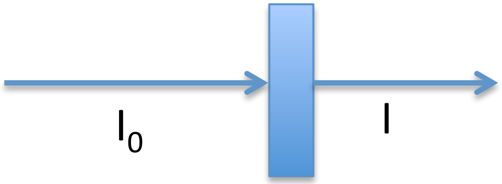
Quantitative measurement of Boron-10 using TOF transmission

Or - How the most boring neutron experiment you could imagine became interesting...

R. Cubitt & C. Boudou

Neutron Transmission of Absorbing Material



Transmission $I/I_0 = \exp(-\lambda L/(\lambda^* L^*))$

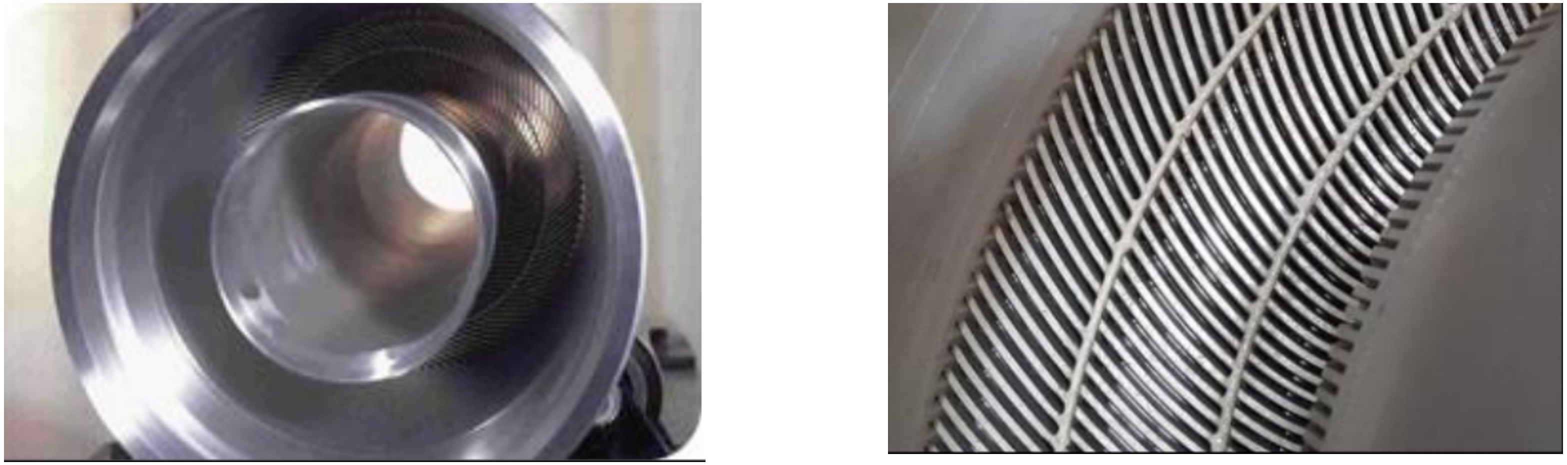
where λ = neutron wavelength
λ^* = thermal neutron wavelength at 2200 m/s
L = sample thickness
L = neutron absorption length$=1/n\sigma$
n = number density of absorbing atoms
σ = absorption cross section at λ^*

for boron 10 Transmission = $\exp(-A\lambda/7.79604)$

where A = surface density of B^{10} (mg/cm^2)

Just measure the transmission vs wavelength
and the gradient is a measure of the density of absorbing material

ILL Fuel element Boral Al/B^{10}



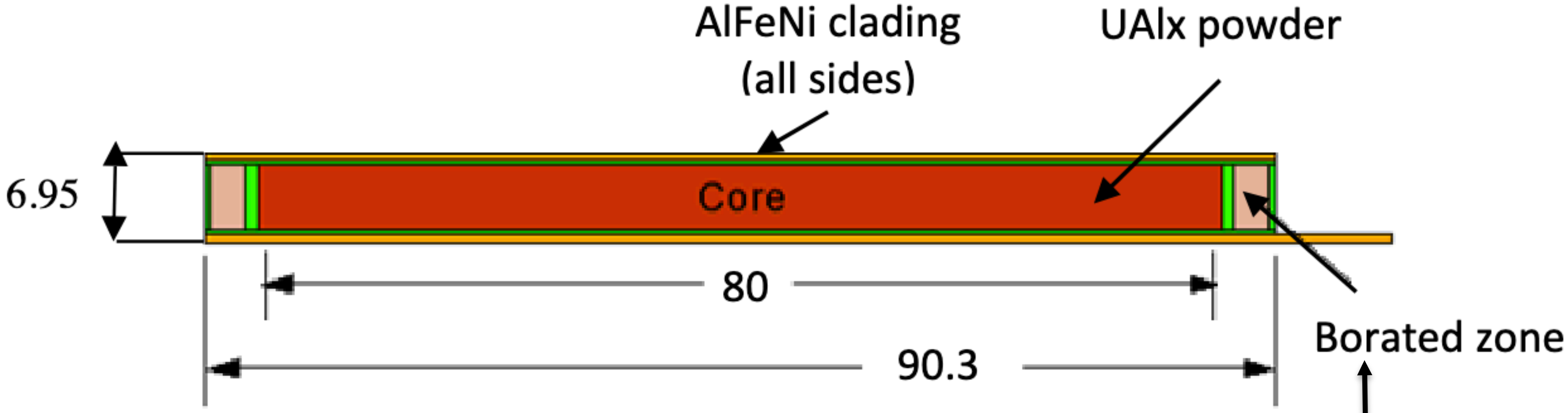
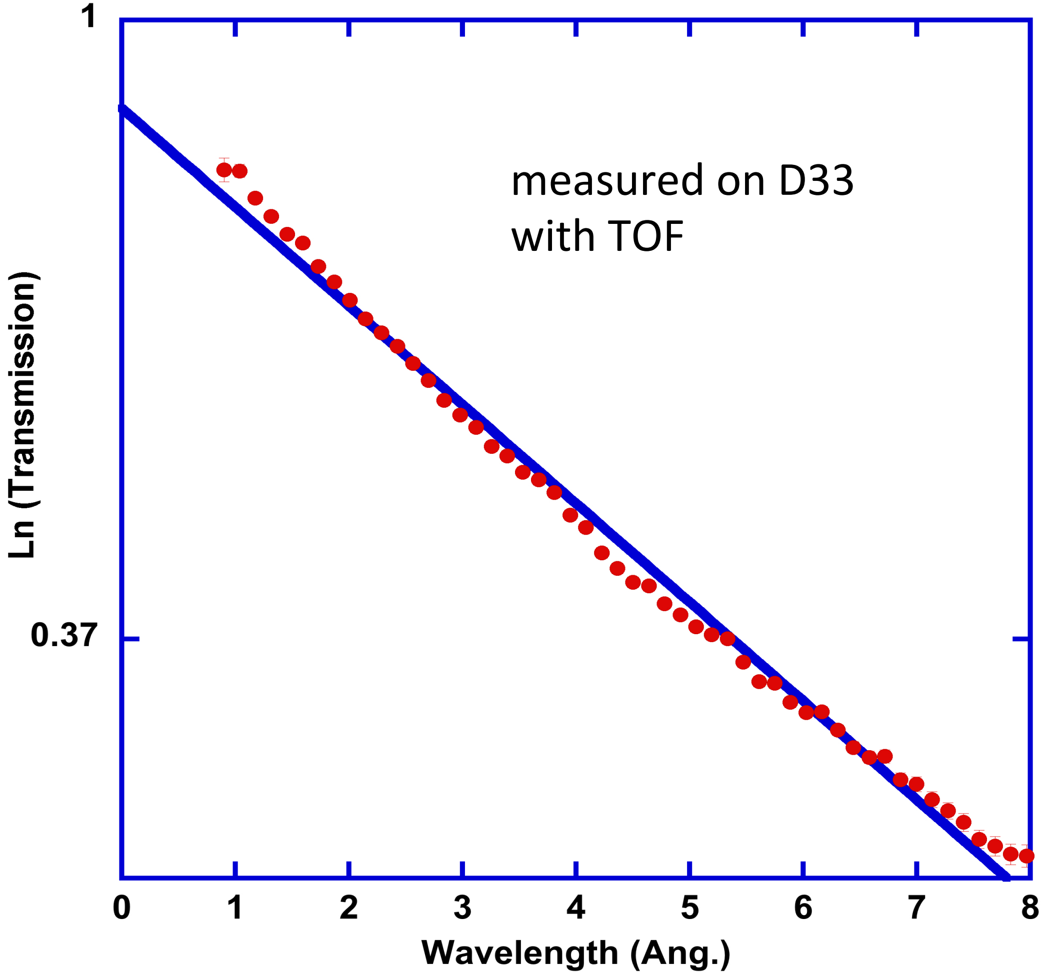


Figure 5: Top view of the fuel plate dimensions (in cm)

Inspection of material at ILL during the manufacturing process

The Problem



measured on D33
with TOF

scattering?

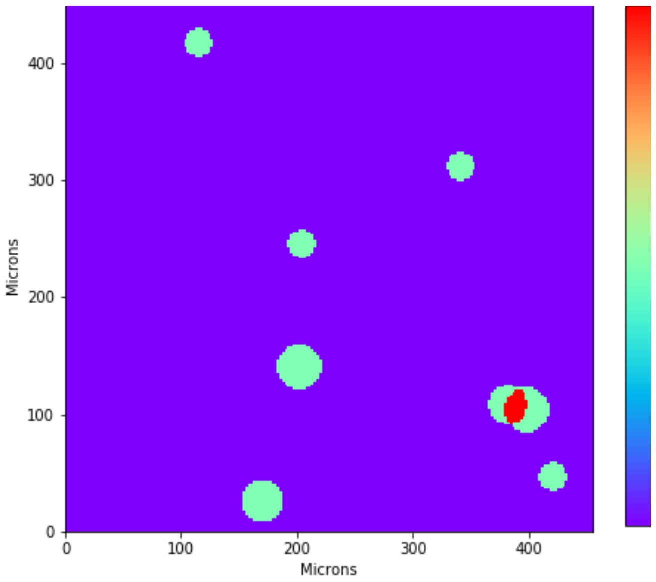
calibration?

reference for
direct beam?

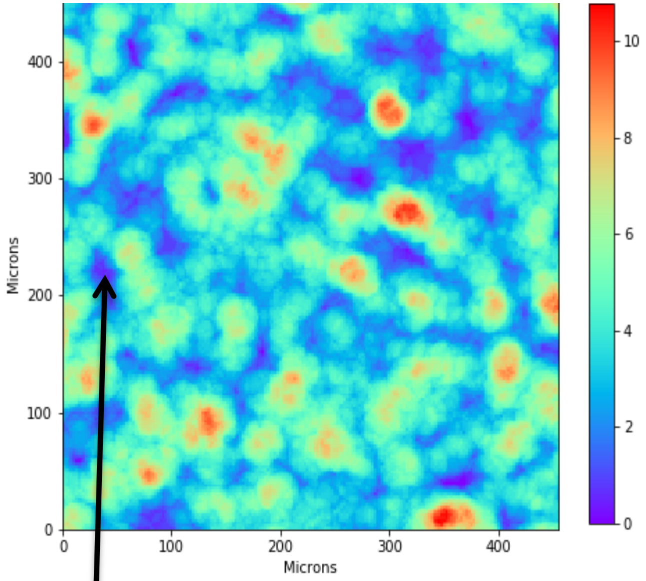
incorrect model?

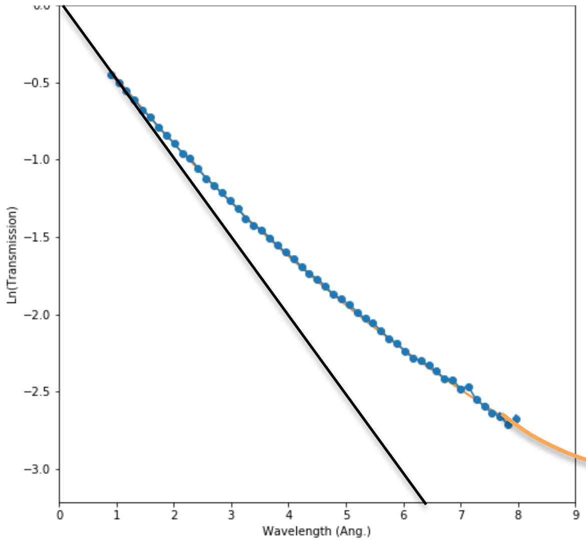
gradient variation corresponds to a large variation of surface density
exponential fit does not have T = 1 at λ = 0 which is unphysical

Modeling with a finite particle size



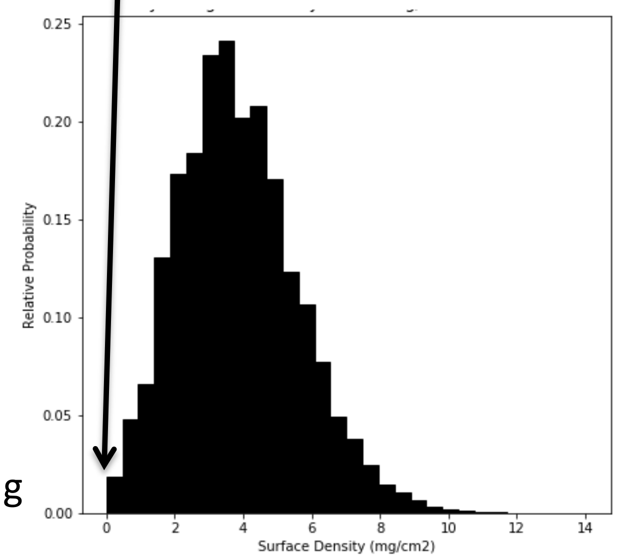
4mg/cm^3 B^{10}
20µm particles



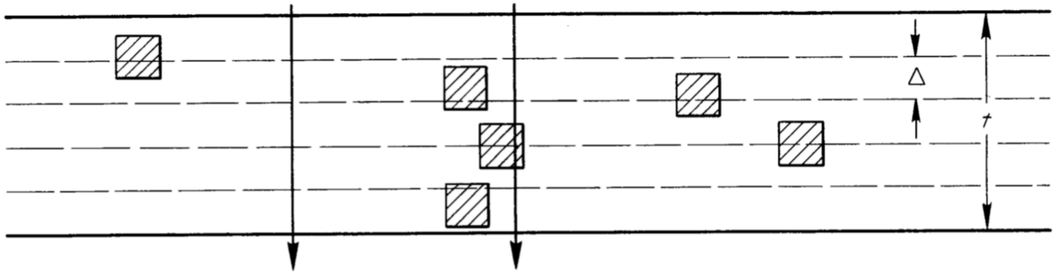


λ➔∞

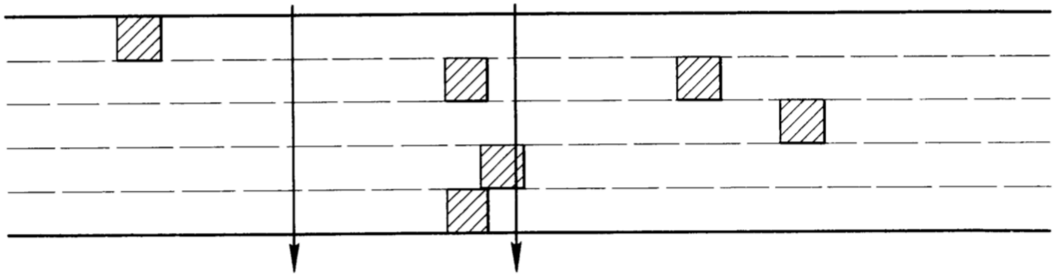
projected
non-absorbing
fraction



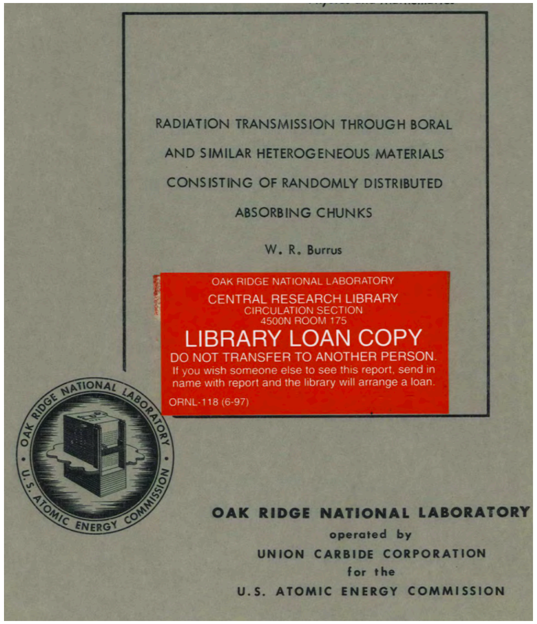
The Burrus Model



UNDIVIDED SLAB



SLAB DIVIDED INTO FIVE SUBLAYERS



RADIATION TRANSMISSION THROUGH BORAL
AND SIMILAR HETEROGENEOUS MATERIALS
CONSISTING OF RANDOMLY DISTRIBUTED
ABSORBING CHUNKS

W. R. Burrus

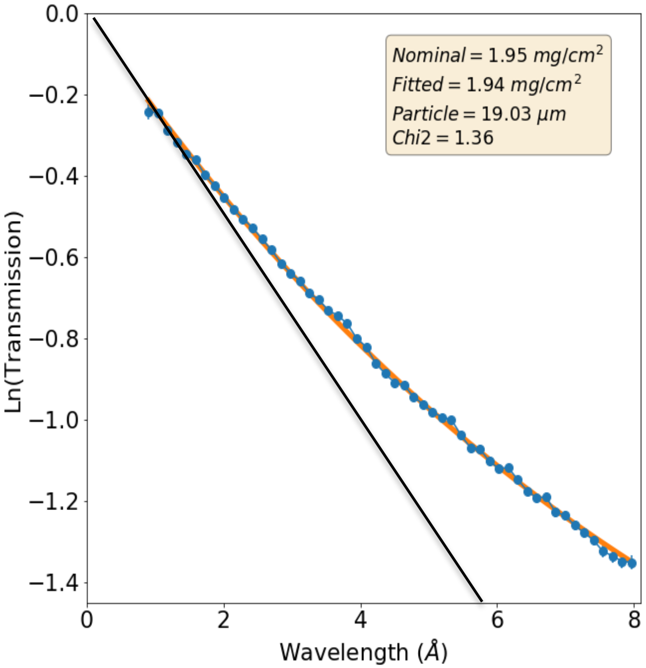
OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

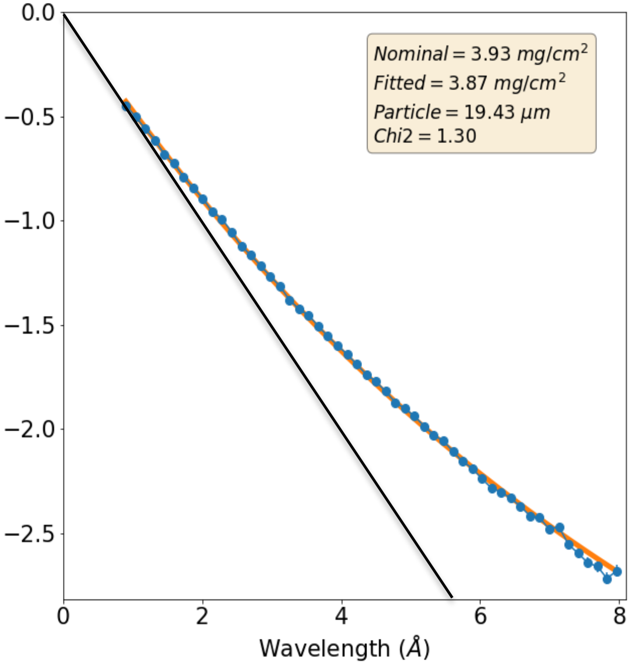
Transmission for N layers = $[V\exp(-\Sigma\Delta)+1-V]^N$

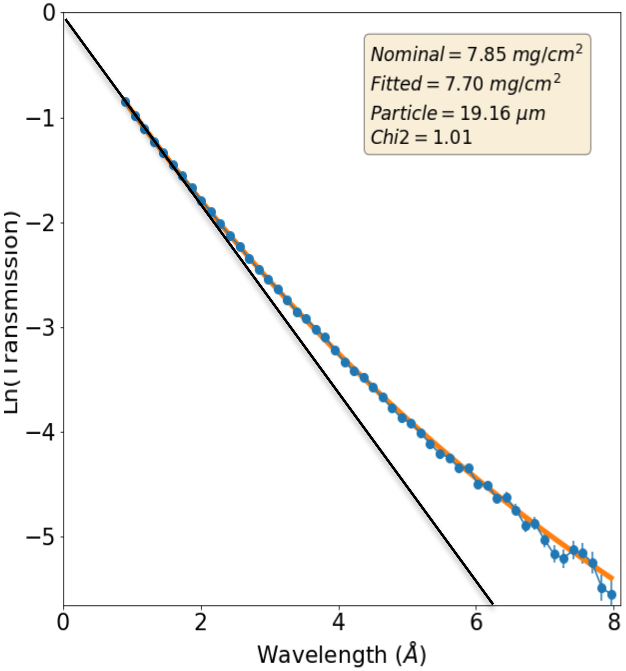
Σ is the total absorption cross section of the absorbing particle
V is the probability of encountering a single particle of size Δ in a layer Δ thick $V=A/(t\rho)$
A is the area density of absorbing particles
ρ is the B^{10} density within a single particle
Δ is the particle size
Number of layers $N=t/\Delta$

A. Machiels Neutron Transmission Through Boral TM: *Impact of Channeling on Criticality.* EPRI, Palo Alto, CA: 2005. 1011819

Model fitting







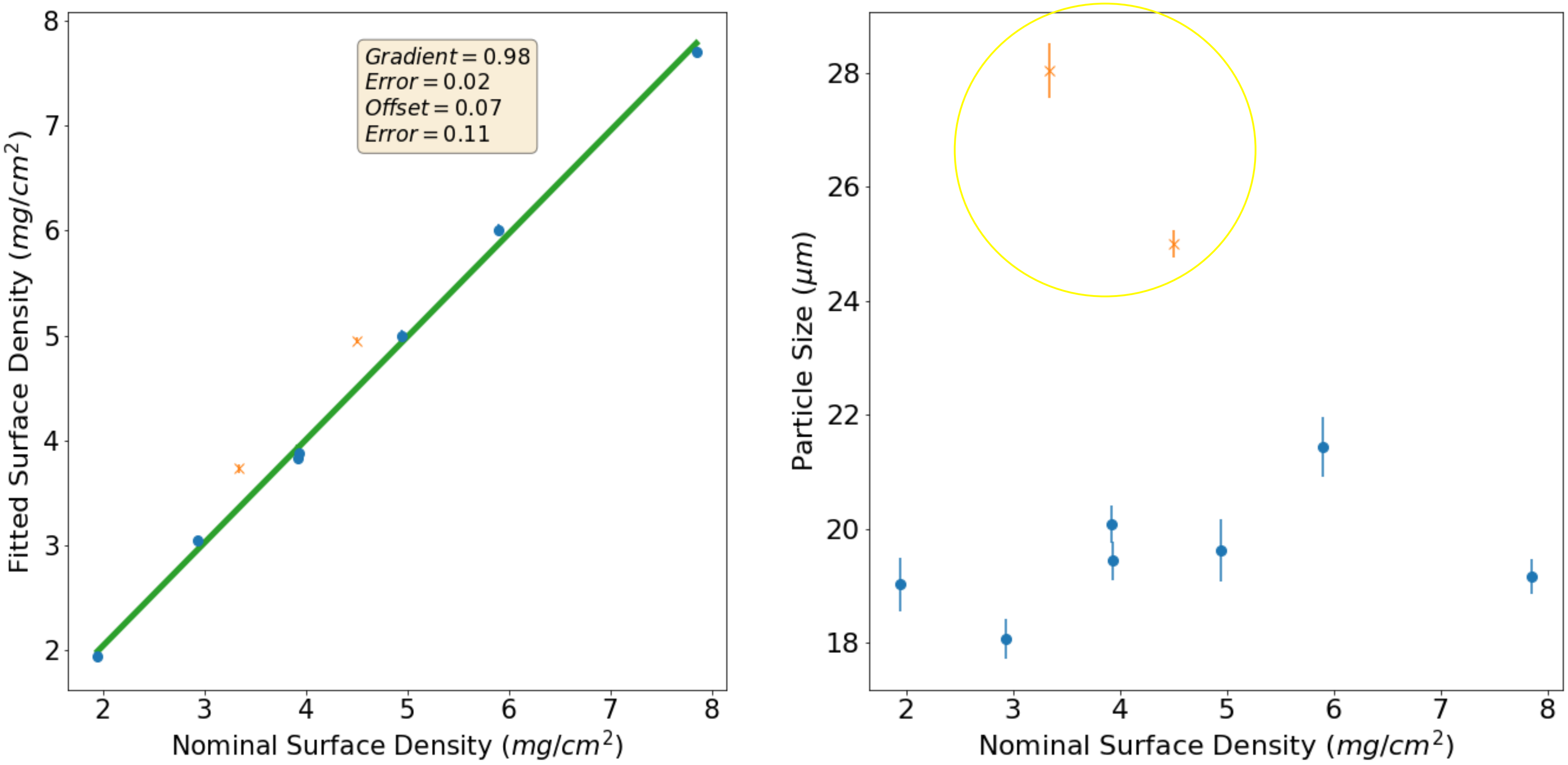
Only 2 unknowns are the area density and particle size

The model naturally has T = 1 at λ = 0

The correct gradient is approached for smaller wavelengths

A monochromatic cold neutron measurement would yield incorrect results

Results from a range of samples



Different batch

Conclusions

With a finite particle size of absorbing material only
a white beam measurement can reveal the true area density

The Burrus method allows not only an accurate measurement of
the area density but the particle size too

Take care with a radiograph of material like this as the variation
in transmission may NOT be a measure of inhomogeneity

Possible applications in soft matter..

We work towards this method becoming a standard operation procedure
(SOP)

Sample Name	Nominal Area Density, D (mg/cm^2)	Measured Area Density, D (mg/cm^2)	Particle size Δ (microns)
3.2	0.0000	0.005(5)	-
4.2	1.9500	1.94(1)	19.0(5)
5.2	2.9300	3.05(1)	18.1(4)
6.2	3.9300	3.88(1)	19.4(3)
7.2	3.9200	3.83(1)	20.1(3)
8.2	4.9500	5.00(2)	19.6(5)
9.2	5.9000	6.01(2)	21.4(5)
10.2	7.8500	7.70(1)	19.2(3)
- 15%	3.3400	3.73(1)	28.0(2)
+15%	4.5100	4.95(1)	25.0(2)

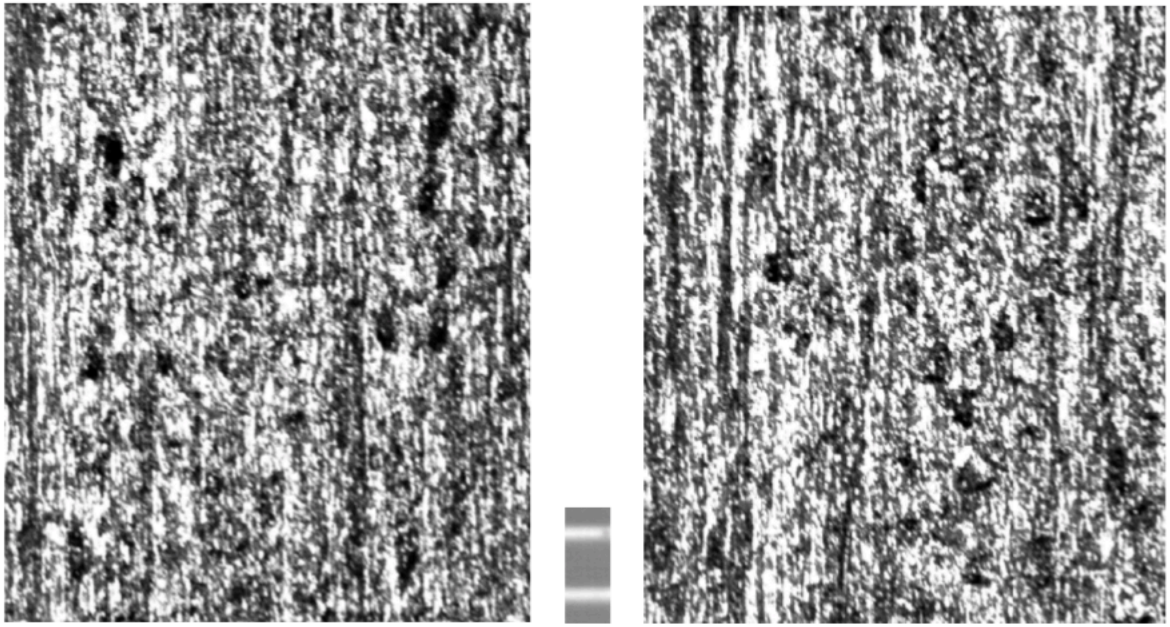


Figure 6. Optical microscopy image of grains (darker areas) which have left the matrix after sanding. The two bars represent 100 microns.