



Muon Scattering Tomography with RPCs

OLEG BRANDT

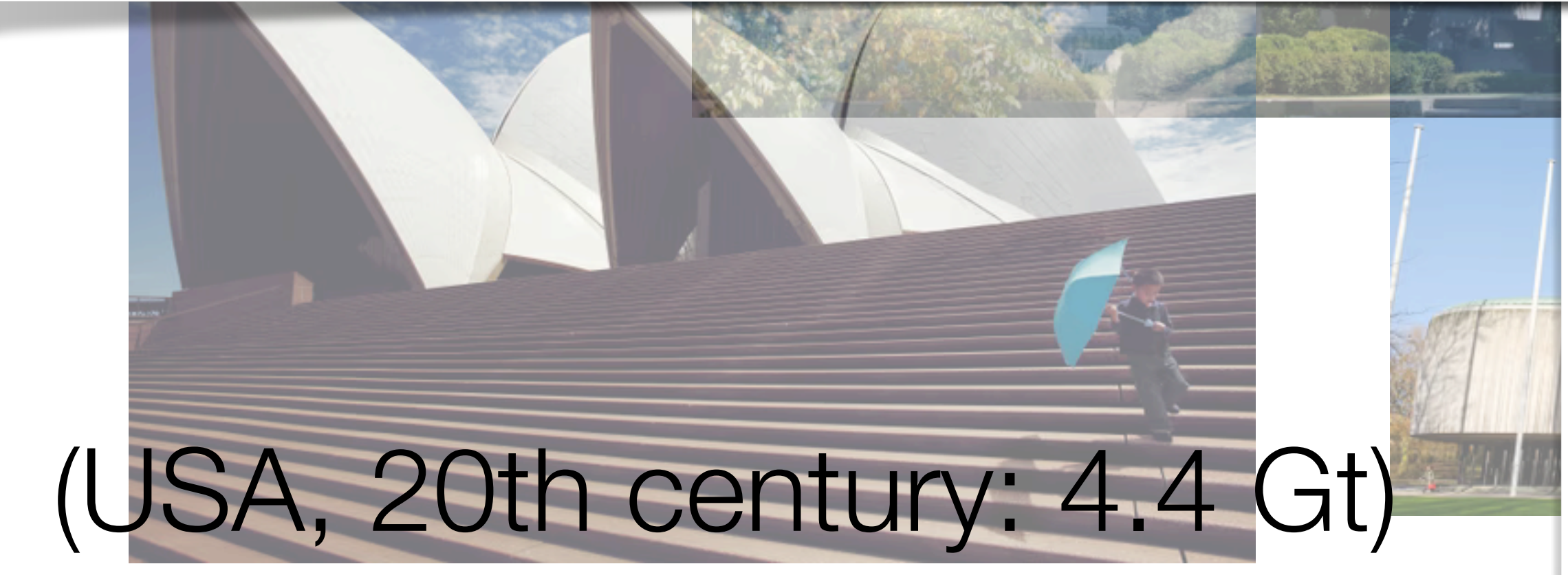


WE LOVE REINFORCED CONCRETE



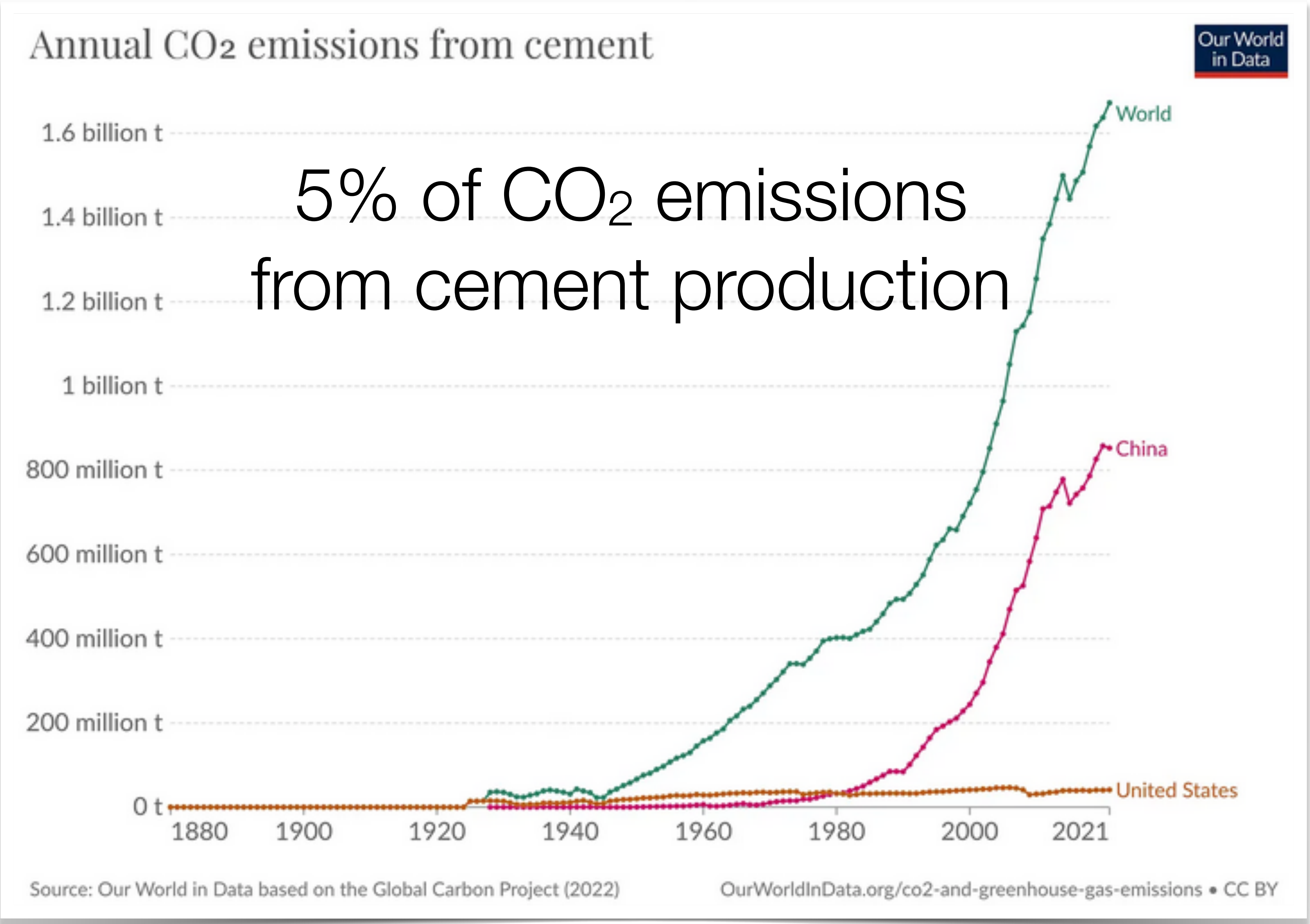


China: 7.2 Gt of cement / 3 years [1]



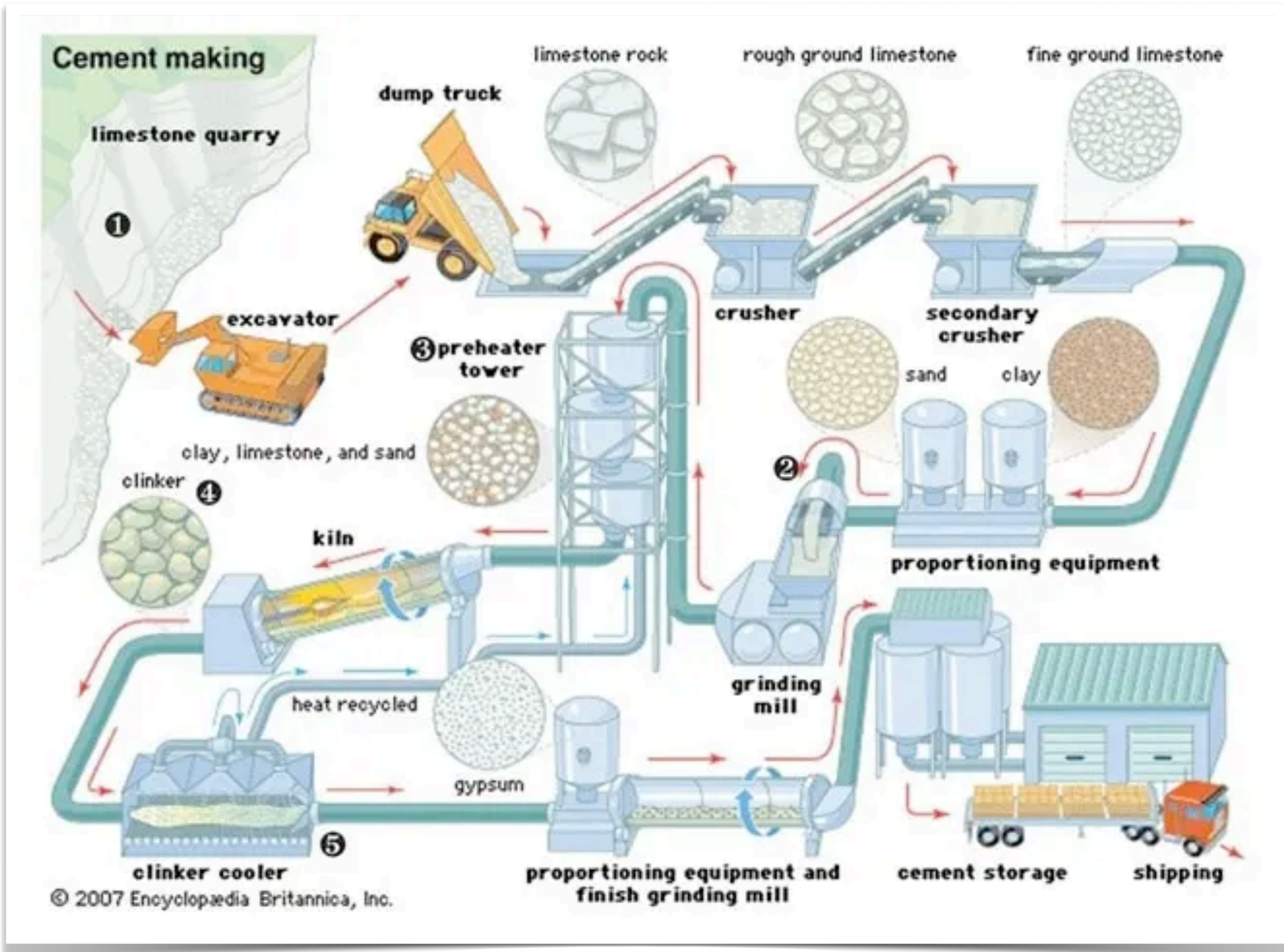
(USA, 20th century: 4.4 Gt)

WHY SHOULD I CARE ABOUT CEMENT PRODUCTION?



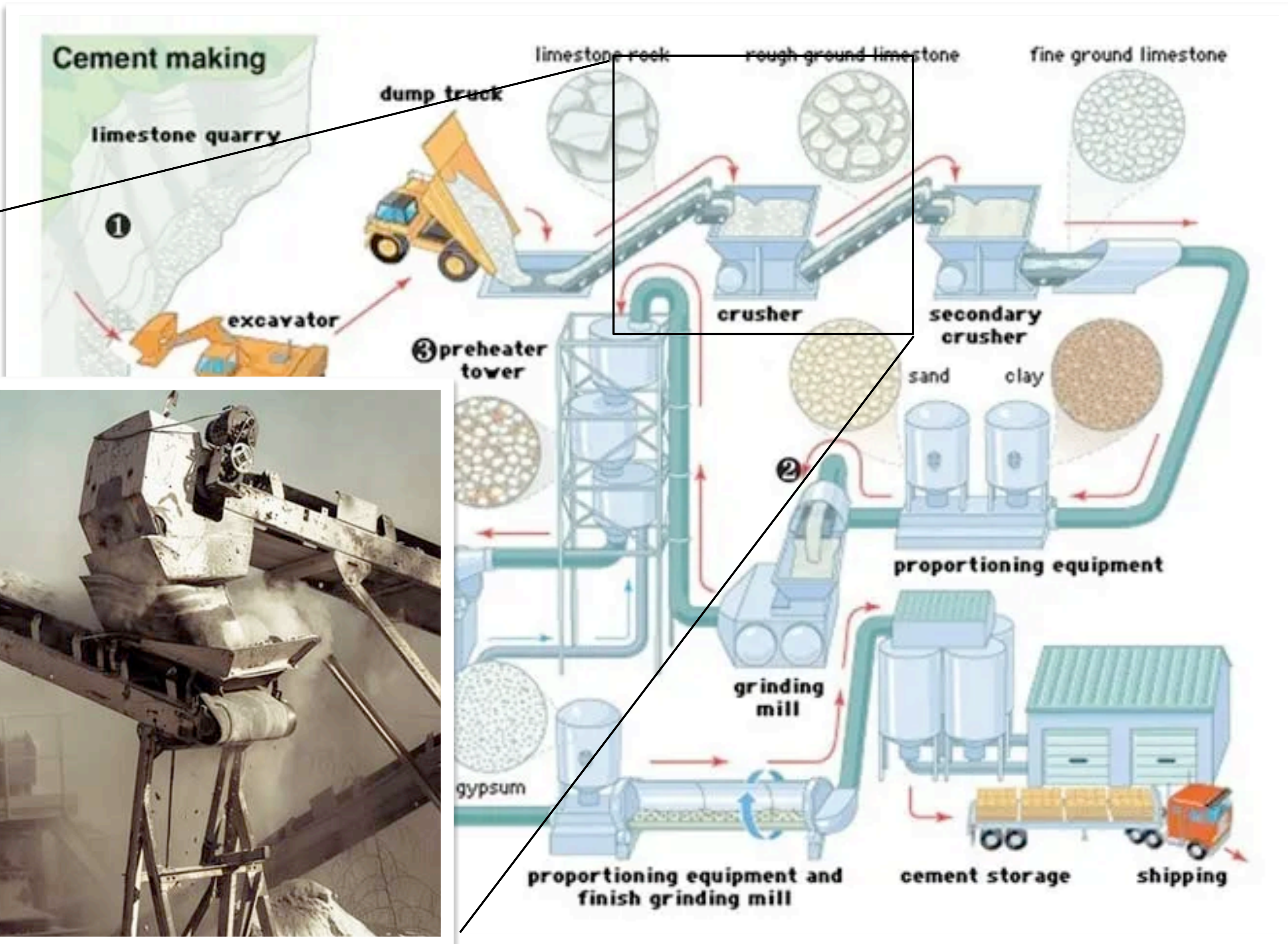


5%
CO₂



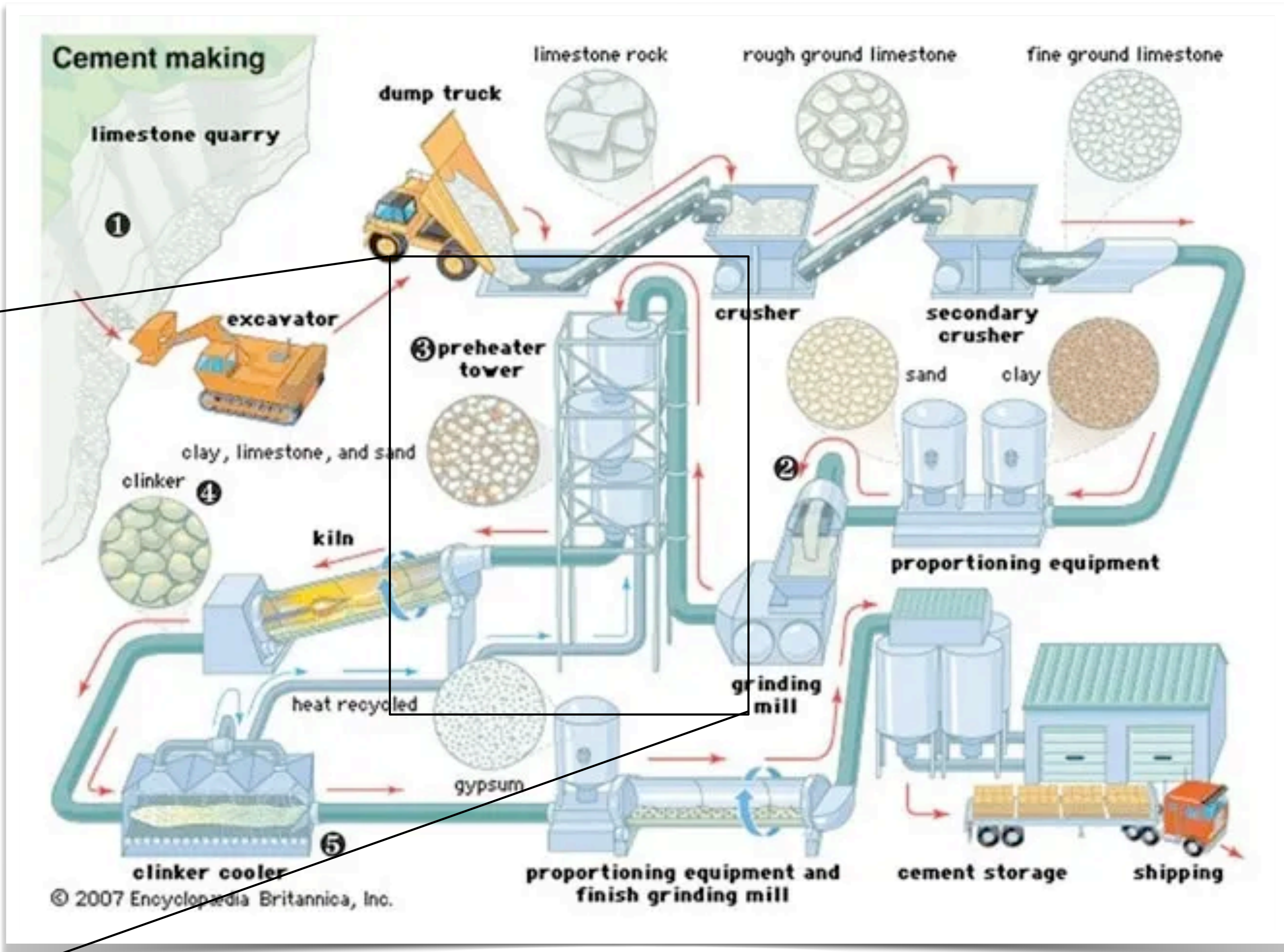
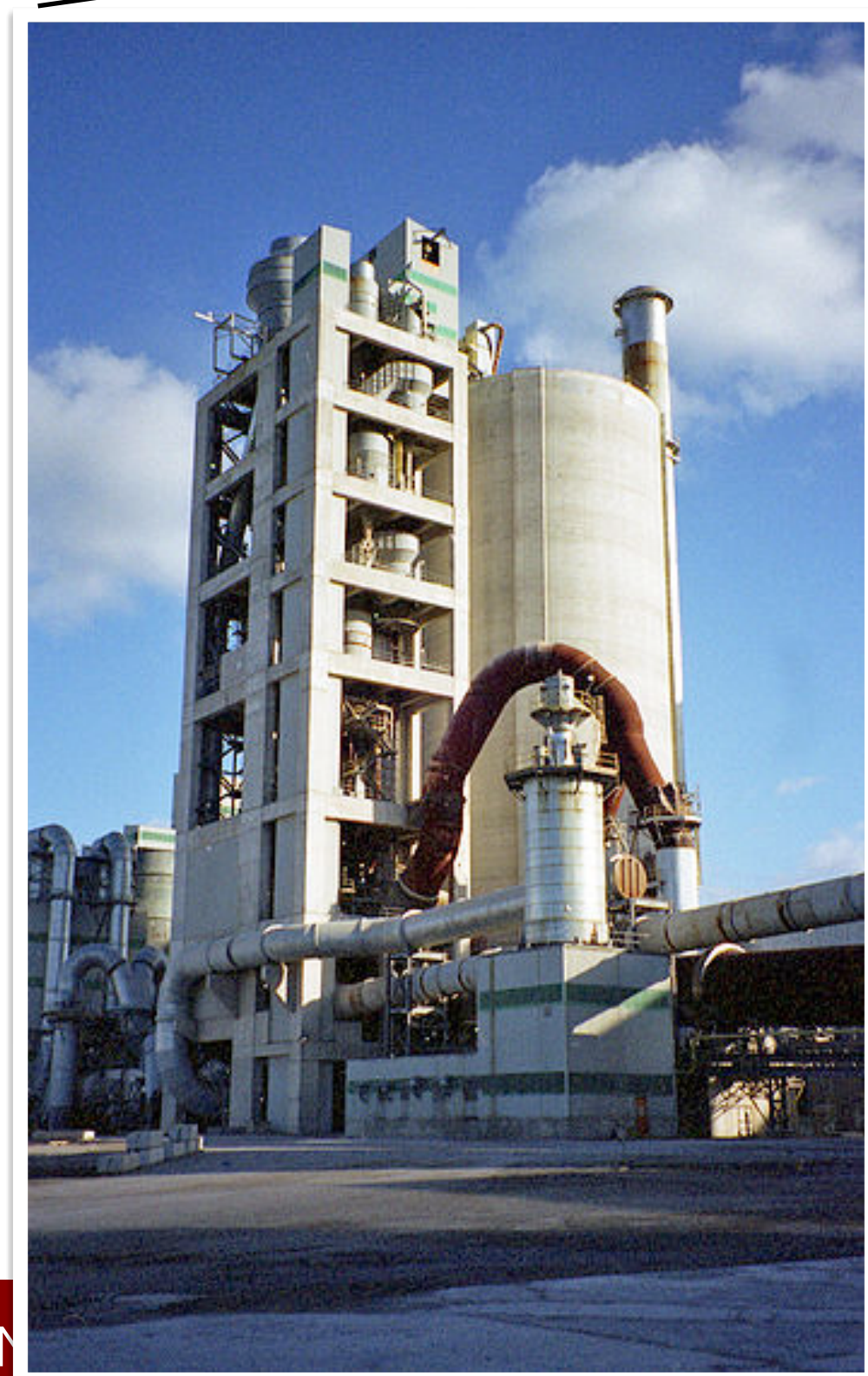


5%
CO₂



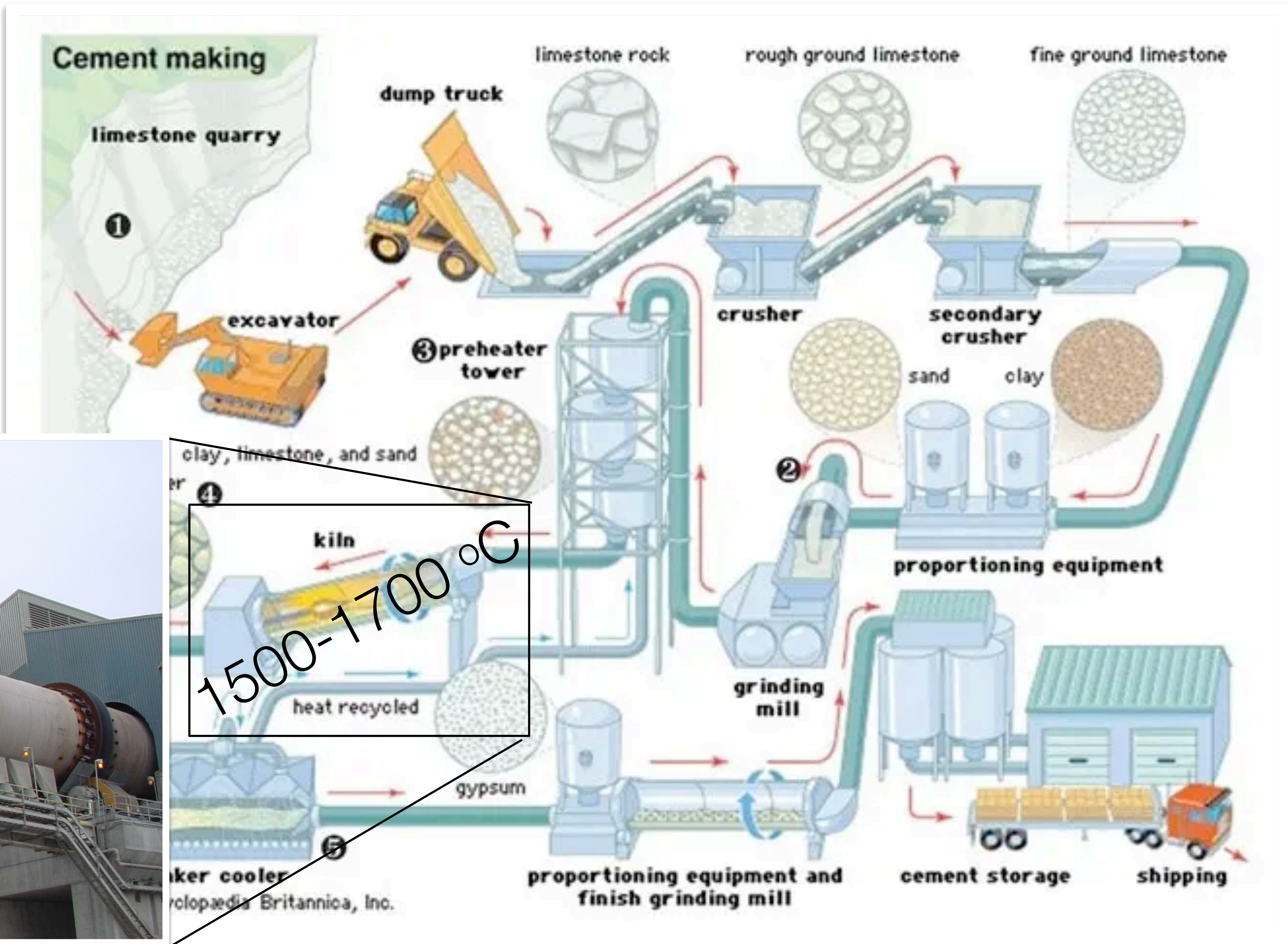


5%
CO₂



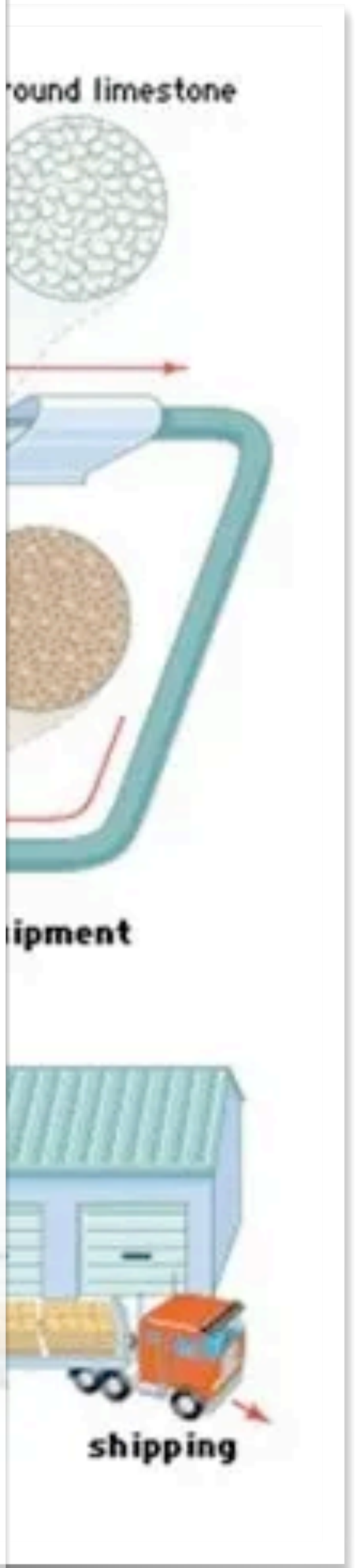
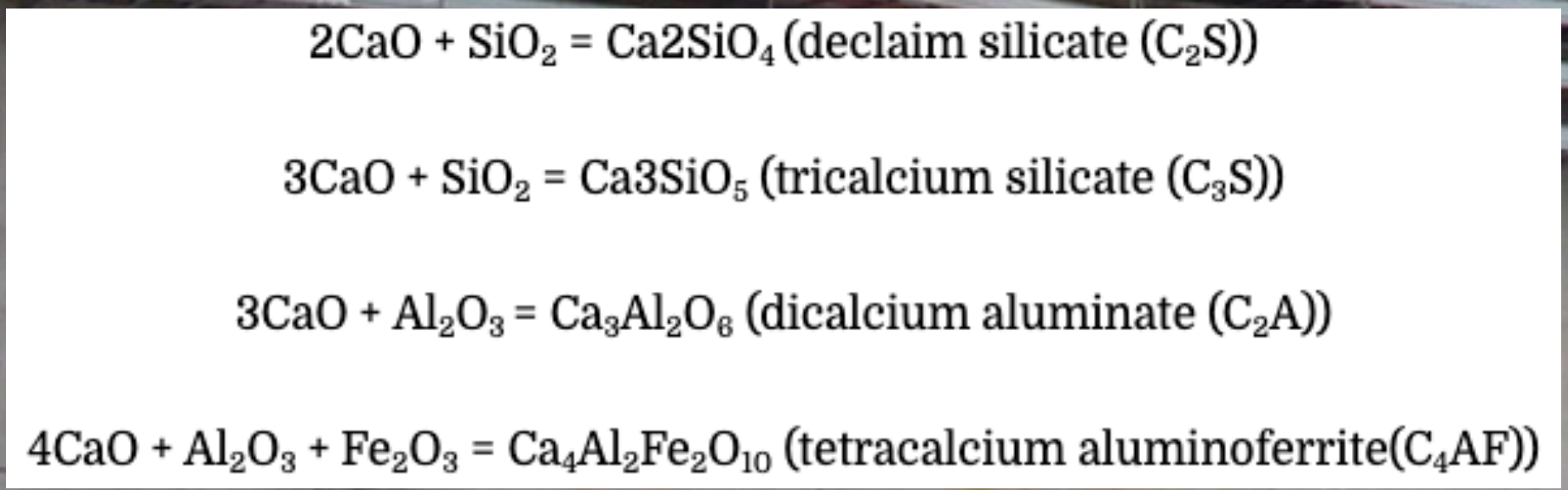
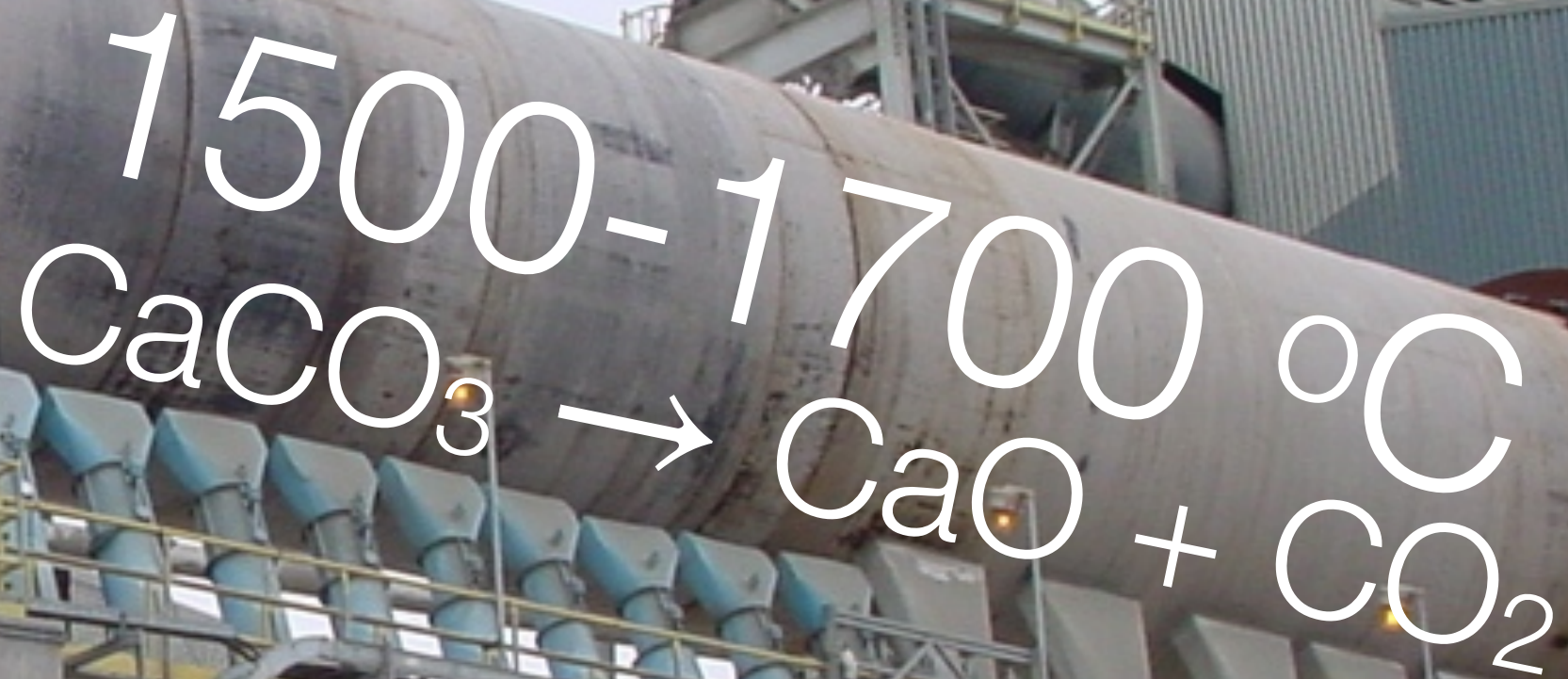


5%
CO₂





5%
CO₂





How can we extend the lifetime of buildings / civil infrastructure?

72,000 bridges alone in UK
4.4% “sub-standard”



Driveways

20-50+ years



Buildings, bridges

50+ years



interior

∞

t



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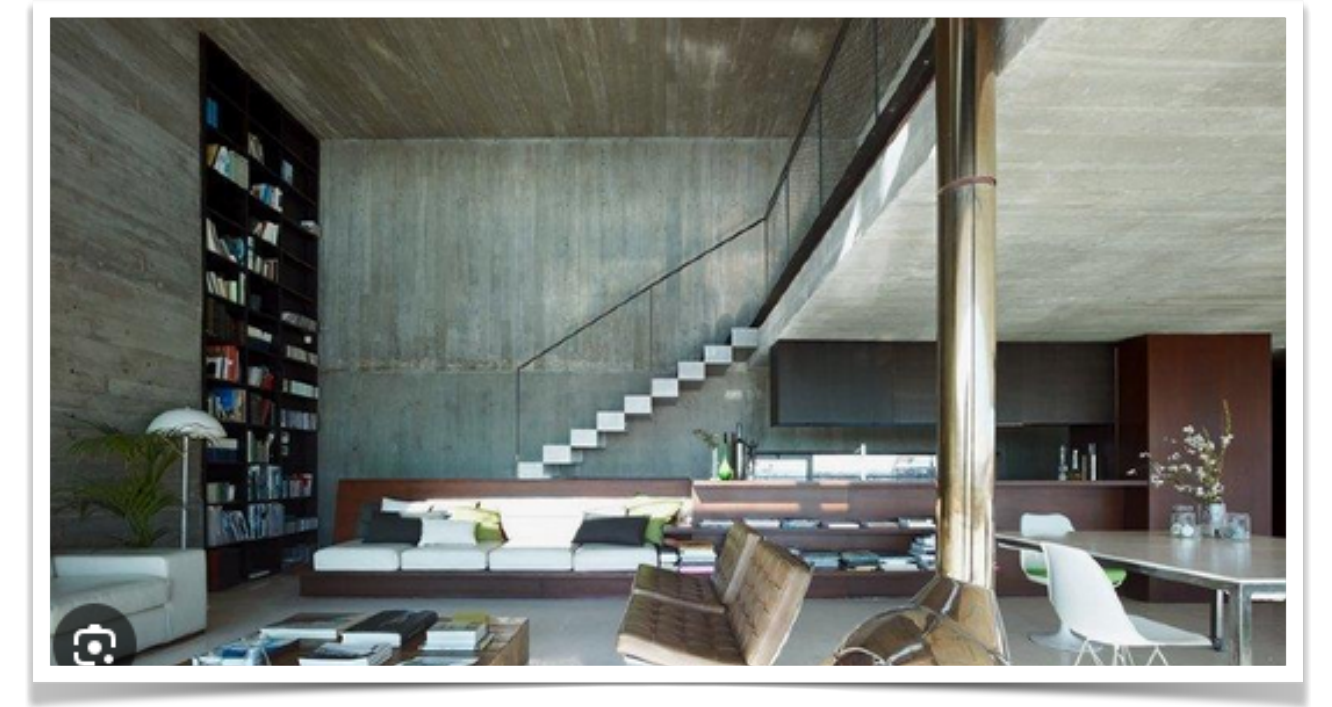
Driveways

20-50+ years



Buildings, bridges

50+ years



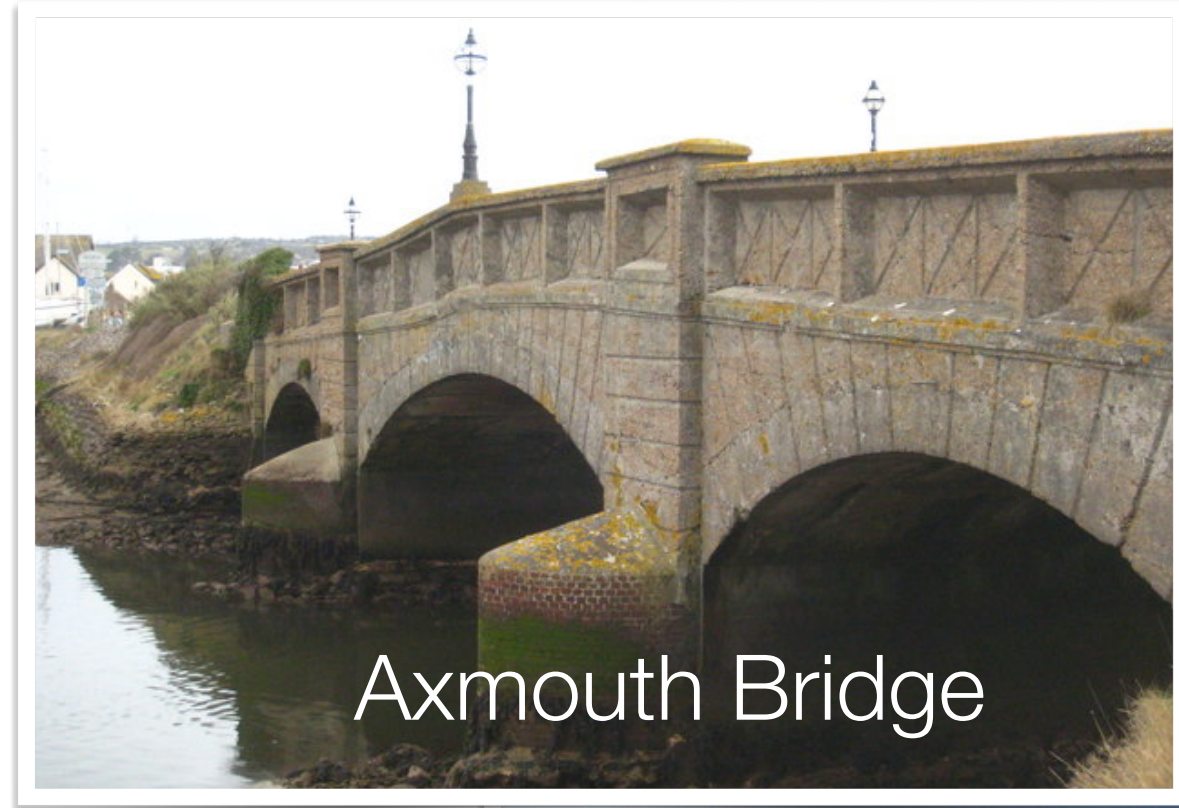
interior

∞

t



How can we extend the lifetime of buildings / civil infrastructure?



Axmouth Bridge

72,000 bridges alone in UK
4.4% “sub-standard”



Driveways

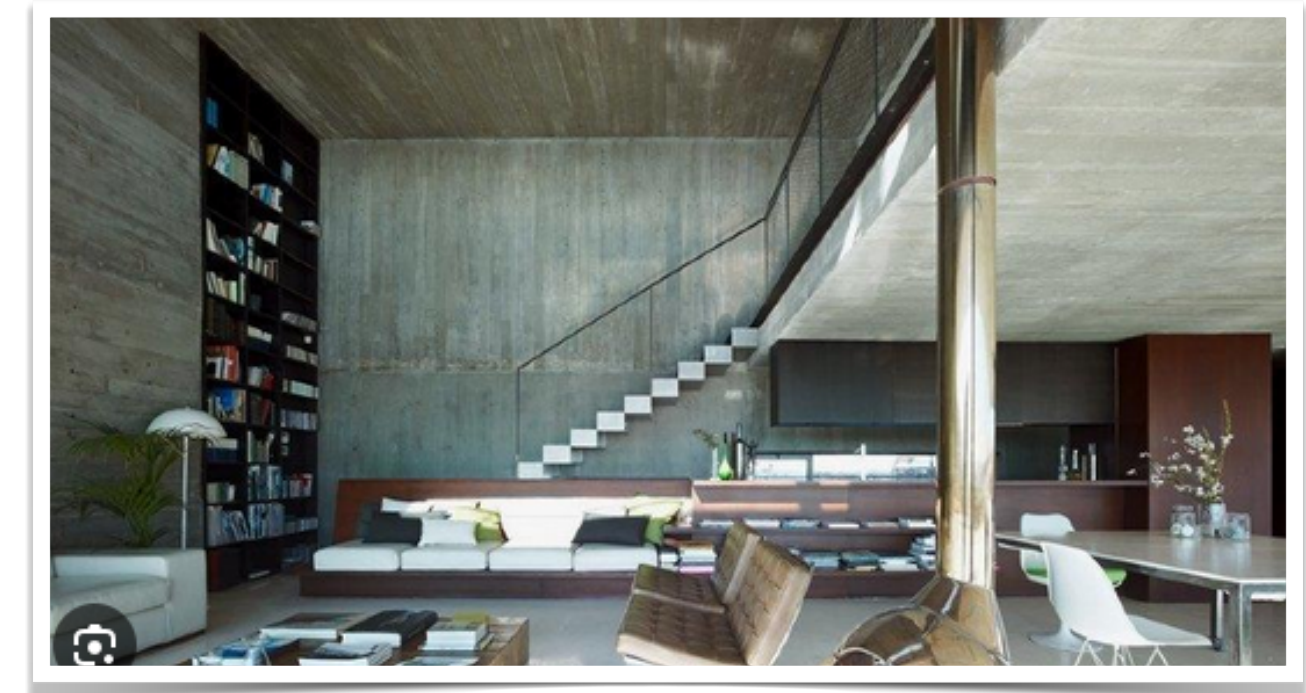
20-50+ years



Skye, Scotland

Buildings, bridges

50+ years



interior

∞

t

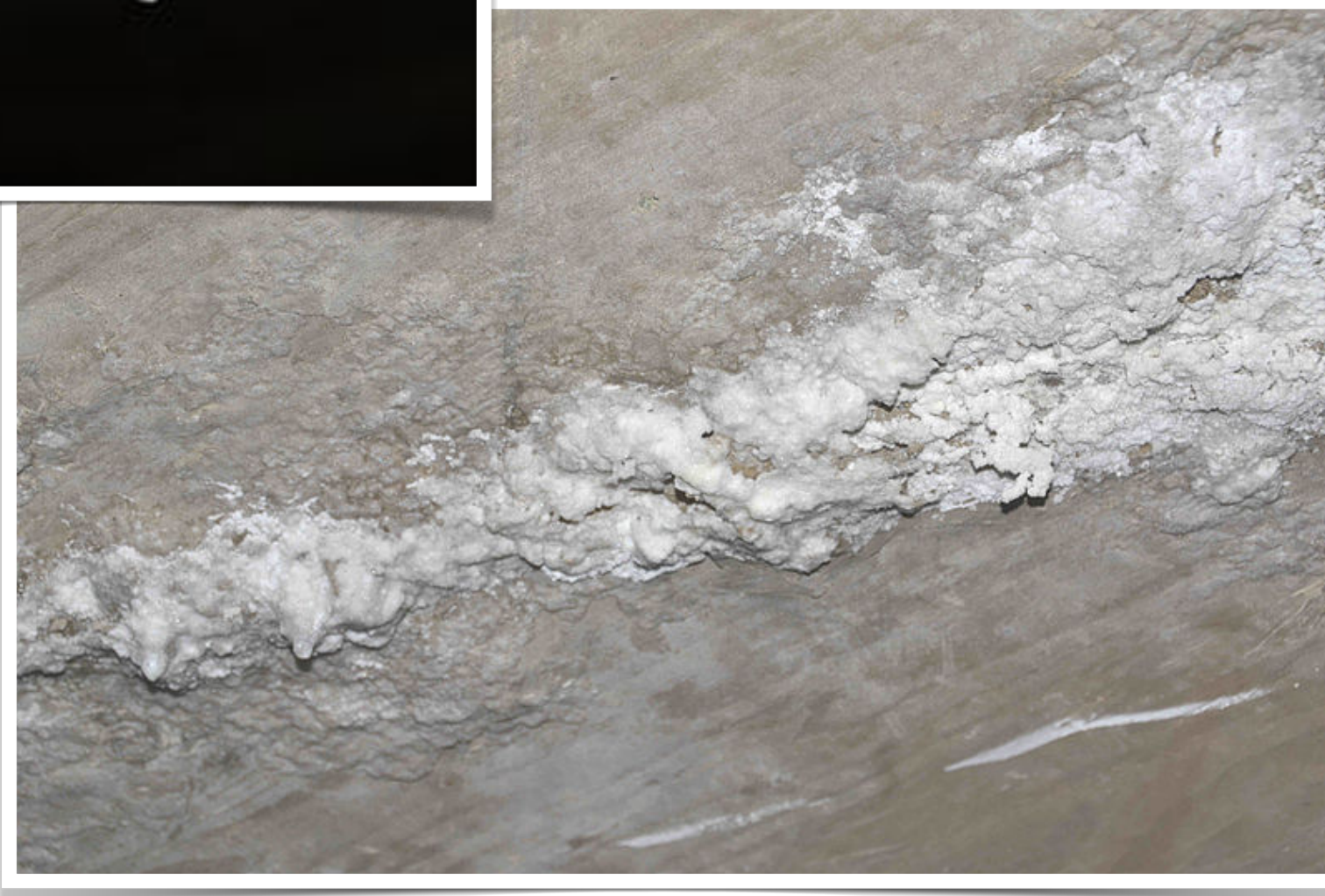


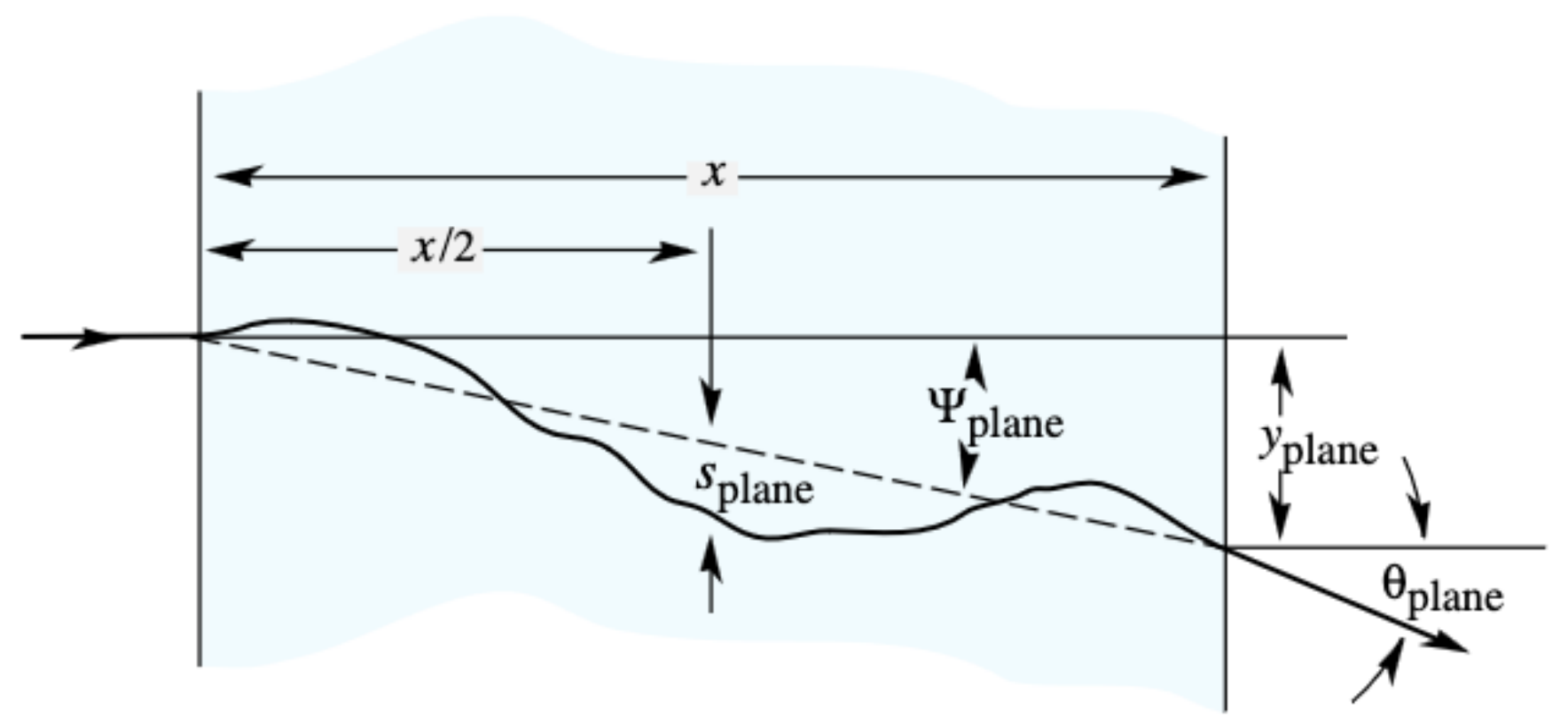
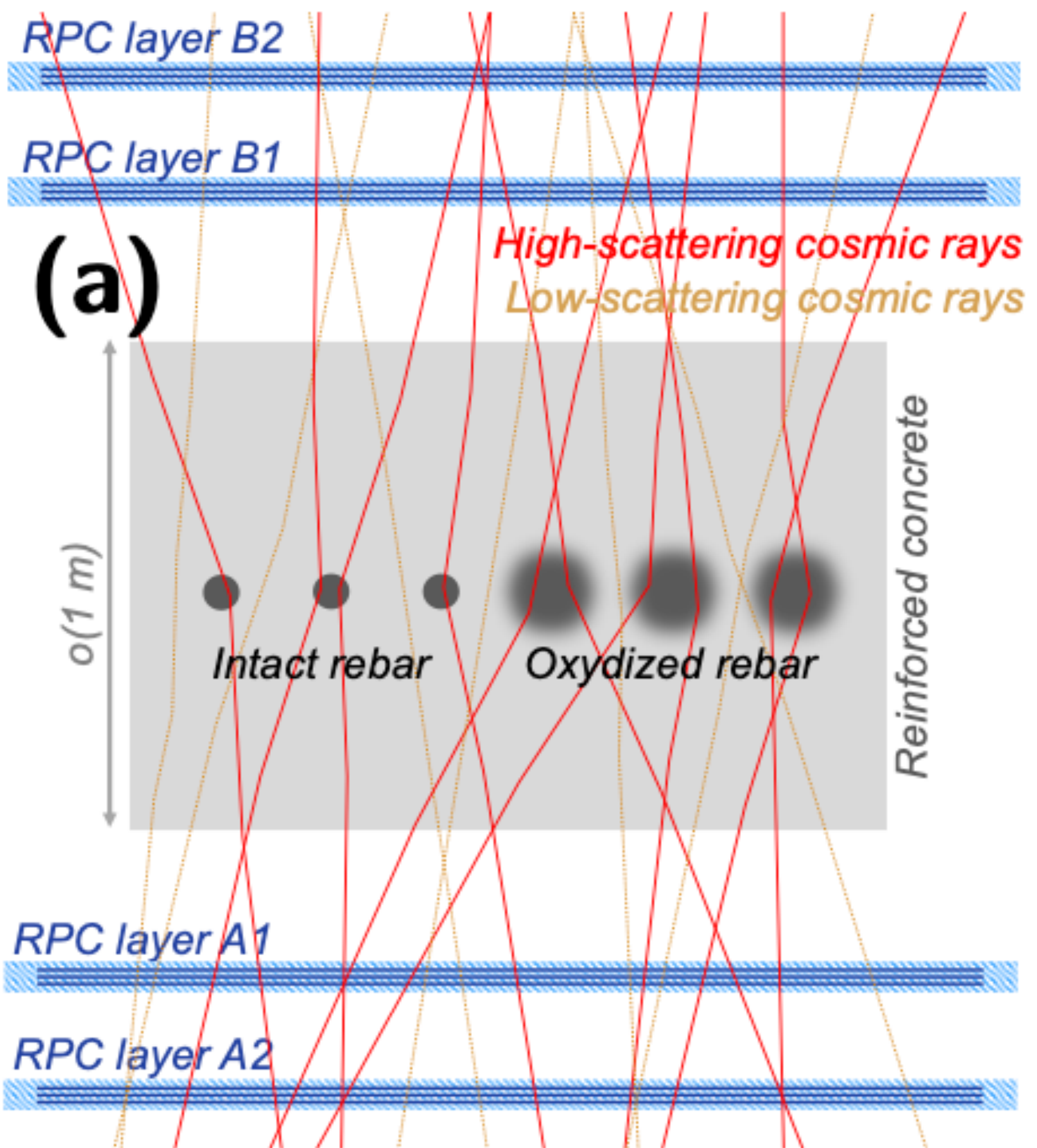
- Lifetime of reinforced concrete ultimately depends on steel rebar conditions
 - So does the lifetime of civil infrastructure



Invisible

Visible





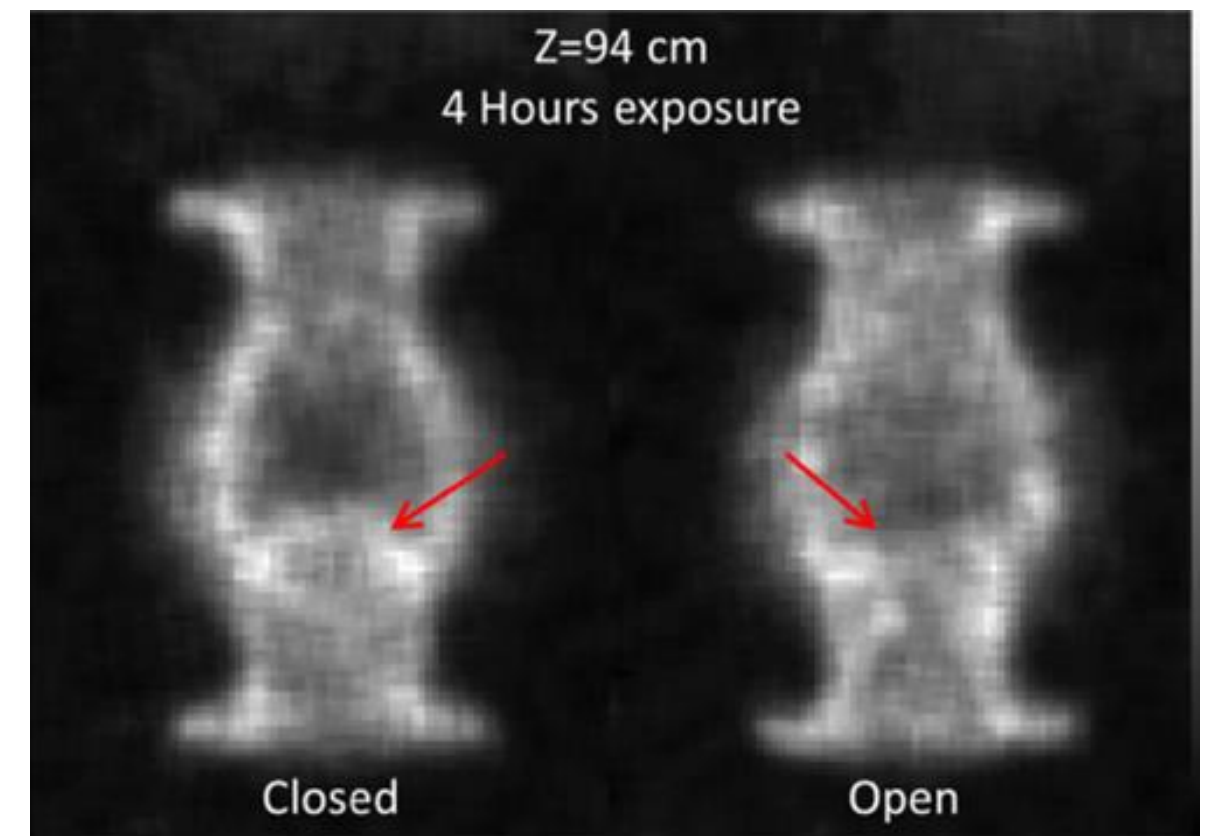
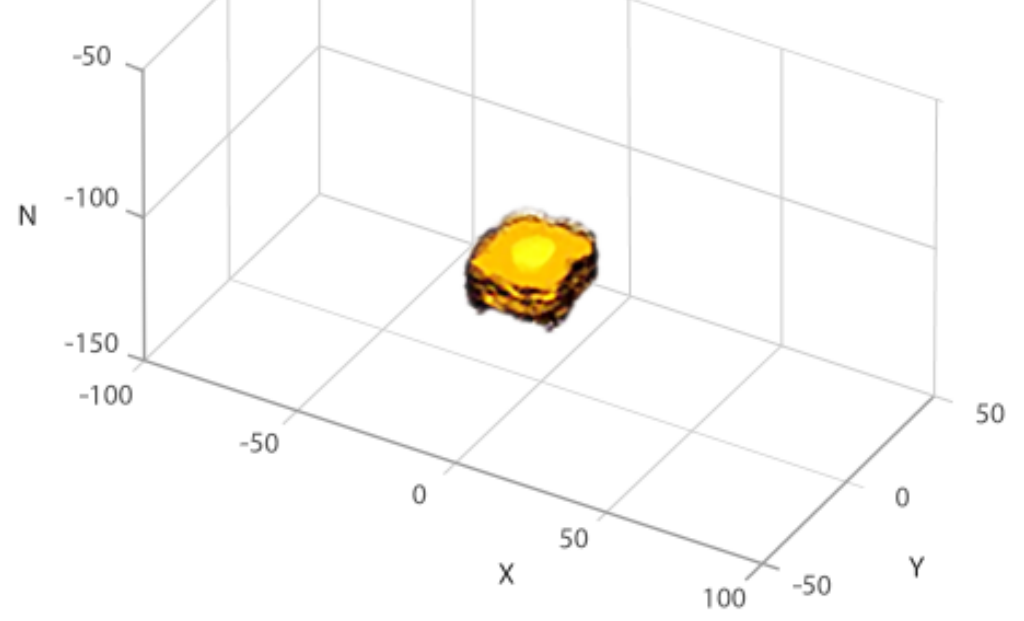
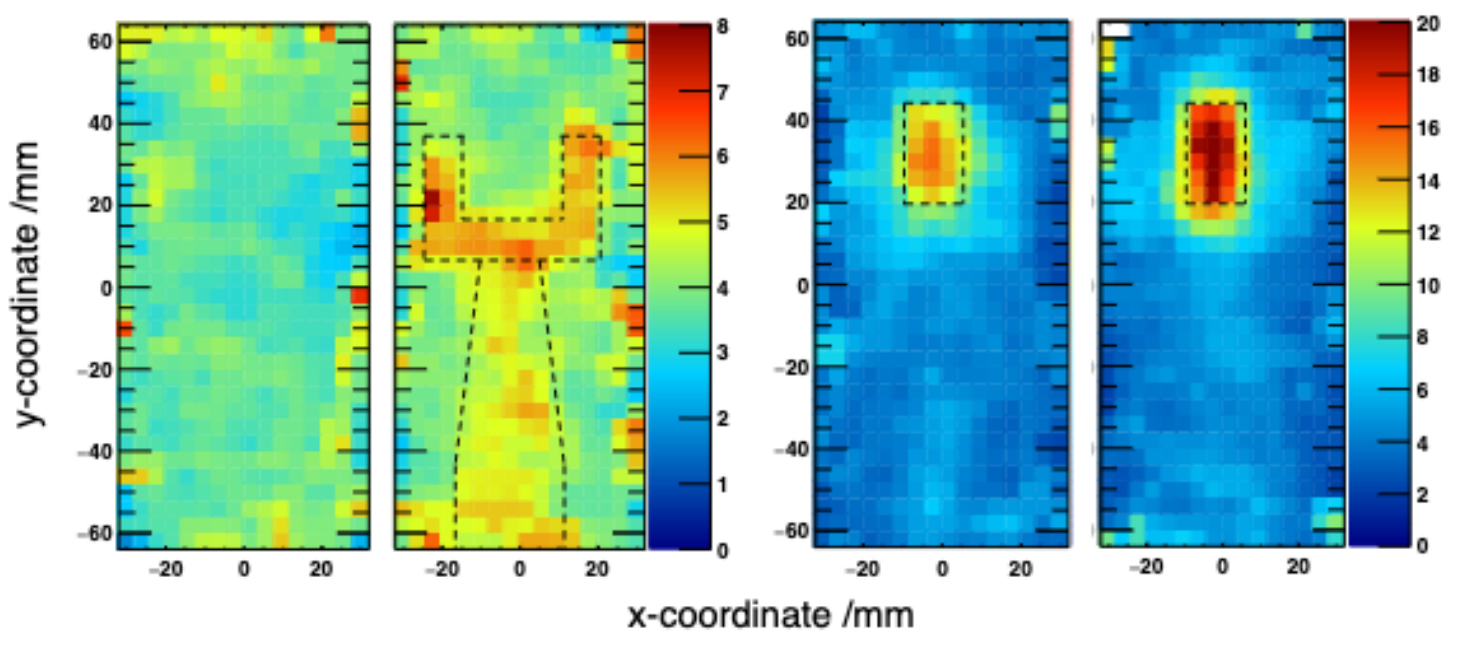
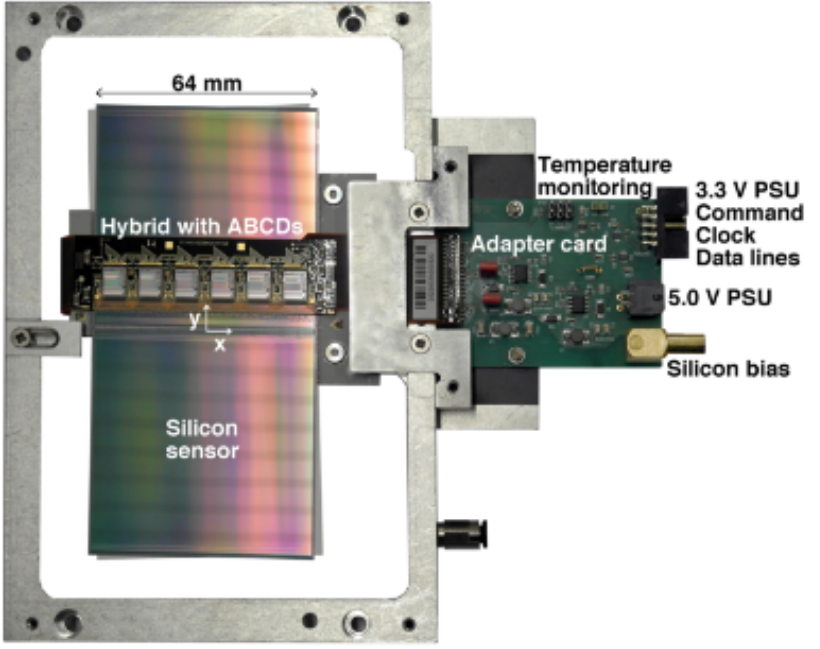
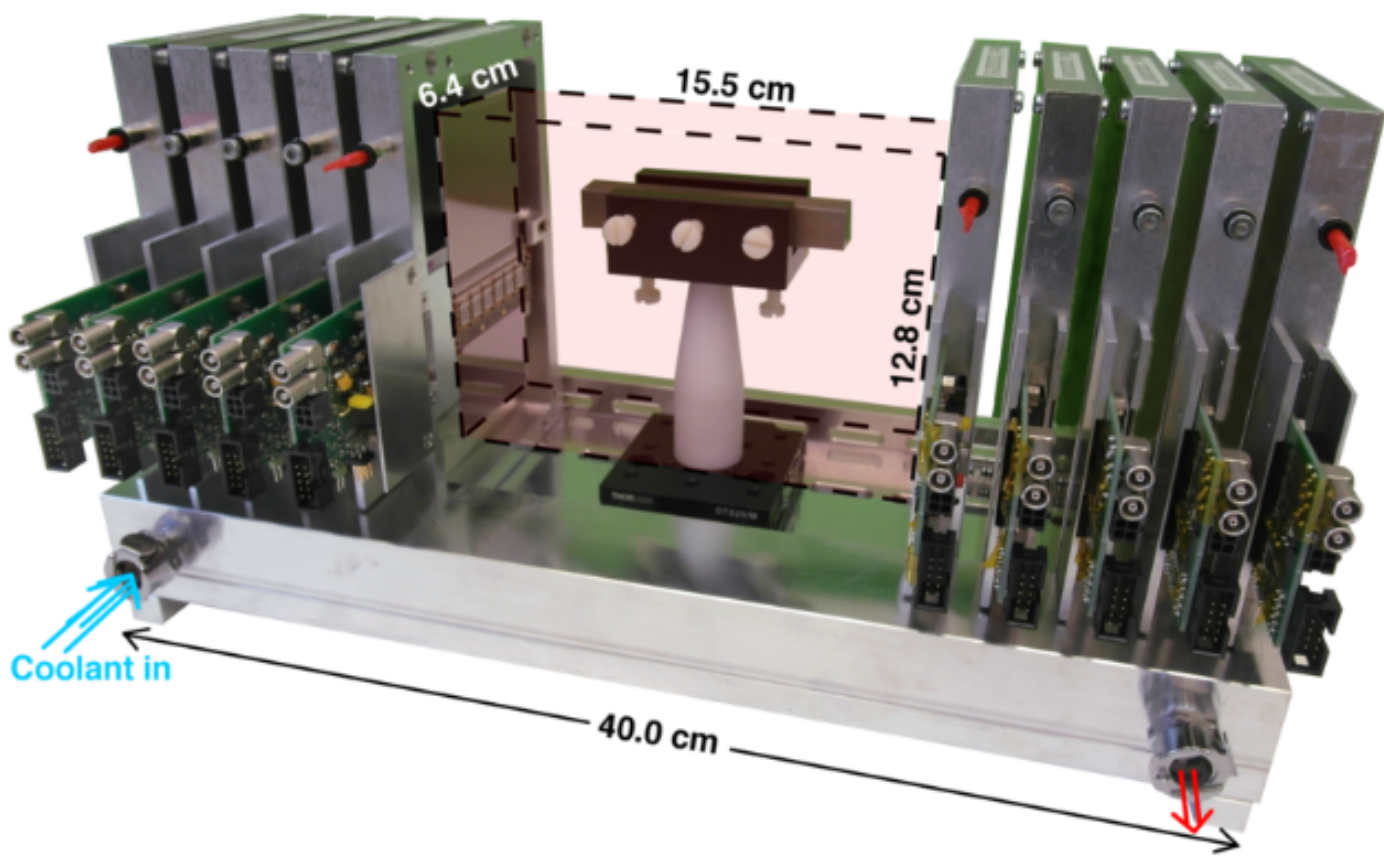
$$y_{\text{plane}}^{\text{rms}} = \frac{1}{\sqrt{3}} x \theta_{\text{plane}}^{\text{rms}} = \frac{1}{\sqrt{3}} x \theta_0$$

$$\theta_0 = \frac{13.6 \text{ MeV}}{\beta c p} z \sqrt{\frac{x}{X_0}} \left[1 + 0.088 \log_{10} \left(\frac{x z^2}{X_0 \beta^2} \right) \right]$$

$$= \frac{13.6 \text{ MeV}}{\beta c p} z \sqrt{\frac{x}{X_0}} \left[1 + 0.038 \ln \left(\frac{x z^2}{X_0 \beta^2} \right) \right]$$

- Concrete: $X_0 = 11.6 \text{ cm}$
- Iron: $X_0 = 1.8 \text{ cm}$
- Lead: $X_0 = 0.6 \text{ cm}$
- Uranium: $X_0 = 0.3 \text{ cm}$

(SOME) MUON TOMOGRAPHY DEMONSTRATORS

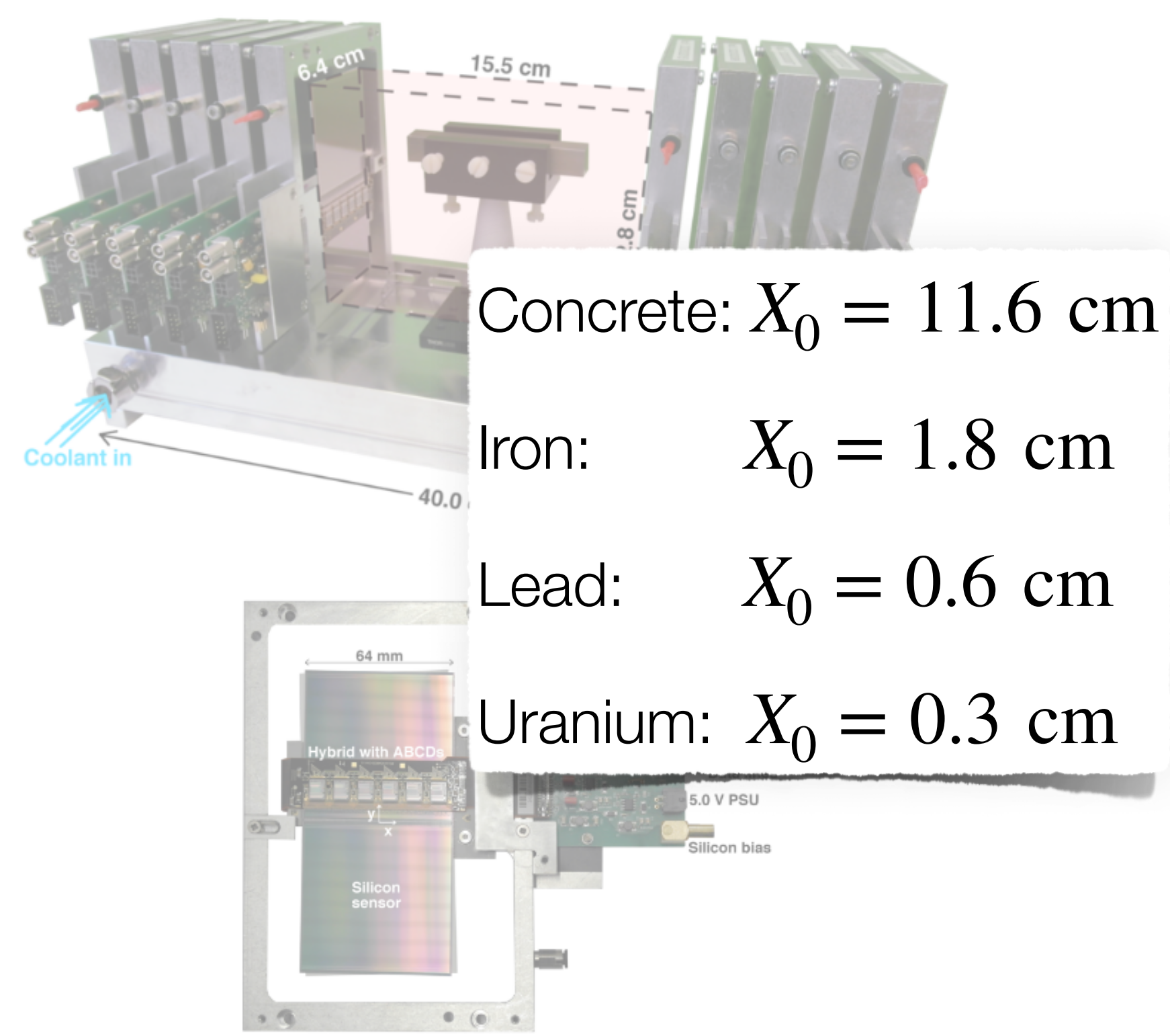


JINST 13 P10028, [LINK](#)

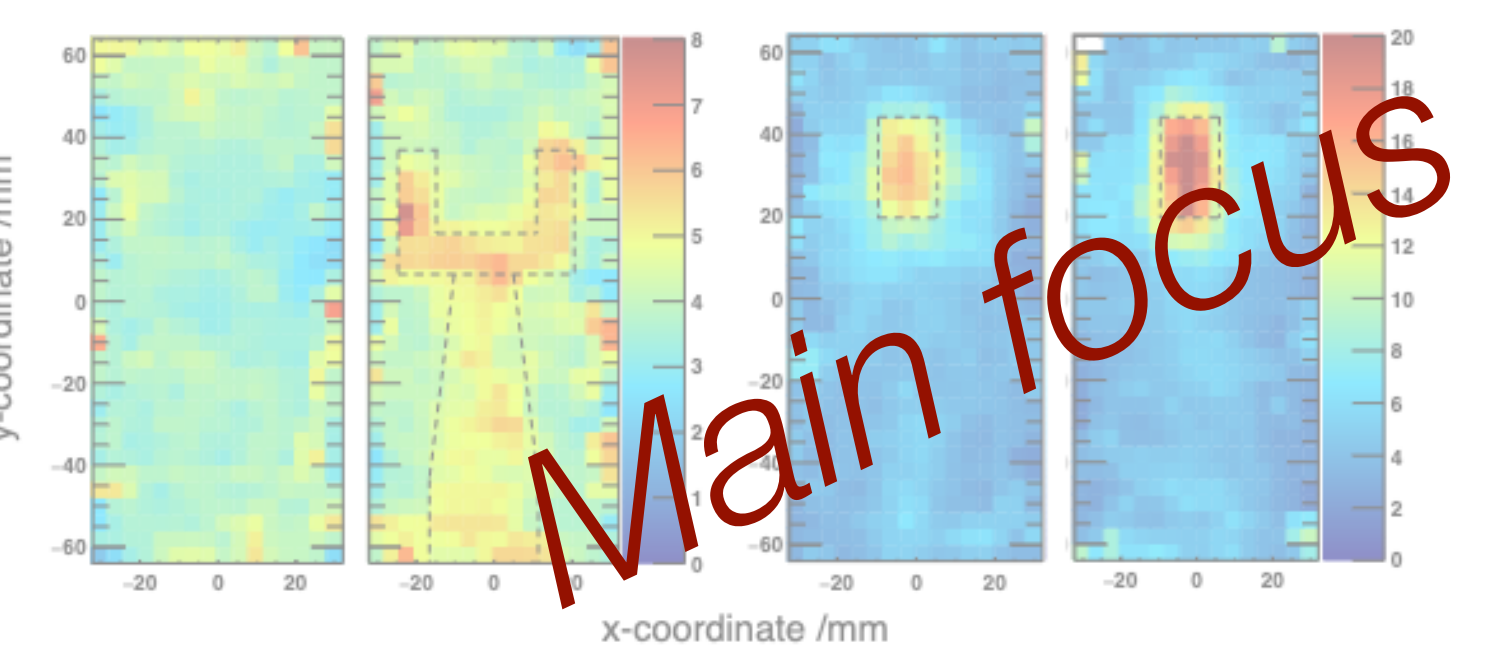
2102.12542, [LINK](#)

AIP Adv. 2015, 5, 067111, [LINK](#)

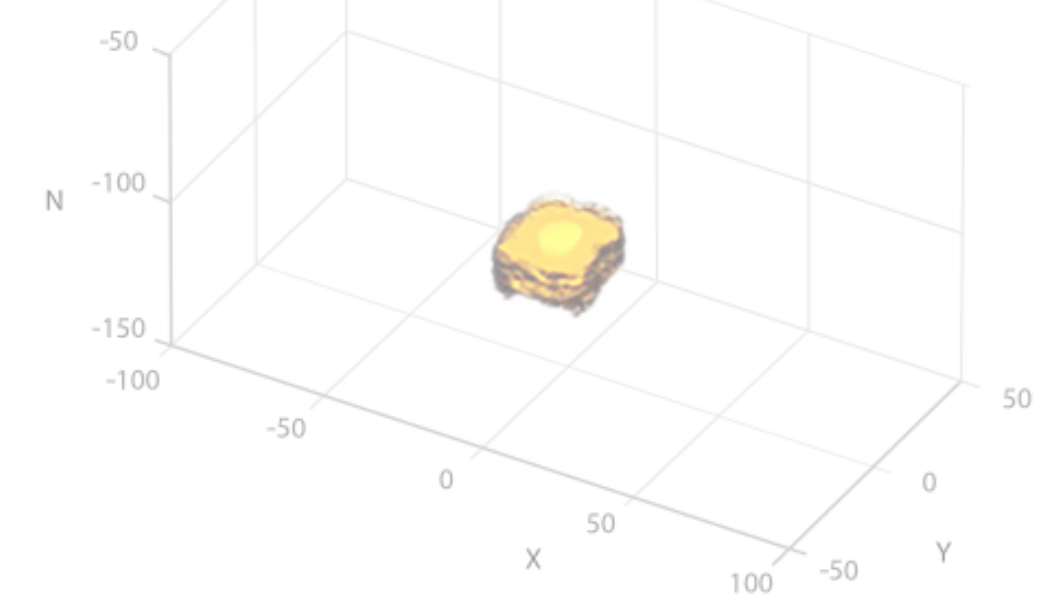
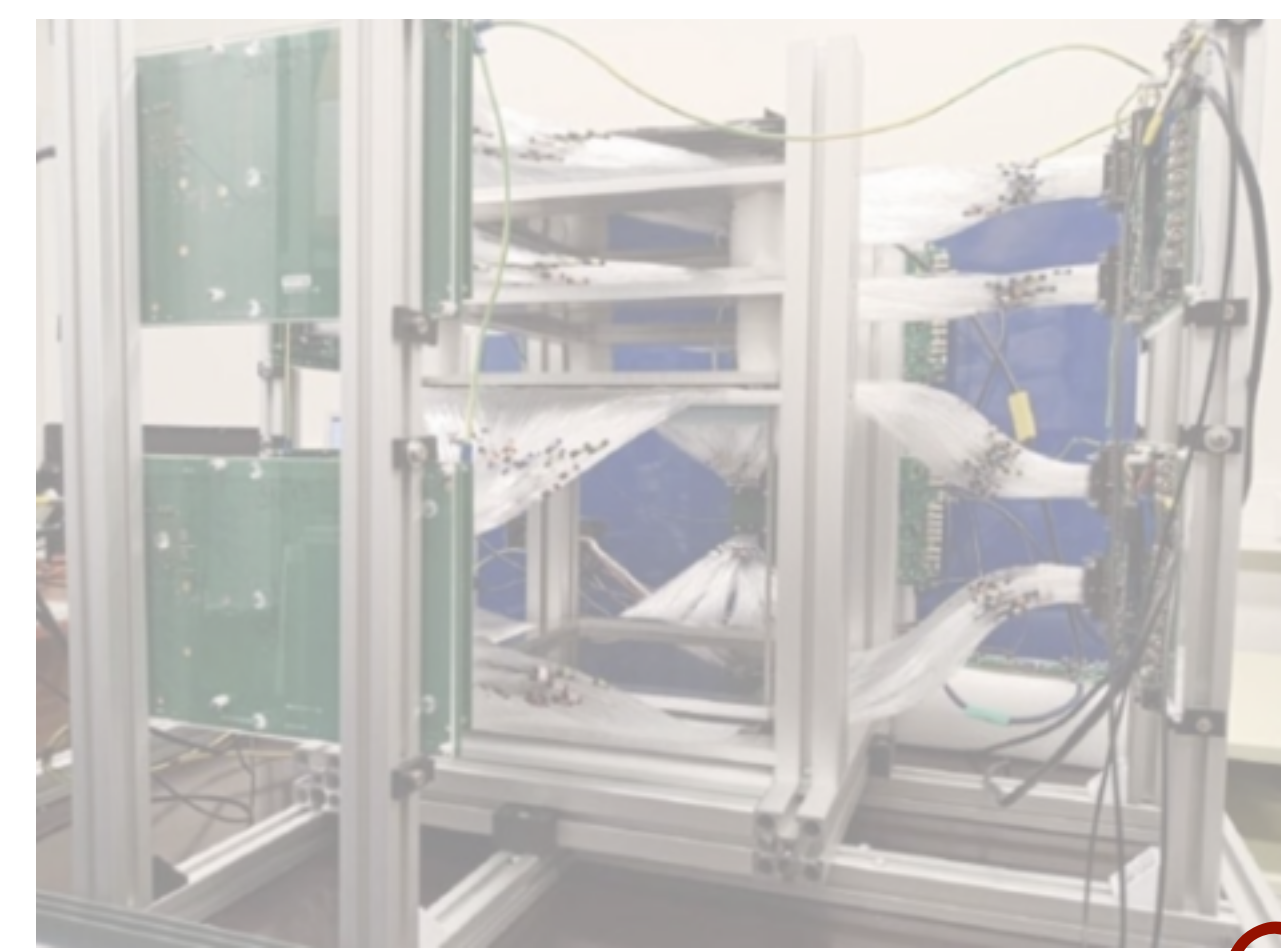
(SOME) MUON TOMOGRAPHY DEMONSTRATORS



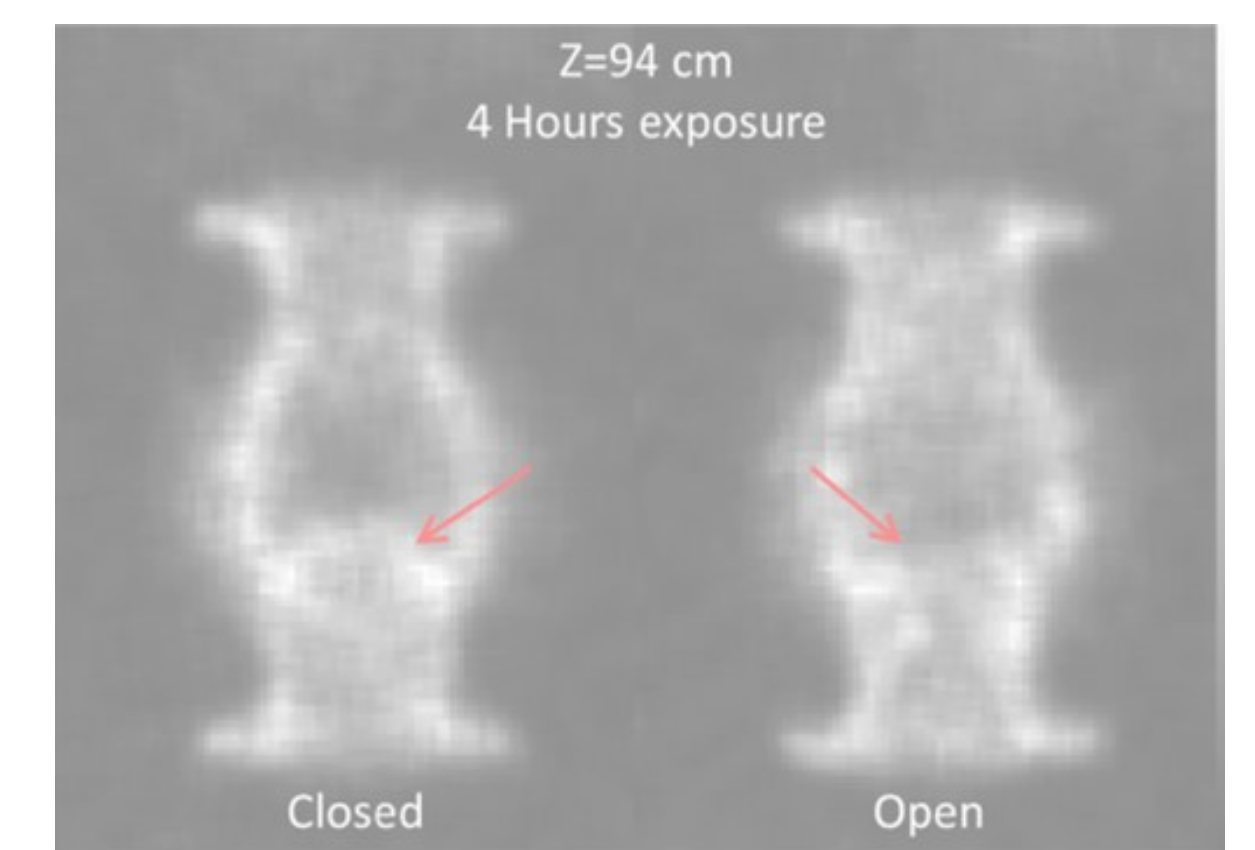
Concrete: $X_0 = 11.6$ cm
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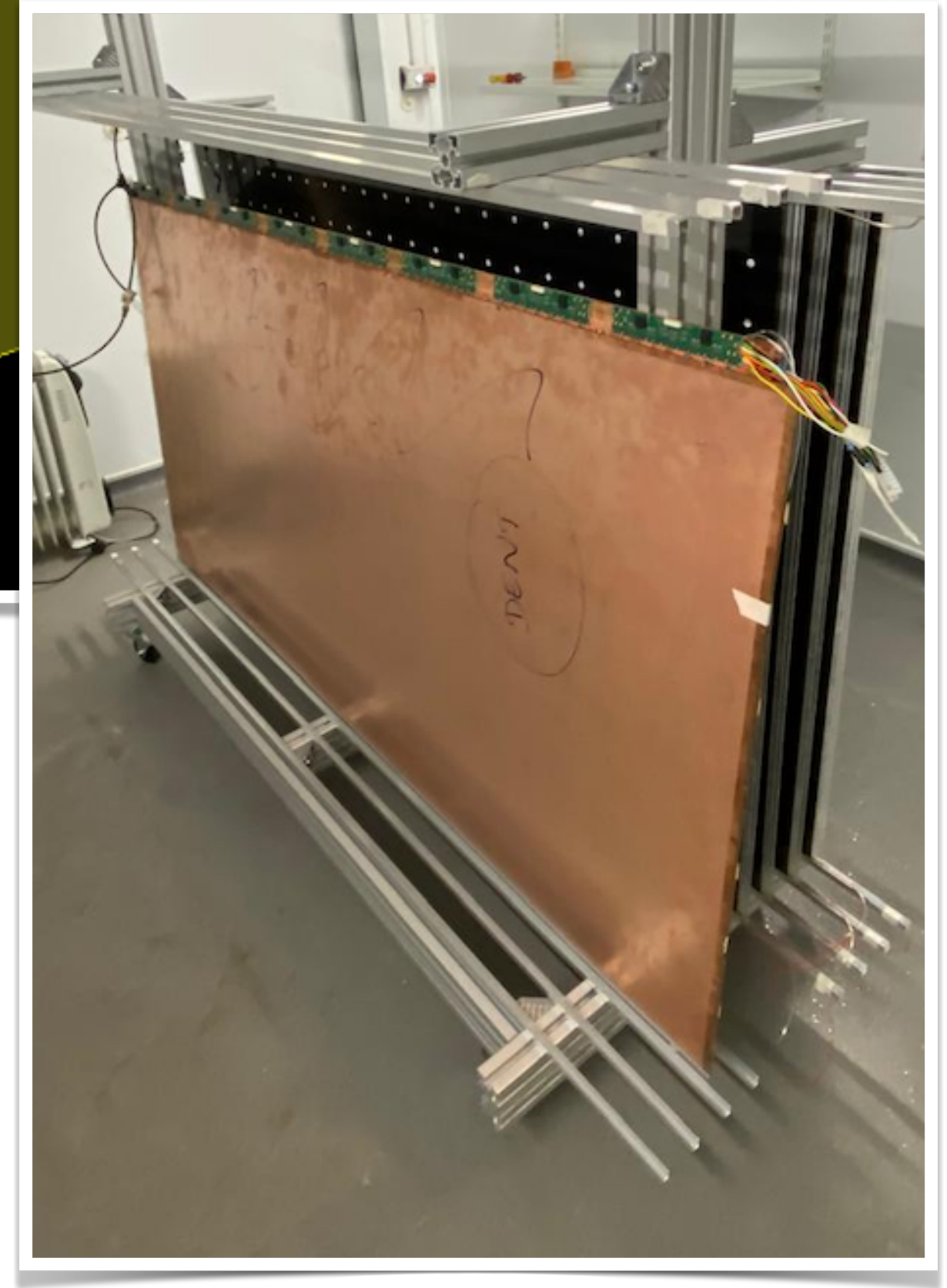
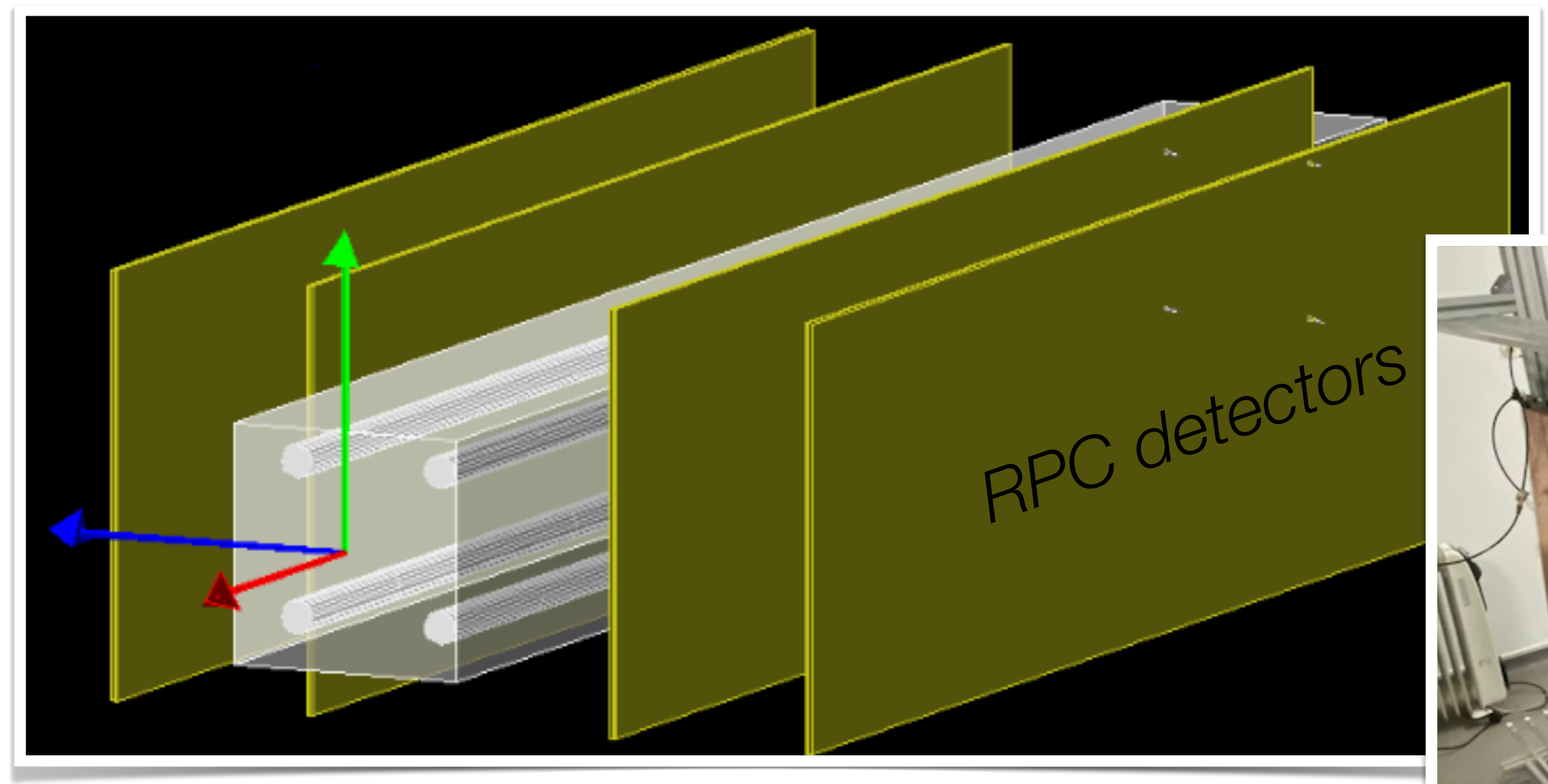
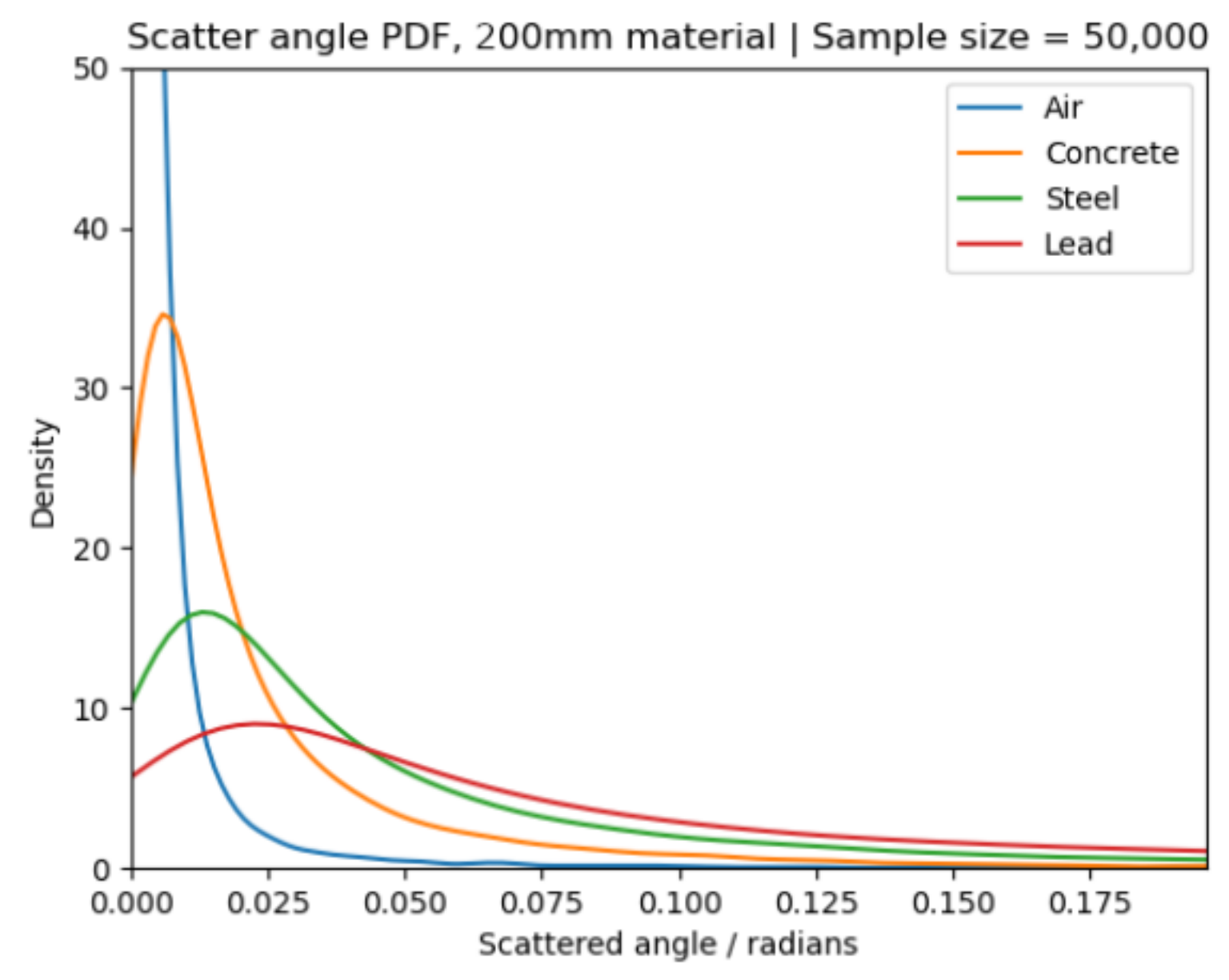
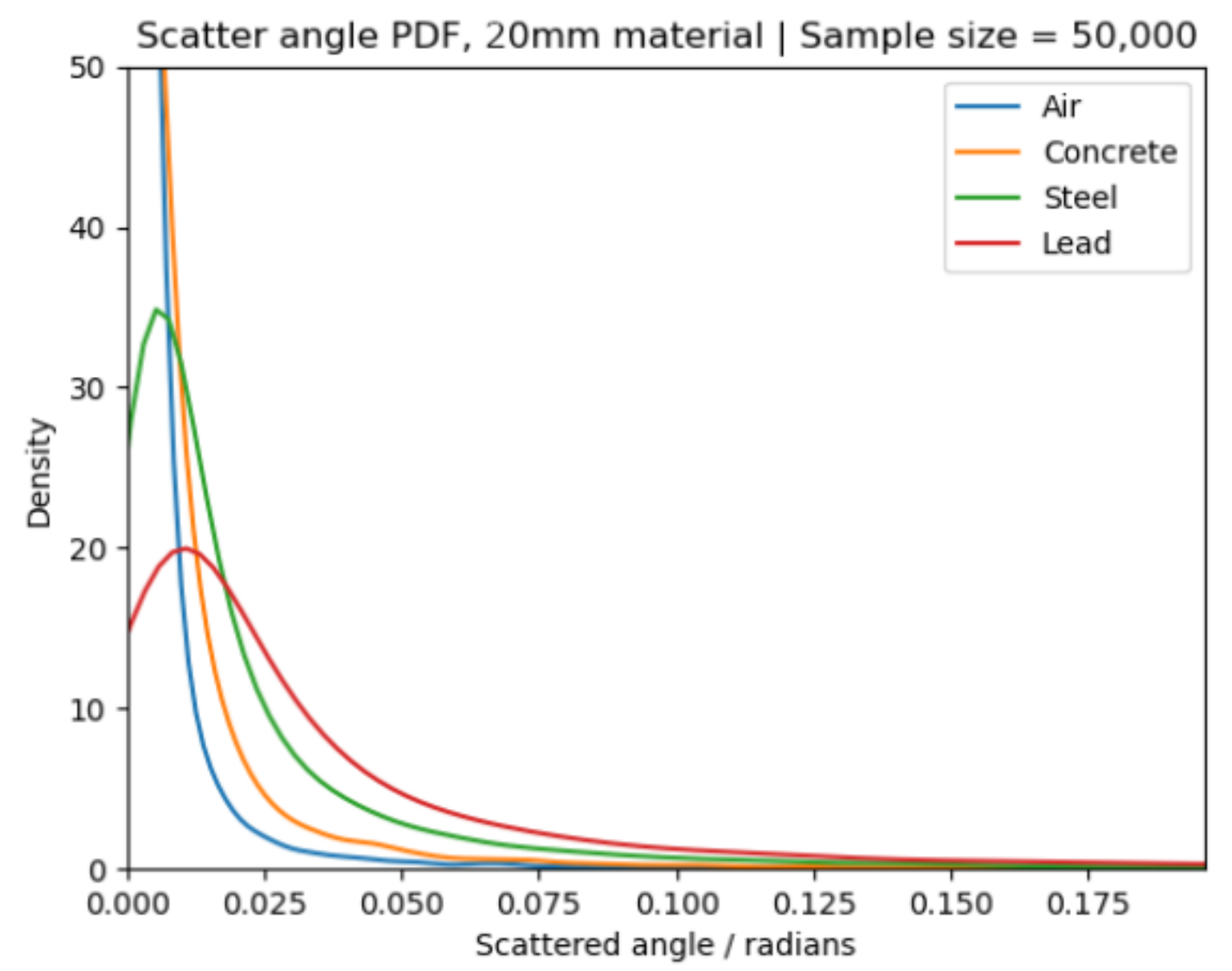


AIP Adv. 2015, 5, 067111, [LINK](#)

MUON SCATTERING TOMOGRAPHY FOR REINFORCED CONCRETE

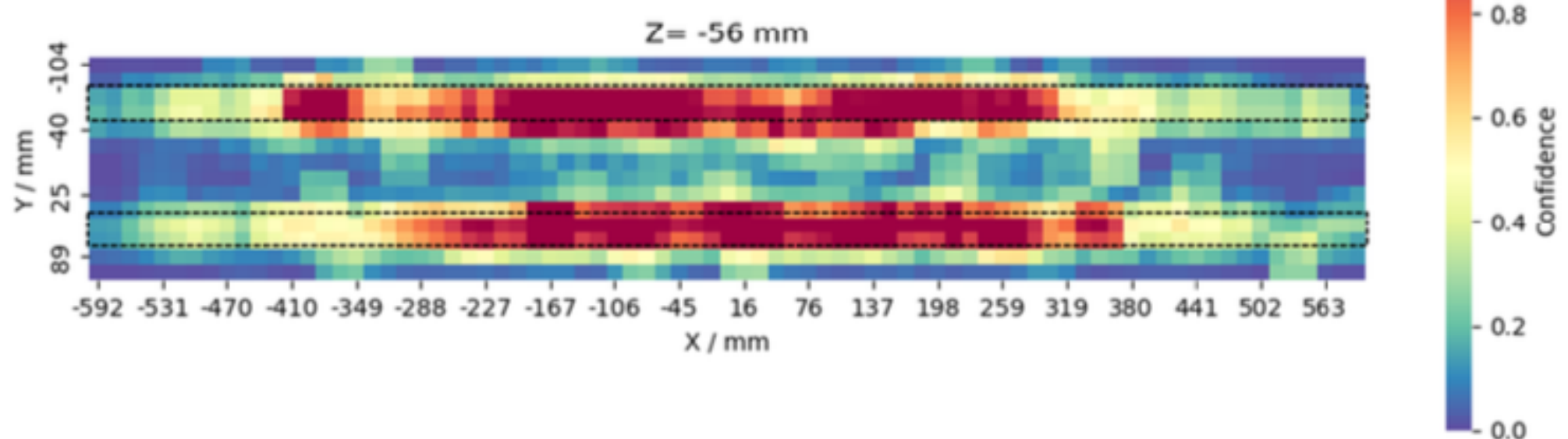


Antony Swan, Master project 2023, [LINK](#)
(supervised by Jon Burr, OB)

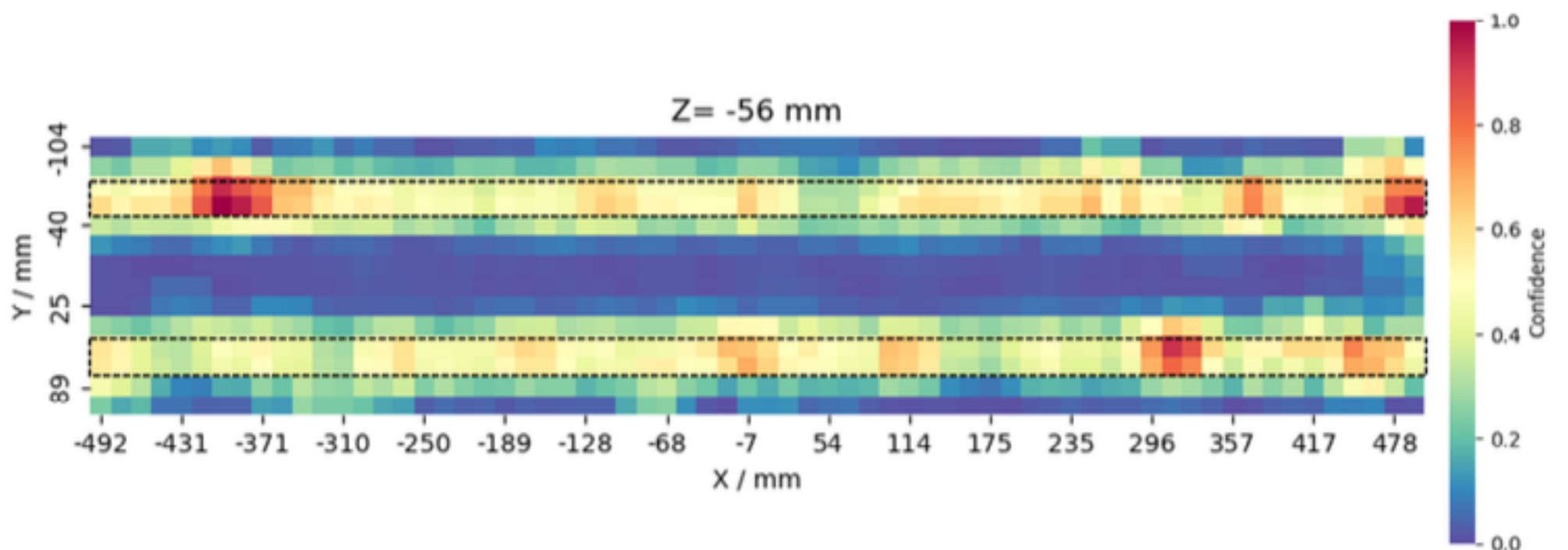




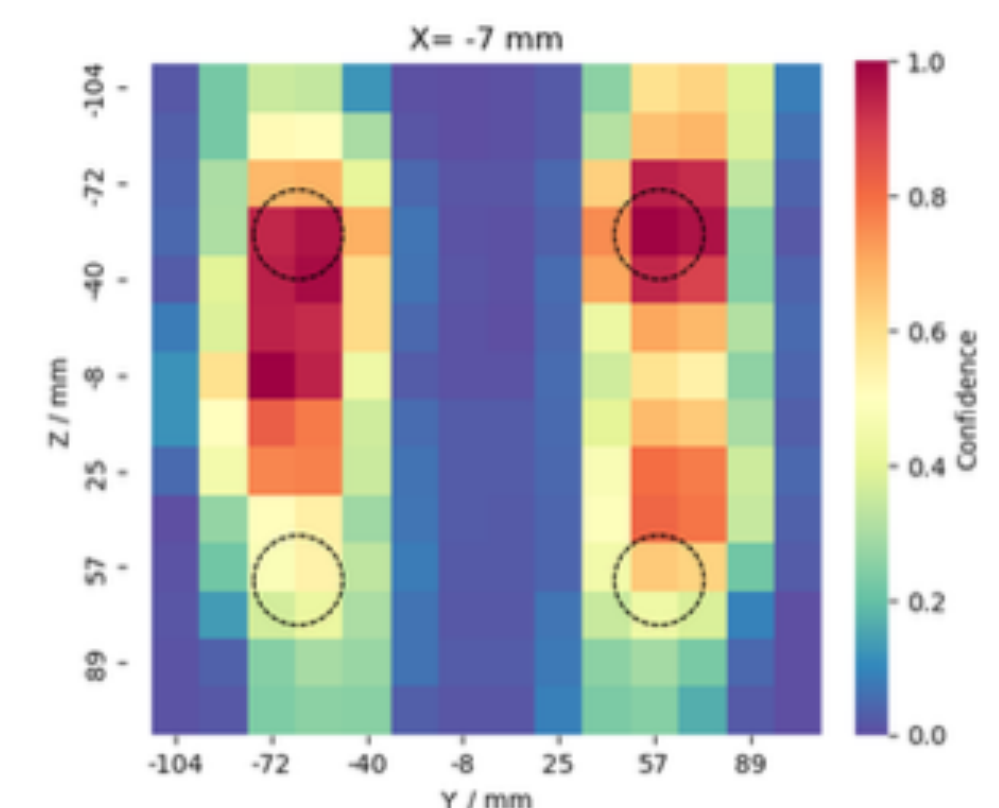
Antony Swan, Master project 2023, [LINK](#)
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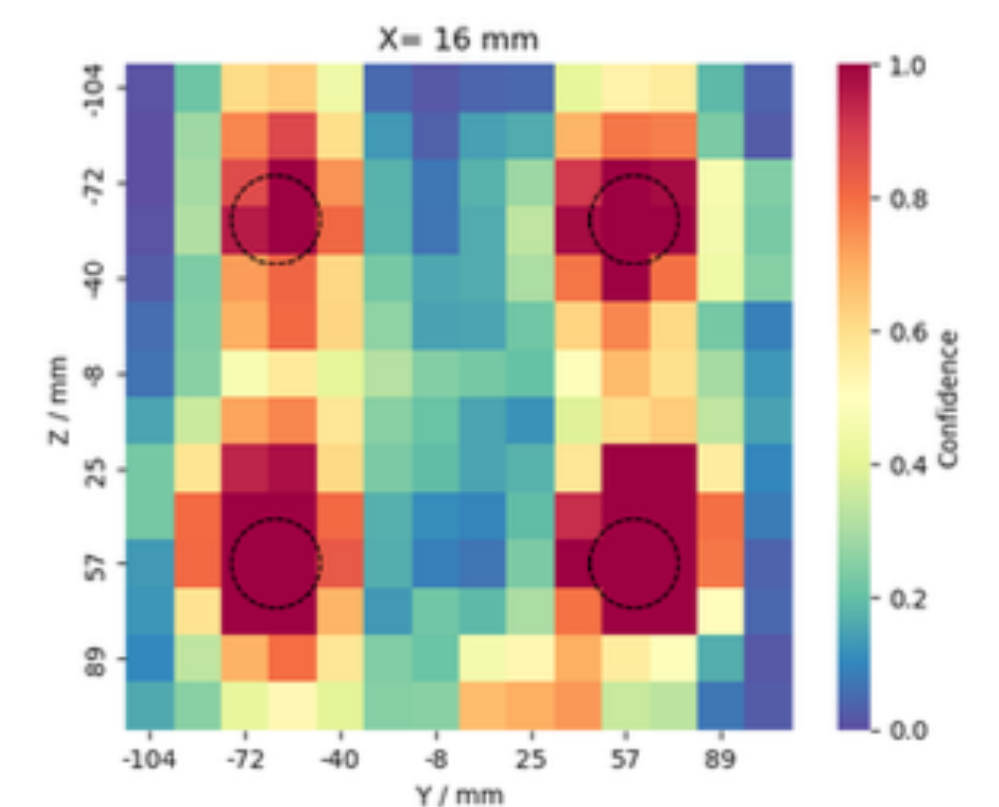
(b) PoCA Summing momentum weighted, XY Cross-section at $Z = -56\text{mm}$, after limiting highest voxel values to the 0.9th quantile



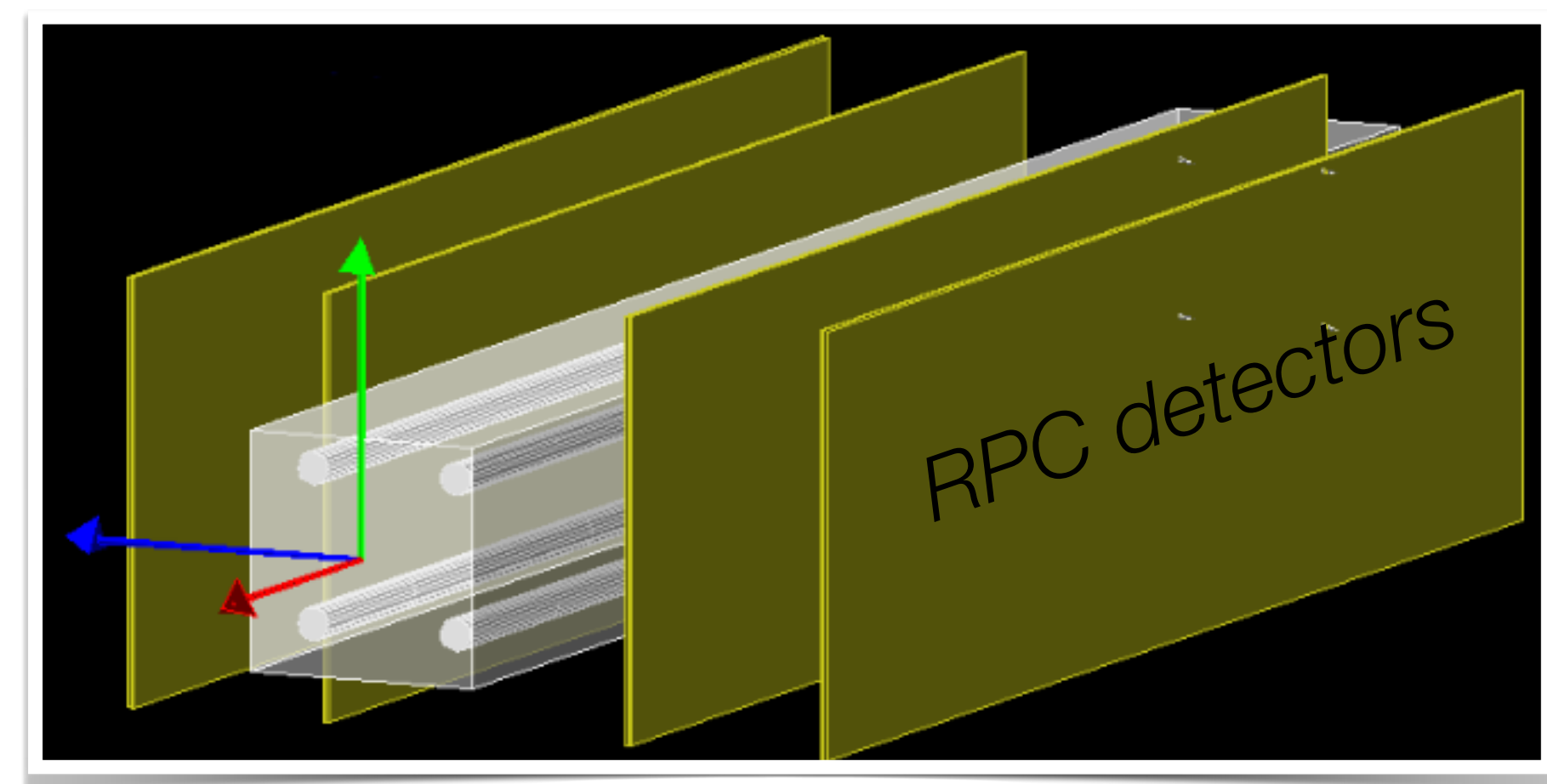
(d) Binned clustering algorithm, XY Cross-section at $Z = -56\text{mm}$, after limiting highest voxel values to the 0.9th quantile



(a) Binned clustering algorithm, ZY Cross-section at $X = -7\text{mm}$, after limiting highest voxel values to the 0.9th quantile.

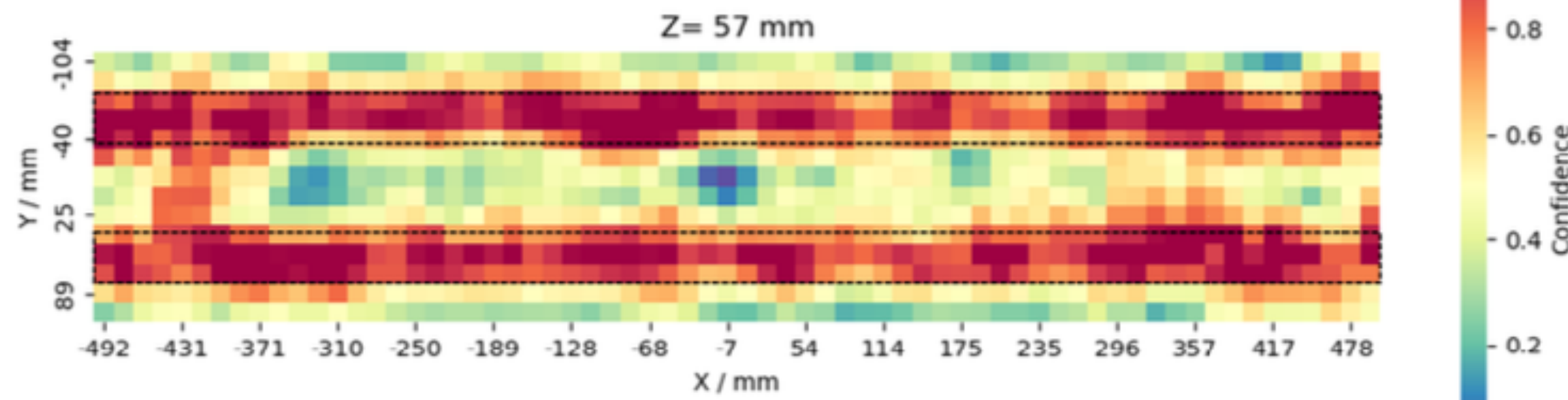


(b) PoCA Summing momentum weighted, ZY Cross-section at $X = 16\text{mm}$, after limiting highest voxel values to the 0.9th quantile.

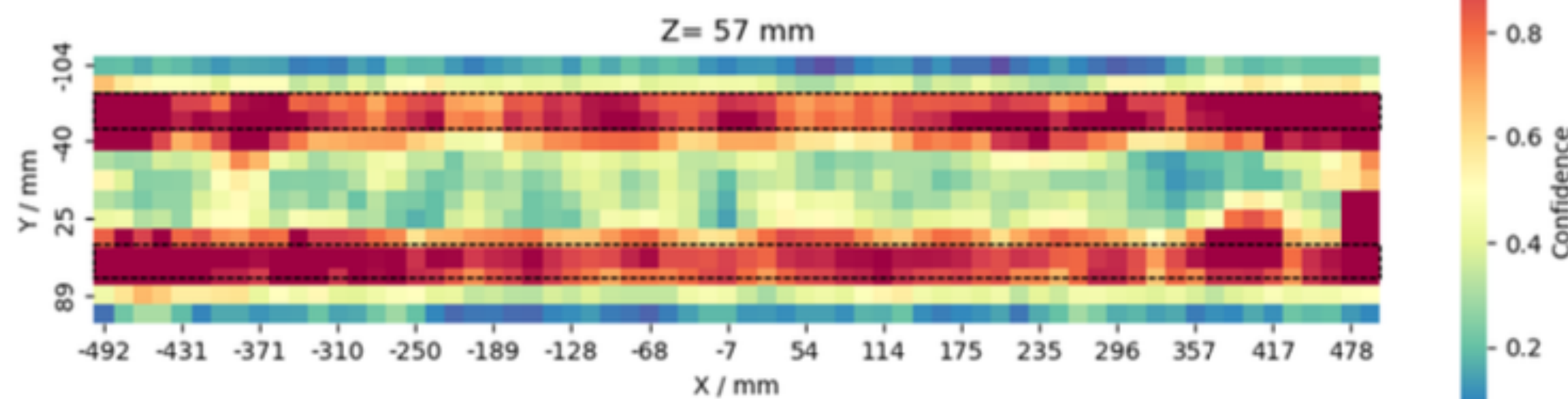




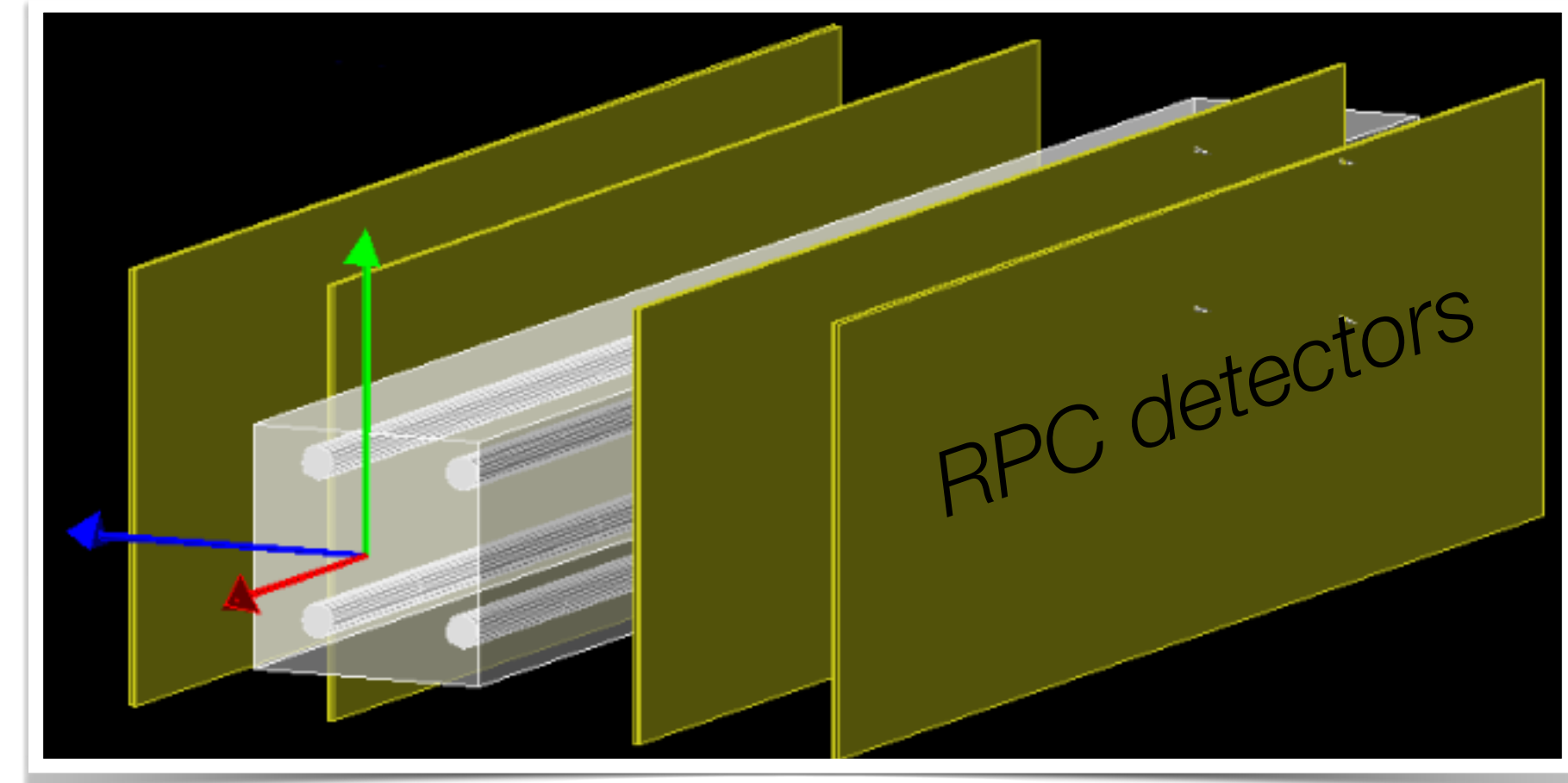
Antony Swan, Master project 2023, [LINK](#)
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(a) Corroded rebar



(b) Not corroded rebar





Interconnecting
steel rebar missing!





- A lot of work on Muon Scattering Tomography around the globe
- Focus on Nuclear Security Applications so far
 - Easier (higher Z contrast, more funding)
 - Stationary
- Our focus on reinforced concrete
 - More challenging (lower Z contrast)
 - Ageing / corrosion even more challenging
 - Construction faults “easy”
 - Historic secrets (treasure chests?!) exciting...
 - Portable
 - But many positives:
 - Gigantic market
 - Gigantic potential to reduce human CO₂ footprint!
 - Non-destructive
 - No radiation concerns
 - Semi-commercial partners exist →
- Stay Tuned





Thank you!



