radiation and Applications in Various Fields of Research (Budva, Montenegro) ed G Ristić(Nis, Serbia: RAD Association, Book of Abstracts) p 47

[3] [http://www.sarad.de](http://www.sarad.de)