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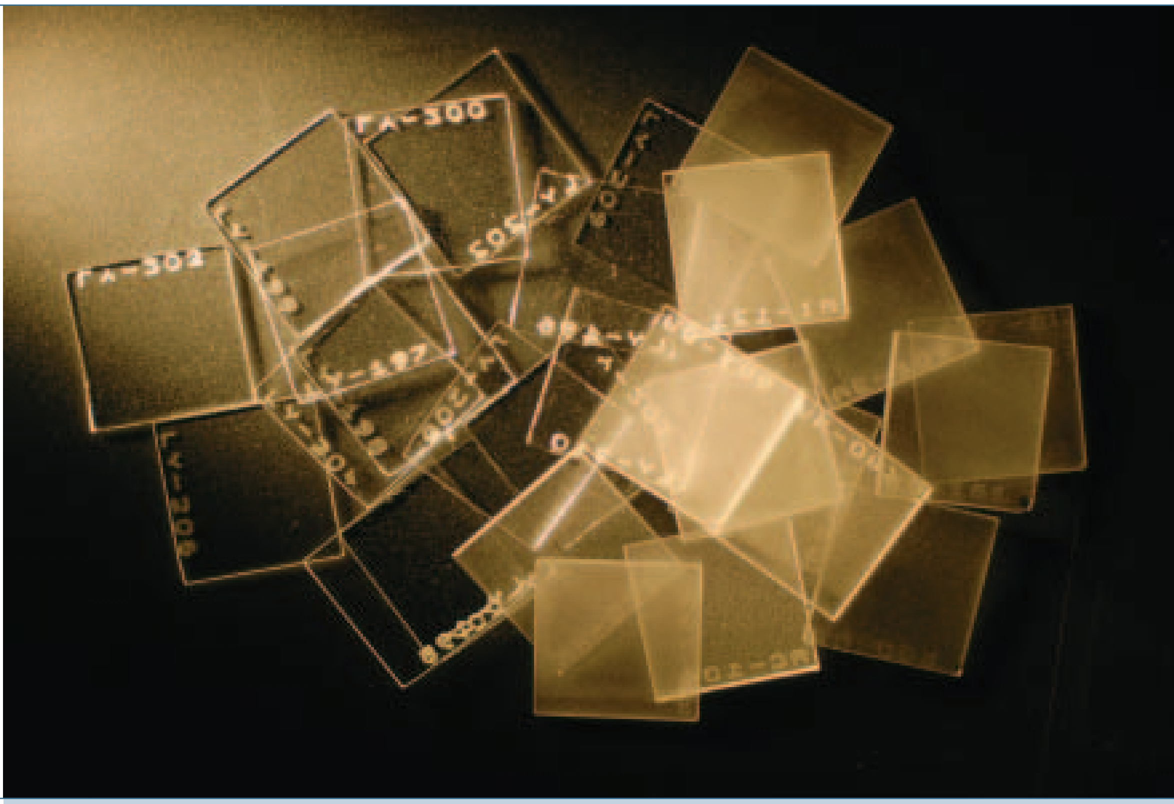

Measuring radon levels at high exposures with alpha-track detectors

Calibration and analysis

Statens strålevern
Norwegian Radiation Protection Authority

Reference:
Ånestad K., Rönnqvist T., Jensen CL. Measuring radon levels at high exposures with alpha-track detectors. StrålevernRapport 2007:4. Østerås: Norwegian Radiation Protection Authority, 2007.

Key words:
Radon, Alpha-track detectors, TADTAC method, GammaRad, high radon exposures.

Abstract:
This report presents the TADTAC method - a track area dependent total area counting method, for measuring radon levels at high exposures with alpha-track detectors. Normally radon levels are measured by counting individual tracks. The TADTAC method is developed by Gammadata Mätteknik AB and implemented at The Norwegian Radiation Protection Authority. Alpha-track detectors used for testing and calibrating the method where exposed at Physikalisch-Technische Bundesanstalt (PTB) in Germany.

Referanse:
Ånestad K., Rönnqvist T., Jensen CL. Measuring radon levels at high exposures with alpha-track detectors. StrålevernRapport 2007:4. Østerås: Statens strålevern, 2007. Språk: engelsk.

Emneord:
Radon, sporfilm, TADTAC-metoden, GammaRad, høy radoneksponering.

Resymé:
Denne rapporten presenterer TADTAC-metoden for analyse av overeksponert sporfilm. TADTAC er en metode for å beregne radonkonsentrasjonen på grunnlag av det totale arealet av spor på en sporfilm, og ikke antall individuelle spor som er vanlig ved standardmetoden. Metoden er utviklet av Gammadata Mätteknik AB og er implementert hos Statens strålevern. Sporfilm benyttet for testing og kalibrering av metoden ble eksponert ved Physikalisch-Technische Bundesanstalt (PTB) i Tyskland.

Head of project: Katrine Ånestad
Approved:

Per Strand

Per Strand, Director, Department of Emergency Preparedness and Environmental Radioactivity

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Measuring radon levels at high exposures with alpha- track detectors

Calibration and analysis

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Contents

1 Introduction

Radon levels measured with alpha-track detectors are normally calculated by counting individual tracks on the exposed detector film. At very high exposures overlapping tracks inhibit the track counting, which will give an upper detection limit for the method. Another way to determine the radon exposure is to calculate the total radiated area on the film. The Swedish company Gammadata Mätteknik AB has developed a track area dependent total area counting (TADTAC) method, based on this principle. The TADTAC method is proving to be well suited for calculating radon levels at high exposures.

The radon detectors used to test the TADTAC method have been calibrated at Physikalisch-Technische Bundesanstalt (PTB) in Germany, over a period from medio April to the end of May 2005. The calibration of detectors from Norwegian radiation protection authorities (NRPA) has been done simultaneously to the calibration of the radon detectors from Gammadata.

This report describes the TADTAC method for calculating radon levels at high exposures and the calibration of the detectors at PTB.

2 Passive etched track radon detectors

Surveys of radon levels in homes and other buildings are carried out using passive etched track detectors exposed over long periods to take account of the short-term variations in radon levels. The detectors can be sent directly to house owners by mail, and returned at the end of the integration time.

Two types of passive etched track radon detectors are commonly used – closed and open track detector. A closed radon detector is a track detector within a closed container, which allows radon-222 to diffuse into it. The closed detector excludes radon decay products which are present in the ambient atmosphere and records only those alpha particles generated by the radon entering the container and the decay products formed from it. An open detector consists of a naked track detecting material exposed to the ambient atmosphere. The open detector records alpha particles originating from both radon and its decay products in the ambient atmosphere. The open detector also responds to alpha particles from Radon-220 and its decay products.

The detectors are based on small pieces of sensitive films of different polymers. Alpha particles from radon and its decay products cause damages to the film. By etching the films these damages become optic visible as tracks and can be measured and used to calculate the radon level.

The Norwegian Radiation Protection Authority (NRPA) has a laboratory for measuring radon levels. NRPA uses the method with CR-39 closed alpha-track detectors of NRPB/SSI design, consisting of antistatic material. The track counting is automatic and the equipment and software, GammaRad, are developed by the Swedish company Gammadata Mätteknik AB. The detector holders and films are shown in Figure 1 and 2. The etching takes place in 20 % NaOH at a temperature of 90˚C for 2 hours and 45 minutes.

NRPA participates in annual intercomparisons of passive radon detectors, held at the Health Protection Agency (earlier National Radiological Protection Board) in England.

Figure 1: Passive etched track radon detector holders from Norwegian Radiation Protection Authority.

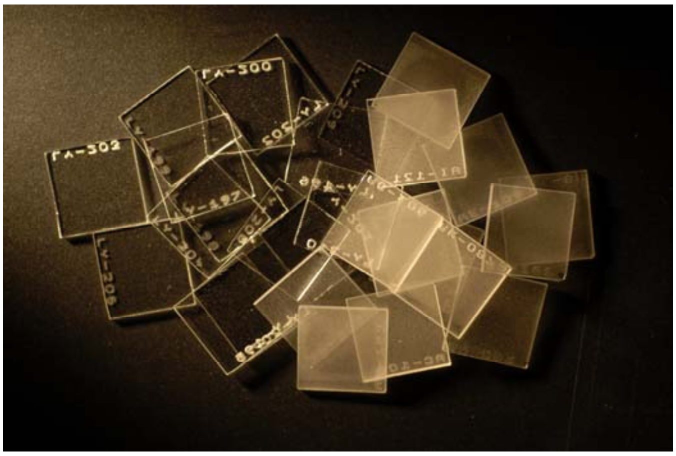

Figure 2: Passive CR-39 etched track radon detector films from Norwegian Radiation Protection Authority. Normally exposed films to the left and overexposed films to the right.

3 Calibration

Surveys of radon levels in Norwegian dwellings have proved that many radon detectors are overexposed because of high indoor radon concentrations. These detectors can not be analysed by normal routines at the GammaRad system because of difficulties with counting individual tracks. To be able to utilise the TADTAC method a calibration at higher exposures was necessary.

NRPA has no facilities for calibrations at high exposures and international intercomparisons are carried out at low and moderate exposures (up to ca. 2.000 kBqh/m^3). A calibration up to about 70.000 kBqh/m^3 requires that the radon activity concentration in the radon reference chamber is some 10.000 Bq/m^3, otherwise the period of calibration will be very long.

The radon detectors were calibrated at Physikalisch-Technische Bundesanstalt (PTB) in Germany, over a period from medio April to the end of May 2005. Calibration of detectors from NRPA and Gammadata were made simultaneously for comparison.

The irradiation of the detectors with radon gas took place in a reference atmosphere at a temperature of 23˚C $\leq t \leq$25˚, a relative air humidity of $0{,}27 \leq f \leq 0{,}38$, and an air pressure of 990 hPa $\leq p \leq$ 1025 hPa. The activity concentration was $c_A \approx 50$ kBq/m^3. After irradiation, the detectors were ventilated for some days in air with low radon concentration, i.e. $\int c_A \, dt < 0{,}5$ kBqh/m^3.

Calibrations were made at 11 different exposures from 2.6 to 70.1 MBqh/m^3. In each exposure, 10 alpha-track detectors were exposed. New films were used in the detectors for all exposures, but for the exposures at 5.26 and 50.2 MBqh/m^3, additional one year old films were used for age comparison. The mean track areas were calculated by using a track area gate of 150-900 μm^2.

4 The TADTAC method

Radon levels are normally calculated by counting individual tracks. The standard method (the GammaRad system) only works for low and moderate exposures. At very high exposures, however, overlapping tracks inhibit the track counting, and the exact radon concentration can not be determined. It is necessary to make a correction for the non-linear correlation.

The Swedish firm Gammadata has developed a track area dependent total area counting (TADTAC) method for calculating radon levels at high exposures. Instead of counting individual tracks on a film, the method calculates the radon exposure based on total radiated area. However, this method can give large uncertainties because the average track area on different films can vary quite a lot due to e.g. the age of the film, the thickness of the film and settings in the counting system. For overexposed films, the light intensity seen by the imaging camera will be different from low exposed films. This will also give different average track areas on the films. These problems could give errors in the order of 30 %, which makes a simple total area counting method insufficient without compensations.

One way to compensate for the different average track sizes on the films is to correct for the differences in the average track size. Even for films which have been exposed up to 50.000 kBqh/m^3 enough individual tracks can be found in order to calculate the average individual track area on the films. This track area can then be used to calculate a virtual track number from the total radiated area.

5 Results

The results of the calibration of NRPA films, using the TADTAC method, are shown in Table 1. "Counts" refer to the virtual counts calculated with the TADTAC method and "standard deviation" is the deviation (1SD) of the 10 films in the exposure.

Table 1: Results of the calibration. Normal conditions.

Exposure (MBqh/m^3)	**Calibration factor (counts/(cm^2*kBqh/m^3))**	**Standard deviation (%)**	**Mean track area (μm^2)**
2.6	3.04	2.8	358
5.26 (new films)	2.91	2.5	378
5.26 (old films)	2.87	2.9	367
7.77	3.00	2.2	396
10.6	3.00	1.7	397
15.1	3.06	1.1	416
20.1	3.22	2.3	421
30.0	3.21	2.7	431
40.0	3.30	2.9	424
50.2 (new films)	3.25	3.0	414
50.2 (old films)	3.02	1.6	410
60.5	3.22	2.6	390
70.1	3.07	5.7	356

As can be seen in Table 1, the standard deviation for the films in each calibration set is very low which indicates that the method is stable. However, at 70.1 MBqh/m^3, the standard deviation increases and the seen track decreases significantly which indicates that the method does not work at that exposure. Only about 200 “individual tracks” were identified at this high exposure, and that is not enough to get reliable results of the mean track area. The differences in mean track area between the different sets are mainly due to the different light intensity seen by imaging camera.

In order to investigate how reliable the method is, the observed track size was changed by changing the grey scale threshold (+/- 10) in the image analysis.

The results from these tests are summarized in Table 2 and 3. Calibration factors and mean track area are given relative the values for the normal conditions in Table 1.

Table 2: Results of the calibration. Low light threshold (small tracks). Relative the values for the normal conditions in Table 1

Exposure (MBqh/m^3)	**Relative calibration factor (%)**	**Relative mean track area (%)**
2.6	-10.2	-13.7
5.26 (new films)	-12.0	-14.0
5.26 (old films)	-11.1	-12.9
7.77	-9.7	-12.9
10.6	-11.3	-11.6
15.1	-8.2	-10.2
20.1	-9.0	-10.5
30.0	-6.9	-8.6
40.0	-6.1	-7.8
50.2 (new films)	-4.9	-6.3
50.2 (old films)	-6.0	-5.6
60.5	-6.2	-2.6
70.1	-2.6	+3.1

Table 3: Results of the calibration. High light threshold (large tracks). Relative the values for the normal conditions in Table 1

Exposure (MBqh/m^3)	**Relative calibration factor (%)**	**Relative mean track area (%)**
2.6	+8.2	+21.2
5.26 (new films)	+7.6	+18.8
5.26 (old films)	+8.4	+16.6
7.77	+7.3	+15.9
10.6	+8.0	+15.6
15.1	+6.9	+13.9
20.1	+6.5	+12.4
30.0	+6.5	+9.3
40.0	+6.7	+6.6
50.2 (new films)	+10.8	+0.2
50.2 (old films)	+8.2	+3.2
60.5	+10.2	-7.7
70.1	-34.2	-4.8

The sensitivity in the calibration factors due to the different conditions above is usually below 10 % as can be seen in the Tables 2 and 3. Therefore, the method should give reliable results during normal variations of the plastic and analysis conditions. However, a correlation between an increased mean track area and an increased calibration factors can be seen. A correction of the calibration factor due to the relative mean track area improves the results. From the data in Tables 2 and 3 (mostly from the "large track data") and also data from similar calibration at Gammadata suggests a correction factor of 0.5 (Table 4).

5.1 Algorithm for calculating radon levels with the TADTAC method

The exposure D (kBqh/m^3) of a high exposed film can be calculated as:

$D = \left(N_H / C_H\right) \times \left(C_P / C_B\right) \times \left(1 + k\left(1 - A_M / A_H\right)\right)$, where

N_H = virtual count density (counts/cm^2) calculated with the TADTAC method

C_H = calibration constant (counts/(cm^2*kBqh/m^3)) with the TADTAC method for the PTB calibration films

C_P = normal calibration constant for individual tracks for the PTB batch of films

C_B = normal calibration constant for individual tracks for the actual batch of films

k = correction constant used when the average track area differs from the normal one

A_M = measured average track area

A_H = average track area of the PTB calibration films

Some of the constants vary depending on the track density of the film. From the calibration results in Table 1 the following "standard calibration table" (Table 4) for normal tracks can be obtained:

The correction constant k is chosen to be constant for all exposures.

Table 4: TADTAC standard calibration parameters.

N_H * 1.247	D (MBqh/m^3)	C_H	A_H	k
0-10000	5-2.5	2.9	370	0.5
10000-15000	2.5-4	2.9	370	0.5
15000-25000	4-6.5	2.9	380	0.5
25000-35000	6.5-9	3.0	390	0.5
35000-50000	9-12.5	3.0	400	0.5
50000-70000	12.5-17.5	3.1	410	0.5
70000-100000	17.5-25	3.2	420	0.5
100000-140000	25-35	3.2	430	0.5
140000-180000	35-45	3.3	425	0.5
180000-220000	45-55	3.2	410	0.5
220000-250000	55-63	3.1	390	0.5

5.2 Test of the TADTAC method with other calibration films

The TADTAC method, with the calibration parameters in Table 4, was tested by reading other calibration films and films from intercomparisons tests, see Table 5.

It should be noted that the low exposures are too low for the method (the background is higher with the TADTAC method compared to counting individual tracks with the standard method). A relative calibration (C_P/C_B) has not been made in this comparison. In most cases the agreement with the true exposures is within 5 %, and that is acceptable.

Table 5: TADTAC method calculation test.

Set of films	N_H * 1.247	A_M	Calculated dose ($kBqh/m^3$)	Exposure ($kBqh/m^3$)	Difference (%)
SSI 2004	600	401	159	168	-5.4
SSI 2004	2728	368	756	795	-4.9
SSI 2004	15873	365	4475	4695	-4.7
NRPB 2001	1221	427	311	321	-3.1
NRPB 2001	7095	430	1802	1897	-5.0
NPPB 2004	1240	356	349	321	+8.7
NRPB 2004	8520	366	2369	2289	+3.5

5.3 Uncertainty and limitation of the TADTAC method

Using the algorithm on the tests described in Tables 1-3, the following uncertainty estimation can be obtained:

- Uncertainty in the PTB-calibration: 3.8 %
- Uncertainty in the normal calibration for the actual batch: 5.0 %
- Uncertainty in the object count counting (standard method) for the PTB-calibration films: 2.0 %
- Uncertainty in the object count counting (standard method) for the normal calibration films: 2.0 %
- Uncertainty in TADTAC method due to variations in track area, statistics: 8-12 %, where the higher uncertainty corresponds to the highest exposures (variations in the TADTAC calibration constant).

The uncertainties above are given at a confidence level of 67 %.

The total uncertainty will be:

5-20 $kBqh/m^3$: about 10 %

20-40 $kBqh/m^3$: about 12 %

40-60 $kBqh/m^3$: about 14 %

The following conditions decide the use of the TADTAC method versus the standard method:

- For using the TADTAC method the plastics must be clear with low background (easily tested by using the method on background films or normal calibration films).
- Exposures below 5000 $kBqh/m^3$ are not suitable for the TADTAC method. The standard method with counting individual tracks works better and without any problems at these exposures.
- In the region 5000-7000 $kBqh/m^3$, a mixture between the two methods is probably best
- Above 7000 $kBqh/m^3$, the TADTAC method should be used.
- The upper detection limit of the TADTAC method is determined by the mean track area. With the calibration films used here, an upper limit of about 60.000 $kBqh/m^3$ can be obtained, but for films with larger track areas the upper limit could be below 50.000 $kBqh/m^3$. The

parameter to observe is the number of “Object Counts”. If the “Object Counts” are less than 500, the upper detection limit is reached.

- Bad quality films, which are grey, could give large TADTAC values. These films can be identified through a significantly lower mean track area. High TADTAC values and a track area below 300 are probably due to bad plastic and should be manually inspected.

This will put an upper detection limit in the region of 7000 kBqh/m^3 for the standard method with counting individual tracks, which corresponds to a track density of about 10.000 tracks/cm^2.

6 Summary and conclusions

Surveys of radon levels in homes and other buildings are carried out using passive etched track detectors exposed over long periods to take account for the short-term variations in radon levels. The Norwegian Radiation Protection Authority (NRPA) has a laboratory for measuring radon levels. Surveys of radon levels in Norwegian dwellings shows that several radon detectors are overexposed because of high indoor radon concentration. These detectors can not be analysed by the standard method and a new method is developed for calculating radon levels at high exposure.

Radon levels are normally calculated by counting individual tracks, and the standard method works for low and moderate exposures. For higher exposures, the tracks overlap more and more, and it is necessary to make a correction for the non-linear correlation.

The Swedish company Gammadata Mätteknik AB has developed a track area dependent total area counting (TADTAC) method for calculating radon levels at high exposures. NRPA has calibrated films and upgraded the analyses equipment for this method. Instead of counting individual tracks, the method calculates the radon exposure based on total radiated area. A source of error with the method is that the size of tracks varies from film to film. To compensate for the different average track sizes on the films a correction factor is included in the calculations. Even for films which have been exposed up to 50.000 kBqh/m^3 enough individual tracks can be found in order to calculate the average individual track area on the films. This track area can then be used to calculate a virtual track number from the total radiated area.

The radon detectors were calibrated at Physikalisch-Technische Bundesanstalt (PTB) in Germany, over a period from medio April to the end of May 2005. PTB has facilities for calibrations at very high exposures, up to about 70.000 kBqh/m^3, with an activity concentration in the radon reference chamber of some 10.000 Bq/m^3. The standard deviation for the films in each calibration set is low which indicates that the TADTAC method is stable. The method gives reliable results during normal variations of the plastic and analysis conditions, but a correlation between an increased mean track area and an increased calibration factors can be seen. A correction of the calibration factor due to the relative mean track area improves the results. From the calibration data and also data from similar calibration at Gammadata a correction factor of 0.5 are suggested.

The following conditions decide the use of the TADTAC method versus the standard method:

- For using the TADTAC method the detector plastics must be clear with low background.
- Exposures below 5000 kBqh/m^3 are not suitable for the TADTAC method. The standard method with counting individual tracks works better and without any problems at these exposures.In the region 5000-7000 kBqh/m^3, a mixture between the two methods is probably best. Above 7000 kBqh/m^3, the TADTAC method should be used.
- The upper detection limit of the TADTAC method is determined by the mean track area. With the calibration films used here, an upper limit of about 60.000 kBqh/m^3 can be obtained, but for films with larger track areas the upper limit could be below 50.000 kBqh/m^3. The parameter to observe is the number of “Object Counts”. If the “Object Counts” are less than 500, the upper detection limit is reached.

- Bad quality films could give large TADTAC values. These films can be identified through a significantly lower mean track area. High TADTAC values and a track area below 300 are probably due to bad plastic and should be manually inspected.

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