Applications of Elemental Analysis in the Mining and Mineral Resource Industry

Part 2

Welcome to our Minerals, Mining & Geology Webinar Series

Applications of Elemental Analysis in the Mining and Mineral Resource Industry

Part 1: *XRF as a flexible tool for elemental analysis of geological samples*

Dec. 1st 2020: 9:00 AM, 4:00 PM (CET)

→ **Get the recording!**

Part 2: *Process Monitoring and Grade Control in the Mining and Mineral Resource Industry by XRF*

Dec. 15th 2020: 9:00 AM, 4:00 PM (CET)

Dr. Adrian Fiege
Product Management XRF
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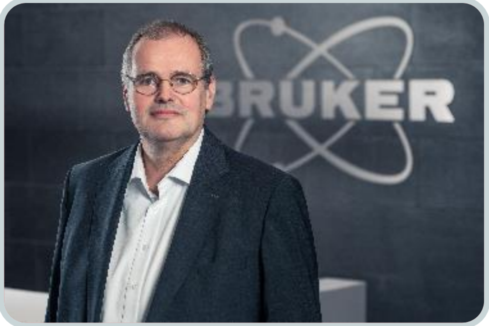


Dr. Kai Behrens
Head of XRF Product Management
Karlsruhe, Germany

Today's Topics

Feedback from Part 1:

- Please tell us more about online-XRF, the S2 KODIAK and typical applications in mining
- Sample preparation as pressed pellet and applications
- Application examples - detection limits and interferences
→ Partially covered

Outline Part 2

- Introduction: When and where to use XRF for Mining operations?
- Sample preparation: Pressed pellets
- Which solution is optimal for my application?
- Application Examples
  - Tungsten and Copper Ore (Online XRF)
  - Iron Ore (EDXRF vs. WDXRF)
  - Nickel Ore (EDXRF vs. benchtop WDXRF)
- Summary & Outlook & Q&A Session

What and when do we analyze in mining operations?

What?

Major, minor and trace elements in all sorts of ores ranging from industrial minerals and commodities, to base metal ore, and to precious metal ores.
-> Focus on decision making elements (grades, tracers, penalty elements)

When?

During exploration

- Individual rock samples
- Drill cores
- ➢ Monitoring to survey geological situation, many elements in wide ranges

During mining operation

- Blast holes
- Drill cores
- ➢ Quick decisions for operation (no delay), mine planning, major elements

During beneficiation and blending

- Grade control at various steps of the process
- ➢ Quick decisions, focus on precision, no further delay of material movement, vital elements

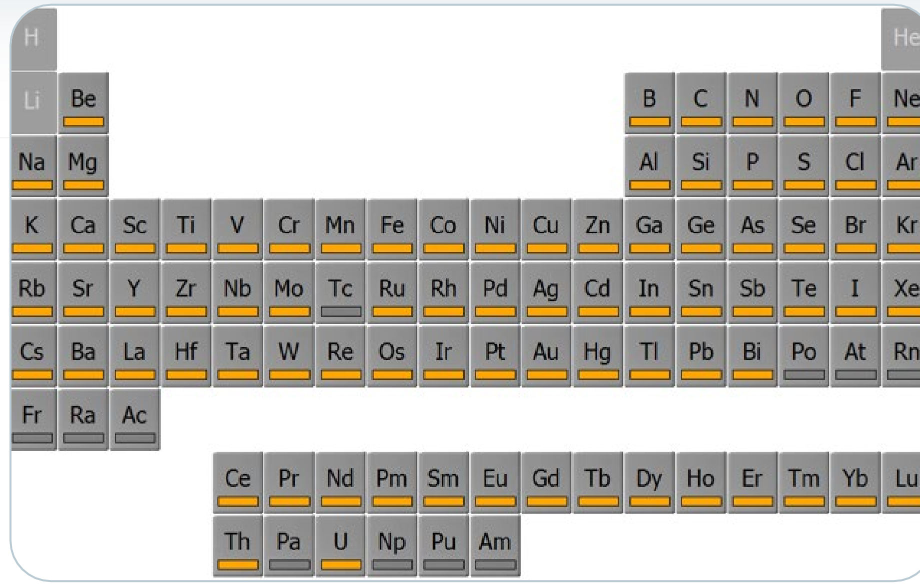
When releasing, shipping, or receiving

- Certify final grade control
- Raw material ID
- Accurate analysis for value determination, highest accuracy

X-ray Fluorescence (XRF) spectrometry
Element range

X-ray Fluorescence (XRF) analysis is qualitative and quantitative method for the determination of element concentrations via excitation of atoms in the sample and detection of the characteristic X-rays.

- High-power WDXRF (4–1 kW):
  Be (B) – Am
- Medium WDXRF (400 W):
  O (F) – Am
- Modern EDXRF:
  C (F) – Am
- Low-power EDXRF:
  Na (Mg) – Am



- Element range XRF:
  (Be) B to Am
- Concentration range:
  Sub-ppm to 100 %

Audience Poll

What are your main goals with elemental analysis – What are you trying to achieve? (Check all that apply.)

- ❑ Check quality of incoming material
- ❑ Increase percentage of recycled material in production
- ❑ Optimize production costs
- ❑ Increase throughput
- ❑ Optimize final product quality
- ❑ Other (specify)

Sample preparation
Pressed pellets vs. Fused beads

Pressed Pellets

Pro's

- Fast & simple sample preparation method
- No loss of volatile elements
- Easily automatable

Con's

- Grain size and matrix effects
- Sample contamination via the grinding vessel

Fused Beads

Pro's

- No Matrix and grain size
- High reproducibility for best accuracy and precision
- Larger calibration range

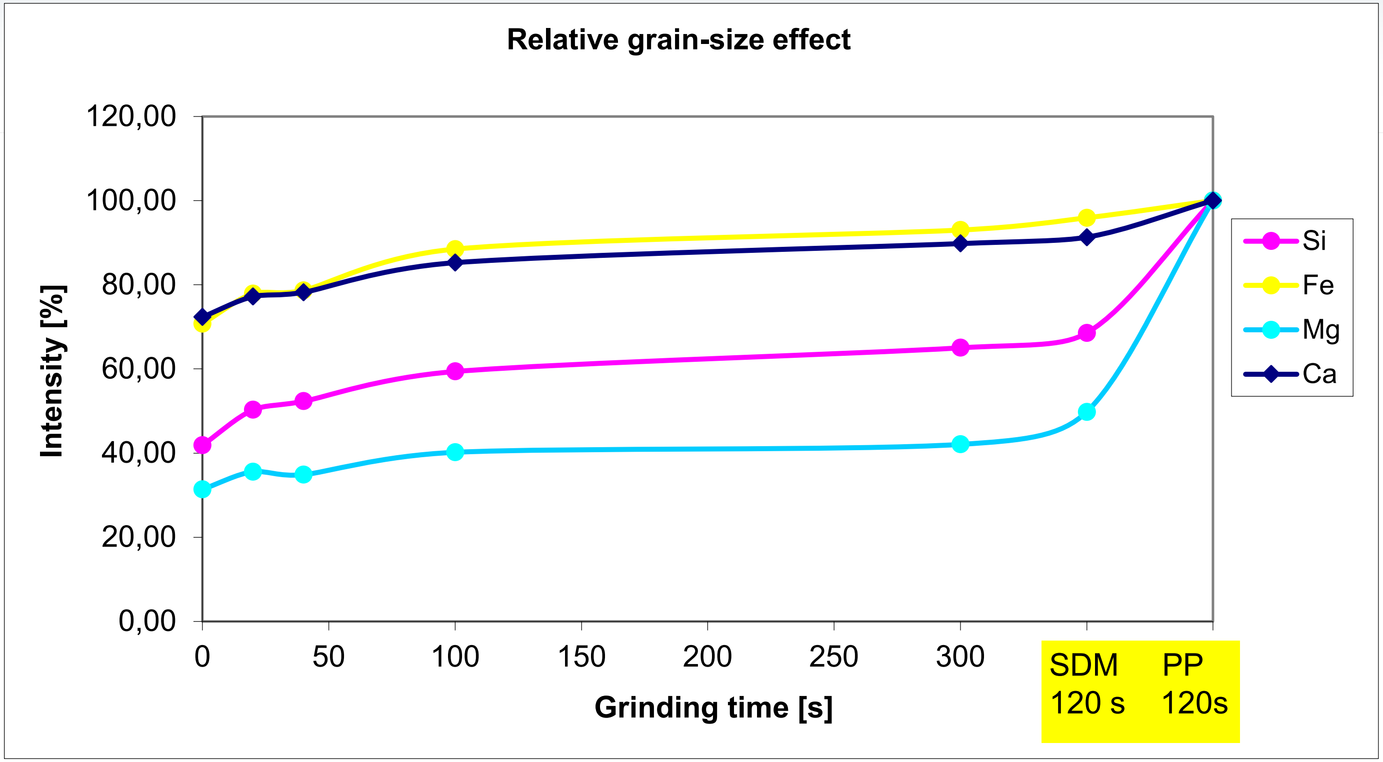
Con's

- More expensive equipment and consumables
- Higher dilution factor → not suitable for traces

Sample preparation
Pressed pellets

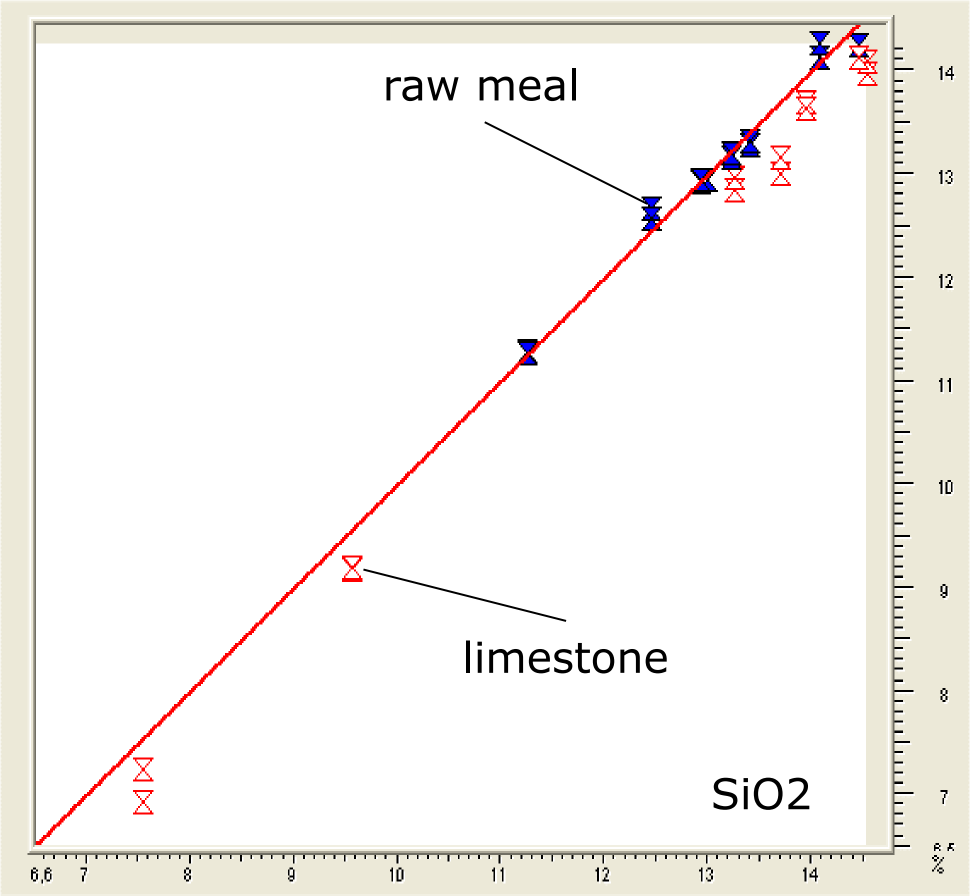
- Fast method
- Easily automatable
- Grain size and matrix effects are not problematic for material-specific calibrations
- But sample contamination via the grinding vessel:
- **Agate: SiO_2 99.91%; traces of Al, Na, Fe, K, Mn, Ca, Mg**
- **Corundum ceramic: Al_2O_3,** traces of K, Na, Si, Ca, Cu, Fe, Mg, Pb, B, Cr, Li, Mn and Ni
  - **Tungsten carbide: C 6%, Co 6% and W 88%**
  - **Chromium steel:** C 1.93%; **Cr 13.21%, Traces of** Cu, Mn, Mo, Ni, P, Si, S, W

Sample preparation
Pressed pellets



- Grinding was originally carried out with a mortar grinder (0-300 s). The grain size could only be reduced minimally.
- SDM = vibrating disc mill is used today to optimally reduce the grain size
- PP = A press pellet was produced from the SDM sample

Sample preparation
Pressed pellets

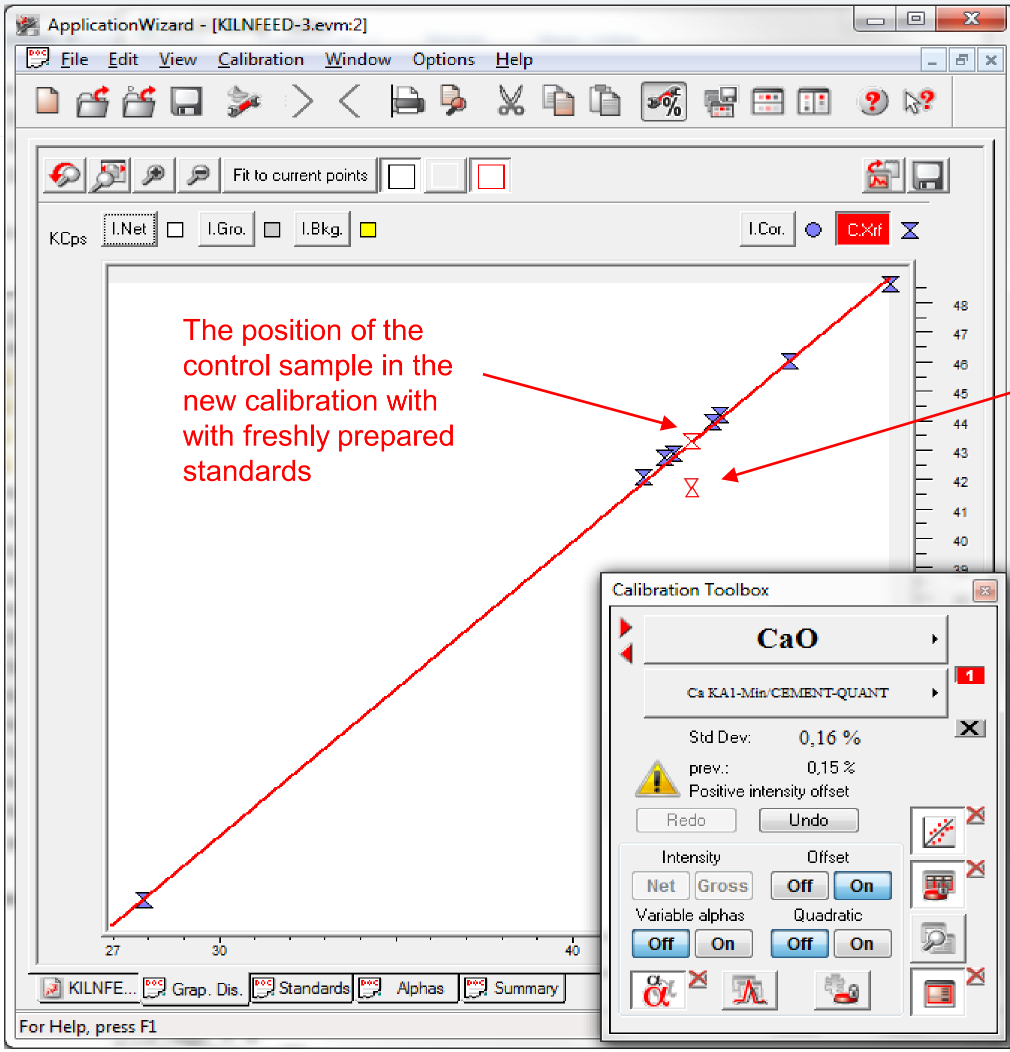


Raw meal and limestone

Matrix and grain size effects not compensated

Solution:
Separation of methods

Sample preparation
Pressed pellets



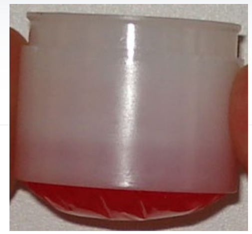
The position of the control sample in the old calibration with old standards

Check control standards again and again with a fresh preparation

Influence for loose powders and liquids

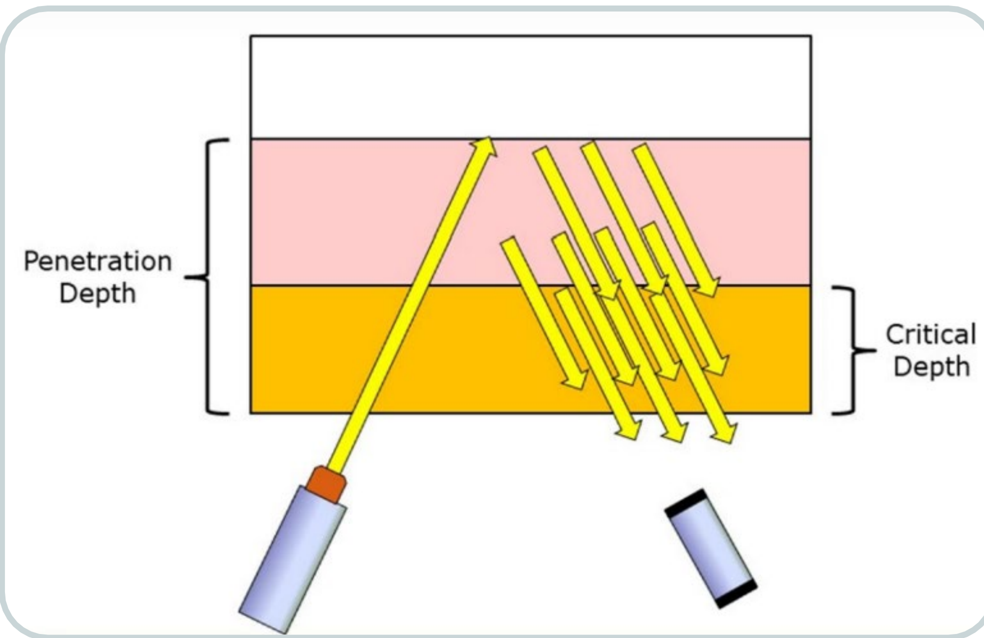
R(kcps) = f (1/d²)

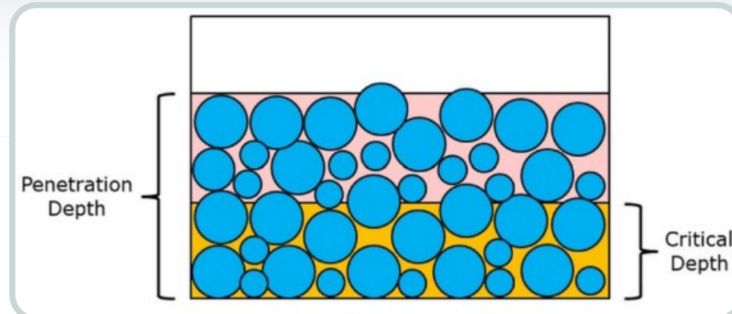
Δd Anode to sample

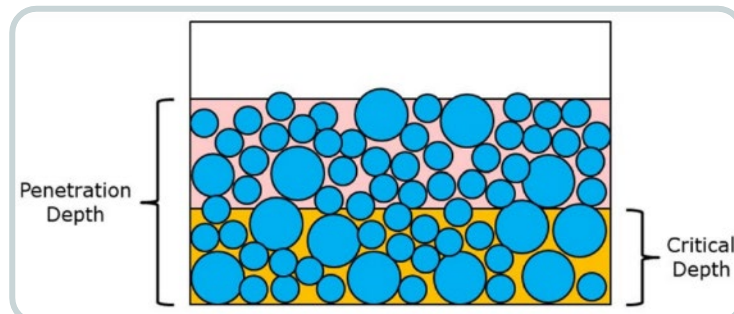


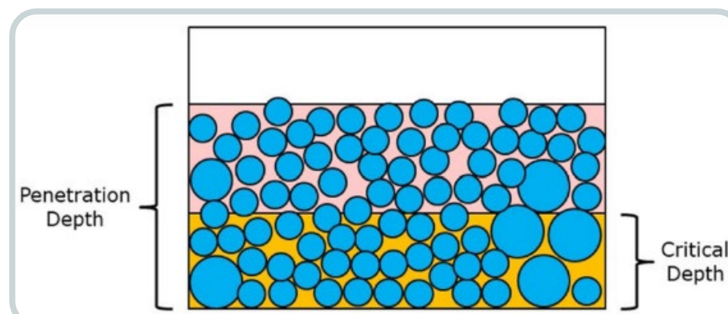
Sample not flat:

→ Distance- and shadow-effect



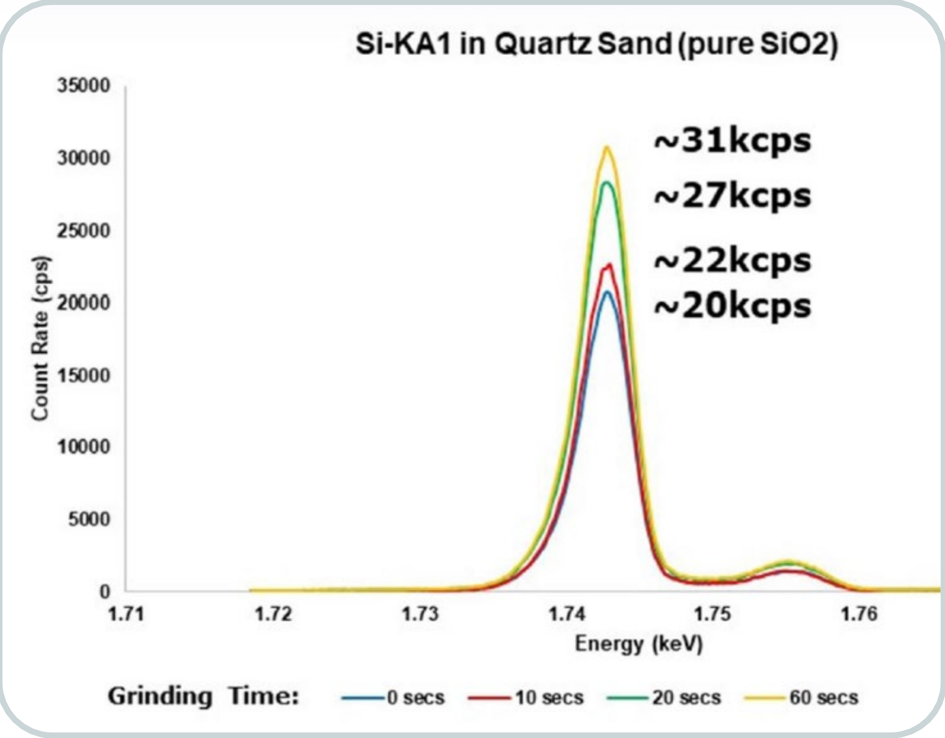


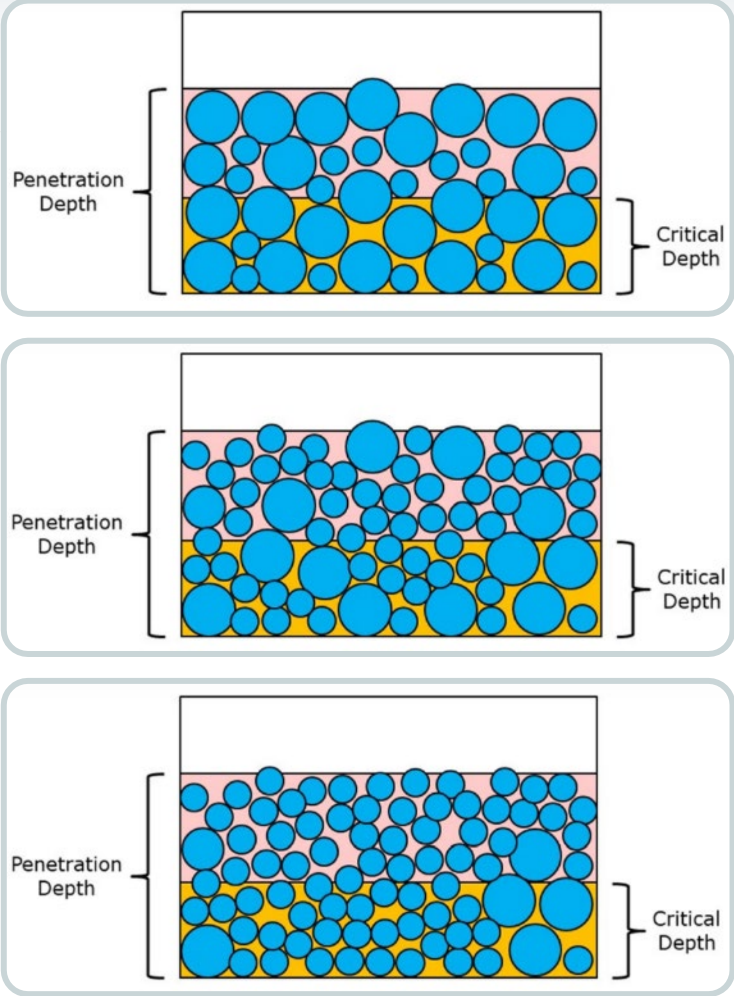




Sample preparation
Grinding

Example: Influence of the grain size





Sample preparation
Thickness of pressed pellet

Z	Element	Line	Energy (keV)	Graphite	SiO2	Fe	Pb
5	B	KA1	0.1833	5.0	1.0	0.3	0.1
9	F	KA1	0.6768	5.0	3.0	0.4	0.3
11	Na	KA1	1.0419	16.0	10.0	0.9	0.9
13	Al	KA1	1.4875	45.0	26.0	2.0	2.0
14	Si	KA1	1.7412	72.0	40.0	4.0	3.0
20	Ca	KA1	3.6910	684.0	88.0	28.0	4.0
56	Ba	LA1	4.4640	989.0	98.0	43.0	5.0
22	Ti	KA1	4.5104	1.3	156.0	47.0	6.0
25	Mn	KA1	5.8981	2.8	338.0	96.0	12.0
26	Fe	KA1	6.4031	3.6	430.0	119.0	15.0
29	Cu	KA1	8.0481	7.1	838.0	28.0	26.0
74	W	LA1	8.3976	8.0	949.0	31.0	29.0
82	Pb	LA1	10.5512	15.0	1.9	57.0	52.0
40	Zr	KA1	15.7749	4.4	6.0	176.0	43.0
42	Mo	KA1	17.4791	5.5	8.0	234.0	47.0
45	Rh	KA1	20.2158	7.3	12.0	355.0	70.0
47	Ag	KA1	22.1630	8.5	16.0	460.0	89.0
56	Ba	KA1	32.1929	13.1	4.0	1.3	242.0

(yellow) = cm (green) = mm (blue) = µm

From hand-picked sample to concentrate: Which analytics should I choose?

Hand-held XRF
- Ideal for quick assessment in the field or check of a truck load

Micro-XRF
- Great tool for exploration / drill cores

Online XRF
- Fastest way to check the quality on your conveyor belt and monitor the production process

EDXRF
- Quick and reliable grade control – mainly for major and minor elements

Benchtop WDXRF
- Grade control down to the ppm level

Sequential, full-power WDXRF
- Combining high throughput with accuracy and precision for most elements and concentrations

Multi-channel WDXRF
- Fastest quality check but not flexible regarding changing requirements

S2 KODIAK
Online XRF

Online XRF multi-element analyzer for real-time results in mining of base metal ores, and industrial minerals:

- Analysis of major, minor and trace elements
- Real-time analysis of fines and lumps up to > 30 cm diameter
- Covers K – U for lumps
- Covers Si – U for fines
- Handling of dry and humid materials
- Integration time from 1 s upwards

- In mining, mineral beneficiation and blending

S2 KODIAK
Benefits for Mining Applications

- The S2 KODIAK can trigger automated rock sorting with predefined cut-off levels
- Real-time screening of ore grades
- Mineral beneficiation
  - Enhanced recovery rate and higher ore grades
- Blending
  - Produce homogenous ore grades
  - Use highest grade ores sparsely
- Shipping:
  - No penalty claims from ore buyers

S2 KODIAK
Mining Applications

- Exploitation in surface and underground mining
  - Copper
  - Iron
  - Mangan
  - Multimetal
  - Uranium
  - Coal
  - Industrial minerals

- Material sorting and separation of waste rocks when
  - Loading, hauling, crushing, milling, flotation, leaching, concentrating, drying, shipment

S2 KODIAK
Ready for 24/7 operation

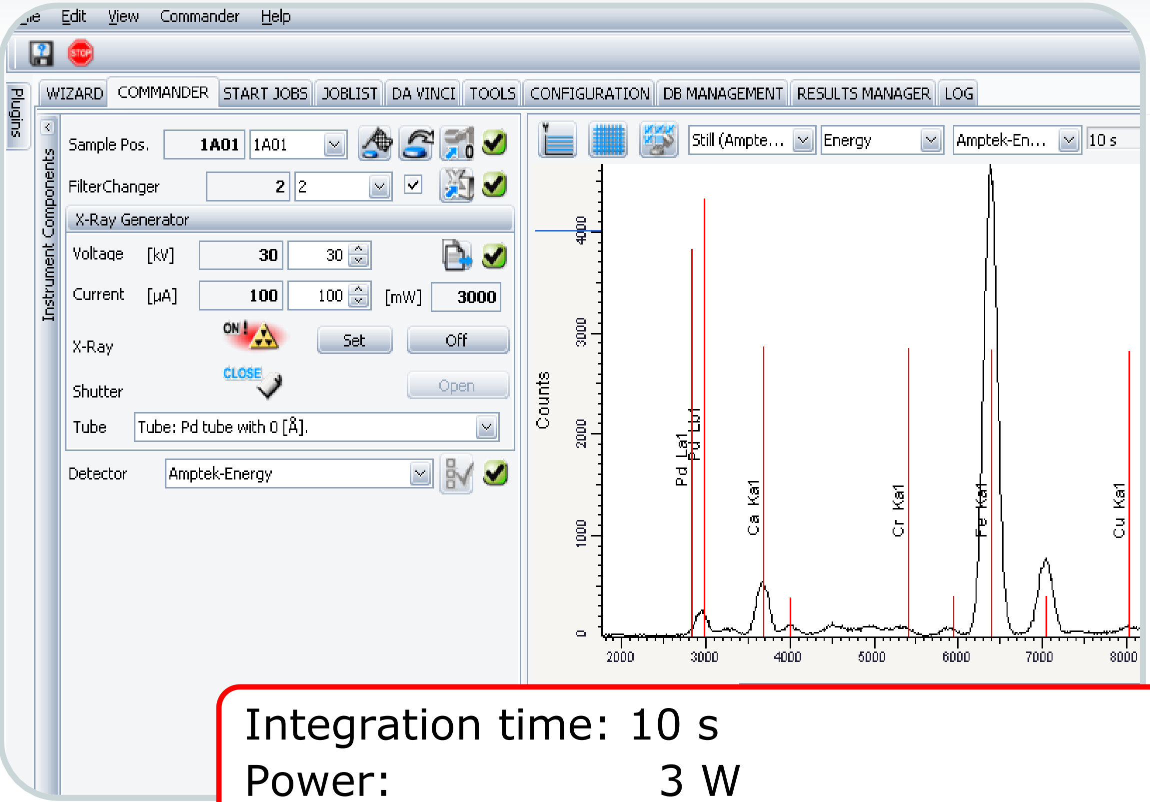
- Autonomous operation 24/7
- Integrated UPS, camera and distance sensor
- TCP/IP data transfer to any plant control SW
- Maintenance-free operation, operates with electrical power only
- Optimal occupational health and safety, operates without radioactive sources

- Corrossion resistant, rugged design (V2A)
- Enhanced cooling concept
- Prepared for rough mining enviroments
- Enclosure protection class
  Storage/cleaning mode: IP69K
  Acquisition mode: IP65

S2 KODIAK
Installation at tungsten mine

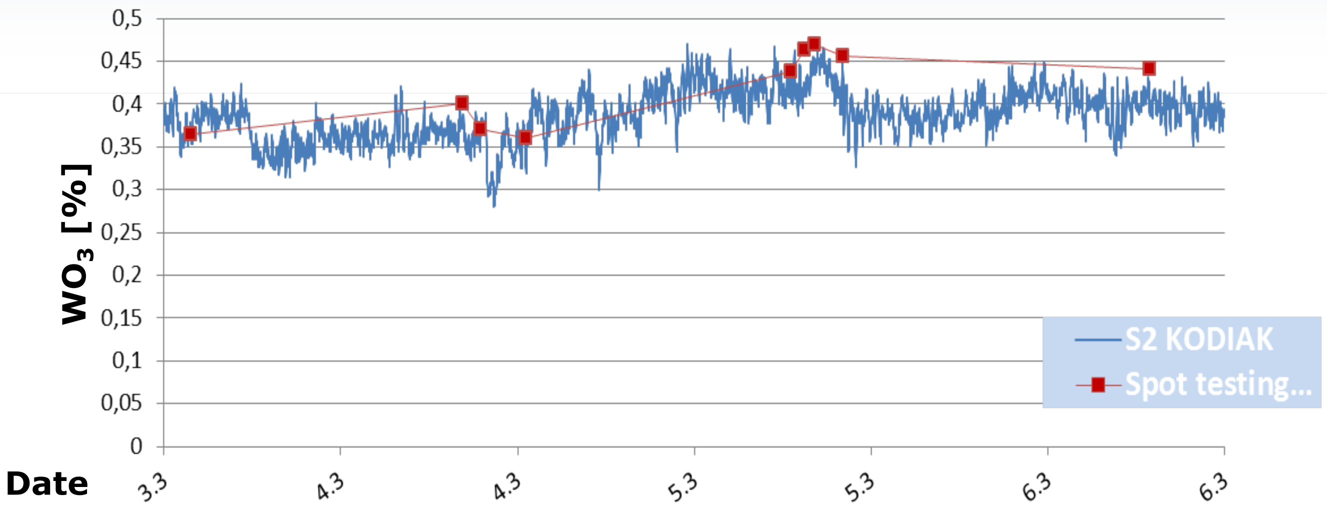
S2 KODIAK, compact, fully radiation safe housing, installed top of the belt
Positioned after first mill, before second mill to analyze feedstock of flotation

Tungsten Ore
Live View of Sample Spectrum



Integration time: 10 s
Power: 3 W
Excitation: 30 kV
Analysis of: K, Ca, Ti, Cr, Mn, Fe, Cu, W, Zn, Mo

S2 KODIAK
Real versus lab based results



- Excellent match between lab based spot testing and S2 KODIAK
- Better adjustment of flotation parameters based on S2 KODIAK:
    - Drop in concentration of WO_3 on 4.3 and 5.3. is only seen with S2 KODIAK
    - Excesson 6.3. in a short period of time
- **Enhance recovery rates possible**

Project Overview
Application Concentrate

- Analysis of Copper Concentrate material
  - **Sorting of concentrates**
    - High copper content, low contamination content
    - Low copper content, higher contamination content

  - blending process to from homogenized final product

  - The concentrate is typically composed as follows:
    - Cu: 10wt% – 50wt%
    - Fe: 10wt% - 30wt%
    - Contaminants: As, Zn, Bi, Se

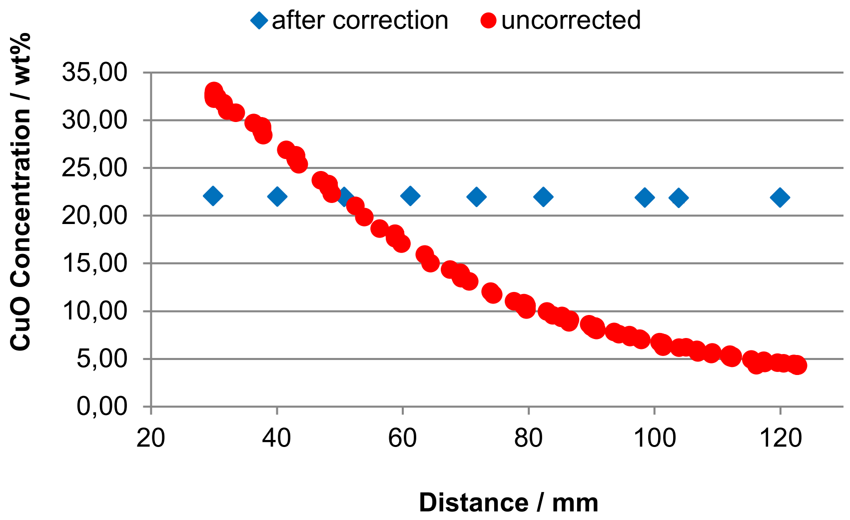
  - Material size: Fines

S2 KODIAK
Distance correction

- Material height variation on the belt
- S2 KODIAK operates with
  - Sample height control
  - Integrated ultrasonic sensor
  - Internal Standardization (Argon peak)
  - Software algorythm

Std.Dev.	CuO	Fe2O3
Abs.	0.07 wt%	0.3 wt%
Rel.	0.3 %	1.5 %

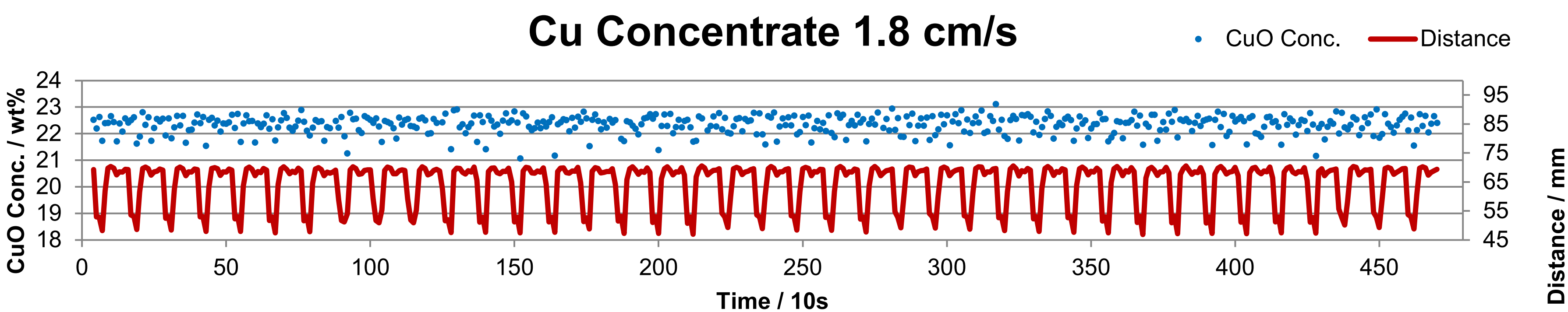
Impact of Distance Correction

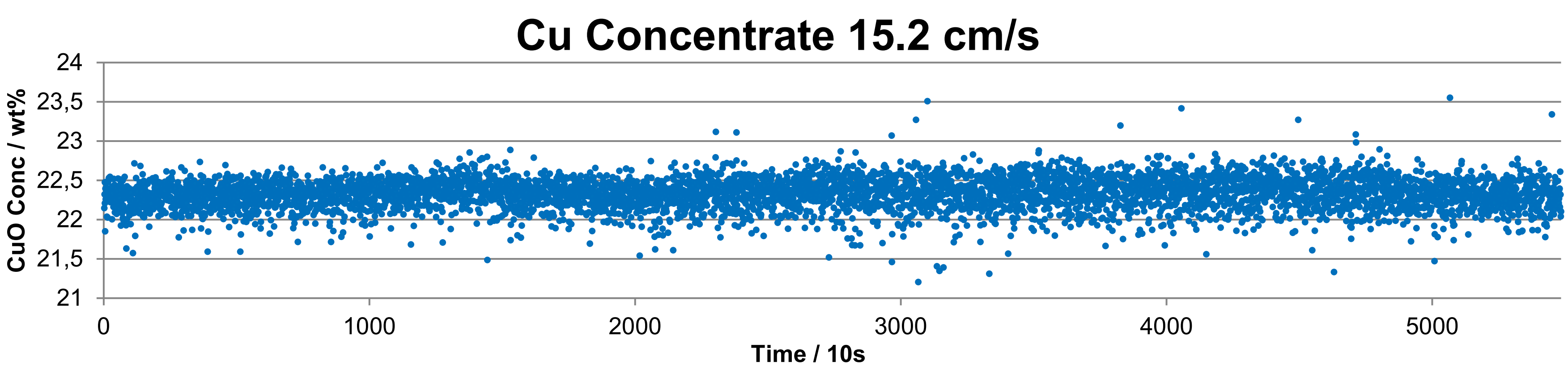


Dynamic Measurements – Cu Concentrate

- Stability test: one weekend; ca. 17 h evaluated

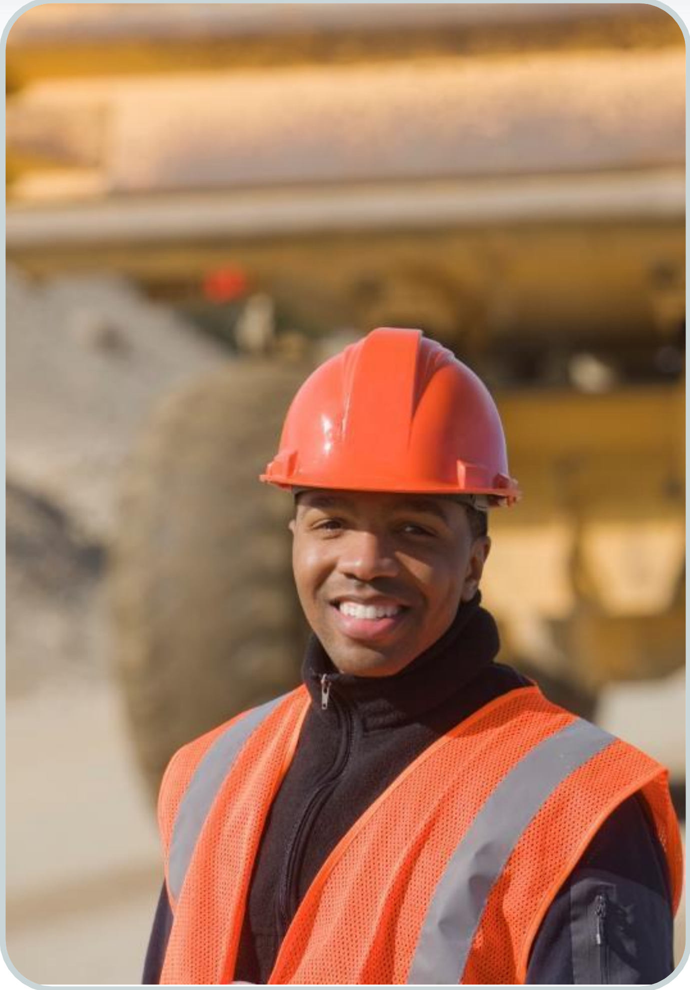
	CuO Conc / wt%	Std. Dev. / wt%	Rel. Dev. / %
1.8 cm/s	22.36	0.34	1.6
15 cm/s	22.30	0.34	1.6





Summary
S2 KODIAK Online XRF

- Within 10 s integration time different fe grades can be determined and values being used for blending and shipment control
- Continuous unattended operation possible
- Arsenic, manganese, calcium possible to integrate w/o additional measurement time
- Depending on origin different methods can be loaded remotely to the S2 KODIAK

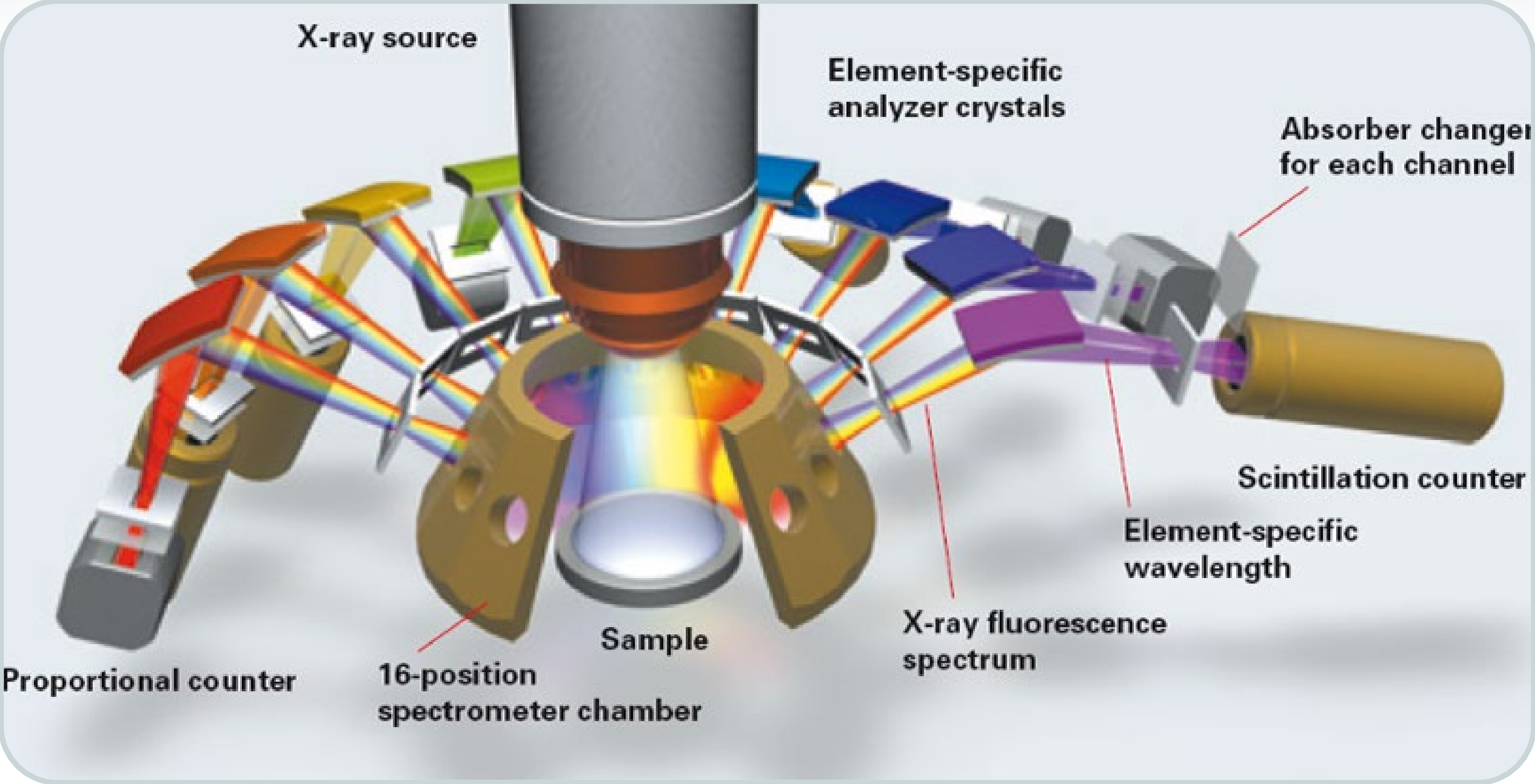


Bruker SIM WDXRF Portfolio
For process control in heavy industries

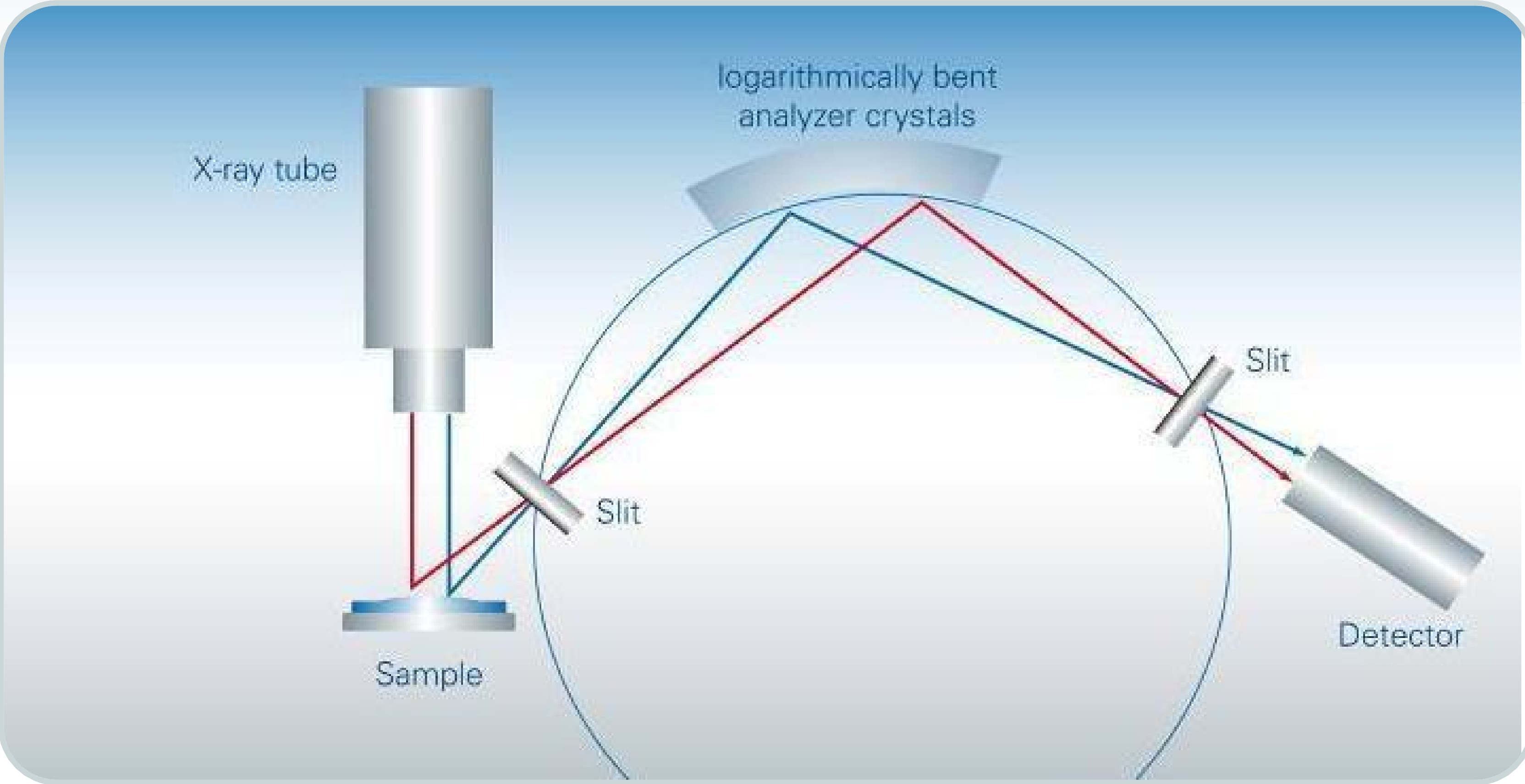
The S8 LION is our solution for fast, precise and accurate industrial process control in

- Cement
- Industrial minerals
- Base metal mining
- Iron and steel
- Non-Ferrous (Al-Base, Cu-Base)
- Commercial service labs

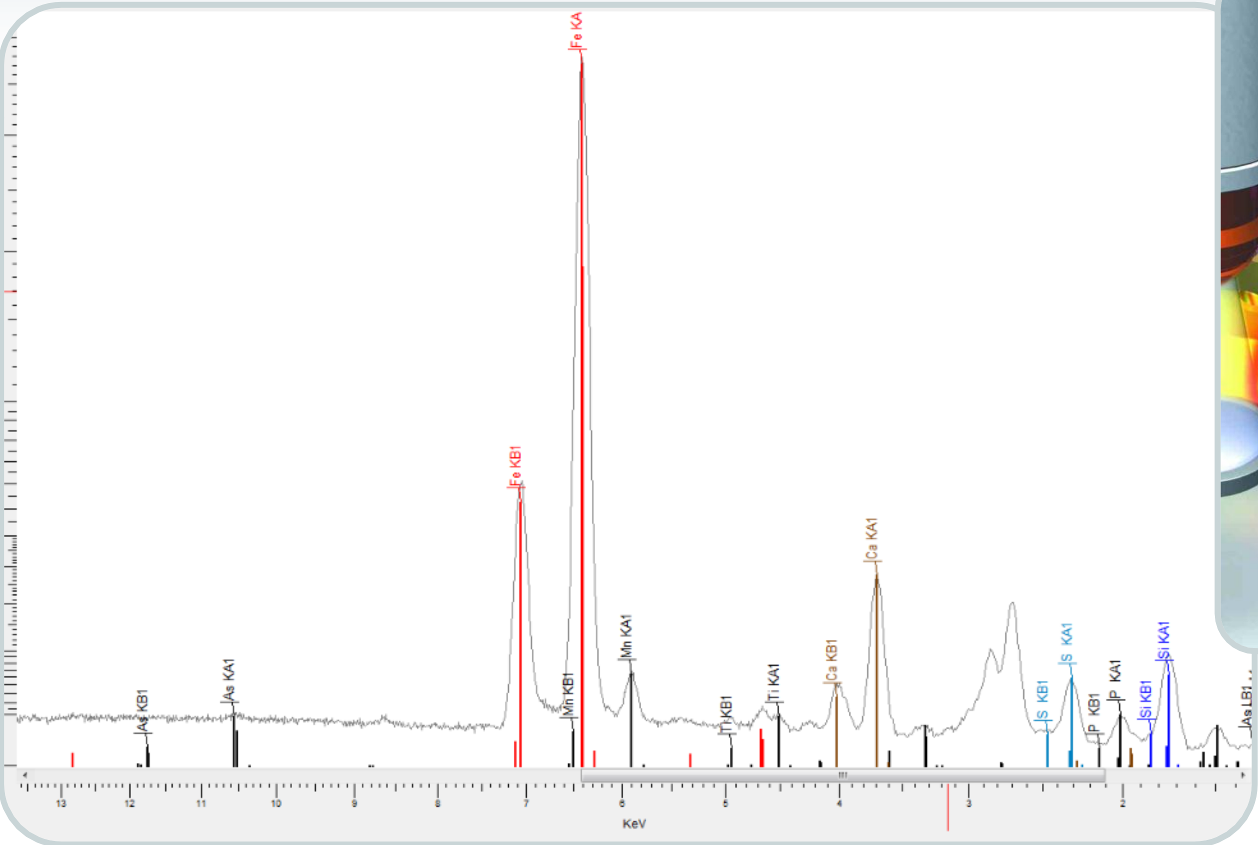
S8 LION
Spectrometer Setup

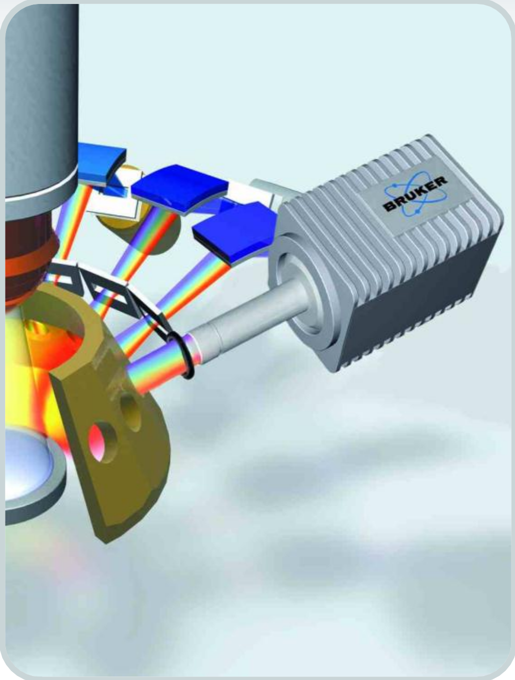


S8 LION
Rowland Circle Geometry



Spectrum Iron Ore - MEC
Dual Mode Data Acquisition





Parallel Measurement of SEC (WDX) and Multi Element Channel
Identification of trace elements, internal backup (second information source)

S8 LION
For central labs and mining service labs

Optimized for highest throughput and optimal cost effciency

Autonomous operation 24/7

- 90 samples in 6 racks
- 15 samples per rack

In addition to the internal loader

- with 10 positions or,
- with 8 position in combination with online sample feed from automated sample preparation

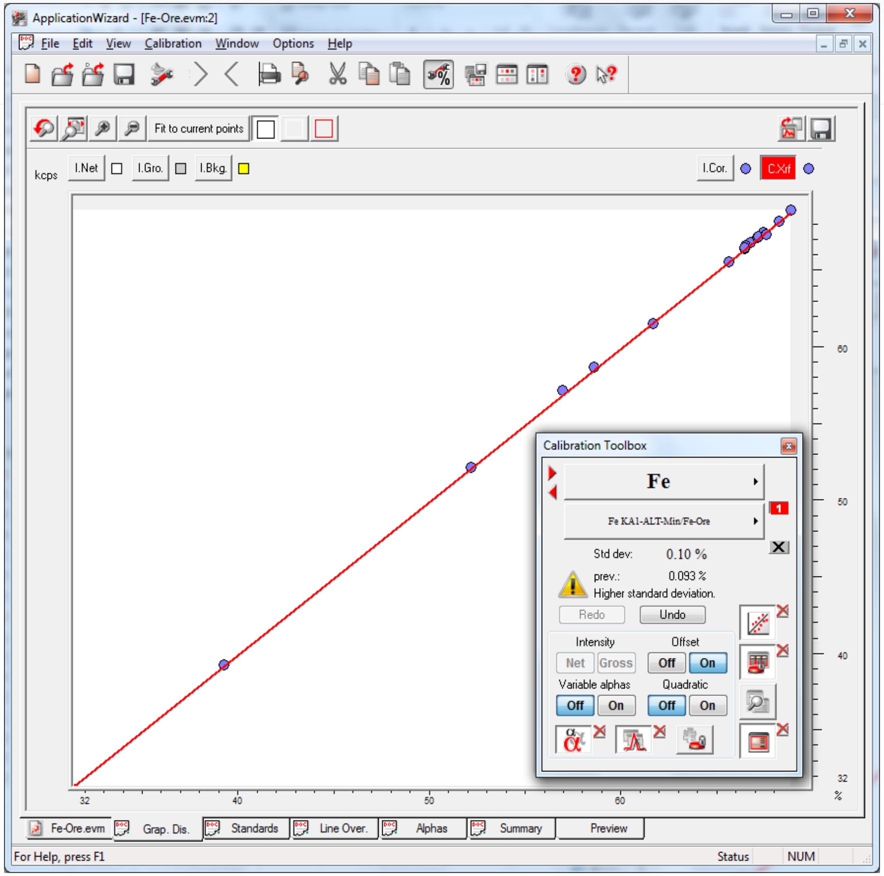
Add an MEC for extra flexibility

Application Example: Iron Ore

Iron Ore Analysis done to:

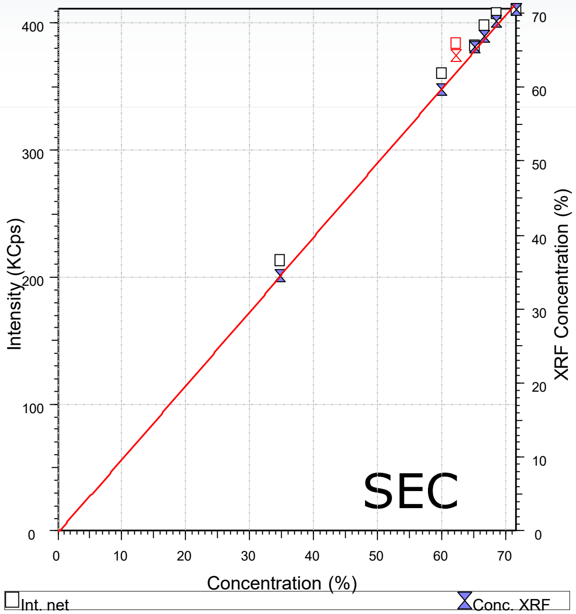
- Evaluate the commercial value (mainly Fe total)
- Control the mining process and the refining process
- Highest accuracy and precision in combination with high sample throughput is needed

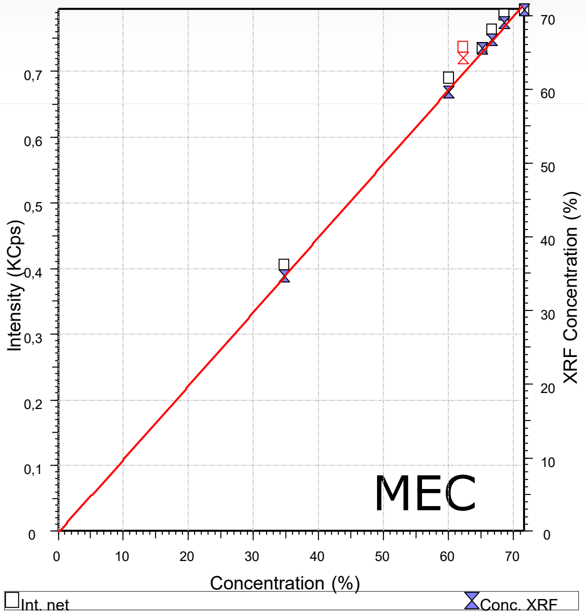
S8 LION – Iron Ore Pressed Pellets



- Calibration curve for Fe ($R^2 = 0.99983$)
- Elements covered: Fe, Si, Ca, Mn, Al, Ti, Mg, P, S, K, Cr, Co, Ni, Zn

More information with the Multielement Channel MEC





Calibration Details for Fe: Range 34.67 -71.50 %

Fe (Single Element Channel) – LiF 200:

Calibration Std. Dev.: 0.563 %

Fe (Multi Element Channel) – SDD:

Calibration Std. Dev.: 0.503 %

S8 LION – Iron Ore
Repeatability of Pressed Pellets

	Fe [%]	SiO2 [%]	CaO [%]	Mn2O3 [%]	Al2O3 [%]	TiO2 [%]	MgO [%]	P2O5 [%]	SO3 [%]
Rep 01	67.18	1.20	0.045	1.02	0.814	0.033	0.262	0.037	0.102
Rep 02	67.18	1.20	0.045	1.02	0.808	0.033	0.262	0.037	0.102
Rep 03	67.21	1.20	0.045	1.02	0.812	0.033	0.261	0.037	0.105
Rep 04	67.19	1.20	0.045	1.02	0.811	0.034	0.263	0.037	0.106
Rep 05 - 16	…	…	…	…	…	…	…	…	…
Rep 17	67.20	1.20	0.045	1.02	0.812	0.034	0.261	0.037	0.121
Rep 18	67.18	1.21	0.045	1.02	0.815	0.033	0.263	0.037	0.123
Rep 19	67.20	1.20	0.045	1.02	0.811	0.033	0.262	0.037	0.123
Rep 20	67.15	1.20	0.045	1.02	0.812	0.033	0.262	0.037	0.124
Min. [%]	**67.14**	**1.199**	**0.045**	**1.018**	**0.808**	**0.033**	**0.260**	**0.037**	**0.102**
Max. [%]	**67.21**	**1.210**	**0.045**	**1.020**	**0.816**	**0.034**	**0.264**	**0.038**	**0.124**
Mean value	**67.17**	**1.203**	**0.045**	**1.019**	**0.813**	**0.033**	**0.262**	**0.037**	**0.114**
Abs. Std. Dev.	**0.022**	**0.003**	**0.000**	**0.001**	**0.002**	**0.000**	**0.001**	**0.000**	**0.007**
Rel. Std. Dev. [%]	**0.033**	**0.22**	**0.56**	**0.058**	**0.27**	**1.03**	**0.28**	**0.75**	**6.06**

Time per sample: 1:40 min

S8 LION for Incoming Material Inspection Iron Ore/Sinter

- According to ISO 9516 (WDXRF)
- Fused beads
  - At commercial and service labs
  - At central labs
  - At customs
- Maximum 60 s measurement time
- Excellent long-term precision for 200 measurements

Sample	Average (%)	Abs. Std. Dev. (%)	Rel. Std. Dev. (%)
Fe (%)	**47.065**	0.013	0.028
SiO_2 (%)	**0.673**	0.006	0.869
P (%)	**0.031**	0.001	0.746
Al_2O_3 (%)	**4.081**	0.014	0.334
Mn (%)	**15.348**	0.016	0.102
CaO (%)	**0.032**	0.001	1.867
MgO (%)	**0.032**	0.002	5.401
TiO_2 (%)	**0.023**	0.003	11.705
K_2O (%)	**0.160**	0.001	0.484

S6 JAGUAR
High Performance Benchtop WDXRF

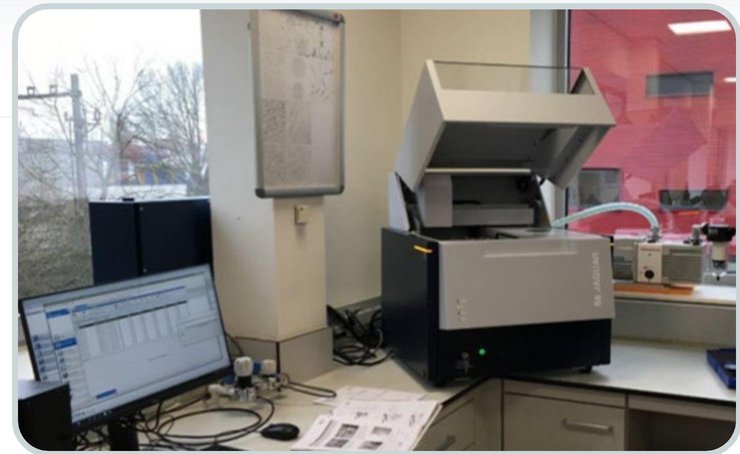
Maintain WDXRF resolution:

- Compact goniometer with high precision gears and closely coupled X-ray beam path
- Optimized analyzer crystals for the entire element range and special applications

Maintain analytical precision and sensitivity:

- Higher power X-ray tube compared to EDXRF (there is no saturation due to single element detection)
- HighSense detection with 2 Mcps count rate
- HighSense XE detector for medium and heavy elements

S6 JAGUAR
Customer feedback

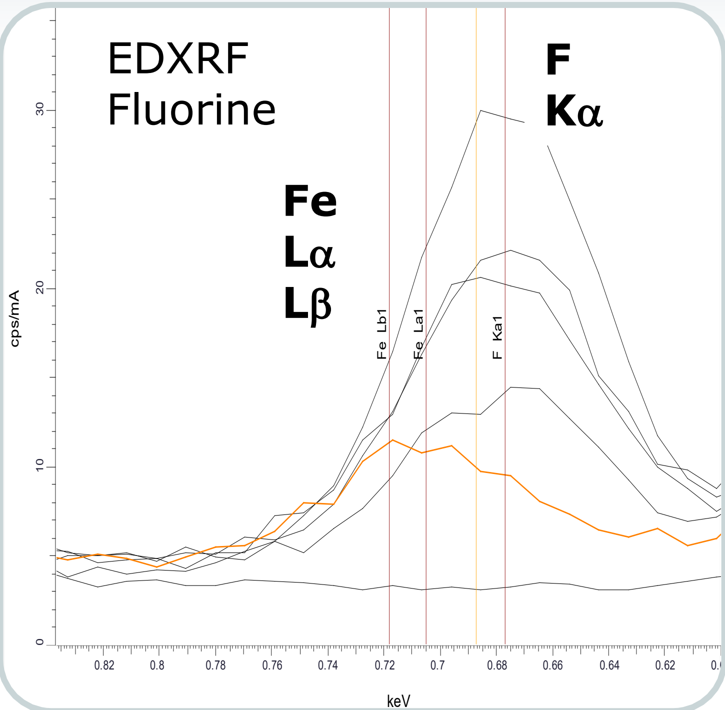


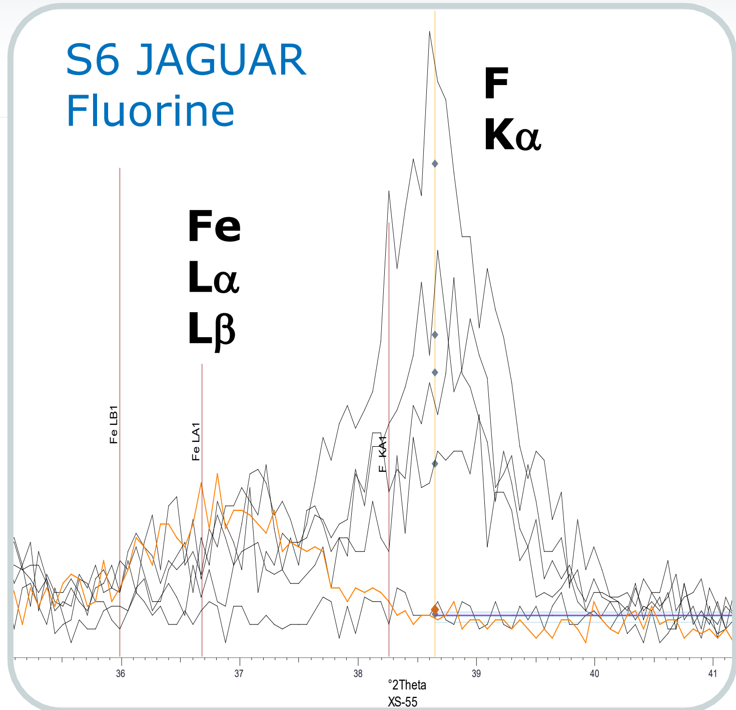
A world-famous manufacturer of refractory and foundry products was looking for a spectrometer for the analysis of main elements in magnesites, etc.,….

- In addition to traces, the analysis of fluorine was also important:
  - Is a large WDXRF spectrometer required?

The S6 JAGUAR showed excellent performance for light and important elements with optimal accuracy, surpassing EDXRF in particular for fluorine.

S6 JAGUAR versus EDXRF
F in Foundry Products

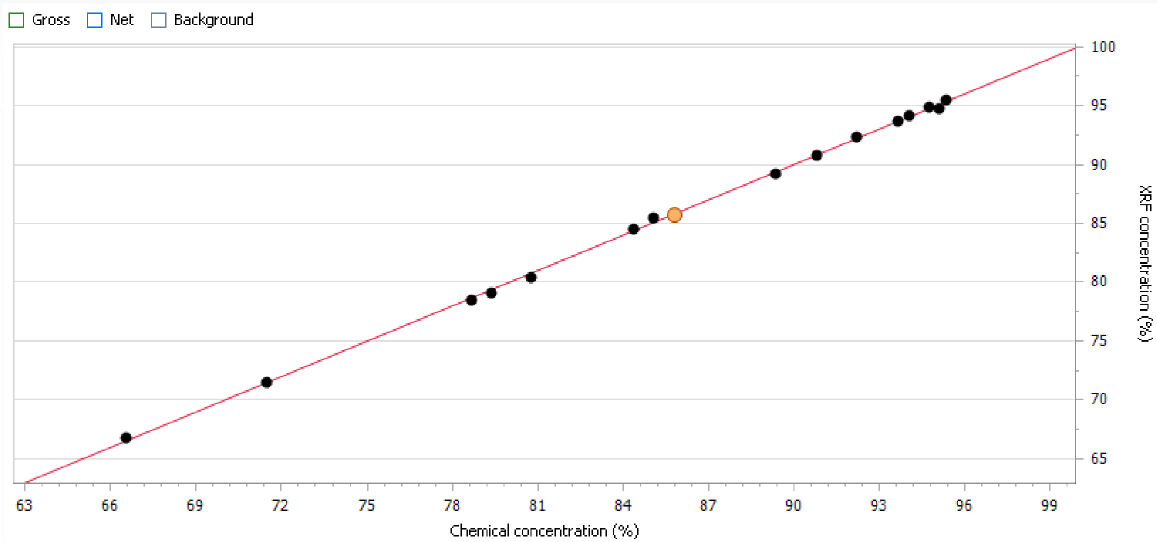




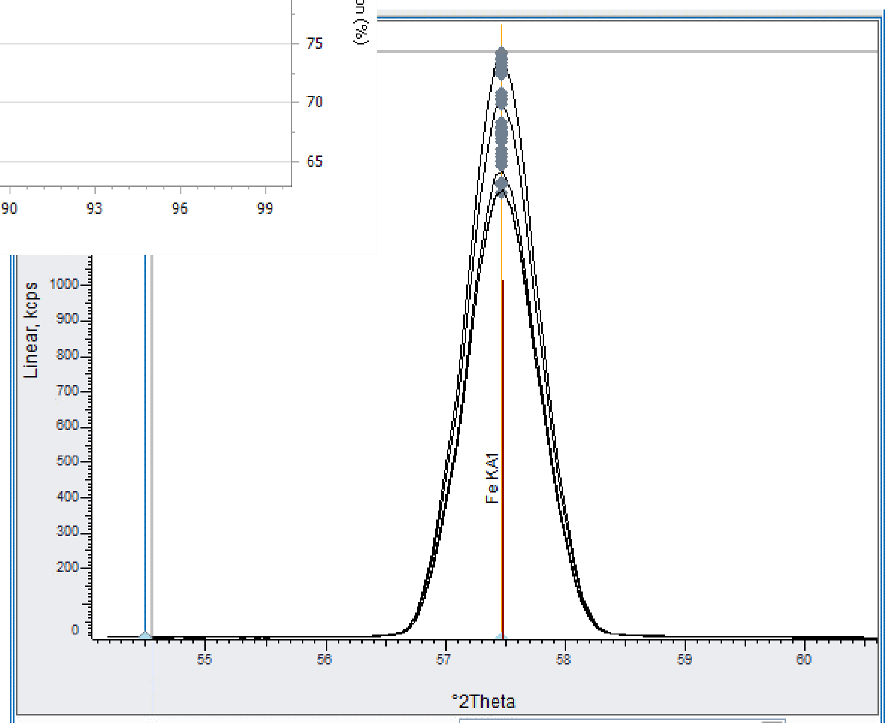
Strong overlap of F Ka and Fe La with **EDXRF** leads to medium accuracy and precision: **Min 3.59 % > 3.78 % < Max 4.07 %**

S6 JAGUAR: Optimal resolution, clear separation of both lines, high sensitivity with 400 W power: **Min 3.97 % > 4.03 % < Max 4.07 %**

S6 JAGUAR – Iron Ore Pressed Pellets



- Fe_2O_3 in Iron Ore > 60 % Fe_2O_3



- Fe Ka1 on LiF200 Scan

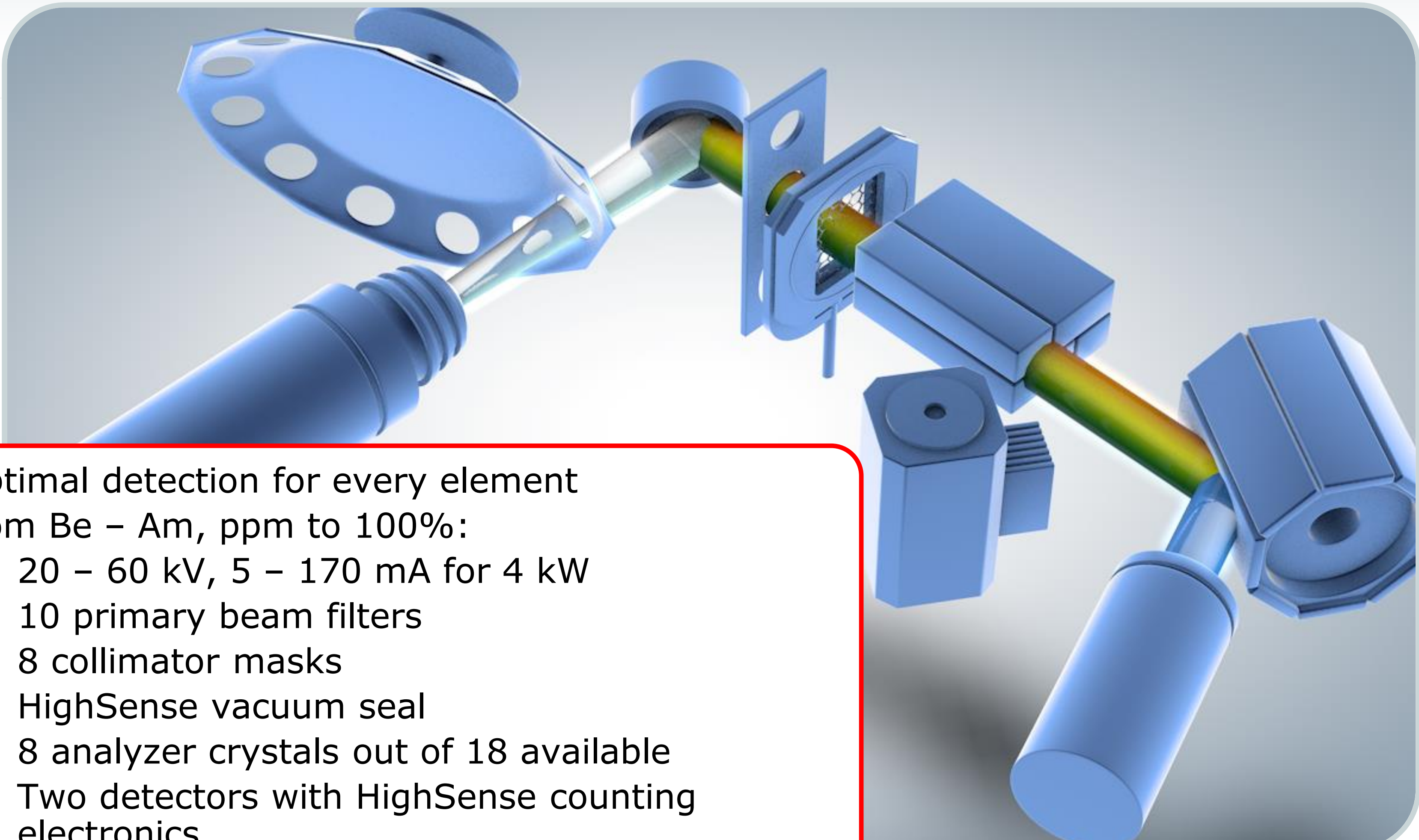
S6 JAGUAR – Iron Ore
Repeatability of Pressed Pellets

	Al2O3 [%]	SiO2 [%]	MgO [%]	MnO [%]	Fe2O3 [%]	TiO2 [%]	P [%]	S [%]
Rep 01	15.91	15.72	0.26	0.02	62.46	0.48	0.118	0.01
Rep 02	15.89	15.70	0.28	0.02	62.68	0.48	0.117	0.01
Rep 03	15.88	15.71	0.25	0.02	62.68	0.48	0.118	0.01
…	…	…	…	…	…	…	…	…
Rep 19	…15.88	15.70	0.26	0.02	…62.76	0.48	0.118	0.02
Rep 20	15.85	15.73	0.27	0.02	62.75	0.48	0.116	0.02
Rep 21	15.88	15.72	0.28	0.02	62.61	0.48	0.118	0.02
Mean value	**15.89**	**15.71**	**0.27**	**0.02**	**62.57**	**0.48**	**0.12**	**0.02**
Abs. Std. Dev.	**0.077**	**0.032**	**0.008**	**0.000**	**0.379**	**0.002**	**0.001**	**0.004**
Rel. Std. Dev. [%]	**0.48**	**0.20**	**2.95**	**0.00**	**0.61**	**0.46**	**0.55**	**19.31**

S8 TIGER Series 2 HighSense

- **HighSense Technology** for
  - Ultimate detection limits
  - Optimal sensitivity
  - Best precision
  - Enhanced light element sensitivity
  - Shortest measurement times
- **Optimal instrument configurations** for
  - Industry
    - Metals
    - Minerals & Mining
    - Petrochemistry
    - Cement
    - Chemistry & Pharma
    - Automotive
  - **Academia and Research**
    - Universities
    - Governmental labs
    - Industrial R&D

S8 TIGER Series 2
HighSense



Optimal detection for every element from Be – Am, ppm to 100%:

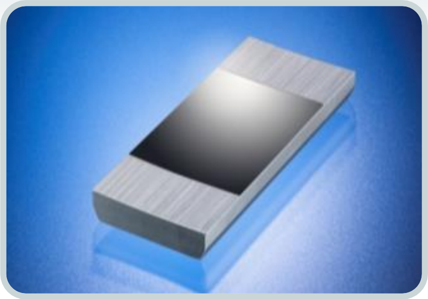
- 20 – 60 kV, 5 – 170 mA for 4 kW
- 10 primary beam filters
- 8 collimator masks
- HighSense vacuum seal
- 8 analyzer crystals out of 18 available
- Two detectors with HighSense counting electronics

S8 TIGER Series 2
HighSense: Analyzer Crystals

BRUKER

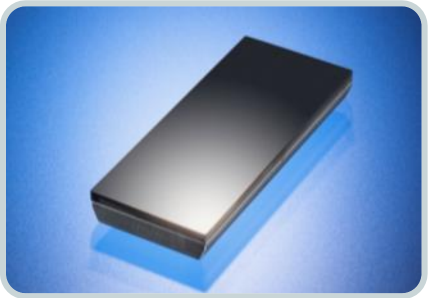
8 position crystal changer

- More than 18 different crystals available:



optimized **HighSense** crystals:

- XS-CEM: long-term stable, temperature independent
- XS-GE-C: plus 40% intensity for P, plus 20% intensity for S
- XS-PET-C: plus 20 % intensity for Al
- XS-B: plus 100% intensity for B
- XS-N-HS: plus 100% intensity for N
- XS-C: 30% reduced background for C
- XS-100 time optimized measurement
- 25% time savings
- XS-400 plus 35 % more intensity in the range of K to U



S8 TIGER Series 2
HighSense: Counting Electronics

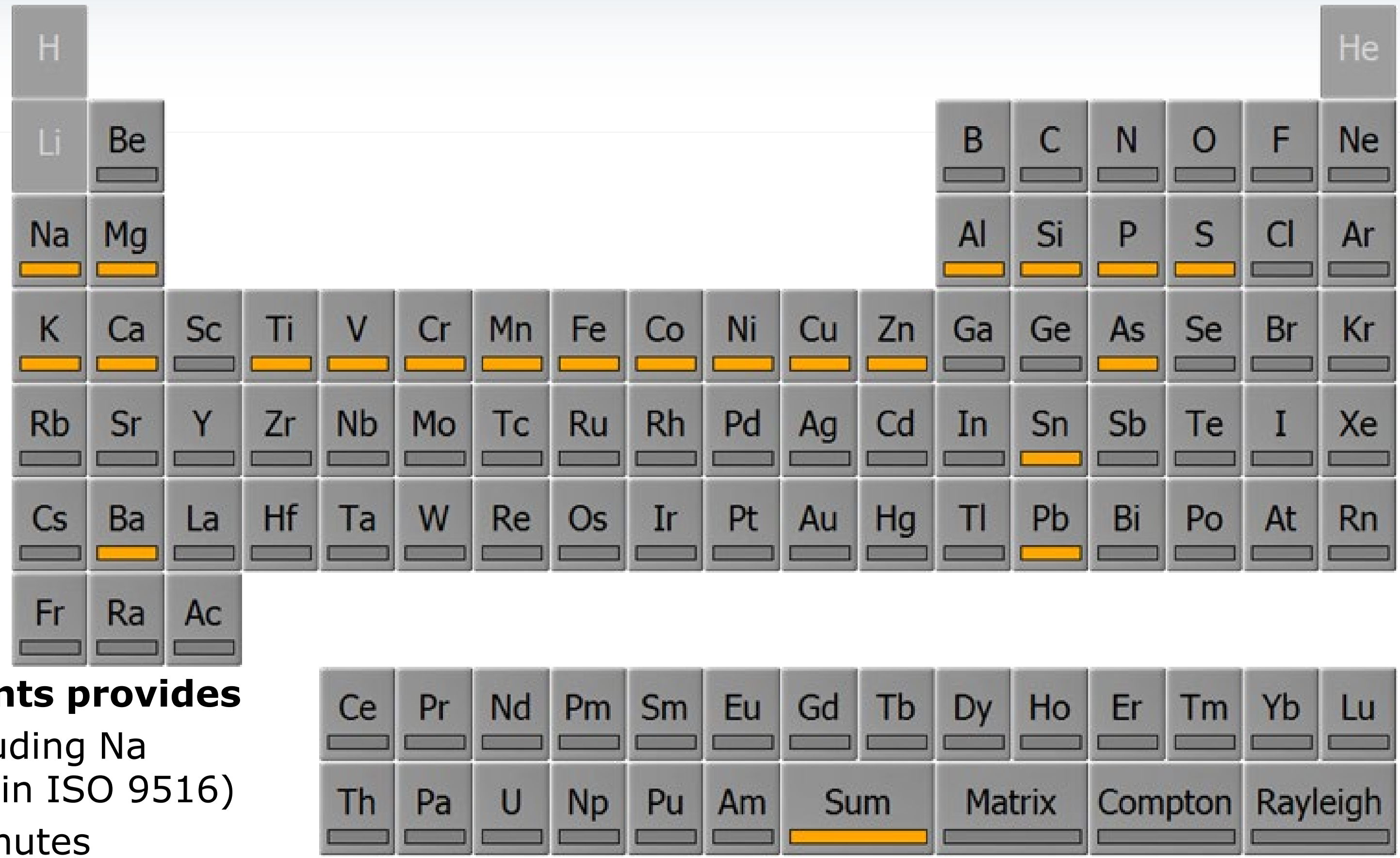
- **HighSense counting electronics**
  - Quick application setup with instant display of PHA scan
  - On-the-fly dead time correction with fast data processing
  - Advanced MCA technology

- Excellent detector linearity
  - FC: up to 4 Mio cps
  - SC: up to 4 Mio cps
  - DynaMatch: up to 13 Mio cps
  - Five times better than conventional WDX spectrometers

- Better analytical precision
- Faster measurements
- Easy application setup due to wide range calibration

GEO-QUANT Iron Ore

Norm compliant Analysis of Iron Ore (ISO 9516)



Selection of elements provides

- 21 elements including Na (Na not required in ISO 9516)
- Typically ~16 minutes
- Correct occurring line overlays of the elements
- Matrix effects

GEO-QUANT Iron Ore
Concentration Range

	GEO-QUANT Iron Ore		ISO 9516	
	Min [%]	Max [%]	Min [%]	Max [%]
Fe_2O_3	18.9	97.0	54.3	100.0
SiO_2	0.6	36.3	0.42	13.9
CaO	0.01	15.8	0.03	17.8
Mn_3O_4	0.021	2.0	0.03	1.1
Al_2O_3	0.1	11.5	0.19	6.6
TiO_2	0.005	10.7	0.03	7.8
MgO	0.02	8.32	0.33	3.3
P_2O_5	0.009	2.7	0.01	1.4
SO_3	0.007	2.3	0.1	1.5
K_2O	0.003	2.6	0.01	0.5
V_2O_5	0.002	0.8	0.003	0.5
SnO_2	0.0001	0.2	0.001	0.02
Cr_2O_3	0.001	0.2	0.001	0.04
Co_3O_4	0.002	0.2	0.001	0.03
NiO	0.001	0.2	0.014	0.017
CuO	0.008	0.2	0.015	0.08
ZnO	0.002	0.4	0.006	0,21
As_2O_3	0.112	0.1	0.01	0.08
PbO	0.004	0.56	0.02	0.34
BaO	0.0012	0.2	0.04	0.45

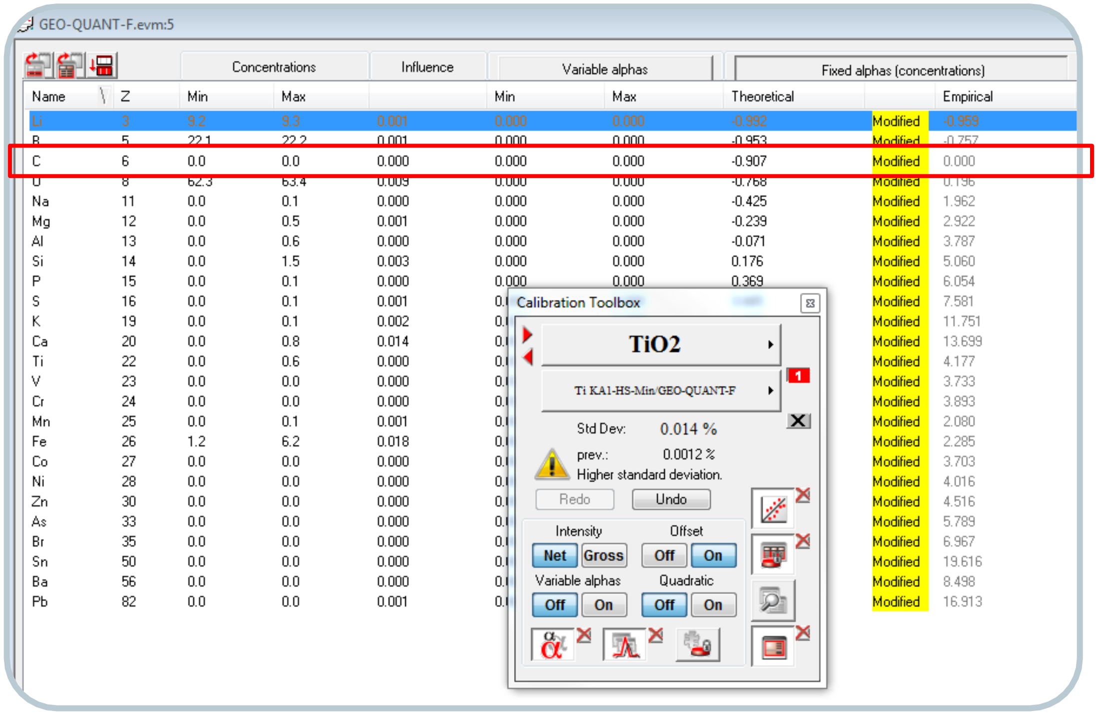
- Covers the ISO 9516 application range
- Includes low grade materials
- **QUANT package**
  - 16 certified reference materials (no synthetic standards)
  - Evaluation samples
  - User Manual
  - Preparation Manual

GEO-QUANT Iron Ore

Calibration details – Matrix Correction

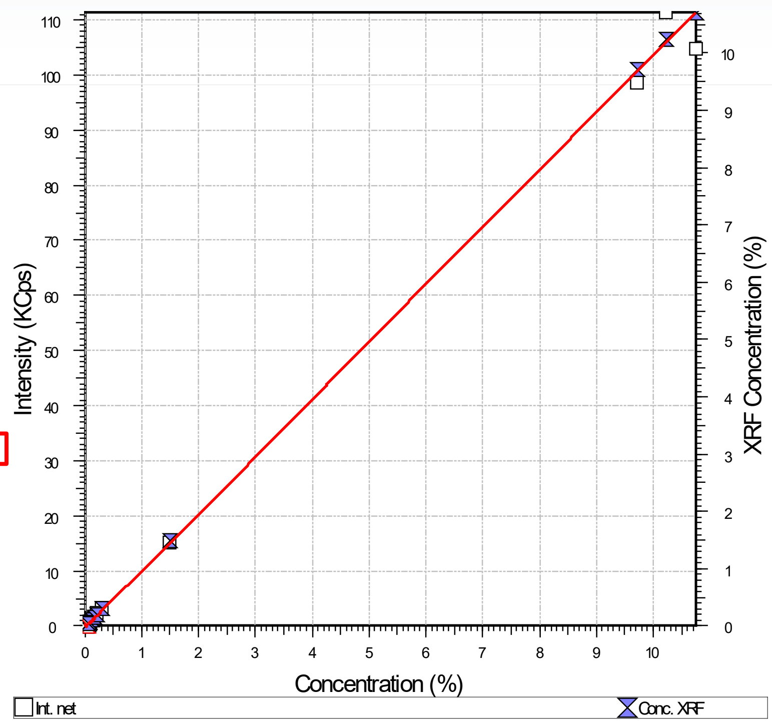
Matrix correction with loss eliminated alphas:

- Carbon is set to zero
- New set of alphas has to be calculated
- No further need for LOI determination



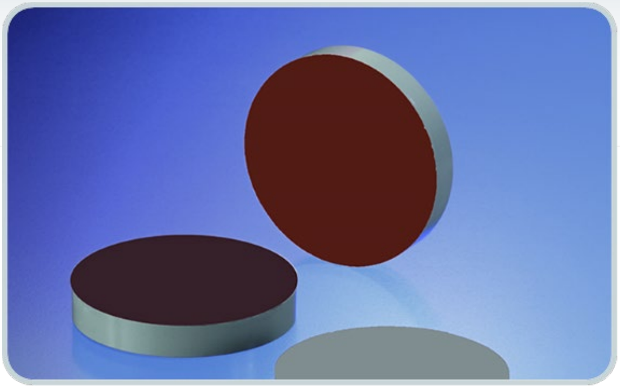
GEO-QUANT-F.evm:5

Name	Z	Concentrations Min	Concentrations Max	Influence	Variable alphas Min	Variable alphas Max	Fixed alphas (concentrations) Theoretical		Empirical
Li	3	9.2	9.3	0.001	0.000	0.000	-0.992	Modified	-0.959
B	5	22.1	22.2	0.001	0.000	0.000	-0.953	Modified	-0.757
C	6	0.0	0.0	0.000	0.000	0.000	-0.907	Modified	0.000
O	8	62.3	63.4	0.009	0.000	0.000	-0.768	Modified	0.196
Na	11	0.0	0.1	0.000	0.000	0.000	-0.425	Modified	1.962
Mg	12	0.0	0.5	0.001	0.000	0.000	-0.239	Modified	2.922
Al	13	0.0	0.6	0.000	0.000	0.000	-0.071	Modified	3.787
Si	14	0.0	1.5	0.003	0.000	0.000	0.176	Modified	5.060
P	15	0.0	0.1	0.000	0.000	0.000	0.369	Modified	6.054
S	16	0.0	0.1	0.001	0.[illegible]	[illegible]	[illegible]	Modified	7.581
K	19	0.0	0.1	0.002	0.[illegible]	[illegible]	[illegible]	Modified	11.751
Ca	20	0.0	0.8	0.014	0.[illegible]	[illegible]	[illegible]	Modified	13.699
Ti	22	0.0	0.6	0.000	0.[illegible]	[illegible]	[illegible]	Modified	4.177
V	23	0.0	0.0	0.000	0.[illegible]	[illegible]	[illegible]	Modified	3.733
Cr	24	0.0	0.0	0.000	0.[illegible]	[illegible]	[illegible]	Modified	3.893
Mn	25	0.0	0.1	0.001	0.[illegible]	[illegible]	[illegible]	Modified	2.080
Fe	26	1.2	6.2	0.018	0.[illegible]	[illegible]	[illegible]	Modified	2.285
Co	27	0.0	0.0	0.000	0.[illegible]	[illegible]	[illegible]	Modified	3.703
Ni	28	0.0	0.0	0.000	0.[illegible]	[illegible]	[illegible]	Modified	4.016
Zn	30	0.0	0.0	0.000	0.[illegible]	[illegible]	[illegible]	Modified	4.516
As	33	0.0	0.0	0.000	0.[illegible]	[illegible]	[illegible]	Modified	5.789
Br	35	0.0	0.0	0.000	0.[illegible]	[illegible]	[illegible]	Modified	6.967
Sn	50	0.0	0.0	0.000	0.[illegible]	[illegible]	[illegible]	Modified	19.616
Ba	56	0.0	0.0	0.000	0.[illegible]	[illegible]	[illegible]	Modified	8.498
Pb	82	0.0	0.0	0.001	0.[illegible]	[illegible]	[illegible]	Modified	16.913



Elemental Analysis of Ni-Laterite Ore
Fast and reliable with the S2 PUMA Series 2

Nickel Laterite (low grade nickel ore) will likely be the **dominant source of nickel** in the foreseeable future.



EDXRF is used for grade control in mining operations and smelters. It allows, e.g.,

- accurate determination of Ni
- analysis of waste rock elements
  - Ca, Mg, Fe, Mn
- evaluation of traces
  - Ti, Cr, Co, Cu, Zn

- Bruker is a trusted EDXRF supplier with many S2 PUMA installations at Ni-Laterite mines
- Time-to-result, ease-of-use, and flexibility are major benefits of the S2 PUMA with XY Autochanger

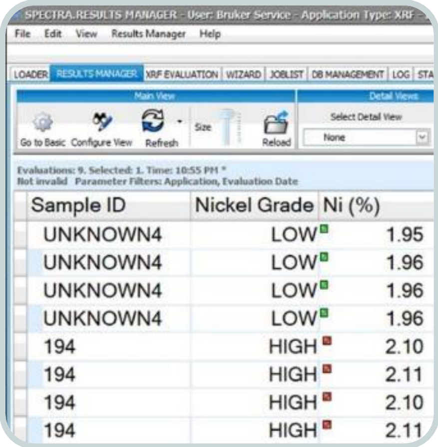
Elemental Analysis of Ni-Laterite Ore
Fast and reliable with the S2 PUMA Series 2

The New S2 PUMA Series 2

Enhanced Speed
- 3 x Higher count-rate, thanks to HighSense technology
- 2 x Higher pump-rate
- Faster Software (up to 90%)

Enhanced Usability & Flexibility
- Improved user interface
- New features, such as Advanced/Basic mode and a Drift Monitoring tool
- … and much more

- Setting thresholds for “High” and “Low” grade ore allows to quickly evaluate the results



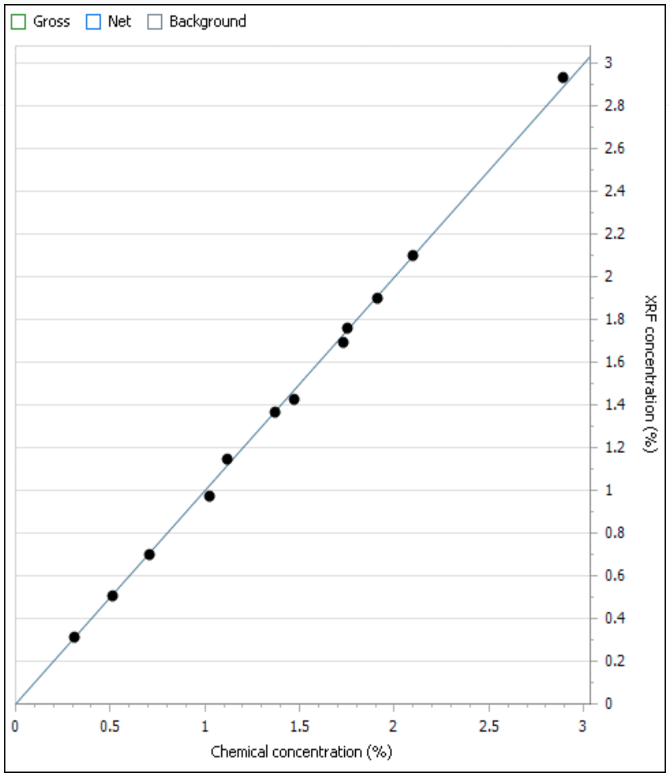
Sample ID	Nickel Grade	Ni (%)
UNKNOWN4	LOW	1.95
UNKNOWN4	LOW	1.96
UNKNOWN4	LOW	1.96
UNKNOWN4	LOW	1.96
194	HIGH	2.10
194	HIGH	2.11
194	HIGH	2.10
194	HIGH	2.11

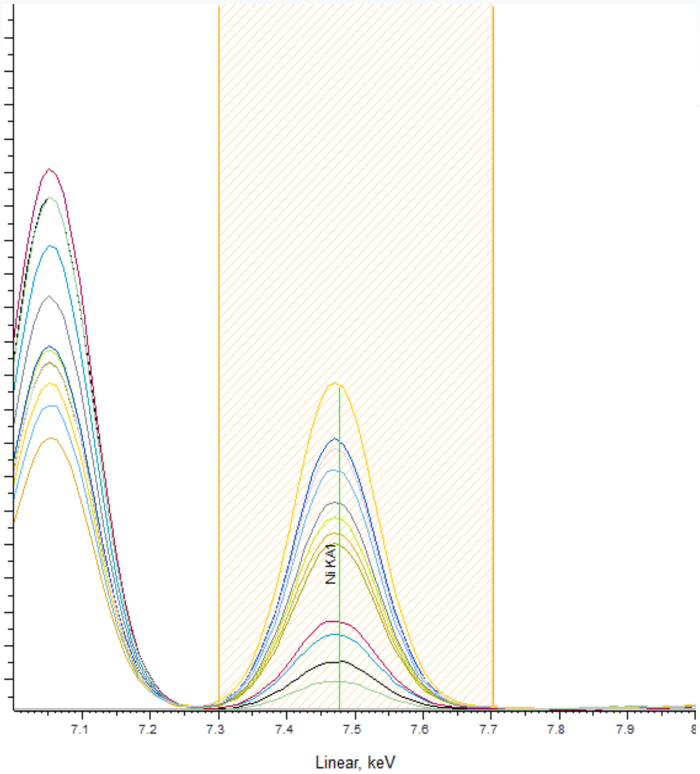
Elemental Analysis of Ni-Laterite Ore
Fast and reliable with the S2 PUMA Series 2

- The new hardware features of the S2 PUMA Series 2 allow to further optimize the analytical settings for Ni-laterite analysis, resulting in better performance and shorter measurement times
- The improved workflow, the faster software, and the higher pump rate decrease the time-to-result even more

- **Analytical procedure:**
  - 25 kV, no beam filter, fixed current, 60 s counting time
  - Pressed pellet preparation

Elemental Analysis of Ni-Laterite Ore
Fast and reliable with the S2 PUMA Series 2





- Calibration curve for Ni in Ni-Laterite (left) and Ni KA1 peaks (right)
- $R^2 = 0.99887$

Elemental Analysis of Ni-Laterite Ore

Fast and reliable with the S2 PUMA Series 2

Sample ID	Time-to-Result [min:sec]	Ni (%)	MgO (%)	Al_2O_3 (%)	SiO_2 (%)	CaO (%)	TiO_2 (%)	Cr_2O_3 (%)	MnO (%)	Fe_2O_3 (%)	Co (PPM)	Cu (PPM)	Zn (PPM)
Rep-1	01:37	1.388	24.05	2.094	48.24	0.32	0.03	0.77	0.21	14.02	375	32	119
Rep-2	01:39	1.393	24.19	2.077	48.17	0.32	0.03	0.77	0.21	14.00	377	31	125
Rep-3	01:39	1.403	24.00	2.102	48.10	0.32	0.03	0.77	0.22	14.05	416	35	119
Rep-4	01:31	1.383	24.08	2.102	48.19	0.32	0.03	0.77	0.21	14.00	376	32	116
Rep-5	01:39	1.393	24.00	2.107	48.13	0.32	0.03	0.77	0.22	14.05	374	33	116
Rep-6	01:32	1.382	24.28	2.086	48.35	0.32	0.03	0.77	0.22	13.96	400	34	124
Rep-7	01:39	1.39	24.18	2.102	48.26	0.32	0.03	0.77	0.22	13.97	369	33	122
Rep-8	01:32	1.384	24.09	2.094	48.19	0.32	0.02	0.77	0.21	14.03	336	33	123
…	..	..	..	..	..	..	..	..	..	..	..	..	..
Rep-120	01:31	1.407	23.84	2.088	47.85	0.33	0.03	0.78	0.22	14.11	357	33	120
Average measured value	**01:31**	**1.391**	**24.09**	**2.101**	**48.19**	**0.32**	**0.03**	**0.77**	**0.22**	**14.02**	**358**	**33**	**120**
Abs. standard deviation		**0.007**	**0.08**	**0.012**	**0.10**	**0.00**	**0.00**	**0.00**	**0.00**	**0.04**	**21**	**1**	**5**
Rel. Standard deviation		**0.50**	**0.32**	**0.57**	**0.21**	**1.46**	**8.00**	**0.26**	**2.25**	**0.29**	**5.77**	**3.31**	**4.03**

- **Excellent analytical performance in ~1.5 min** (time-to-result) (most EDXRF spectrometers require 4-5 min)

XRF – The right tool for all tasks

S8 LION:

- Simultaneous instrument with shortest measurement times (<2 min), 4 kW, highest precision

S8 TIGER

- Sequential WDXRF for high demanding grade control. Analytical flexibility for major, minors and traces, optimal settings for each elements

S6 JAGUAR

- Benchtop WDXRF: lower throughput but similar performance compared to full-size WDXRF, better spectral resolution than ED

S2 PUMA

- Versatile tool for minor and major elements for quick decisions in mobile and small labs

S2 KODIAK

- On-belt analysis for quickest automated decisions along the production of high grade materials

Q&A

Any questions?

Thanks for your time and interest!

Innovation with Integrity