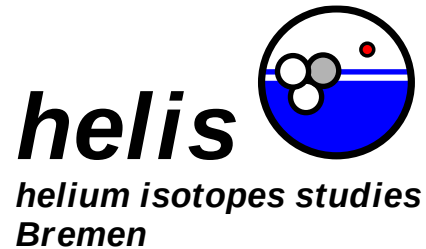


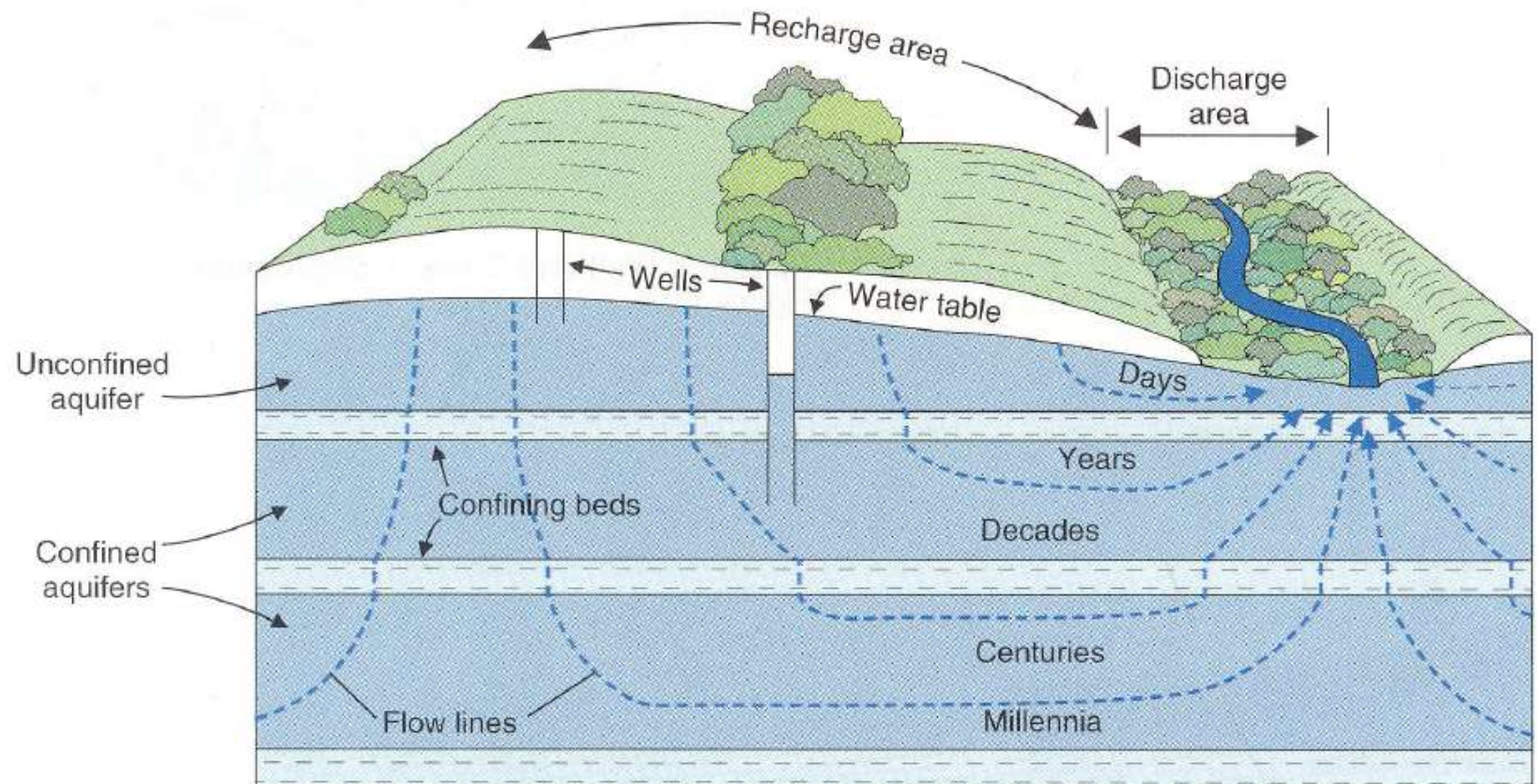
Umwelttracer zur Grundwasser Datierung



Jürgen Sültenfuß
suelten@uni-bremen.de



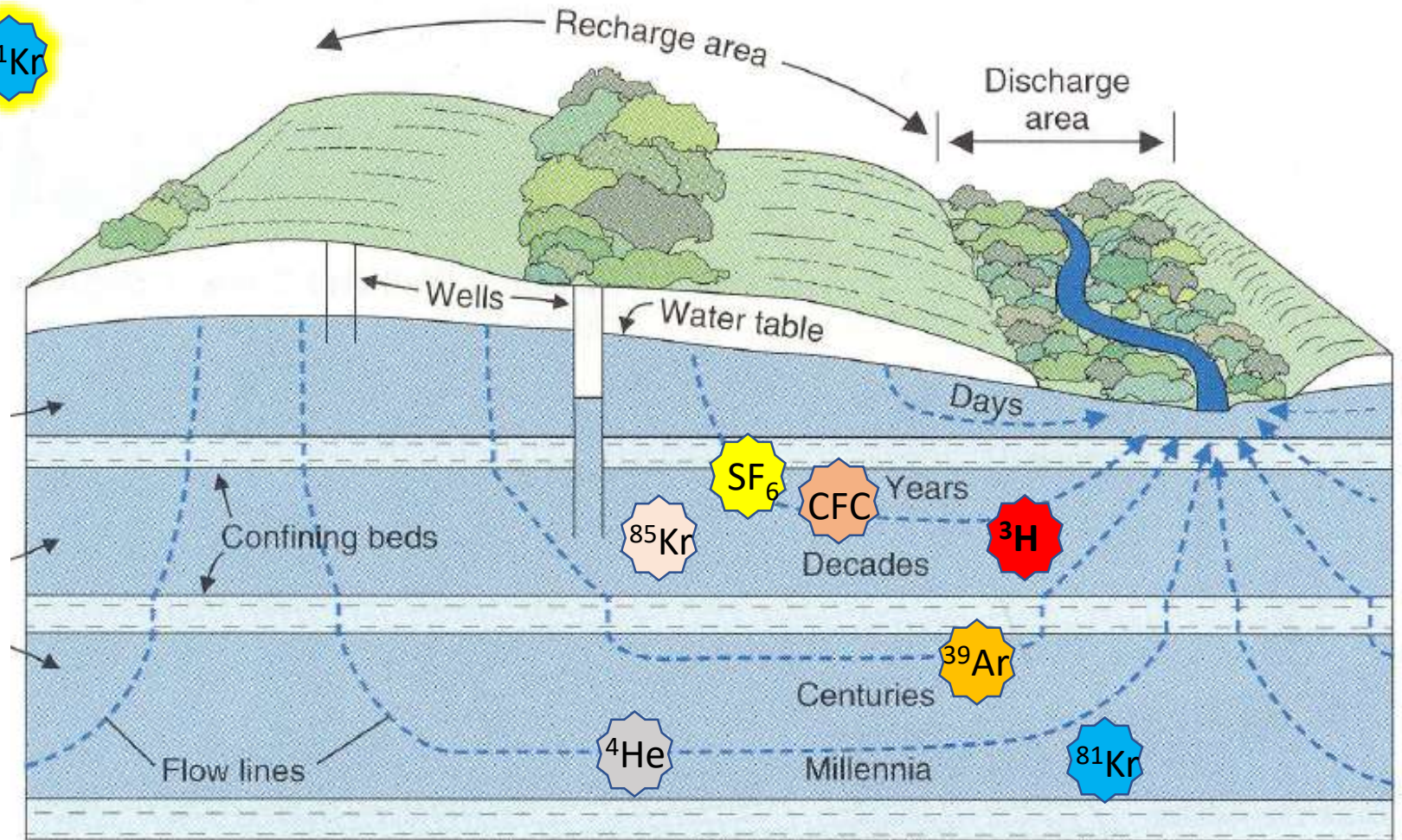
Institut für Umweltphysik
Abt. Ozeanographie



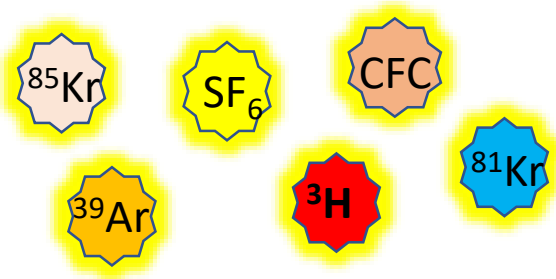
Grundwasseralter: Probennahme ↔ Kontakt zur Atmosphäre

„Wasserpaket“ : Dispersion << Advektion

Atmosphärische
Umwelttracer



Atmosphärische Umwelttracer



Datierung mit Tracern

bisher: etablierte Messverfahren und Methoden angewandt

künftig: Eignung/Zweckmäßigkeit gegeben?

neue Tracer?

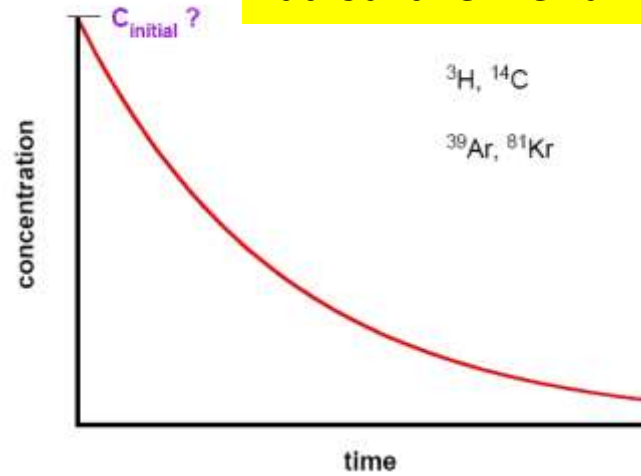
neue Messverfahren?

neue Interpretationsmethoden?

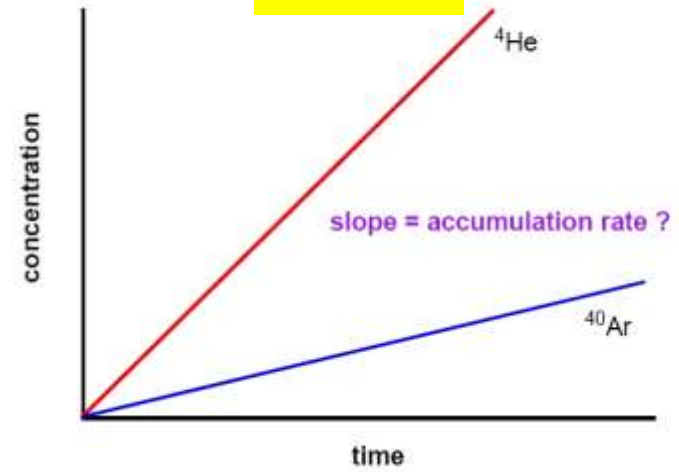
4 verschiedene Typen Uhren



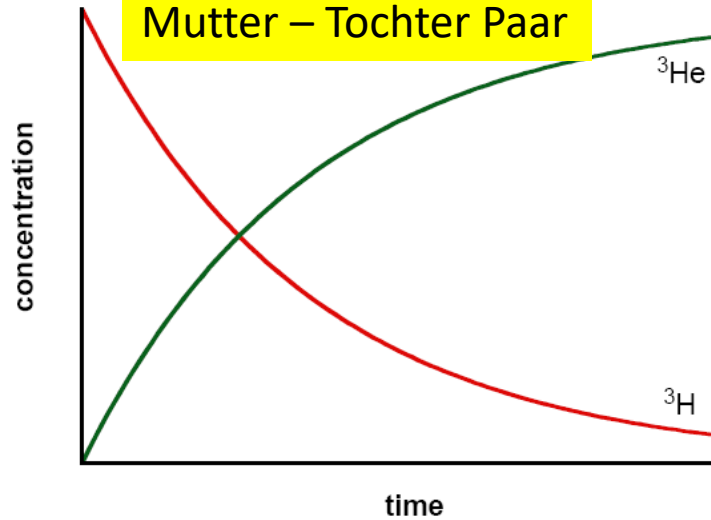
radioaktiver Zerfall



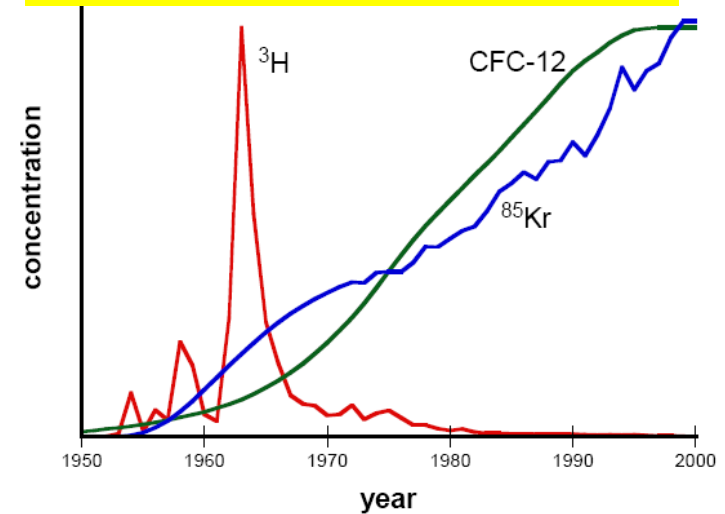
Zuwachs



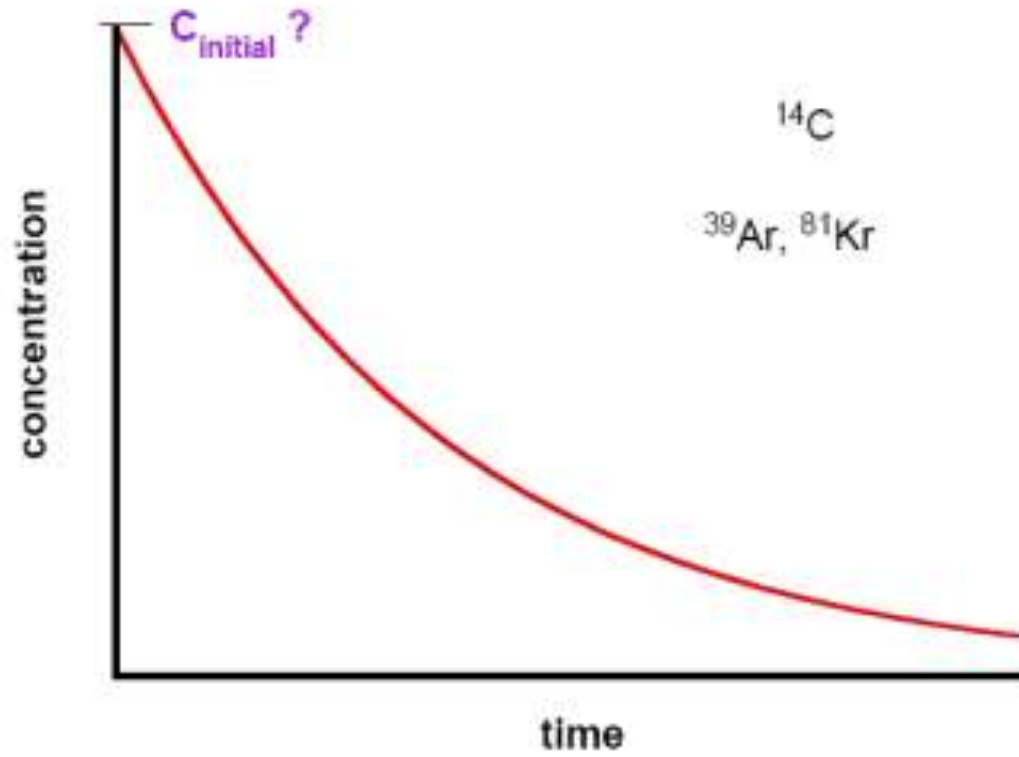
radioaktiver Zerfall
Mutter – Tochter Paar



zeitliche Änderung des Eintrags



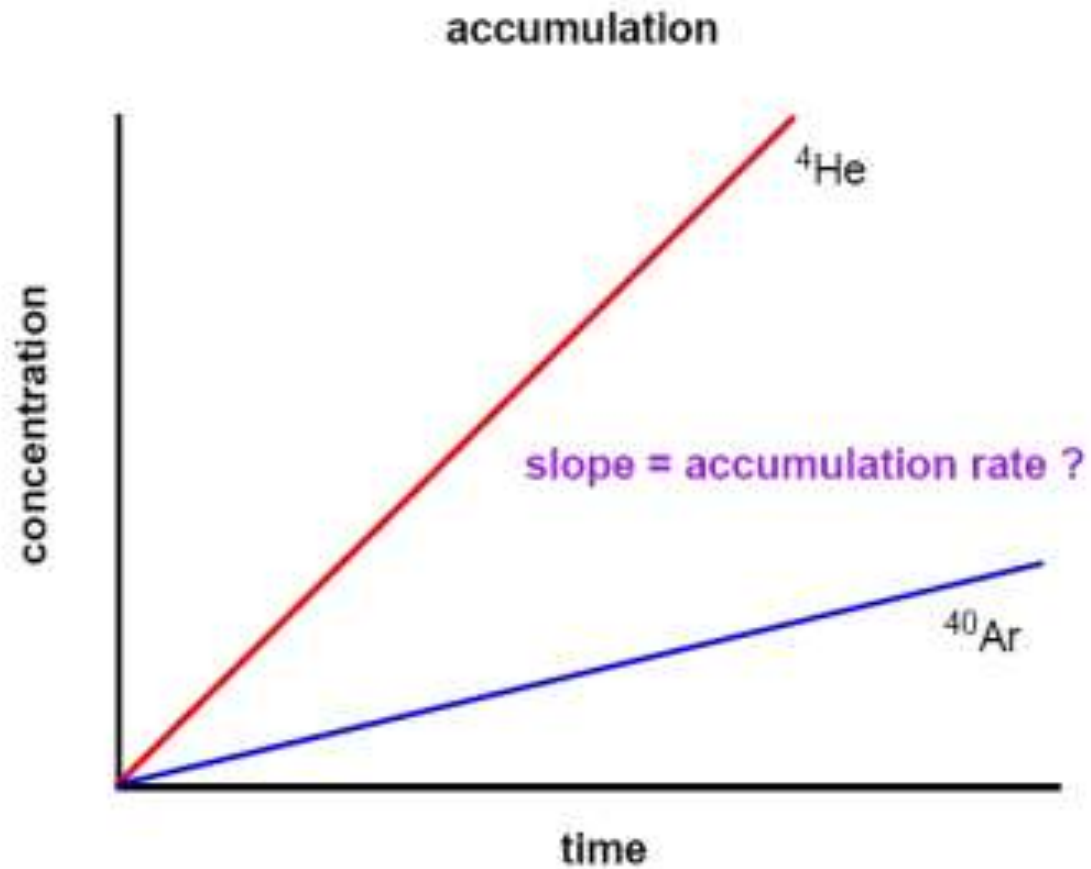
radioactive decay



$$t = -\frac{1}{\lambda} \ln \left(\frac{A(t)}{A(0)} \right)$$

Radioaktiver Tracer:

vergleiche gemessene Konzentration mit Konzentration zum
Infiltrationszeitpunkt
Ist Anfangskonzentration bekannt?



Anreicherung eines stabilen Isotops:

Annahmen:

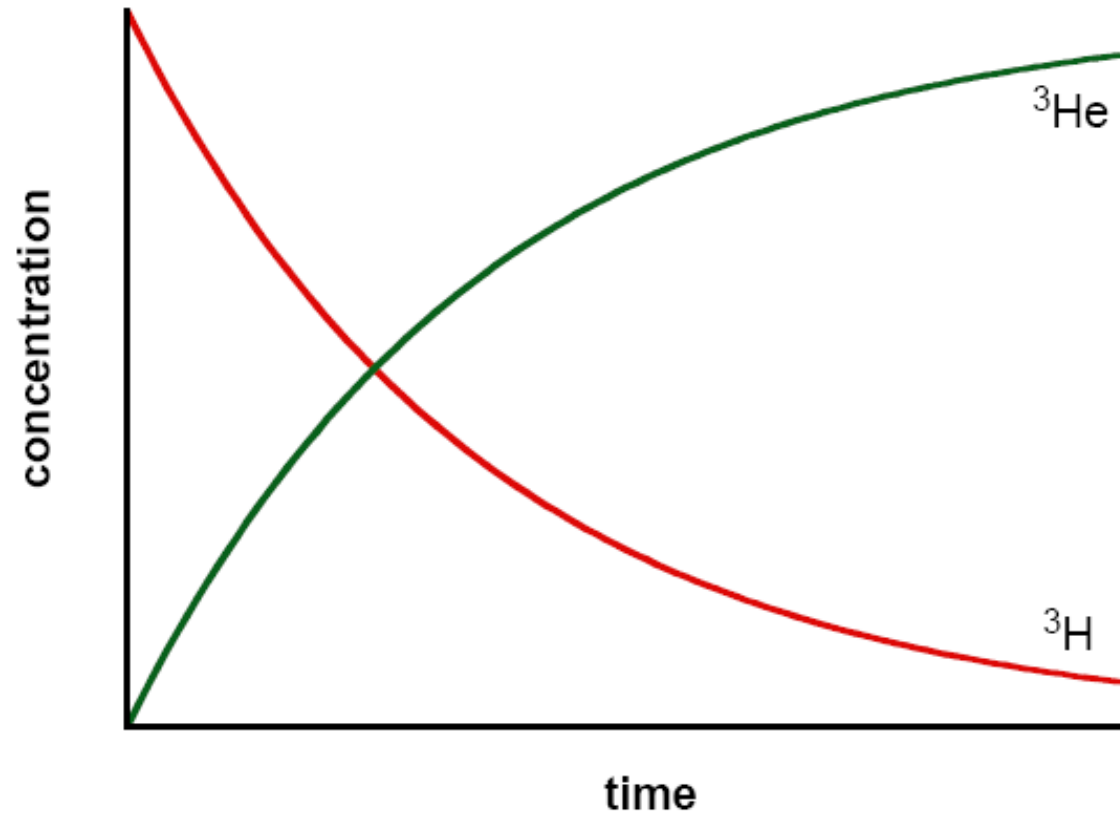
- Tracer Konzentration zum Zeitpunkt der Infiltration = 0
- Anwachsrate = konstant

Radioaktiver Tracer + Zerfallsprodukt

leite Alter aus Verhältnis von 2 inerten Stoffen ab

⇒ unabhängig vom Eintrag

mother - daughter pair



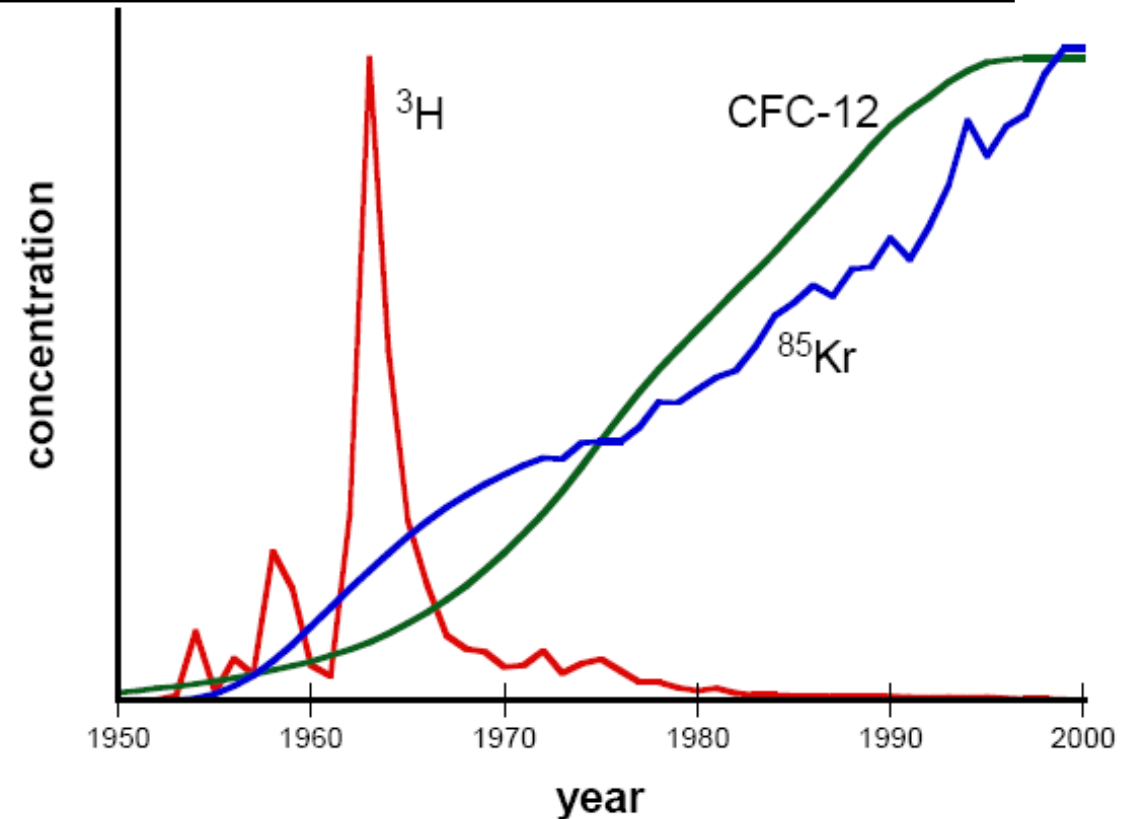
$$t = \frac{1}{\lambda} \ln \left(1 + \frac{{}^3\text{He}_{\text{tri}}(t)}{{}^3\text{H}(t)} \right)$$

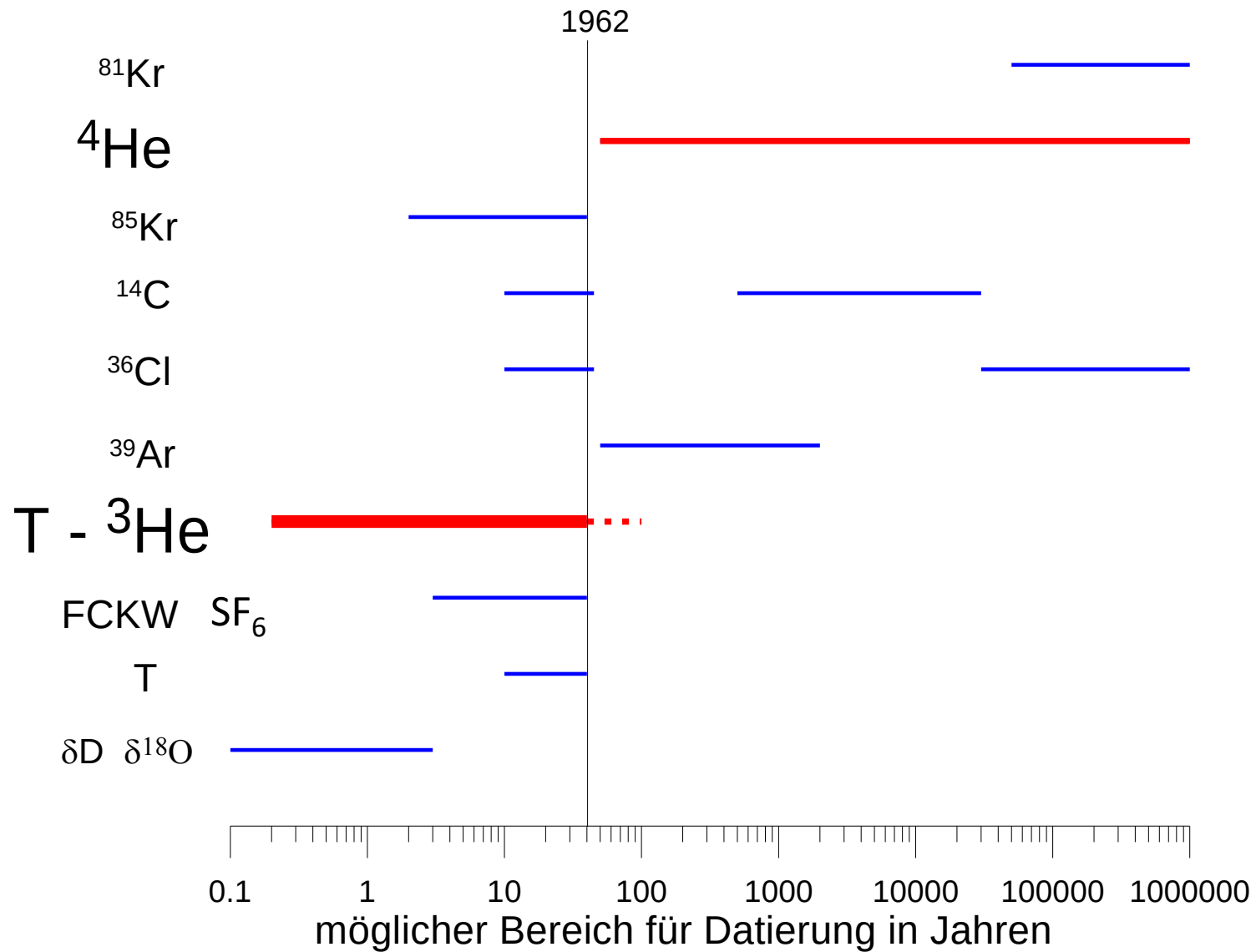
Tracer mit variierender atmosphärischer Konzentration

hier: *anthropogene Tracer*

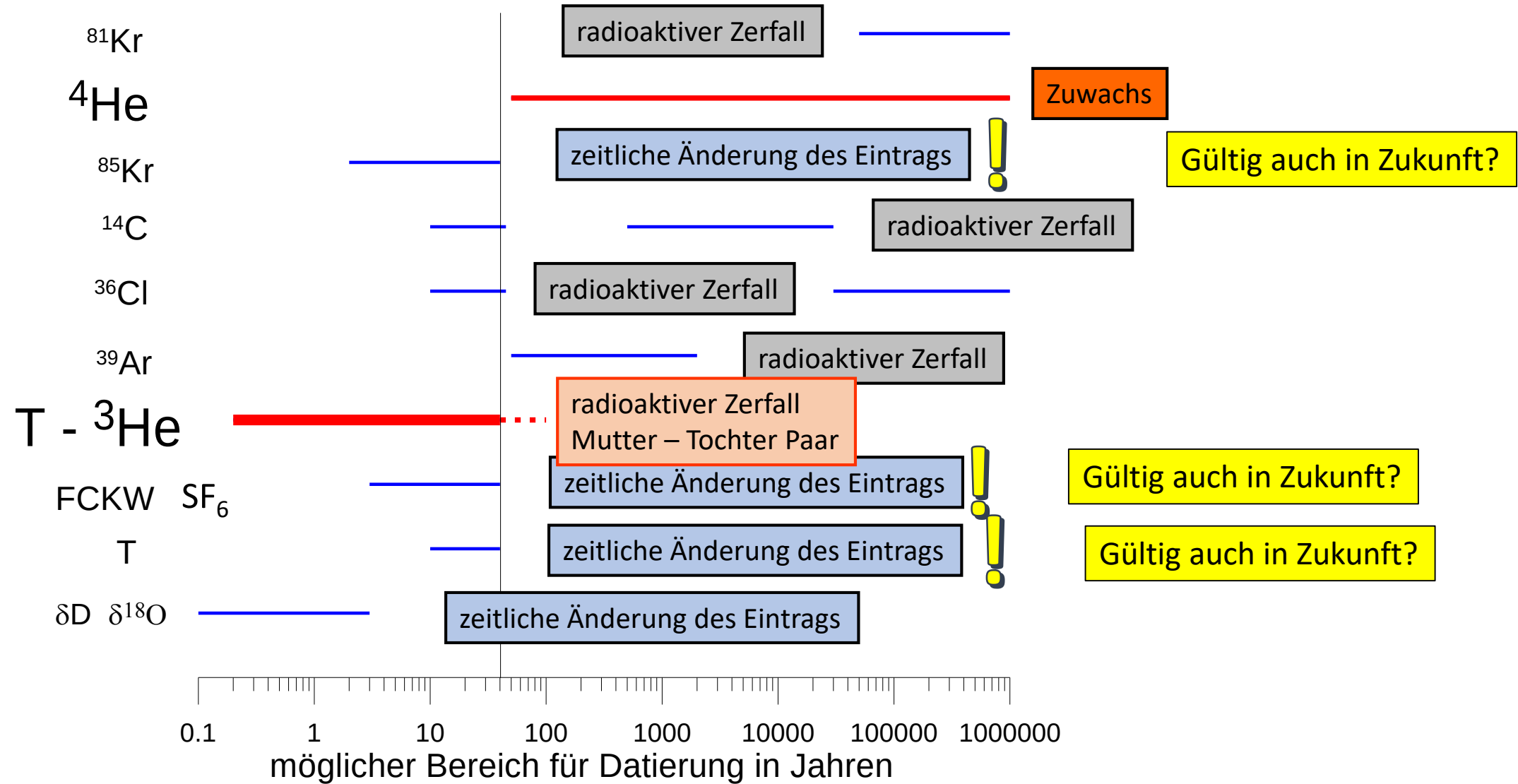
vergleiche Konzentration der Probe mit der atmosphärischen Konzentration

- atmosphärische Konzentration = monotone Funktion?
- zeitliche Änderungen der Konzentration muss bekannt sein



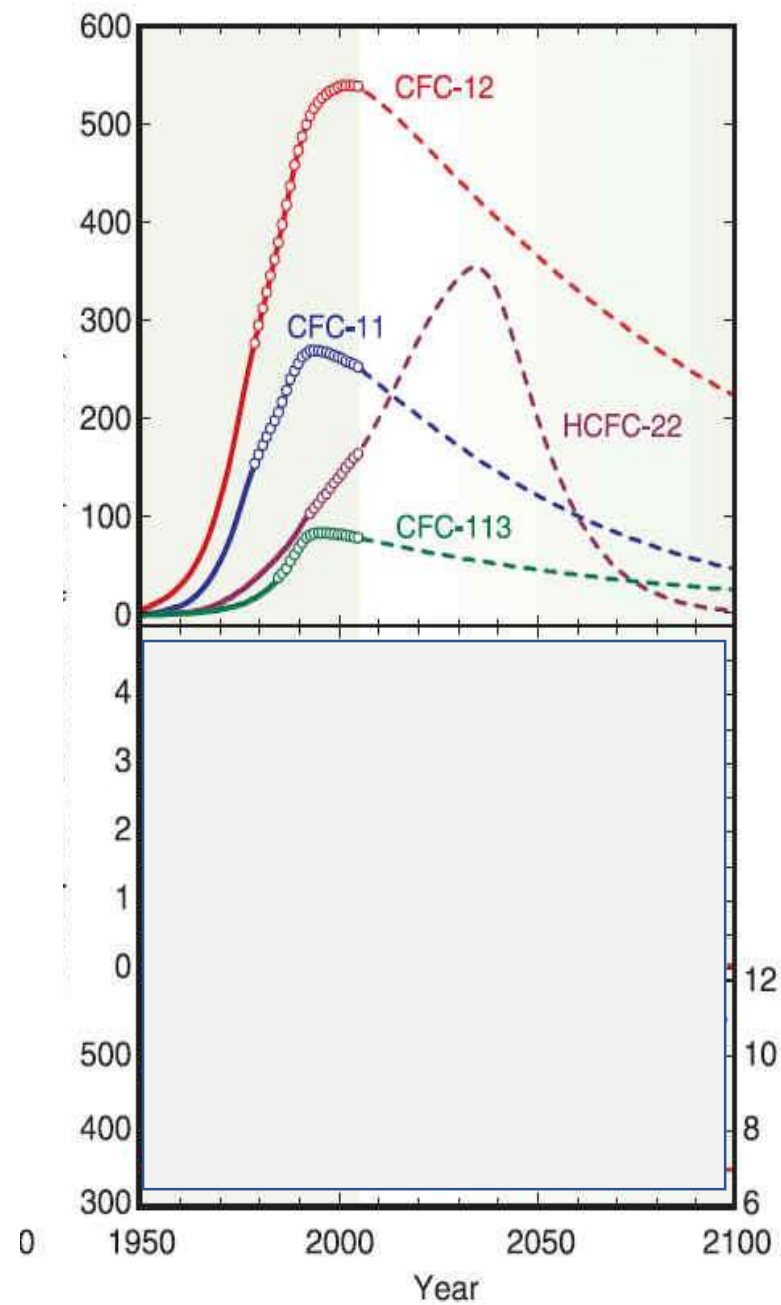
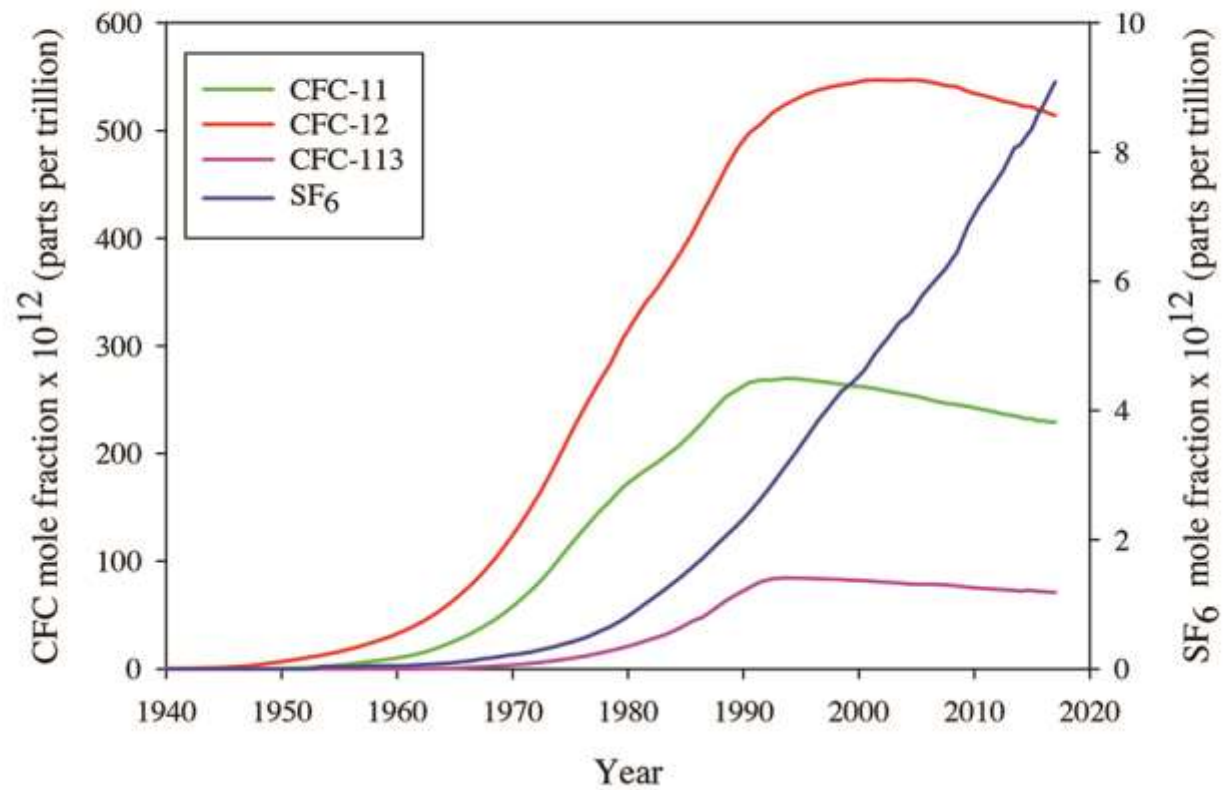


Uhren



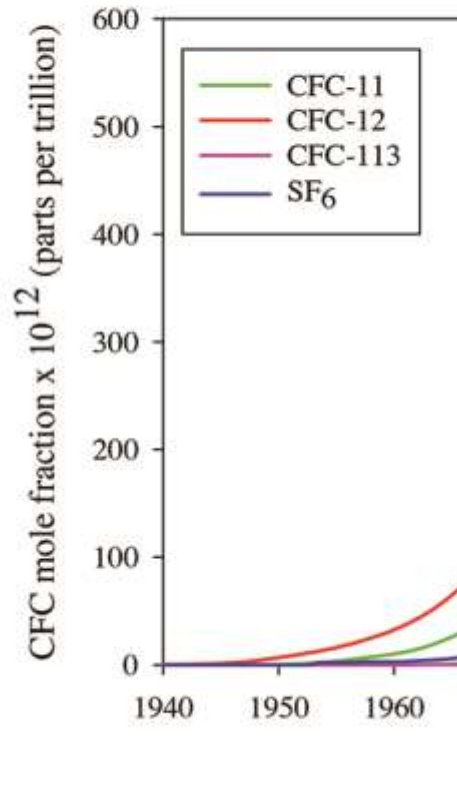


Atmospheric CFCs and SF₆ in the Northern Hemisphere





Atmospheric CFCs and SF₆ in the Northern Hemisphere



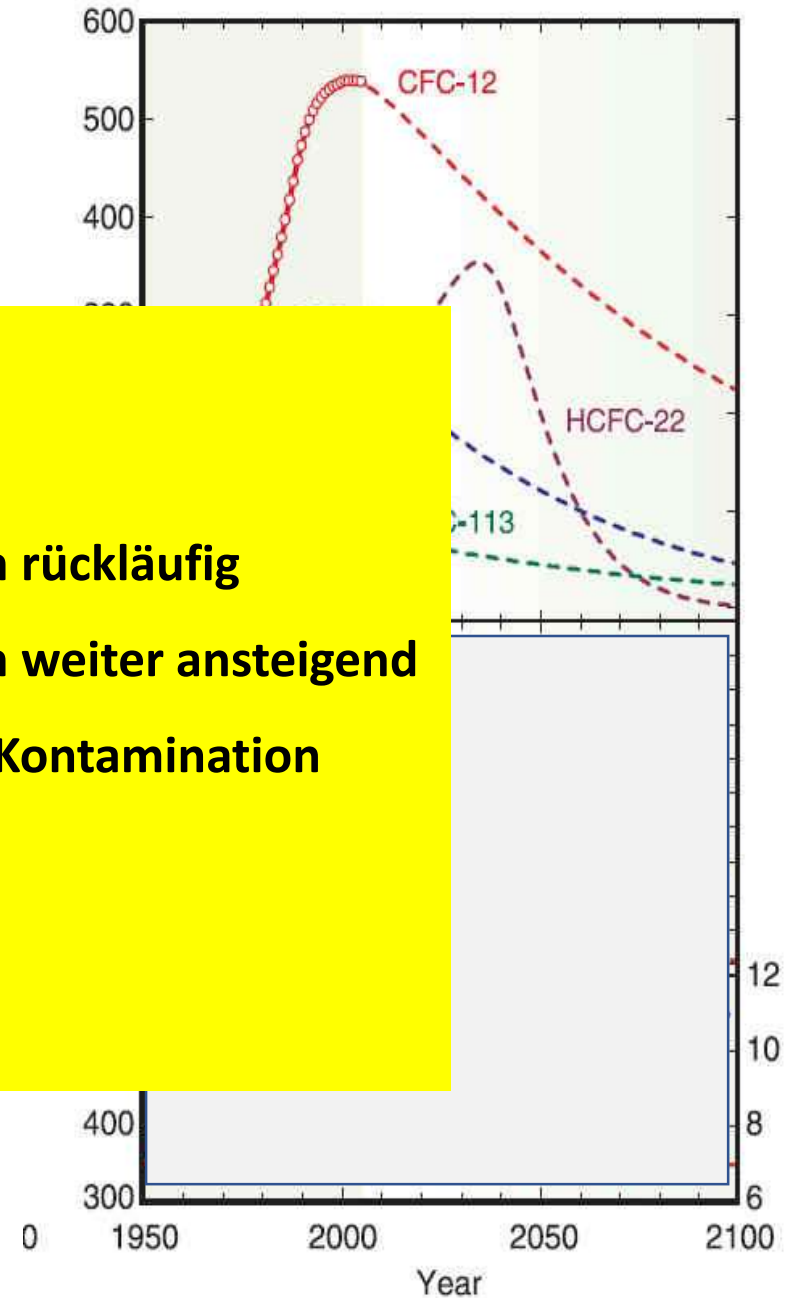
Neue tracer sind nicht zu erwarten

FCKWs: atmosphärische Konzentration rückläufig

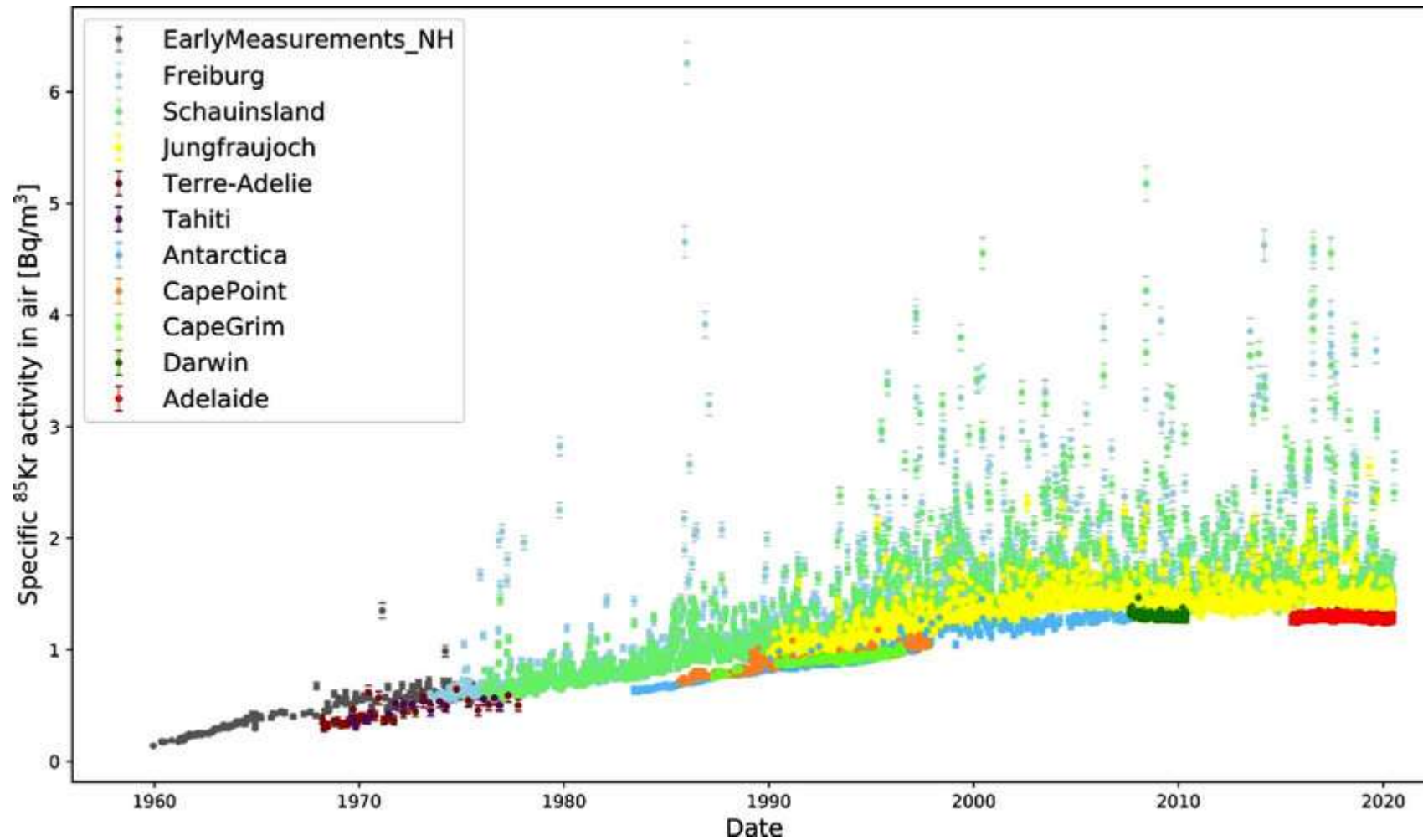
SF₆: atmosphärische Konzentration weiter ansteigend

ABER Untergrundproduktion, Kontamination

Messtechnik beschränkt verfügbar



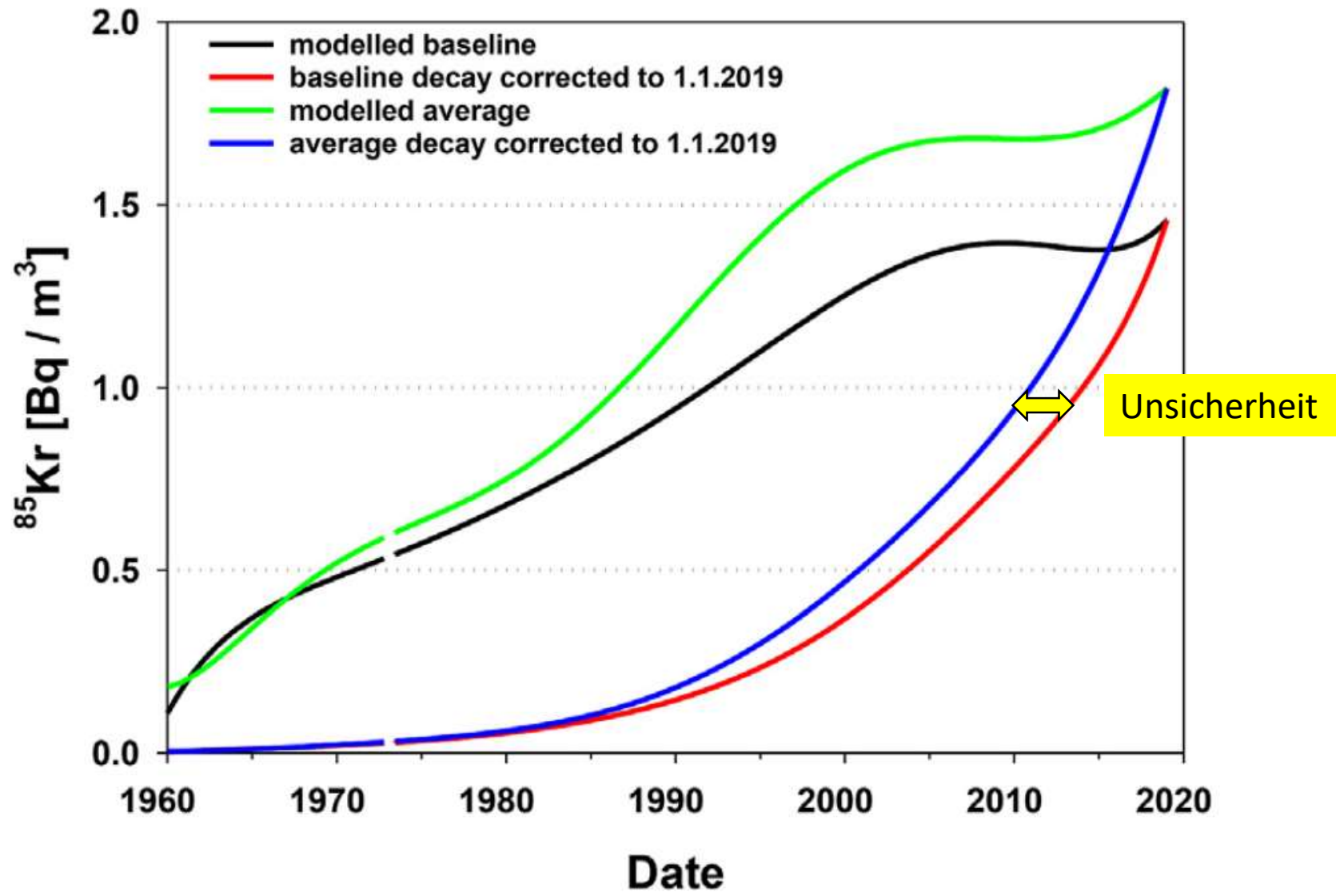
^{85}Kr aus Wiederaufarbeitung von Kernbrennelementen

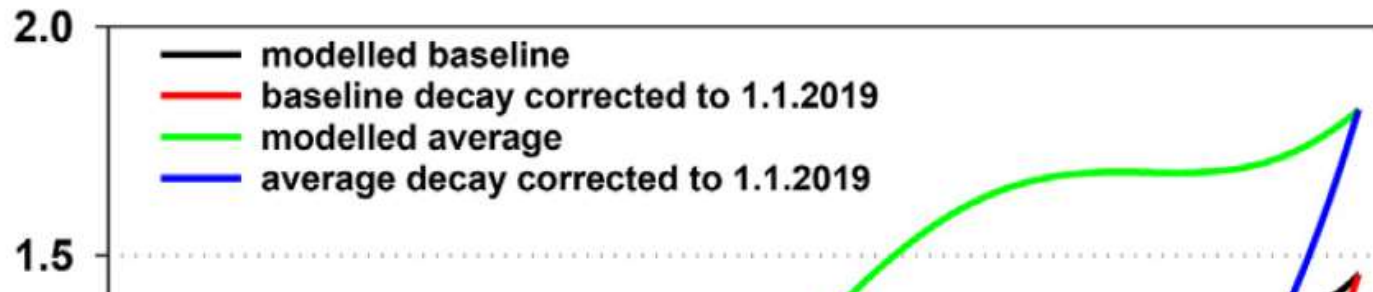


$t_{1/2} = 10.76\text{a}$

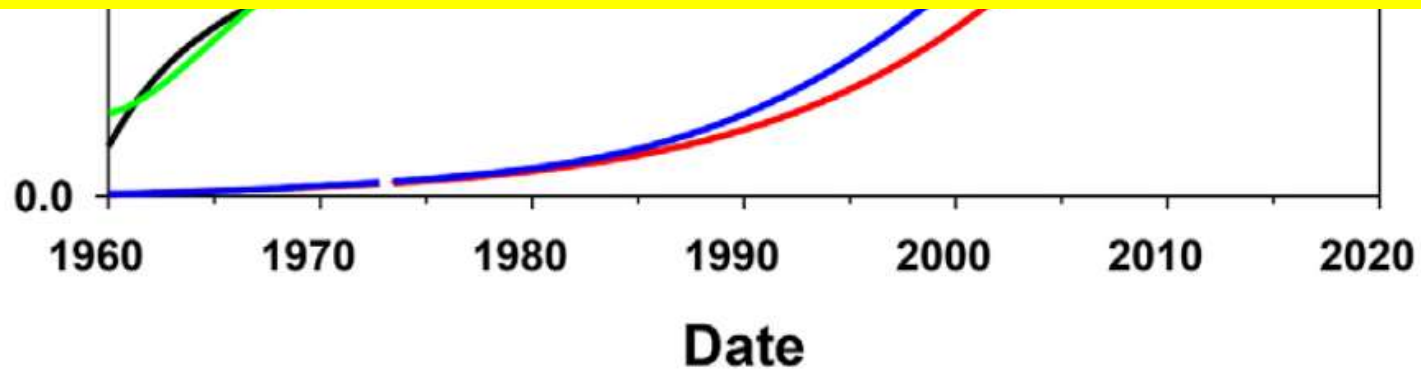
mit Abstand größte Quelle:
La Hague

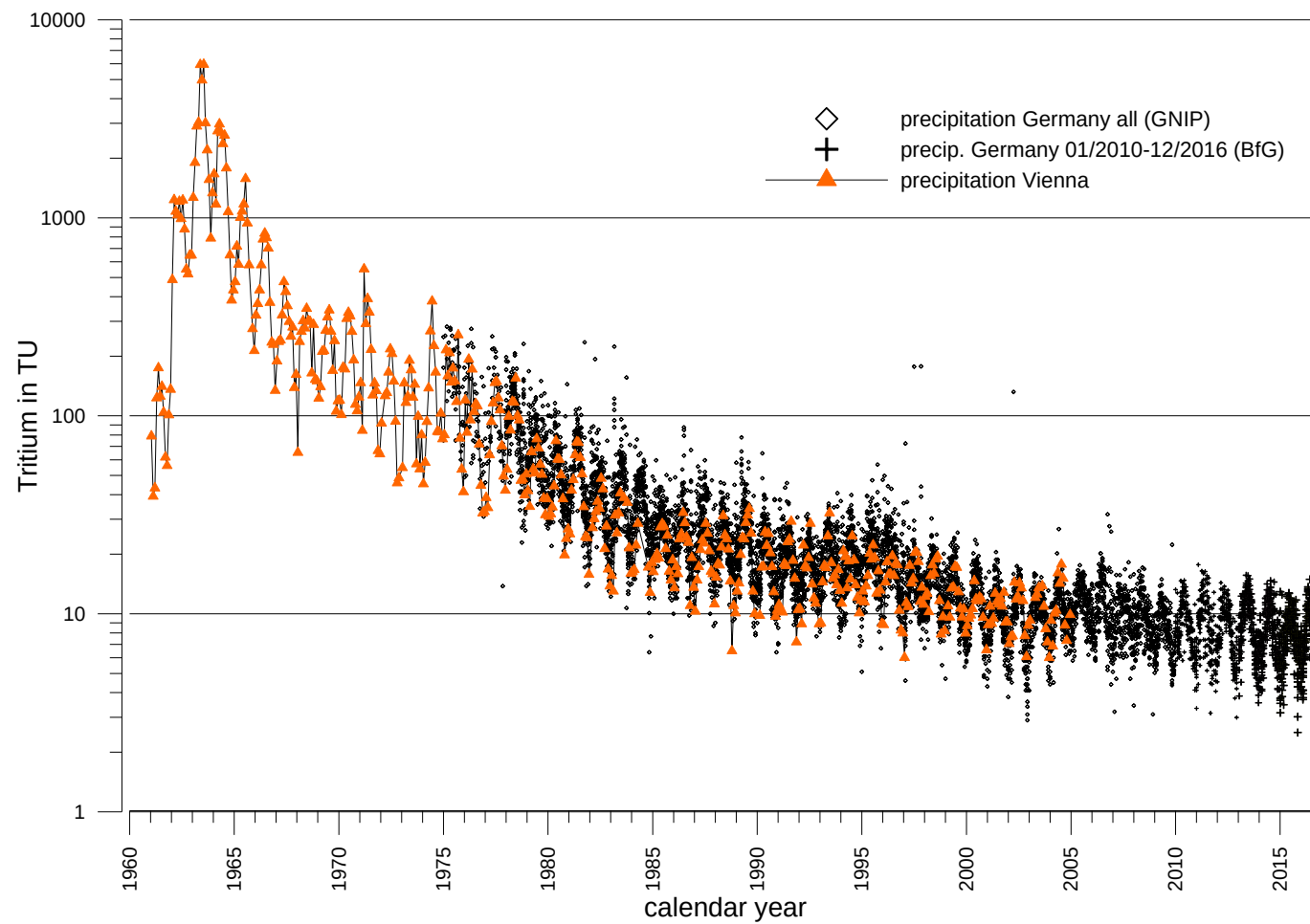
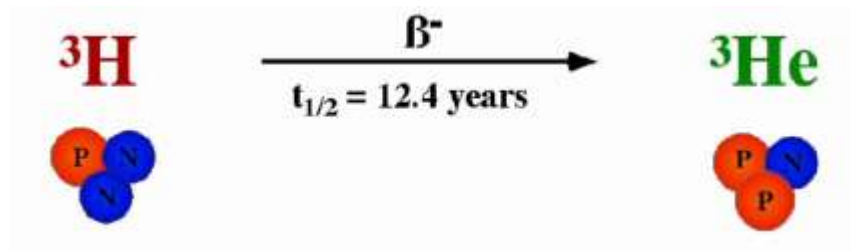
Time series of atmospheric Kr-85 concentration in week-long samples at Schauinsland near Freiburg (Germany). [GFM07]

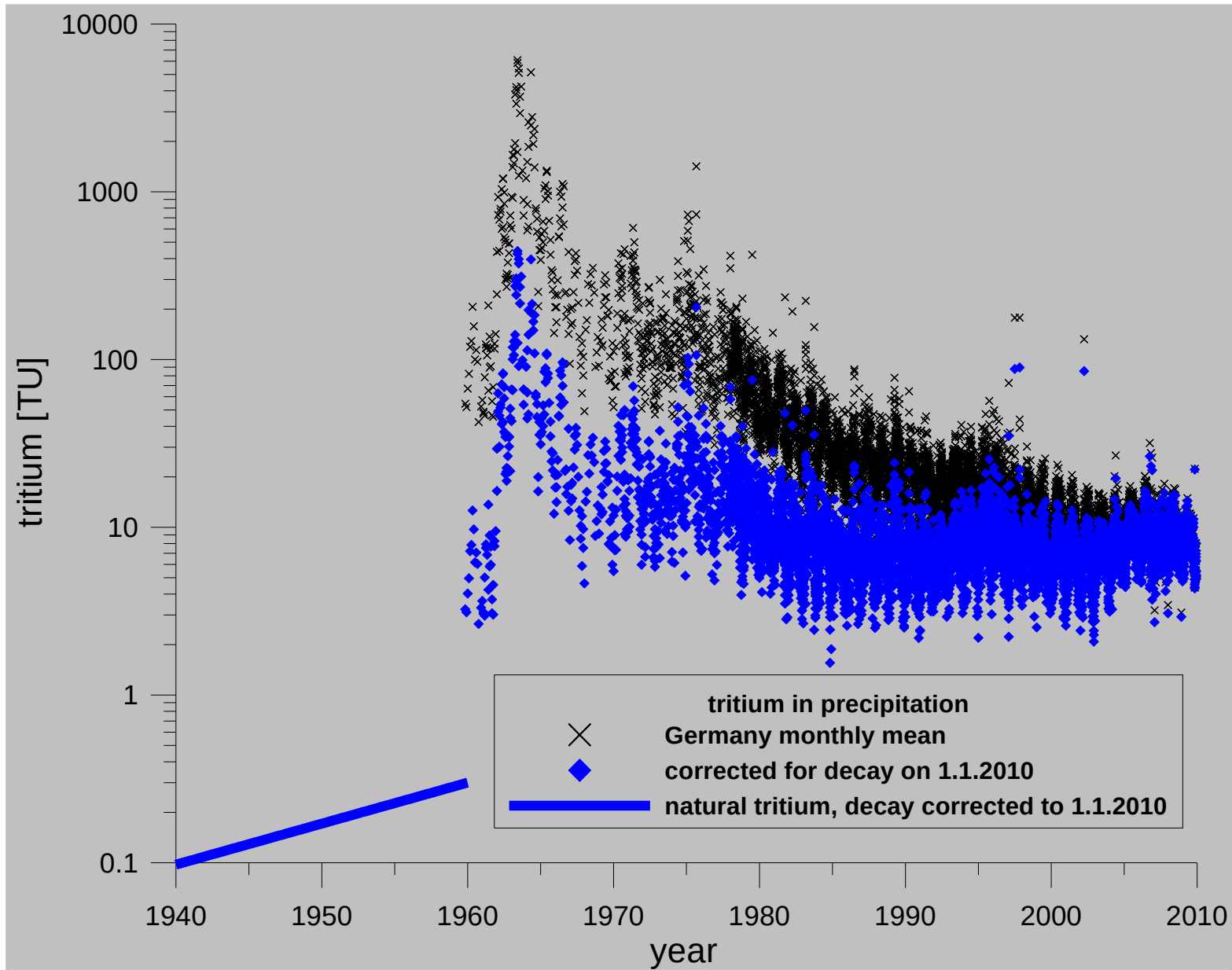




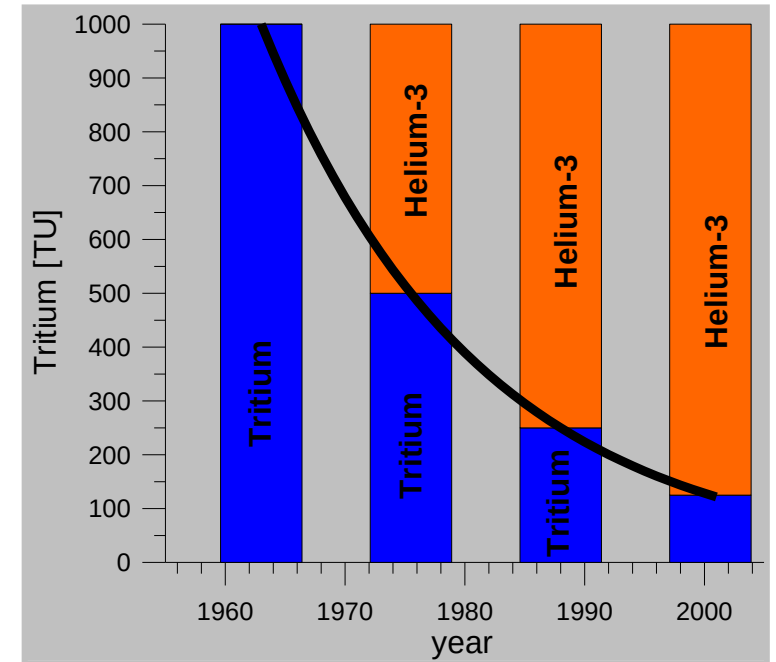
^{85}Kr : atmosphärische Konzentration weiter gering ansteigend
 altes Messverfahren beschränkt verfügbar: große Probenmenge 300l
 neues Messverfahren (ATTA) noch beschränkt verfügbar: geringe Probenmenge 10l

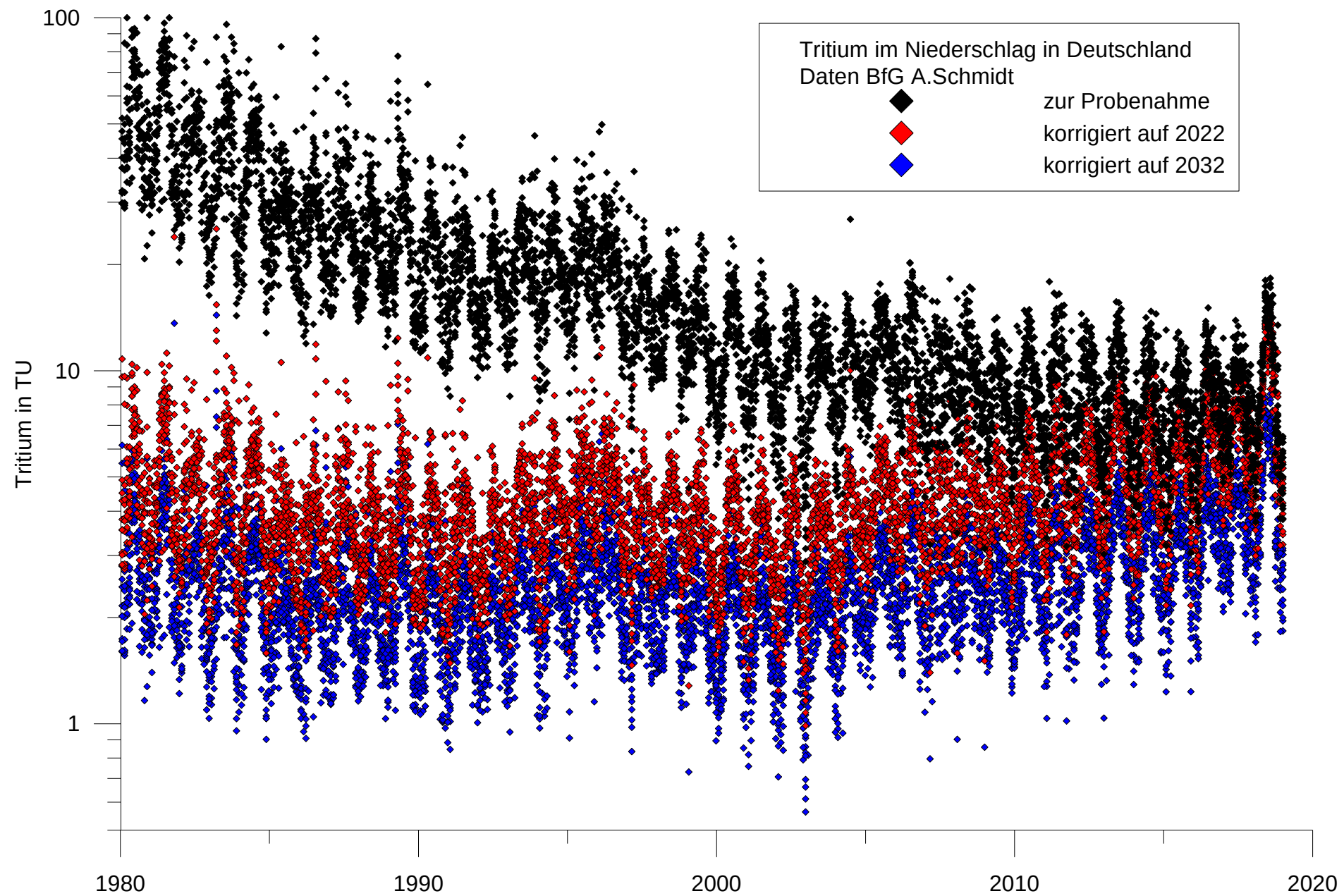


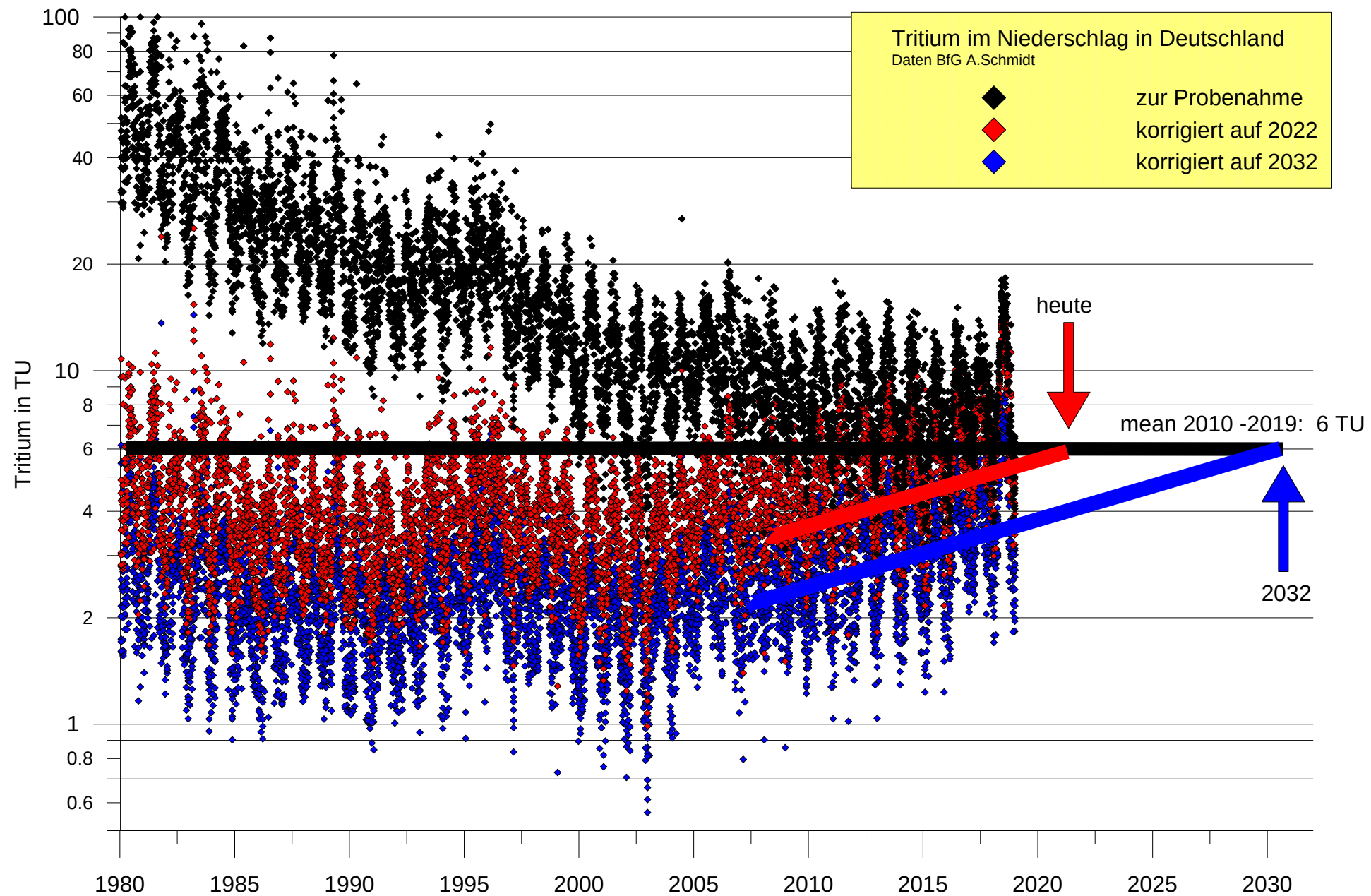


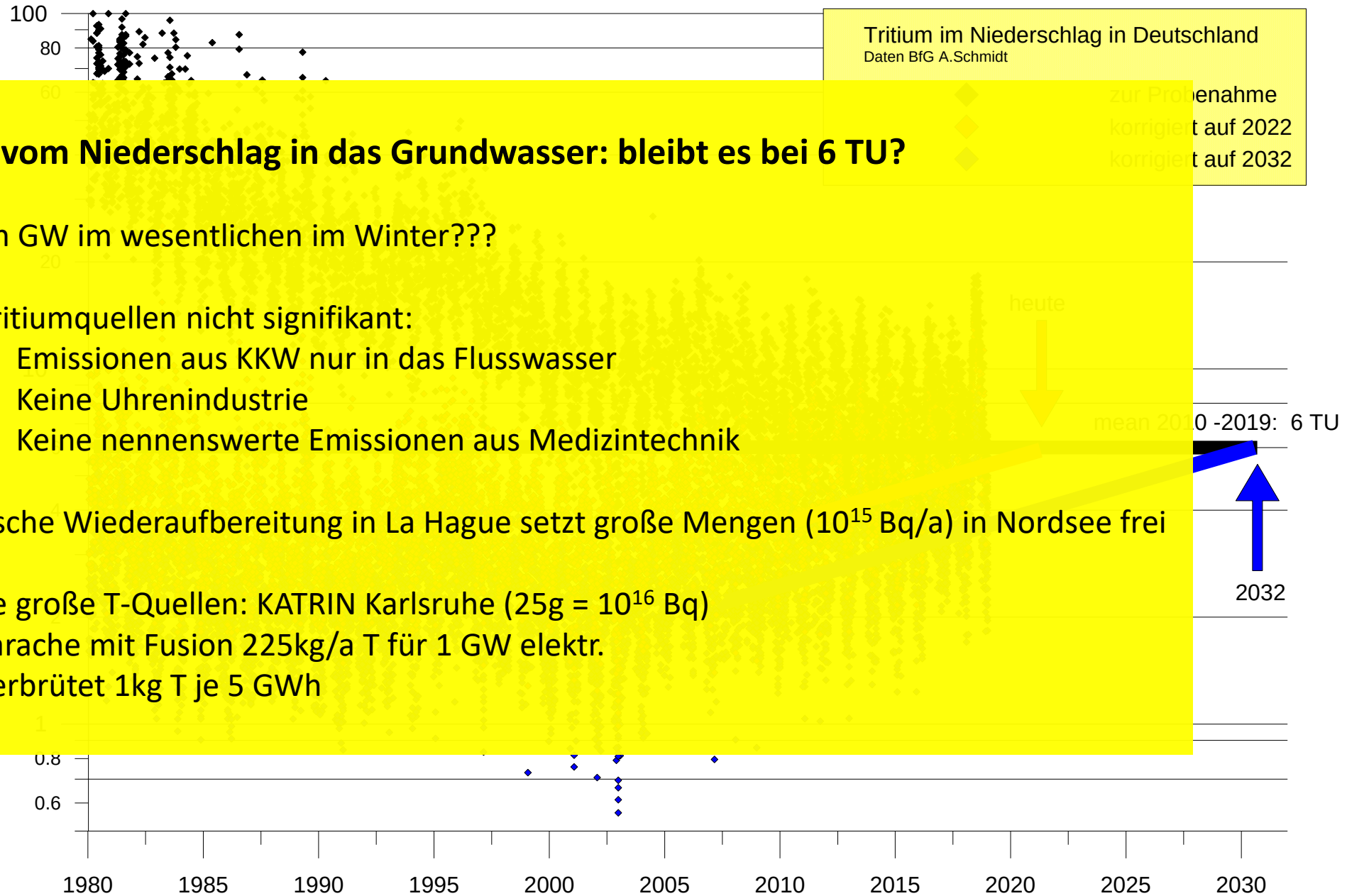


^3H und ^3He im Grundwasser



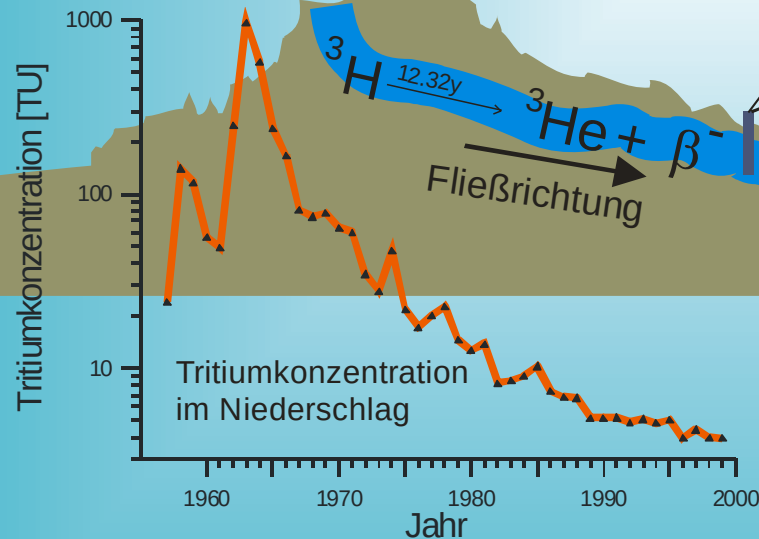






Eine radioaktive Uhr im Grundwasser: Altersbestimmung von Grundwasser mit radioaktivem Wasserstoff (Tritium, ^3H)

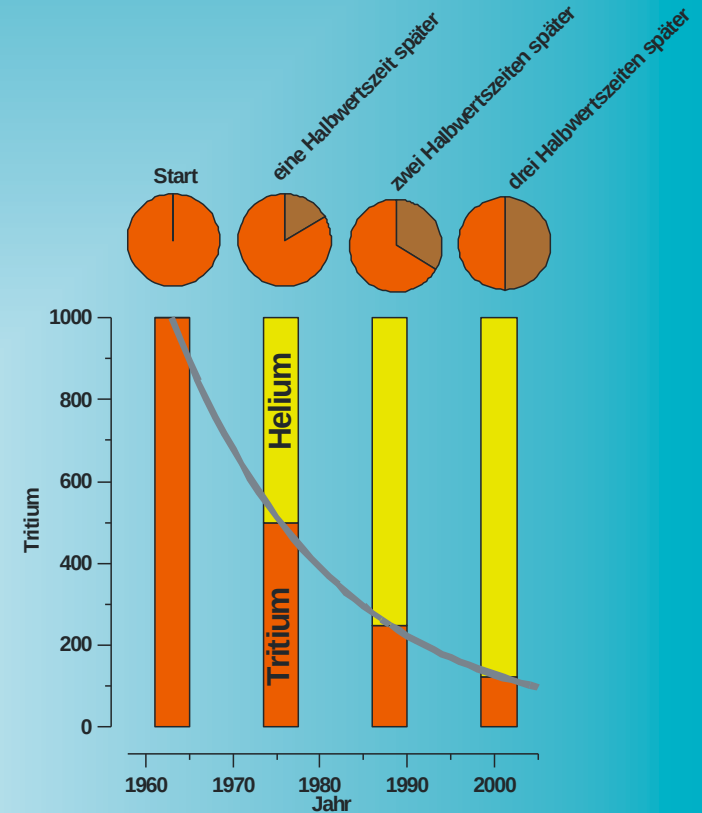
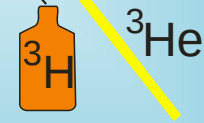
Wasserstoffbomben-
Tests 1962/63



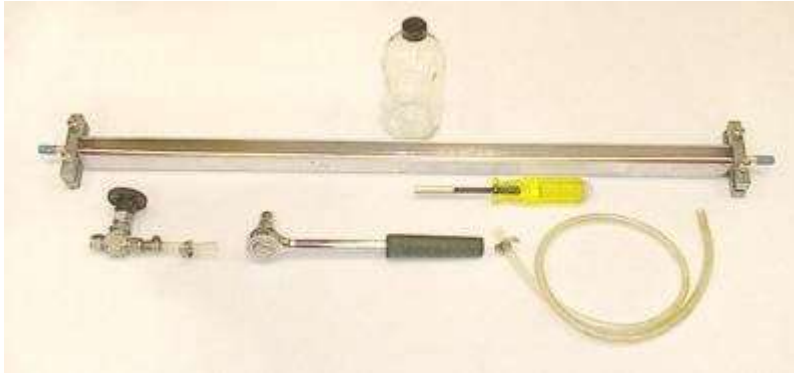
Tritium: radioaktiver Wasserstoff
zerfällt zu Helium



Fließrichtung



einfache **Probennahme**

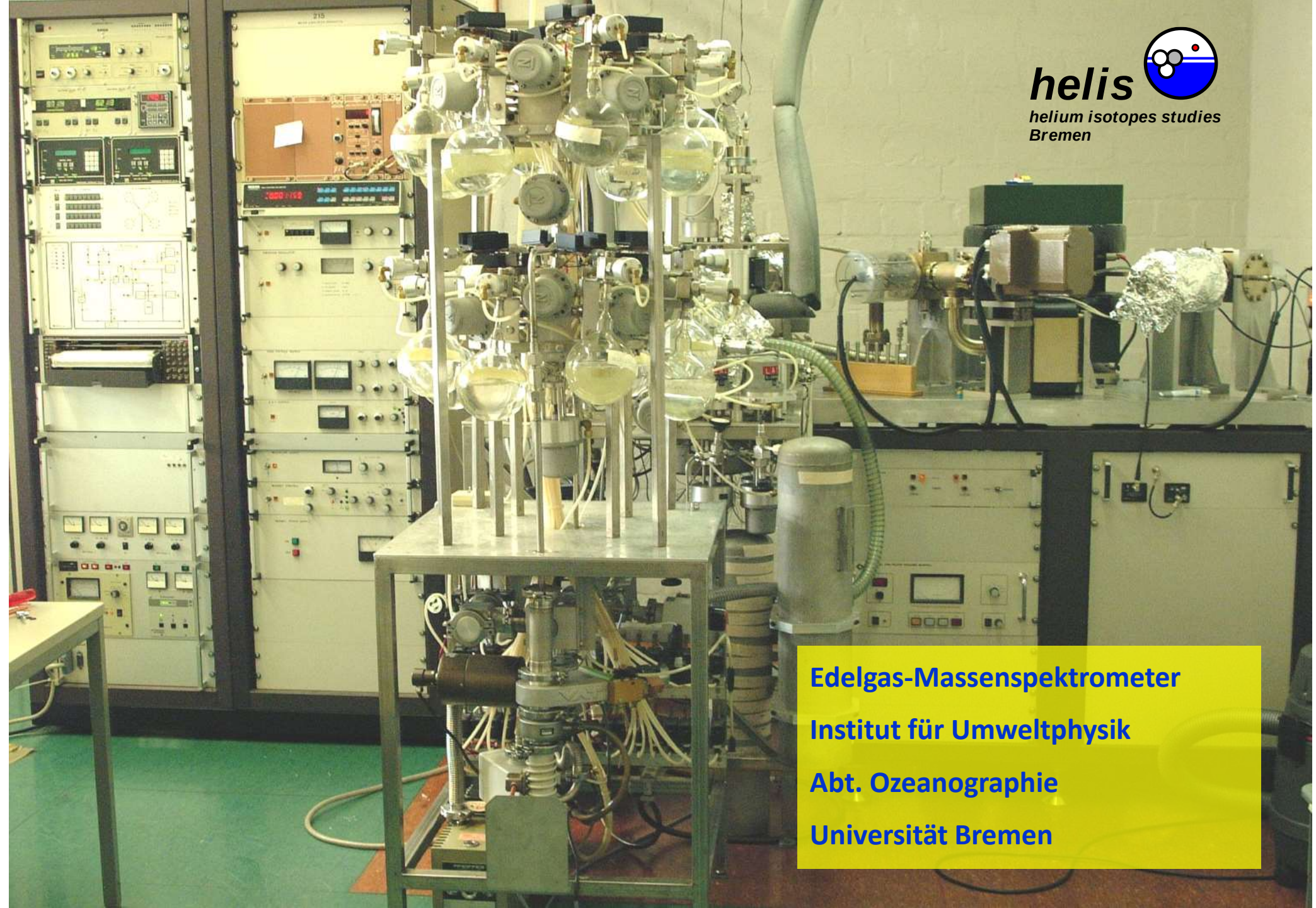


Probenaufarbeitung im Labor:

zur Tritium-Messung:
vollständige Entgasung der Probe
anschließend Lagerung für ^3He -Anwachs

zur He-Messung:
Extrahieren der Probengase aus dem Wasser





Edelgas-Massenspektrometer
Institut für Umweltphysik
Abt. Ozeanographie
Universität Bremen

Probenaufbereitung im Labor



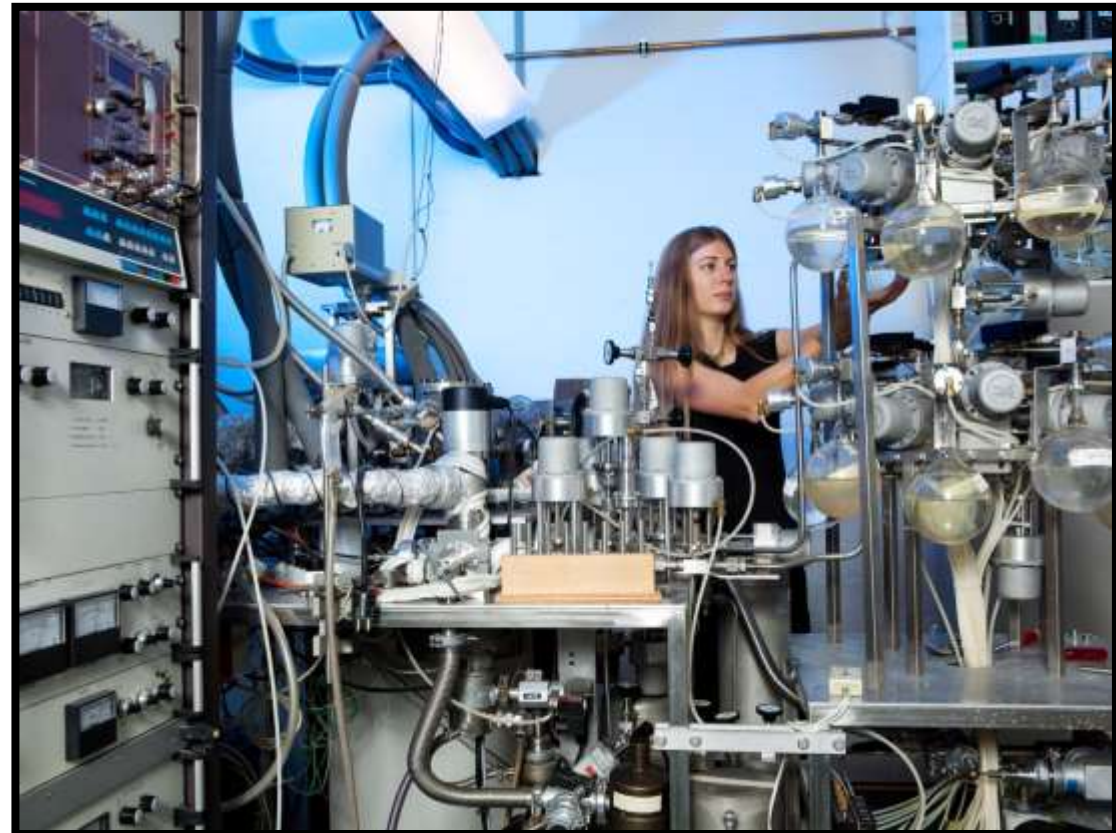
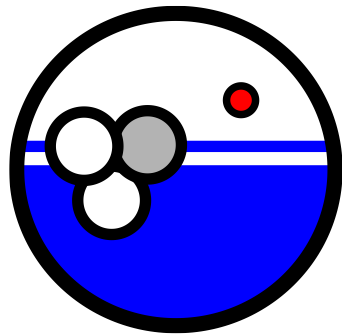
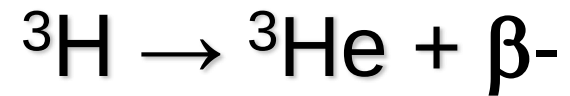
low-level tritium analysis

Tritium analysed by ^3He -ingrowth method:

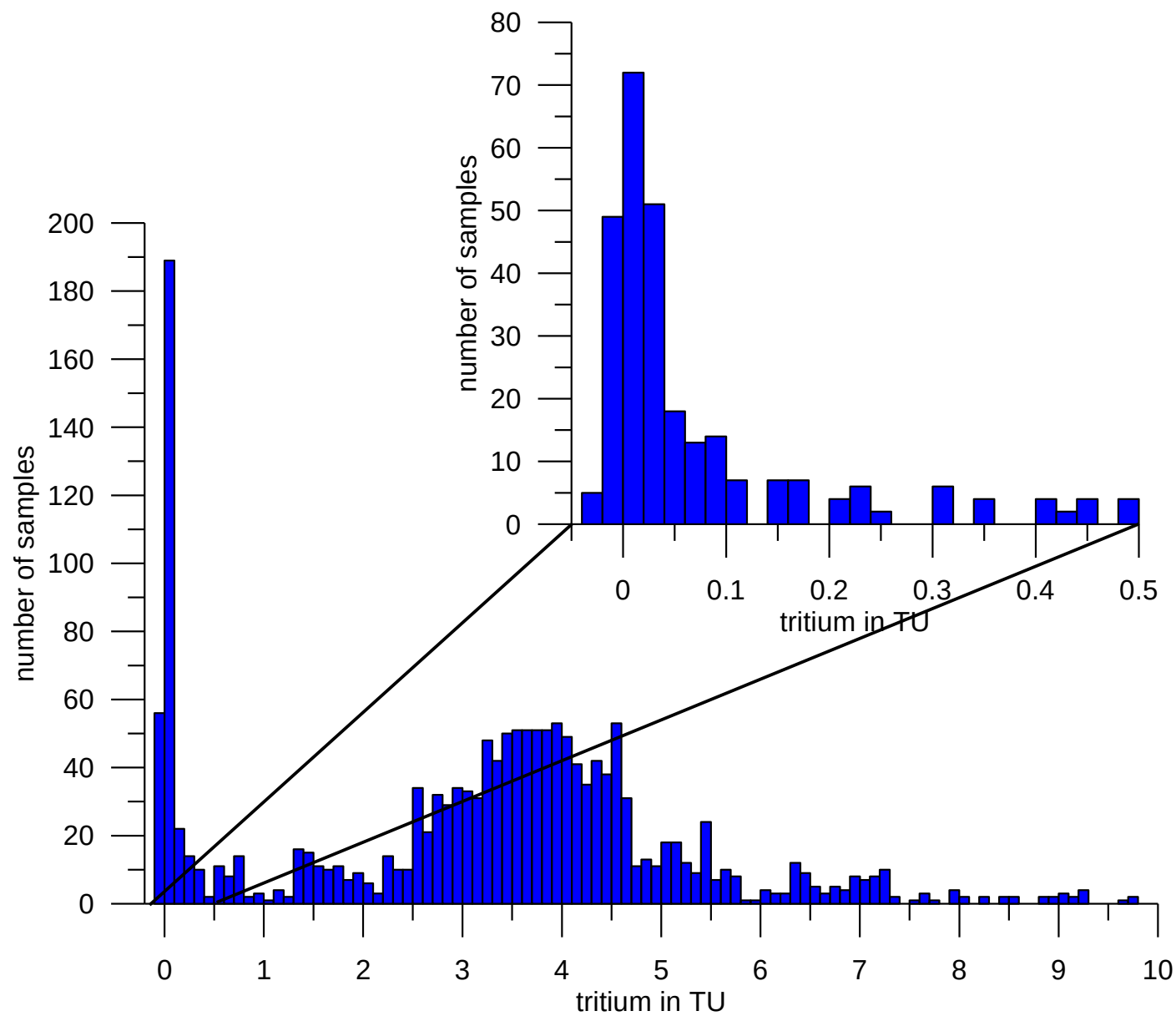
- degass water
- store it for accumulation of ^3He 4 - 8 months
- analyse ^3He with high resolution noble gas mass spectrometer.

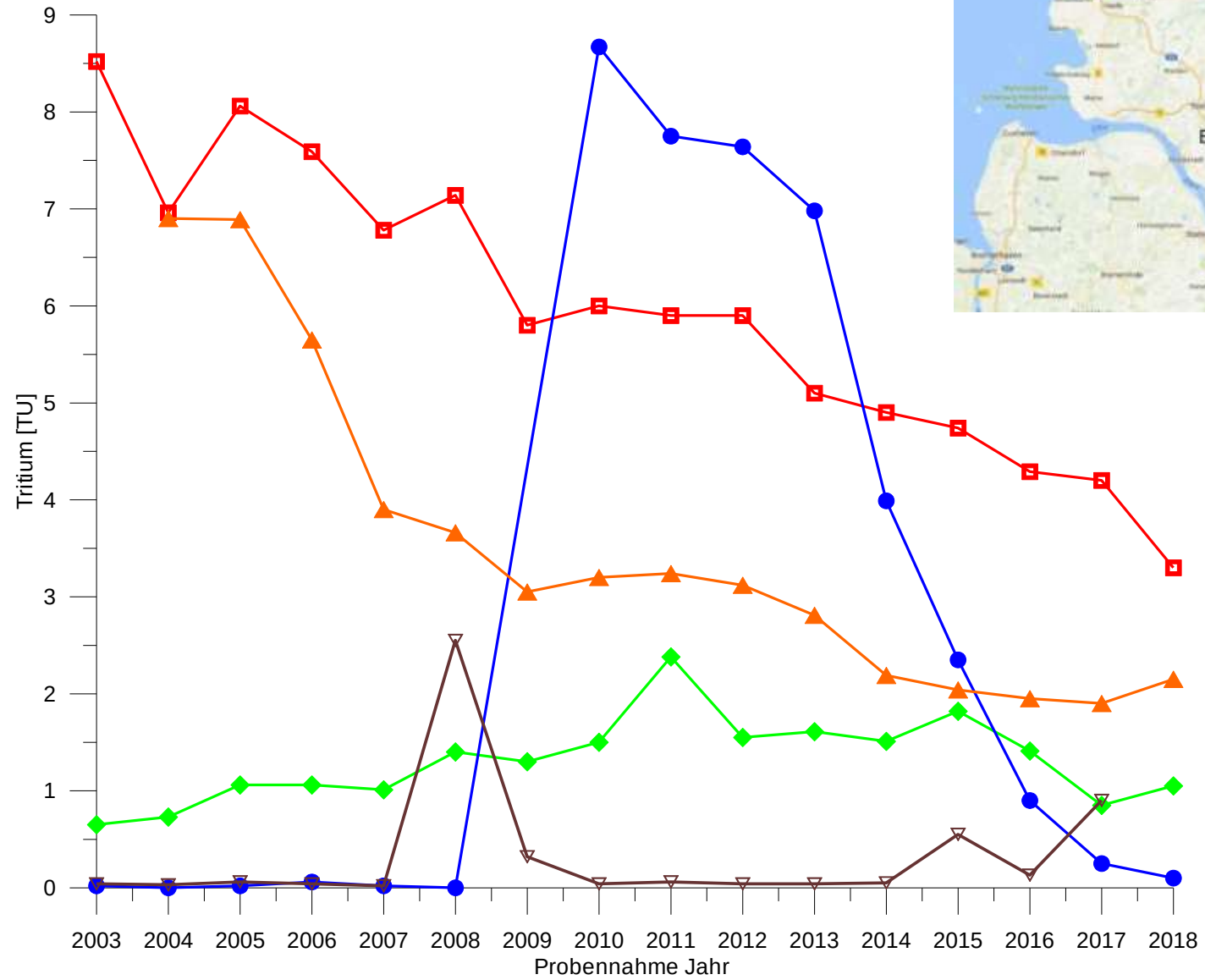
⇒ detection limit 0.01TU

detection limit with conventional counting 0.3 – 1 TU.



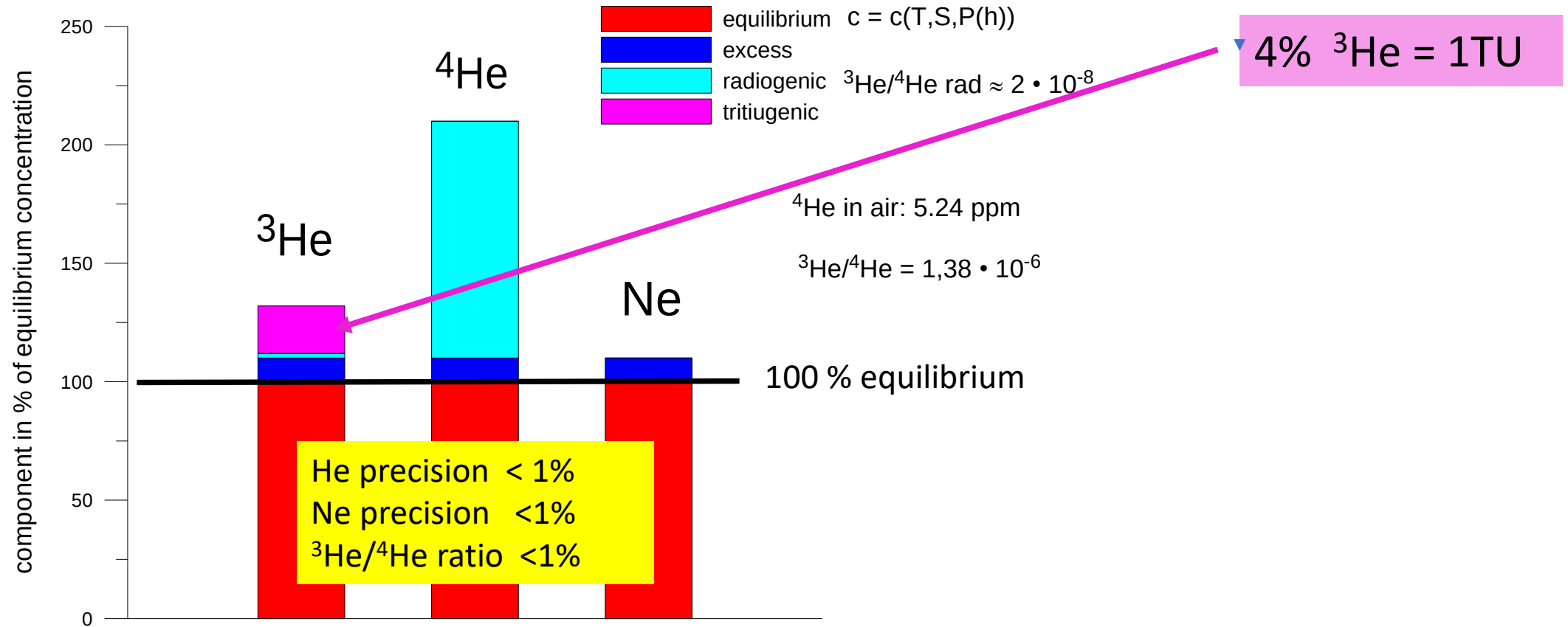
Tritium im Grundwasser in Norddeutschland





Datierung mit Tritium & Helium-3:

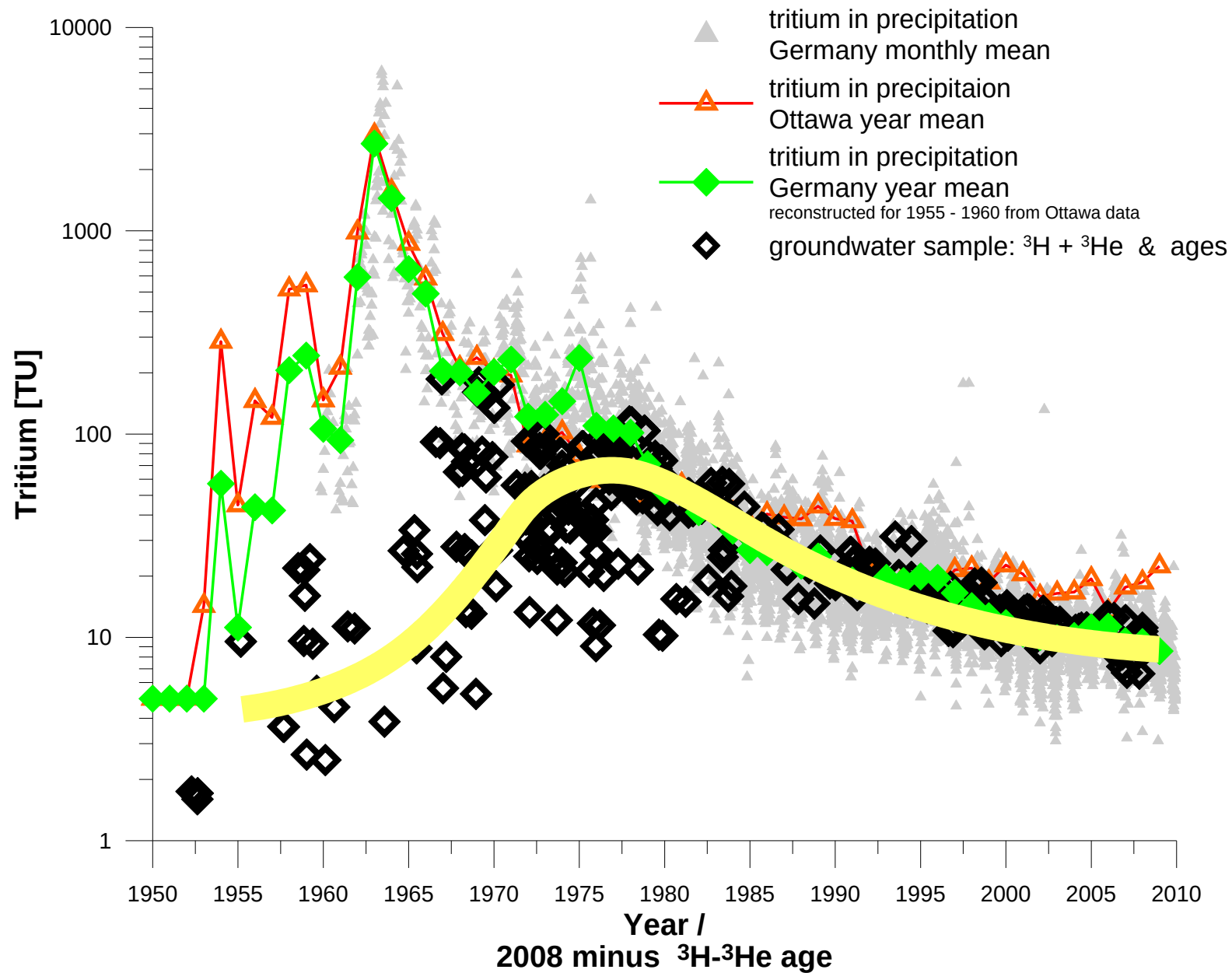
Trenne Komponenten von ^3He und ^4He um tritiogenes ^3He zu erhalten



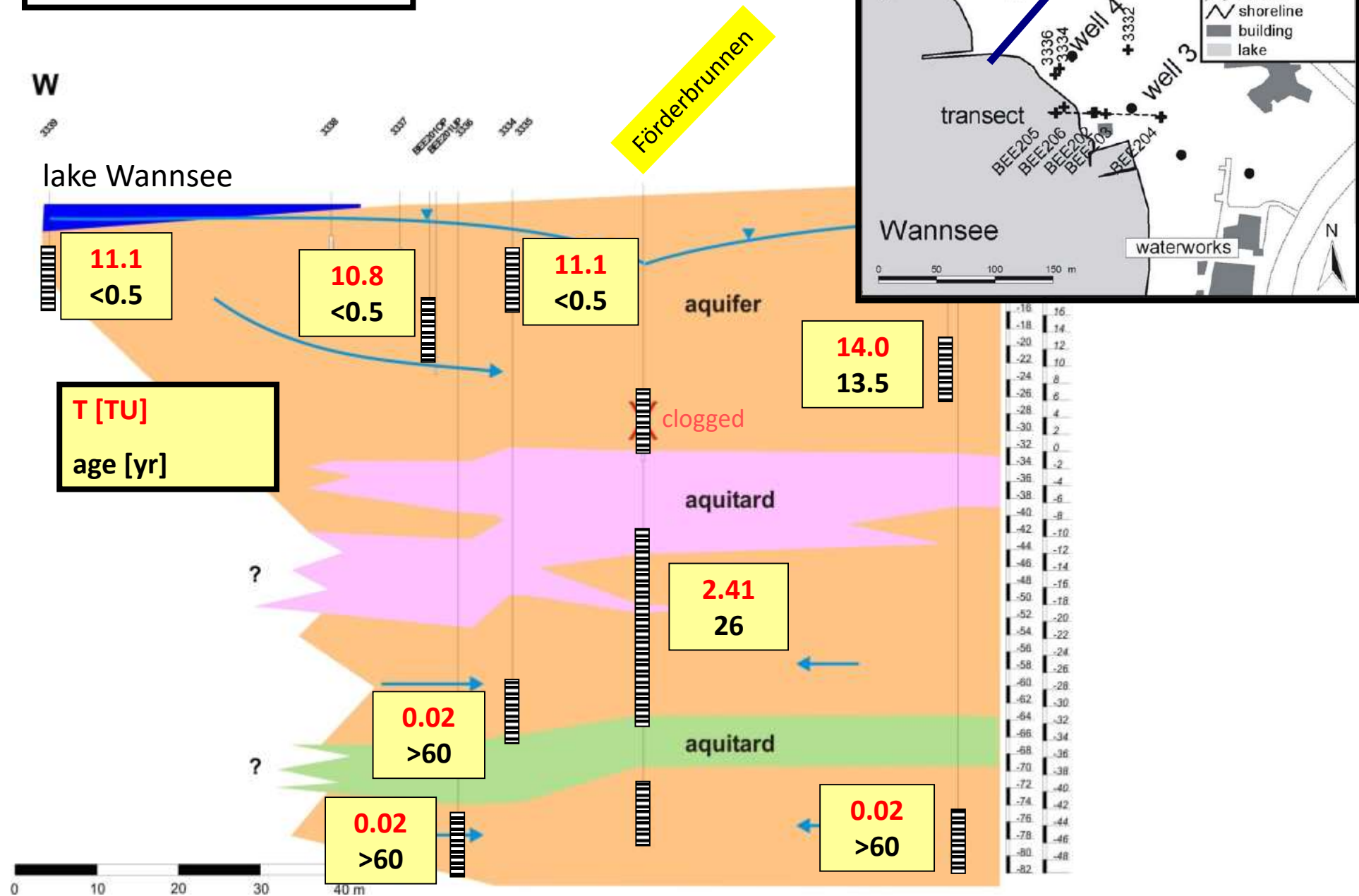
beste mögliche Auflösung ca. 0.5 TU
→ zeitliche Auflösung (heute) ca. 1.5 Jahre

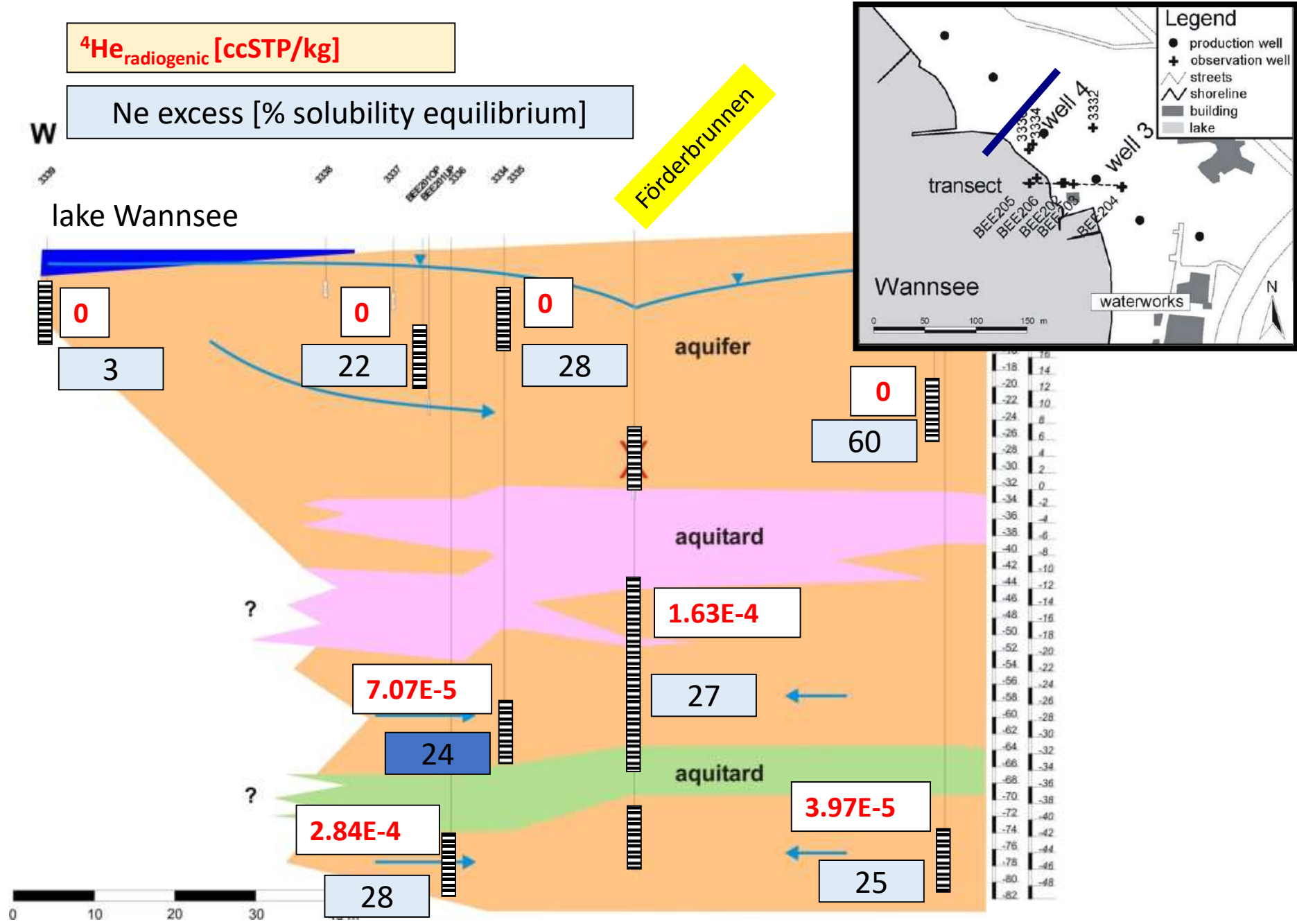
$$t = \frac{1}{\lambda} \ln \left(1 + \frac{^3\text{He}_{\text{tri}}(t)}{^3\text{H}(t)} \right)$$

^3H und ^3He im flachen Grundwasser Norddeutschland

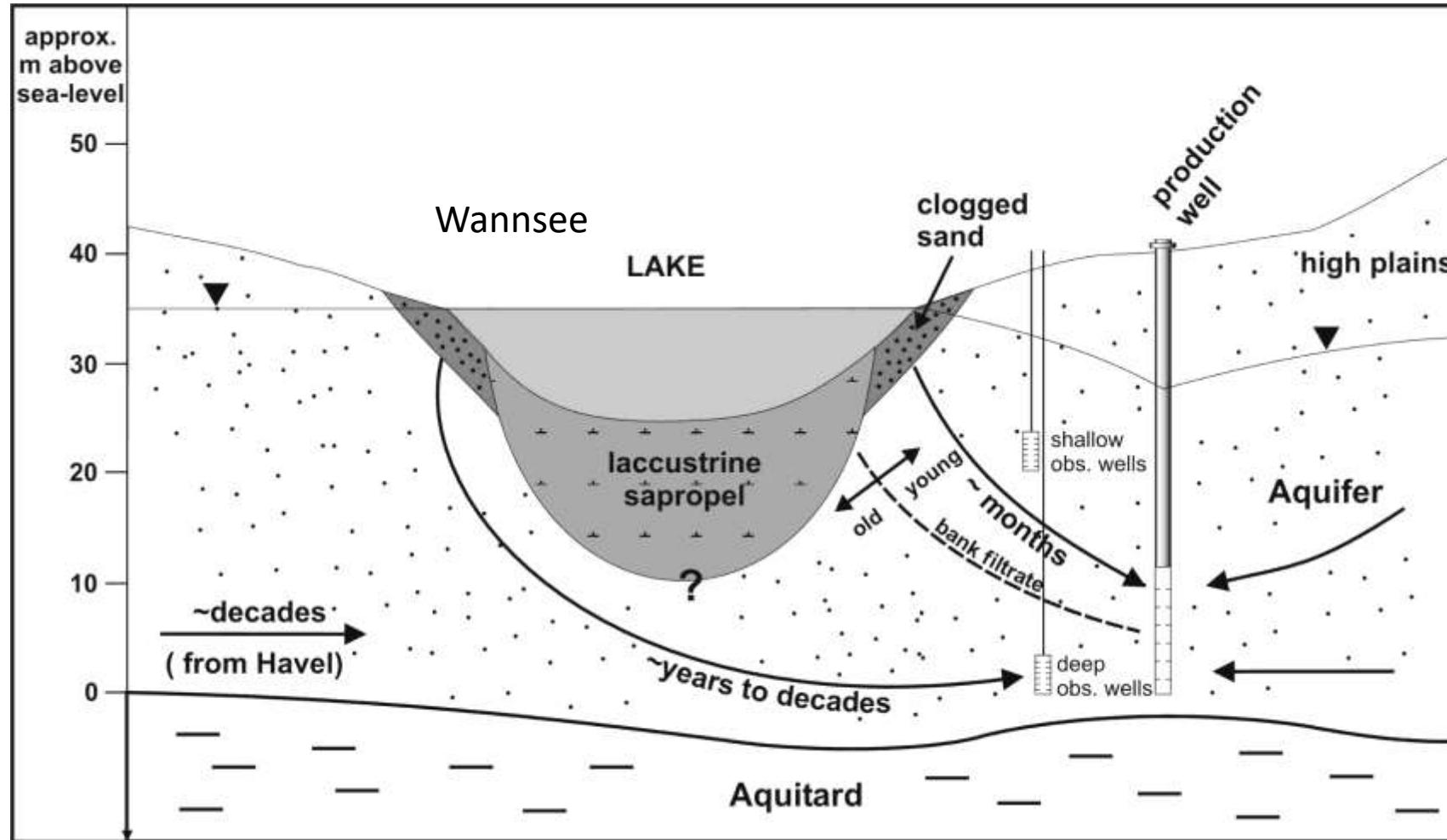


Berlin – Wannsee 2005

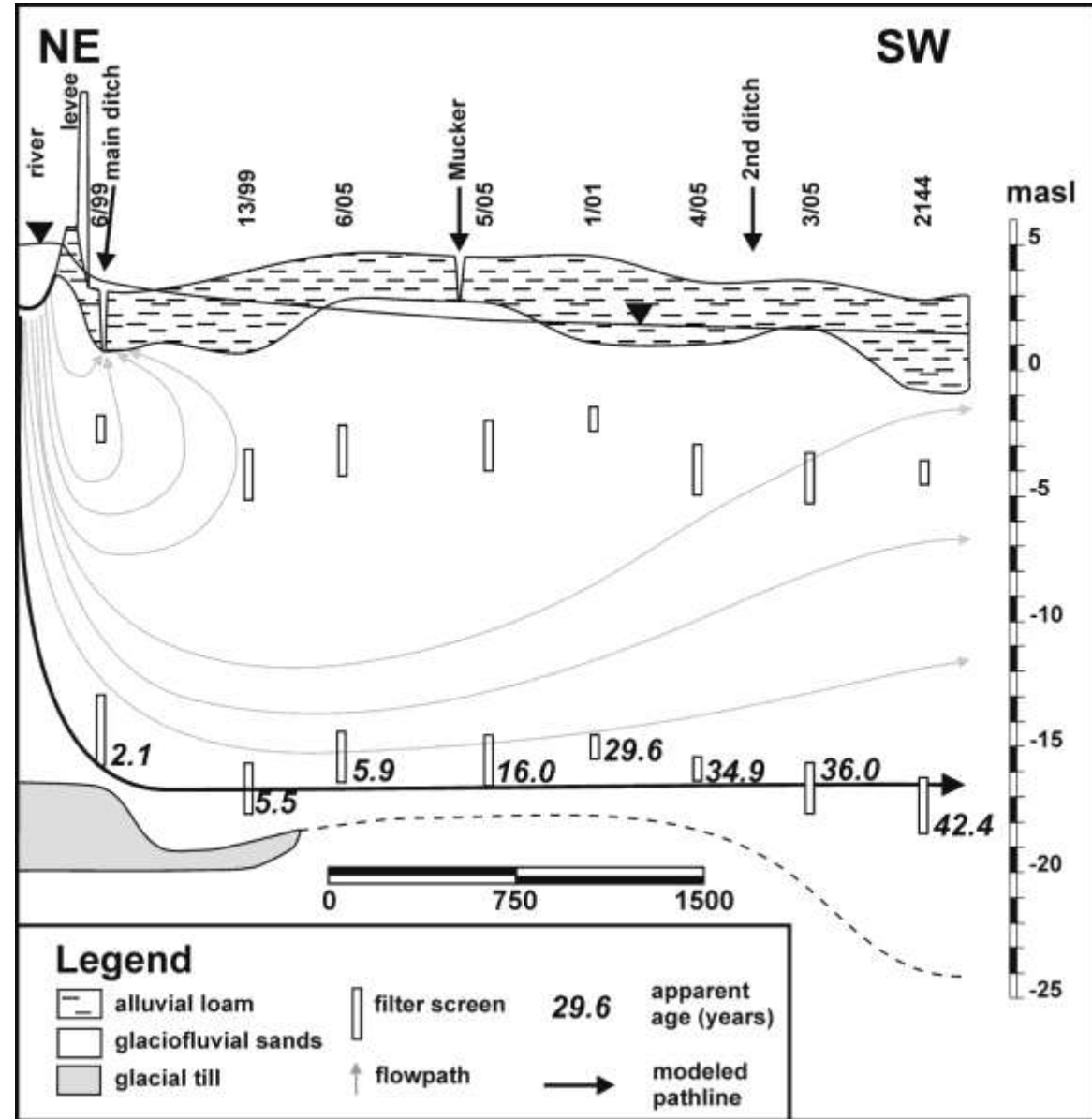
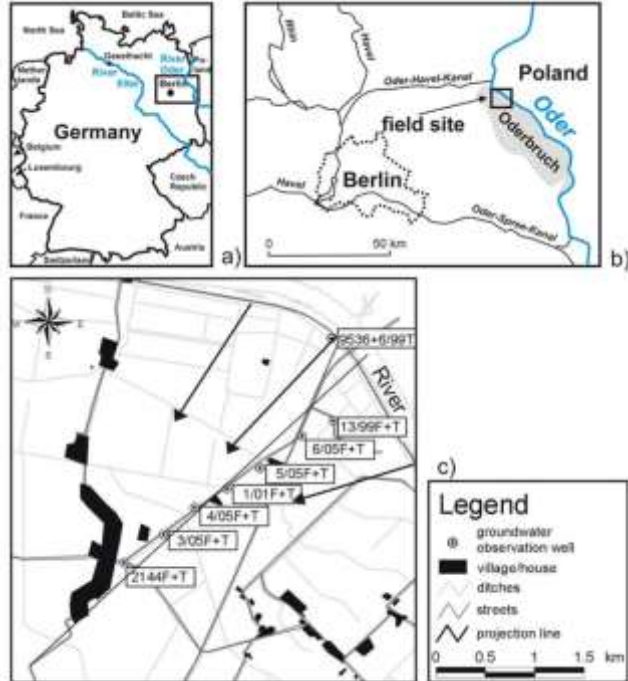




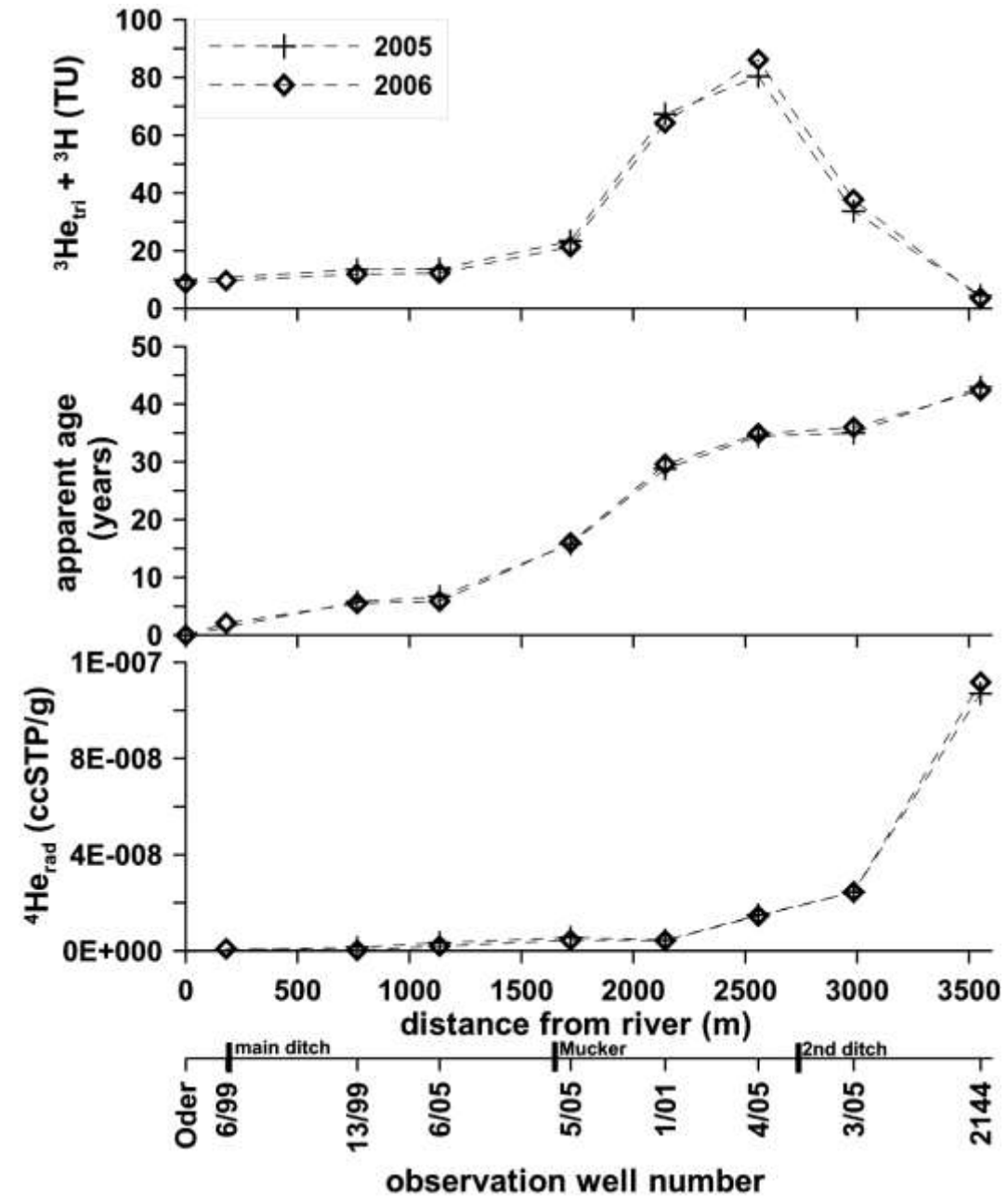
schematische Fließpfade



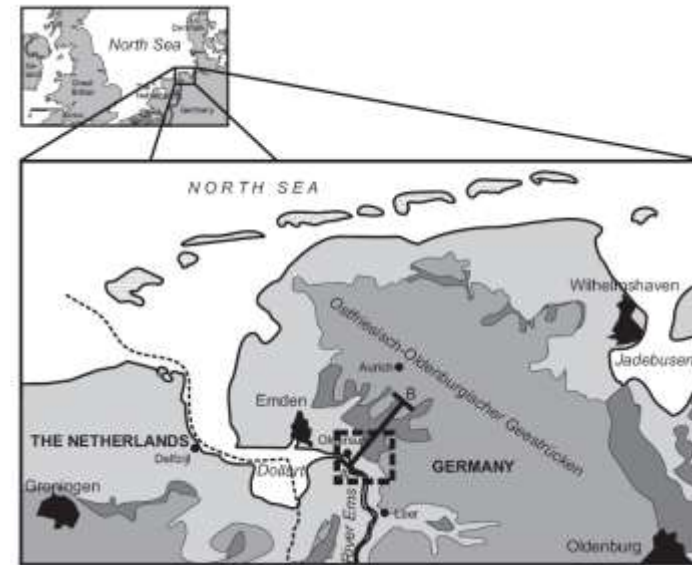
Oderbruch



Entwicklung
entlang des Fließpfades
im Oderbruch



Versalzung des Emshinterlands

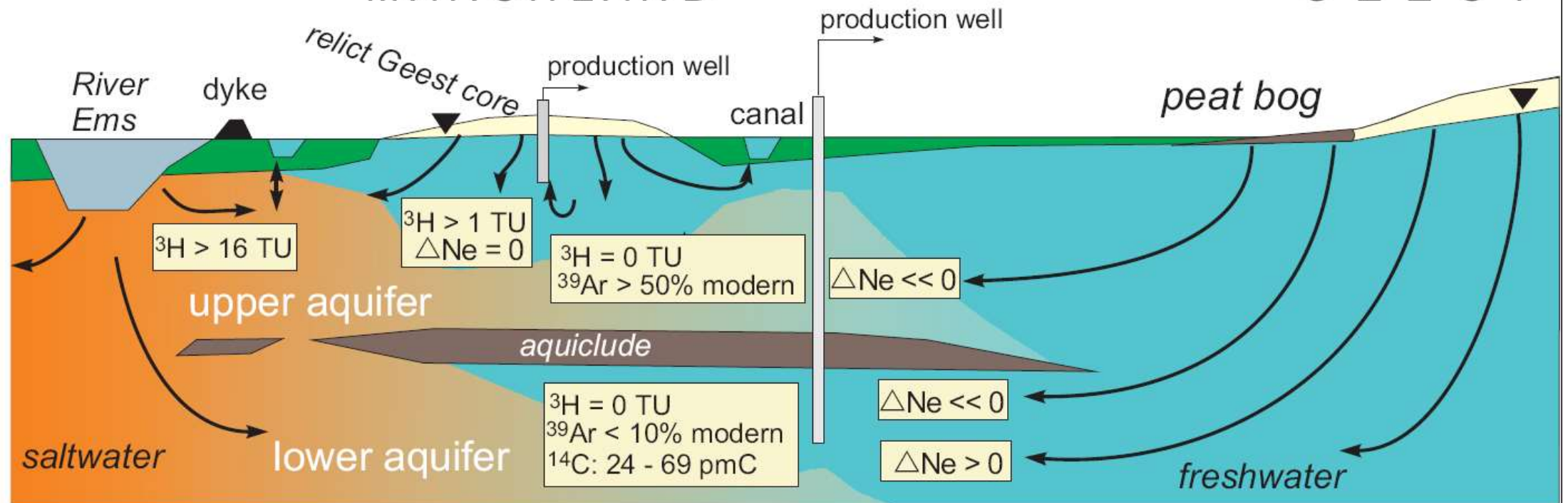


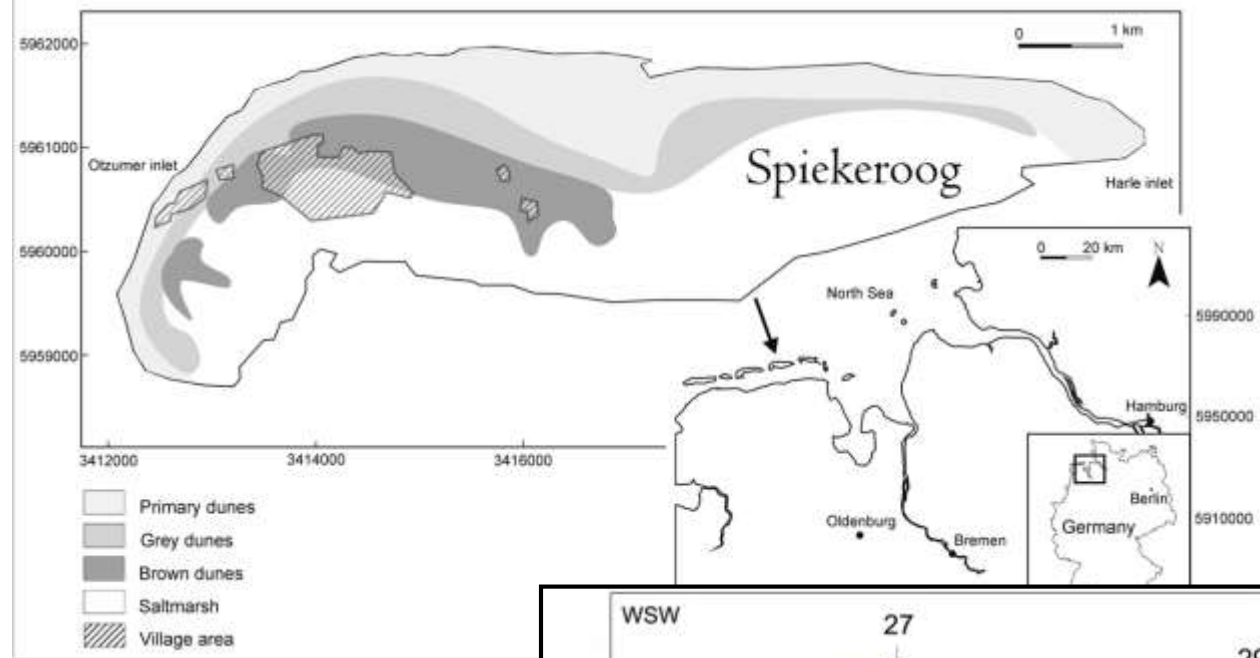
A

MARSHLAND

B

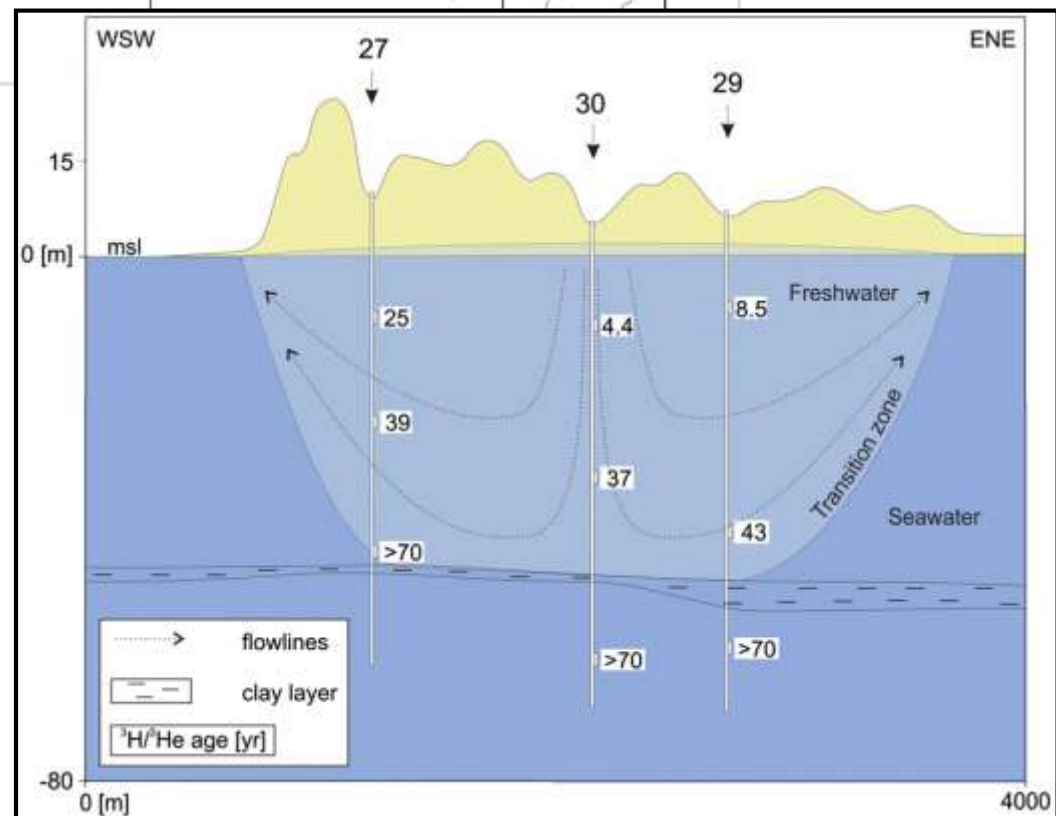
G E E S T



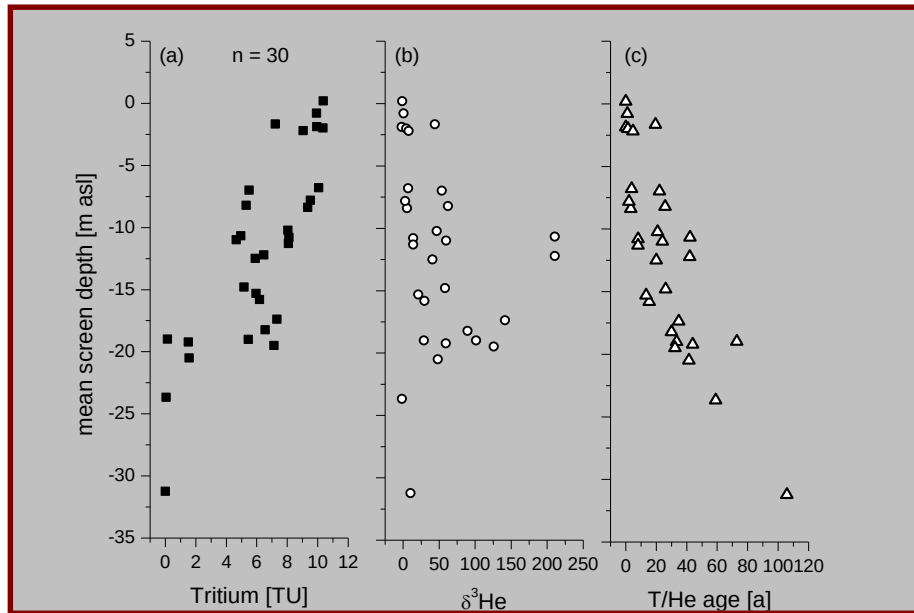
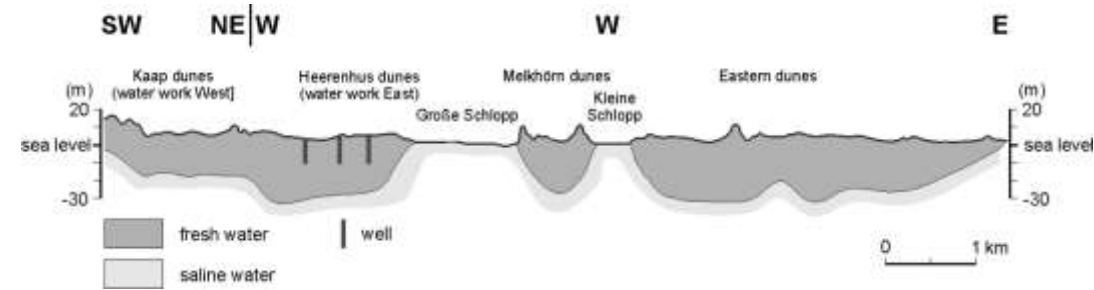


$^3\text{H} - ^3\text{He}$ - age on the East Frisian Island Spiekeroog

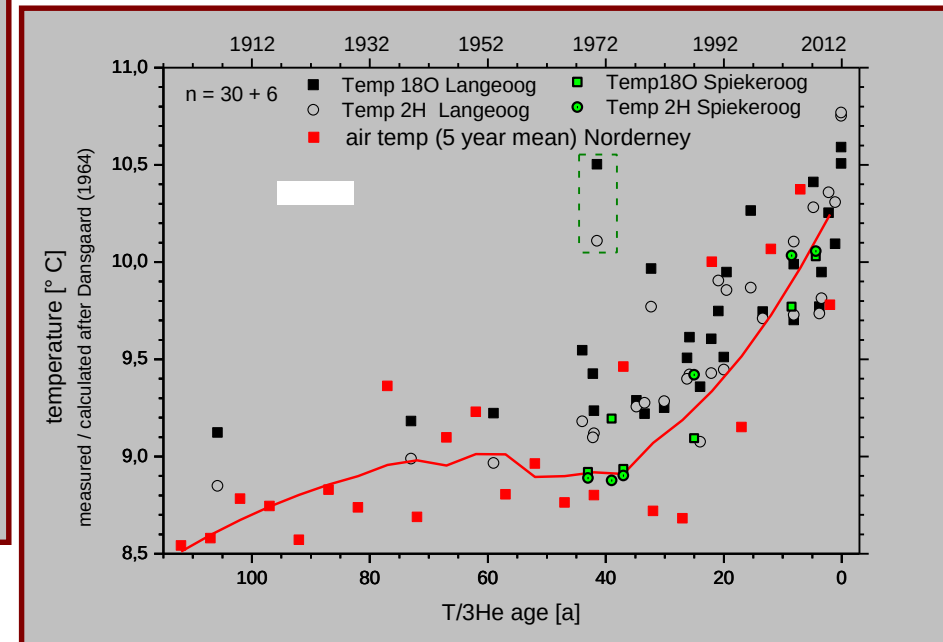
Röper et al.2012
J.Hydrol.



$^3\text{H} - ^3\text{He}$ - age on the East Frisian Island Langeoog



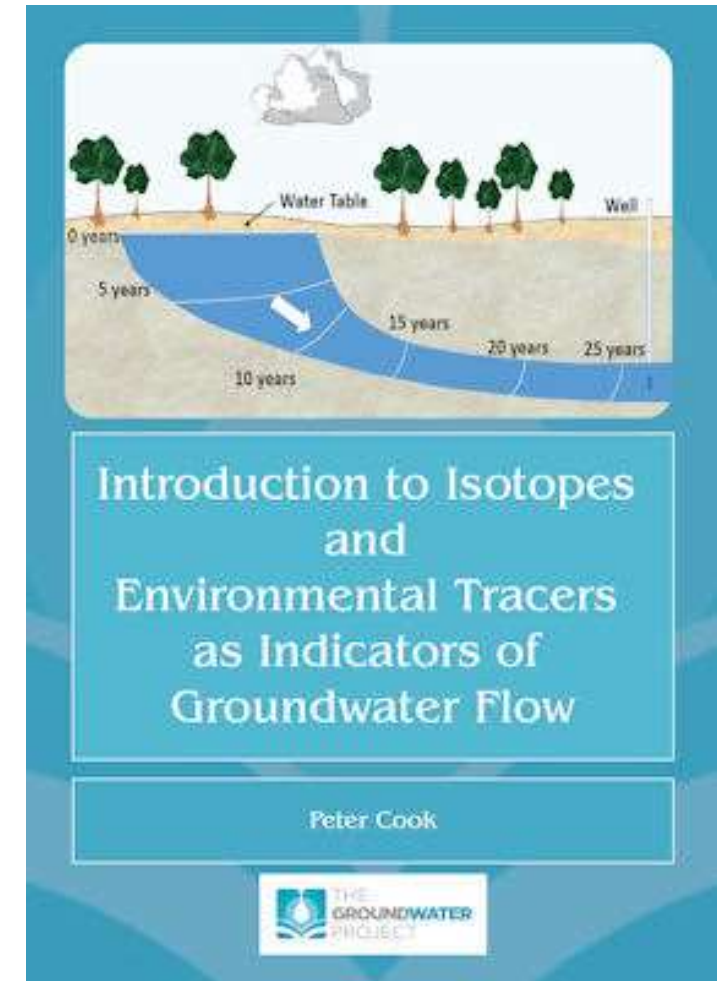
Houben et al. 2014, WRR



	Eintrag klar	Untergrundproduktion	Abbau/Austausch	Messverfahren
FCKW	nein	nein	Ja	GC
SF6	nein	ja	nein	GC
Tritium	nein	nein	nein	β-counter, MS
3He	ja	nein	nein	MS
85Kr	ja	nein	nein	β-counter, ATTA
39Ar	ja	ja	nein	β-counter, ATTA
14C	nein	nein	ja	β-counter, AMS
81Kr	ja	ja	nein	ATTA
36Cl	nein	ja	ja	AMS

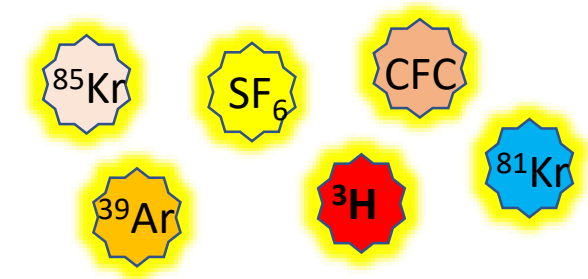
Introduction to Isotopes and Environmental Tracers as Indicators of Groundwater Flow

by Peter Cook



<https://gw-project.org/download/introduction-to-isotopes-and-environmental-tracers-as-indicators-of-groundwater-flow>

Atmosphärische Umwelttracer



Datierung mit Tracern

künftig: Eignung/Zweckmäßigkeit gegeben?

teils teils... abnehmend

neue Tracer?

nicht in Aussicht

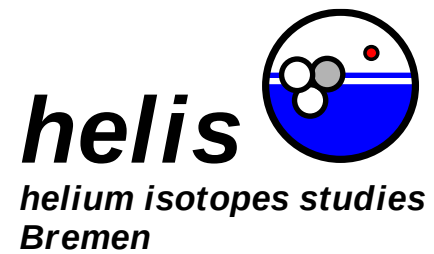
neue Messverfahren?

ja: ATTA für ^{85}Kr , ^{81}Kr und ^{39}Ar
aber für alle Tracer begrenzte Messkapazitäten

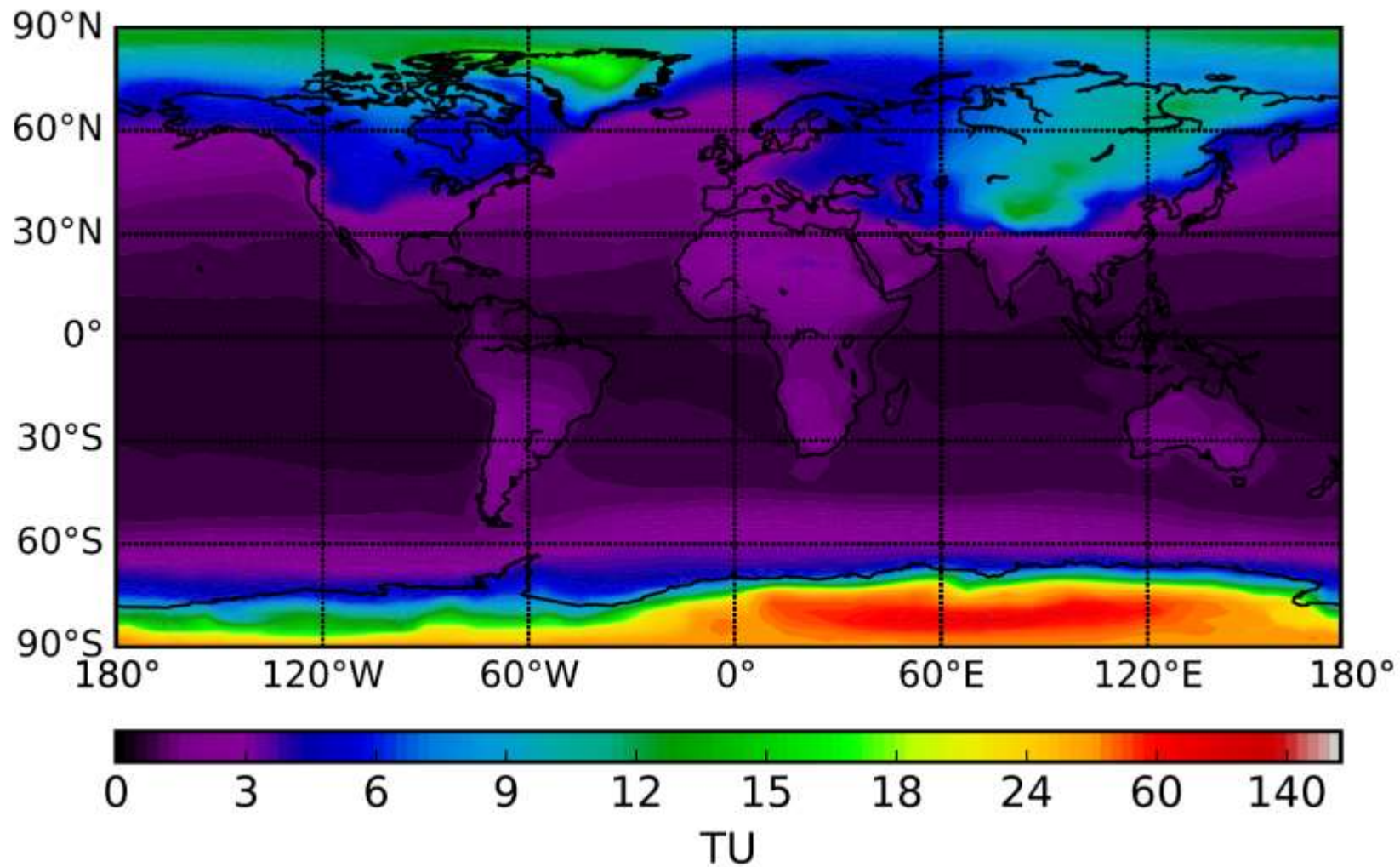
neue Interpretationsmethoden?

Kombination mehrere Tracer: aber teuer

See your local tracer dealer!

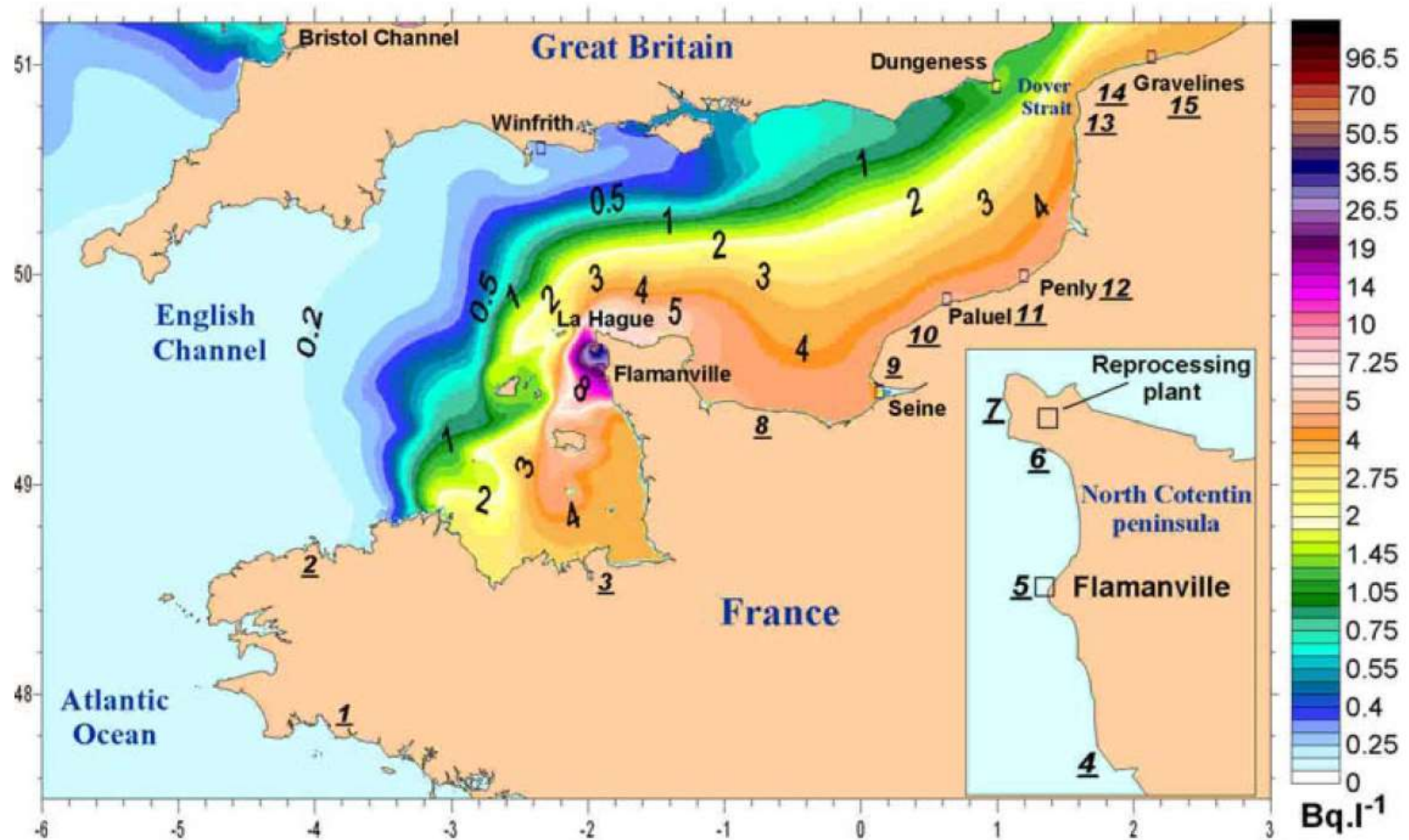


Tritium in precipitation 1998 – 2008



Courtesy of Alexandre Cauquoin, AWI, modeling the global bomb tritium transient signal with the AGCM LMDZ-iso

Tritium along the French coast

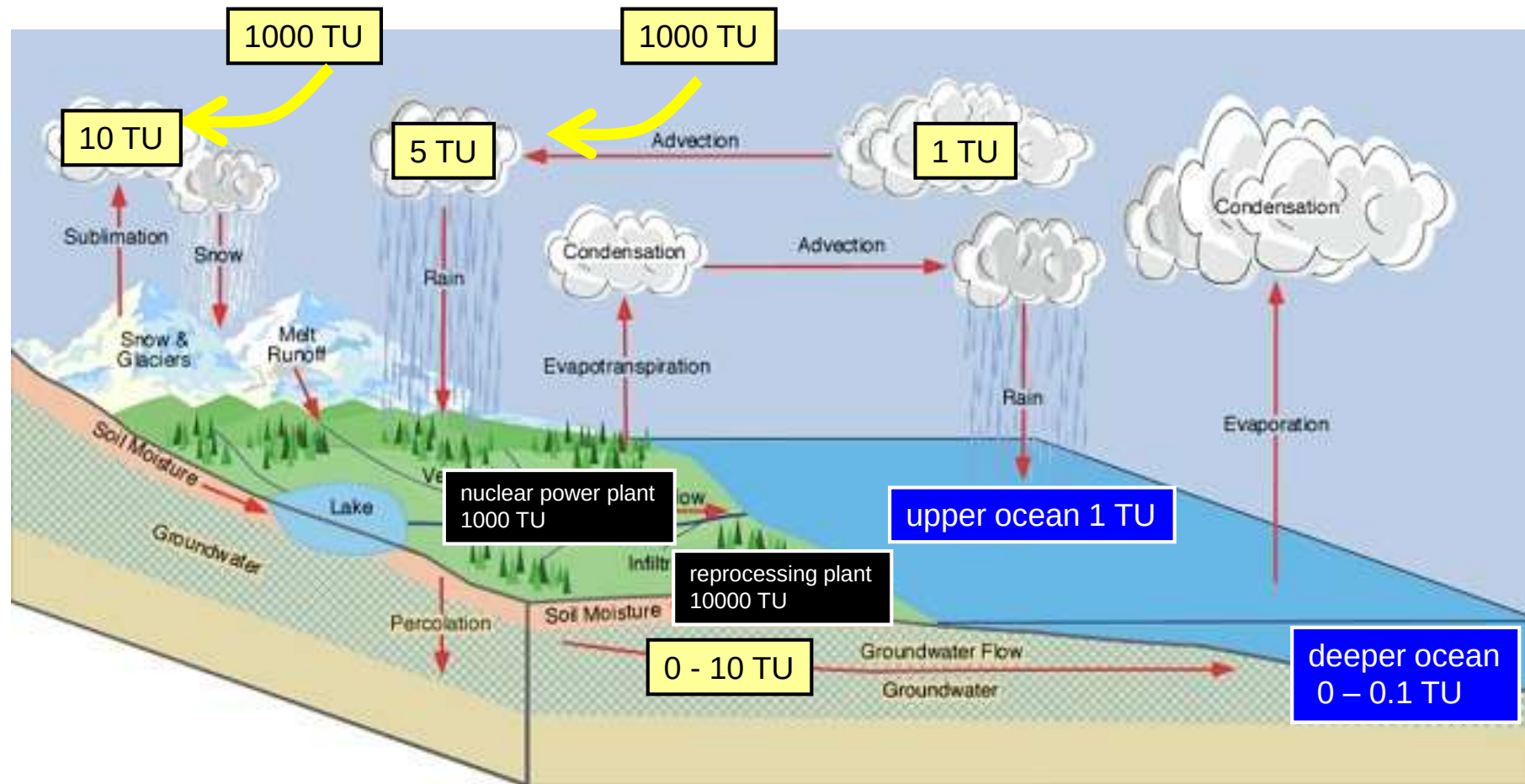


1 Bq/l = 8.4TU

average tritium concentrations in seawater in the English Channel in 2001-2002
calculated using the TRANSMER model
Masson et al. 2005, *Radioprotection*

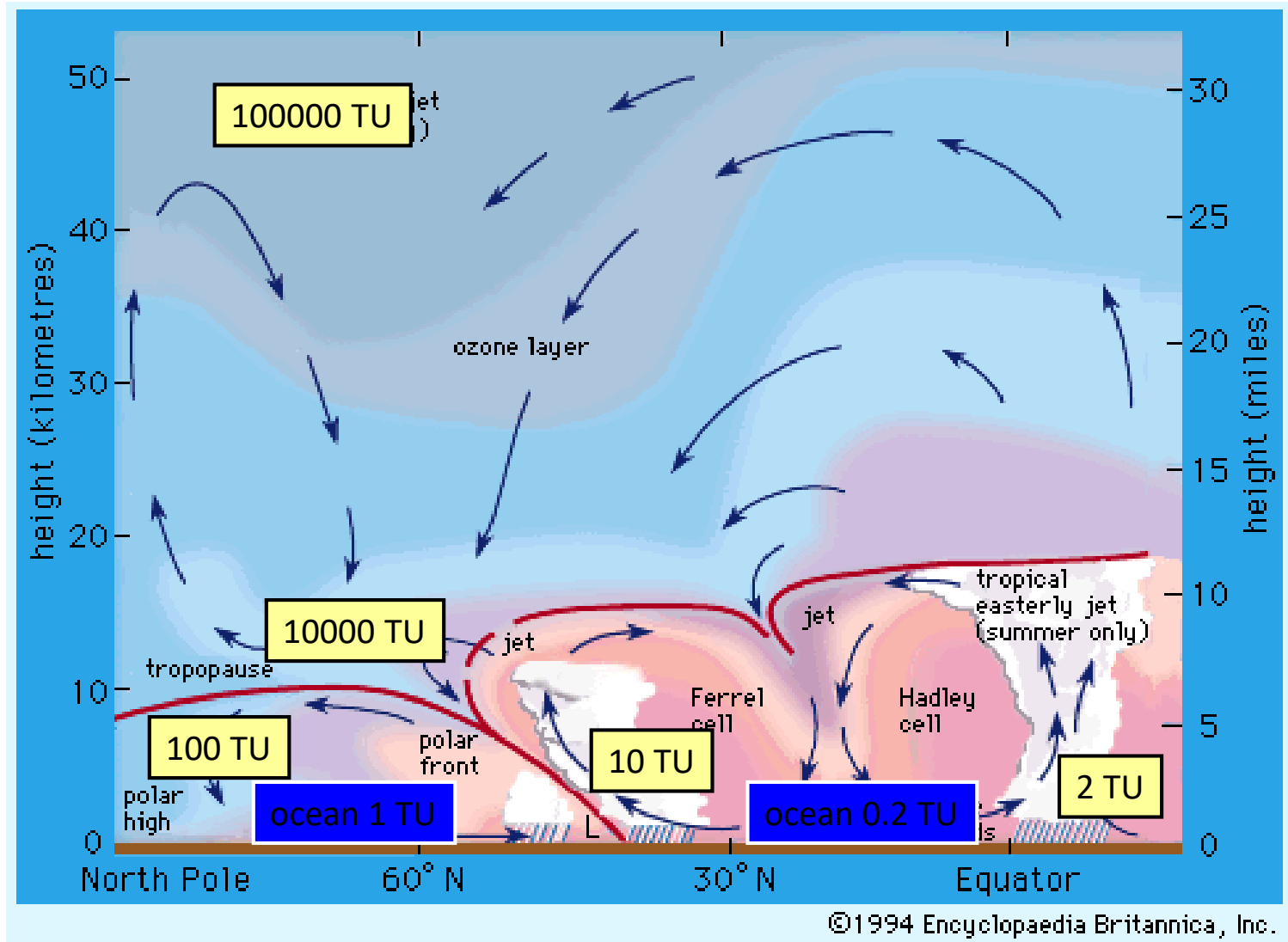
tritium concentration in the hydrological system

groundwater and oceans as reservoir for tritium



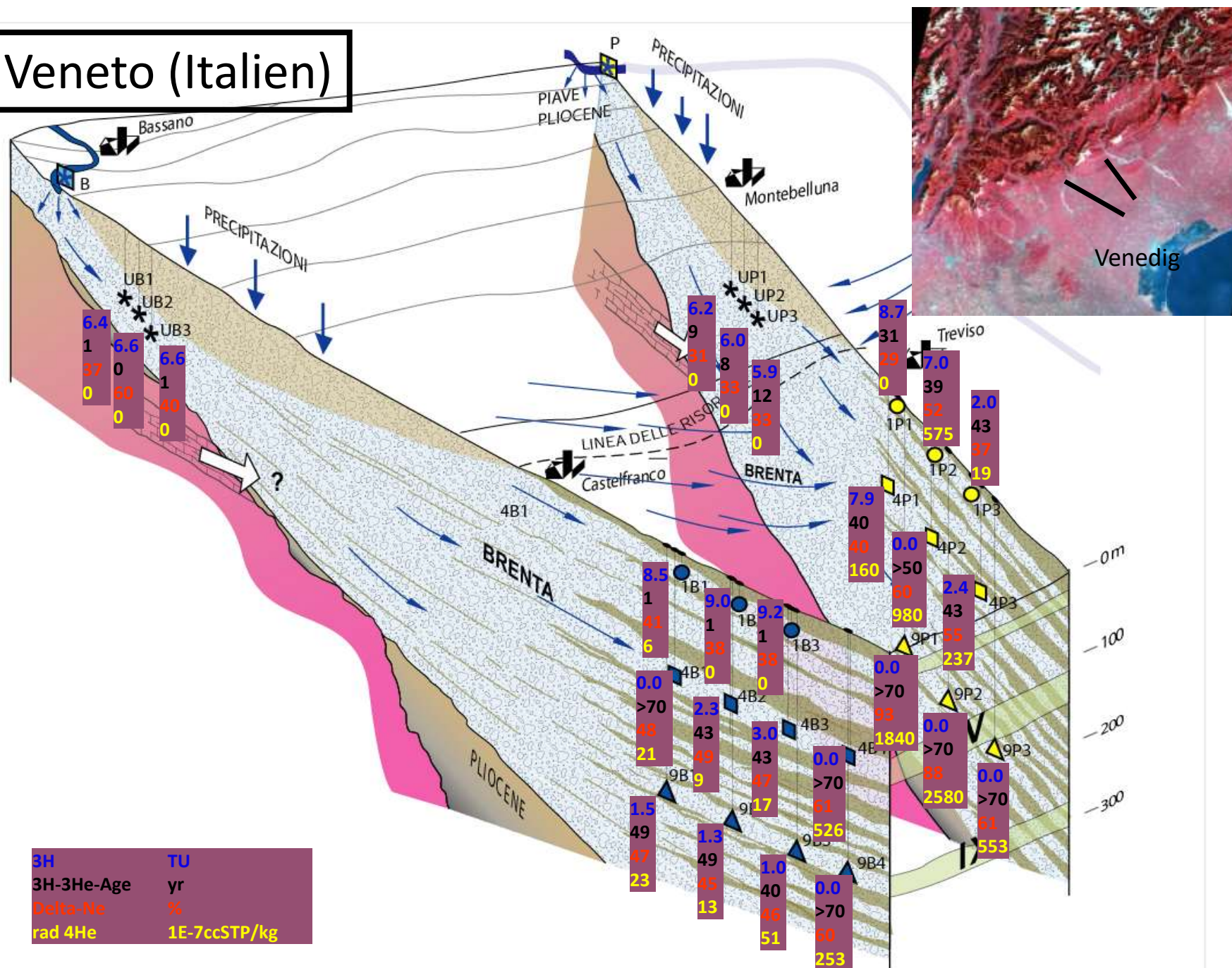
groundwater at Fukushima near coast line:
on 22. Aug.2013 420.000.000 TU

Tritium concentration in the Hydrological System 1

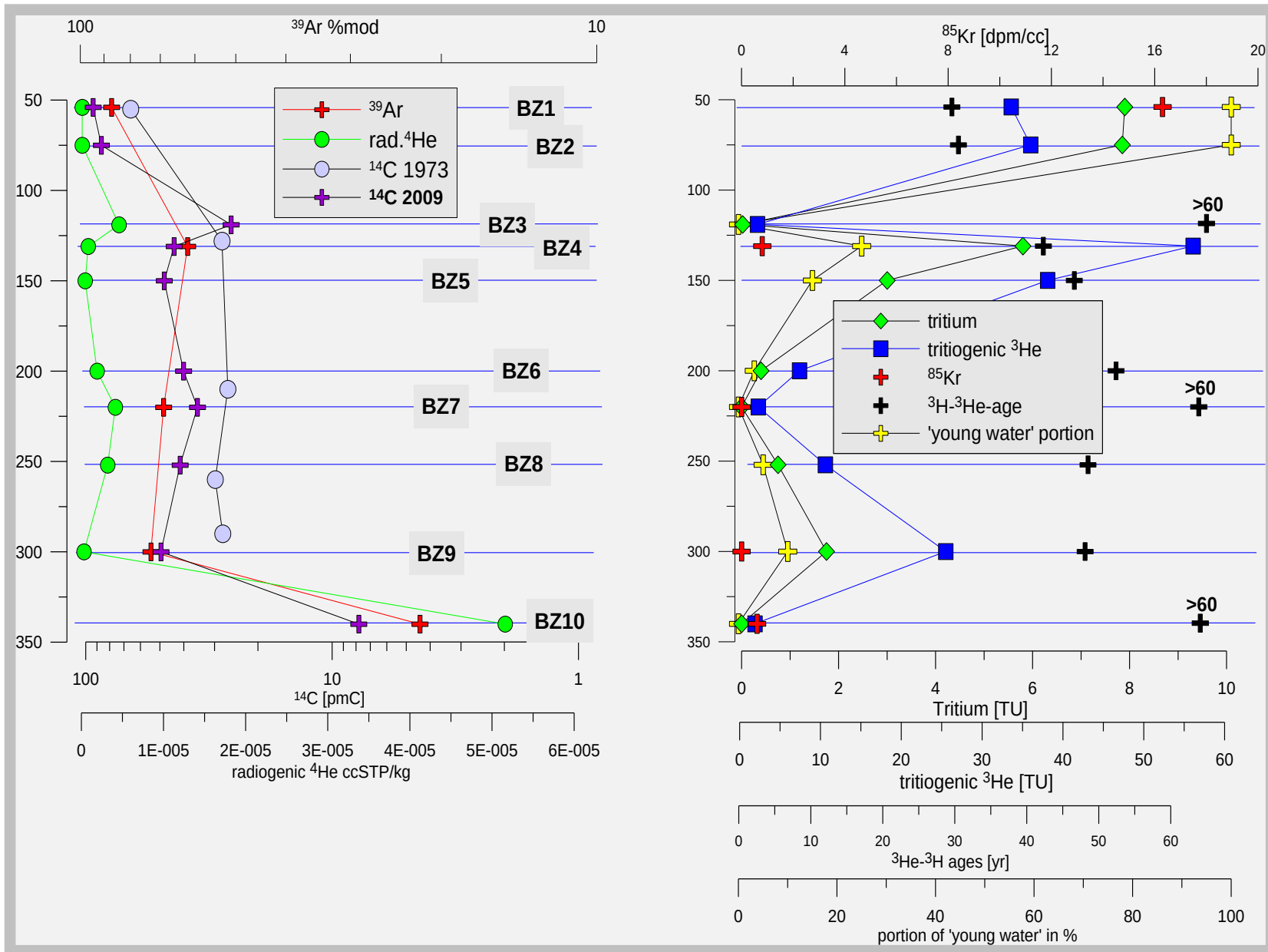


water mass ocean: $1.4 \cdot 10^{21}$ kg H_2O
atmosphere: $1.3 \cdot 10^{16}$ kg H_2O

Veneto (Italien)



depth profile near Scorze



investigating Tritium



*helium isotopes studies
Bremen*

Jürgen Sültenfuß suelten@uni-bremen.de



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Abt. Ozeanographie