Universität Zürich[UZH]

Physik Intitut

High sensitivity Radon studies

Review

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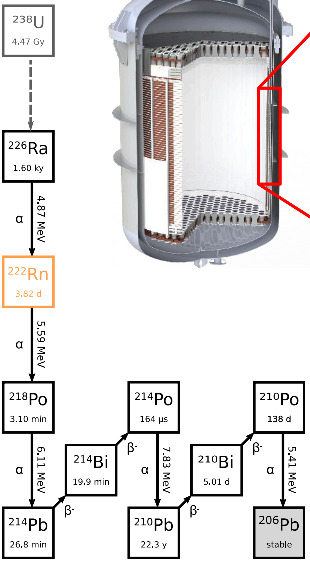
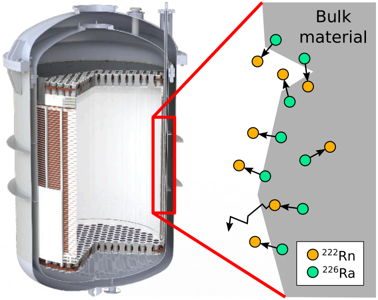
October 3, 2024 - Low Radioactivity Techniques (Kraków)

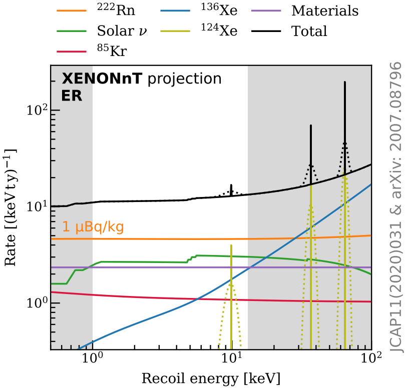
LOW RADIOACTIVITY TECHNIQUES 2024 WORKSHOP IX

Why we care about radon...





- ^{222}Rn can distribute homogeneously: No fiducialization possible
- Important background for low energy WIMP, $0\nu\beta\beta$ decay and solar and reactor neutrino searches



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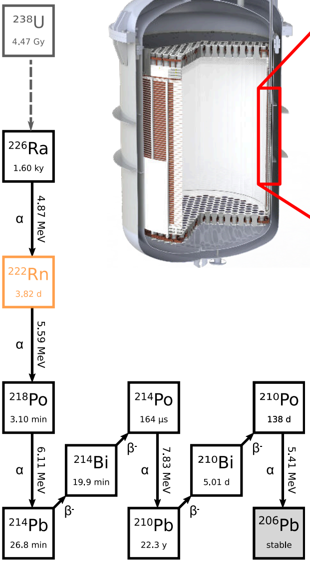

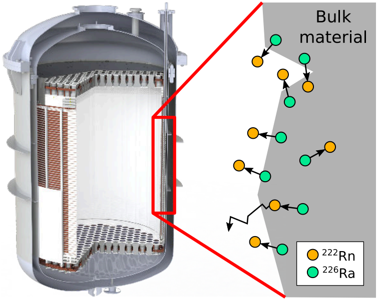

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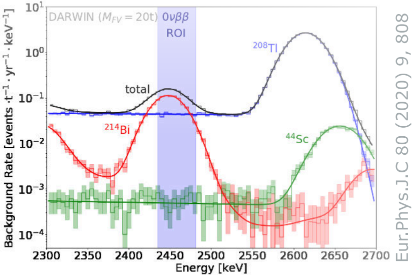

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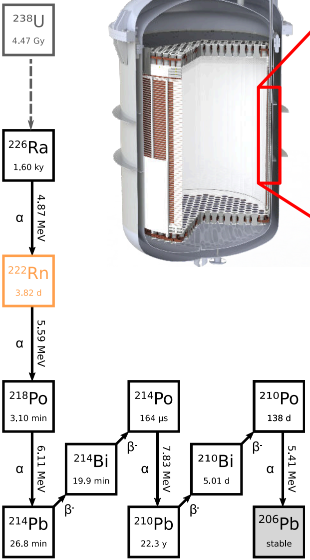

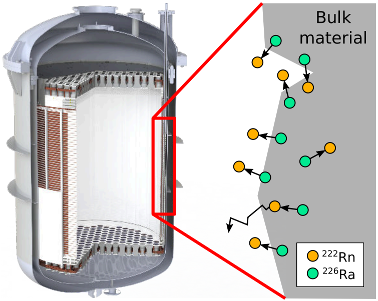

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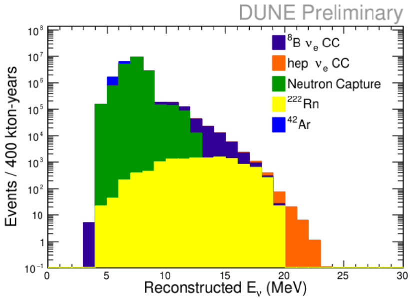
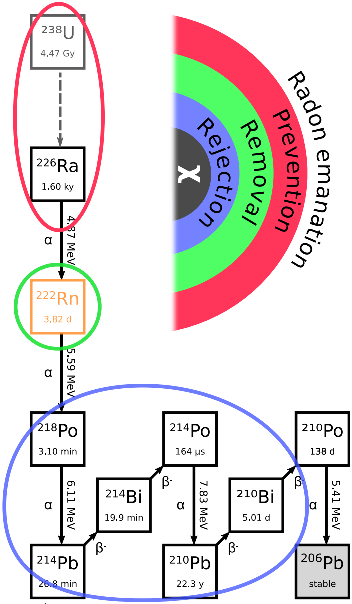


… and what we can do against it!



- Methods that **prevent** radon from entering the active volume
- Material pre-selection, radon barriers, new detector designs

- Active **removal** of radon that has already entered the detector
- E.g. distillation, adsorption, etc.

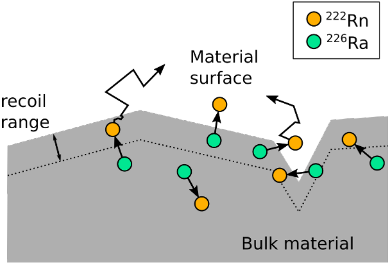
- **Rejection** of radon-induced events in the analysis
- ER/NR separation, convection, time coincidence, …

$\Rightarrow$ **Optimal combination needed!**

Radon release mechanism

Emanation by recoil

- α-decay:
  $^{226}\mathrm{Ra} \xrightarrow{4.9\,\mathrm{MeV}} {}^{222}\mathrm{Rn} + \alpha$
- 86 keV recoil energy
  $\Rightarrow \sim$ 14 nm (steel)



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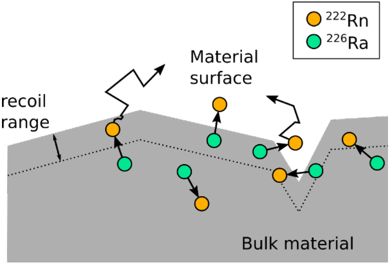

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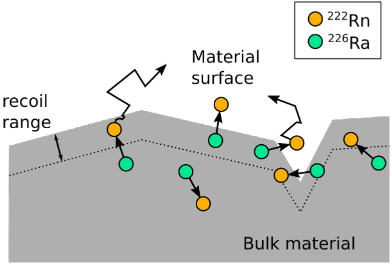
Emanation by diffusion

$$\underbrace{\frac{\partial}{\partial t}\eta(x,t) = D\frac{\partial^2}{\partial x^2}\eta(x,t)}_{\text{2nd Fick's law}} - \overbrace{\lambda \cdot \eta(x,t)}^{\text{Decay}}$$

- Diffusion constant D depends on material and temperature
- Decay constant λ depends on radon isotope (i.e. $T_{1/2}^{222Rn} \gg T_{1/2}^{220Rn}$)

Radon release mechanism



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- Diffusion constant D depends on material and temperature
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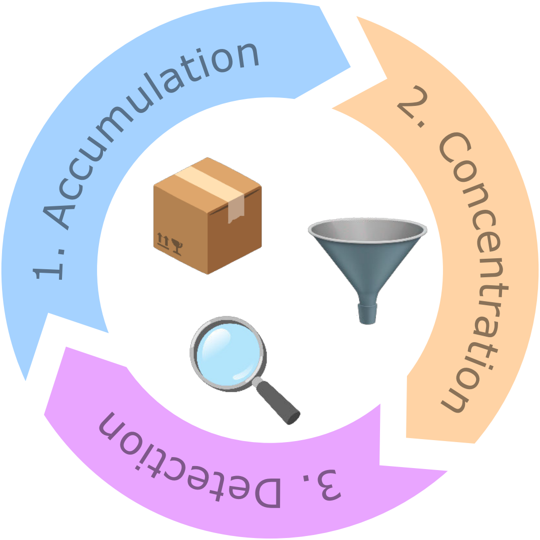
Which one dominates?

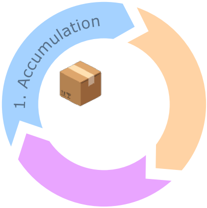
Strongly depends on the material, and the type of sample!

- Probes surface impurities, not bulk impurities!
- Knowing ^{226}Ra contamination does not tell you ^{222}Rn emanation rate (only upper limit).

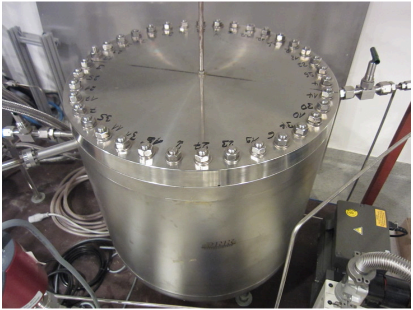
^{222}Rn measurement



^{222}Rn measurement (1. Accumulation)

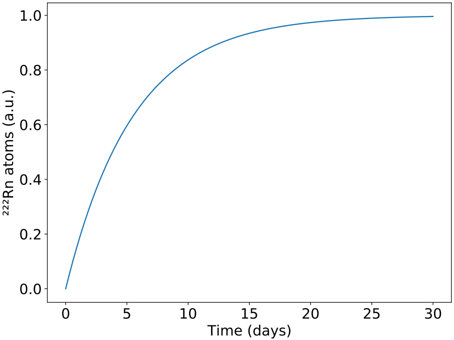


1. Place sample in leak tight container
2. Fill container with radon free carrier gas (e.g. N_2, He, ...)
3. Wait for the radon to accumulate



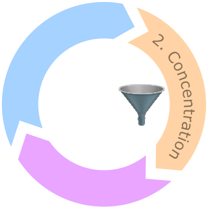
→ Container must have a very low intrinsic emanation rate!

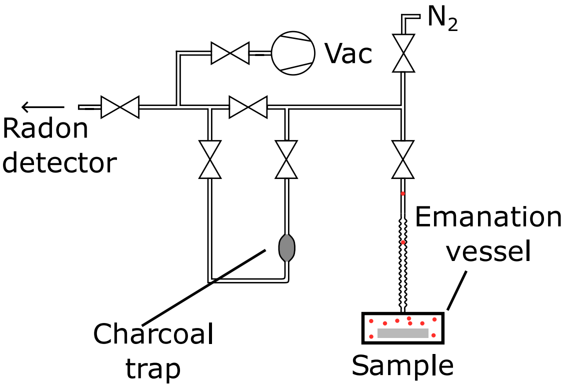
$$A(t) = A_{eq} \cdot \left(1 - e^{-\lambda_{222Rn} \cdot t}\right)$$



^{222}Rn measurement (2. Concentration)

1. Transfer emanated radon with carrier gas
2. Trap radon in a cold trap (e.g. charcoal) and remove all carrier gas
3. Heat the trap up to release the radon
4. Transfer the radon atoms to the detector using the gas flow required for the measurement.





— Duration of the transfer typically around half an hour

— Note that this makes this approach unsuitable for measurement of ^{220}Rn.

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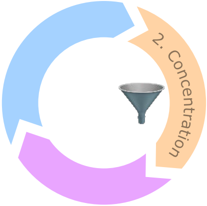

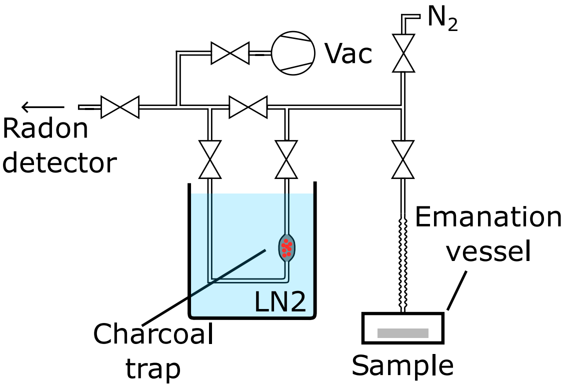

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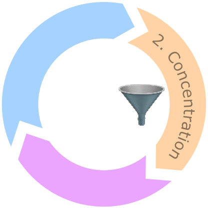

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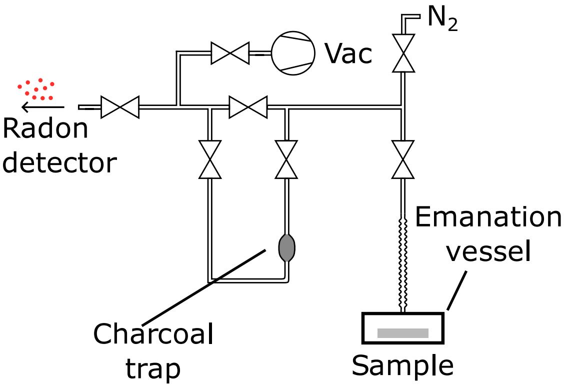

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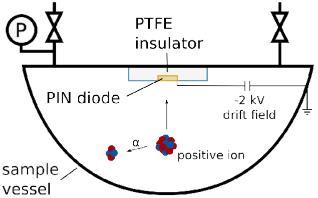
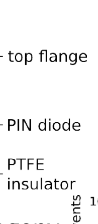
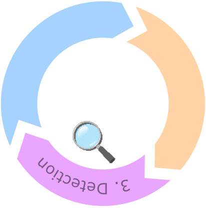
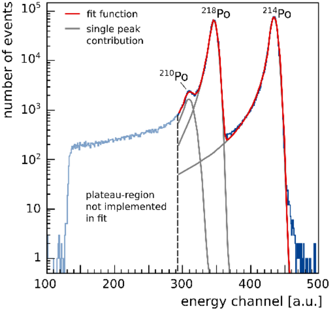
^{222}Rn measurement (3. Detection)







1. Detection of alpha decays of radon progeny (MeV energies, monoenergetic)
2. Detectors include: Electrostatic radon monitors, proportional counters, liquid scintillator detectors, cryogenic alpha spectrometers
3. Often a purifier (getter) is needed to maintain the radon detection efficiency
4. Activity decreases following the decay of radon in the detector



PhD Thesis S. A. Brünner, Heidelberg (2017)

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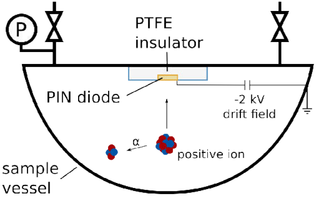

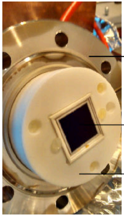

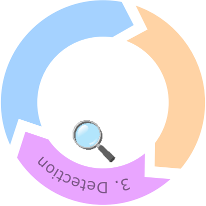

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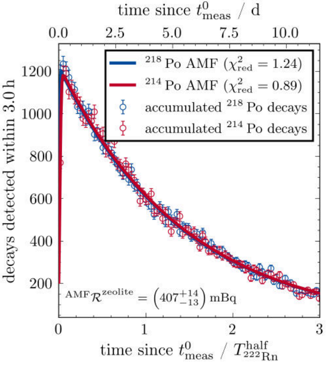
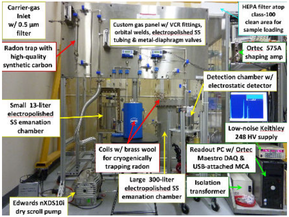


JINST 19 (2024) 04, P04014

Radon screening facilities used by LZ

Detector	Type	Chamber volumes (L)	Chamber blank rates (mBq)	Transfer efficiency (%)	Detector efficiency (%)	Cross-calibration (measured/EXO-activity)
SDSM&T	PIN-diode	13 300	0.2 0.2	94 80	25	0.89 ± 0.15 1.11 ± 0.28
Maryland	PIN-diode	4.7	0.2	96	24	1.13 ± 0.19
UCL	PIN-diode	2.6 2.6	0.2 0.4	97 97	30	1.49 ± 0.15
Alabama	Liquid Scint.	2.6 2.6	<0.4	34	36	0.83 ± 0.17

Eur.Phys.J.C 80 (2020) 11, 1044



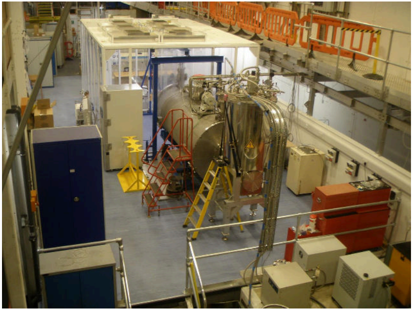
South Dakota School of Mines and Technology

Maryland

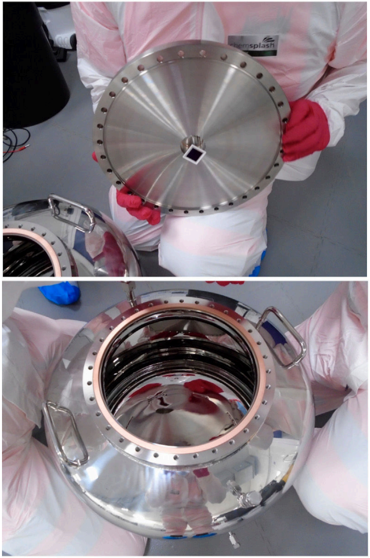
Alabama

Facility at Boulby Underground Laboratory (UK)

- two 80 liter electrostatic monitors MDA 90%: 40μBq
- Cold radon emanation facility (CREF) (MDA 90% $<$ 0.1mBq).
- Large 200 liter and small 2.7 liter emanation chamber. That can be stabilized at $\sim$77K.



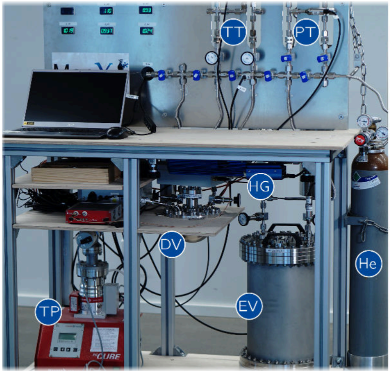
AIP Conf.Proc. 2908 (2023) 1, 080005

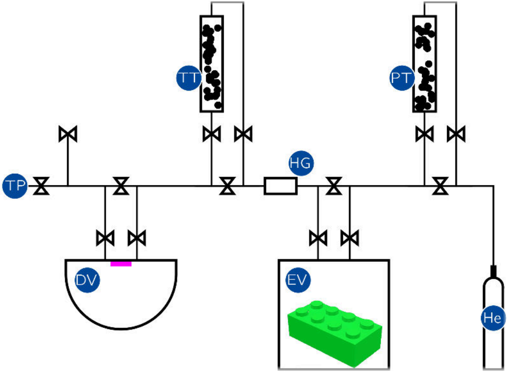


Front.in Phys. 11 (2023) 1310146

Radon screening at U. Freiburg (MonXe)

- Hemispheric electrostatic detector (1.2 liter)
- Electropolished emanation vessel (20 liters)
- Good collection and detection efficiency: $(36.3 \pm 0.2(\mathrm{stat.}) \pm 1.4(\mathrm{syst.}))\%$
- Minimum detectable activity (MDA) $\sim 60\mu$Bq (@ 90% C.L.)

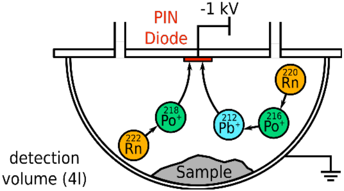




JINST 19 (2024) 04, P04014

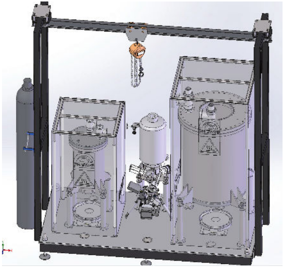
Radon measurement at MPIK (XENONnT)

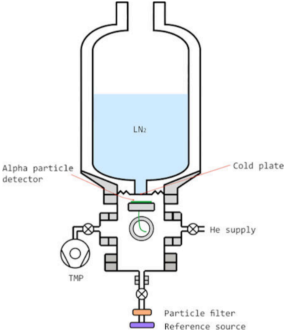
- $>$20 ultralow background miniaturized proportional counters
- Sensitivity $\sim$ 20μBq
- Fully automated ^{222}Rn concentration system
- $\sim$ 15 sample vessels (0.1 – 80 lit.)
- 3 electro-static radon monitors (^{222}Rn & ^{220}Rn)

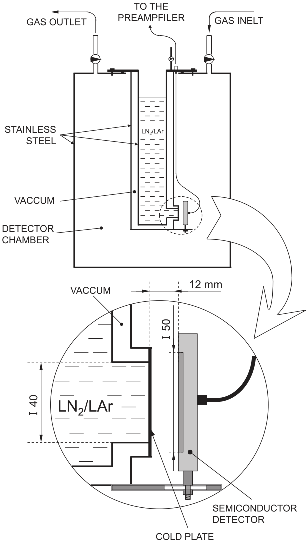


Cryogenic radon detector (Jagiellonian University)

- Cryosorption of ^{222}Rn and ^{220}Rn in front of silicon detector
- Minimum detectable activity: $\sim 20\mu$Bq
- Systematic studies of detection efficiency depending on gas pressure and geometry

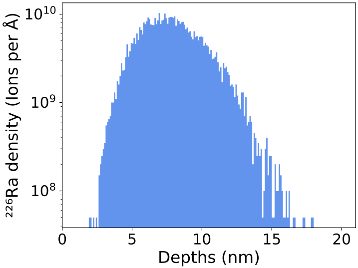


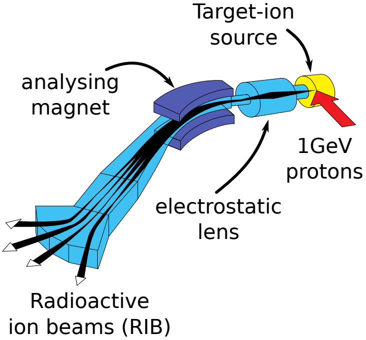




J Radioanal Nucl Chem 277, 199–205 (2008)

How to compare? - Reliable calibration sources!



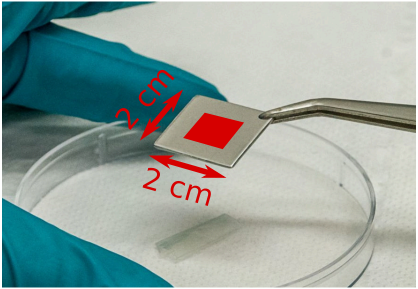


— Proof of concept (2017) $2{\times}5E11$ ^{226}Ra ions ($\approx$ 7 Bq) implanted at 30 keV at ISOLDE facility (CERN)

— Ion range distribution (SRIM) $\mu = 7.9\,\mathrm{nm}, \sigma = 2.3\,\mathrm{nm}$

\+ Expected emanation fraction due to recoil: 23%

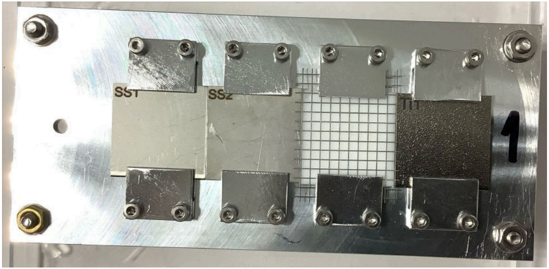
\+ Mechanically stable



Appl.Radiat.Isot. 194 (2023) 110666

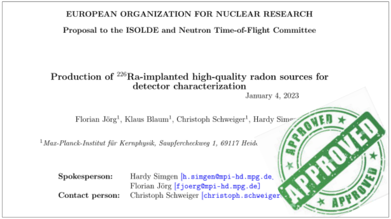
How to compare? - Reliable calibration sources!

- Recoil dominated emanation of $^{222}\mathrm{Rn}$
  $\rightarrow$ Good stability with pressure, temperature, gas-type, etc.
- Emanation from a bare metal surface
  $\rightarrow$ Low outgassing of impurities



Applicability and future production:

- Valuable samples for radon mitigation studies and detector calibration
- Study radon emanation from different material types
- Beam time approved for 20 new samples, 10 are already done



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Production of ^{226}Ra-implanted high-quality radon sources for detector characterization

January 4, 2023

Florian Jörg[1], Klaus Blaum[1], Christoph Schweiger[1], Hardy Sim

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Spokesperson: Hardy Simgen [h.simgen@mpi-hd.mpg.de
Florian Jörg [fjoerg@mpi-hd.mpg.de]

Contact person: Christoph Schweiger [christoph.schweiger

APPROVED

Thank you very much!

LOW
RADIOACTIVITY
TECHNIQUES

2024
WORKSHOP IX

JAGIELLONIAN UNIVERSITY
IN KRAKÓW