

SPECIFIC CHARACTERISTICS OF RADON "PASSIVE/OPEN"  
MODEL DETECTORS COMPARED TO  
"PASSIVE/CLOSE" AND "CHARCOAL" DEVICES.

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-- ABSTRACT --

All passive/open detectors, also called Unfiltered alpha Track Detectors (UTDs), are built around KODAK LR115 film, only material sensitive to all ambient alpha particles and capable to work in "open" mode.

The principle of "open" detectors is not new. They are largely used worldwide, often by scientists (in France, Italy, Japan, Norway, Sweden etc.). However, their particular functioning needs some explanation and some reminders. This paper is more aimed to discuss generalities than details of calculation.

The estimation of the Potential Alpha Energy (PAE) concentration is about 4 times better than that from other passive detectors and it includes thoron progeny. The film is more sensitive to ambient decay products than it is to Radon as track count is higher for alpha's of greater initial energy.

Passive/open radon detectors can be used as part of a short-term or long-term system or as personal monitoring devices. Their

exposure can even be fractioned. They can be instantaneously put on "on" or "off". Being extremely light and flat, they can be mailed to the lab in a regular envelope.

Passive/open radon detectors can easily fill a variety of needs and seem to be so far, the best risk indicators.

## MEASUREMENTS AND HEALTH HAZARDS.

All evaluations of health hazards are based on the Potential Alpha Energy measurements ( PAE, joules or J ) of inhaled radon progeny. This is the result of P.A.E. concentration (PAEc,  $\mu\text{J}\cdot\text{m}^{-3}$  ) per volume of air inhaled. This volume is equal to a respiratory flow rate multiplied by an exposure duration. The radon ( $^{222}\text{Rn}$ ) and thoron ( $^{220}\text{Rn}$ ) gases, inoffensive in themselves, are not included in this PAE.

The U.S. Environmental Protection Agency (EPA) recommends a PAEc of  $0.42 \mu\text{J}\cdot\text{m}^{-3}$  i.e. 0.02 Working Level (WL) or, there again,  $75\text{Bq}\cdot\text{m}^{-3}$  of radon if it was in equilibrium with this same energy of radon progeny (= EERC = Equilibrium Equivalent Radon concentration ). These 0.02 WL are obtained by supposing a 75% presence-time in such an atmosphere and an average inhaled volume of  $0.8 \text{ m}^3\cdot\text{h}^{-3}$ .

It is only in the case where the equilibrium Factor (F) between radon progeny and the radon gas is worth 0.5 that the recommendation of  $75 \text{ Bq}\cdot\text{m}^{-3}$  EERC corresponds to  $150 \text{ Bq}\cdot\text{m}^{-3}$  (or  $4\text{pCi}/\text{l}$ ) of radon gas, the well-known EPA recommendation for CRn (Taking into account the definition :  $\text{EERC} = \text{F}\cdot\text{CRn}$  where CRn is the radon activity Concentration).

In the absence of a simple, cheap and direct measurement of the radon progeny or health risks, there is no real choice, we measure the concentration of the radon gas, then we assume an equilibrium factor (F) to evaluate the PAEc of the radon

progeny. The "open" model detectors change this state of affairs.

For thoron, 0.02 WL (still =  $0.42 \mu\text{J}\cdot\text{m}^{-3}$  of progeny) is in equilibrium with only  $5.5 \text{ Bq}\cdot\text{m}^{-3}$  of thoron gas, or  $11 \text{ Bq}\cdot\text{m}^{-3}$  thoron gas if  $F=0.5$ . Although ignored by the recommendations of the EPA, thoron can sometimes reach the same PAEC level as radon. The "open" detectors take this into account.

#### CHARCOAL DETECTORS.

There exists a temperature sensitive adsorption competition between all the gases and ambient vapours, including radon and water vapour. Only a rigorous procedure can enable us to deduce the initial radon concentration by measuring the radioactive emission of the formed radon progeny. Due to the short life-span of its progeny (<11 hours), the thoron gas is not measurable.

The information stored is "spurious" because the gamma emission halves every 4 days. Any time-interval before analysis heavily penalizes the accuracy level : forgetfulness of the client, length of transportation time, insufficiency in the analysis laboratory's capacity etc. In practise, the success of "blind tests" can sometimes be compromised.

These detectors can only be "short term" (2 to 5 days) and no storage for later re-measuring is possible.

It should be noted that the charcoal detectors are the only ones to take samples of radon in the room. One single detector takes samples of about 1% of radon in a room of 10 m<sup>3</sup>.

#### ALPHA TRACK DETECTORS (ATD).

"Open" or "close" models, all the ATDs work on the same principle. They individually record every alpha particle which reaches the surface of a sensitive plastic with the proper energy and angle.

Their accuracy rate cannot be better than a statistical precision. The sigma of accounting dispersion is  $\sqrt{N}$ , if N be the average number of counted tracks, whatever the surface area explored. Statistically speaking, that means that at equal exposure rate, 5% of the detectors will be outside the margin range :  $N \pm 2 \sqrt{N}$ . For example, a month's exposure at 150 Bq.m<sup>-3</sup>, with F=0.5, can give in the region of  $150 \pm 25$  tracks per 1cm<sup>2</sup> explored, within classical conditions of treatment.

All the ATDs have the big advantage of enabling us to count all the incidental alpha particles indelibly : this allows for average measurements over long periods and later re-readings.

#### "CLOSE" MODEL ATD.

For "close" detectors, ambient radon progeny are excluded from measurement by the admission filter while the half-life of thoron (55 s.) just allows it to partially enter the casing.

Therefore, we can only think of recording the radon gas and a steady stream of thoron gas permitted by the filter. As a matter of fact, we also record the radon progeny formed inside the casing, mostly fixed on the interior walls.

The recording becomes stable only after balancing the radon pressure and reaching equilibrium with its radon progeny, i.e. after more than 3 hours. If alpha particles were all in a position of being recorded, for 2 tracks due to radon progeny there would be 1 track due to radon. But that depends on the dimensions, geometry and statism of the casing.

This largely unknown proportion of recorded radon progeny is at the source of results dispersion. We can only take this into account, generally speaking, when practically calibrating the detector. However, some statism fluctuations are unforeseeable.

Exposure is not stopped when the casing is closed. True time exposure is at least 4 days more than opening time, except if the analysis can be done beforehand. The later analysis is carried out, the higher the result. The opposite is true for charcoal detectors.

Only "close" detectors, fitted with highly efficient filters, are insensitive to thoron. Like charcoal detectors, they are 100% insensitive to ambient radon progeny but they can only be exposed as "long term" devices ( > 1 month).

## "OPEN" MODEL ATD.

The "open" detectors work like the "close" detectors whose casing would be the room space where the measuring is being carried out. The radon progeny recorded are those we really breathe and not those fixed on the inside walls of the casing.

The main difference is that the volume of air involved in the measurement is not limited to the dimensions of the casing. It is in fact limited by the distance covered by the alpha particles in the air and a detection angle-limit in the region of 45°. Everything happens as if we were carrying out the measurement in a greater volume for the most energetic alphas which have the greatest distance to cover. For example, the maximum measuring distance is about 33mm for  $^{222}\text{Rn}$  (5.5 MeV), 40mm for  $^{218}\text{Po}$  (6.0MeV) and 60mm for  $^{214}\text{Po}$  (7.7 MeV).

LR115 film is characterized by a window of sensitivity, say between 1.2 to 4.8 MeV, depending of etching and counting conditions. So it is insensitive to alpha emission at less than a minimum distance : <5mm for  $^{222}\text{Rn}$ , <12mm for  $^{218}\text{Po}$ , <32mm for  $^{214}\text{Po}$  , under regular pressure. That is also why it can work in "open" mode : it is insensitive to radon progeny plated out on the film.

These detectors can be instantaneously put on "start" or "stop", how ever often we wish, by the interposition of a simple polyester screen. This screen does not even have to be closely placed up against the film. It also prevents perfectly well

background noise during storage. The short half-life of thoron is no longer a problem for its recording. The detectors can be simultaneously short term, long term or even time fractionated.

The absence of casing enables us to design extremely light and streamlined detectors, the source of various decisive advantages.

Several other advantages are due to LR115 film itself, or to the choice of device : low noise/simple etching/high contrast tracks/possibly large film area/ ...

#### SPECIFIC FEATURES OF "OPEN" DETECTORS.

- Concentration of radon gas.

Since only a part of the tracks is due to gas, we have to extrapolate on a certain "F" so as to calculate the concentration level of radon. If assumed F is 0.5 and true F is 0.7, the radon concentration level is over-estimated by about 30% (Fig.1). But, at the same time, the energy level of ambient radon progeny has increased by 40%, i.e. the over-reckoning is aiming at a better calculation of the overall risk.

For short information on calculation principle, see ATTACHMENT.

It should be noted that the equilibrium factor can be calculated by a simple, simultaneous usage of an "open" ATD and a "close"



ATD. The "open" ATD equals the result of the "close" one for only one specific F data set in the calculation.

- PAEc (WL) / EERc (Bq.m<sup>-3</sup>).

As there are generally more tracks emerging from radon progeny than radon gas (a 6/1 relationship for F=1.0 and 3/1 for F=0.5 and 1/1 for F=0.08), measurement accuracy is better for the radon progeny than for the gas. If assumed F is 0.5 and true F=0.7, the PAEc (WL) or EERc (Bq.m<sup>-3</sup>) will be under-estimated by about 7%. In the same situation, a "close" detector would have been under-estimated by 30%, i.e. 4 times worse (Fig.2&3).

- Thoron and its progeny.

In the case of thoron presence, the radon gas concentration (Bq.m<sup>-3</sup>) and PAEc of the radon progeny (WL) are over-estimated. The "close" ATDs already show this type of effect. We must admit to only measuring an "Equivalent Concentration" of radon or Equivalent PAEc. However, since no passive method allows us to make the distinction between radon and thoron, over-estimation is preferable to an insensitivity to thoron and to high F, in terms of health hazards.

Thoron comes mainly from materials. It remains more concentrated near its sources (walls, floors...) due to its 55s half-life, while some thoron progeny may be more homogeneous thanks to their 10 hours half-life. If an open detector, fixed on the wall, records more tracks than in the middle of the room, there

is probably thoron present in the room space. We can use as many detectors as we wish, even within a reduced area space, since they do not disturb the environment.

**- Sensitivity to air pressure.**

Accuracy increases with altitude. Indeed, every 100-meter, if no temperature change, the atmospheric pressure decreases by 1% and the free circulation of alpha particles in the air increases by 1%. Therefore, theoretically, the volume of measurable air increases by about  $(1\%)^3$  i.e. roughly +3% tracks. In practice the effect is a little less than that.

Therefore, we should take altitude into account if it is higher than about 400 meters. It should be noted that the respiratory flow rate also increases with altitude and that the PAEC recommendations do not take this into account.

**- Personal monitoring and public market.**

The "open", light and flat detectors enable us to carry out personal monitoring easily, with acceptable aesthetics included. The time-span passed in the various concentrations come up against is then automatically integrated, without any reaction time span, by passing from one room space to another and with no sensitivity to air movement. The average "exposure" to PAE, of each person monitored, ( $J.h.m^{-3}$  or WLM) is the only one true risk parameter we should try to reduce.

For "in situ" detectors, it becomes very easy to carry out fractionated detection in time. The latter is often envisaged but unrealizable without "open" detectors.

Its sending under normal postal envelopes renders its use much more simple and easily acceptable for the public at large.

- Direct progeny measurement.

Interposition of about 10 $\mu$ m Aluminium sheet against LR115 film, filters the lowest energies and allows to record only ambient radon decay products.

#### DISCUSSION.

Apart from the fact that passive detectors leave us no choice in the matter, the main argument in favour of the measurement of radon gas as an indicator of health hazards derives from the assumption that only its "free" radon progeny, i.e. ambient but non-fixed on aerosols, are dangerous. Since its radon progeny instantaneously fix themselves onto any support found, the "free" fraction (ff) is all the more elevated since there are few aerosols involving radon. In this case, the equilibrium factor F is weak since the radon progeny can only fix themselves on partition walls and are therefore no longer ambient. Whence as a compensation of these parameters : few ambient radon progeny but nevertheless free, so dangerous. The health risk would therefore be directly proportional to the sole concentration of the radon gas.

This is inaccurate because very small-sized aerosols are also very dangerous and cannot be neglected. Another reason is that this is only true at general equilibrium. Practically airing has a big influence. For example, an airing of 20% per hour does not allow to obtain more than  $F = 0.84$  even without plating phenomenon, and independently of the free fraction.

Plating and airing are two independent ways of decreasing "F".

Last example : let us think of a room showing a stable radon concentration of  $100 \text{ Bq/m}^3$ . If we renew efficiently the air in that room and then close all through-ways : about 8 days will be necessary to recover the initial value of  $100 \text{ Bq/m}^3$ , due to radon entries.

Moreover, scientists usually prefer to measure one single parameter at a time. They tend to forget that radon gas is harmless by itself and that "open" detectors also measure the potential energy of the ambient radon progeny better than other passive detectors, the latter energy being the direct cause of risks. Above all, the family father needs a single, most suitable figure to take into account the overall risks involved, including "F" and thoron as well. It is not the same thing with post-mitigation control measurements, which should be expressed in terms of radon gas, since we try to reduce gas entries.

## DISPLAY OF "OPEN" DETECTOR RESULTS.

After process and batch calibrations within a radon chamber whose equilibrium factor "F" and chamber pressure (at least altitude) are known, the measuring results can be expressed in several ways. For example, by introducing an assumed F at 0.5 in the calculations, we can assert :

- Radon gas concentration ( $\text{Bq.m}^{-3}$ ).

In most cases, F is understood as being between 0.35 and 0.60, then the error remains lower than  $\pm 15\%$ .

- "Equivalent radon concentration" ( $\text{Bq.m}^{-3}$ ).

If real F is  $> 0.60$  or if there is thoron in the room space, the radon concentration is automatically over-estimated by a factor which reflects about the real increase in alpha energy and from there the increase of risk. Therefore, the figure obtained is an excellent, overall indicator of the health hazard.

- Potential Alpha Energy conc. ( $\mu\text{J.m}^{-3}$  or WL) or EERC ( $\text{Bq.m}^{-3}$ ).

The result can be expressed in PAEC with an error below 7% (the error being higher if  $F < 0.30$ ) ie 4 times less than all passive detectors on which a great error derives from the "F" hypothesis. Moreover, this PAEC includes thoron progeny as well.

- Exposure ( $\text{kBq.h.m}^{-3}$  or WLM).

The use of personal monitoring automatically brings into play the time spent in the premises. It is submitted to the same comments as previously made for F and thoron. The 0.02 WL limit for "in situ" control, for 75% of presence time, in fact corresponds to an individual annual exposure limit of 0.77 WLM, or  $2.7 \text{ mJ.h.m}^{-3}$ , or  $485 \text{ kBq.h.m}^{-3}$  EERC .

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## LIST OF TABLE and FIGURE CAPTIONS

ATTACHMENT : Things to bear in mind.

Fig.1 : Estimated radon concentration. Theoretical curves.

Fig.2 : Estimated Potential Alpha Energy. Theoretical curves.

Fig.3 : Radon ageing. Theoretical curves.

--- ATTACHMENT ---

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The Potential Alpha Energy (PAE) of any atom in the radon or thoron decay schemes is the total alpha energy emitted during the decay of this atom along the decay chain down to  $^{210}\text{Pb}$  or  $^{208}\text{Pb}$  respectively. So an atom which is not an alpha emitter can have a significant contribution to the total PAE, due to one of its daughters.

Ex.: PAE of one  $^{214}\text{Pb}$  atom = 7.7MeV or  $7.7 \times 6.24 \times 10^{-12}\text{J}$ .

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The total PAE inside of a certain volume is the sum of the PAE of all daughter atoms which are present in this volume :

$$\text{PAE}_{\text{tot}} = N_1 \cdot \text{PAE}_1 + N_2 \cdot \text{PAE}_2 + N_3 \cdot \text{PAE}_3 + \dots$$

where  $N_i$  = Number of atom(i), and  $\text{PAE}_i$  = PAE of each atom(i).

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The Number  $N_i$  of atoms of each element is related to its period  $T_i$  (s) and activity  $A_i$  (Bq) :

$$N_i = (A_i \cdot T_i) / 0.69$$

Ex.: for  $^{218}\text{Po}$  which period is 183s :  $N = 183 / 0.69 = 265$  atoms for each 1Bq of activity.

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After calculation, we obtain the general formula :

$$\text{PAE}_{\text{tot}} = 10^{-9} \cdot (0.58 \cdot A_1 + 2.9 \cdot A_2 + 2.1 \cdot A_3)$$

with 1, 2, 3 respectively for  $^{218}\text{Po}$ ,  $^{214}\text{Pb}$ , ( $^{214}\text{Bi}$  or  $^{214}\text{Po}$ ) and PAE expressed in joule and  $A_i$  in becquerel.

Note that  $^{214}\text{Pb}$  is not an alpha emitter.

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At equilibrium, ( $F=1$ ), radon gas activity  $A_{\text{Rn}} = A_1 = A_2 = A_3$  and PAE is called  $\text{PAE}_{(\text{eq})}$ .

For  $F=0.5$ , any  $A_i$  combination giving  $\text{PAE}_{(\text{eq})} / 2$  is OK, thanks to  $F$  definition  $F = \text{PAE}_{(\text{actual})} / \text{PAE}_{(\text{eq})}$ .

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On the other hand, the number of tracks ( $N_t$ ) obtained after film exposure and processing, has the general form :

$$N_t = K \cdot D \cdot (A_{\text{Rn}} + 1.70A_1 + 4.95A_3)$$

where  $K$  = calibration factor, and  $D$  = exposure Duration.

Note that  $^{214}\text{Pb}$  is no more present, but that  $^{222}\text{Rn}$  is.

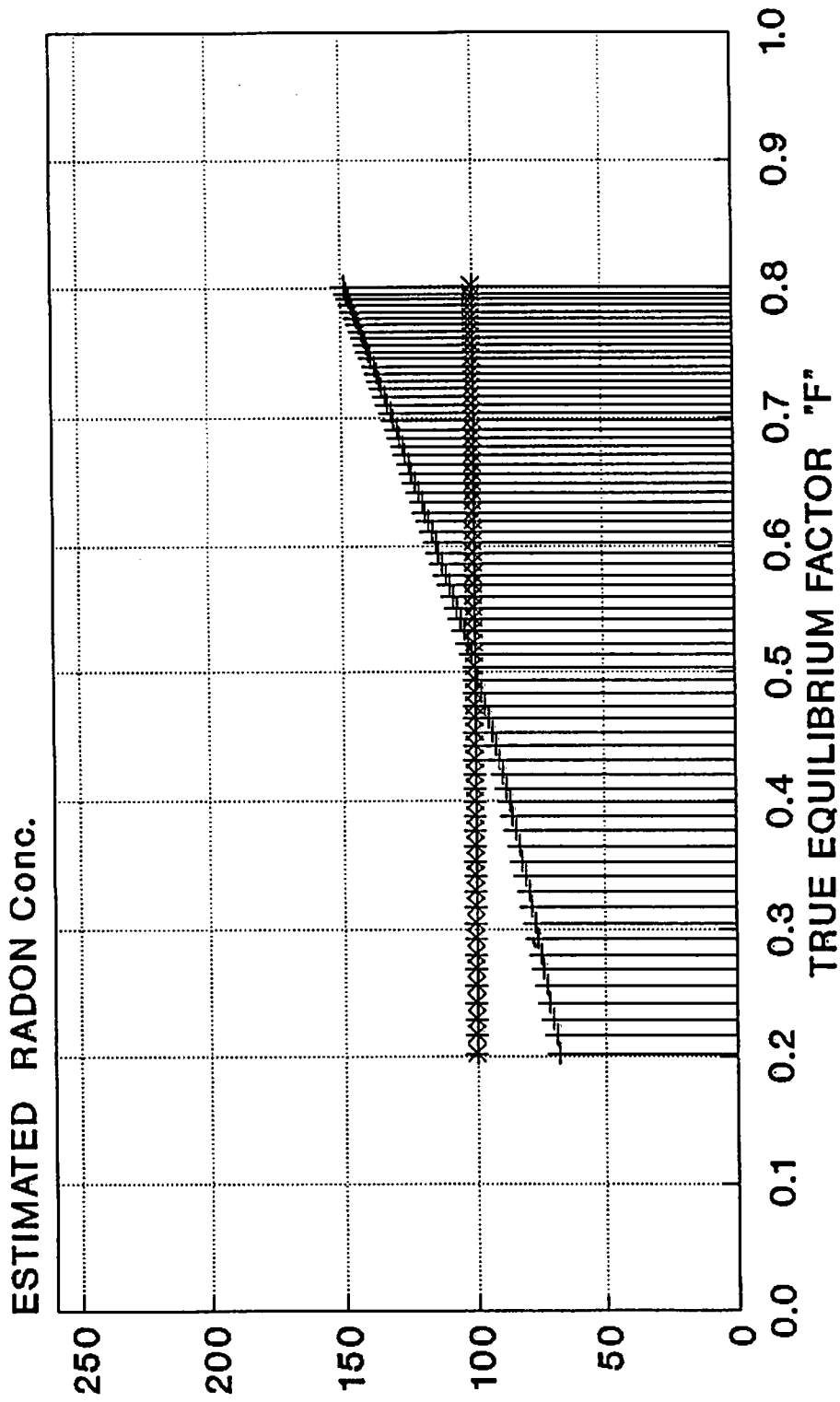
Numeric coefficients comes from differences of analysed air volume vs initial alpha energy.

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Theoretical curves shown (Fig. 1 to 3) are based on an equilibrium limited by radon ageing and airing rate. When plating time is the main bounds set to " $F$ ", these curves can be a little different, but conclusions regarding "open" detectors remain applicable.



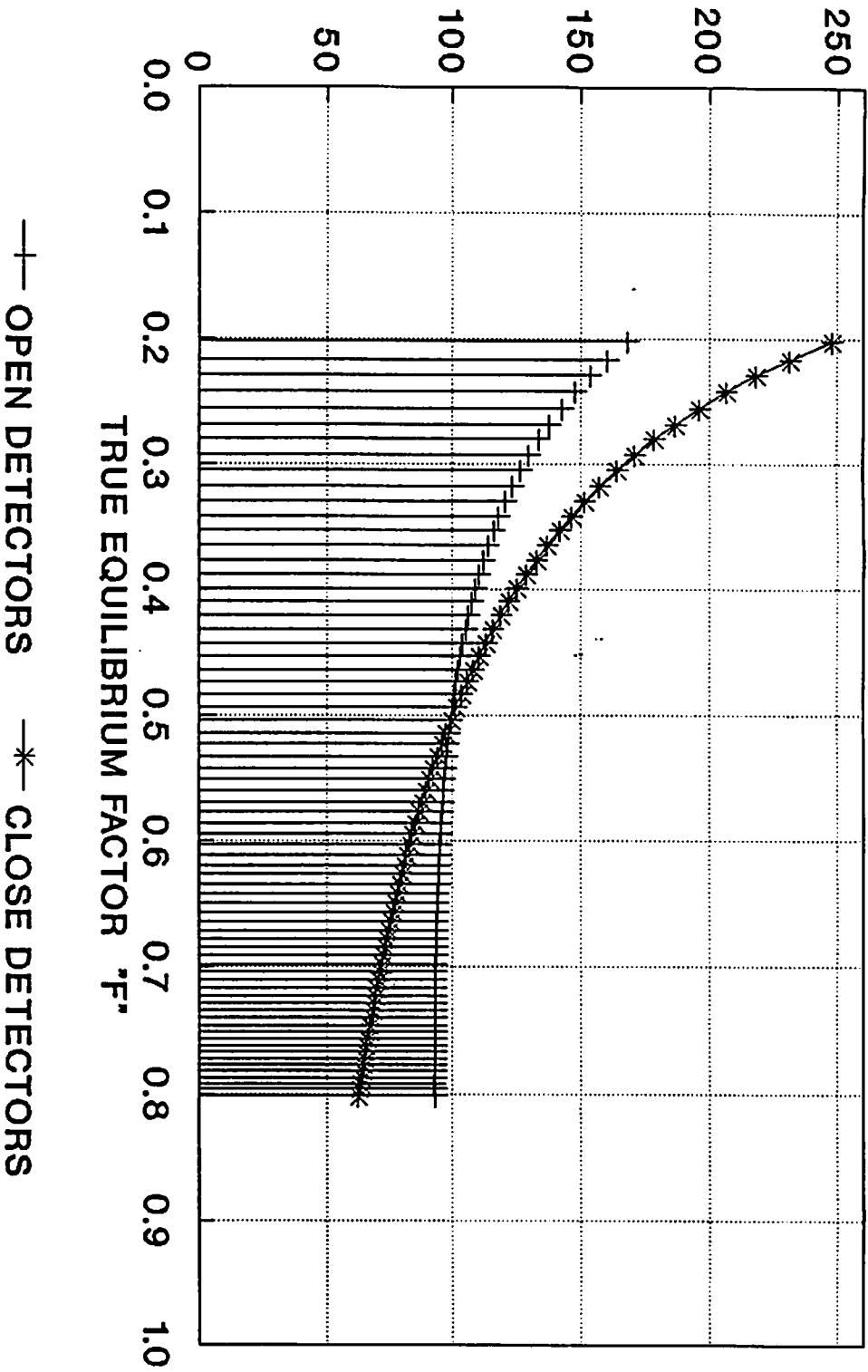
( Relative curves / Assuming  $F = 0.5$  )



+ OPEN DETECTORS    \* CLOSE DETECTORS

( Relative curves / Assuming  $F = 0.5$  )

ESTIMATED P.A.E.



( Constant radon conc. / 0 % airing )

