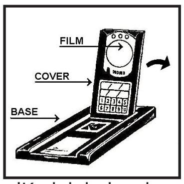
Kodalpha Radon-Dosimeters
and LR155 SSNTD Specifications

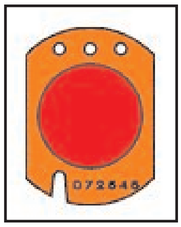
I) Design and measuring principle of the Kodalpha Radon-Dosimeters



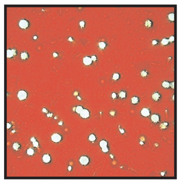
'Kodalpha' radon dosimeter

The Kodalpha Radon Dosimeter is a measuring device using a so-called 'solid-state nuclear track detector' (SSNTD). The result of the Radon measurement obtained by this type of measuring system represents the average Radon concentration over the entire measurement period. As this type of dosimeter requires no electric power for operation it is further classified as 'passive' radon measuring device.

Design:
The Kodalpha Radon Dosimeter is a small, black box with dimensions 4.0 x 7.5 x 0.5 cm. The Radon-sensitive part, being the actual dosimeter, is a small film badge that is attached to the inside of the hinged lid of the dosimeter. These film badges are LR115 type nuclear track films produced by KODAK. The LR115 type films consist of a 100 µm thick polyester base that is coated with a 12 µm thin, α-sensitive layer of red coloured cellulose nitrate. These high quality films are the result of more than 30 years experience of the KODAK company in SSNTD technology.


'LR115' film badge

Measuring principle:
The LR115 type film is sensitive to α-particles. When an α-particle hits the film it causes localised damage to the molecular structure of the cellulose nitrate layer. This damage can be visibly observed when the exposed film is etched in a bath of diluted sodium hydroxide solution amongst other specific conditions. After this processing small holes are visible under the microscope that can be counted and thus be precisely quantified. The holes have diameters from 1 µm to 15 µm and are located where the film was hit by a-particles.

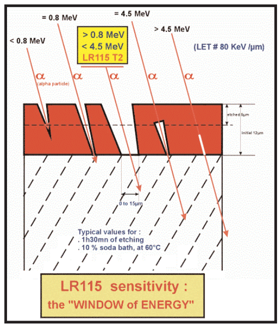

α-particle tracks on 'LR115' film

Radon as well as its decay products (also called Radon progeny) Polonium-218 (Po-218) and Po-214 emit α-particles by their radioactive decays. When the LR115 SSNT filmis exposed to Radon containing atmosphere, the α-particles of both, Radon and its decay products will leave tracks on the film that can be precisely identified and counted. The number of tracks per square centimetre, taking into account the exposure time and the specific developing process, is indicative of the Radon concentration. When the dosimeters are used as so-called 'open - type' dosimeters (see section IV), the Radon decay products as well as Thoron and its decay products are detected by the LR115 film.

NOTE: LR115 film is NOT sensitive to other types of radiation, like β-, γ- or X-rays!

The detection of α-particles with LR115 films:
The distance that α-particles travel in air is dependent on their energy and usually ranges to only a few centimetres. Therefore, these particles can only be detected if they are emitted from the decaying source within a certain distance to the film's surface.

Unique to this type of detection device, α-particles that are generated too close to the film's surface cannot be detected by the LR115 film. In such cases their energies are too high (> 4.5MeV) and they pass through the nitro cellulose layer without causing any interaction thus leaving no tracks.



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For the detection of α-particles, a minimum distance is therefore necessary between the film and the source of the α-particles.

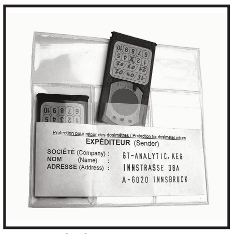
- The **minimum distance** for Radon is about 5 mm and 30 mm for its most energetic decay product Po-214.

- The **maximum distance** for detection is approximately 35 mm for Radon (α-energy: 5.59 MeV) and about 60 mm for its most energetic decay product Po-214 (α-energy: 7.83 MeV).

This particular feature of LR115 films has two major advantages:

- LR115 Films are insensitive to the surface deposition of α-emitting Radon decay products, such as Po-218. Of this reason, the dosimeters are not influenced by the plateout effect (see also section-II)!

- Dosimeters using LR115 films are designed to keep the films 'Radon-proof' in order to avoid undesired exposure during storage that could result in incorrect results. The air volume between the film's surface and the protection screens is less than the minimum distance necessary for the detection of α-particles. Of this reason, no background counts are observed with Kodalpha dosimeters as long as their lids remain closed or the films are being kept inside the plastic envelopes that are supplied for return shipments to laborytory analysis after exposure.



used dosimeters in Radon-protection envelope

II) A comparison of the LR115 films with other Nuclear Track Detectors

Nuclear track detectors for Radon measurements other than LR115 films, are mainly made from polycarbonate. The mostly used types of such detector materials are 'CR39' and 'Makrofol'. In contrast to the LR115 film with its very thin α-sensitive layer (12 µm), polycarbonate detectors are thick-layer detection foils (approx. 1 mm) thus featuring significant differences.

Sensitivity, size of the nuclear tracks, saturation:
Although other detector materials may show higher sensitivity to α-radiation, the nuclear tracks that are produced by α-particels on these foils are much larger than those obtained with LR115 films. The larger size of the tracks is disadvantageous regarding the saturation level of the detectors. The higher the saturation level the longer the dosimeters can be exposed even in high Radon concentration areas. The sensitivity of the LR115 films is about 1.5 - 2.4 nuclear tracks/cm^2, for a total Radon exposure of 1 kBq.h/m^3. The exact value for each batch of film is precisely determined by the analytical laboratory by means of sophisticated calibration procedures.

(The saturation level indicates the maximum density of nuclear tracks on the film at which single tracks can still be distinguished. High densities of nuclear tracks are caused by high Radon concentrations and/or long exposure times. Oversaturation of the detectors causes overlapping nuclear tracks and may lead to inaccurate results.)

- The typical saturation level of LR115 film is approximately 600 tracks/mm^2 (diameter of tracks: 1 - 15 µm) compared to 50 - 400 tracks/mm^2 with other detector materials (diameter of tracks: 5 - 80 µm).

- The maximum exposure (saturation level) of LR115 film is in the range of 70 MBq.h/m^3 which is significantly higher compared to other types of dosimeters.

- The minimum exposure, signifying the lower detection threshold, is only 2 kBq.h/m^3.

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The 'total exposure' indicated in the unit 'kBq.h/m^3' is a very important parameter in radon dosimetry. It is calculated by multiplication of the radon concentration with the exposure time. (For example: The total exposure is the same if a detector is exposed for 2000 hours to 50 Bq/m^3 or for 50 hours to 2000 Bq/m^3. In both cases, the total exposure is 100 kBq.h/m^3).
Regarding LR115 films and other nuclear track detectors for radon measurements, the total exposure is determined by the number of nuclear tracks per mm^2, and by means of a well known calibration factor (conversion factor). The average Radon concentration (in Bq/m^3) can finally be calculated by dividing the total exposure by the exposure time (in hours).

The values for the maximum exposure of LR115 detectors (70 MBq.h/m^3) and for their lower threshold (2 kBq.h/m^3) can be used to calculate the approximate maximum and minimum exposure times for these Radon dosimeters. However, a raw estimation of the Radon level that can be expected at a particular measurment location is helpful for this calculation :

Examples:

1) An extremly high Radon level of 30000 Bq/m^3 can be expected at the specific location where the dosimeter will be placed for the radon measurement.

The **maximum** theoretical exposure time is calculated as :
$70 \bullet 10^6$ Bq.h/m^3 / 30000 Bq/m^3 = 2333 hours (~ 97 days!!!)

2) An average Radon level of 200 Bq/m^3 can be expected at the specific location where the dosimeter will be placed for the radon measurement.

The **minimum** theoretical exposure time is calculated as :
2000 Bq.h/m^3 / 200 Bq/m^3 = 10 hours.

Plateout-Effect:
The term 'plateout effect' describes the deposition of Radon decay products on the surface of the detector's sensitive film layer or inside the housing that encloses detectors of the 'closed - type' (see below). The degree and the local distribution of the deposition of decay products depends on several factors, like the electrostatic behaviour and geometry of the dosimeter.

The plateout effect has an adverse influence on the precision of the Radon measurement as α-particles emitted from decay products will also be detected on the film. These decay products cannot be differentiated from Radon α-particles and thus falsely inflate the final result. It is primarily the dosimeters using 'CR39' or 'Makrofol' detectors that are affected by the plateout effect, whereas it only plays a minor role in the dosimeters using LR115 film.

As explained above, the reason why LR115 films are not sensitive to deposited decay products is that α-particles, generated too close to the film's surface can't be detected due to their high energies. In addition, LR115 films are usually applied in 'open - type' (Kodalpha) dosimeters.

Chemical treatment (etching) and analysis of the dosimeters:
Prior to analysis, the detector films are chemically treated in an etching process. After the etching the nuclear tracks on the films are visible under a microscope. The stability and control of the critical parameters (temperature and concentration of the etching bath, etching time…) are the basic requirements in order to obtain reliable and accurate results. Even small variations in the bath's temperature may cause incorrect results. However, since the etching time of LR115 films is only 1.5 hours (compared to ~ 8 hours for other detectors) and the fact that LR115 films are etched in large vessels minimising changes in temperature, the analysis results of LR115 radon dosimeters are very reliable and accurate.

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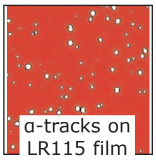
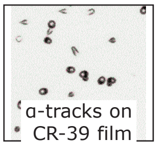
The etching process of the LR 115 film also leads to a slight but controlled depletion of the red coloured cellulose nitrate layer. This controlled loss is important as excess removal of the cellulose nitrate layer can lead to incorrect results. The thickness of the remaining cellulose nitrate layer is automatically measured by the laboratory by means of photo-optic techniques. This procedure is an important part of the quality assurance protocol of the analytical laboratory.

For the analysis and determination of results, nuclear track detectors are viewed under the microscope and transmitted light through the film is used to count tracks. When an exposed and processed LR115 film is viewed under these conditions each track that was casued by an α-particle can be seen as a brilliant point of light. This is very different to Radon dosimeters using 'CR39' or 'Macrofol' detectors since nuclear tracks on these foils absorb light and thus appear as dark spots. Of this reason, tracks on LR115 films are more easily distinguishable from superficial defects in the sensitive layer, such as those caused by scratches. Also dust particles that inevitably will deposit during the manipulation of the detectors in the laboratory are not counted as nuclear tracks on LR115 film. The deposition of dust particles on the surface of other detectors however may be an issue.


α-tracks on LR115 film


α-tracks on CR-39 film

III) Measurement uncertainties of LR115 detectors

The table below indicates typical values for measurement uncertainties (formerly also referred to as 'measurement errors') of Kodalpha Radon dosimeters at 2∗sigma confidence level. The measurement uncertainties in '%' and 'Bq/m^3' are correlated to different exposure times and Radon concentrations. The exact values depend on the production batch of the films and the temperature of the etching bath.

	Kodalpha measurement uncertainties as [±Bq/m³] and [±%] at 2∗σ confidence level					
exposure (days)	±	±	±	±	±	±
90	8 - 11 17% - 21%	12 - 15 12% - 15%	24 - 30 6% - 8%	34 - 42 4% - 5%	38 - 47 4% - 5%	46 - 58 3% - 4%
75	9 - 19 18% - 23%	13 - 16 13% - 16%	26 - 33 6% - 8%	37 - 46 5% - 6%	41 - 52 4% - 5%	50 - 64 3% - 4%
60	10 - 13 21% - 26%	15 - 18 15% - 18%	29 - 37 7% - 9%	41 - 52 5% - 6%	46 - 58 5% - 6%	50 - 71 4% - 5%
45	12 - 15 24% - 30%	17 - 21 17% - 21%	34 - 42 8% - 11%	47 - 60 6% - 8%	53 - 67 5% - 7%	65 - 82 4% - 5%
30	15 - 18 29% - 37%	21 - 26 21% - 26%	41 - 52 10% - 13%	58 - 73 7% - 9%	65 - 82 6% - 8%	80 - 101 5% - 7%
15	21 - 26 41% - 52%	29 - 37 29% - 37%	58 - 73 15% - 18%	82 - 104 10% - 13%	92 - 116 9% - 12%	113 - 142 8% - 9%
7	30 - 38 60% - 76%	43 - 54 43% - 54%	85 - 108 21% - 27%	120 - 152 15% - 19%	134 - 170 13% - 17%	165 - 208 11% - 14%
	50 Bq/m³	**100 Bq/m³**	**400 Bq/m³**	**800 Bq/m³**	**1000 Bq/m³**	**1500 Bq/m³**

Note: according to international standards and norms, measurement uncertainties of Radon measurement devices must be less than ± 20%.

Quality assurance / Validations:
The high quality of the Kodalpha dosimeters is proven by validation tests in which Kodalpha dosimeters have been participating on a regular basis (at least twice a year) for the last 17 years.

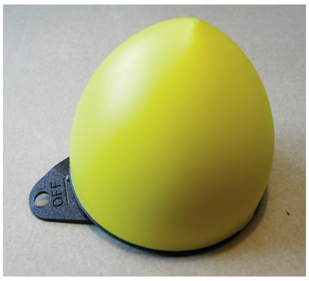
The dosimeters are analyzed by the laboratory of the Dosirad company in France who are specially dedicated to this delicate work. Dosirad can look back to more than 17 years of experience in the application and analysis of LR115 dosimeter films. They are able to analyze large numbers of dosimeters within short periods providing high reliability in the analysis results.

IV) 'Closed - type' Radon dosimeters versus 'Open - type' dosimeters

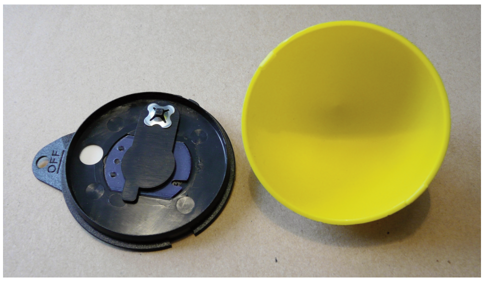
Almost all commercially available Radon dosimeters are so-called 'closed - type' dosimeters (also referred to as 'filtered' dosimeters). The detector (e.g. 'CR-39' foil) is placed inside a small casing of defined volume and shape, serving as the metering chamber.
Special, calibrated casings are also available for the application of LR115 films as 'closed - type' dosimeters (see pictures below). They are commercially available under the brand name 'DRF' dosimeters.

Radon can permeate into the dosimeter's active volume (metering chamber) through an opening which is covered by a filter. The important charcteristic of a 'closed - type' dosimeter is, that only Radon gas can pass through the filter and get inside the metering chamber but not its decay products. In most cases, the filters are also impermeable to Thoron and Thoron decay products.

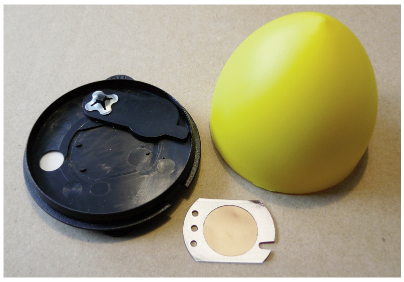
*(**Thoron** is a Radon-isotope originating from the decay of the element Thorium. Thorium, like Uranium is a naturally occurring radioactive element. It is found in small amounts in most rocks and soils, where it is about three times more abundant than uranium, and is about as common as lead. Compared to the 'ordinary' Radon which has the isotopic number 222 and a half-life of 3,8 days, Thoron has the isotopic number 220 and a half-life of only 55.6 seconds. Although Thoron itself is currently not considered a health risk due to its short half-life, some of its decay products that have significantly longer half-lifes can reach indoor concentrations that may be of concern.)*



A closed-type dosimeter ('DRF' dosimeter), specially designed for use with LR115 film.



A 'DRF' dosimeter with the upper part of its casing removed. The LR115 film is in the center on the bottom of the dosimeter, protected from exposure by a mechanic shutter.



An opened 'DRF' dosimeter with the LR115 film removed from the dosimeter casing.

In contrast to the 'closed - type' dosimeter, the Radon sensitive film of the 'open - type' dosimeter is not enclosed by a casing but directly exposed to the atmosphere of the measurement location. LR115 dosimeter films are mainly used for 'open - type' dosimeters, also called „Kodalpha dosimeters". In this case, Radon and Thoron as well as their particularly dangerous decay products can be detected.

'Kodalpha' Radon dosimeter, an 'open - type' dosimeter for use with LR115 detection films

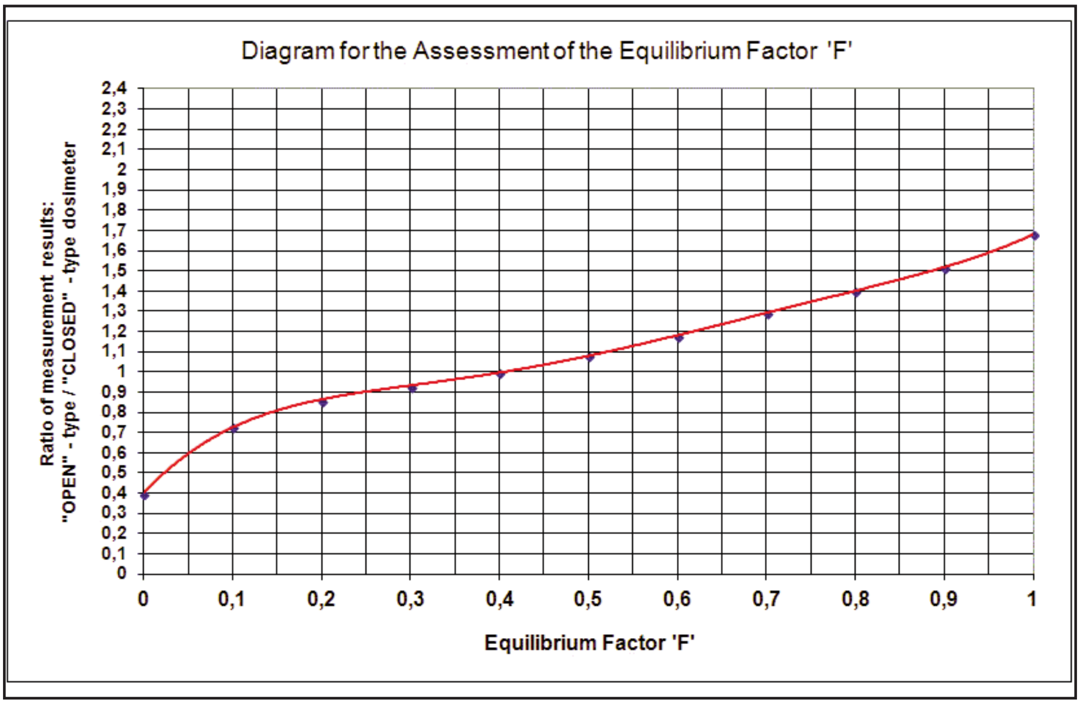
The ratio between Radon and its progeny in air is indicated by the so-called equilibrium factor 'F'. In regular indoor air the equilibrium factor 'F' has a value between 0.3 an 0.6. In the analysis of 'open - type' Kodalpha dosimeters an equilibrium factor of 0.4 is assumed and used for the calculation of results. Like with 'closed - type' dosimeters, also the results of 'open - type' Kodalpha dosimeters are indicated as the average radon concentration (in the unit Bq/m³) that was determined by the dosimeter.

A simple way to estimate the equilibrium factor 'F':
By means of parallel measurements with an 'open - type' and a 'closed - type' dosimeter the equilibrium factor 'F' can be estimated in a very simple way using the graph that is depicted on the next page. Instead of a 'closed - type' dosimeter, the measurement can also be made with an electronic radon detector (e.g. a 'Ramon 2.2' Radon monitor) since these instruments only measure radon concentrations regardless of the equilibrium factor of the ambient air, like 'closed - type' dosimeters do. However, as 'open - type' dosimeter, a Kodalpha unit must be applied for this specific measurement task.

A determination of the factor 'F' is done in the following way:

1) In order to determine the value for the Y-axis, divide the analysis result of the 'open - type' dosimeter by the result of the 'closed - type' dosimeter.
2) Locate the point on the graph that refers to the Y-value, found in the first step.
3) The corresponding value on the X-axis indicates the equilibrium factor 'F'.

Example:
The results of a parallel measurement with an 'open - type' and a 'closed - type' dosimeter are 812 Bq/m^3 for the 'open - type' and 576 Bq/m^3 for the 'closed - type' dosimeter.
The value for the Y-axis is calculated as: 812/576 = 1.4. The Y-value of 1.4 on the graph corresponds to the value 0.8 on the X-axis. The equilibrium factor therefore is 0.8.



Assessment of the radiation dose related health risk:
It is a fact that the health risk related to Radon exposure is NOT due to Radon gas as such but to the radiation dose received from the radioactive decay products of Radon. The decay products (also referred to as 'Radon progeny' or 'Radon daughters') can attach to dust particels in air and in contrast to Radon gas, inhaled radon progeny is retained by the human respiratory tract to a much higher extent.

Of this reason, Radon legislation and norms for (Uranium-) miners originally required the measurement of radon progeny at their workplaces by means of special measurement equipment, called 'Working-Level Meters'. Hence, the measurement unit for Radon decay products is called 'Working Level' (WL).
Radon guidelines and norms for the general public though, generally refer to the exposure to Radon gas, mainly for the simple reason that it is easier to measure Radon gas than Radon progeny. However, one of these two normative approaches may be more reasonable in terms of health risk assessment than the other, mainly so, as equilibrium factors can vary from measurement location to measurement location.

Therefore, we believe that the measurement of Radon AND its decay products by means of 'open - type' Kodalpha dosimeters allows a much better estimation of the real dose related health risk.

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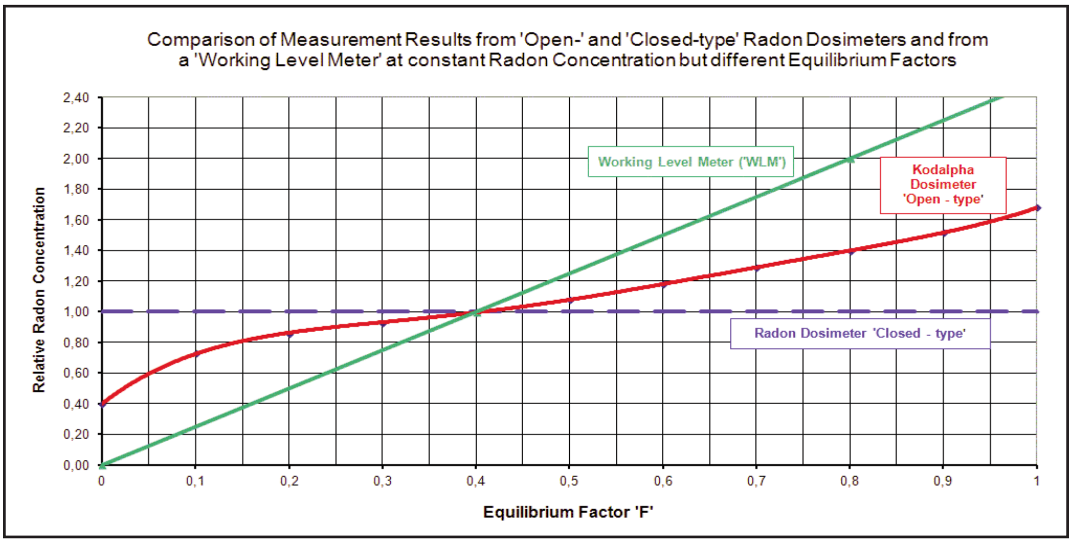
Due to the fact that Radon related health risk is determined by the amount of Radon decay products that are always present with Radon gas to some extent, guidelines and norms considering only the Radon gas must assume that the equilibrium factor is known and identical for each measurement location! Only this assumption allows a good assessment of the dose related health risk based on the measurement of Radon gas.

Current national and international Radon norms therefore assume that the common equilibrium factor 'F' in indoor air is 0.4!

Of this reason, the specific calibration parameter for the 'open - type' Kodalpha dosimeters was adjusted by the analsis lab in order to agree with an equilibrium factor 'F'=0.4
The results for radon concentrations thus measured with Kodalpha dosimeters are exactly the same as those obtained with 'closed - type' dosimeters, provided that the equilibrium factor in the measurement location was 0.4.

However, if 'F' differs from the assumed value of 0.4, 'closed - type' dosimeters over- or underestimate the health risk, despite the fact that their results for the Radon concentration may be correct.

The graph below shows the theoretical results of a 'closed - type' dosimeter, an 'open - type' dosimeter and a Working Level Meter ('WLM') at constant Radon level but for different equilibrium factors.



A 'closed - type' dosimeter indicates the same Radon level regardless of the equilibrium factor (blue dashed line) whereas a Working Level Meter only measures the amount of radon decay products, rising proportionally with the equilibrium factor but independently from the radon concentration (green line). Note: Increasing results of a 'WLM' also mean an increases in the dose related risk. Finally, the red line represents the theoretical results of a Kodalpha dosimeter. If the equilibrium factor 'F' = 0.4, the results of all instruments indicate the same dose related risk.

However, if the equilibrium factor is different from 0.4, the results of an 'open - type' dosimeter are closer to the results of a Working Level Meter than those of a 'closed - type' dosimeter. In cases of lower equilibrium factors than 0.4, a 'closed - type' dosimeter will thus overestimate the dose related risk but underestimate it, if 'F' is higher than 0.4!

Of this reason, we are convinced that 'open - type' Kodalpha dosimeters are a very useful measurement method for Radon screening with the aim to estimate the dose related health risk due to Radon exposure by means of an unexpensive and single measurement.

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