PAUL SCHERRER INSTITUT PSI

SINCHRON
A NEW CHRONOMETER FOR NUCLEAR DATING

EPFL

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A Missing Link: Towards the preparation of a ^{32}Si target for nuclear astrophysics experiments

30th Conference of the International Nuclear Target Development Society: INTDS 2022
Thursday, September 29, 2022 :: WHGA/001 :: Paul Scherrer Institut :: PSI, Villigen

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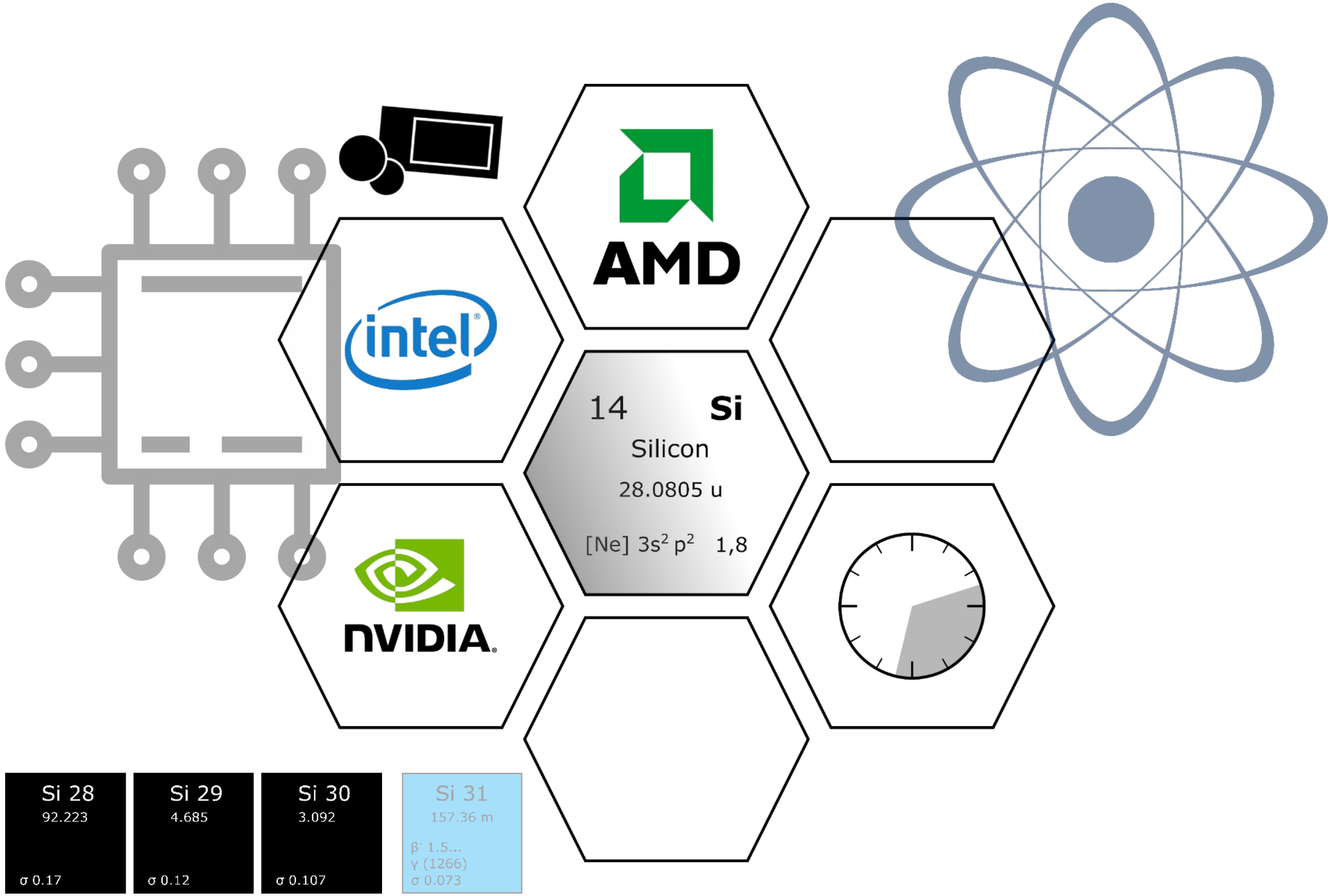
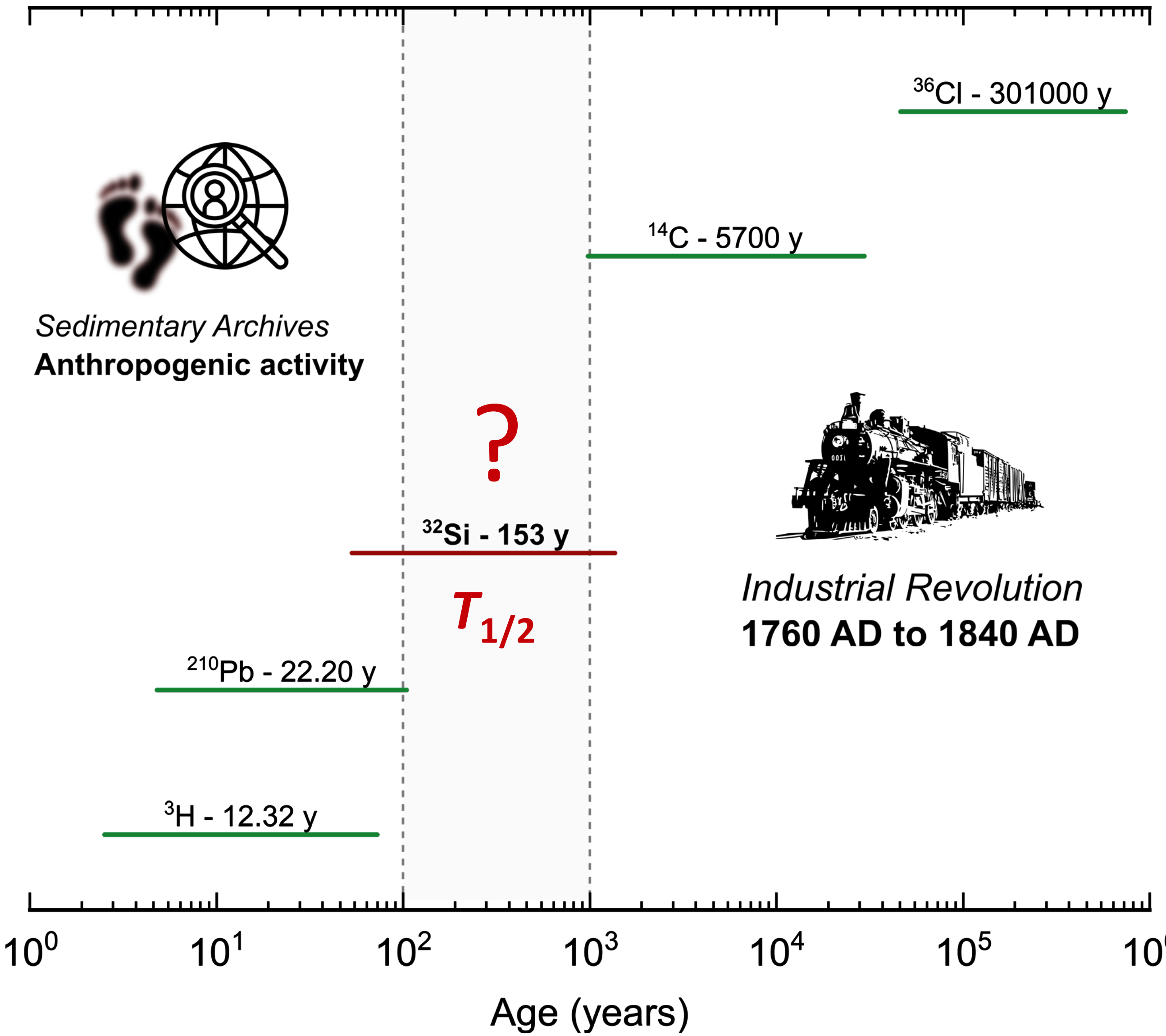
Agenda

Introduction	Results	Conclusion & Outlook
1	2	3
About Radiosilicon: ^{32}Si	Radiochemical separation Example: $T_{1/2}$	Putting the efforts into perspective: Future of ^{32}Si

About Radiosilicon: ^{32}Si

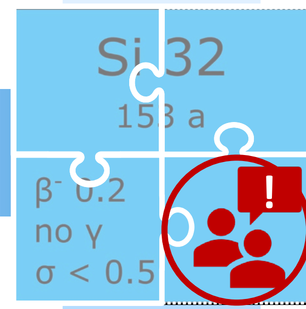


QUESTION: Radioactive silicon-32: Why is it of great interest?



Relatively long-lived radionuclide

Well-known **Production Route**



Anthropogenic Input not as Important as for ^{14}C

Chemical Stability
of the Compounds (e.g., SiO_2)

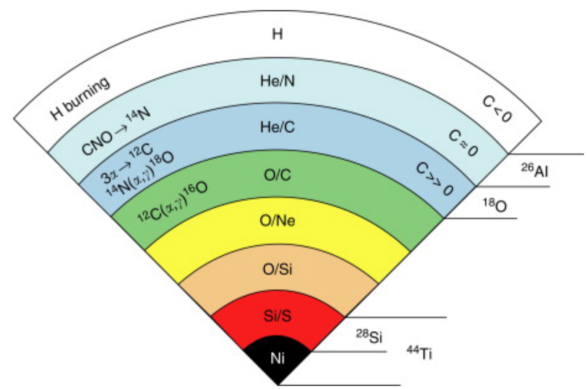
Ideal candidate **for nuclear dating … but precise $T_{1/2}$ needed!**

About Radiosilicon: ^{32}Si

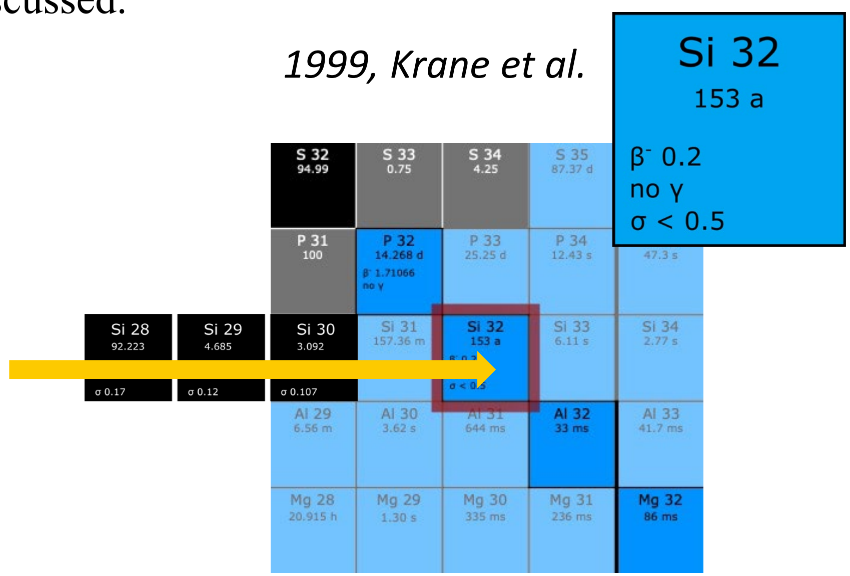
SILICON CARBIDE GRAINS OF TYPE C PROVIDE EVIDENCE FOR THE PRODUCTION OF THE UNSTABLE ISOTOPE ^{32}Si IN SUPERNOVAE

M. Pignatari[1,14], E. Zinner[2], M. G. Bertolli[3,14], R. Trappitsch[4,5,14], P. Hoppe[6], T. Rauscher[1,7], C. Fryer[8,14], F. Herwig[9,10,14], R. Hirschi[11,12,14], F. X. Timmes[10,13,14], and F.-K. Thielemann[1]

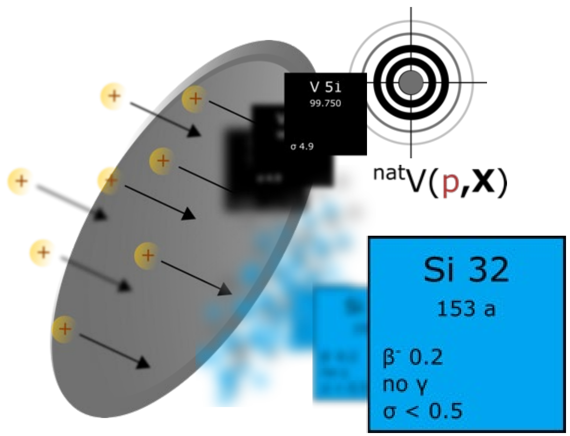
"The abundance of ^{32}Si in silicon carbide grains can provide constraints on the neutron density reached during a supernovae (SN) explosion in the C-rich He shell material. The impact of the ***large uncertainty of the neutron capture cross sections*** in the ^{32}Si region is discussed."

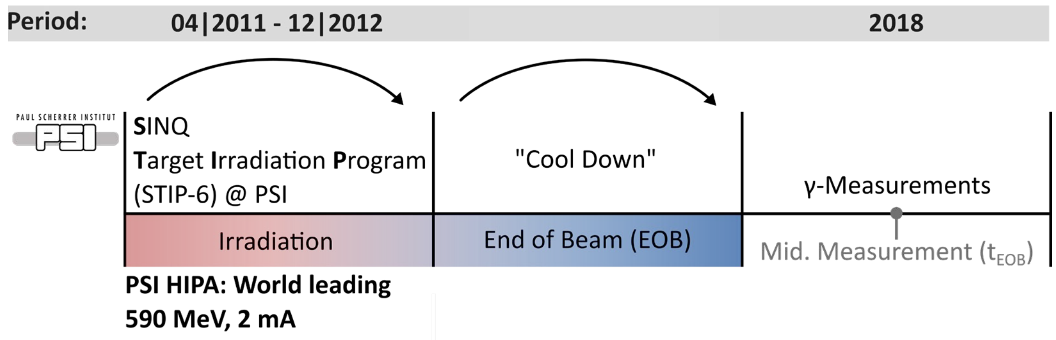


1999, Krane et al.

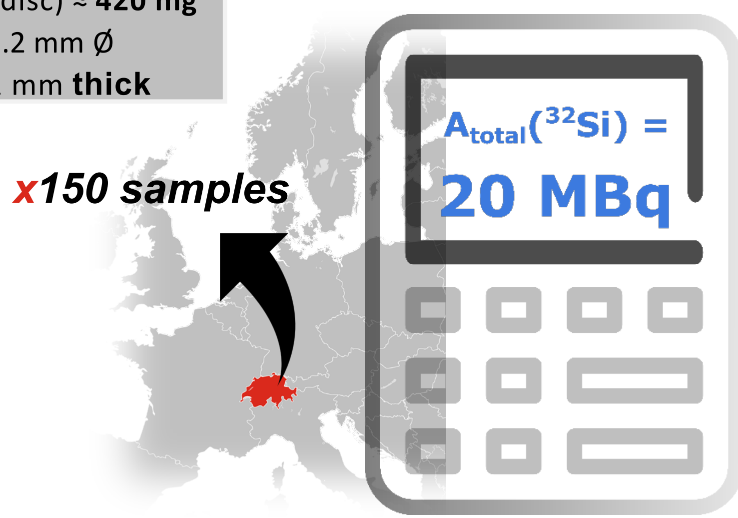


SOLUTION: *No material?* Artificial production (long-term proton irradiation)





m(disc) ≈ **420 mg**
≈ 9.2 mm Ø
≈ 1 mm **thick**



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Measurement	Method	Institution
Number of atoms	ICP-MS	PSI/SL
Number of atoms	AMS	LIP/ANU
Activity	LSC/Čerenkov	PTB
Activity	LSC/PS	IRA
Decay	PS	IRA
Decay	IC/Čerenkov	PTB

$$T_{1/2} = N\frac{\ln(2)}{A}$$

Agenda

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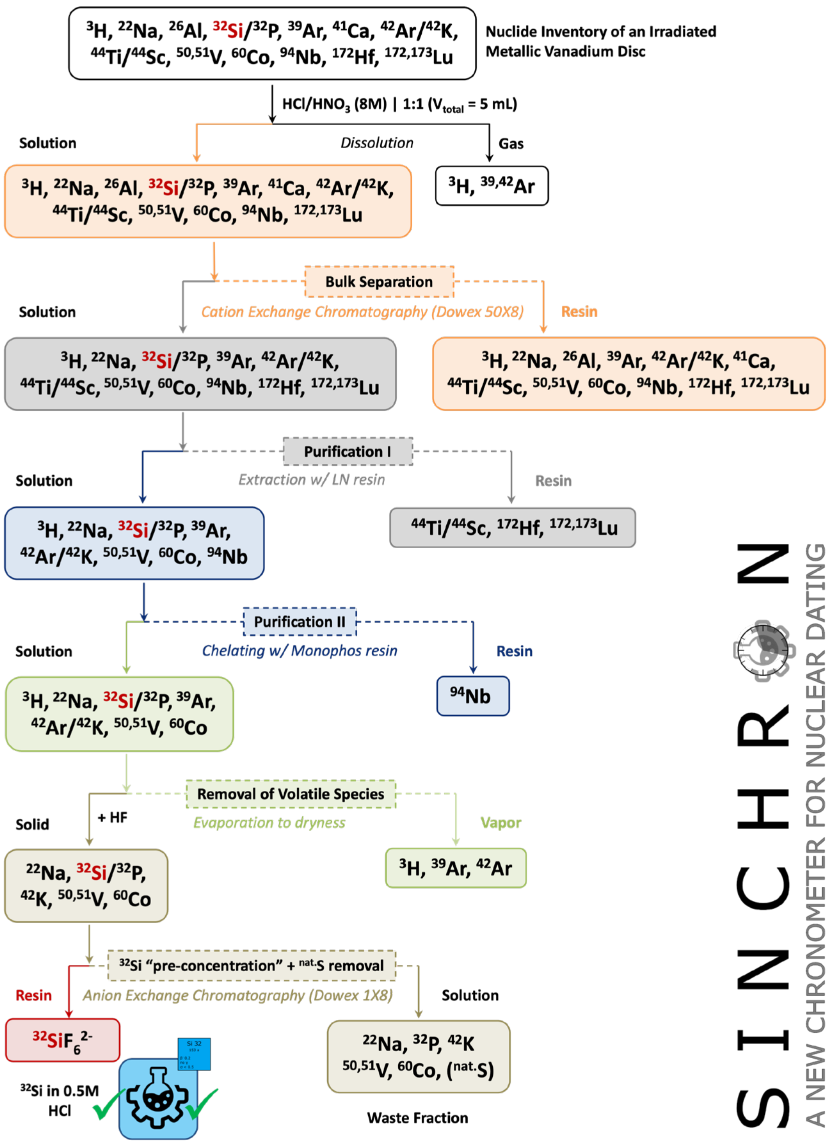
About Radiosilicon: ^{32}Si	**Radiochemical separation** **Example: $T_{1/2}$**	Putting the efforts into perspective: Future of ^{32}Si

Mario Veicht, I. Mihalcea, D. Cvjetinovic, and D. Schumann
Radiochemical separation and purification of non-carrier-added silicon-32 (Radiochim. Acta, 08|2021).

Radiochemical separation



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Column Chromatography

$^{32}Si(OH)_4$ (aq)

Orthosilicic acid

$H_2{}^{32}SiF_6$ (aq)

Hexafluorosilicic acid

Radiochemical separation

^{3}H, ^{22}Na, ^{26}Al, $^{32}Si/^{32}P$, ^{39}Ar, ^{41}Ca, $^{42}Ar/^{42}K$, $^{44}Ti/^{44}Sc$, $^{50,51}V$, ^{60}Co, ^{94}Nb, ^{172}Hf, $^{172,173}Lu$

Nuclide Inventory of an Irradiated Metallic Vanadium Disc

HCl/HNO_3 (8M) | 1:1 (V_{total} = 5 mL)

Dissolution

Gas: ^{3}H, $^{39,42}Ar$

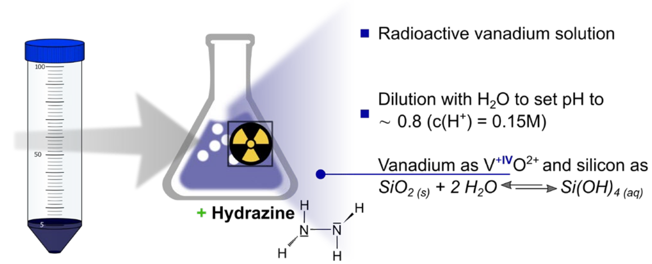
Solution: ^{3}H, ^{22}Na, ^{26}Al, $^{32}Si/^{32}P$, ^{39}Ar, ^{41}Ca, $^{42}Ar/^{42}K$, $^{44}Ti/^{44}Sc$, $^{50,51}V$, ^{60}Co, ^{94}Nb, $^{172,173}Lu$

Bulk Separation

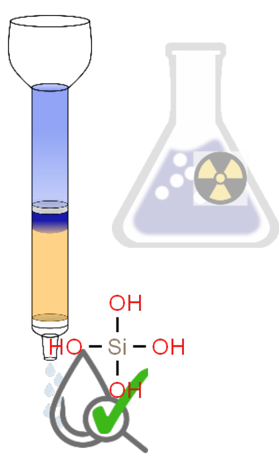
Cation Exchange Chromatography (Dowex 50X8)

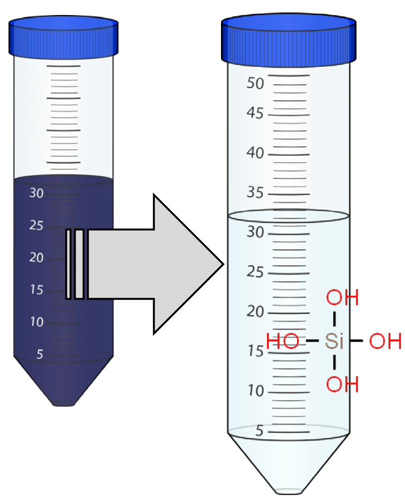
Resin: ^{3}H, ^{22}Na, ^{26}Al, ^{39}Ar, $^{42}Ar/^{42}K$, ^{41}Ca, $^{44}Ti/^{44}Sc$, $^{50,51}V$, ^{60}Co, ^{94}Nb, ^{172}Hf, $^{172,173}Lu$

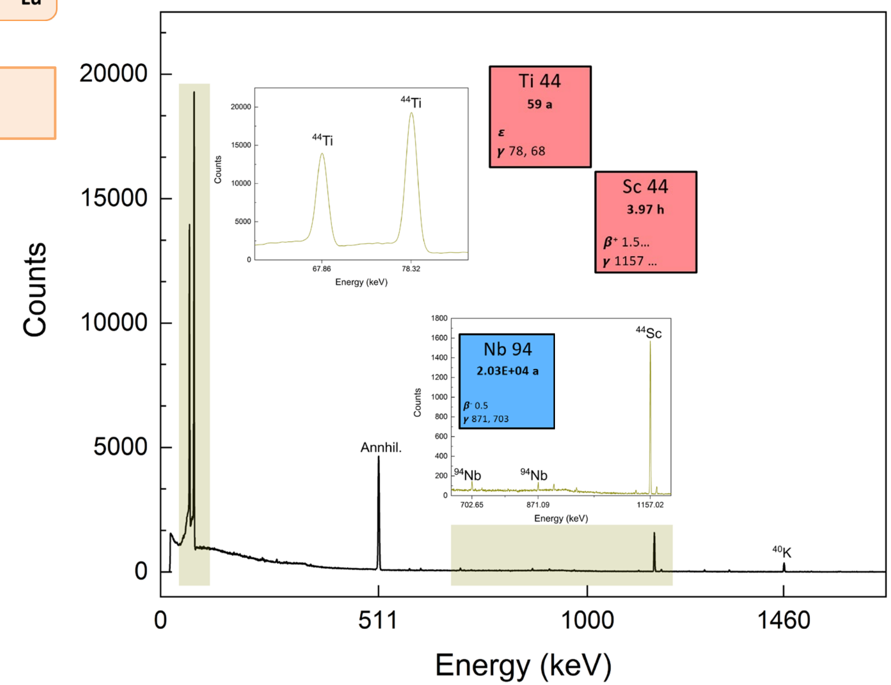
Dissolution of an p-irradiated vanadium disc (m(disc) = 400 mg) in 2.5 mL 8M HNO_3 / 2.5 mL 8M HCl: **Initial vanadium solution**



Bulk separation: Cation-Exchange Resin







Radiochemical separation

LN® - Purification

Solution

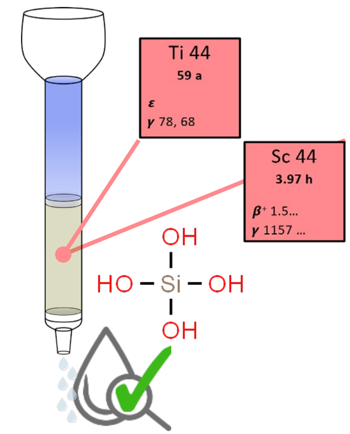
^{3}H, ^{22}Na, $^{32}Si/^{32}P$, ^{39}Ar, $^{42}Ar/^{42}K$, $^{44}Ti/^{44}Sc$, $^{50,51}V$, ^{60}Co, ^{94}Nb, ^{172}Hf, $^{172,173}Lu$

Purification I

Extraction w/ LN resin

Resin

$^{44}Ti/^{44}Sc$, ^{172}Hf, $^{172,173}Lu$



Monophos® - Purification

Solution

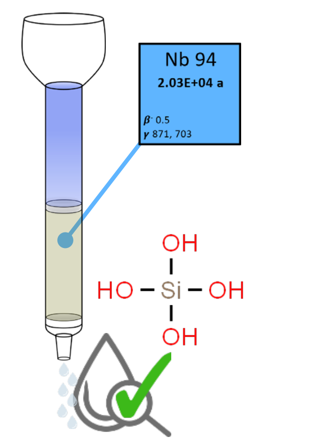
^{3}H, ^{22}Na, $^{32}Si/^{32}P$, ^{39}Ar, $^{42}Ar/^{42}K$, $^{50,51}V$, ^{60}Co, ^{94}Nb

Purification II

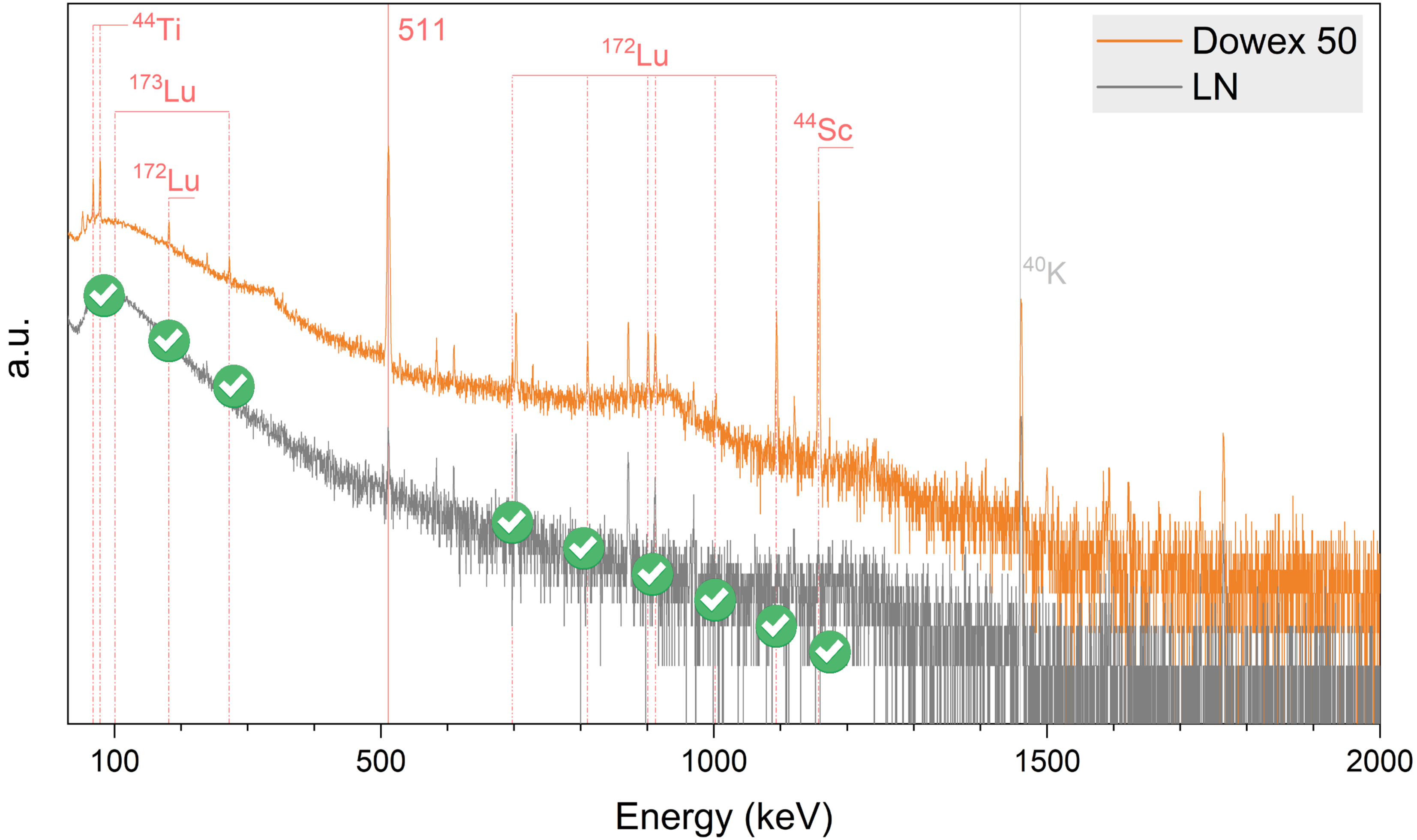
Chelating w/ Monophos resin

Resin

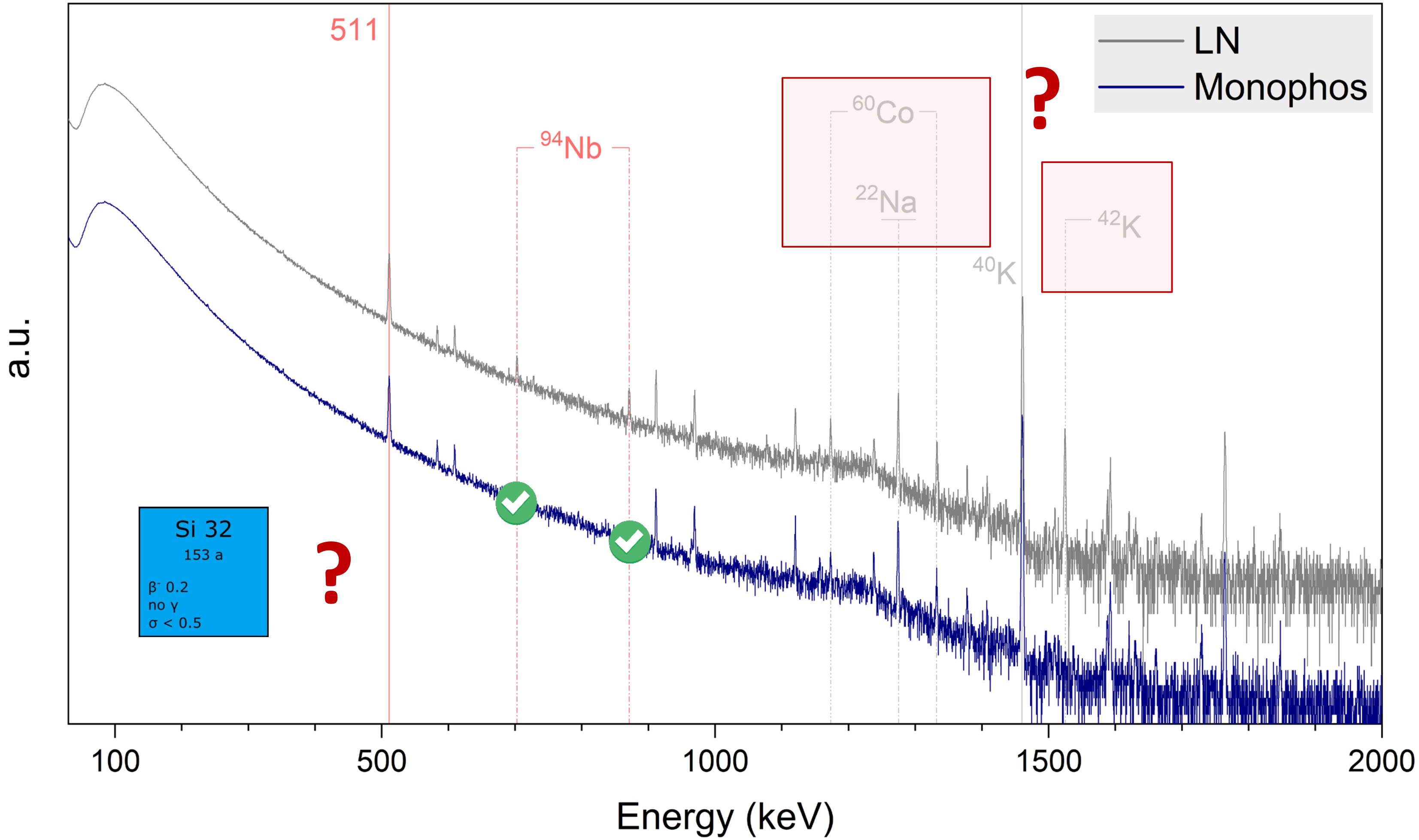
^{94}Nb



- Long-term gamma-spectrum: after **LN® separation (Purification I)**



- Long-term gamma-spectrum: after **Monophos® separation (Purification II)**

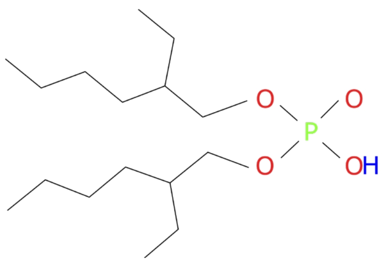


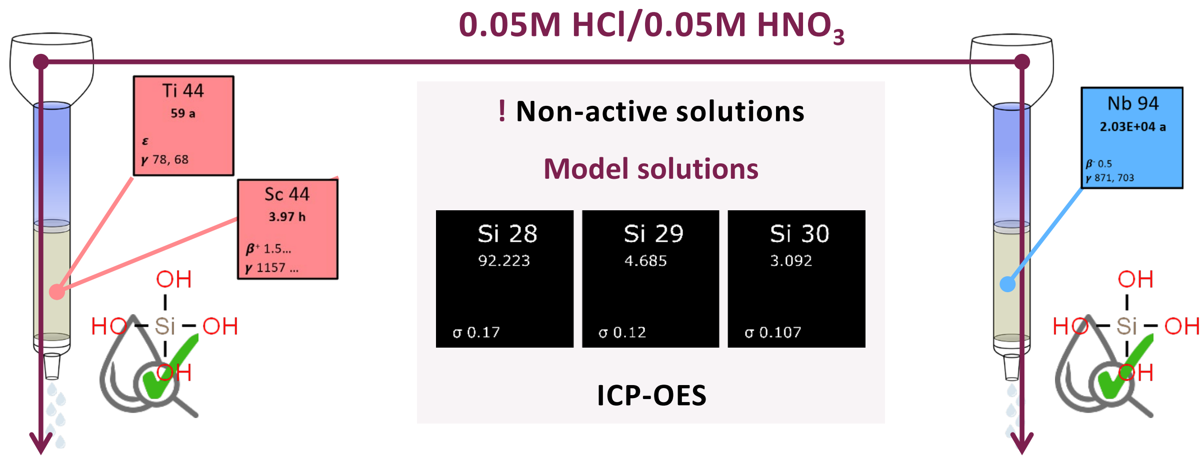
Radiochemical separation

LN®

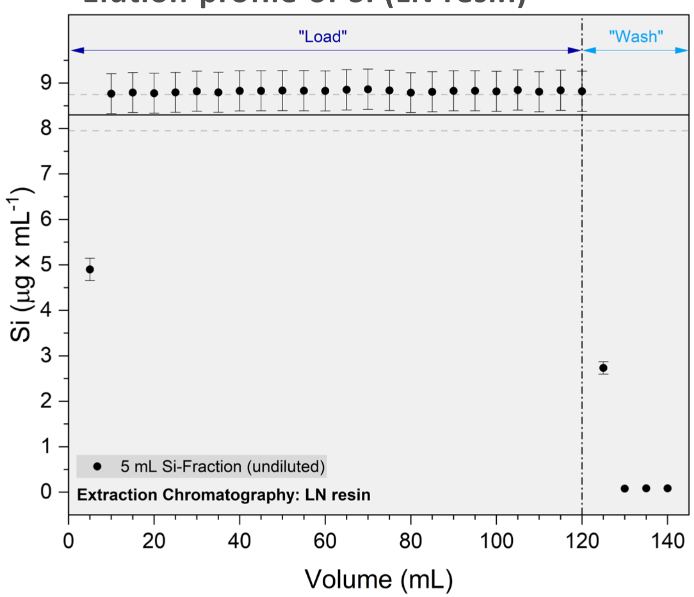
Monophos®

LN® Resin

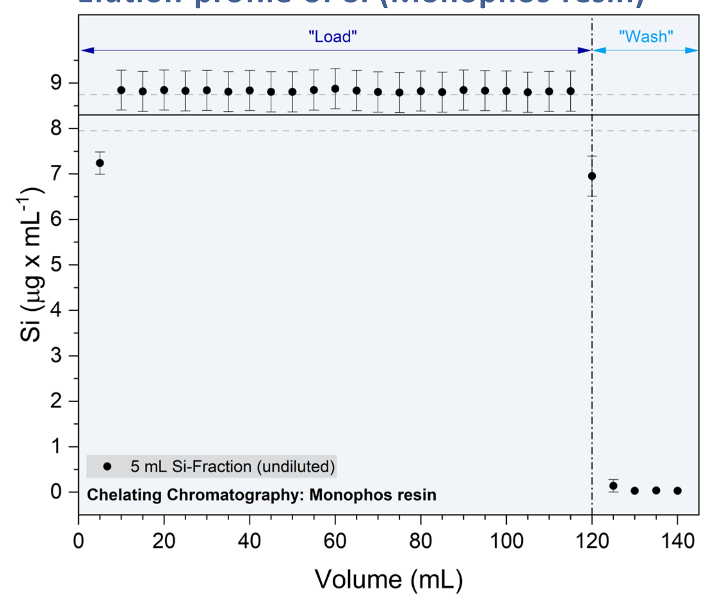




Elution profile of Si (LN resin)



Elution profile of Si (Monophos resin)



Radiochemical separation

Solution

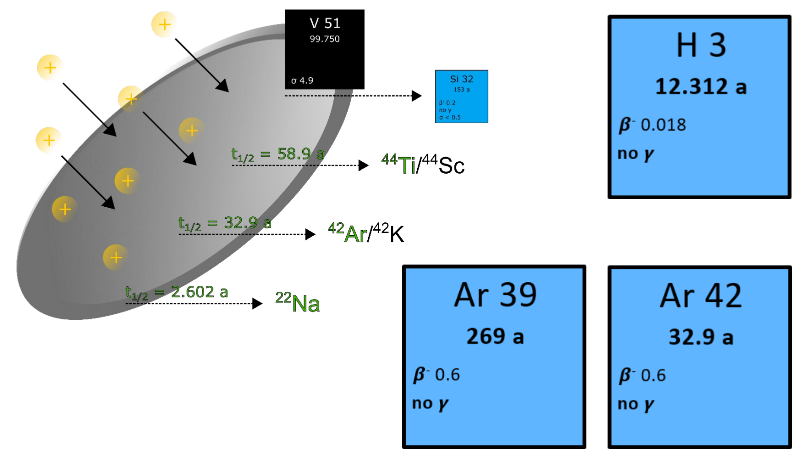
^{3}H, ^{22}Na, $^{32}Si/^{32}P$, ^{39}Ar, $^{42}Ar/^{42}K$, $^{50,51}V$, ^{60}Co

Removal of Volatile Species

Evaporation to dryness

Vapor

^{3}H, ^{39}Ar, ^{42}Ar

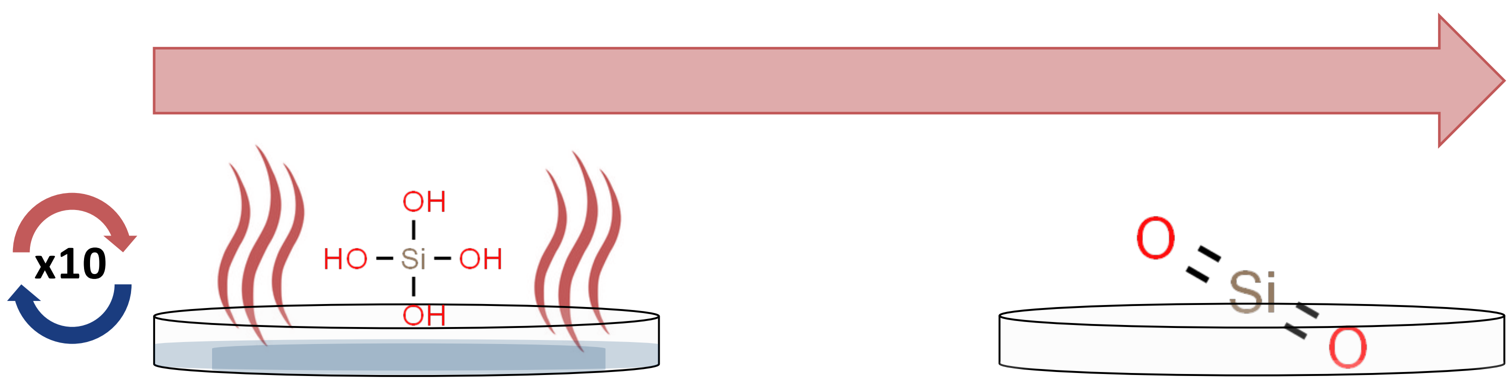


Evaporation to dryness

- isotopic exchange ($^{3}HOH/H_2O$) -

Recovery of SiO_2 with HF

- 1x V-disc = 1x fraction (20 mL 0.1M HF) -

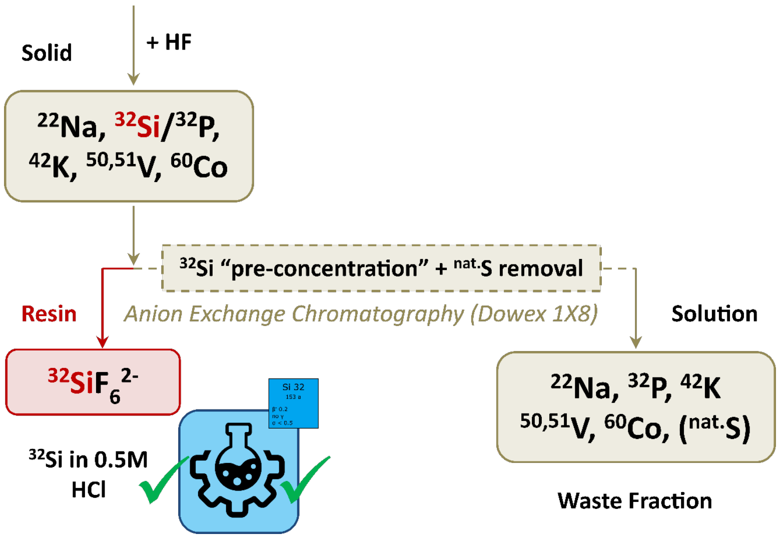


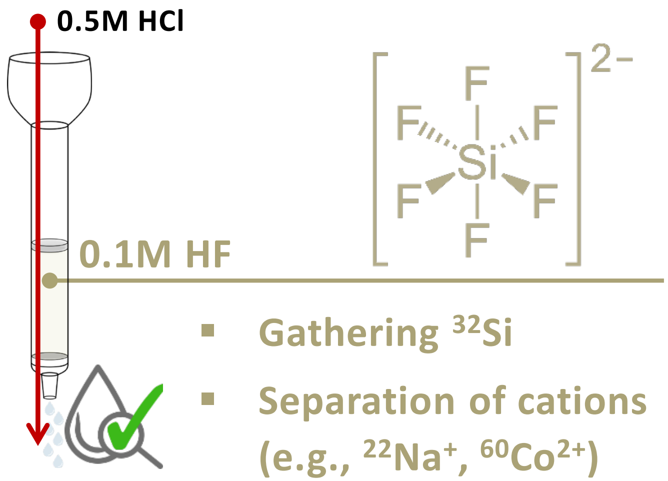
each 25 mL ultra-pure water

✔ Removes $^{39/42}Ar$

✔ Removes ^{3}H

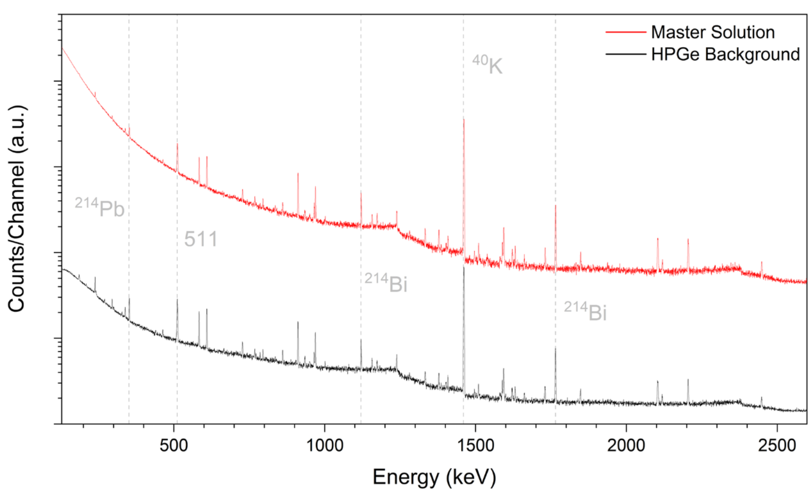
Radiochemical separation



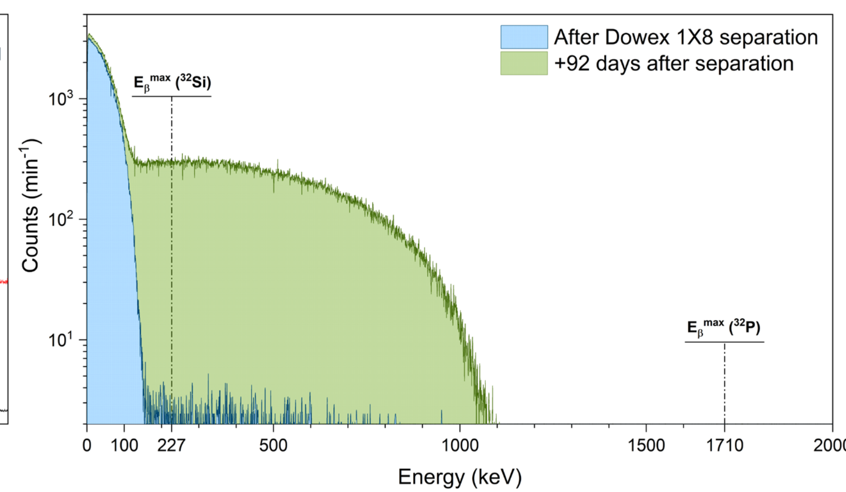


- Gathering ^{32}Si
- Separation of cations (e.g., $^{22}Na^{+}$, $^{60}Co^{2+}$)

Long-term gamma-measurement

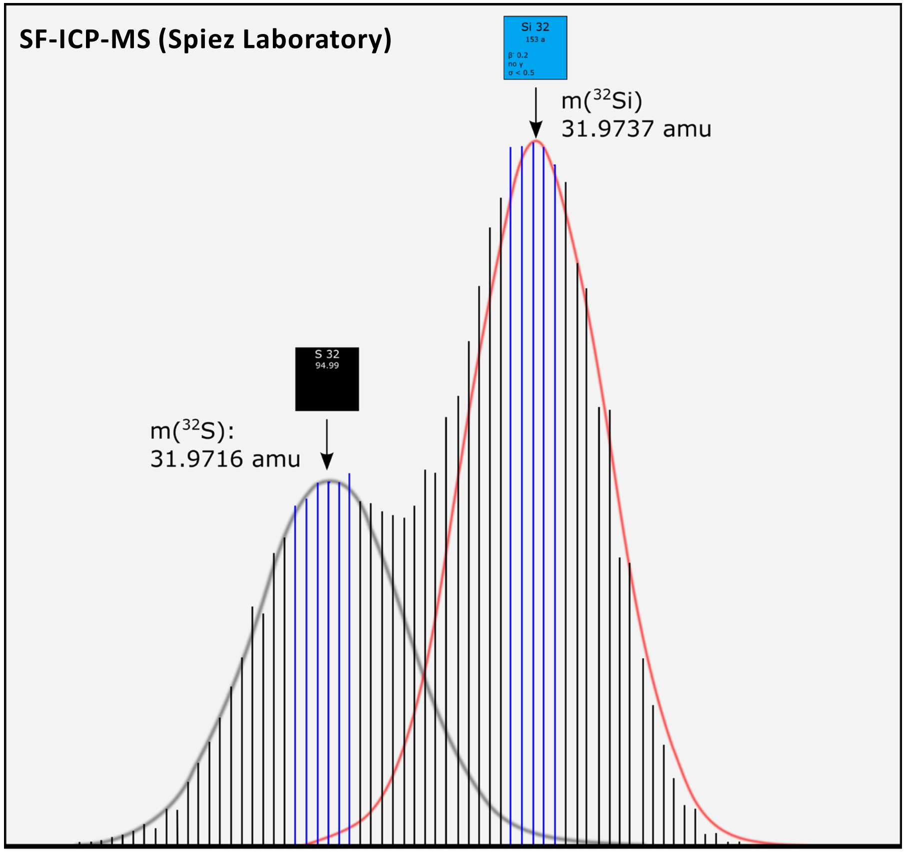


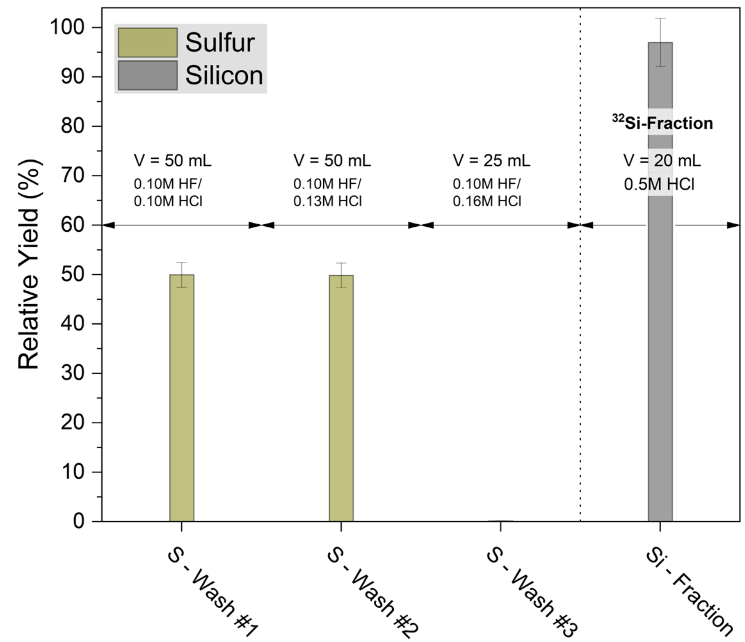
Long-term LSC measurement



Resolution of ^{32}S and ^{32}Si (Δ amu = 0.0021)

Removal of sulfur from the matrix (ICP-OES)

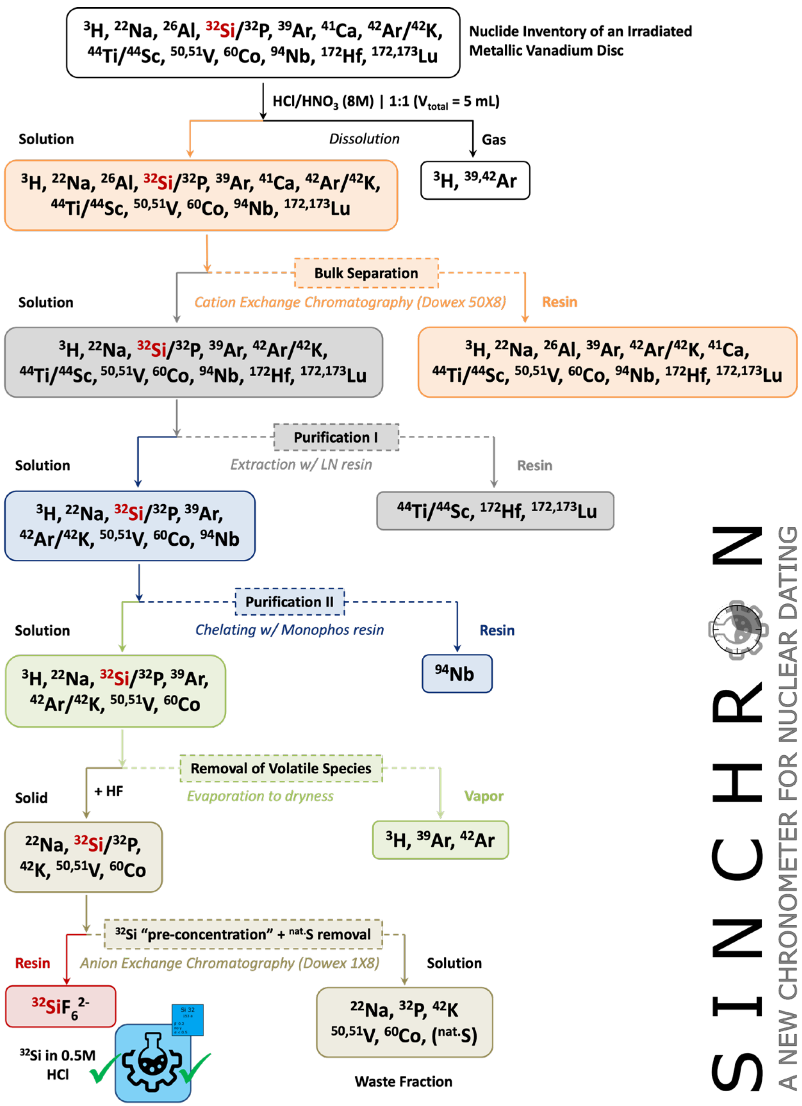




Mass resolving power (m/Δm) at least 15'000

Stable Sulfur is added and simultaneously removed

Avoids transfer into the ^{32}Si solution



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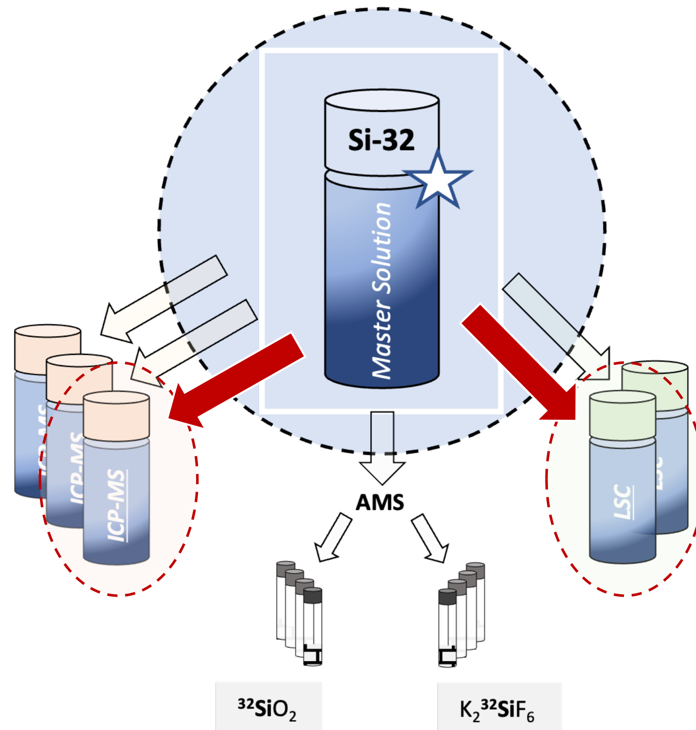

"Direct Method"

$$T_{1/2} = N\frac{\ln(2)}{A}$$

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Putting the efforts into perspective: future of ^{32}Si

Si 32
153 a
β^- 0.2
no γ
σ < 0.5

- ✓ **^{32}Si**: Redetermination of the half-life
- ✓ **Application**: Dating Tool in Environmental Sciences

- ✓ Highly selective and robust wet-chemical separation system
- ✓ World-wide unique amount of **^{32}Si** stored at PSI: Approx. **22 MBq**

PSI's contribution for further basic scientific investigations

- ✓ Ongoing half-life determination: Thanks to a high activity concentration

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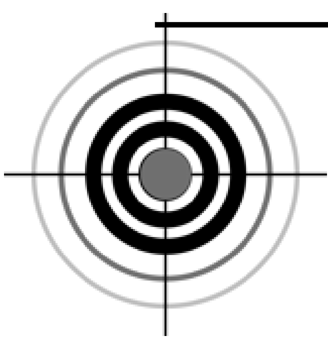

^{32}Si(n,γ)^{33}Si (only one measurement from 1999, Krane et al.)

→ **Generally a large uncertainty of the neutron capture cross-section**

→ **Critical review of vital importance for <u>nuclear astrophysics</u>**

Acknowledgement

Special thanks go to

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