X-Ray Powder Diffraction and Rietveld Analysis with Applications to Cementitious Materials – II

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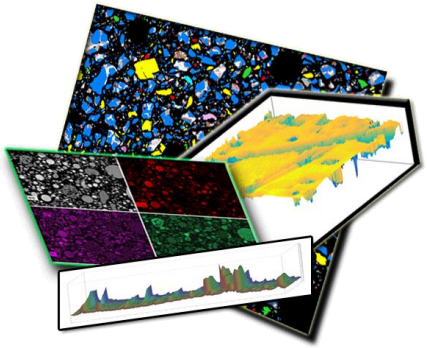

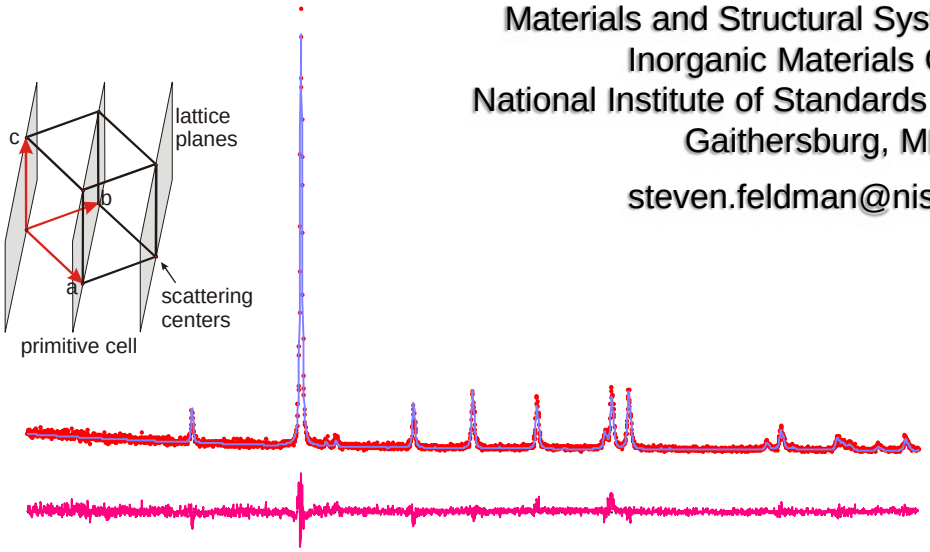

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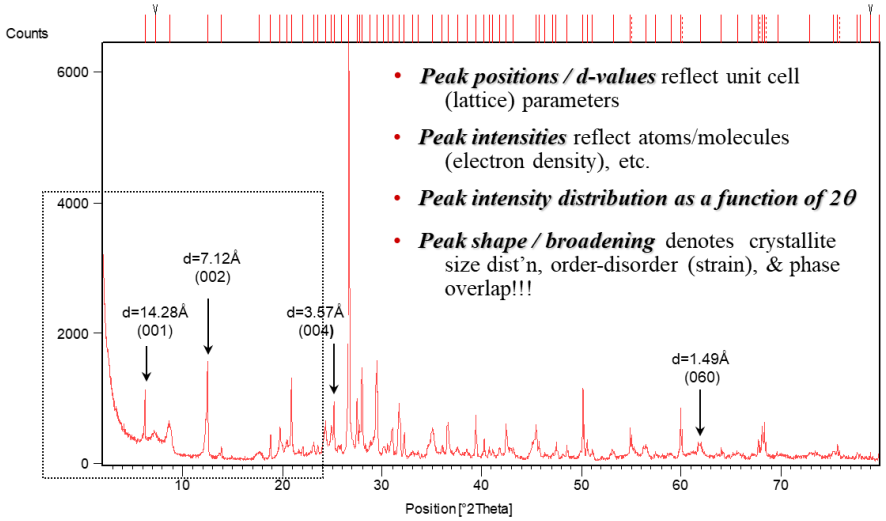
Optimizing Data Collection, and Sources of Error

Data Collection and Minimizing Error

Measurement considerations

Recall: Four parameters of special interest in an XRD Pattern

- ✓ *Position of the diffraction peaks*
- ✓ *Resolution of diffraction peaks*
- ✓ *Peak intensities*
- ✓ *Intensity distribution as a function of 2θ angle*



This requires accurate representation of the inherent scattering from the crystal lattices of all crystallites and phases present.

Data Collection and Minimizing Error

Measurement considerations

What is the optimum instrument configuration?

- ✓ choice of x-ray tube
- ✓ incident and diffracted beam optics
- ✓ low- or high-resolution

Collect data appropriate to the task at hand:

- ✓ qualitative or quantitative phase analysis
- ✓ unit cell determination / indexing
- ✓ solution of an unknown crystal structure
- ✓ refinement of a partially known structure

Data Collection and Minimizing Error

Sources of Error

- Measurement-dependent:
  - ✓ Resolution / step size
  - ✓ Counting statistics
- Specimen-dependent:
  - ✓ Particle-size and statistics
  - ✓ Preferred orientation
  - ✓ Absorption effects
  - ✓ Sample displacement
  - ✓ Phase composition (noncrystalline present?)
- Instrument-dependent
- Sample preparation (Paul S.)

Data Collection and Minimizing Error

Measurement considerations

What angular range must be covered?

- ✓ most intense lines of all phases should be measured

What step size must be used?

- ✓ step size ≈ FWHM / 5 (minimum)

What count time should be used?

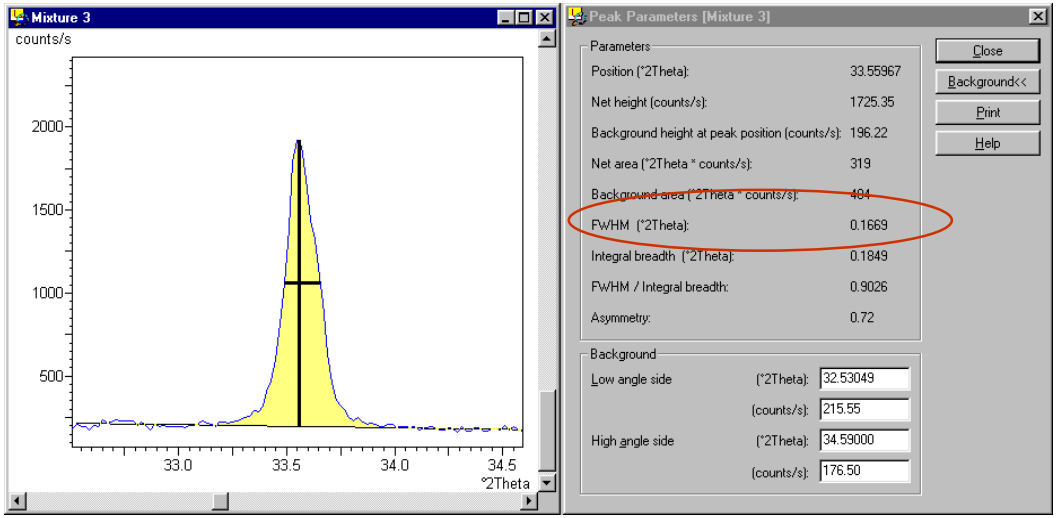
- ✓ ~10000+ counts in the main peak(s)

Data Collection and Minimizing Error

Measurement considerations

Data Collection: Step size example

Peak is 0.167°
(~0.2°) FWHM



@ 0.02° step-1 = 10 steps across peak (above FWHM)

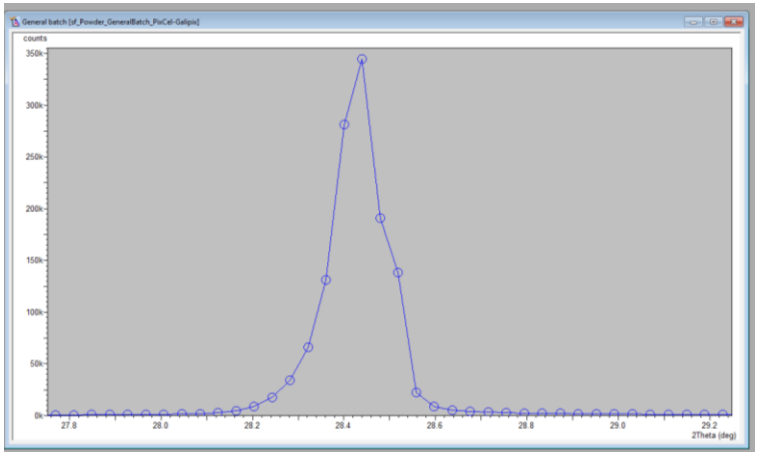
@ 0.03° step-1 = 7 steps across peak (above FWHM)

@ 0.04° step-1 = 5 steps across peak (above FWHM)

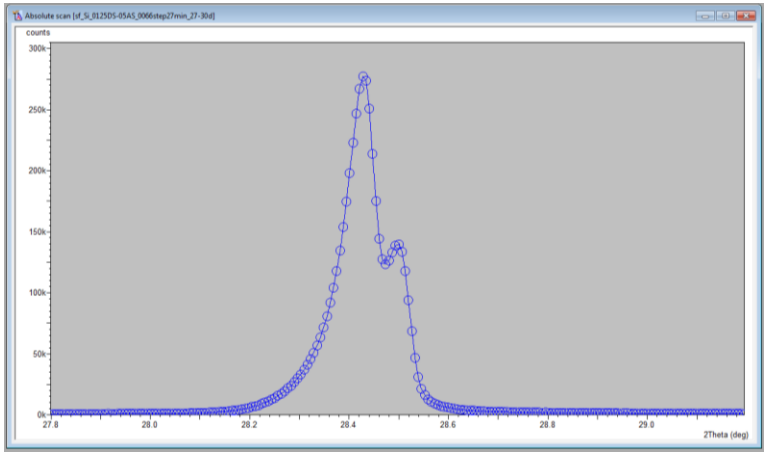
Data Collection and Minimizing Error

Measurement considerations

Data Collection: Step size example (FWHM = 0.167°2θ)



@ 0.04° step^{-1} = 4 steps across peak (above FWHM)

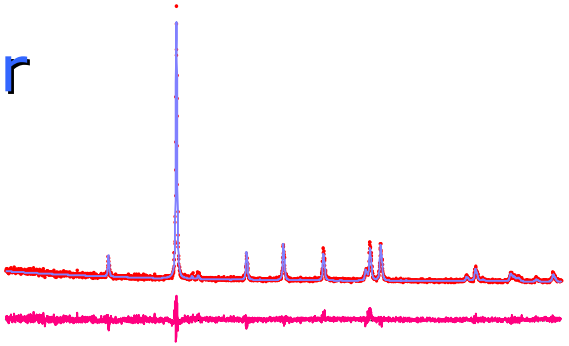


0.015° step^{-1} = 10 steps across peak (above FWHM)

Which is better????

Data Collection and Minimizing Error

Measurement considerations



Counting Statistics

The magnitude of statistical counting error depends only on the *total number of counts* received at the detector.

Std. Dev. = $\sqrt{Counts}$

Desired σ (%)	*N Required*
0.2	*250,000*
0.4	*62,500*
0.6	*27,790*
0.8	*15,625*
1.0	*10,000*
1.5	*4,444*
2.0	*2,500*
3.0	*1,111*
4.0	*625*
5.0	*400*

Ex 1: Peak intensity = 100 counts

$\sqrt{100} = 10$ → *Std. Err. = 10 / 100 = 10%*

Ex 2: *Peak intensity = 10000 counts*

$\sqrt{10000} = 100$ → *Std. Err. = 100 / 10000 = 1%*

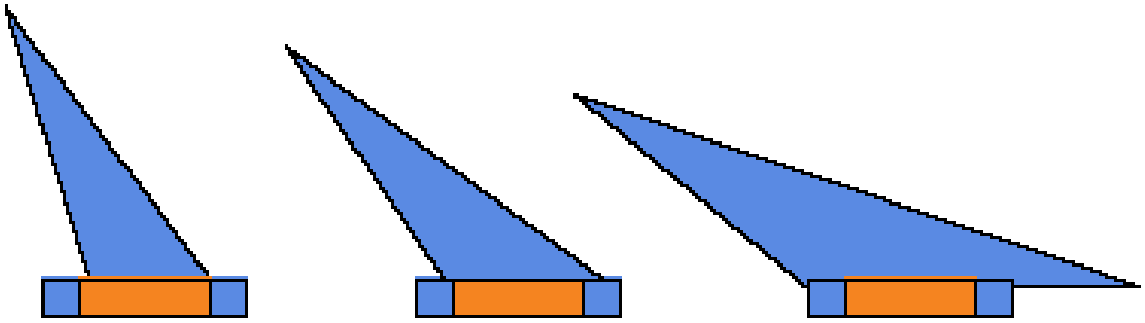
Data Collection and Minimizing Error

Measurement considerations

Sample length and thickness requirements

The sample must be equal to or longer than the spread of the incident beam at the lowest diffraction angle used.

- Make sure that you never over-irradiate the sample at low 2Theta angles…



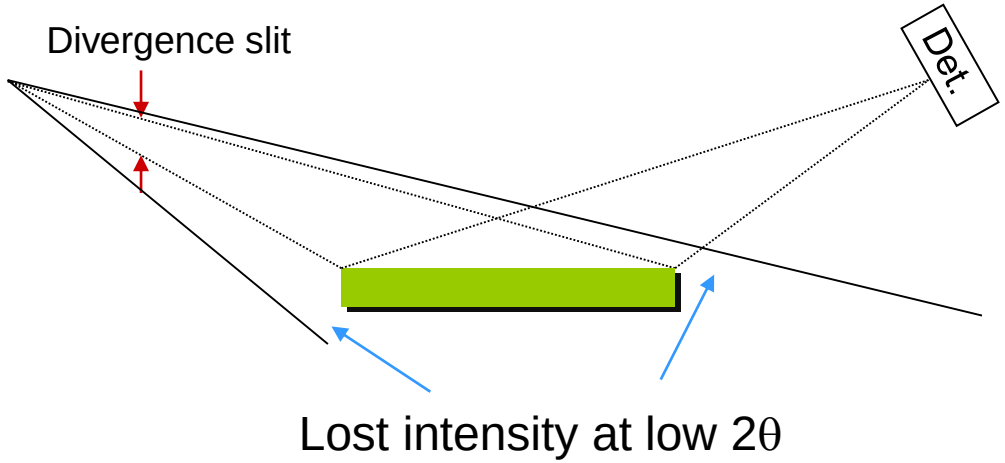
… it will give a very high background!

Data Collection and Minimizing Error

Measurement considerations

Sample length and thickness requirements

The sample must be equal to or longer than the spread of the incident beam at the lowest diffraction angle used.

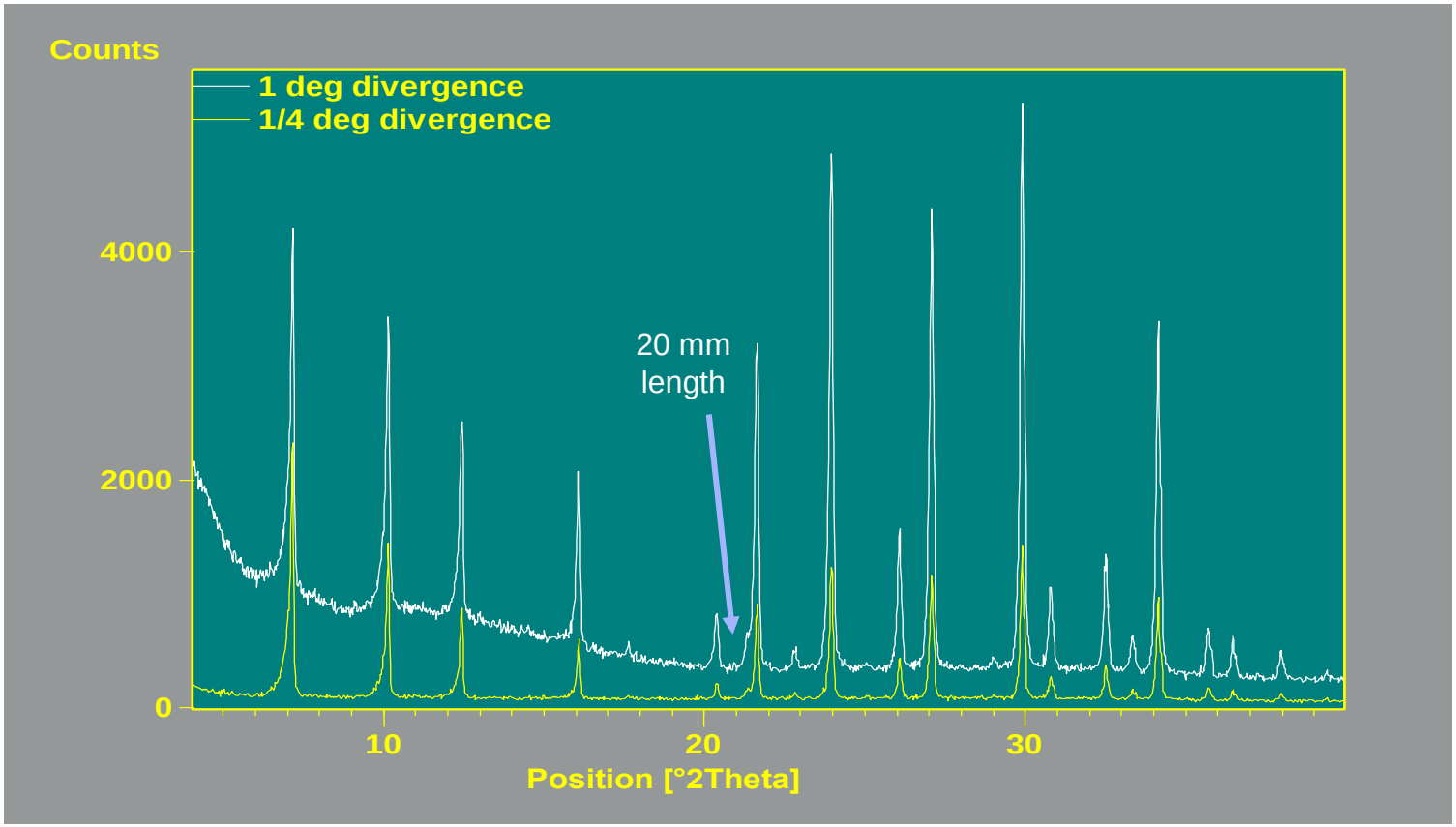


Therefore, select the proper fixed divergence slit

Data Collection and Minimizing Error

Measurement considerations

Divergence slits and peak intensities



Data Collection and Minimizing Error

Measurement considerations

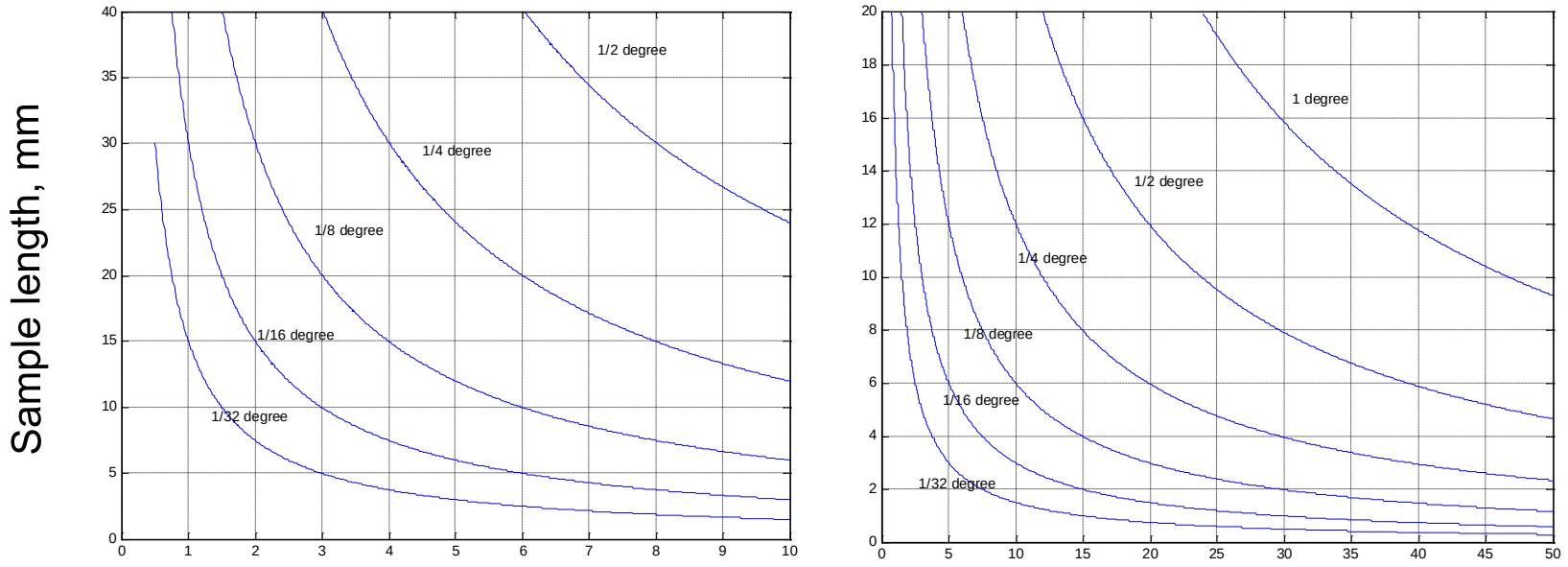
Sample illuminated length as a function of divergence slit and start angle

(240 mm radius goniometer)

Illuminated sample length:

$$L = R_o \tan \alpha / \sin \theta$$

where R_o is the goniometer radius in centimeters, and α is the angular aperture of the divergence slit in degrees.



Data Collection and Minimizing Error

Sources of Error

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  - ✓ Phase composition (noncrystalline present?)
- Instrument-dependent
- Sample preparation (Paul S.)

Data Collection and Minimizing Error

Specimen-dependent considerations

Particle-size, particle statistics, and relative intensities

Intensity Measurements on Different Size Fractions of <325-Mesh Quartz Powder (after Klug and Alexander [1974], p. 366)

Specimen No.	15-50μ Fraction	5-50μ Fraction	5- 15μ Fraction	<5μ Fraction
1	7.612	8.688	10.841	11.055
2	8.373	9.040	11.336	11.040
3	8.255	10.232	11.046	11.386
4	9.333	9.333	11.597	11.212
5	4.823	8.530	11.541	11.460
6	11.123	8.617	11.336	11.260
7	11.051	11.598	11.686	11.241
8	5.773	7.818	11.288	11.428
9	8.527	8.021	11.126	11.406
10	10.255	10.190	10.878	11.444
Mean area	8.513	9.227	11.268	11.293
Mean deviation	1.545	0.929	0.236	0.132
Mean % deviation	18.2	10.1	2.1	1.2

Large particle size (>50μ) can lead to *poor particle statistics* and irreproducible *relative* intensities.

Reproducible intensities from pure quartz powders have been shown to be obtainable with Cu-Kα radiation only when size fractions <15μ were used.

Data Collection and Minimizing Error

Specimen-dependent considerations

Particle-size, particle statistics, and relative intensities

Only with sufficiently small particle-size will the theoretical relative intensity distribution of all diffraction lines from each mineral be present.

- ✓ With only large particles, there is an inadequate representation of all lattice planes, alignments, and orientations.

Data Collection and Minimizing Error

Specimen-dependent considerations

Particle-size, particle statistics, and relative intensities

<325-mesh (47μ) powders may not be sufficiently fine for anything but qualitative measurements.

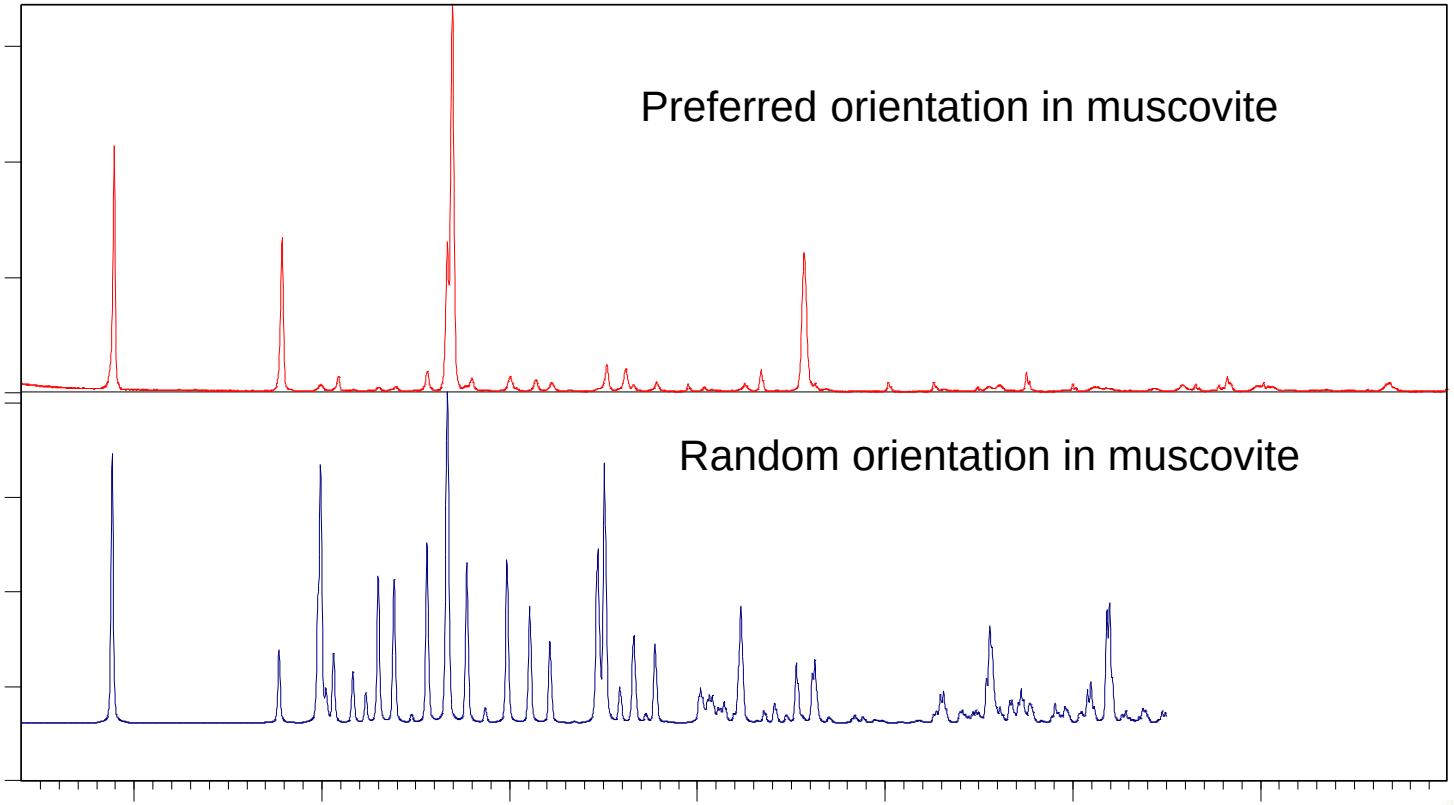
10μ powders are suitable for applications where a few percent error can be tolerated.

- ✓ Micronize important samples, preferably by wet milling.

Data Collection and Minimizing Error

Specimen-dependent considerations

Preferred orientation: intensity artifact



Data Collection and Minimizing Error

Specimen-dependent considerations

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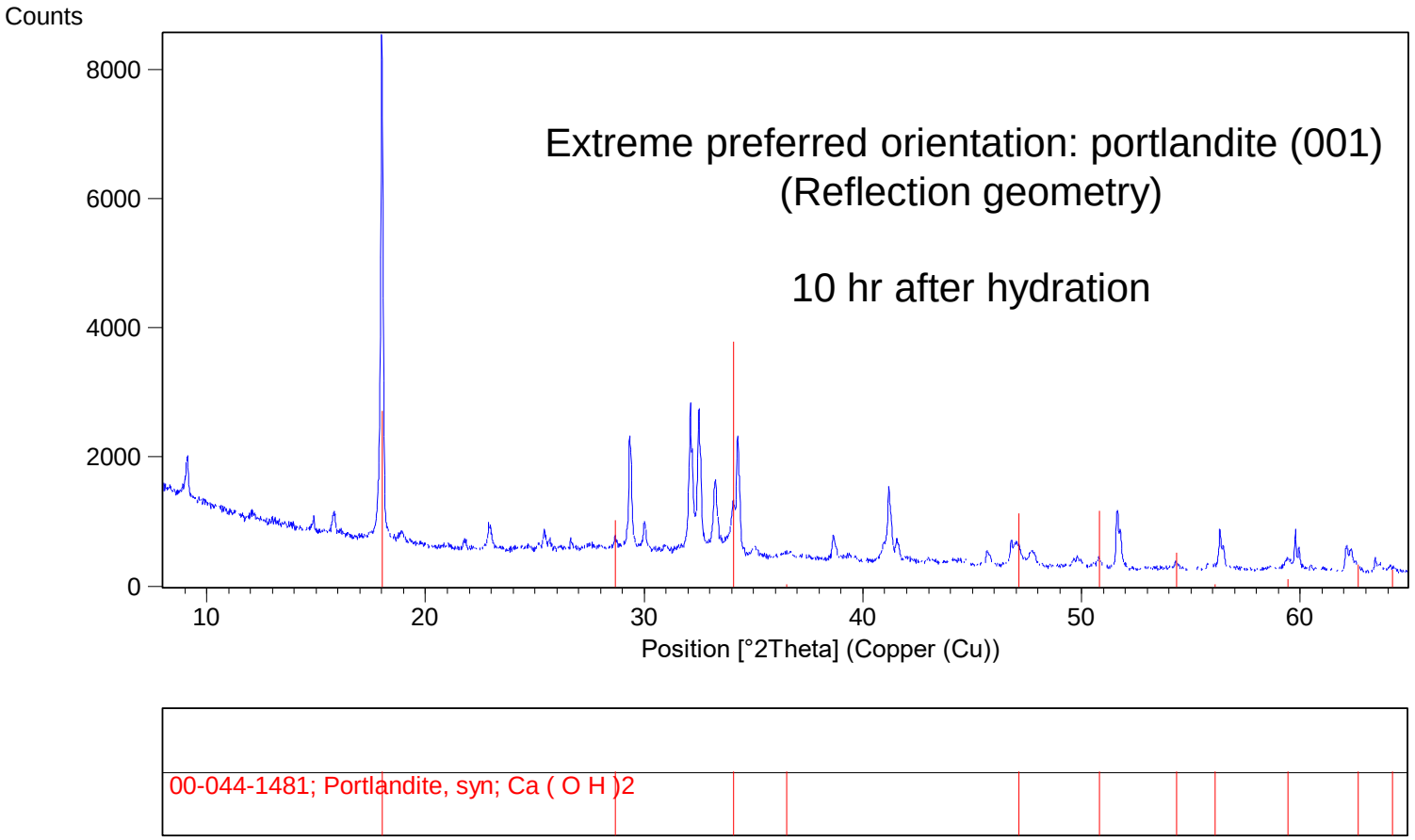

Data Collection and Minimizing Error

Specimen-dependent considerations

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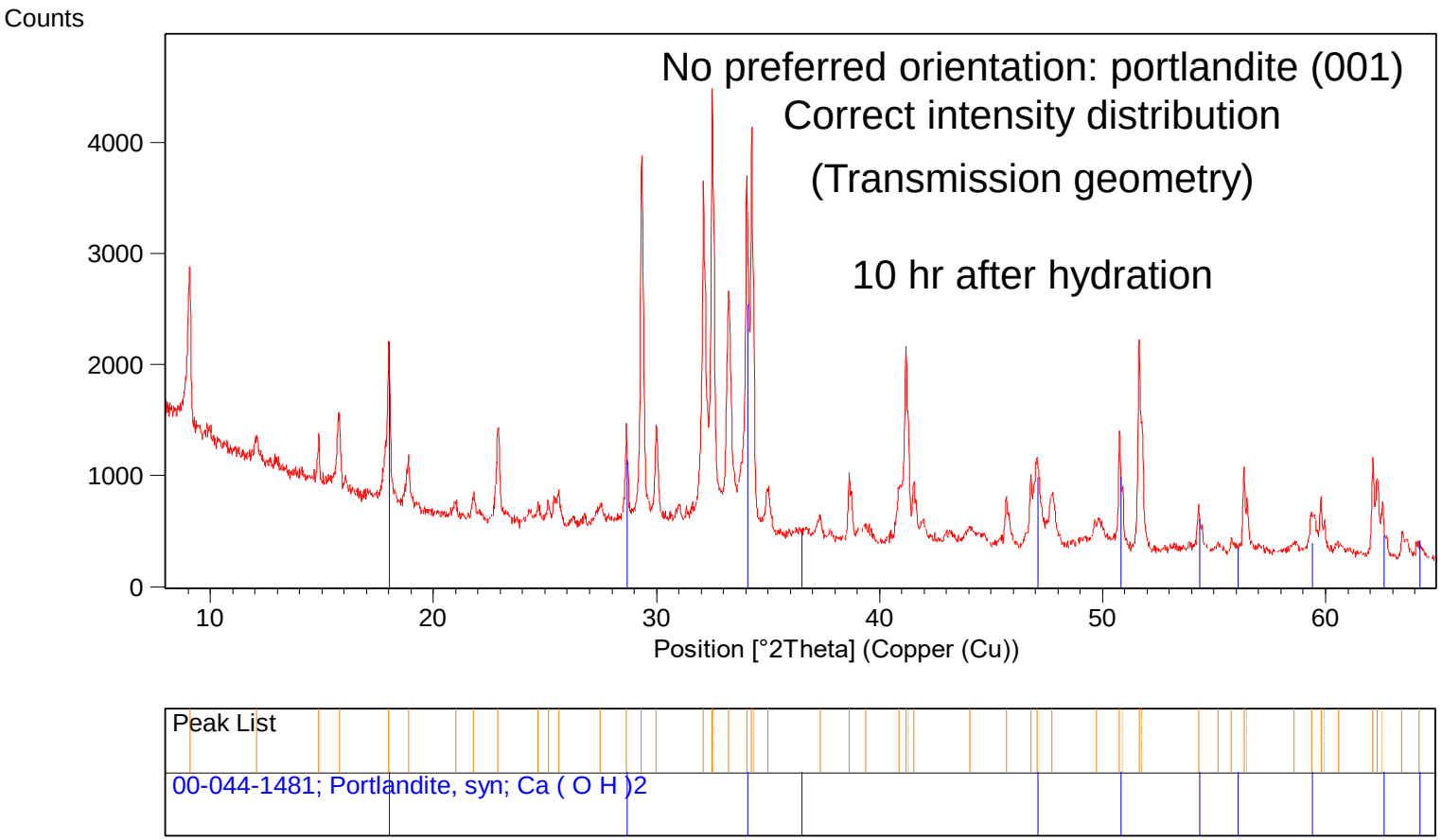

Data Collection and Minimizing Error

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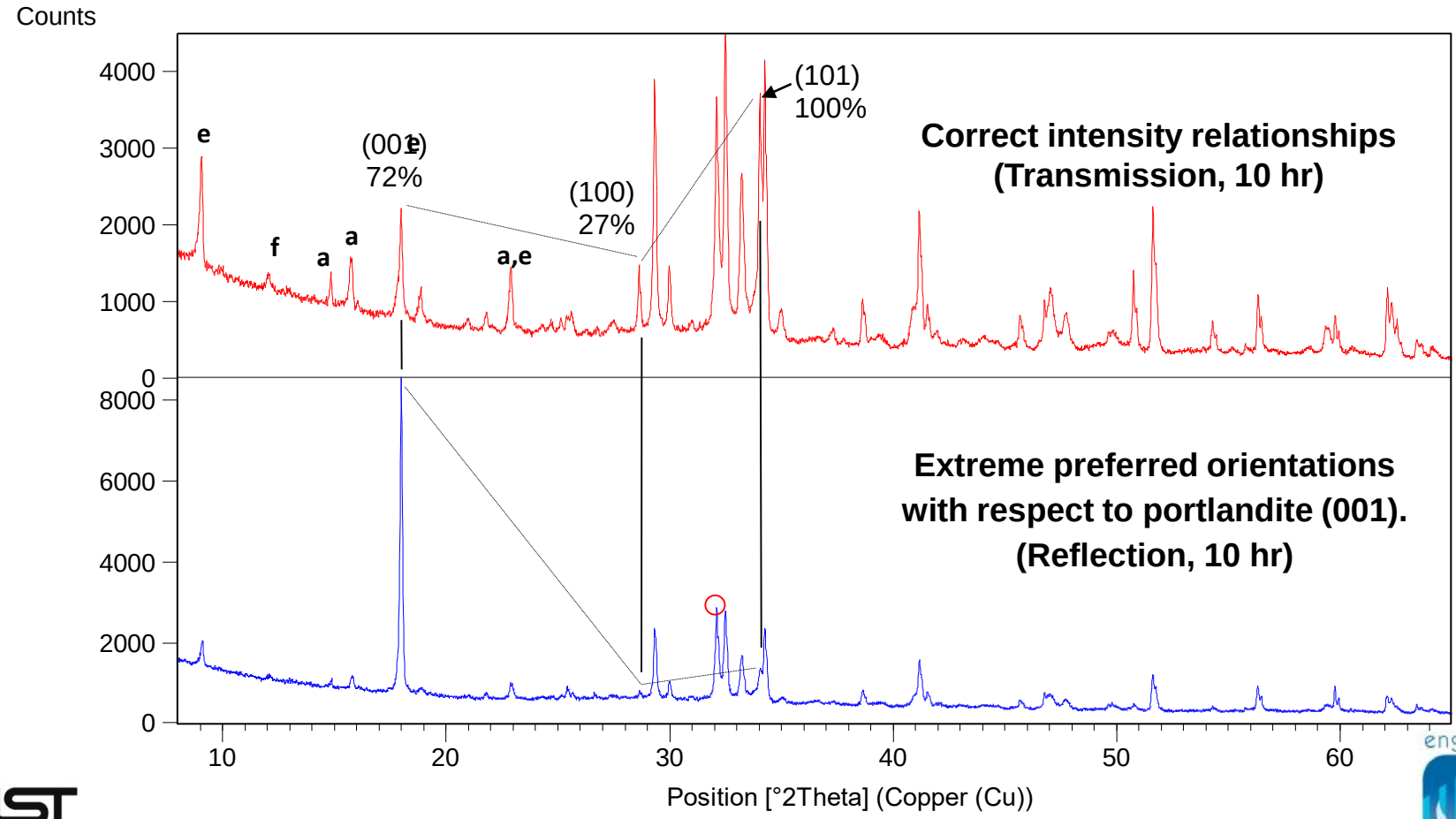


Data Collection and Minimizing Error

Specimen-dependent considerations

Microabsorption

The loss (attenuation) of scattered intensity inside a particle. If this loss is different between two phases, the quantitative phase analysis will be affected.

--- Brindley (1945)

- Depends on grain diameter and linear absorption coefficient, μD
- Mitigate absorption contrast by grinding to particle size <1μ
- Can be ignored if the product μD is equal for all phases
- Apply Brindley correction during Rietveld
- Use appropriate wavelength for the experiment

Data Collection and Minimizing Error

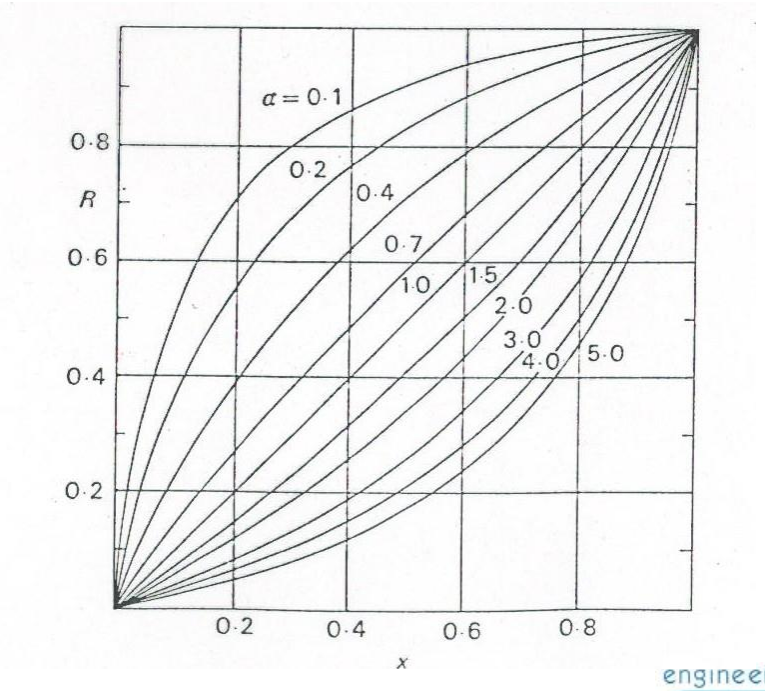
Specimen-dependent considerations

Microabsorption

Quantity:intensity relationships are seldom linear for highly variable mixtures!!!

Mass Absorption Coefficients (MAC) For Selected Elements (with CuKα radiation)

Element	MAC
Al	50.2
Si	65.3
K	148
Ca	171
Fe	304



Data Collection and Minimizing Error

Specimen-dependent considerations

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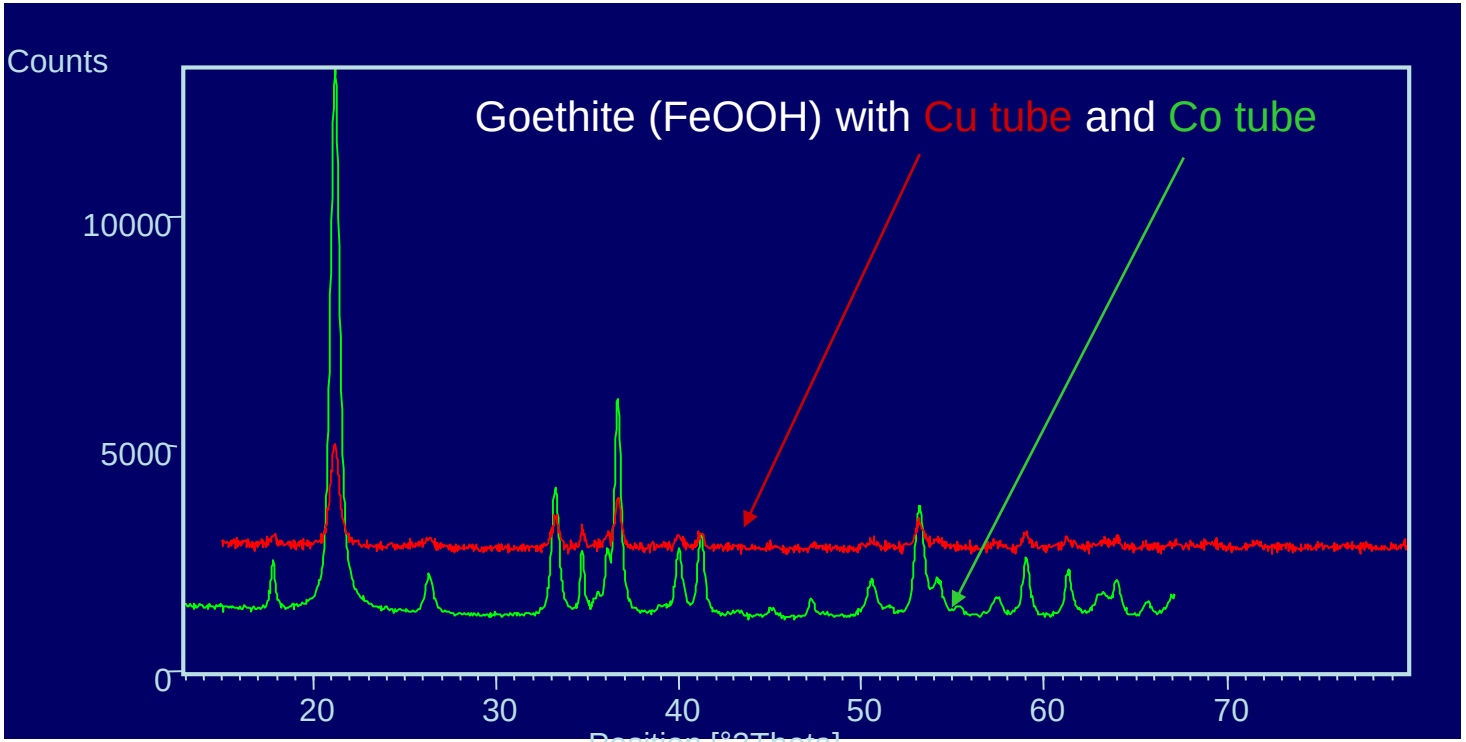


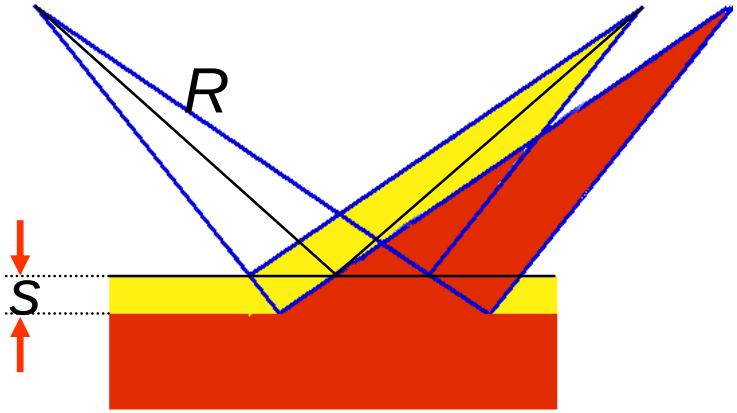
Data Collection and Minimizing Error

Specimen-dependent considerations

Sample (height) displacement

Displacement error (or transparency) in focusing geometry:

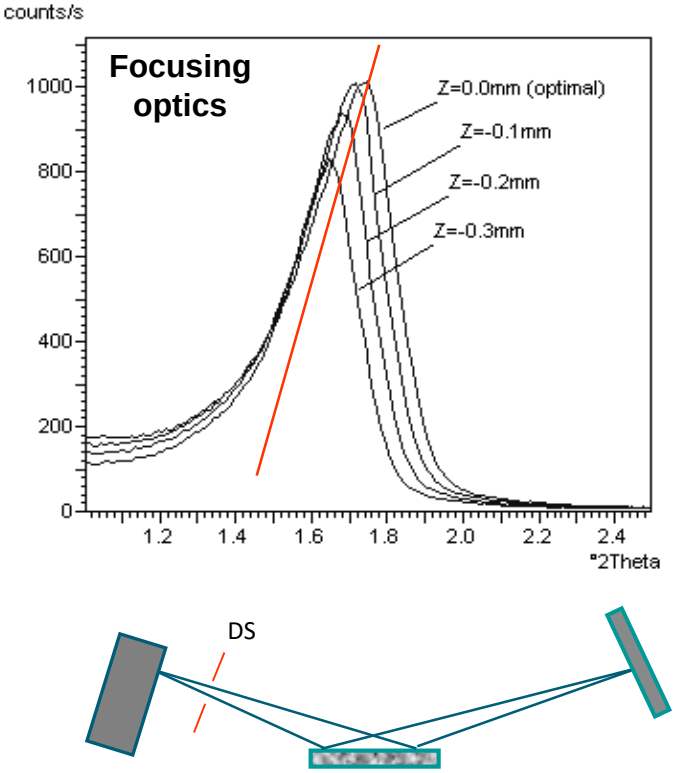
Sample stage and/or sample above or below diffraction plane: peaks are displaced from original position by

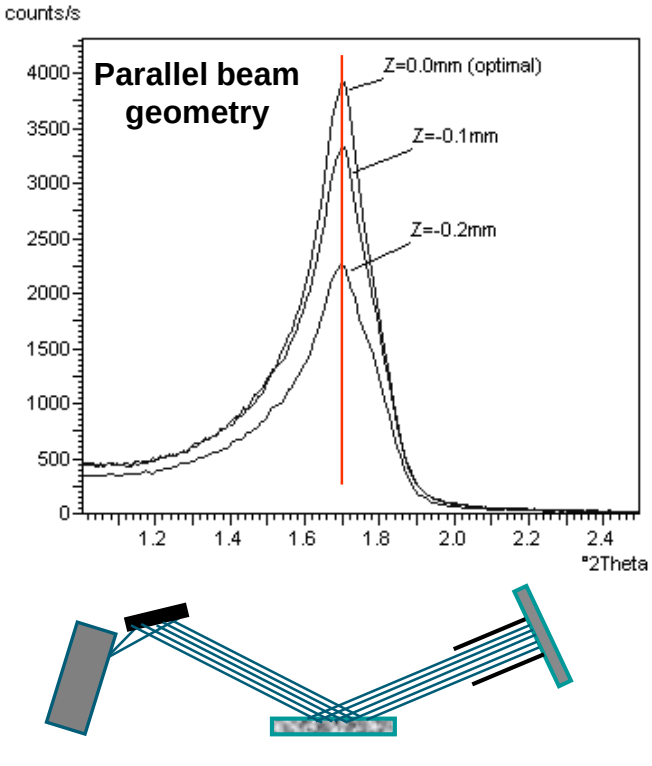


Data Collection and Minimizing Error

Specimen-dependent considerations

Sample (height) displacement





Reflection (focusing): flat samples

Intensity, resolution, and peak position are height dependent

Parallel Beam: uneven surfaces

Resolution limited; intensity is height dependent

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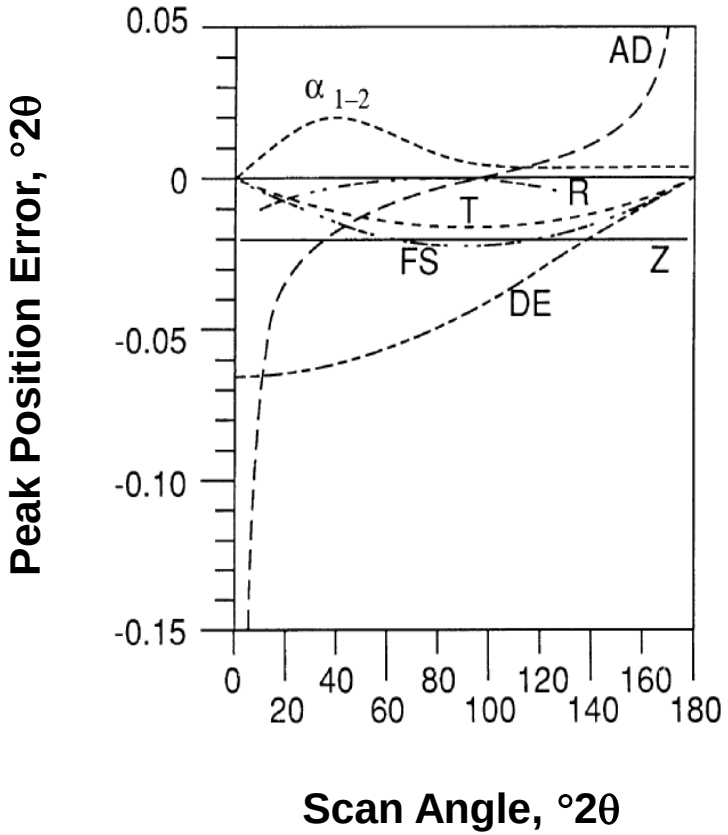
Data Collection and Minimizing Error

Instrument-dependent considerations

Summary of positional errors as a function of 2θ



$\alpha_{1\text{-}2}$ = α_1 shift due to α_2
AD = Axial Divergence
DE = 100 mm sample displ.
FS = Flat sample
R = -1 mm rec. slit position
T = 100 cm^{-1} transparency
Z= 0.02° zero angle offset

Quantitative Phase Analysis

Quantitative Phase Analysis

Established methods of phase analysis in the cement industry

1. Microscopy / Point Counting
   - ✓ Accurate, but time-intensive, subjective, and interstitial phases cannot be easily distinguished; limited use for plant control
2. Bogue Method
   - ✓ Gives theoretical (potential) compositions based on calculation from elemental analysis (with inherent limitations)
3. XRD Analysis
   - ✓ Actual (not Bogue) clinker phase composition
   - ✓ Determination of free lime (CaO and Ca-sulfates)
   - ✓ Limited historical use, but many modern benefits

Quantitative Phase Analysis

Established methods of phase analysis in the cement industry

The Bogue Method

Assumption 1: The composition of clinker phases are chemically pure (ideal stoichiometry); weight % can be calculated based on elemental analysis.

Fact: Actual clinker composition typically differs appreciably from that of pure C3S, C2S, C4AF, and C3A compounds.

Example: Alite (C3S)

$(Ca_{0.98}Mg_{0.01}Al_{0.067}Fe_{0.00333})_3 (Si_{0.97}Al_{0.03}) O_5$ vs. Ca_3SiO_5

(also large Al/Fe variation in ferrites)

Quantitative Phase Analysis

Established methods of phase analysis in the cement industry

The Bogue Method

Assumption 2: The clinker melt crystallizes to form solid phases under conditions of thermodynamic equilibrium at high temperature.

Fact: Equilibrium conditions are rarely achieved in industrial production and therefore ideal (pure) phases seldom result.

Assumption 3: Measured concentrations of CaO are all attributable to C3S, C2S, C4AF, or C3A.

Fact: Bogue calculations are typically not corrected for free lime and minor phases are ignored

Quantitative Phase Analysis

Established methods of phase analysis in the cement industry

The Bogue Method

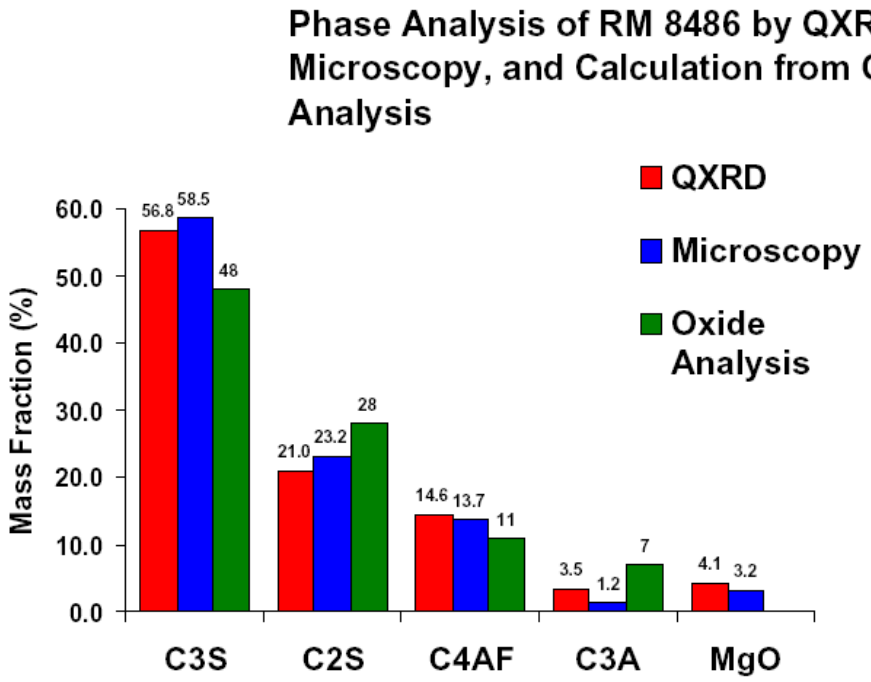
Additionally:

- ✓ No information is provided about polymorphs
  (*e.g.*, o-C3A vs c-C3A)
- ✓ Elemental data poorly correlated with setting time, and strength
- ✓ Minor phases (*e.g.*, alkalis) are neglected

Quantitative Phase Analysis

Established methods of phase analysis in the cement industry

The Bogue Method



Bogue:

- C_3S overestimated
- C_2S underestimated
- C_3A overestimated
- MgO ignored

-- *P. Stutzman*

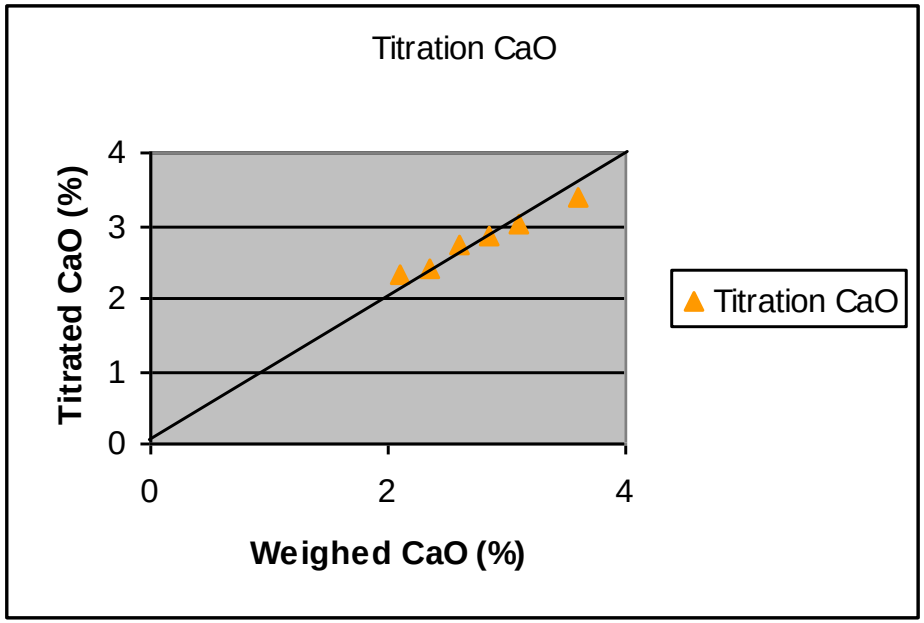
Quantitative Phase Analysis

Established methods of phase analysis in the cement industry

'Traditional' XRD methods: Free lime by calibration

Free Lime: Titration

Can be very accurate……



Quantitative Phase Analysis

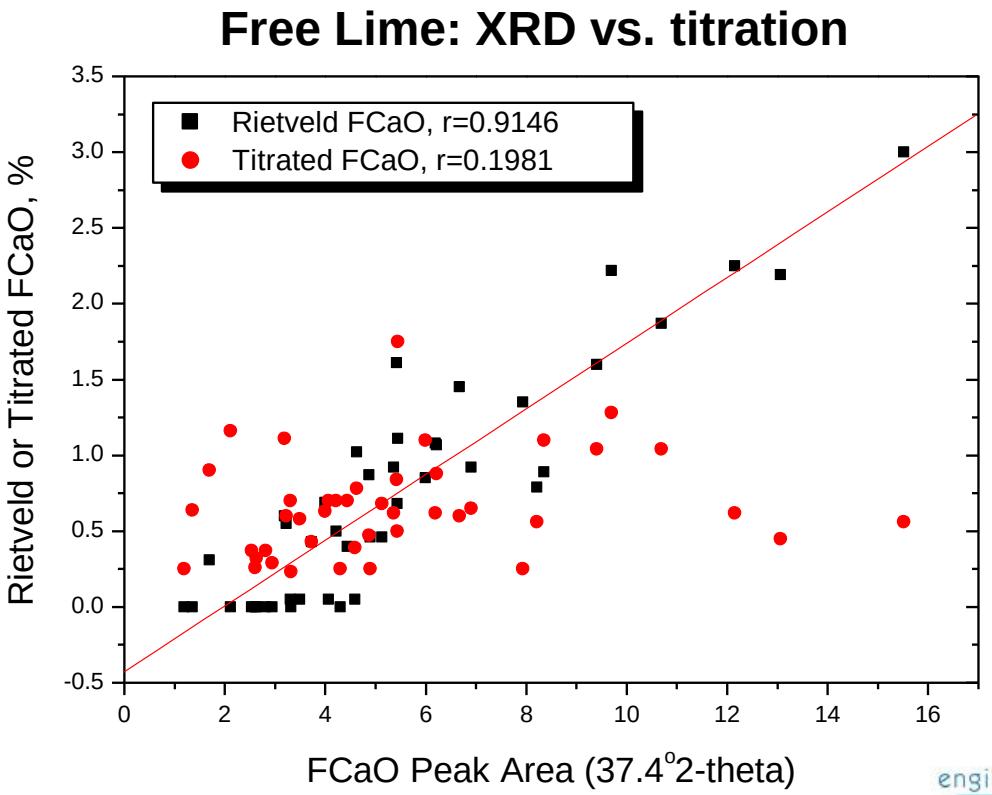
Established methods of phase analysis in the cement industry

'Traditional' XRD methods: Free lime by calibration

Can be very accurate……

…but not always

Titration *can be* highly variable.



Quantitative Phase Analysis

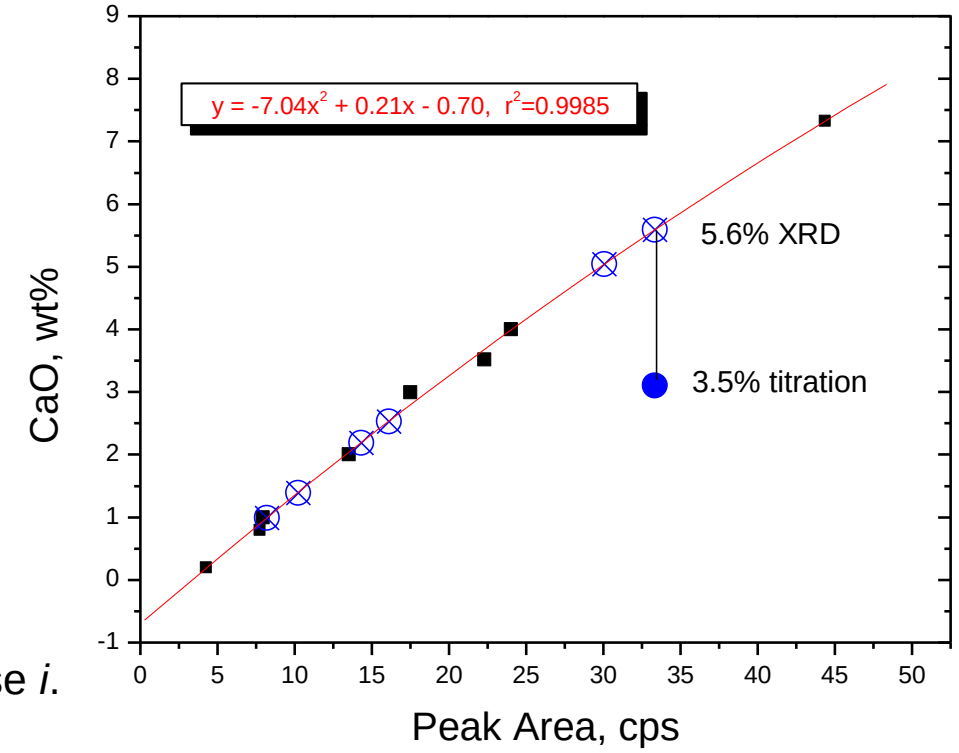
Established methods of phase analysis in the cement industry

'Traditional' XRD methods: Free lime by calibration

Quantity (x) – Intensity (I) relationship in XRD:

$$I_i = K_i \frac{X_i}{\rho_i \mu_m}$$

where
I_i = peak intensity of phase *i*,
X_i = weight percent of phase *i*,
ρ_i = density of phase *i*, and
μ_i = mass absorption coefficient of phase *i*.



Quantitative Phase Analysis

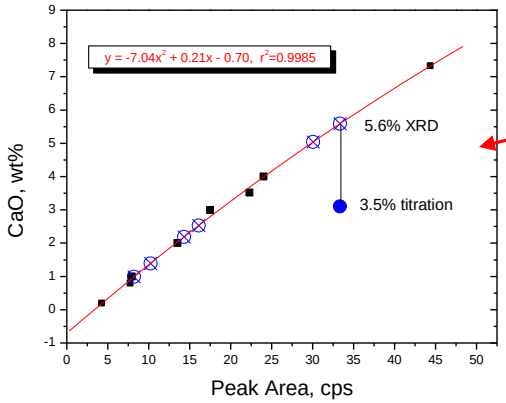
Established methods of phase analysis in the cement industry

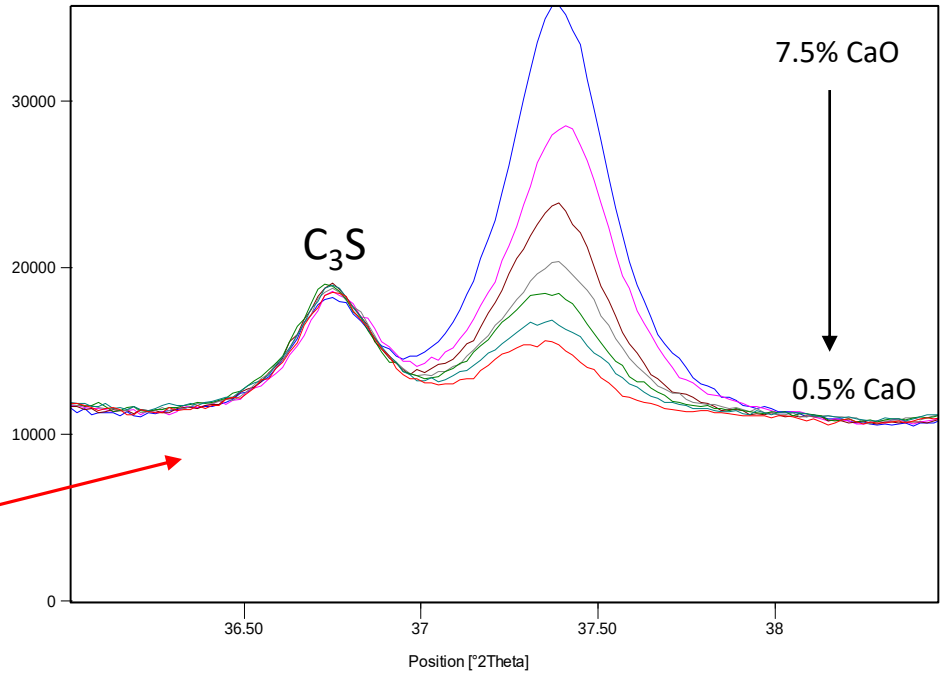
'Traditional' XRD methods: Free lime by calibration

Fast, accurate, and sensitive at low concentrations with no interference from other 'lime' phases ($CaOH_2$)

Suitable standards are required.

Free-standing peak needed!!





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Quantitative Phase Analysis

Established methods of phase analysis in the cement industry

‘Traditional’ XRD methods: Limitations

Classical methods for clinker/cement analysis are limited by:

- ✓ Substantial peak overlap among major phases
- ✓ Peak position and/or intensity shifts
- ✓ *Calibration standards* are unstable, difficult to obtain, or impure

Quantitative Phase Analysis

Established methods of phase analysis in the cement industry

'Traditional' XRD methods: Limitations

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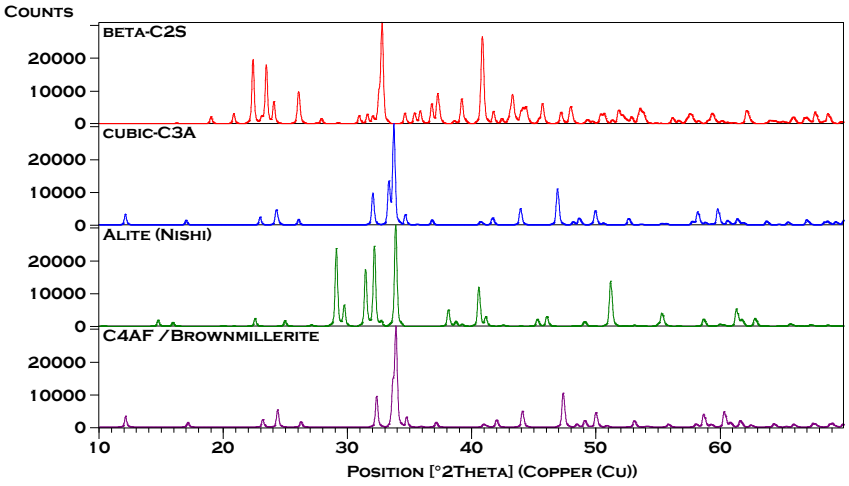

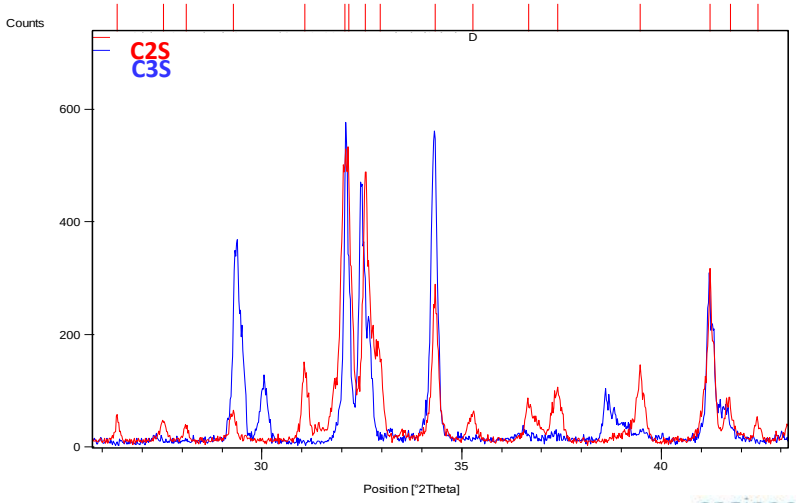

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Quantitative Phase Analysis

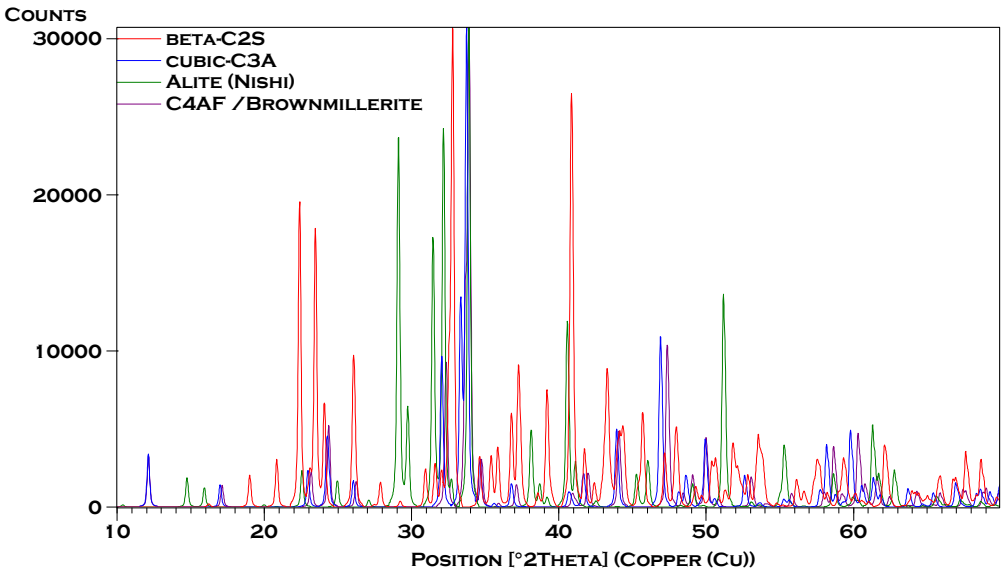
Established methods of phase analysis in the cement industry

'Traditional' XRD methods: Limitations

Classical methods for clinker/cement analysis are limited by:

- ✓ Substantial peak overlap among major phases

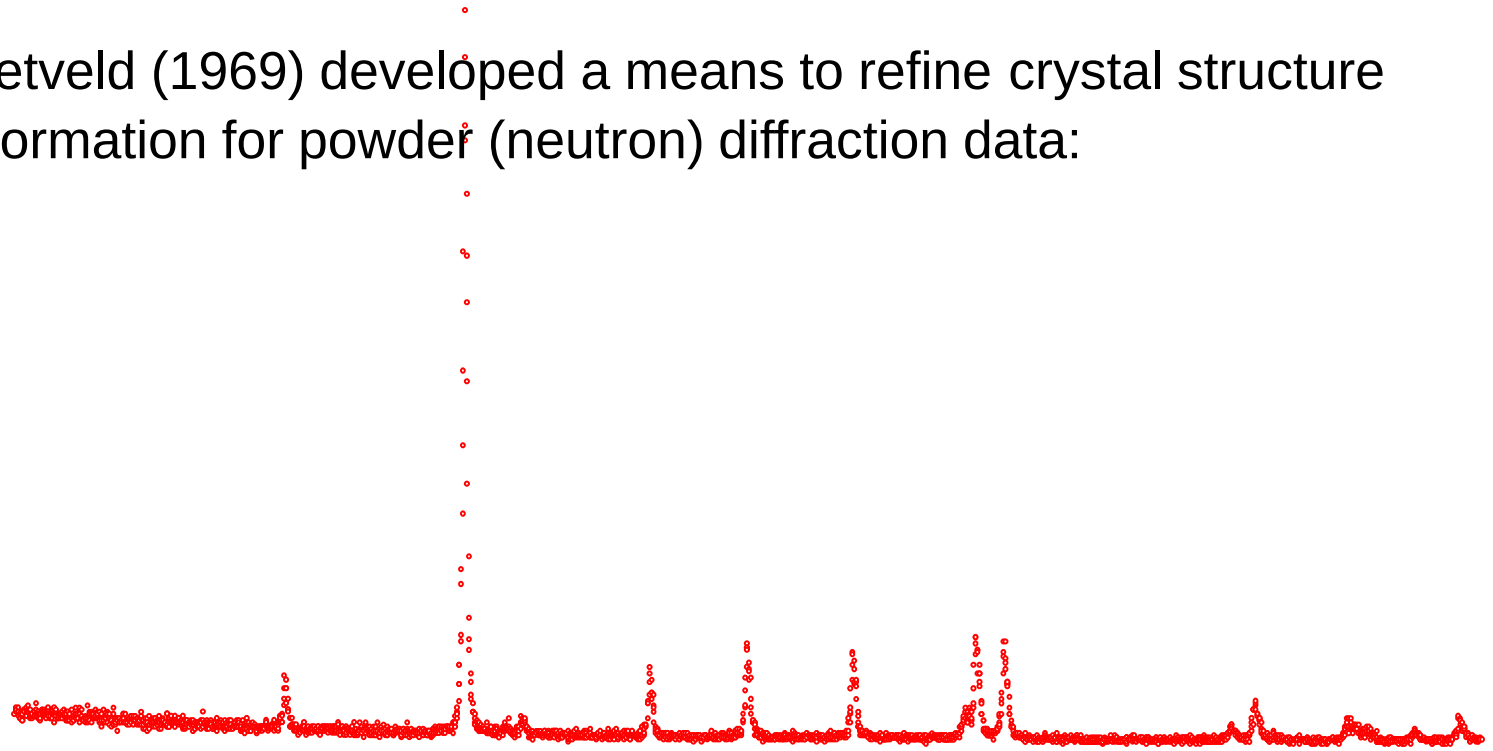
All 4 major clinker phases:



Quantitative Phase Analysis

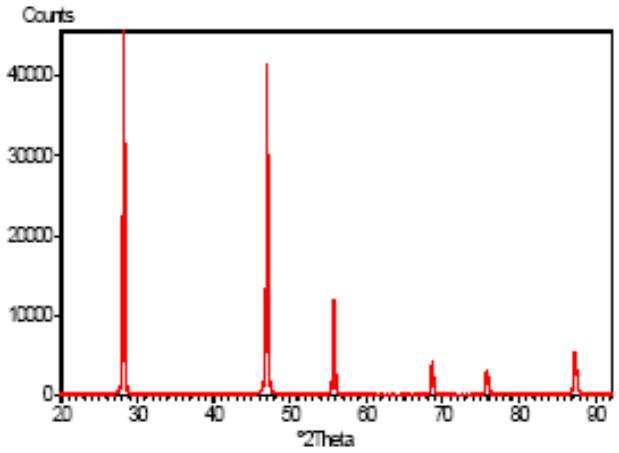
The Rietveld Method

Rietveld (1969) developed a means to refine crystal structure information for powder (neutron) diffraction data:



Quantitative Phase Analysis

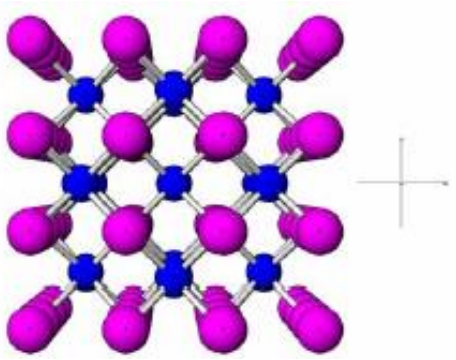
The Rietveld Method



NaCl calculated

Structure Solution

Rietveld (simulation)



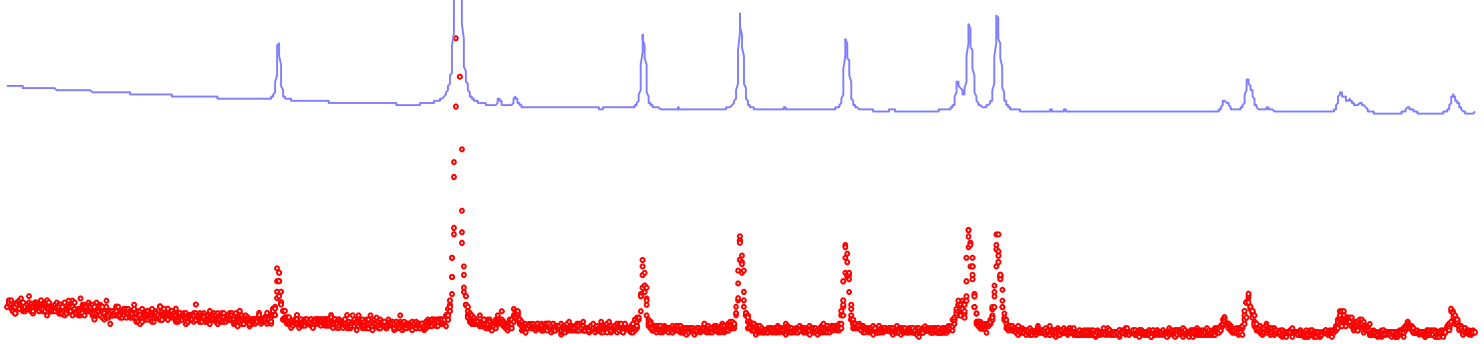
NaCl

Quantitative Phase Analysis

The Rietveld Method

Rietveld (1969) developed a means to refine crystal structure information for powder (neutron) diffraction data:

- ✓ Using ‘initial’ crystal structures and profile parameters, a simulated diffraction pattern is calculated, and

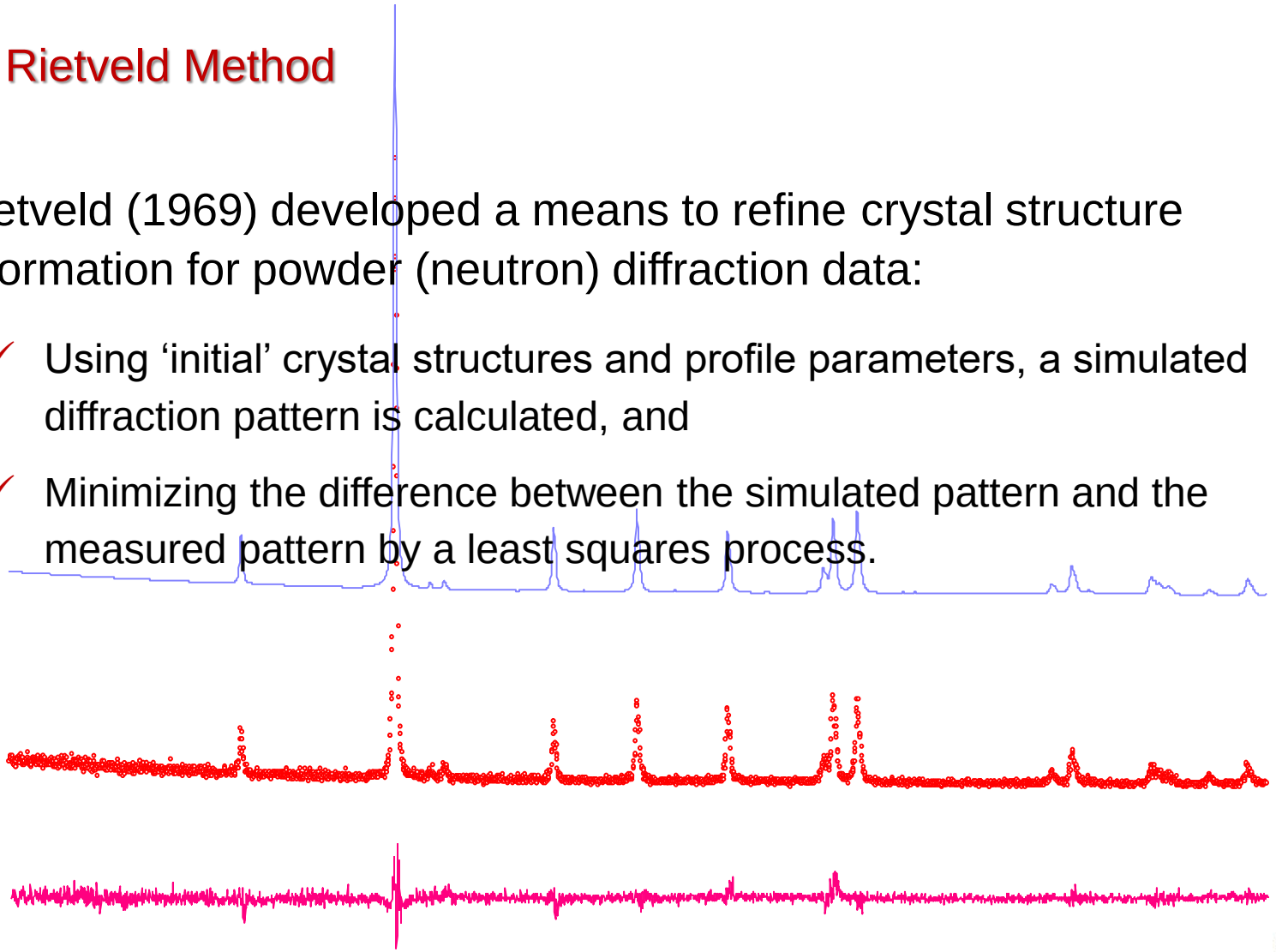


Quantitative Phase Analysis

The Rietveld Method

Rietveld (1969) developed a means to refine crystal structure information for powder (neutron) diffraction data:

- ✓ Using ‘initial’ crystal structures and profile parameters, a simulated diffraction pattern is calculated, and
- ✓ Minimizing the difference between the simulated pattern and the measured pattern by a least squares process.



Quantitative Phase Analysis

The Rietveld Method

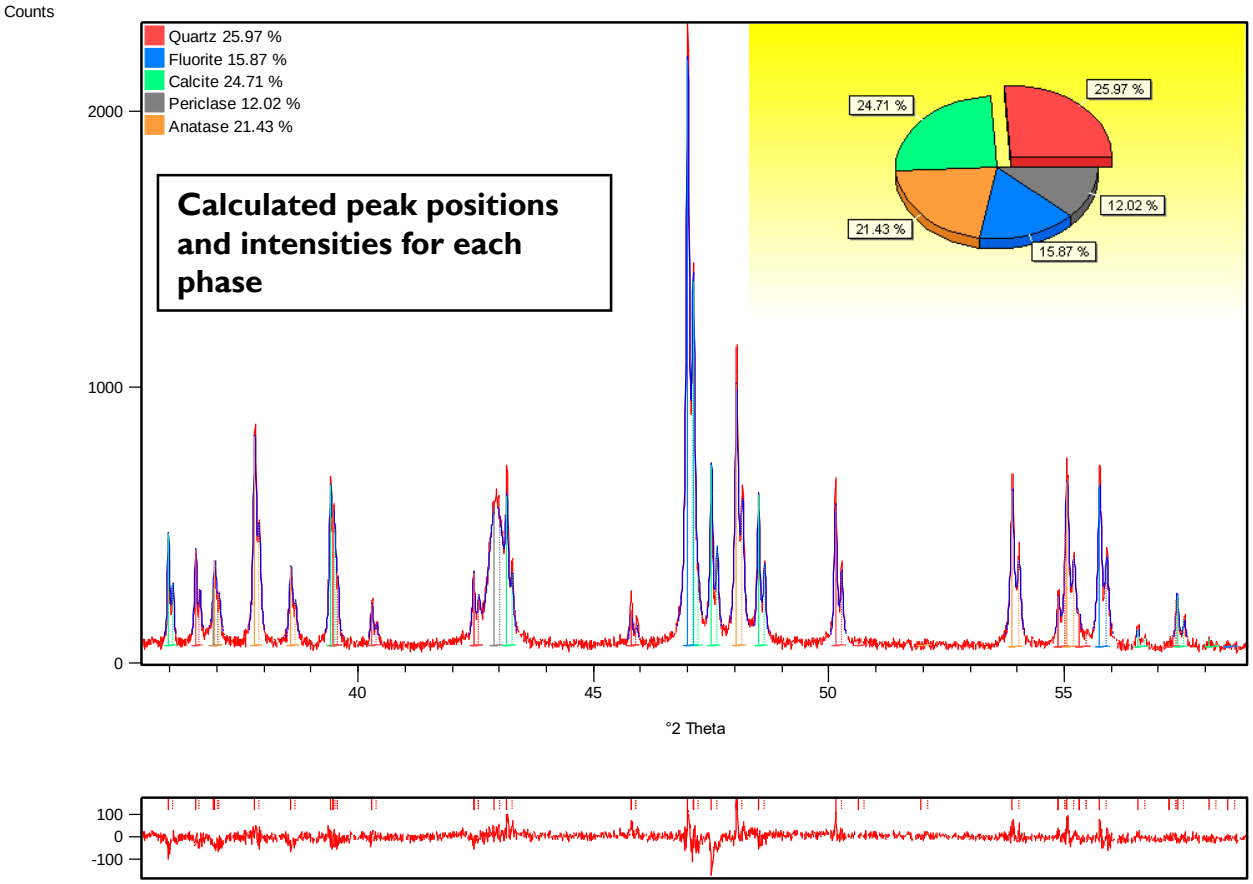
Advantages

- ✓ Models each phase independently ∴ overlapped peaks and complex mixtures can be analyzed,
- ✓ Is not limited by the unavailability of suitable calibration standards,
- ✓ Can refine site occupancies (solid-solution effects),
- ✓ Can model and correct orientation and other errors,
- ✓ Can calculate amorphous content

Quantitative Phase Analysis

The Rietveld Method

Rietveld uses all peaks and the complete profile (all data points) for the analysis



Quantitative Phase Analysis

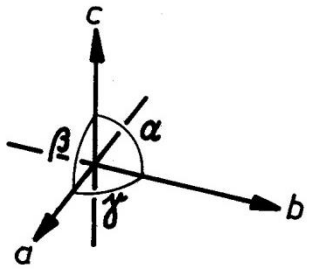
The Rietveld Method: **Required input**

Structural parameters: Crystal structures for calculation of the diffraction pattern

- ✓ Space group information → Generation of reflections (peak positions)
  - Symmetry and translation vectors
  - Unit cell parameters
- ✓ Atom types and positions → Peak intensities
  - Site occupancy
  - Electron density / scattering

Space Group P 32 2 1; SG Number 154
Red Cell P 4.912 4.912 5.404 90 90 120 112.959

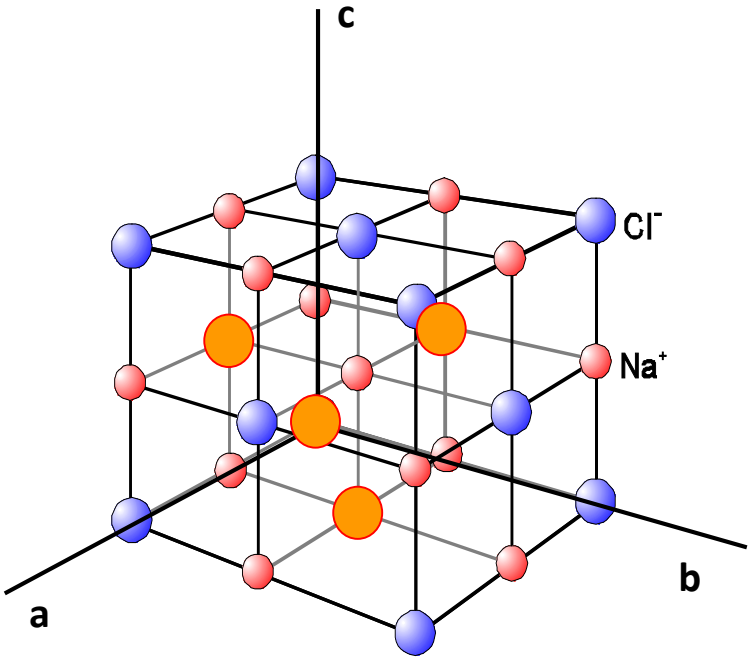
Atom	#	OX	SITE	x	y	z	SOF
Si	1	+4	3 a	0.4705(3)	0	0.6667	1.
O	1	-2	6 c	0.4152(7)	0.2678(6)	0.7851(4)	1.



Quantitative Phase Analysis

The Rietveld Method: **Required input**

Halite: Face-Centered Cubic Structure (FCC)



Cl^-	Na^+
(0, 0, 0)	(1/2, 1/2, 1/2)
(1/2, 1/2, 0)	(0, 0, 1/2)
(1/2, 0, 1/2)	(0, 1/2, 0)
(0, 1/2, 1/2)	(1/2, 0, 0)

Quantitative Phase Analysis

The Rietveld Method: **Required input**

Overview

1. Accurate phase ID is required
2. Input crystal structures for each phase
3. A calculated pattern for all phases is generated from the crystal structure data.

Quantitative Phase Analysis

The Rietveld Method: **Required input**

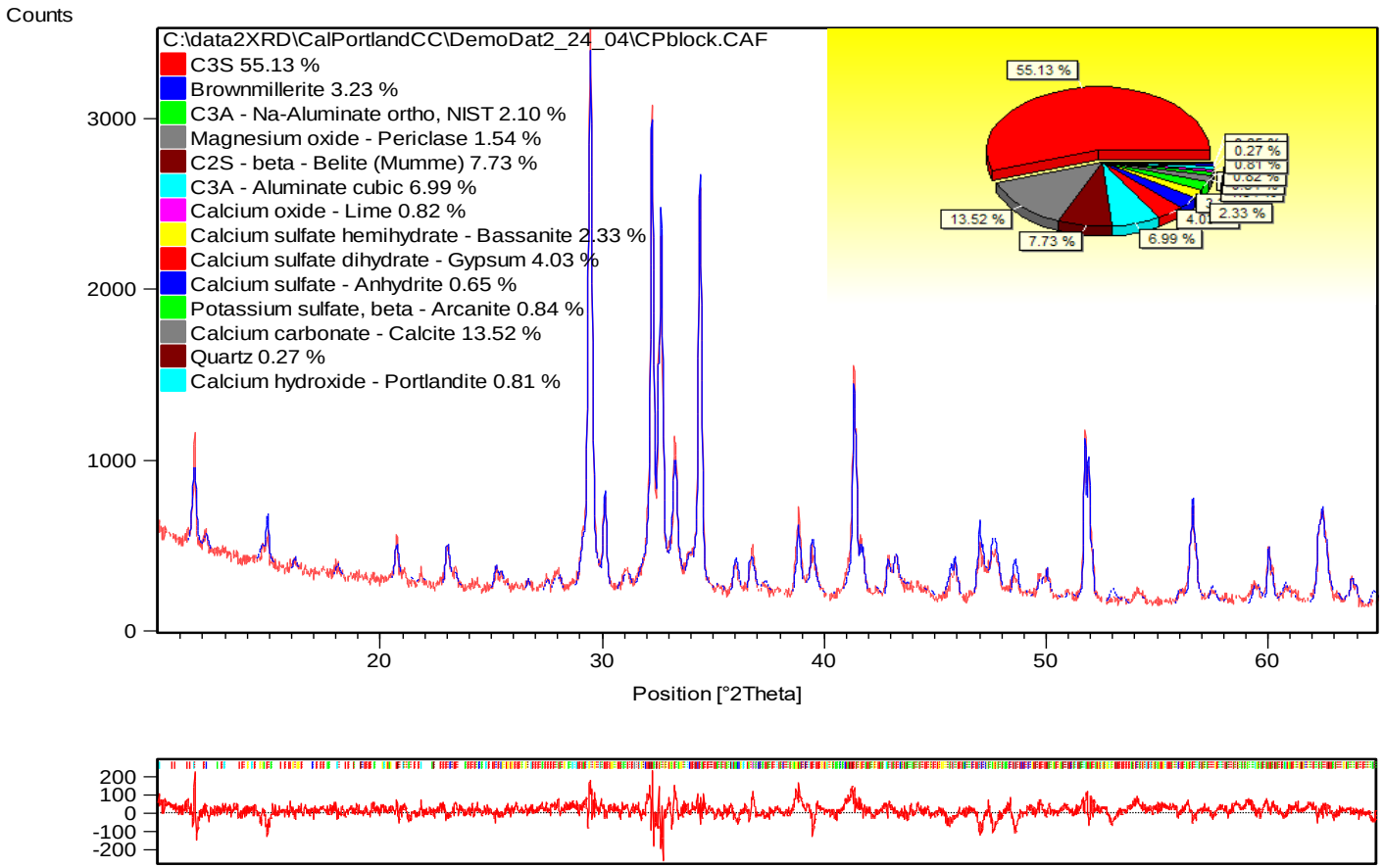
Overview

1. Accurate phase ID is required
2. Input crystal sructures
3. A calculated pattern for all phases is generated from the crystal structure data.
4. The calculated pattern is fit to the raw data (‘refined’) by modifying the appropriate:
   - ✓ unit cell parameters,
   - ✓ scale factor,
   - ✓ peak shape and profile parameters, *etc*.

Quantitative Phase Analysis

The Rietveld Method: **Example**

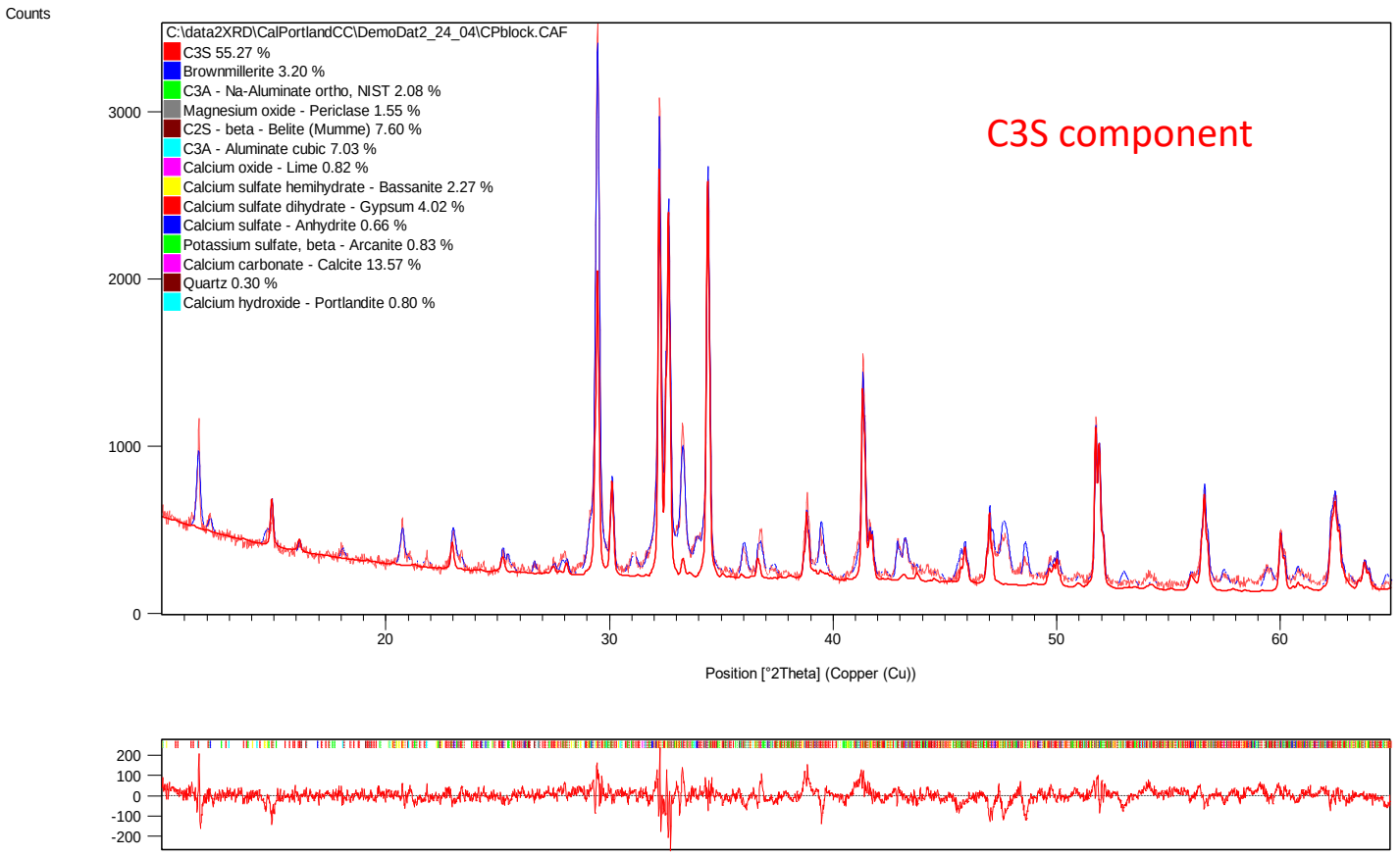
A Refined Cement Sample ‘A’ with Quantitative Data Shown



Quantitative Phase Analysis

The Rietveld Method: **Examples**

A Refined Cement Sample 'A' with Quantitative Data Shown



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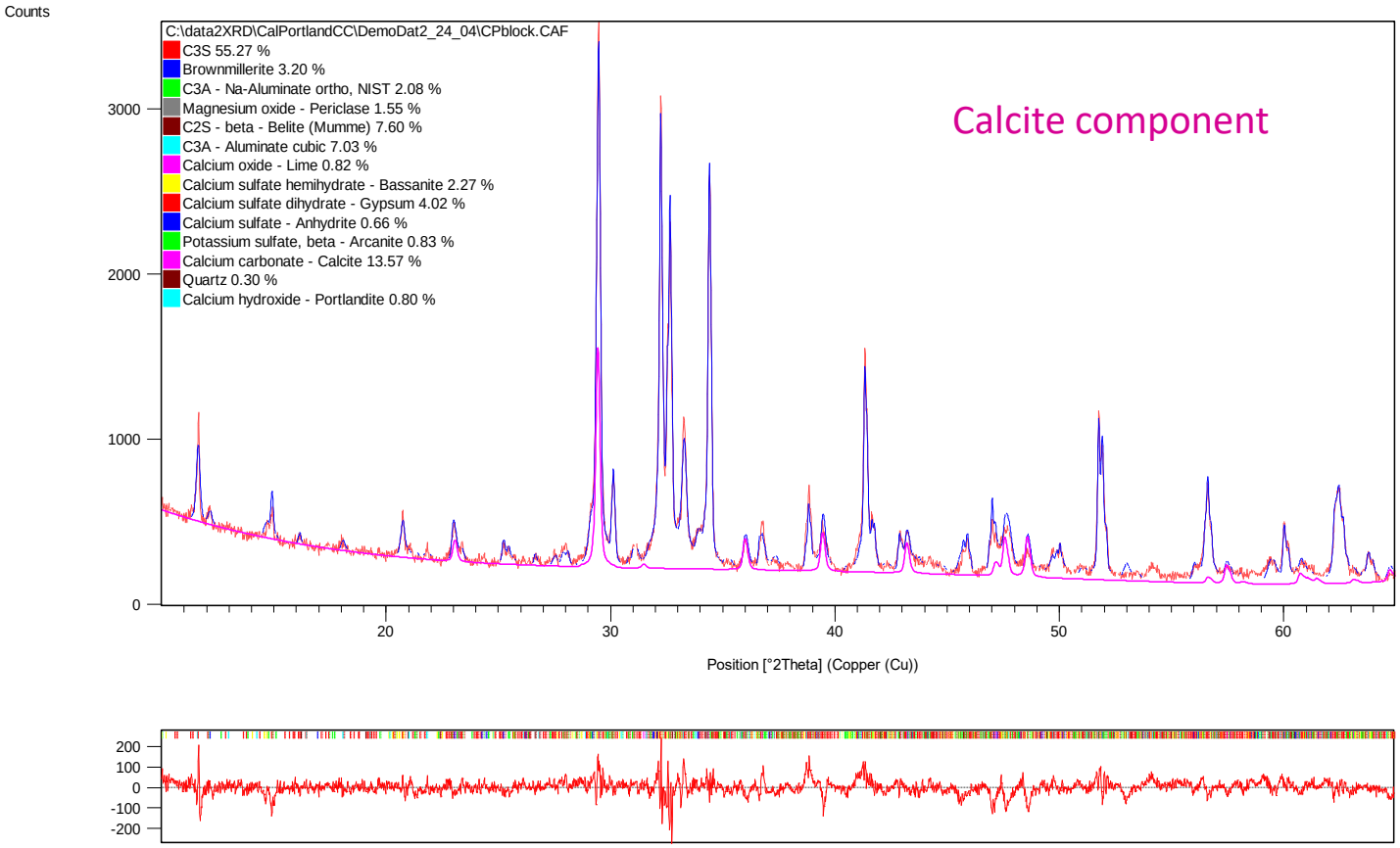
Quantitative Phase Analysis

The Rietveld Method: **Example**

A Refined Cement Sample ‘A’ with Quantitative Data Shown



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Quantitative Phase Analysis

The Rietveld Method: **Refinement procedures**

The starting model consists of :

1. Global parameters: affect the entire pattern, regardless of phase(s)
2. Structure parameters: describe the crystallographic parameters
3. Profile parameters: describe the width and shape of diffracted peaks

Quantitative Phase Analysis

The Rietveld Method: **Refinement procedures**

1. Global Parameters (Phase independent)

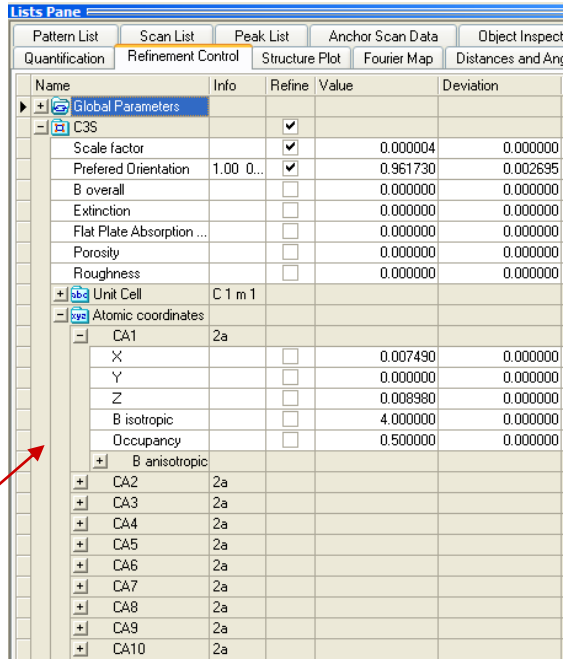
- ✓ Pattern background
  - Typically refinement of some polynomial function, or
  - Chebechev II, or
  - Manually fit (user-defined background)
- ✓ Error correction
  - Zero point (OR sample displacement)
  - Absorption
  - Extinction
- ✓ Wavelength

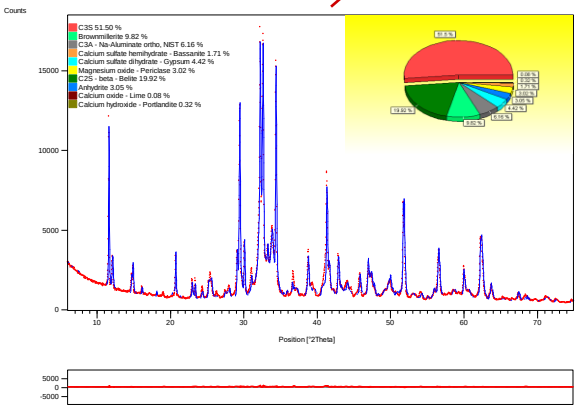
Quantitative Phase Analysis

The Rietveld Method: **Refinement procedures**

2. Structure Parameters (Phase specific)

- ✓ Space group
- ✓ Lattice parameters
- ✓ Atom co-ordinates
- ✓ Site occupation factors
- ✓ Displacement factors (temperature factors)





Partial list of atom positions for a C3S structure

Quantitative Phase Analysis

The Rietveld Method: **Refinement procedures**

3. Profile Parameters (Phase specific)

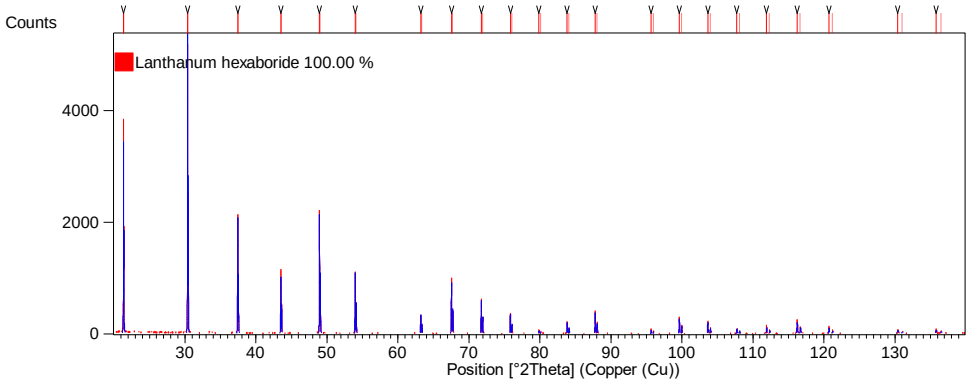
- ✓ Peak shape – will change peak intensities
  - Pseudo-Voight profile function (refinable Gaussian or Lorentzian profile contributions)
- ✓ Peak width
  - Cagliotti function (FWHM calculation)
- ✓ Peak asymmetry
- ✓ Anisotropic broadening

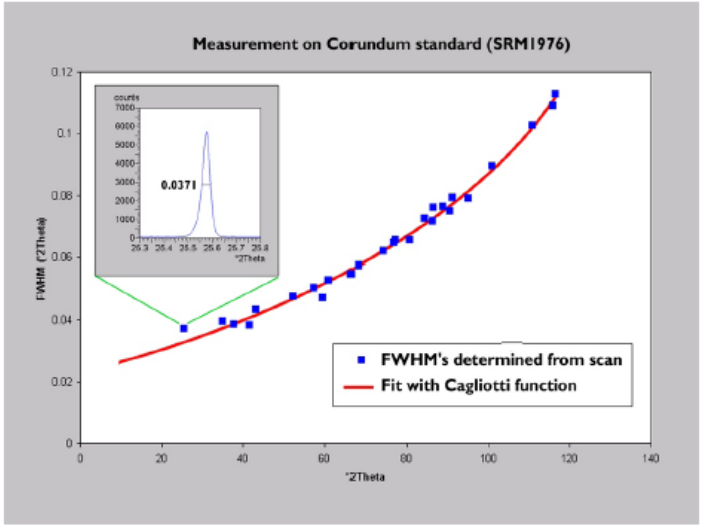
e.g., how the data is distributed around the peaks

Quantitative Phase Analysis

The Rietveld Method: **Refinement procedures**

Instrument resolution and contribution to peak broadening





H_k is the Cagliotti function where u, v and w are refinable parameters:

$$H_k = \left(U \tan^2 \theta + V \tan \theta + W\right)^{1/2}$$

Quantitative Phase Analysis

The Rietveld Method: **Refinement procedures**

4. Miscellaneous Parameters

- ✓ Scale factor: ~proportional to weight % of phase
- ✓ Preferred orientation
- ✓ Absorption correction
- ✓ Extinction correction
- ✓ etc.

Quantitative Phase Analysis

The Rietveld Method: **Algorithms**

We can calculate the net intensity of a diffraction pattern, Y_{ic} , at each point *i* in the pattern according to:

$$Y_{ic} = Y_{ib} + \sum_{p} \sum_{k=k_1^p}^{k_2^p} G_{ik}^{p} I_k$$

Where:

Y_{ib} = the intensity of the background at point *i* in the pattern,
G_{ik} = the normalized peak profile function,
I_k = the intensity of Bragg reflection *k*, and
$K_1 – K_2$ = reflections contributing to the i^{th} point in the pattern.
(subnote 'c' stands for calculated and superscript 'p' stands for possible phases present)

- or, in plain English -

The intensity at any given point in the diffraction pattern is equal to the Background Contribution + Profile Shape + Bragg Peak Intensity for all possible phases and peak shapes.

Quantitative Phase Analysis

The Rietveld Method: **Algorithms**

The intensity I_k is given by the expression:

$$I_{hkl} = \left|F_{hkl}\right|^2$$

- OR -

$$I_k = SM_k L_k \left|F_k\right|^2 P_k A_k E_k$$

Where

S = Scale factor

M_k = Reflection multiplicity,

L_k = Lorentz-Polarization factor

P_k = Preferred orientation

A_k = Absorption

E_k = Extinction

F = Structure Factor

Quantitative Phase Analysis

The Rietveld Method: **Algorithms**

The Structure Factor F_k is given by the expression:

$$F_k = \sum_{j=1}^{n} f_j \exp\left[2\pi i\left(h_r^t r_j - h_k^t B_j h_k\right)\right]$$

Where:

N_j is the site occupancy factor (0,1) for the jth atom,

f_j is the atomic scattering factor for the jth atom,

h, k, and l are the Miller indices, and x_j, y_j, and z_j are the positional coordinates for the jth atom in the unit cell.

Quantitative Phase Analysis

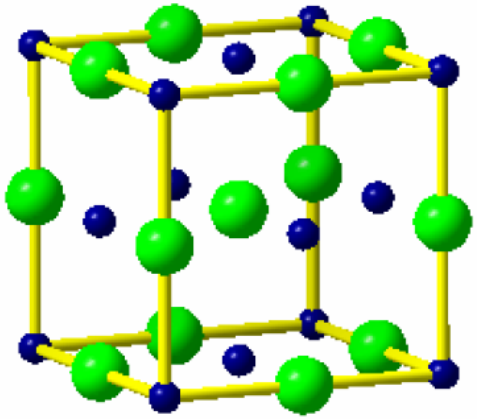
The intensity of an x-ray peak is a function of the type and position of the atoms in the unit cell – *i.e.,* electron density and therefore scattering power ('Form Factor, *f*)

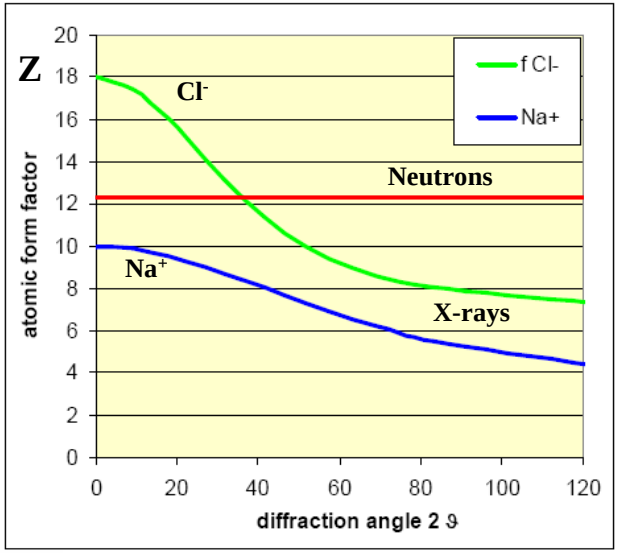
Amplitude

- Amplitude f_i of a scattered wave
  - represents the scattering power of an atom
  - varies with $(\sin\vartheta)/\lambda$
  - for $2\vartheta = 0$: f_i = number of electrons of the scattering atom

NaCl-structure
Na^+ : 10 electrons: f Na^+=10 (ϑ =0)
Cl^- : 18 electrons: f Cl^- = 8 (ϑ =0)

Reduces the intensities of peaks at higher angles.





Quantitative Phase Analysis

The Rietveld Method: **Algorithms**

Rietveld scale factor $\propto$ wt.% phase present in the sample:

The weight fraction of phase p can then be derived as:

$$W_p = \frac{(SZMV)_p}{\sum_i (SZMV)_i}$$

analyte phase

all phases

where:

W_p is the weight percent of phase p

S is the refined Rietveld scale factor,

Z is the number of formula units per unit cell

M is the mass of the formula unit,

V is the volume of the unit cell.

Quantitative Phase Analysis

The Rietveld Method: **Agreement indices and quality of the refinement**

1. Best method is to evaluate the difference plot,
2. Agreement indices or 'R' values are the quantities that are minimized during the refinement.

Weighted profile R-factor (R_{wp}) is perhaps the most useful:

R_{wp} is a measure of the fit between the observed and calculated patterns

$$R_{wp} = \left[\frac{\sum w_i (Y_{io} - Y_{ic})^2}{\sum w_i Y_{io}^2} \right]^{\frac{1}{2}}$$

R_{exp} reflects the quality (statistics) of the data.

$$R_{exp} = \left[\frac{N - P}{\sum_i^N w_i y_i (obs)^2} \right]^{\frac{1}{2}}$$

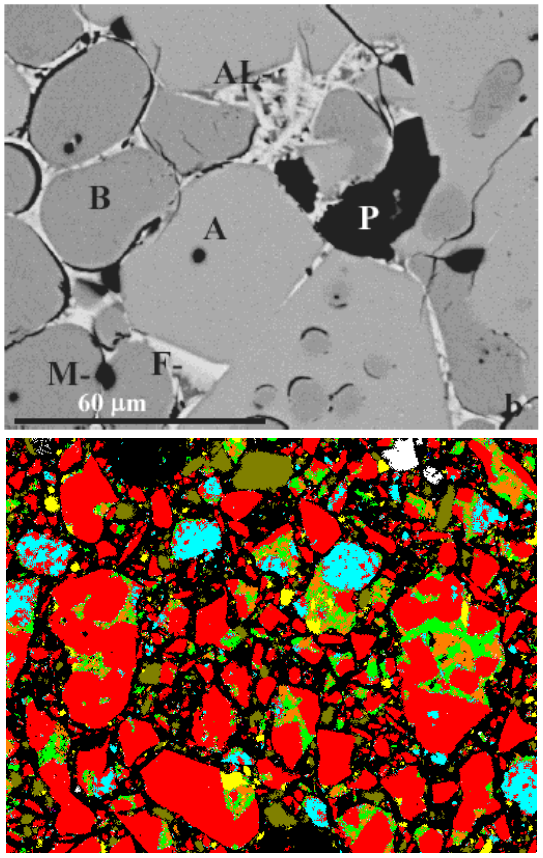
$X^2 = Rwp/Rexp = GOF$

Quantitative Phase Analysis

The Rietveld Method: **Agreement indices and quality of the refinement**

'Independent calibration': Why it's needed

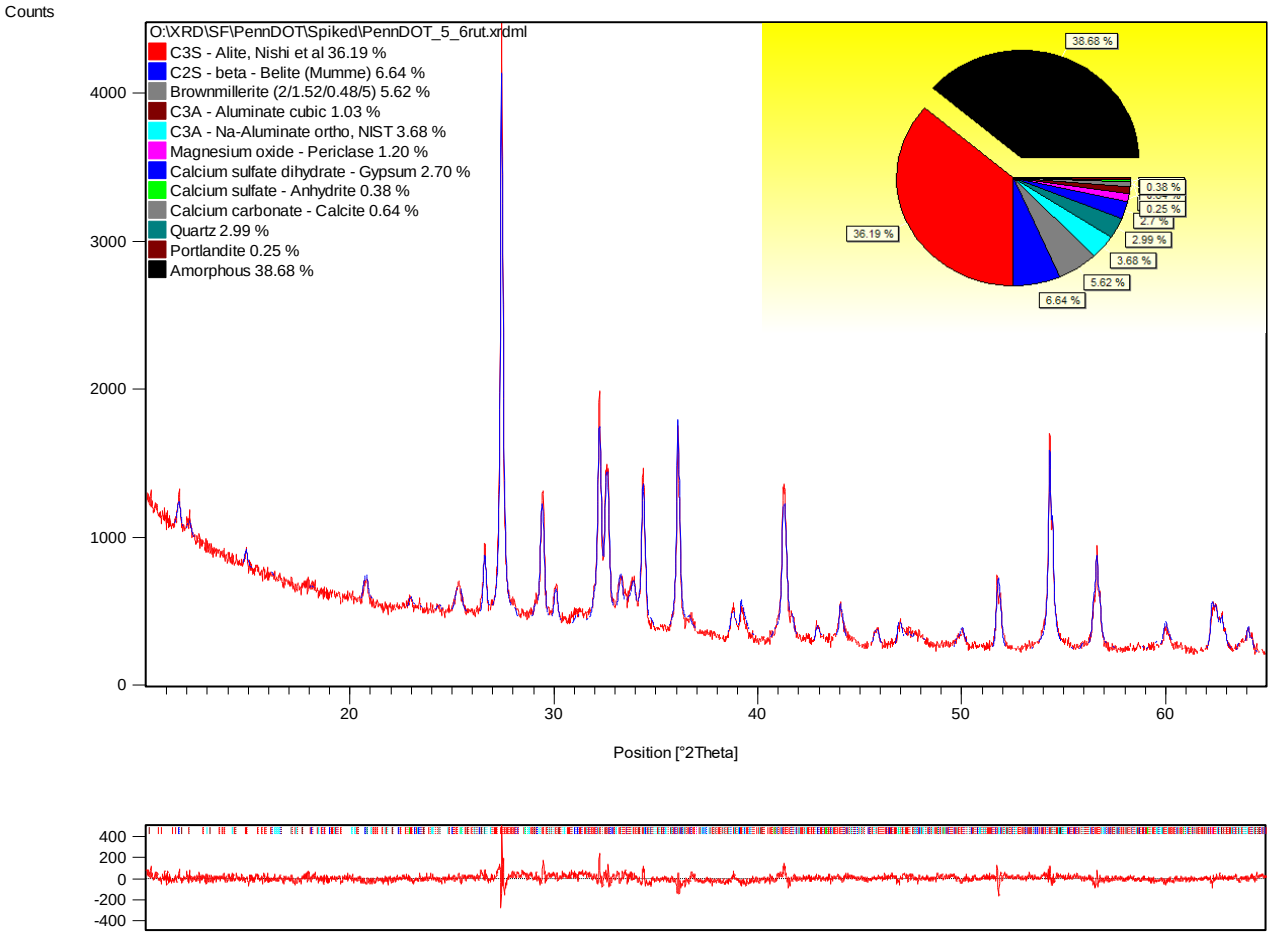
Rietveld is very precise, but in order to obtain the most accurate absolute concentrations, it is best to obtain independent characterization data for construction of control files to obtain true, 'referenced' phase concentrations.



Additional Rietveld Examples

Quantitative Phase Analysis

The Rietveld Method: **Additional examples**



Cement / Fly Ash blend with 24% rutile added as internal standard for amorphous calculation

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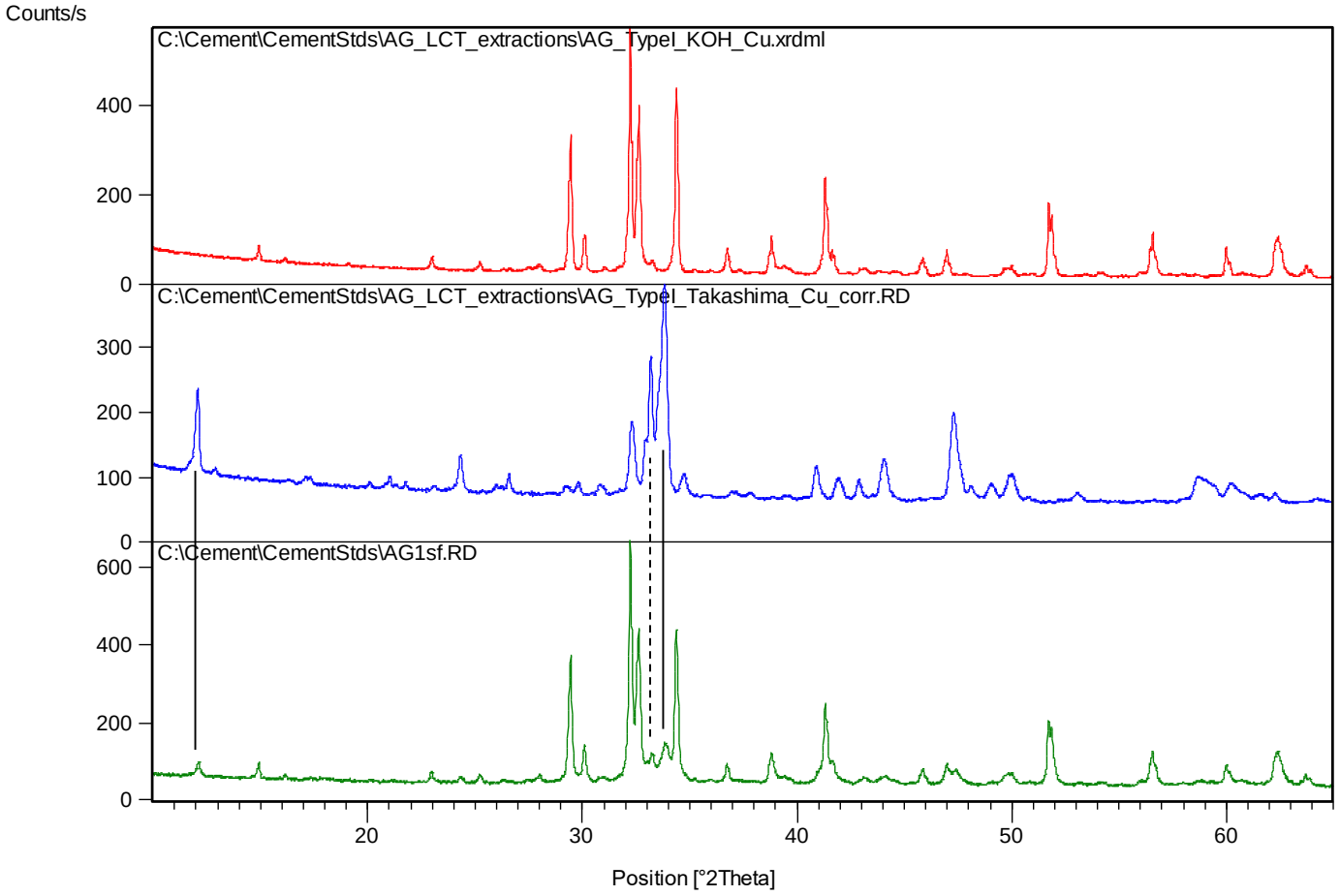
Quantitative Phase Analysis

The Rietveld Method: **Additional examples**



Selective extraction of interstitial phases (red) and silicates (blue). Bulk sample is shown in green.

Summary

Quantitative Phase Analysis

The Rietveld Method: **Refinement strategies and tips**

What parameters *can* be refined?

- Lattice parameters
- Atomic positions
- Site occuancy
- Isotropic temperature factor (B)
- Profile parameters (*u,v,w,* & other peak shape parameters)
- Preferred orientation
- Background contribution
- Zero point (or sample height)

Quantitative Phase Analysis

The Rietveld Method: **Refinement strategies and tips**

What parameters *should* be refined (for QPA)?

- Scale factor - all phases
- Lattice parameters – *all phases* (or at least major phases)
- Atomic positions - *never*
- Site occupation – rarely (only if needed)
- Temperature factors – *rarely* (never)
- Profile parameters - *major phases only*
- Preferred orientation – *as needed*, constrained to direction
- Background contribution – *always* (noncrystalline?…)
- Zero point (or sample height) - *always*

Summary

Rietveld analysis provides:

- Refined unit cell dimensions - phase chemistry and solid solutions (zoning)
- Crystal structure parameters/atom site occupancy and structural disorder
- Peak width and shapes - coherent domain size (*i.e.*, crystallite size)
- Preferred orientation - crystal texture
- Background modeling - characterization of amorphous material,
- Determination of polymorphic forms,
- Independent measure of CaO, $Ca(OH)_2$, $CaCO_3$, etc.
- AND…

…Standardless quantification (wt %) for each phase

Thank-you!


WHAT ON EARTH AM I DOING IN HERE ON THIS BEAUTIFUL DAY?!
THIS IS THE ONLY LIFE I'VE GOT!!