

Designing ultra-radiopure, high-strength copper-alloys for future rare-event searches

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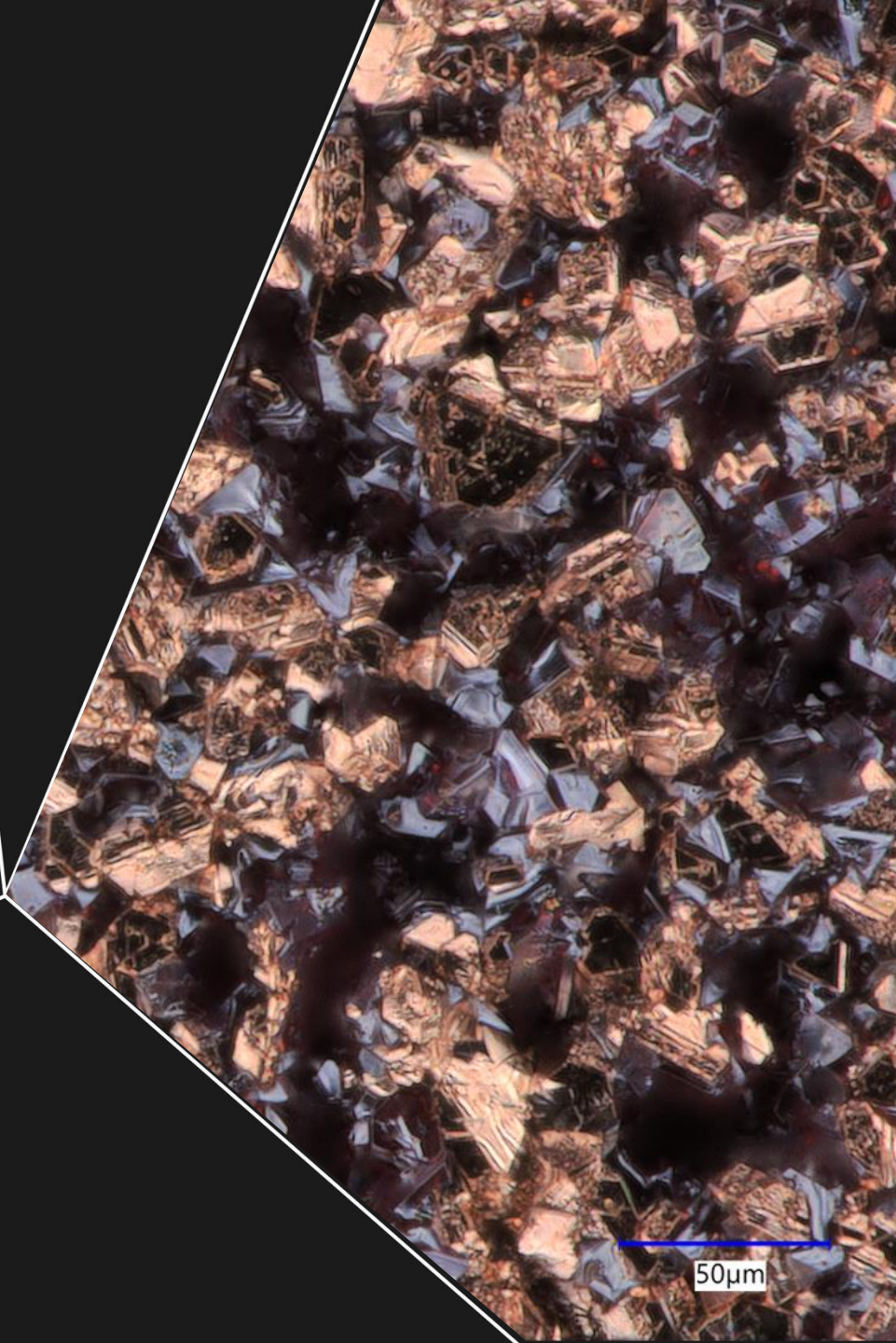
PureAlloys



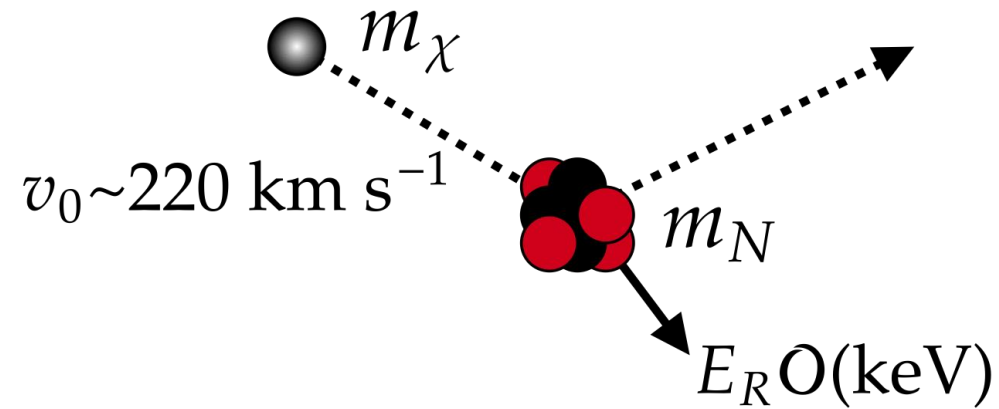
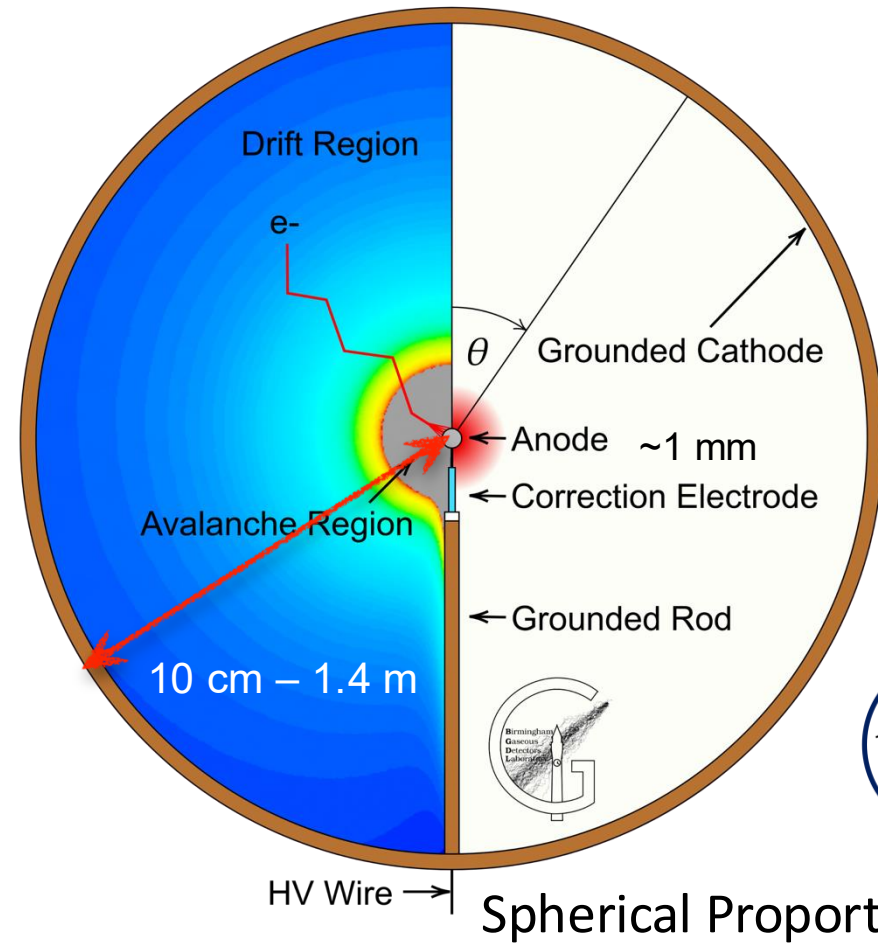
PureCuAlloys



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Motivation: Dark Matter Direct detection



NEWS-G S140 in SNOLAB

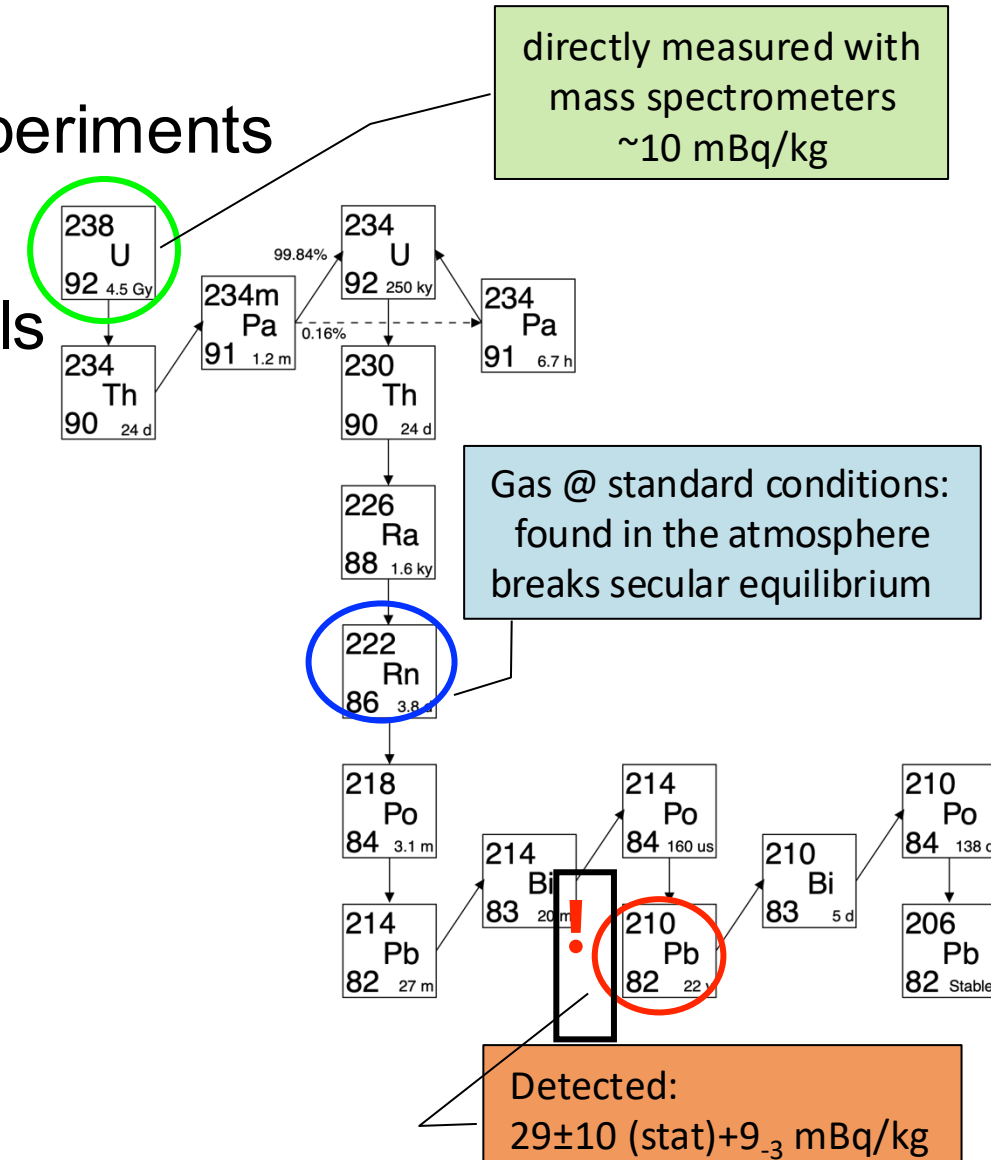
Radiopure **Cu** for rare event searches

- Cu: common material for rare event searches experiments

- ✓ Electrically conductive
- ✓ Strong enough to build low-pressure gas vessels
- ✓ No long-lived isotopes (^{67}Cu $t_{1/2}=62\text{h}$)
- ✓ Low cost/commercially available at high purity

- Backgrounds

1. Cosmogenic: $^{63}\text{Cu}(n,\alpha)^{60}\text{Co}$ from fast neutrons
2. Contaminants: $^{238}\text{U}/^{232}\text{Th}$ decay chains

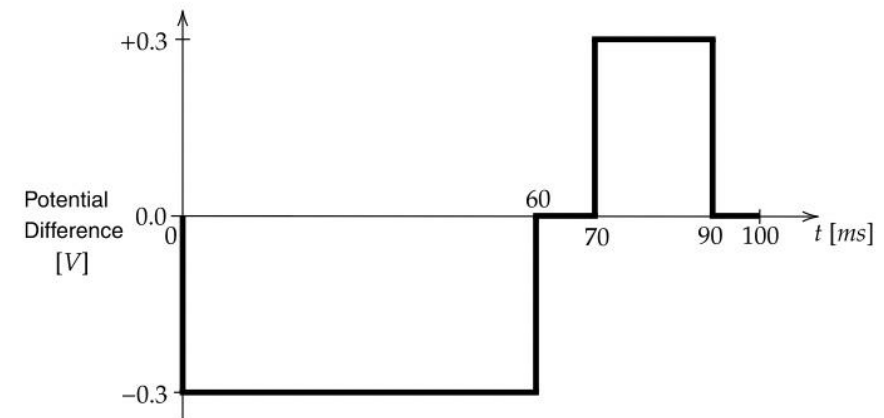
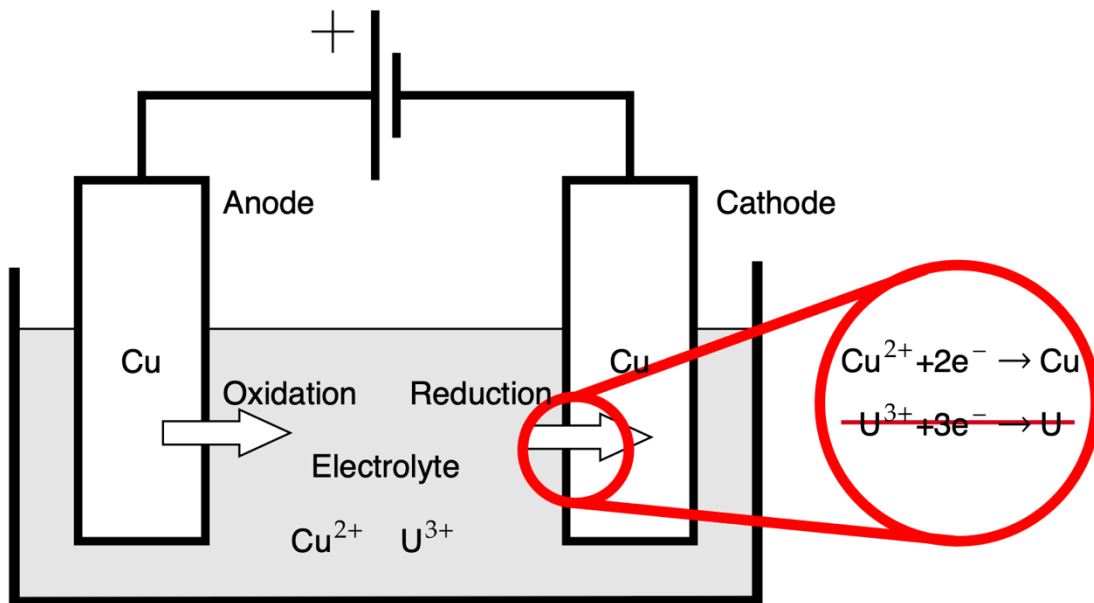


Electroformed **Cu** (EFCu) for rare event searches

Reduction potential for copper and possible radiocontaminants.

Reductants		Oxidants	E^0 (V)
$\text{Cu}^{2+} + 2e^-$	$\rightleftharpoons$	Cu	+0.34
$\text{Pb}^{2+} + 2e^-$	$\rightleftharpoons$	Pb	-0.13
$\text{U}^{3+} + 3e^-$	$\rightleftharpoons$	U	-1.80
$\text{Th}^{4+} + 4e^-$	$\rightleftharpoons$	Th	-1.90
$\text{K}^+ + e^-$	$\rightleftharpoons$	K	-2.93

Cu 'high reduction potential' → preferentially deposited
→ Additive-free, electroforming



rare event searches:
e.g. LEGEND, NEWS-G, ANAIS, Majorana,
nEXO, DarkSPHERE

NIMA 988 (2021) 164844

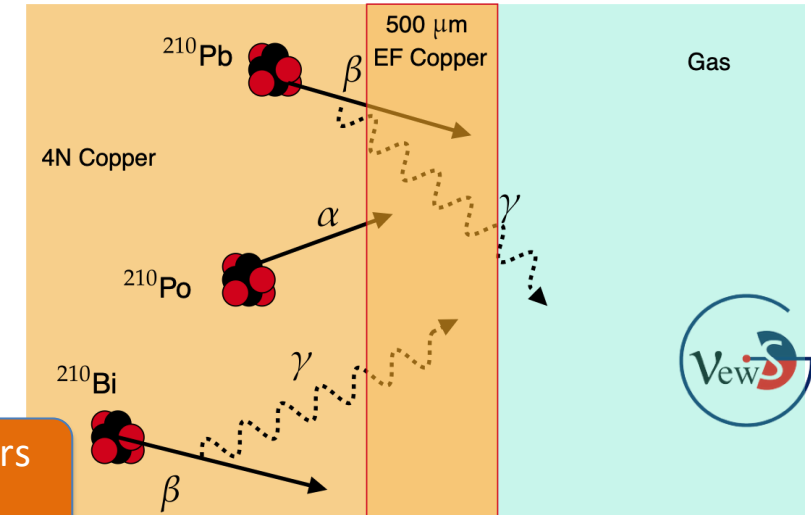
Ultra-pure Cu electroforming

Majorana Demonstrator

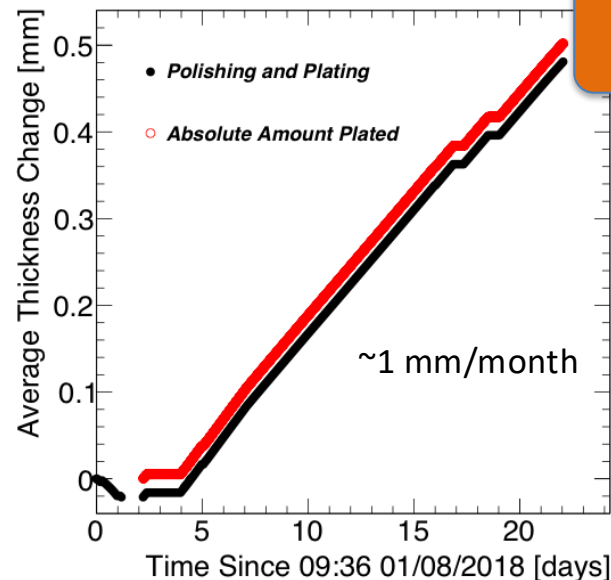
#	Material	Method	K (10^{-9} g/g)	^{232}Th (10^{-12} g/g)	^{238}U (10^{-12} g/g)
<i>Metals</i>					
1	Cu Electroformed Stock Sample	ICPMS		<0.17	
2	Cu Electroformed Stock Sample	ICPMS		0.011 ± 0.005	0.017 ± 0.003
3	Cu Electroformed Stock Sample	GDMS	<2.2	<50	<70
4	Cu Electroformed Stock Sample	ICPMS		<0.029	<0.008
5	Cu Electroformed Stock Sample	ICPMS		<0.029	<0.009
6	Cu Electroformed Stock Sample	ICPMS		<0.029	<0.008
7	Cu Electroformed Stock Sample	ICPMS		<0.030	<0.009
8	Cu Electroformed, machined part, guide clip	ICPMS		0.330 ± 0.022	0.123 ± 0.005
9	Cu Electroformed, machined part, guide clip	ICPMS		0.112 ± 0.009	0.078 ± 0.002

NIMA 828 (2016) 22

NEWS-G EFCu coating



NIMA 988 (2021) 164844



Giovanni Rogers
Today, 11:40

- ✓ 500 μm electroplated layer to NEWS-G detector inner surface
- ✓ Demonstrated potential to electroform full detector on feasible time scale

Sample	Weight [g]	^{232}Th [$\mu\text{Bq kg}^{-1}$]	^{238}U [$\mu\text{Bq kg}^{-1}$]
C10100 Cu (Machined)	-	8.7 ± 1.6	27.9 ± 1.9
Cu Electroformed	-	<0.119	<0.099
Hemisphere 1	0.256	<0.58	<0.26
Hemisphere 2	0.614	<0.24	<0.11

Motivation of ultra-pure, high-strength **Cu-based alloys**

- ✓ Retain EFCu capabilities for rare event searches
- ✓ Option for stronger material compared to EFCu
- ✓ Scale up the current geometries for gas vessels (or gas pressure, wall thickness)
→ maximising the physics potential

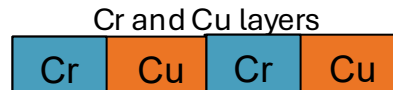
fundamental science
applications:
e.g. DarkSPHERE, XLZD,
nEXO, NEXT

Alloying EFCu with **Cr** additions

1. Cr and Cu layers from separate solutions
2. Solution heat treatment at **1000°C** (homogenisation)
3. Aging at **400°C – 12 hours** (precipitation strengthening)



	[Th]		[U]	
Sample	pgTh/gSample	±sd	pgU/gSample	±sd
EFCu	0.011	0.005	0.017	0.003
Cr	8.72	0.32	2.37	0.61
Cu-Cr(0.585wt%) projection	0.062	0.007	0.031	0.007



EFCu	72 HV
Cu-0.585Cr	121 HV

Suriano et al. AIP Conf Proc 1921, 1003 (2018) 080001

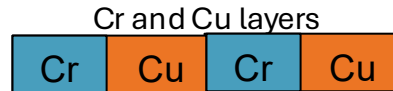
Motivation of ultra-pure, high-strength **Cu-based alloys**

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- ✓ Option for stronger material compared to EFCu
- ✓ Scale up the current geometries for gas vessels (i.e. maximising the physics potential in DM experiments)

Alloying EFCu with **Cr** additions

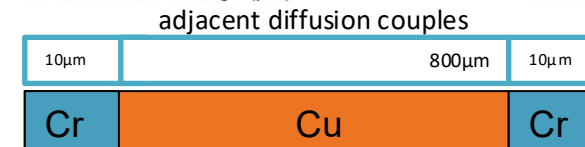
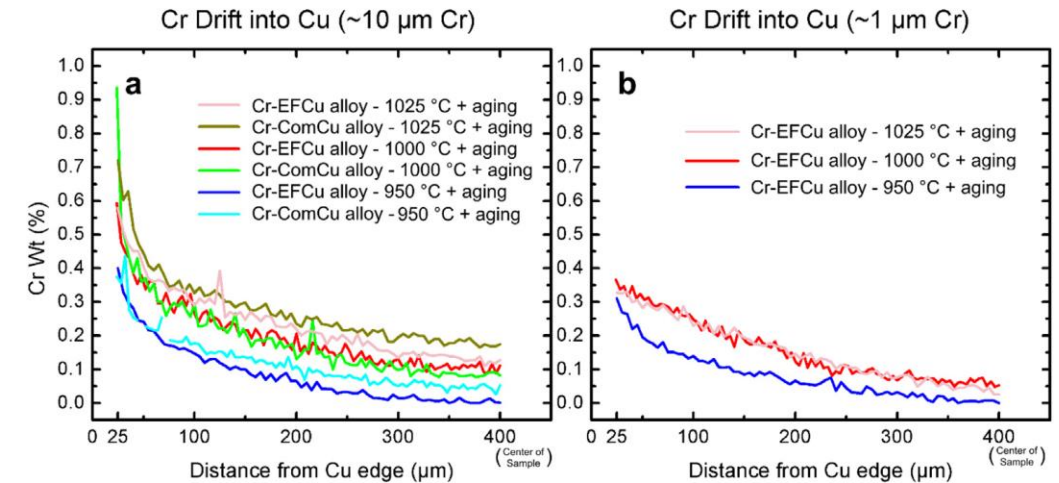
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Cu-0.585Cr	121 HV

**~70%
harder**

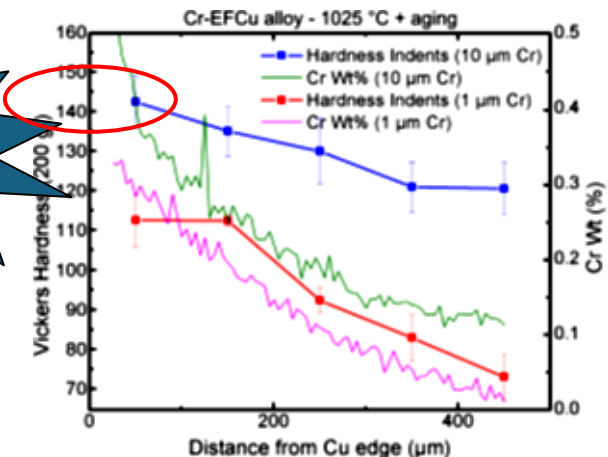


Homogenisation 24h:

**950°C
1000°C
1025°C**

**Aging:
500°C – 12 hours**

**~100%
harder**

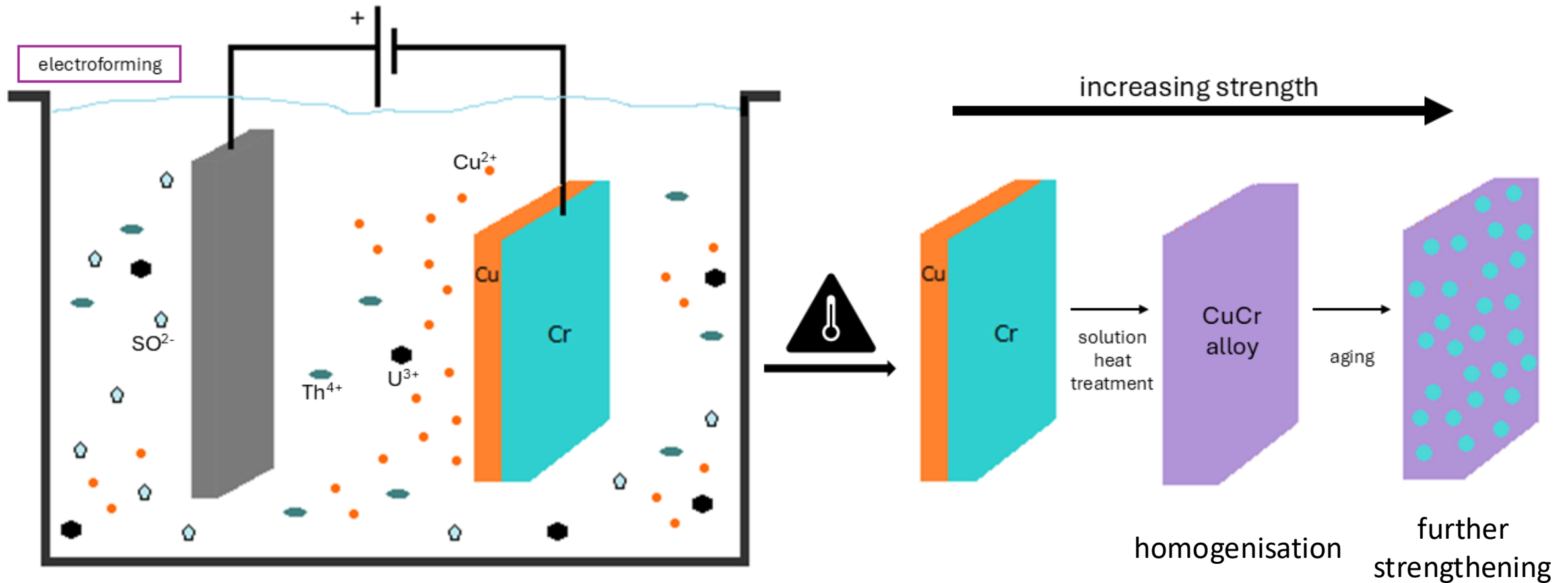


Suriano et al. AIP Conf Proc 1921, 1003 (2018) 080001

A. Vitale et al. NIMA 1003 (2021) 165291

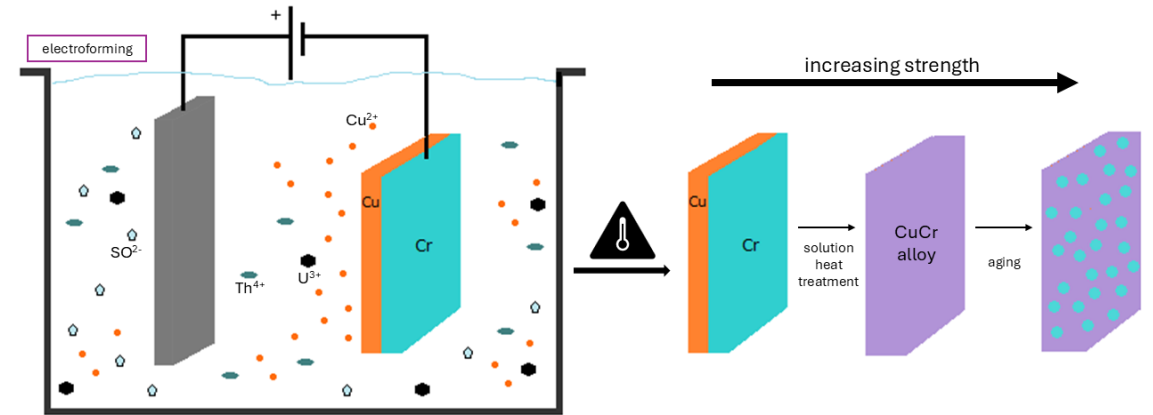
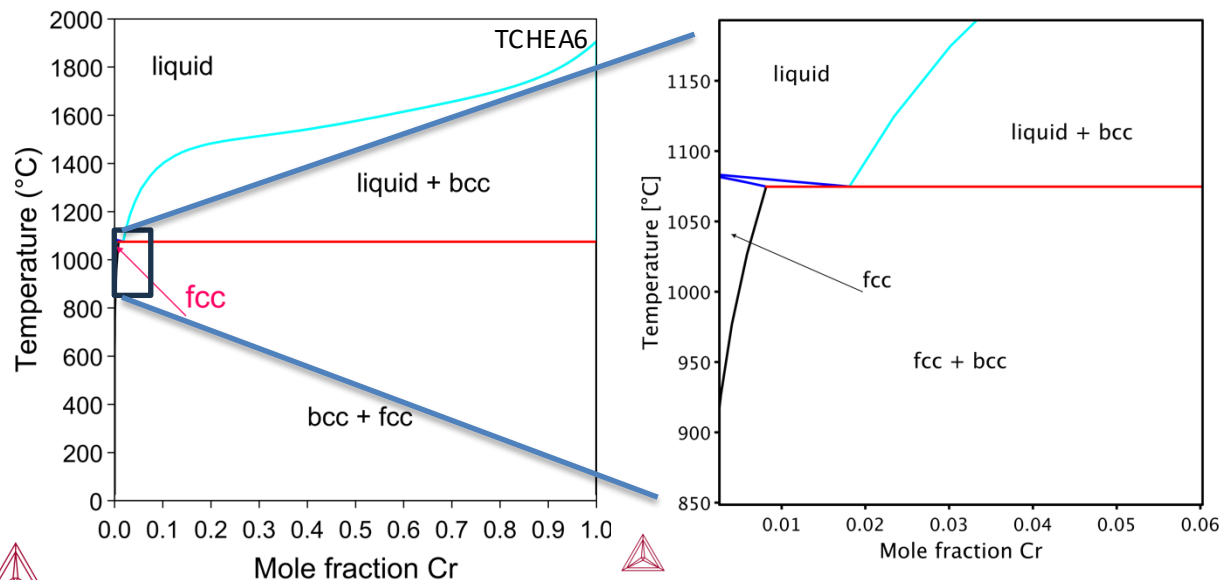
Designing using CALPHAD-based tools

Proposed manufacturing process for radiopure Cu-based alloys



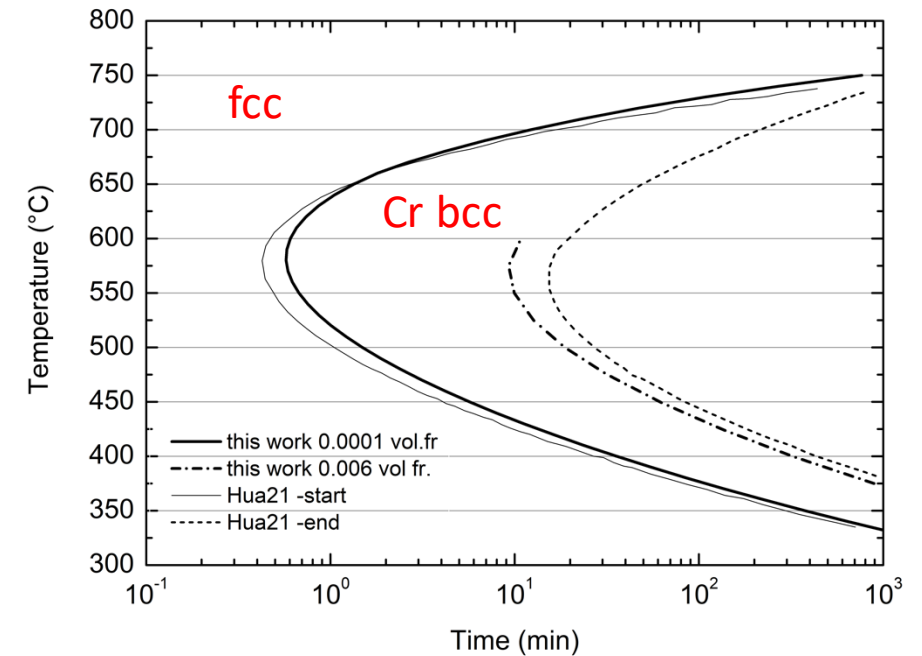
Modelling solution heat treatment and aging

Cu-Cr phase diagram



Cu-0.5Cr

Calculated TTT diagram using TC-PRISMA

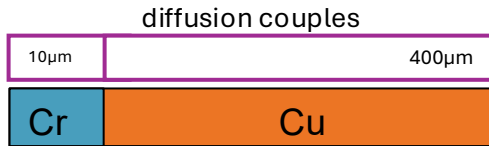


TCHEA6 - MOBHEA3

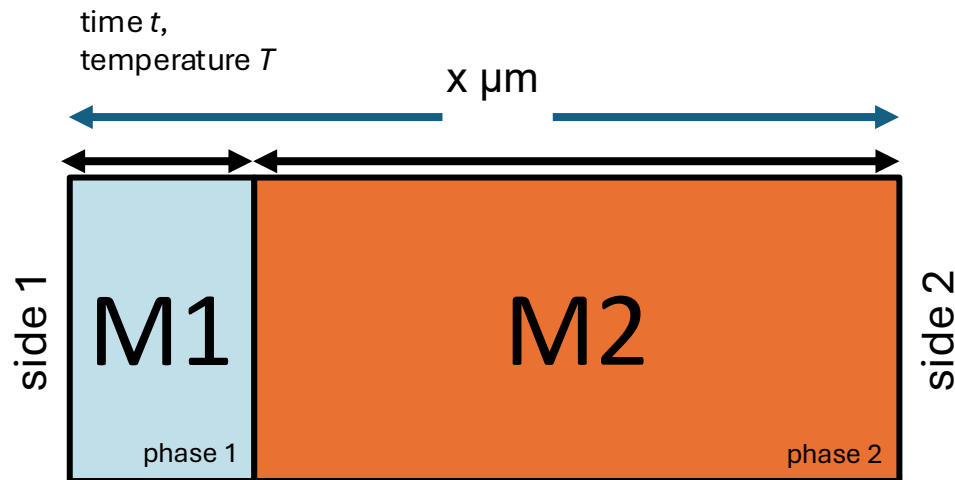
Compared with
TCCU3 - MOBCU3

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Modelling solution heat treatment using **DICTRA**

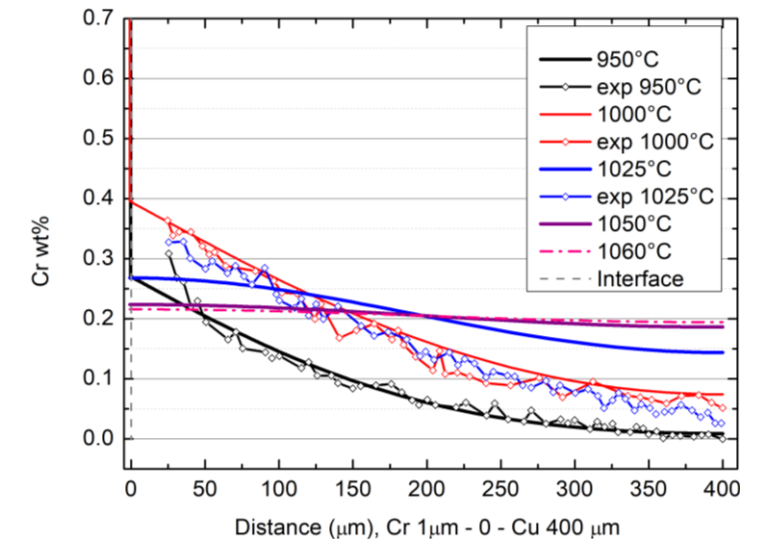
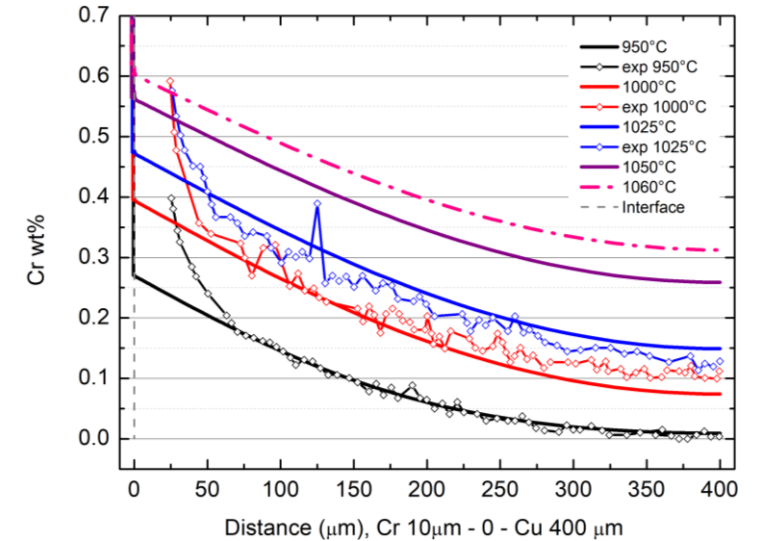
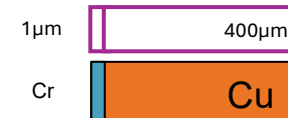


Optimise T and t
for solution heat
treatment



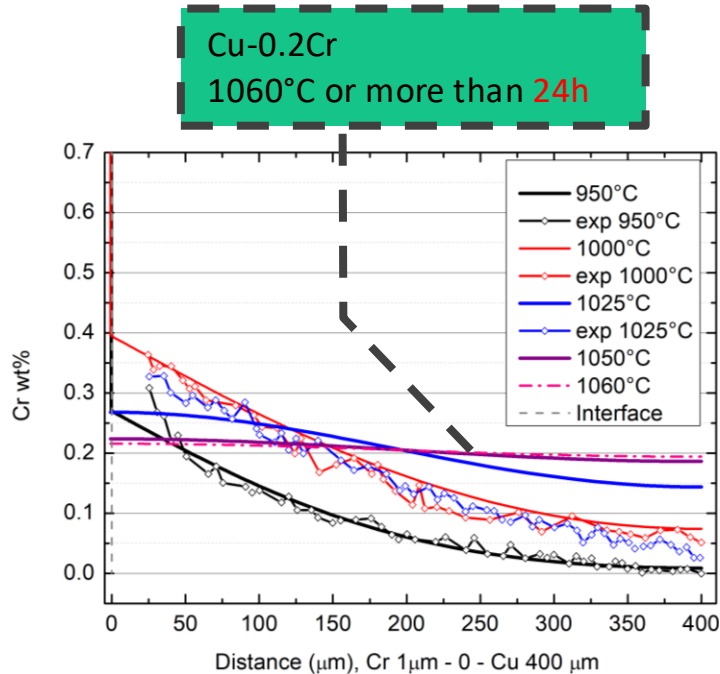
D. Spathara et al. Metall Trans A (2018)

Thermo-Calc databases
TCHEA6 - MOBHEA3
24h isothermals



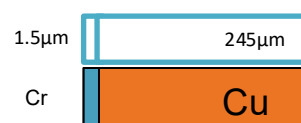
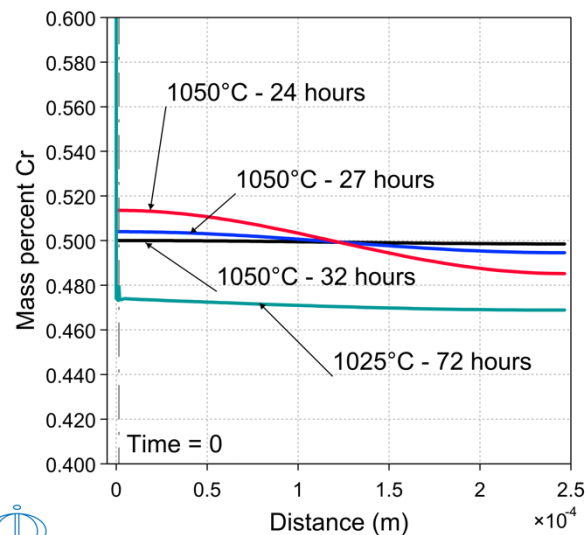
D. Spathara NIMA (2026)

Modelling solution heat treatment using **DICTRA**

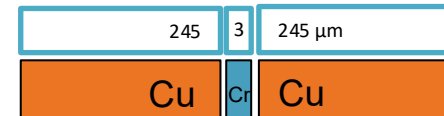
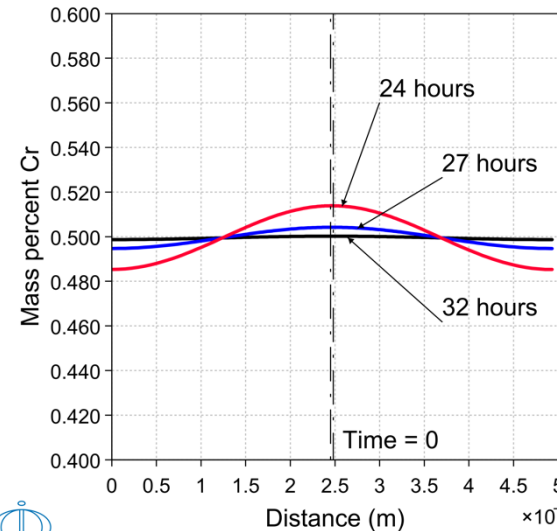


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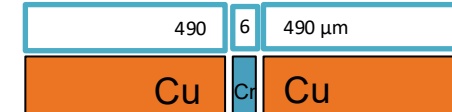
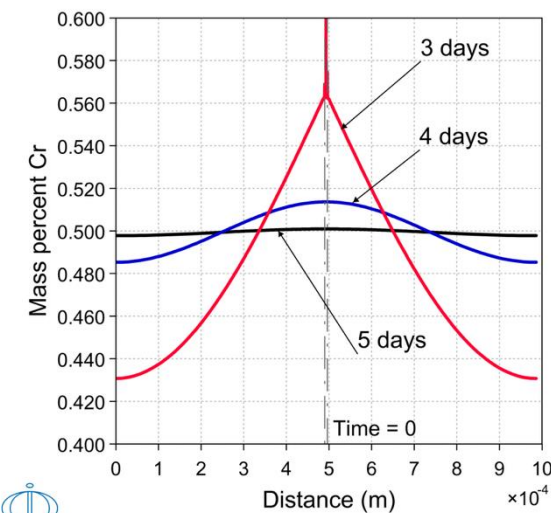
Solution heat treatment → Cu-0.5Cr



Thermo-Calc databases
TCHEA6 - MOBHEA3

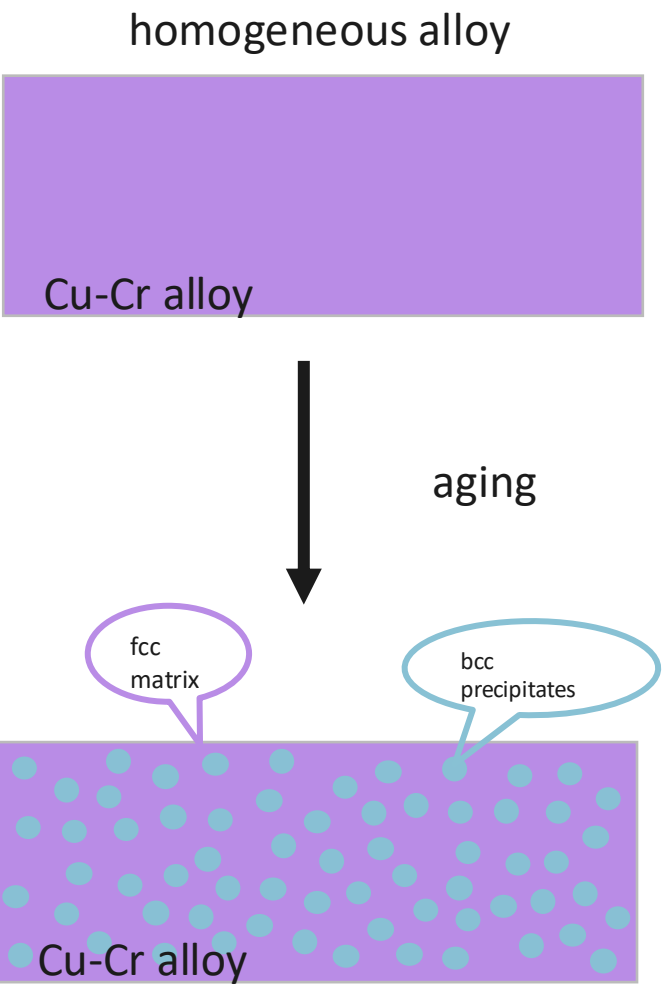


D. Spathara et al. Commun Phys (2025)

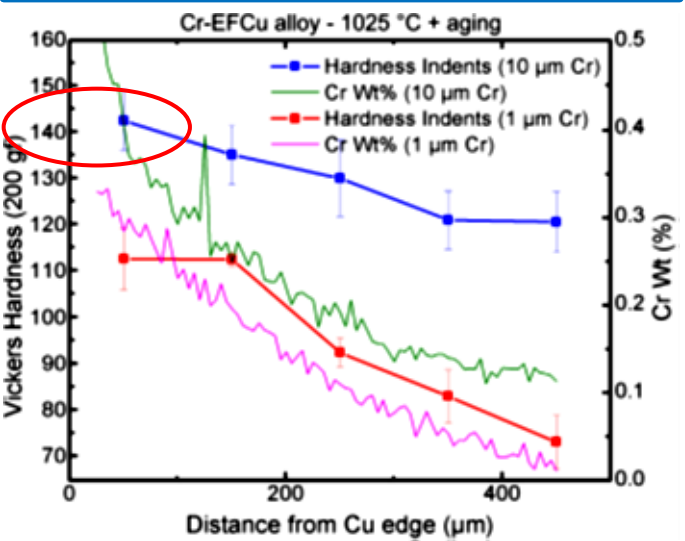


Strengthening mechanism during aging

Optimise T and t for aging



500°C – 12 hours



Cu-0.4Cr 140 HV

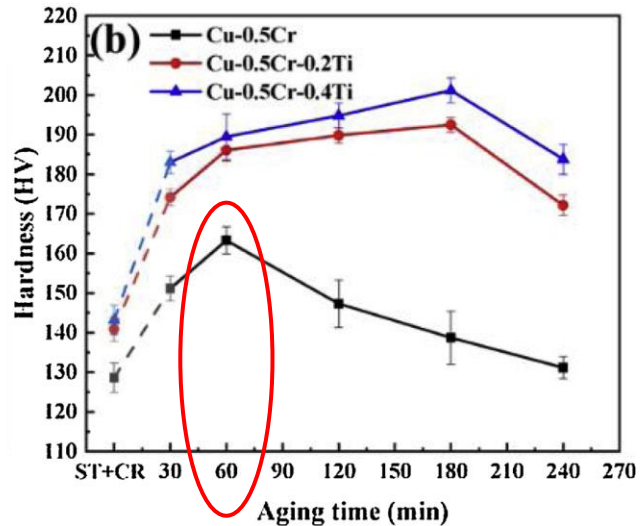
Vitale et al. 2021

400°C – 12 hours

EFCu 72 HV
Cu-0.585Cr 121 HV

Suriano et al. 2018

450°C – 60 min



Cu-0.5Cr 150 HV
Cu-0.5Cr0.2Ti 230 HV
Cu-0.5Cr0.4Ti 280 HV

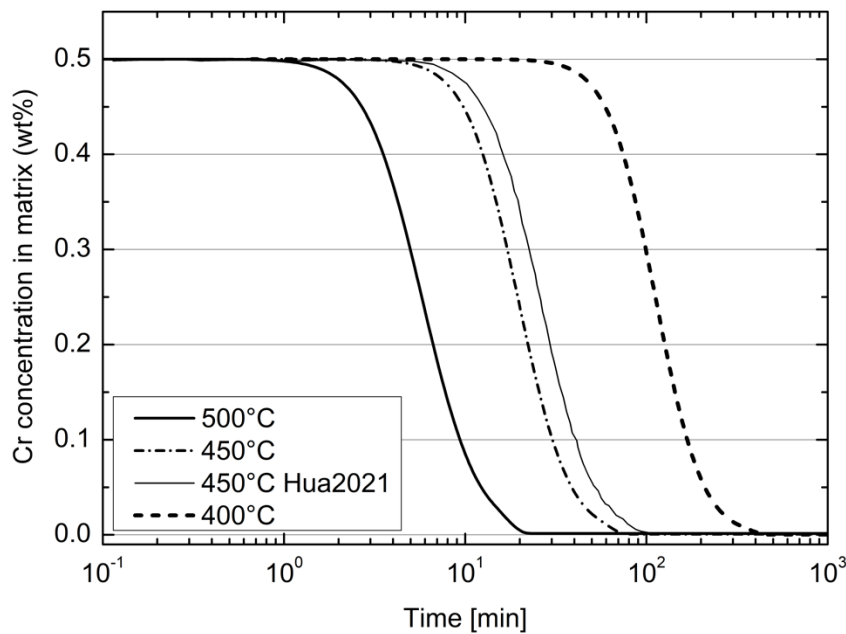
Huang et al. 2021

Predicting strengthening during aging using TC-PRISMA

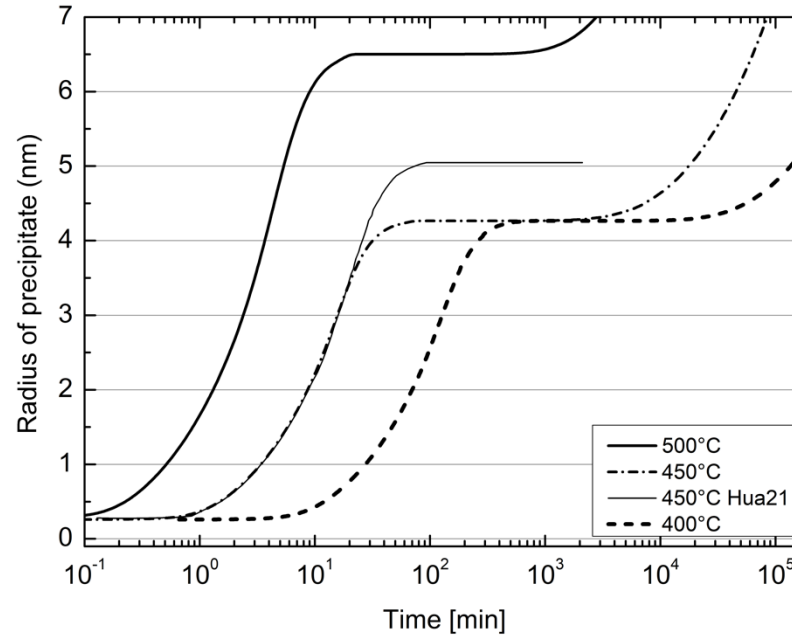
Cu-0.5Cr

Thermo-Calc databases
TCHEA6 - MOBHEA3

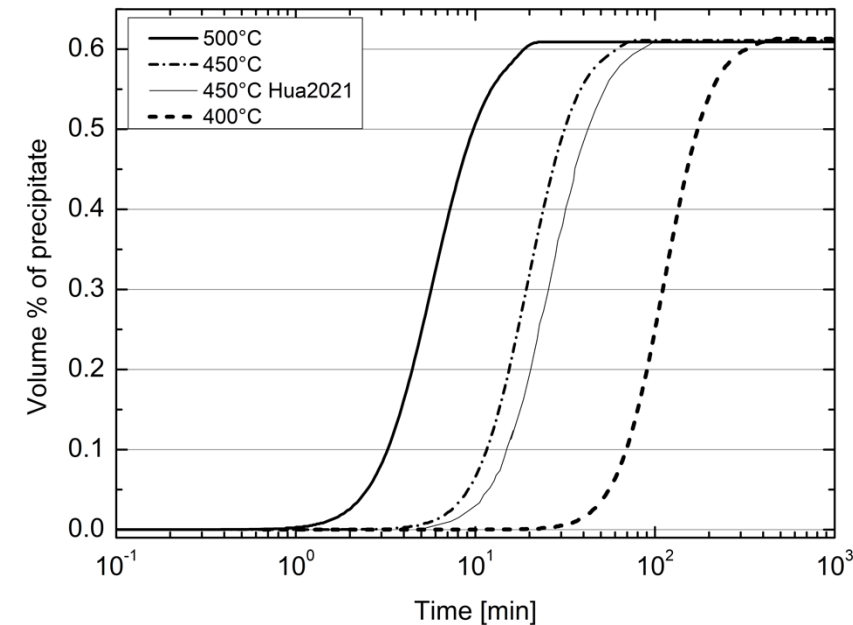
Cr concentration in the matrix



mean radius of precipitates

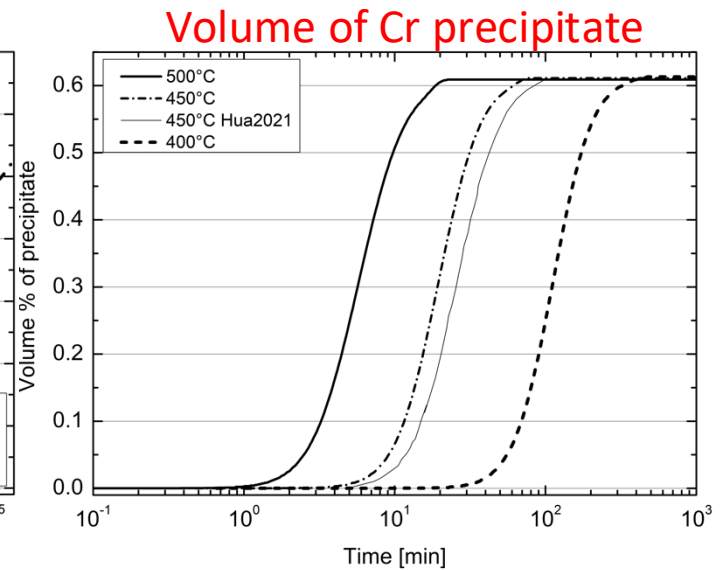
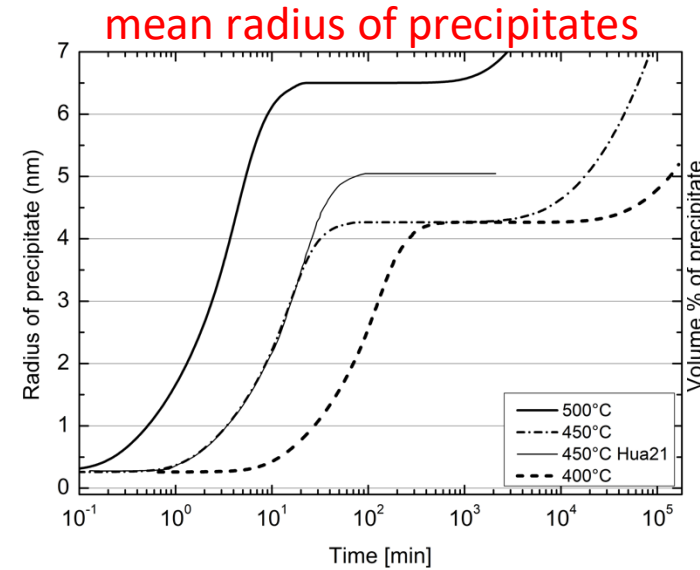
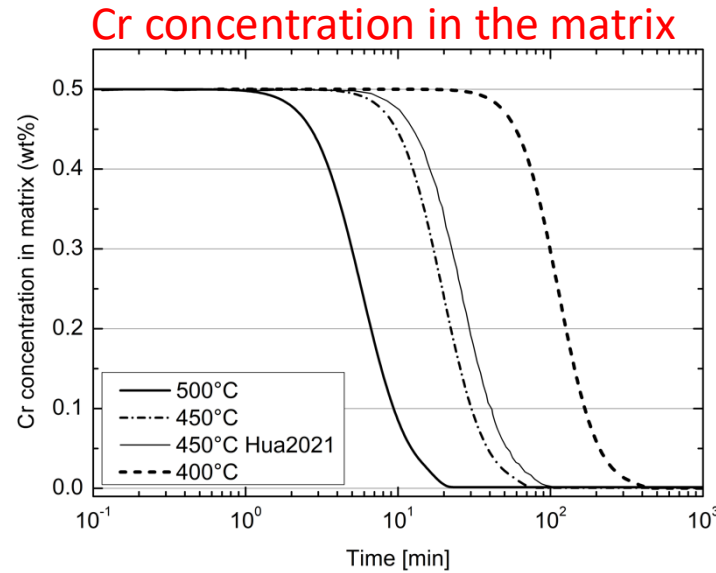


Volume of Cr precipitate



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Predicting strengthening during aging using TC-PRISMA



Cu-0.5Cr

solid solution strengthening

$$\Delta\sigma_{ss} = G(|\delta| + \frac{1}{20}|\eta|)^{3/2} \sqrt{\frac{\chi_{Cr}}{3}}$$

precipitation strengthening

$$\Delta\sigma_{os} = \frac{0.81 G b}{2\pi(1-\nu)^{1/2}} \frac{\ln(2r/b)}{(\lambda - 2r)}$$

$$\lambda = \left(\sqrt{\frac{2\pi}{3f}} - 1.63 \right) r$$

Parameter	Value
Shear modulus $G(\text{Cu})$	46 GPa
Factor δ	0.0435
Factor η	0.1492
Burgers factor b	0.2556 nm
Poisson's ratio ν	0.34
Cr atomic frac. χ_{Cr}	Calculated (at%)
Mean radius of precip. r	Calculated (nm)
Precipitate volume fraction f	Calculated

Huang et al. 2021

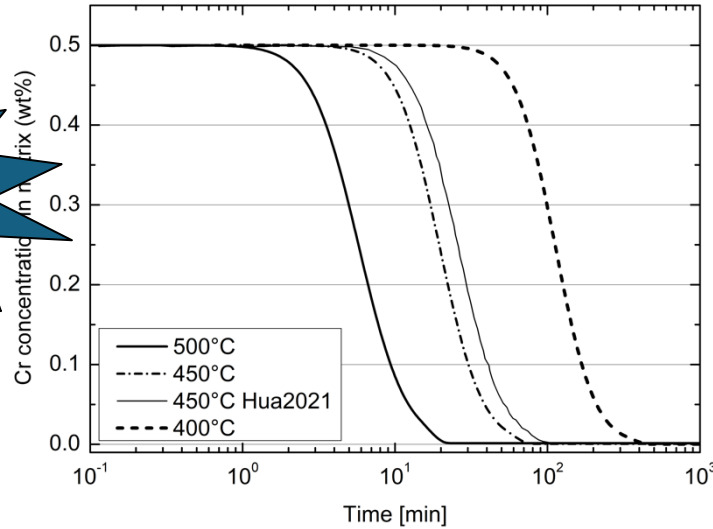
D. Spathara NIMA (2026)

Dimitra Spathara | dimitra.spathara@uni-hamburg.de | September 2026

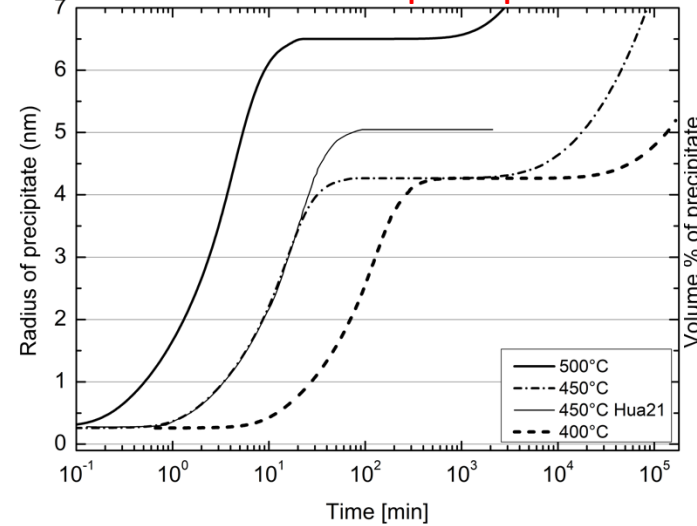
Predicting strengthening during aging using TC-PRISMA

Effect of Ti
(Huang et al.
2021)

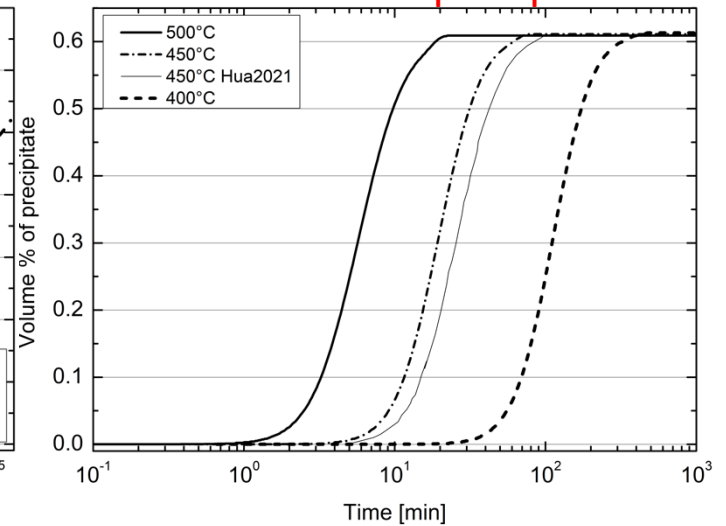
Cr concentration in the matrix



mean radius of precipitates



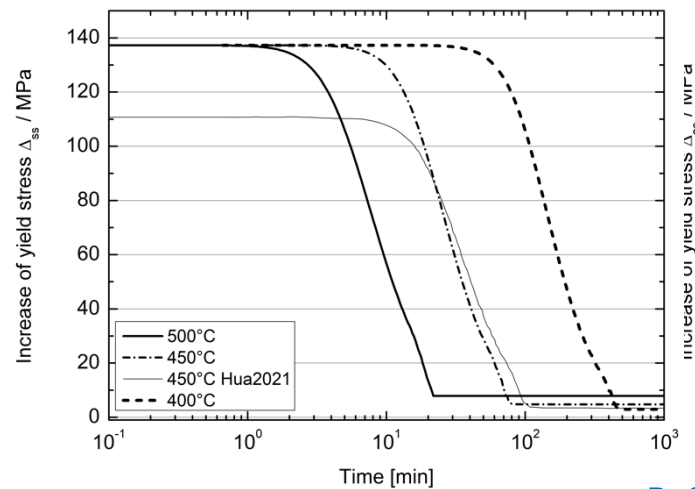
Volume of Cr precipitate



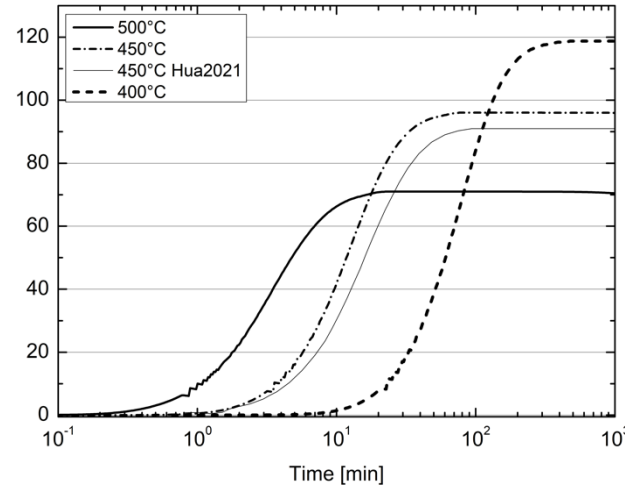
Cu-0.5Cr

Thermo-Calc databases
TCHEA6 - MOBHEA3

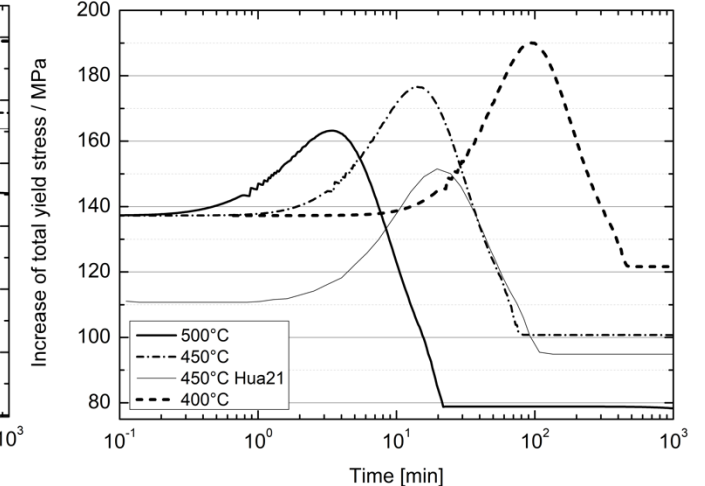
solid solution strengthening



precipitation strengthening



total strengthening

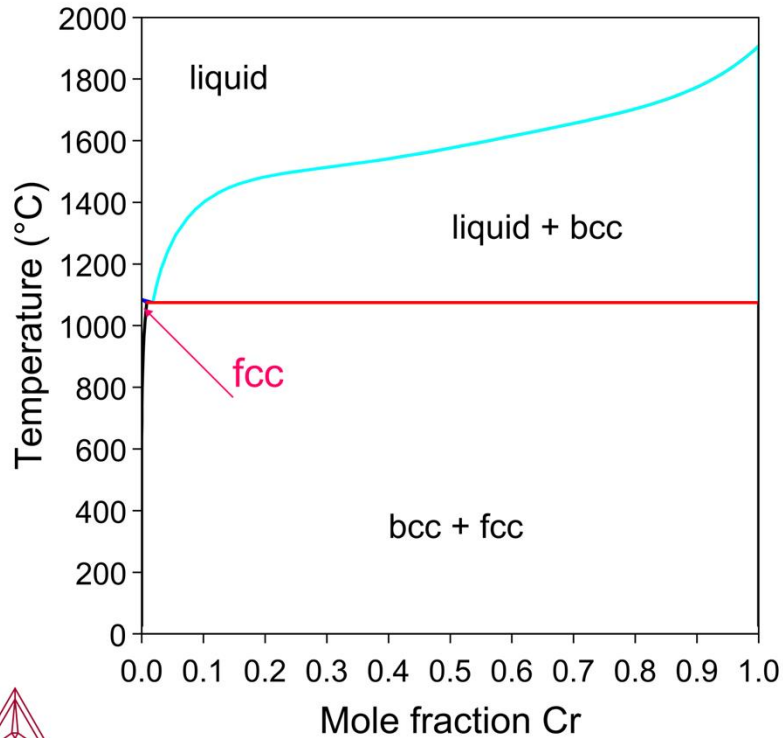


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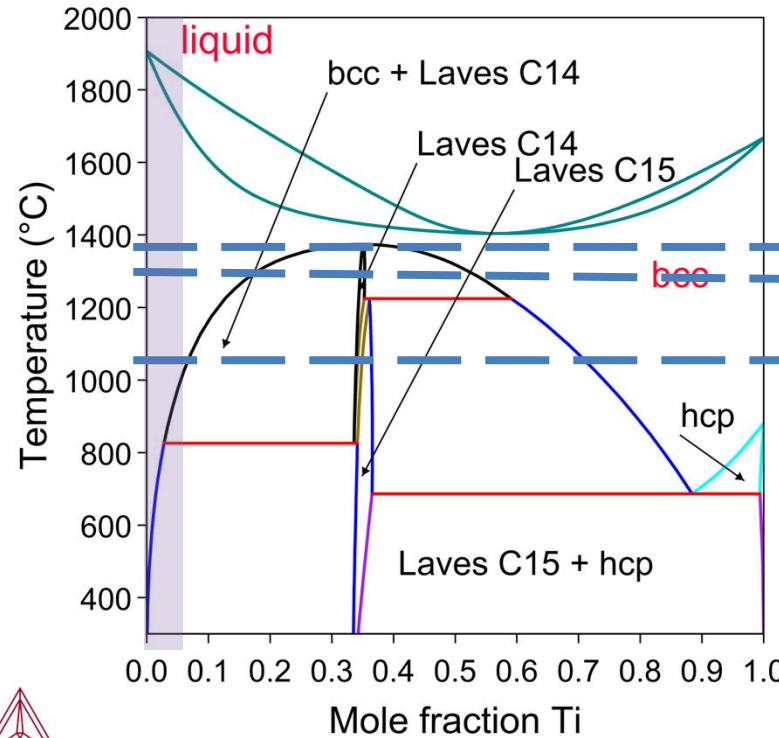
Dimitra Spathara | dimitra.spathara@uni-hamburg.de | September 2026

From Cu0.5Cr to Cu0.5Cr**x****Ti** alloys

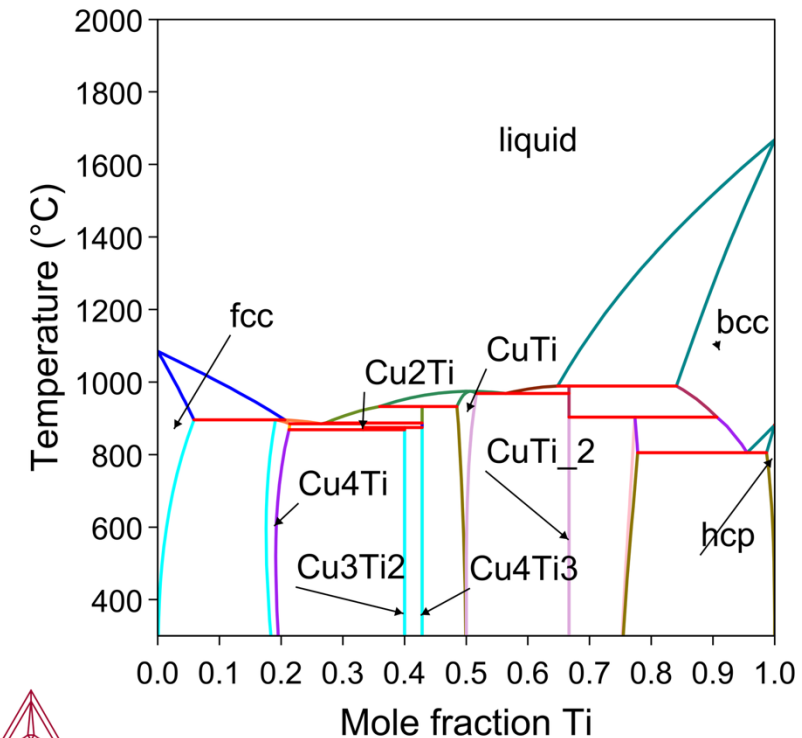
Cu-Cr



Cr-Ti



Cu-Ti



Strategy:

1. CrTi alloy @ T ?
2. CuCrTi alloy @ 1050°C



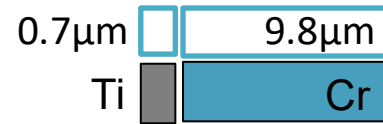
Cr-Ti



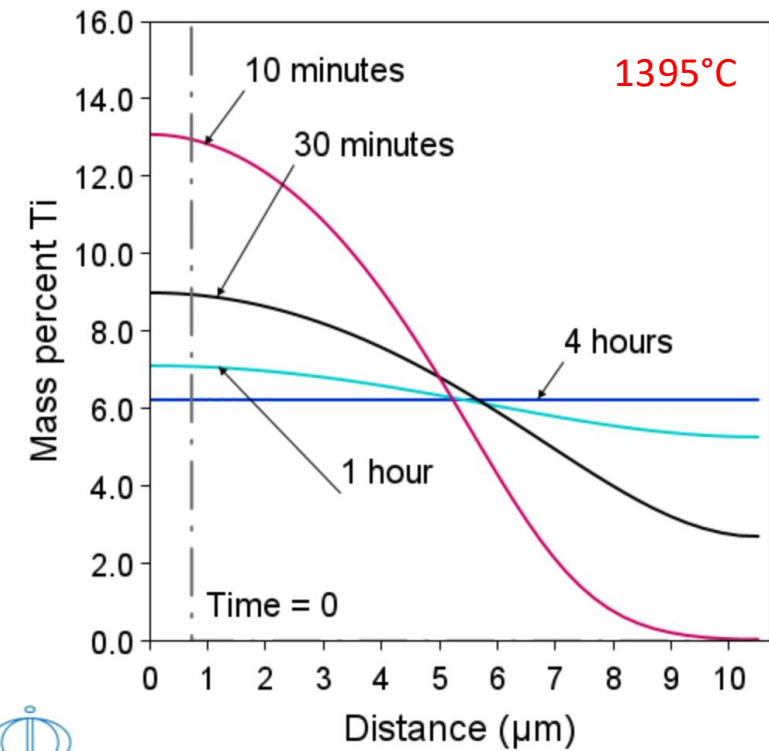
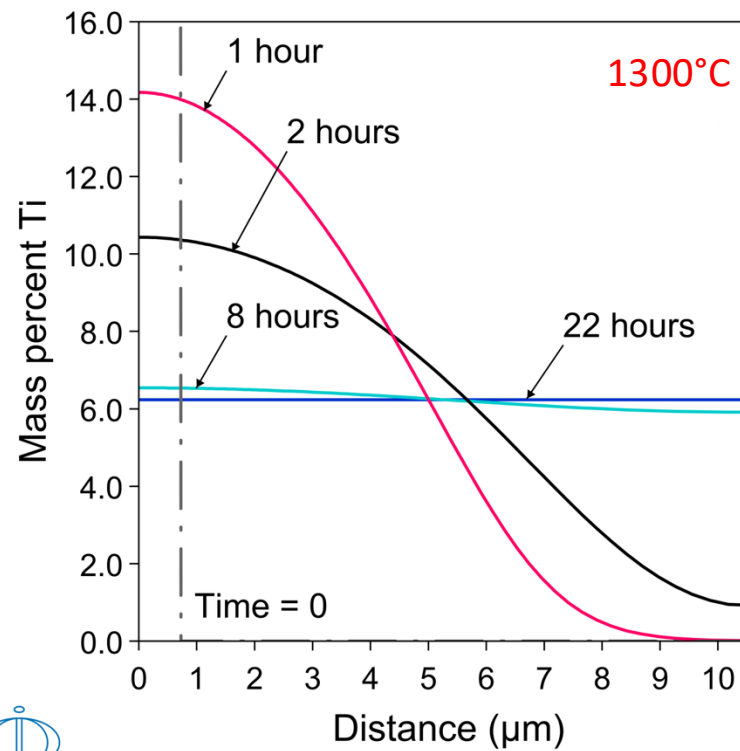
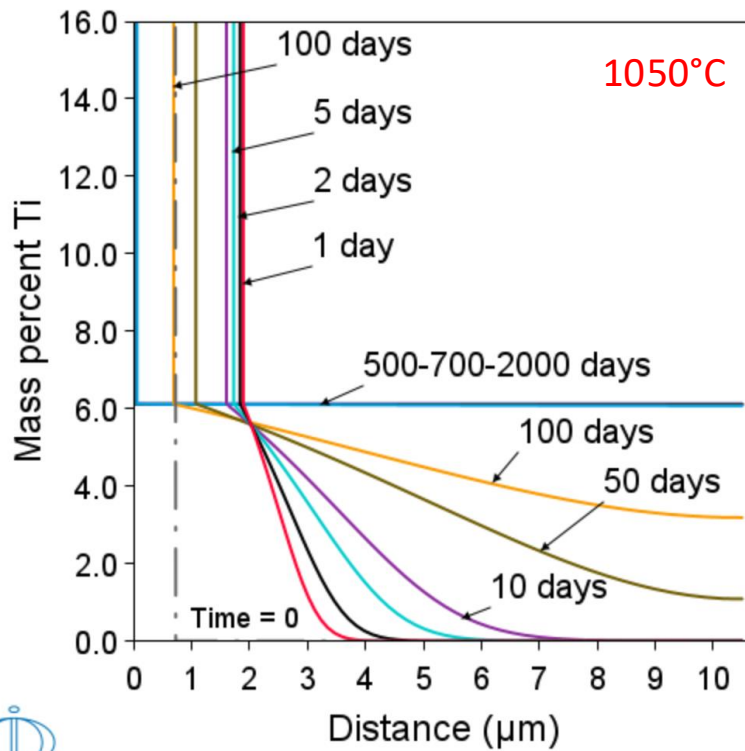
Cu-0.5Cr-xTi

D. Spathara et al. Commun Phys (2025)

1. Cr-6.23Ti alloy



3 temperatures



D. Spathara et al. Commun Phys (2025)

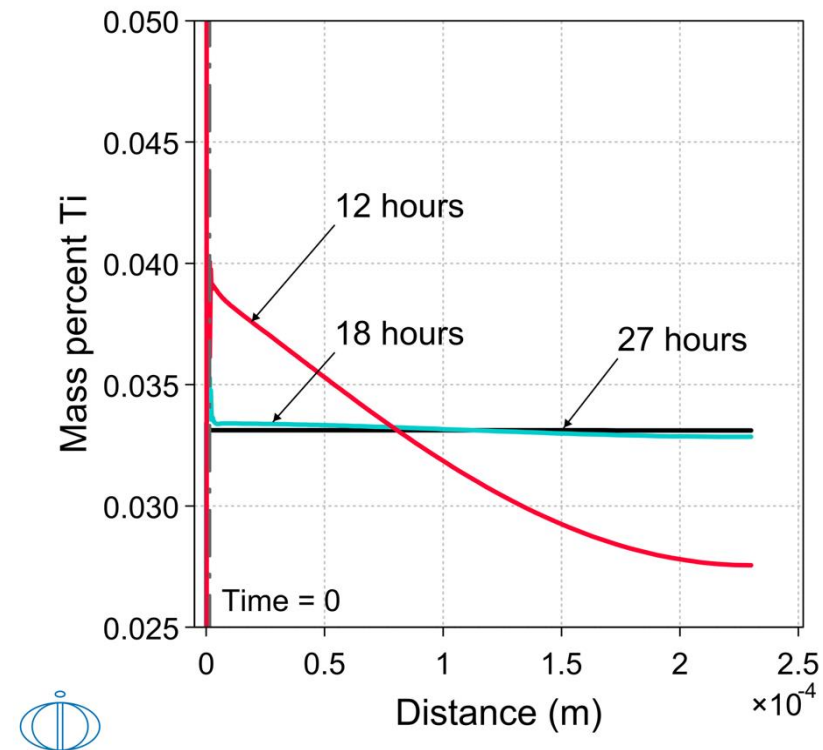
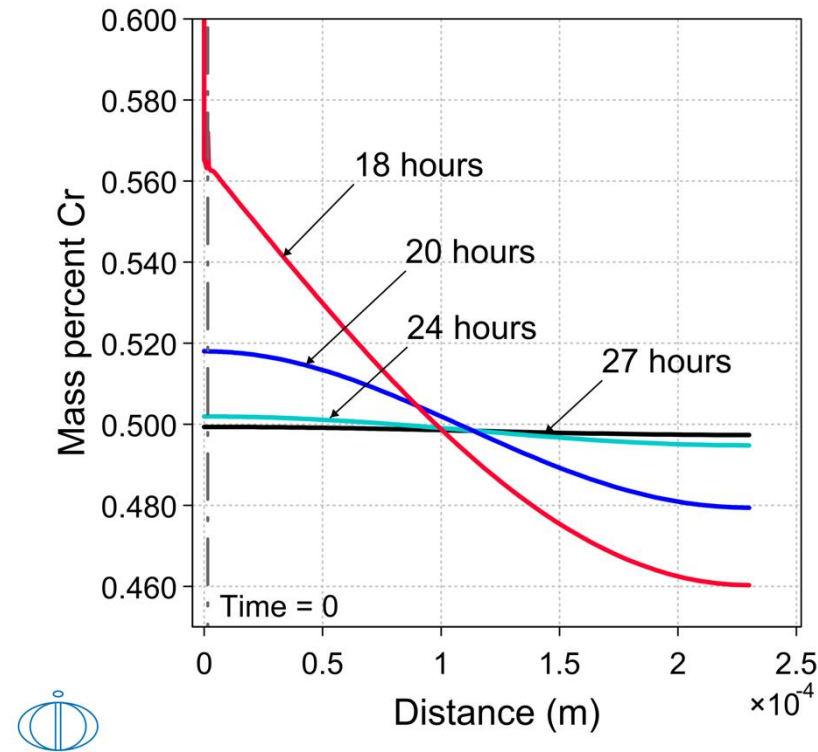
2. Cu-0.5Cr-0.032 Ti alloy

Patrick Knights
Poster Session

arxiv.org/abs/2606.24524
arxiv.org/abs/2508.21029

1.5 μm 228.5 μm
Cr-6.23Ti Cu

1050°C

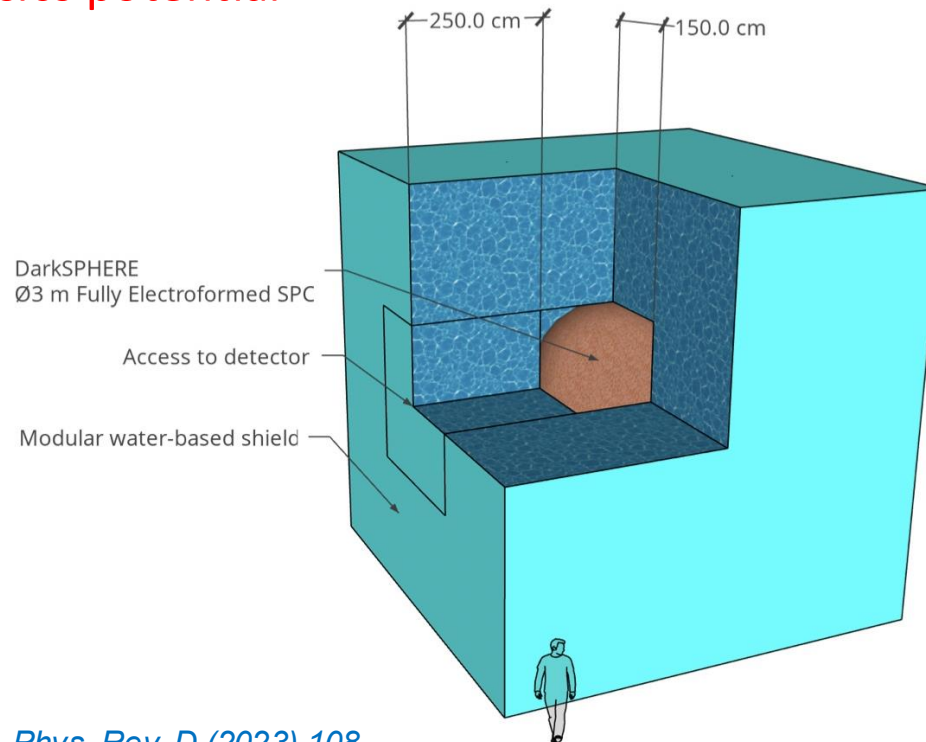
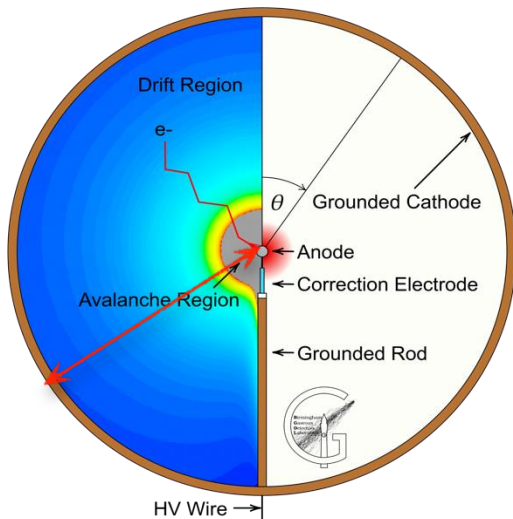


D. Spathara et al. Commun Phys (2025)

case study: DarkSPHERE

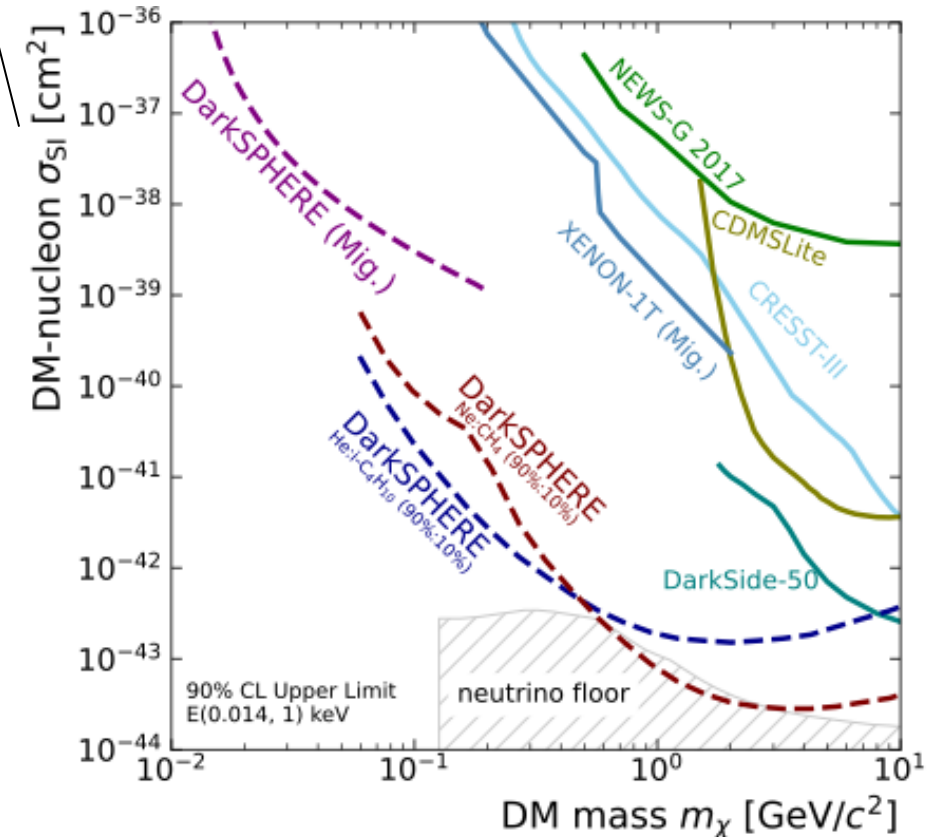
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- ✓ Option for stronger material compared to EFCu
- ✓ Scale up the current geometries for gas vessels (or gas pressure, wall thickness)

→ maximising the physics potential



Phys. Rev. D (2023) 108

a high-purity CuCr alloy with double the strength over EFCu, would allow operation at 10 bar and reduce the required data collection time to 150 days.

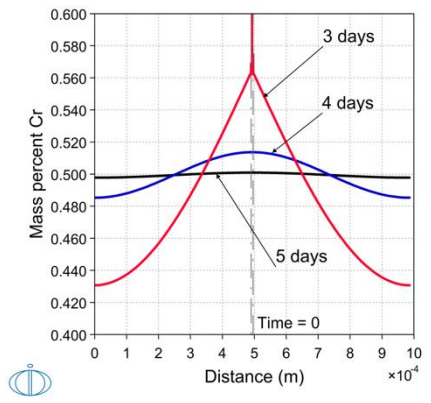
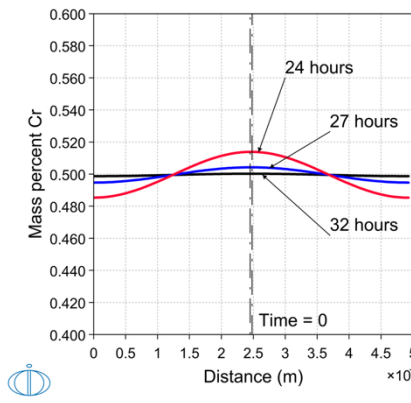
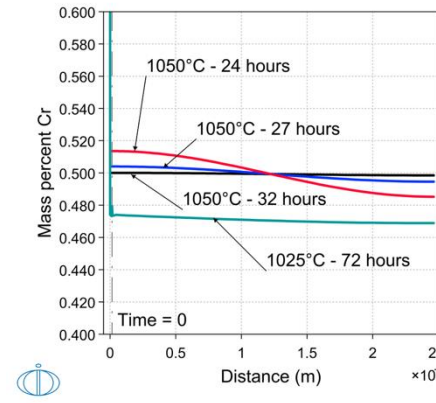
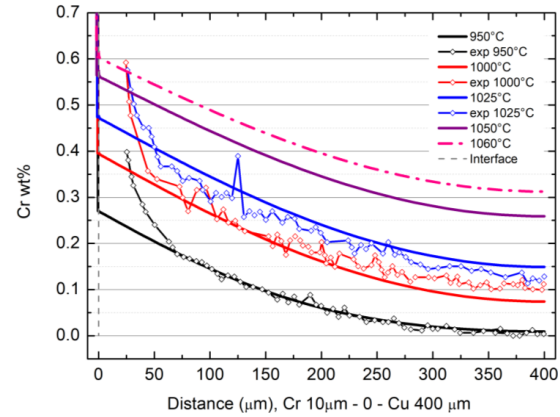
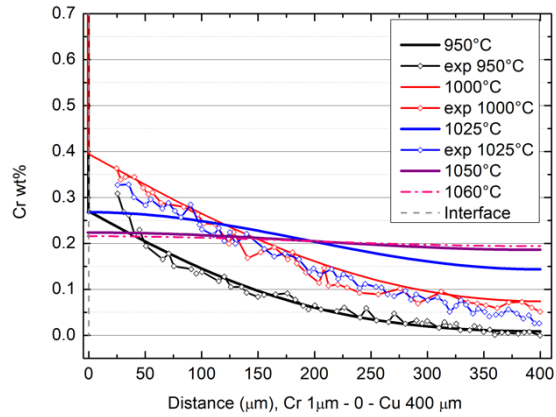


Commun Phys (2025)

Summary

- ✓ Based on early experimental trials, **synthesis** of radiopure CuCr alloys using **electrodeposition**
- ✓ A **methodology** for **designing** Cu-based alloys, avoiding trial-and-errors, **minimising energy** and **resources** with **predicted** mechanical properties
- ✓ **Validated** solution heat treatment simulations
Aging time/ duration needs to be explored further with experiments
- ✓ Designed Cr/Cu and Cr/Ti and Cu/CrTi **layer configurations** to manufacture radiopure CuCr and CuCrTi
- ✓ Next steps: manufacture + characterise CuCr and CuCrTi alloys, **component**

Thank you for your attention!



More on PureAlloys:

<https://dematerializ.github.io/purealloys/>

