Production and characterization of a ^{222}Rn-emanating stainless steel source

ICRM-LLRTM Conference - 2022

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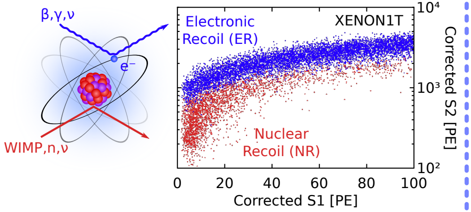
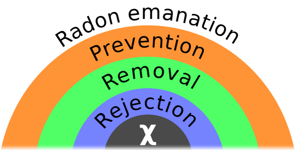
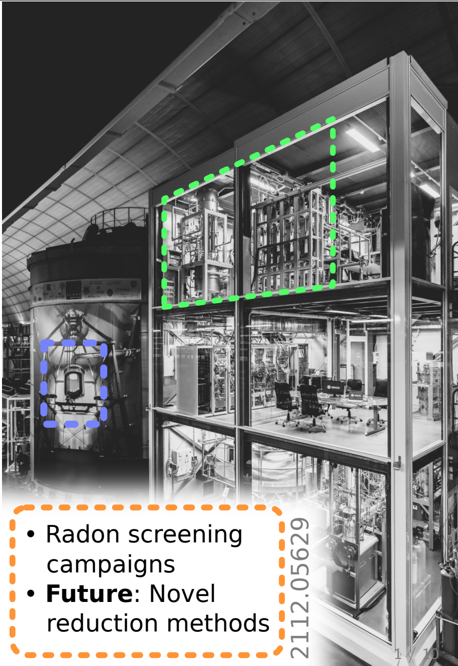
Radon in rare-event searches (XENONnT)

- Senstivity is limited by ^{222}Rn-induced decays
- XENONnT: 1.8µBq/kg $\approx$ 5000 atoms in 6 tons of LXe ($\rightarrow$ Valerio D'Andrea's talk)

E. Shockley PhD thesis (2021)







- Radon screening campaigns
- **Future**: Novel reduction methods

2112.05629

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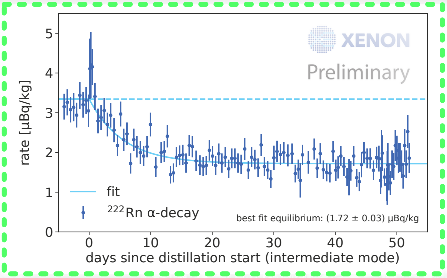

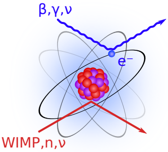

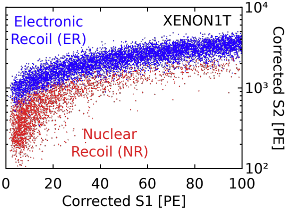

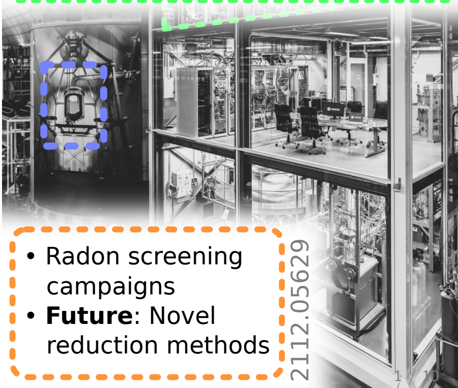

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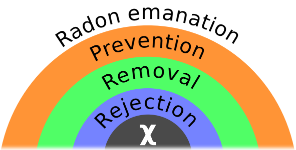
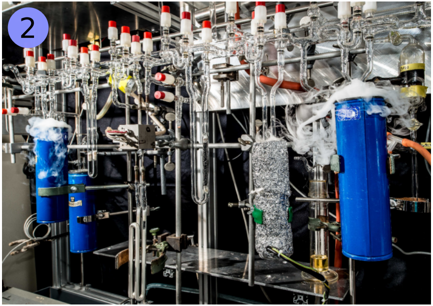
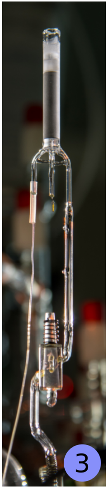


1. Extraction of ^{222}Rn e.g. from ^{226}Ra solution
2. Transfer and purification of the sample
3. Counting (proportional counters, electrostatic radon monitors) MDA $\approx 30\,\mu$Bq



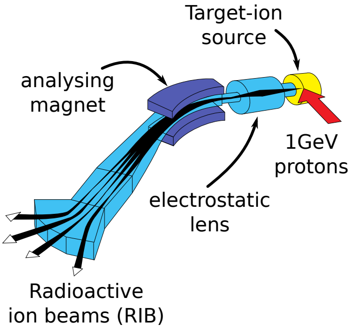


Appl. Radiat. Isot. 67, 5 889-893 (2009)

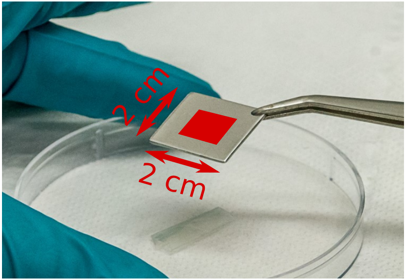
- Need reliable ^{222}Rn sources (see also talk by S. Röttger)
- Radon mitigation using surface coatings

Production of the samples by ISOLDE @ CERN

- 5×10^{11} ^{226}Ra ions ($\approx 7\,$Bq) implanted
- *Off-line* implantation using uranium carbide target
- **G**eneral **p**urpose **s**eparator
- Ion beam (30 keV) irradiated area of about $1 \times 1\,\mathrm{cm}^2$



Rep. Prog. Phys. 62, 4 527 (1999)



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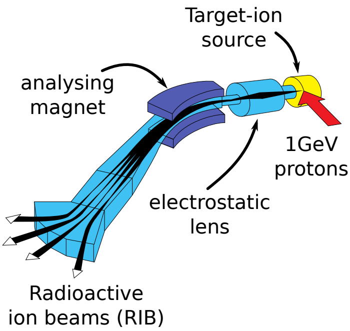

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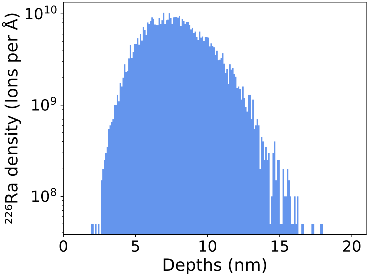
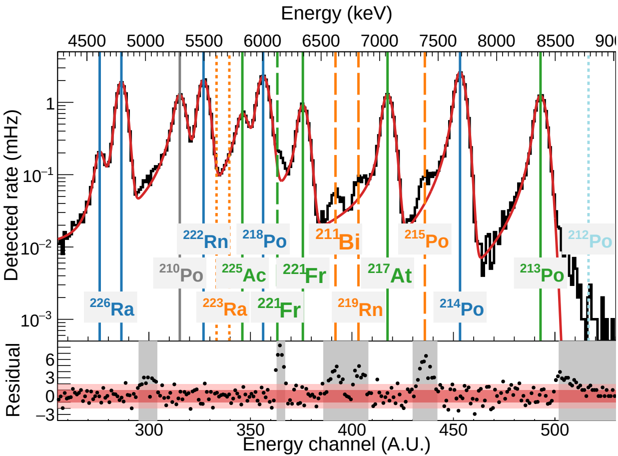
Simulated implantation profile

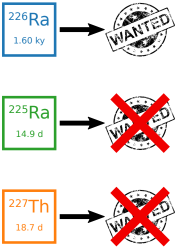
- Ion range distribution (SRIM) $\mu = 7.9\,\mathrm{nm}, \sigma = 2.3\,\mathrm{nm}$

+ High radon emanation fraction (expectation: 23%)
+ Mechanical stability assessed by wiping test: <1% removal





Contaminants



^{139}Ce (138 d) on Sample B

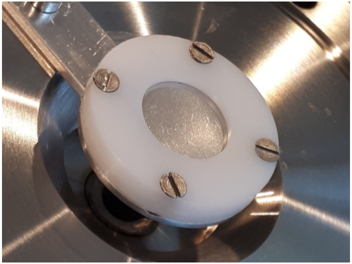
α-spectrum from 13 weeks after implantation:

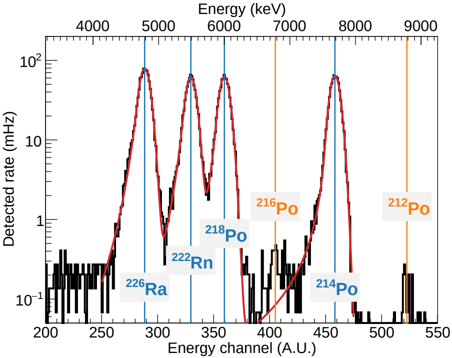
- Unwanted isotopes decay with $\mathcal{O}(\text{weeks})$ of half-life $\rightarrow$ **no problem**

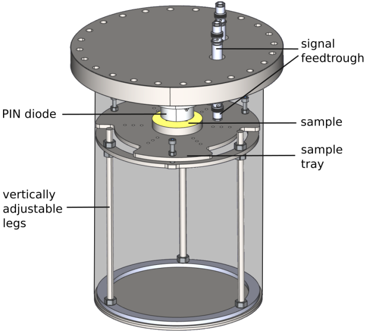
Alpha spectrometry (Si-PIN)

✓ Implantation confined within opening of holder ($1.9\,\mathrm{cm}$)

α-activity	^{226}Ra (4.9 MeV)
Sample A	$(8.7 \pm 1.9)\,\mathrm{Bq}$
Sample B	$(9.1 \pm 0.7)\,\mathrm{Bq}$

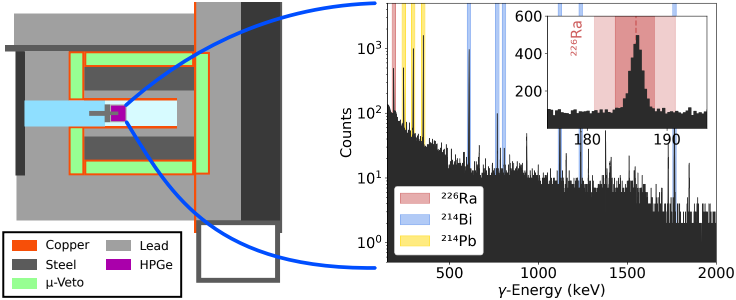






Eur. Phys. J. C 81, 343 (2021)

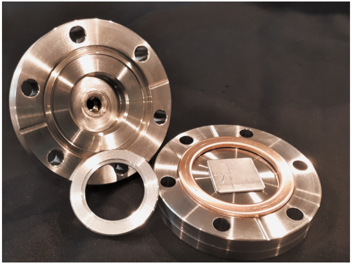
D. Budjáš PhD thesis (2009)



0.63 kg p-type HPGe crystal

- 15 mwe at MPIK, active & passive shielding
- N_2-flushed sample chamber $\Rightarrow$ emanated ^{222}Rn removed

Activity (Bq)	Sample A	Sample B
^{226}Ra (186 keV)	7.4 ± 0.9	8.4 ± 1.0
Rn-daughters	5.2 ± 0.3	6.0 ± 0.3



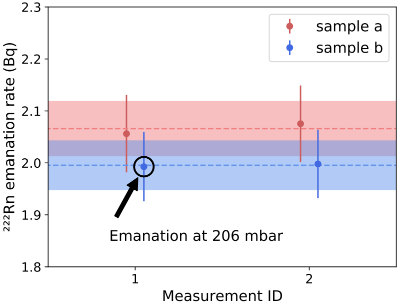
Emanation vessel

- Sample enclosed in 2x CF-40 Flange
- Aluminum holder for fixation
- Vessel filled with helium (1050 mbar)

Results

- Measured with miniaturized proportional counters
- Very good agreement

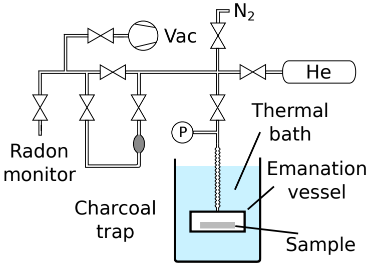
Sample	^{222}Rn emanation
Sample A	(2.07 ± 0.05) Bq
Sample B	(2.00 ± 0.05) Bq

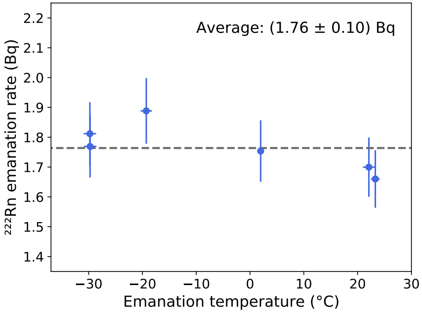


Thermal dependence of radon emanation

Used setup

- Emanation vessel placed in thermal bath with 200 mbar Helium
- $^{222}\mathrm{Rn}$ emanation is collected on active charcoal trap ($\mathrm{LN_2}$ temperature)





Result

- $^{222}\mathrm{Rn}$ is then filled into electrostatic radon monitor
- No temperature variation down to $-30^{\circ}\mathrm{C}$

Summary and Outlook

Activity (Bq)	Sample A	Sample B
Implantation	about 7	about 7
^{222}Rn emanation	2.07 ± 0.05	2.00 ± 0.05
γ-spectrometry	$7.4 \pm 0.1_{\mathrm{stat}} \pm 0.9_{\mathrm{syst}}$	$8.4 \pm 0.3_{\mathrm{stat}} \pm 1.0_{\mathrm{syst}}$
α-spectrometry	$8.70 \pm 0.06_{\mathrm{stat}}\ {}^{+2.0}_{-1.8}{}_{\mathrm{syst}}$	$9.13 \pm 0.10_{\mathrm{stat}}\ {}^{+0.7}_{-0.4}{}_{\mathrm{syst}}$

- Recoil dominated emanation of $^{222}\mathrm{Rn}$
- Emanation from a bare stainless steel surface

Applicability and improvements:

- Samples applied for radon mitigation studies; calibration of α-spectrometers; characterization of a novel radon detector
- Future implantation: Use **h**igh **r**esolution **s**eparator, for less contamination?
- Laser ionization source (RILIS) could potentially increase ^{226}Ra yield

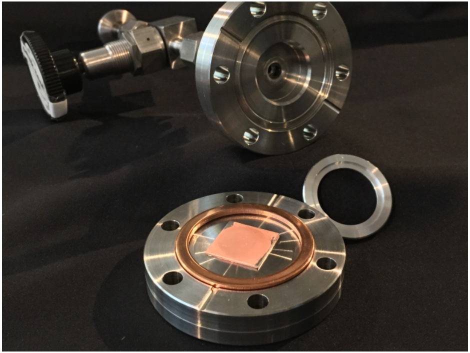
Bonus: Comparison to the PTB sample

		MPIK	PTB
	Obtained samples	2×SS	4×Al + 4×W
Production	Implanted activity	about 7 Bq	0.5 kBq - 1 kBq
	Ion Energy	30 keV	30 keV
	^{226}Ra source	Produced in UC_x	^{226}Ra drop-cast on foil
	Ionization	Surface (3 pA)	Surface & Laser (10 nA)
Measurements	Emanation process	Recoil	Recoil
	Mechanical stab.	✓	✓
	Environment	cold, pressure	warm, humidity
	Reference	This work (# 30)	Appl. Radiat. Isot. **181**, 2022

⇒ **Very promising source production process!**

Backup slides

Radon-tight sealing of one sample



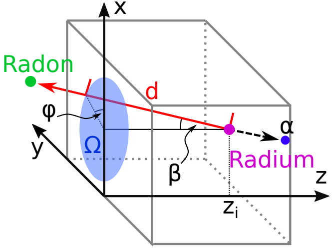
- Electrochemical plating of 5 μm copper
- ^{222}Rn reduction factor: $\approx$ 1500 validated using emanation measurement
- Small amount of ^{226}Ra dissolved into electrolyte

Activity (Bq)	Sample		Electrolyte
γ-Spectrometry	^{226}Ra	Rn-daughters	Rn-daughters
before coating	8.4±1.0	6.0±0.3	$\lesssim$ 0.012
after coating	7.7±1.0	7.2±0.4	0.34±0.02

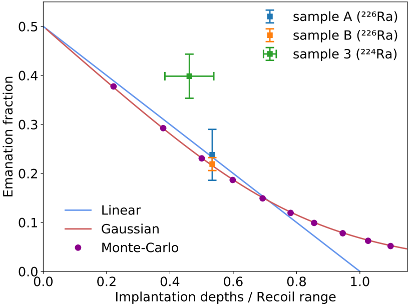
Linear model

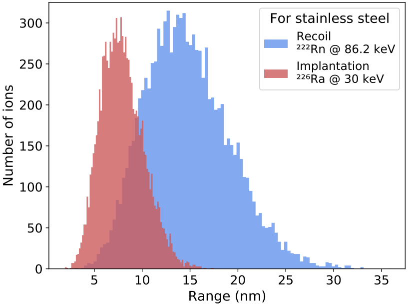
$$\Omega = \int_0^{2\pi} \int_0^{\beta_{crit}} \Big(\sin(\beta) \Big)\, d\beta\, d\varphi$$

$$\Rightarrow \quad F = \frac{1}{2} \cdot \left(1 - \frac{z_i}{R}\right), \text{ for } z_i \leq R$$



Gaussian and Monte-Carlo model





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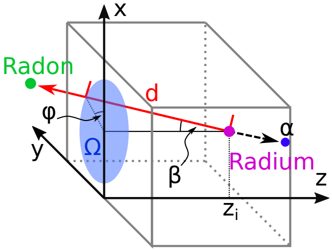

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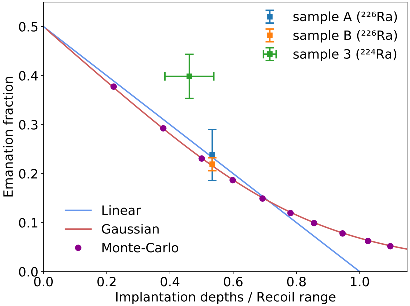
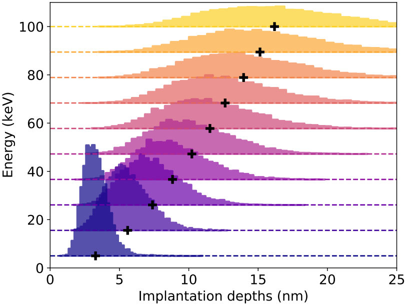
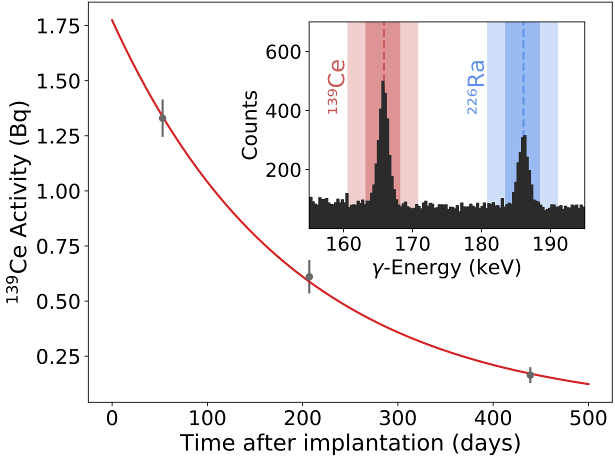




Short-lived isotopes (^{139}Ce)?



- Single γ-emission at 165.9 keV, matching ^{139}Ce
- Decay of this activity found with (130 ± 5) days, matching literature value of $T_{1/2}(^{139}\mathrm{Ce}) = 137.6\,\mathrm{days}$