A BETTER UNDERSTANDING OF THE MORPHOLOGY AND THE STRUCTURE OF THE PLASTICS VERSUS THE TEMPERATURE, CONDUCIVE TO CORRECT RADON MEASUREMENTS AND TO ADVANCED RADON MONITORS

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I just want to say one word to you. Just one word. Plastics.

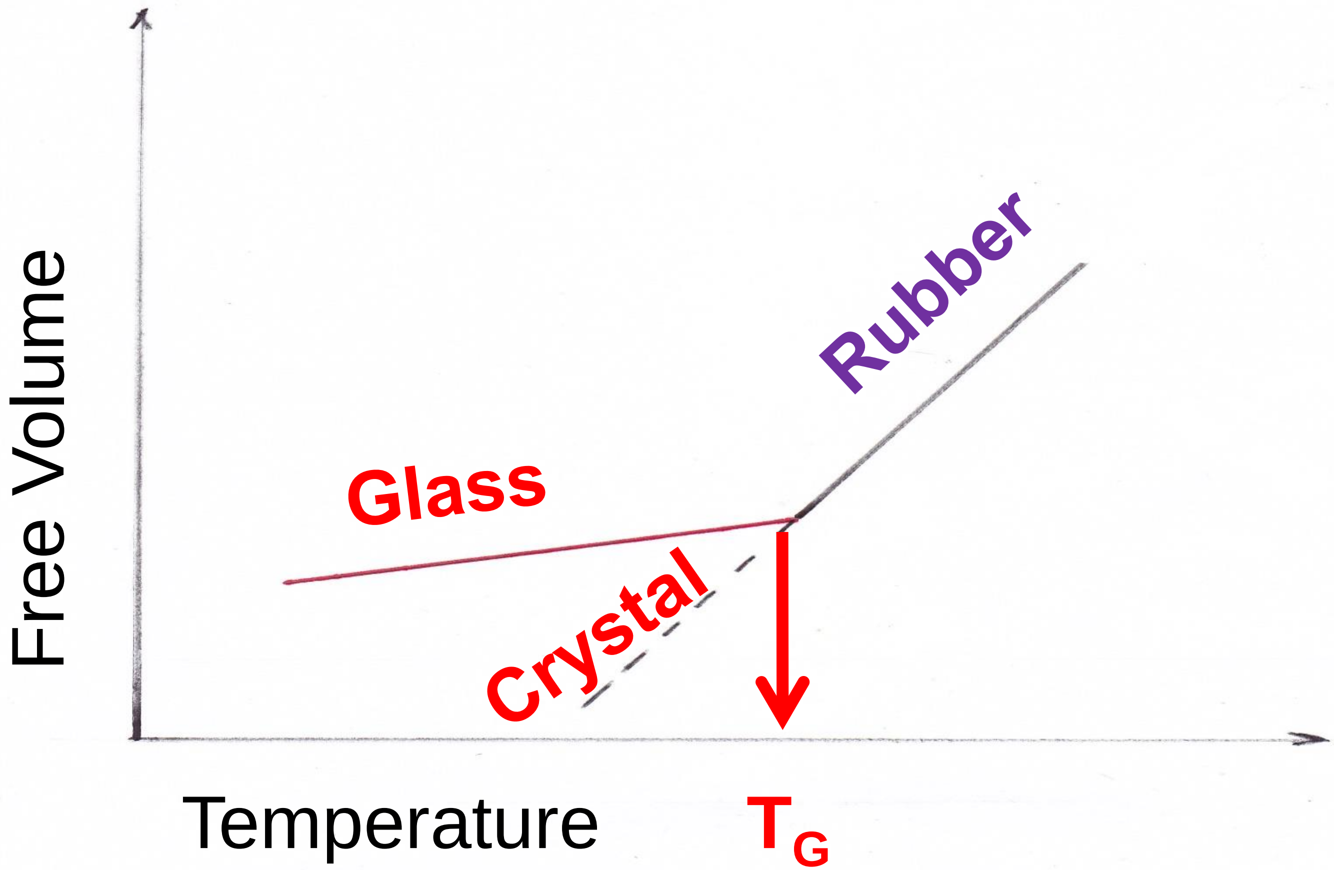
INSTEAD OF D. HOFFMAN, IT WAS THE GRADUATE L. TOMMASINO, WHO WORKED SINCE 1967 ON PLASTICS, FOR:

- **The neutron- and Rn-dosimetry**
- **The development of the permeation Rn monitors**
- **The development of the film-badge Rn monitors**

FROM GLASS TO RUBBER AT TG = ~ 600 °C

Plastics very successful for their small T_G

GLASS/PLASTIC SIMILARITIES



T_G : Transition temperature from Rubber to Glass

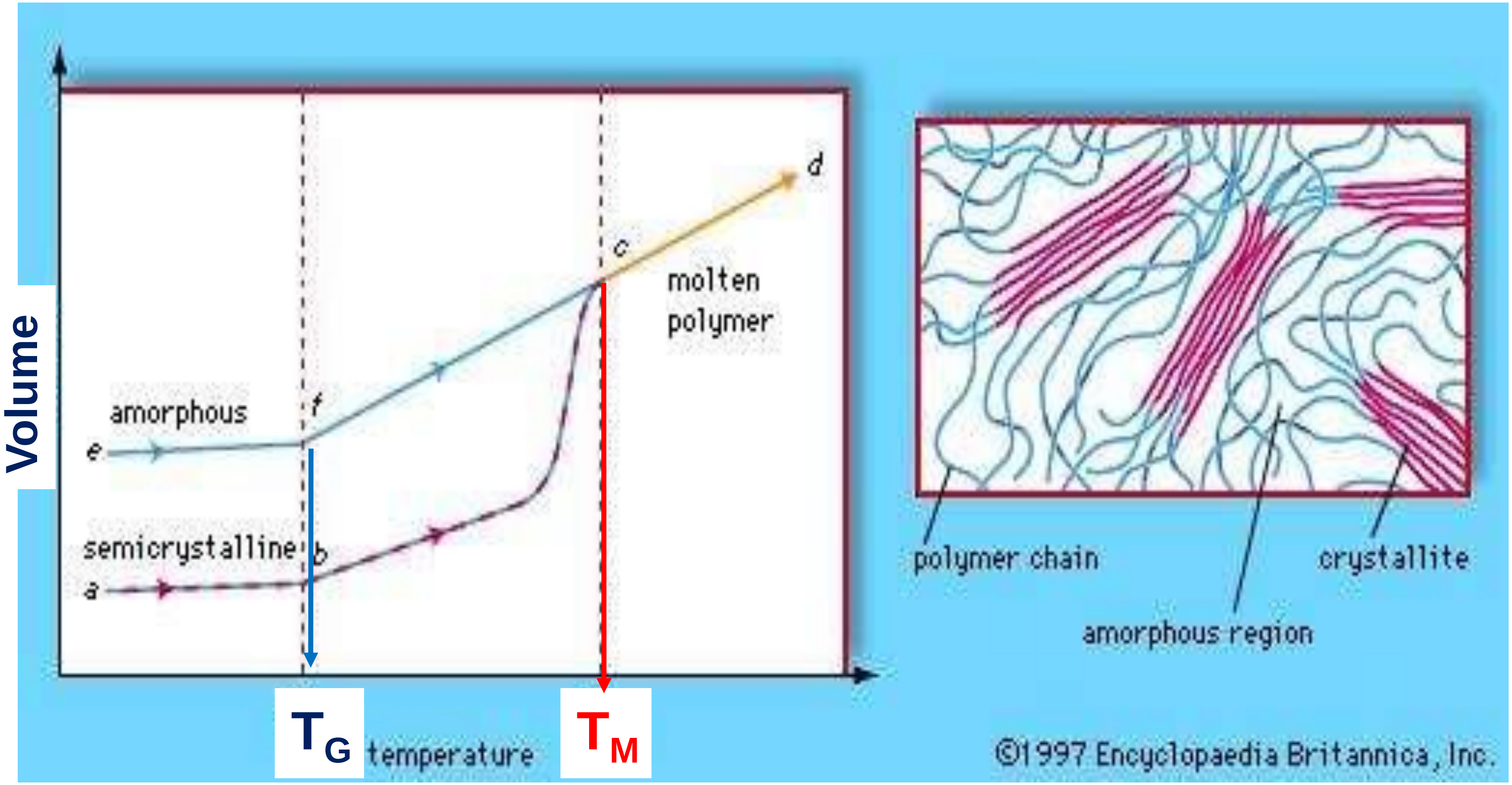
PLASTICS VS SODA-LIME GLASS

GLASS-LIKE	T_G
Soda-lime Glass	~ + 600 °C
Polyethylene Therephthalate	~ + 70 °C
Polycarbonate	~ + 150 °C

RUBBER-LIKE	T_G
Polyethylene	~ - 80 °C
Rubber	~ - 70 °C

Unfortunately, plastics have been too successful !

THERMOPLASTICS:
Amorphous (low-density); T_G
Crystalline (high-density); T_M

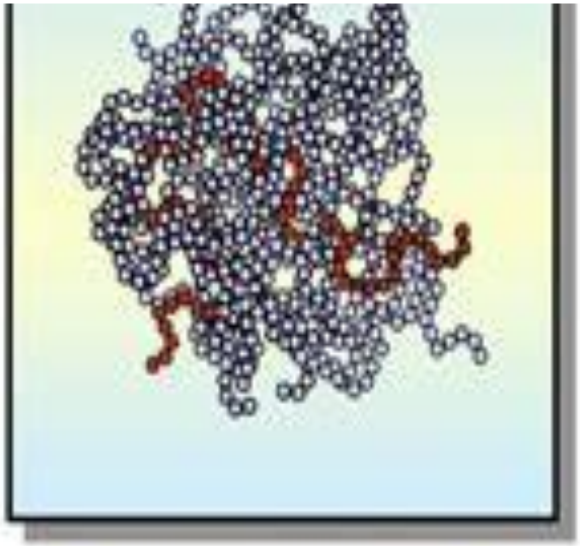


AMORPHOUS(Low density)

Glass to rubber at T_G

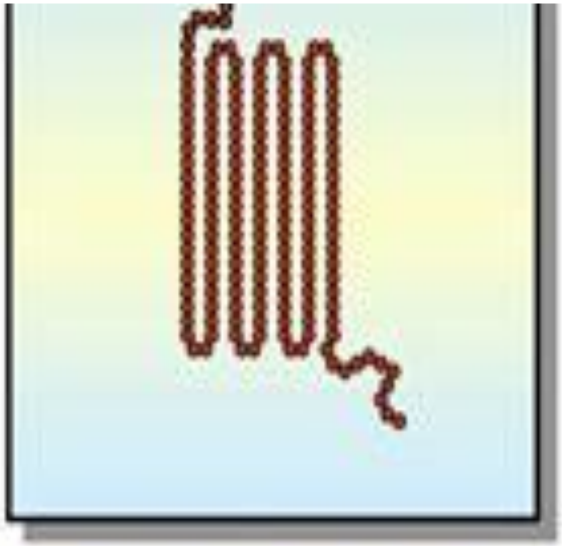
CRYSTALLINE (High density)

Crystal to liquid at T_M



RANDOM COILS

Like "cooked spaghetti"



SEMICRYSTALLINE POLYMERS

A bit like "uncooked spaghetti"

Amorphous Polymers with Plasticizers

THERMOPLASTICS: Amorphous, Crystalline	T_G	T_M
POLYETHYLENE-Low-density Amorphous	-80	
POLYETHYLENE-High-density Crystalline		+ 140
POLYCARBONATE-Makrofol N Amorphous	+ 150	
POLYCARBONATE- Makrofol DE Crystalline		+220
POLYETHYLENE-THEREPHTHALATE Amorphous	+ 70	
POLYETHYLENE-THEREPHTHALATE Crystalline		+270

THERMOPLASTICS

-Amorphous Polymers with T_G

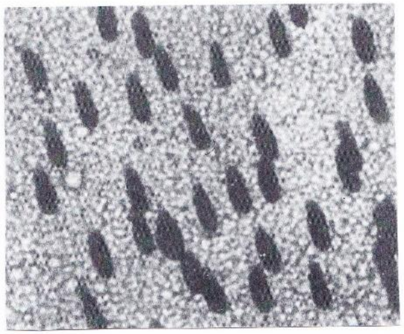
-Crystalline Polymers with T_M

THERMOSETS

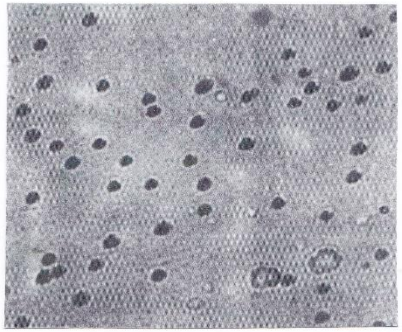
Cross-linked Polymers; High density;

No critical temperature; They just decompose or burn at high temperatures

F. F. TRACKS IN POLYTHYLENE THEREPHTHALATE



Crystalline



Amorphous

Different sensitivities (V_T/ V_B) since
V_B crystalline << V_B amourphous

TRACK DETECTORS BY THERMOPLASTICS

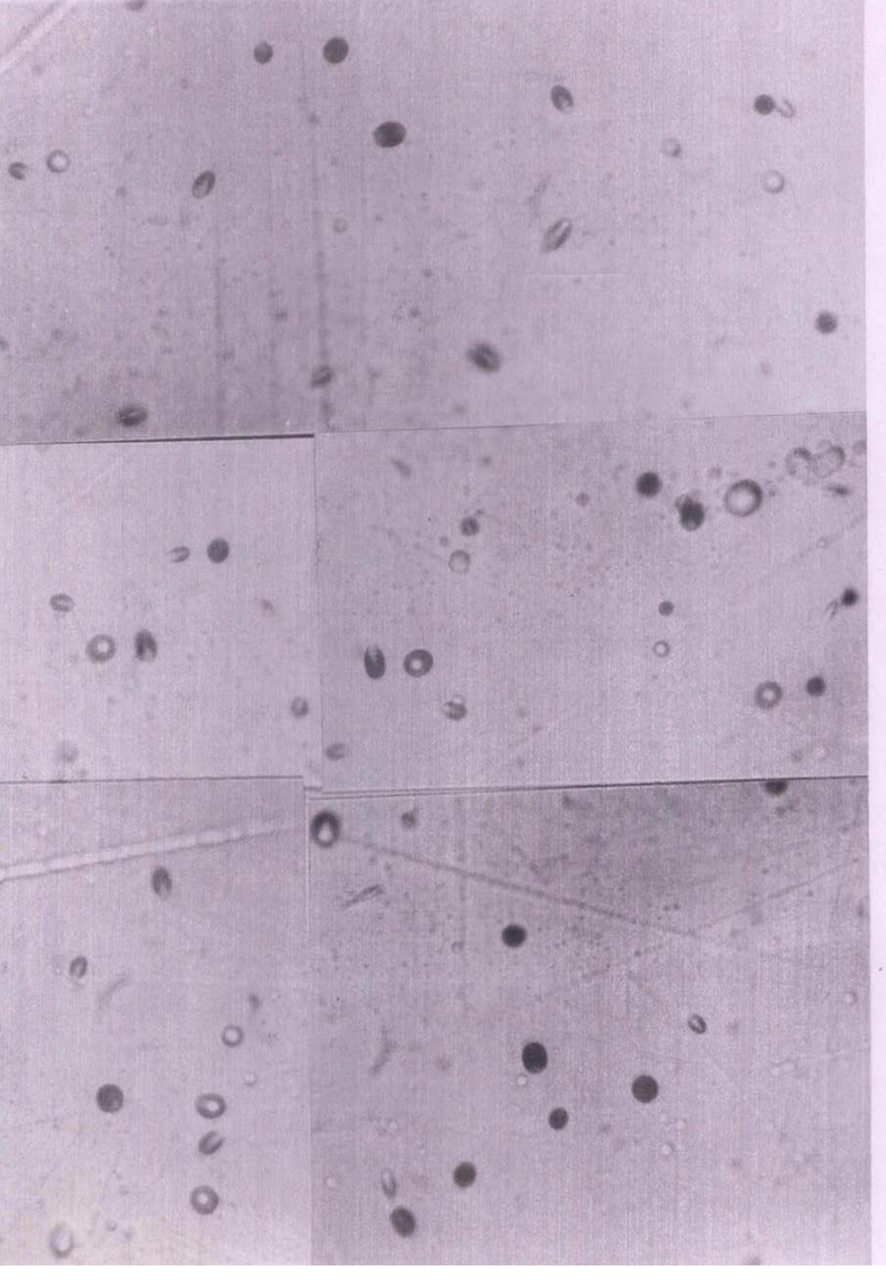
- AMORPHOUS PLASTICS (Poor detector)
-CRISTALLINE PLASTICS (Good detector)

TRACK DETECTORS BY THERMOSETS-

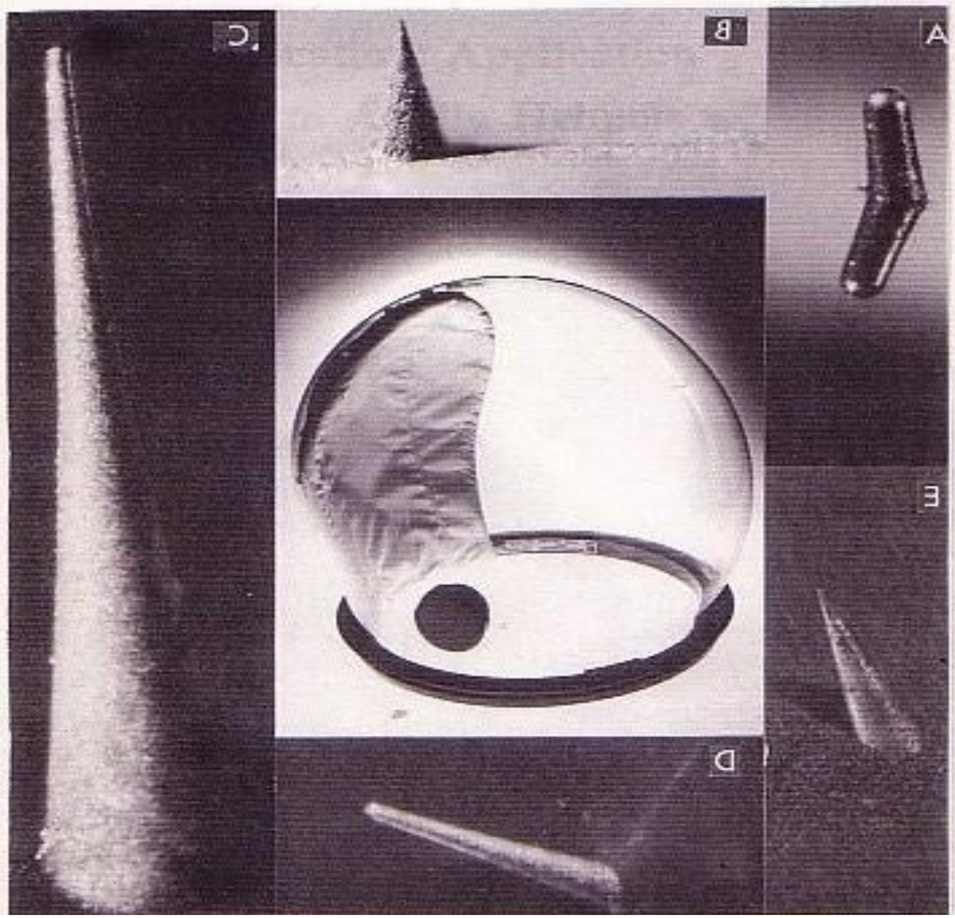
-highly cross-linked (e.g. CR-39) with unique thermal stability (Excellent Detector)

CR-39 TRACK-DETECTION CHARACTERISTICS:

-High Radiation sensitivity
-High optical clarity and uniformity
-Extremely tight molecular structure
-High thermal stability



Consumer products, made of crystalline Polycarbonate and CR-39, useful for retrospective dosimetry



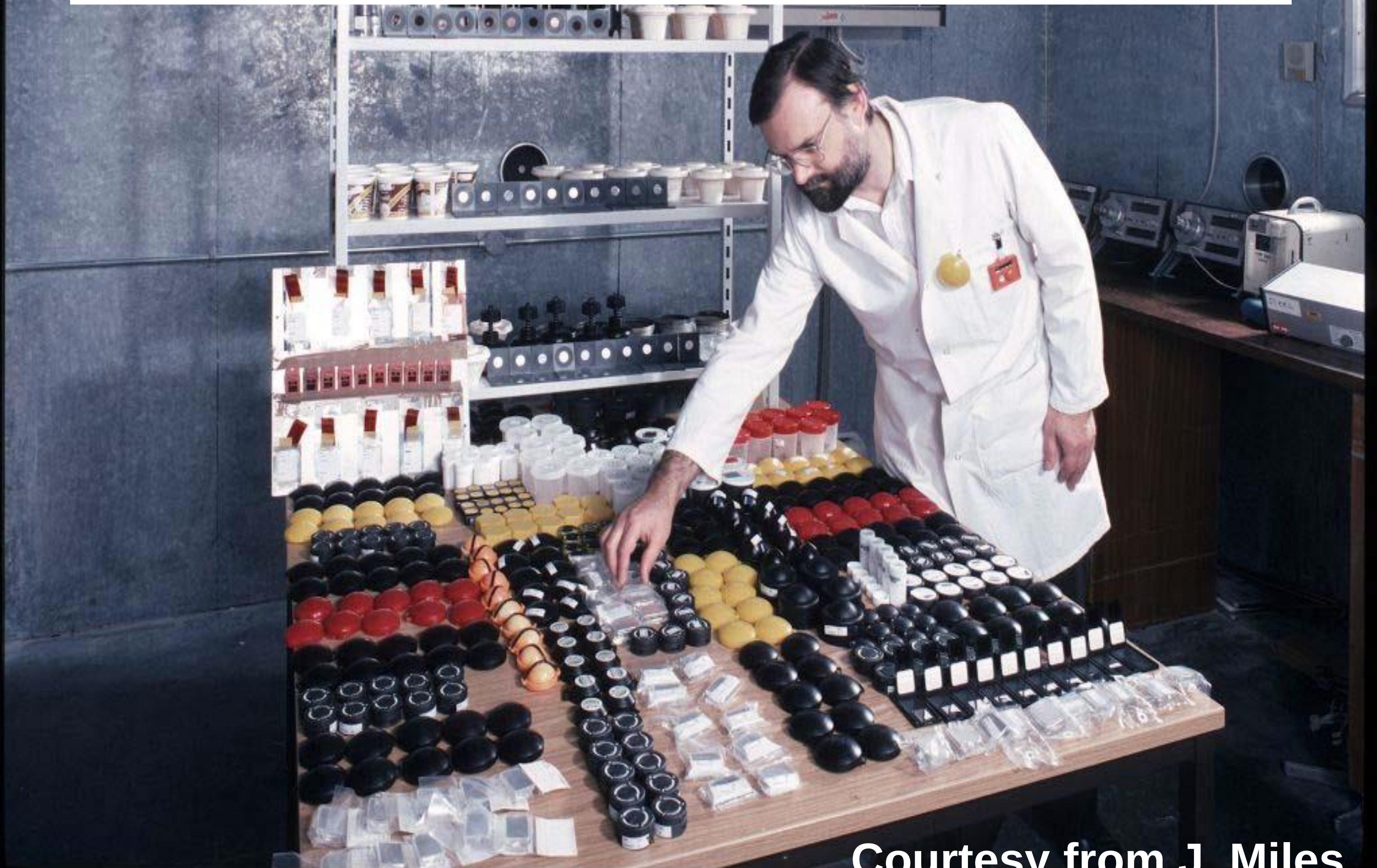
A track hole on the crystalline PC-mask of the Apollo8 astronaut (Courtesy of R. L. Fleischer)

CDs and bottles, made of crystalline polycarbonate. respectively for retrospective Radon- and Neutron-dosimetry


BTI
MODEL NO.
BD-100R
SERIAL NO.
22.0

Existing Rn-monitors , mission-oriented towards measurements in homes (20-25 °C and R.H. $\leq$ 50)

Calibrations and intercomparisons aimed at Rn-measurements in homes



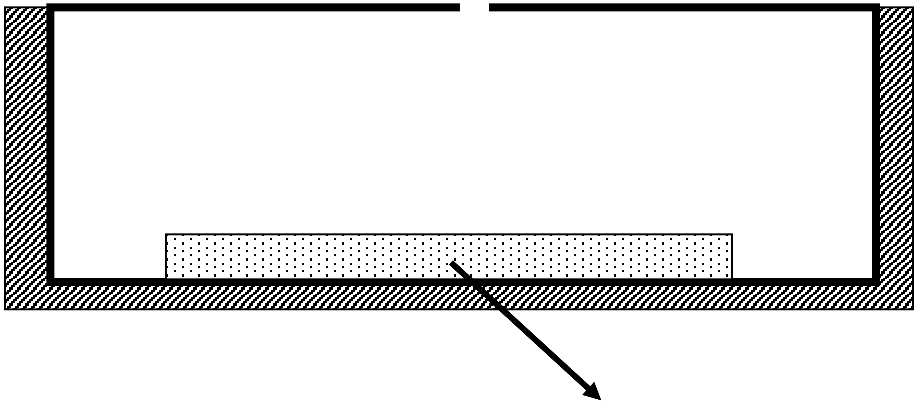
Courtesy from J. Miles

WITH THE HOME MONITORS,

a variety of errors may occur if used in workplaces or any place with severe environmental conditions

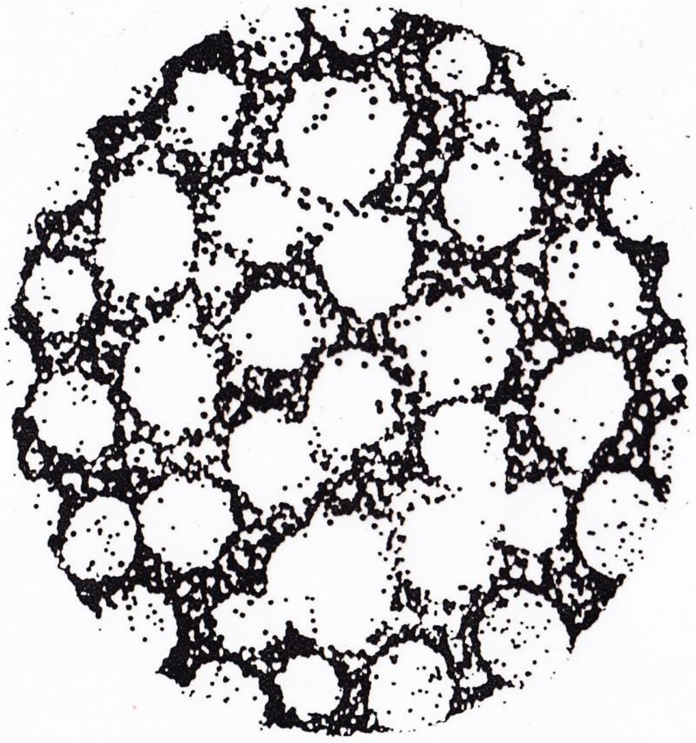
(0÷40 °C, up to 100 R.H.)

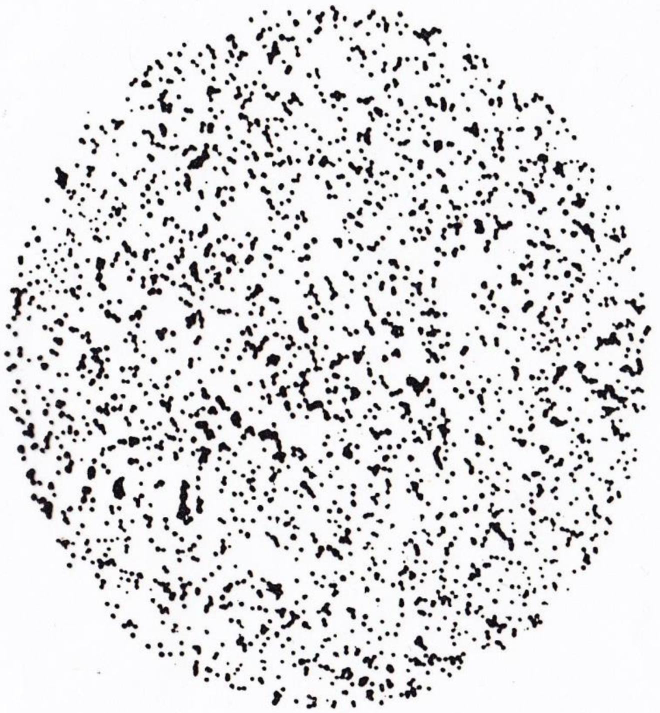
Most monitors based on diffusive chambers, with the only requirements of a height $\leq$ 2.5 cm and conductive walls (Frank and Benton,1977)



Detector

Problems of humidity for in-air diffusion-chambers first used in soil





Response ratio [Thoron]/[Radon]

82%

(Tokonami et al., 2001)

67%

(Tokonami et al., 2001)

3%

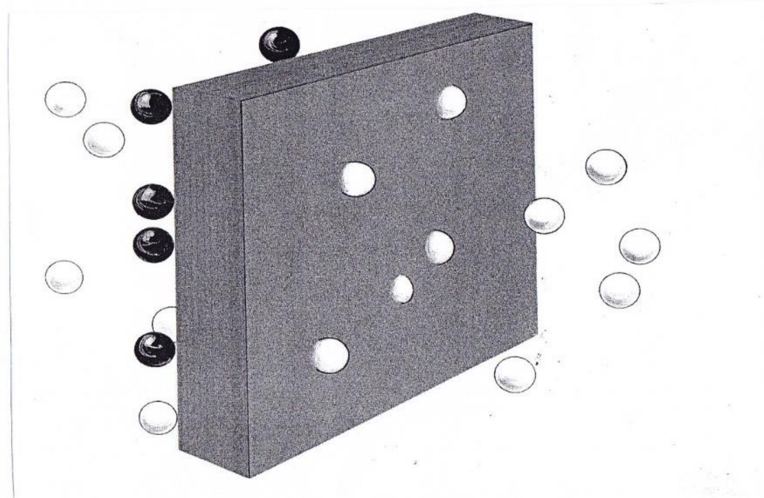
(Tokonami, 2005)

Most hidden errors for water-filled Rn-entry ports

Rn-Diffusion through the interface-air, $\tau \geq 10$ min.
Rn-permeation through water, $\tau \geq 10000$ hours

PERMEATION SAMPLING BY LOW-DENSITY (RUBBER-LIKE) POLIETHYLENE

Permeability to Radon three orders of magnitude larger than that to water vapor

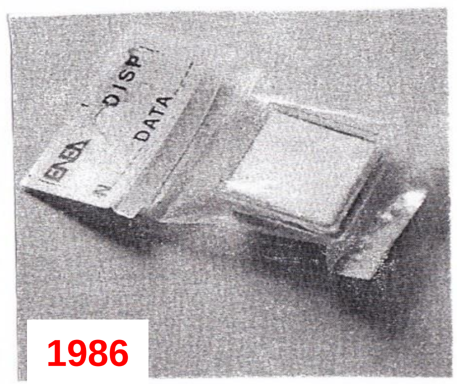


+

fast thermodynamic equilibrium of the Rn at the rubbery interface (Henri's Law)

Permeation samples to stop water vapor, thoron, etc….but a long permeation time, τ_M

$$\tau_M = dV/PS$$

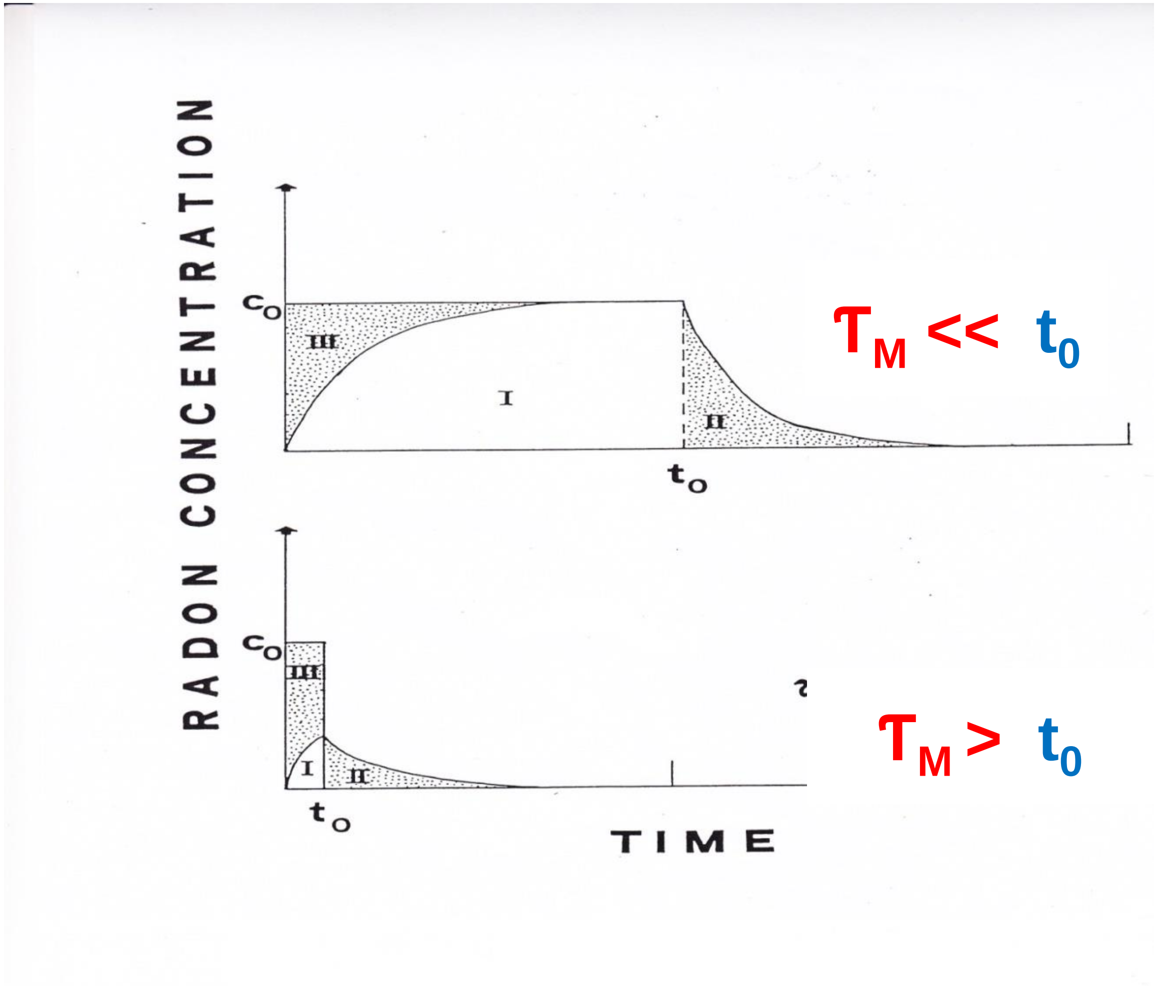


τ_M=34 hours

τ_M= 6 hours

τ_M=33 hours

$\tau_M = dV/PA$

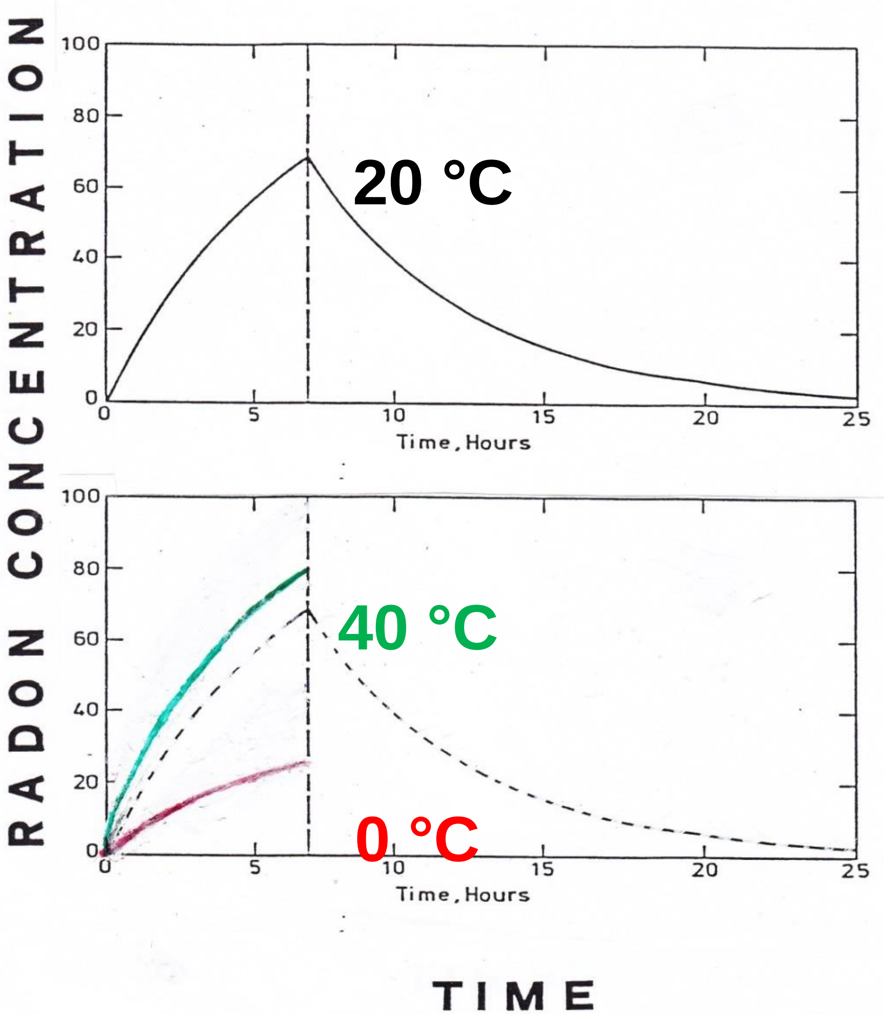


AREA II = AREA III, provided constant P

-Very wrong! P changes with temperature

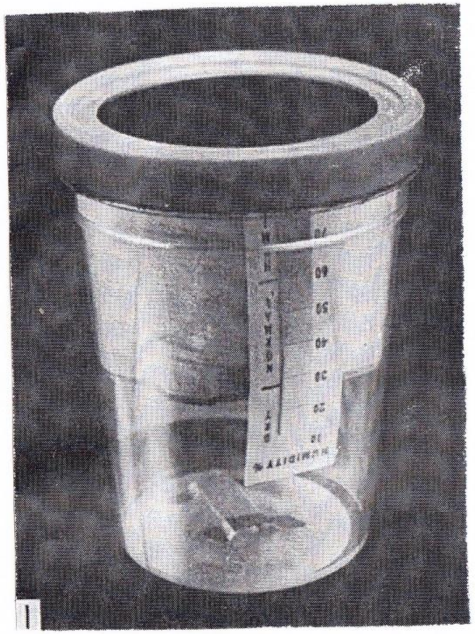
Temperature-T (°C)	PE-Permeability-P ($10^{-7} cm^2/s$)
0 °C	0.15 ± 0.04
20 °C	1.20 + 0.04
40 °C	3.60 + 0.50

Permeation time, T_M=dV/PA

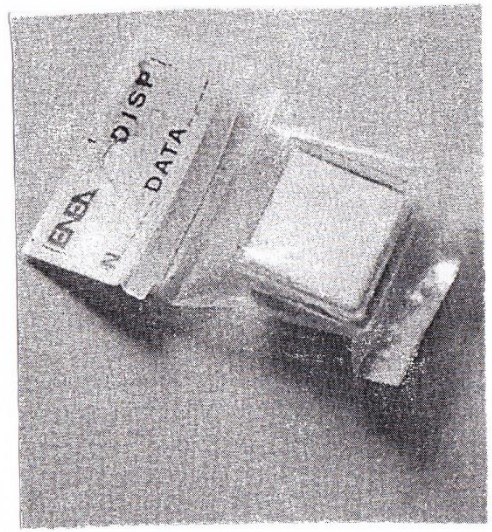


Responses at 0°C, 20 °C, 40 °C with T_M= 34 h

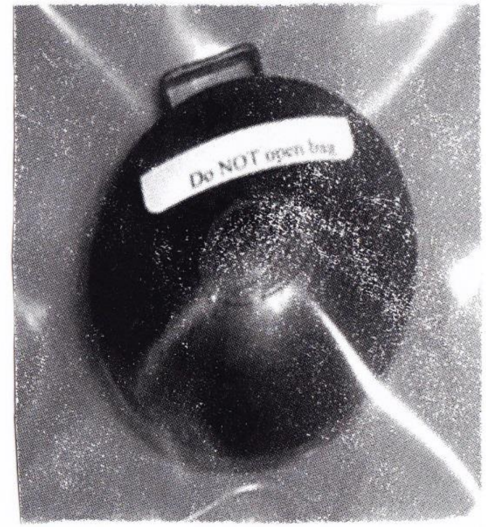
$\tau_M = dV/PA$



τ_M=34 hours



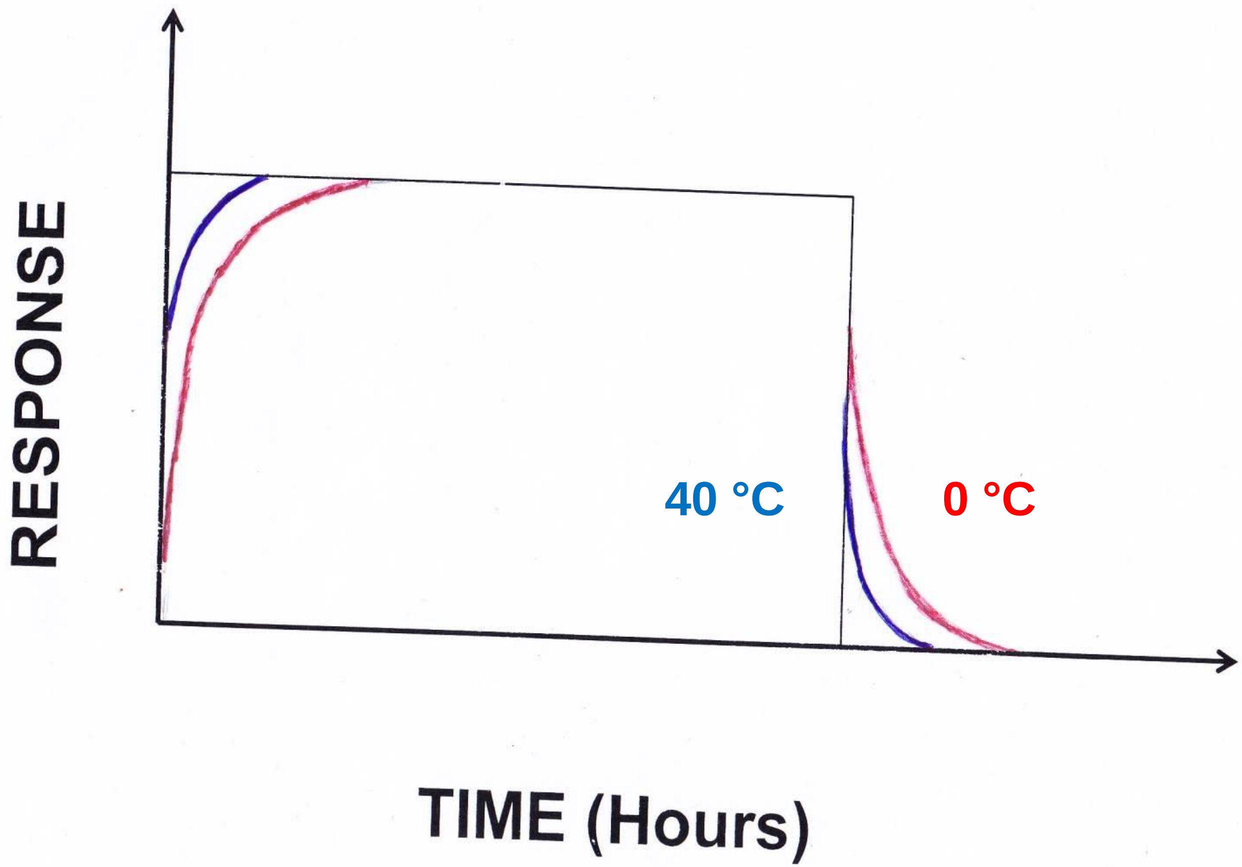
τ_M= 6 hours



33 hours

Temp.	C_{in}/C_o	C_{in}/C_o	C_{in}/C_o
0°C	0.32	0.73	0.33
40°C	0.92	0.99	0.92

$\tau_M \leq 1$ hour $t_0 = 8$ hours



For an exposure of 8 working hours , $\tau_M \leq 1$ hour as in diffusive chambers

For existing permeation monitors, τ_M (dV/PA) $\leq$1 hour only for small air volumes (but too small responses)

τ_M $\leq$1 hour and any desired response by Rn-sorption-based radiators

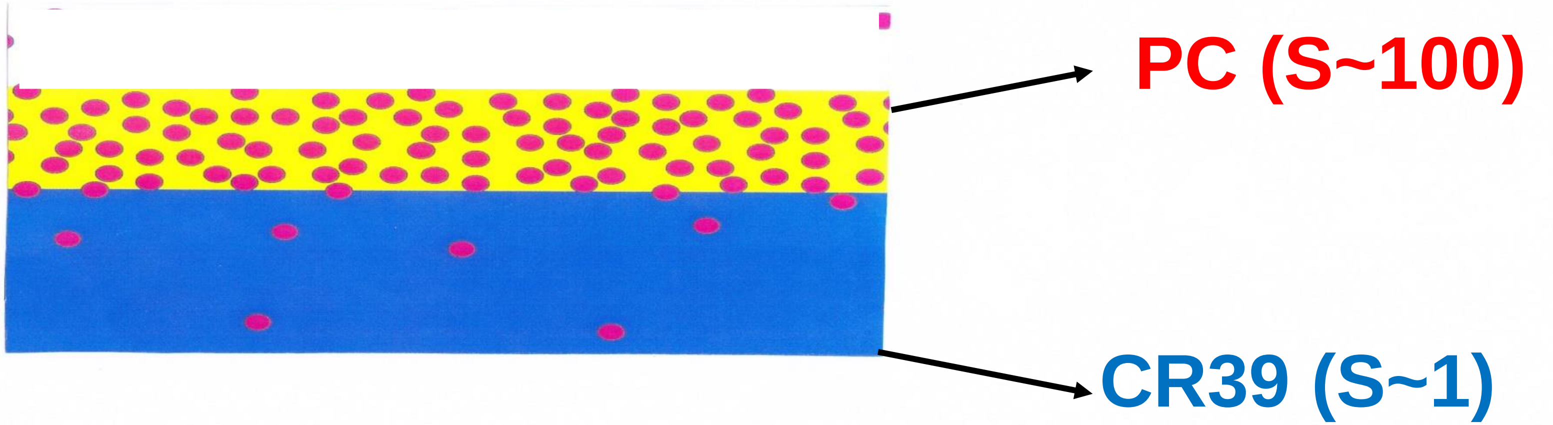
GAS (RADON) SORPTION IN SOLIDS
(Mc Bain, 1909)

1. ABSORPTION:
Gas-sorption into the solid bulk

2. ADSORPTION:
Gas-sorption onto the solid surface

Absorber	Solubility, S
Liquid Scintillators	~ 10
Polycarbonate	~ 100
CR-39	~ 1

First Rn-film badge made of
AMORPHOUS POLYCARBONATE (Radiator)
CR-39 (Detector)



Time to equilibrium: $T=d^2/6D$

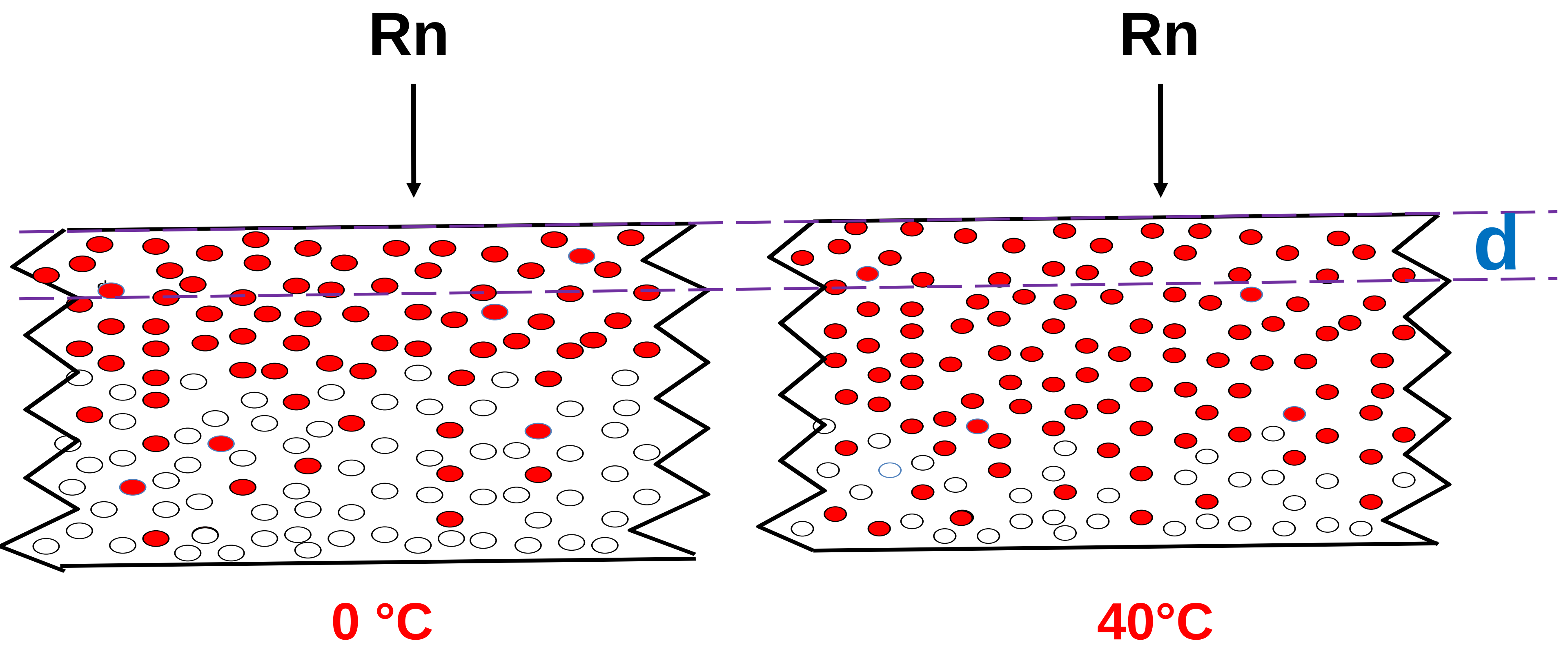
MEDIUM	$D(cm^2/s)$
Air	$\sim 10^{-1}$
Polycarbonate	$\sim 10^{-10}$

CD equilibrium-time ~ 1 month

FAST EQUILIBRIUM TIME
by a small film thickness, d

20-µm-polycarbonate: T ≤ 3 hours

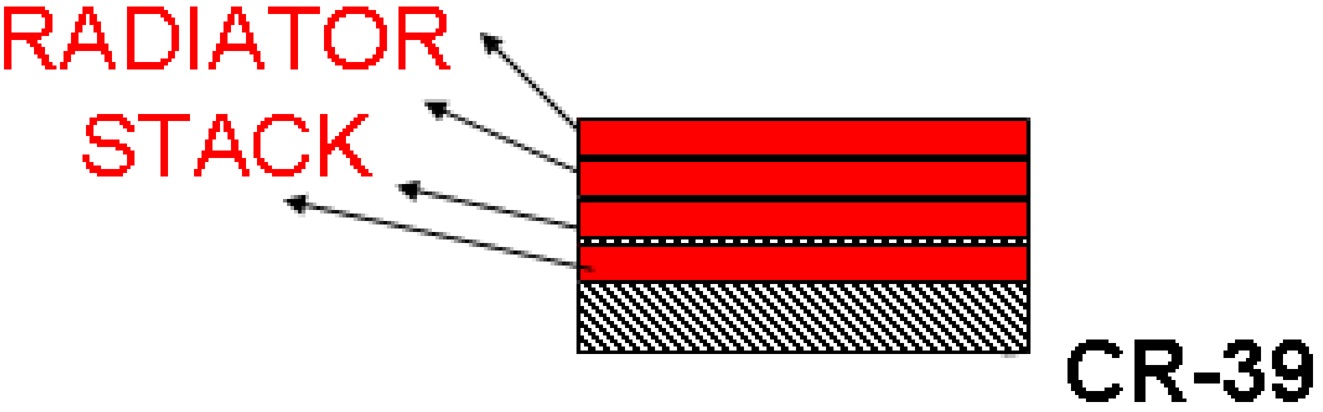
5-µm-polycarbonate: T ≤ 10 minutes



$$T_{Abs} = (d^2/6D)$$

Small d: fast and no temperature-dependent response

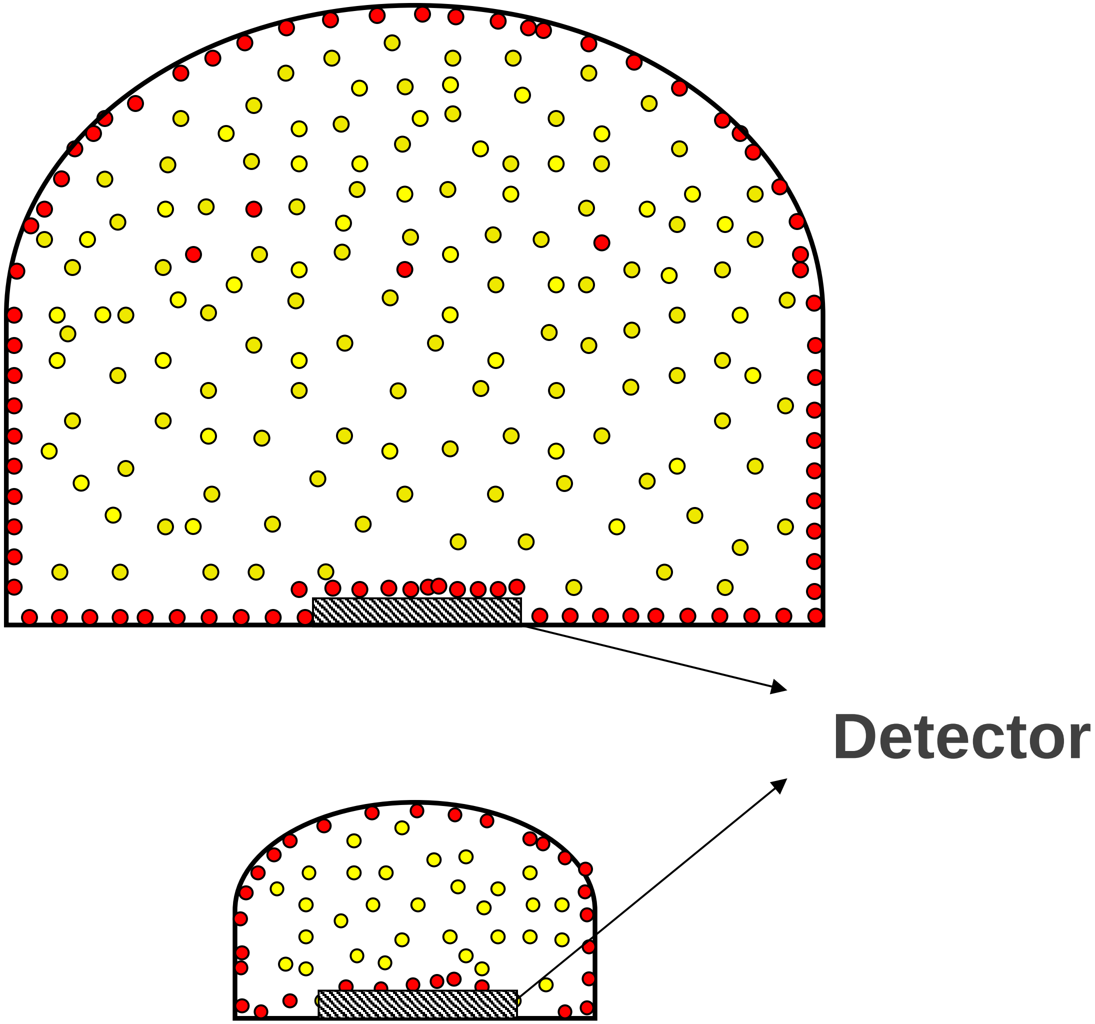
The stack absorption-time, T_{abs}, is that of a single film



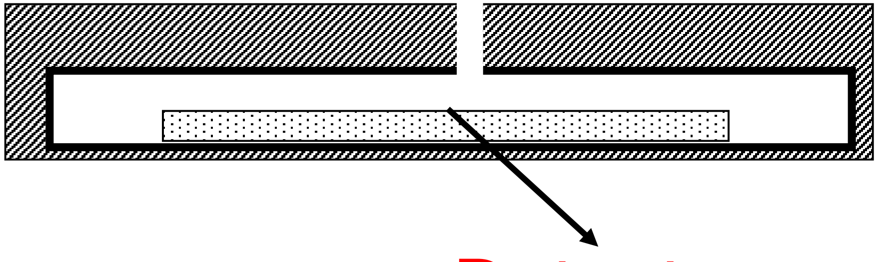
$$\epsilon_{max} = KCSR_{max}$$

For $d \leq R_{max}$, different responses for different d

ϵ_{max}= KCSR_{max}; Not valid for large air-space radiators, i.e. with airspace with height > 2.5 cm

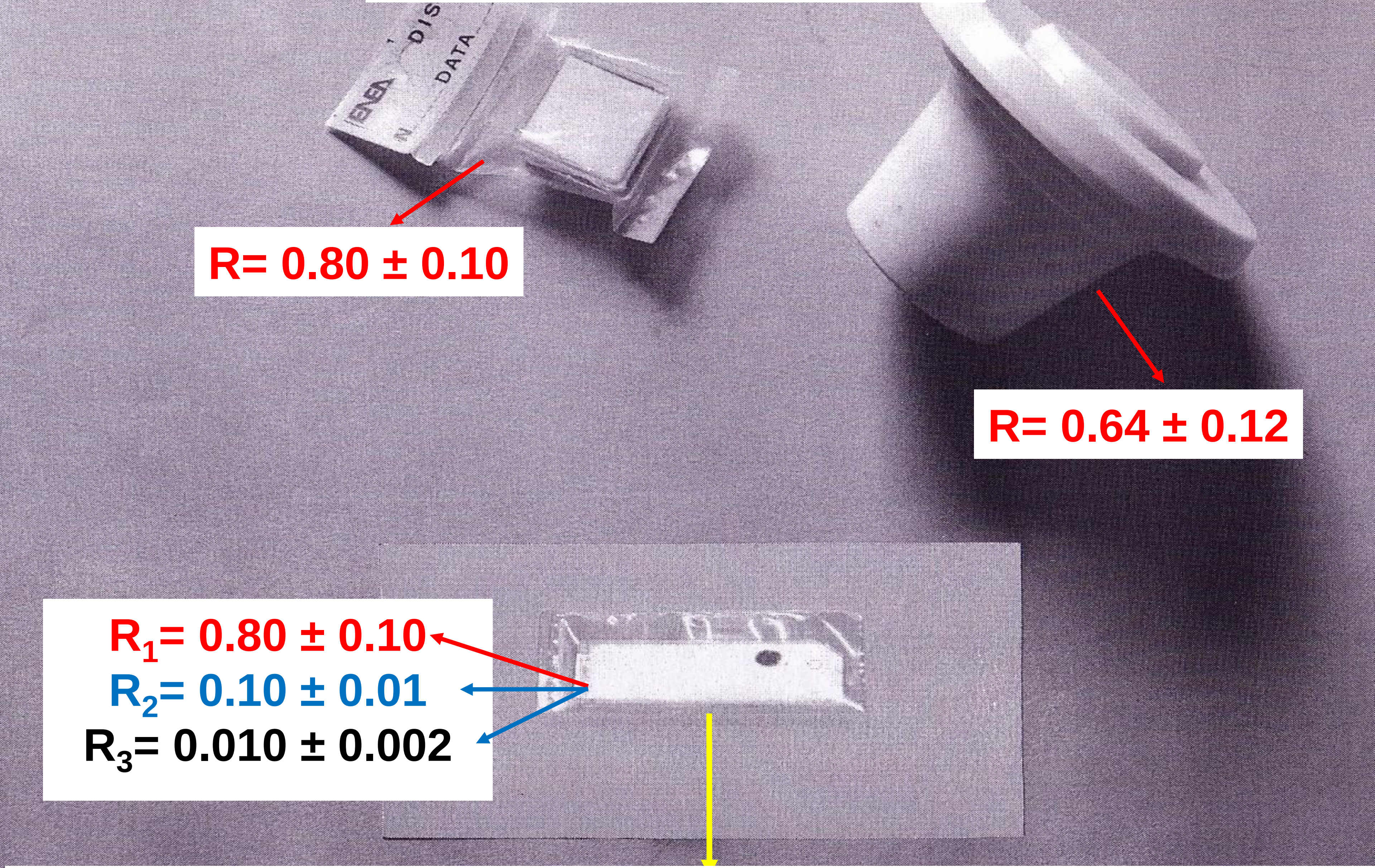


Diffusive chambers for Rn monitoring must have heights ≤ 2.5 cm (Frank and Benton,1981)



For heights ≤ 0.5 cm the Rn absorption by the plastic holder is dominant.

R (Tracks.m^3/cm^2.kBq.h



All-encompassing Rn Monitor, used indoors, in soil, in water.

-Easily wearable and deliverable

-Enclosable in any (x-*, γ-, n-) personnel-dosimetry holder*

-*The holder of* choice: a heat sealed Tyvek Bag

FROM: $R = k \cdot C \cdot S$(Solubility)$\cdot d$(Thickness):

- Badges with any desired response

Or alternatively:

-a new method to evaluate Solubility, S

Large S nd Large D by amorphous plastics	S	D (cm^2/s)
POLYETHYLENE- Rubbery Low-density (Amorphous)	~ 4	~10^{-7}
POLYCARBONATE Low density (Amorphous)	~ 100	~10^{-10}
POLYETHYLENE-THEREPHTHALATE Low density (Amorphous)	~ 10	~10^{-9}

The largest Permeability, P= S.D, with rubbery polyethylene

Radon absorption per unit surface, $Q_{Rn} = (D/\lambda)^{1/2}.S.C$ -Large Q_{Rn} for amorphous polymers -Low Q_{Rn} for crystalline polymers	S	D (cm^2/s)
POLYCARBONATE-Makrofol N Amorphous	~ 100	$\sim 10^{-10}$
POLYCARBONATE-Makrofol DE Crystalline	~ 30	$< \sim 10^{-10}$
POLYETHYLENE-THEREPHTHALATE Amorphous	~ 10	$\sim 10^{-9}$
POLYETHYLENE-THEREPHTHALATE Crystalline	~ 1	$< \sim 10^{-9}$

$P_{(Permeability)} = S.D$

The largest P with the rubbery Polyethylene

(For permeation membrane)

Rn-absorption per unit surface

$$Q_{Rn} = (D/\lambda)^{1/2}.S.C$$

-The lowest Q_{Rn} for crystalline polymers

(For detector housing)

-The largest Q_{Rn} with glassy polymers

(For film-badge radiator)