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Unlock the Power of XRF in Metal Production

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Outline

01

Introduction

02

XRF in Metal Applications

03

XRF Technology

04

XRF in Metals – Central lab applications and Process Control

05

Live Demo: New S8 TIGER Series 3

06

Benchtop EDXRF and WDXRF applications in Metals

07

Live Demo: Slag Sample Preparation and Analysis with the S2 PUMA Series 2

08

Q&A Session

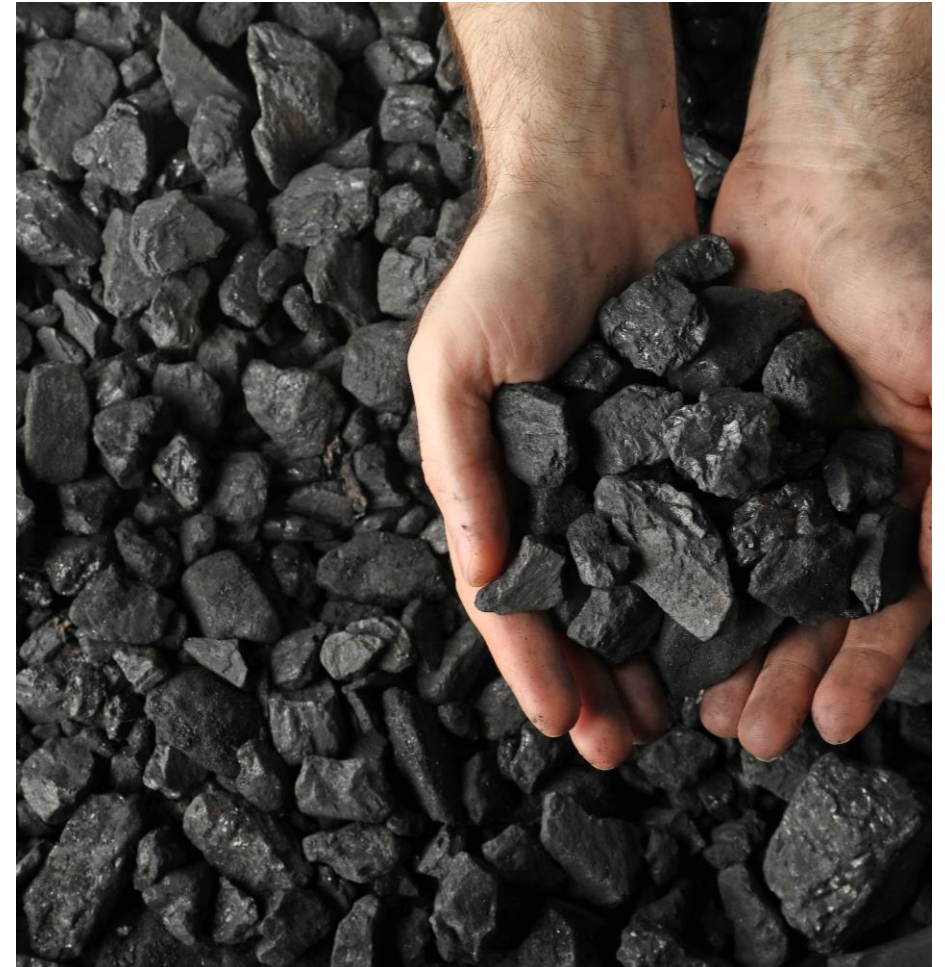
Why XRF analysis is key in today's technology change for better environment and why precision and speed count!

- Metals play a vital role in today's life, despite any change in technology – Aluminum is required to reduce weight for energy saving, copper will be needed for the new e-mobility and steel and still on high demand for housing
- New initiatives are driving the demand for extensive analysis:
 - Durability: traces of copper are harmful for corrosion resistance of steel – this is key parameter for any use of scrap
 - Energy saving: blast furnace slags are providing insight information about the kiln status in steel making
 - High purity: Copper for energy transportation requires high purity copper to reduce the electrical resistance
- Just a few examples where XRF is a great help!



Raw Materials are key for later high performance metals, cost efficient production and environmental protection

- High grade ores with exact grades enable cost efficient production (Fe, Ni, Cr, W, Mo,...)
 - Penalty elements with negative influence on later products or the environment to be reduced in mineral beneficiation (As and Pb in Cu ores, Cu and P in iron ores,...)
- Energy generation and additives to be characterized prior to their use for impurities (Toxic elements in coal, limestone for iron)
- Process control in the mining and beneficiation process is vital
- leads to efficient metal production
 - Exact grades to determine commercial value
 - XRF is THE analytical tool to accomplish all this



In Process and Quality Control

Cost determines the Way

Aluminum Electrolysis

- Incoming materials: Bauxite, alloy elements such as Si, Mg
- Required: Anode coke
- Process control mainly by XRD
- XRF used for incoming materials inspection:
 - major elements in Bauxite
 - Trace elements in coke
- Final production inspection by XRF, but mainly by OES

Copper - Nickel Smelter - Electrolysis

- Incoming materials: Copper Ore or Nickel Ore
- Incoming inspection
 - for copper concentration, but also precious metals (Au, Pt, AG, Pd,...)
 - Traces (Pd, As)
 - For nickel concentration, but other minor elements (Fe, Cr, W)

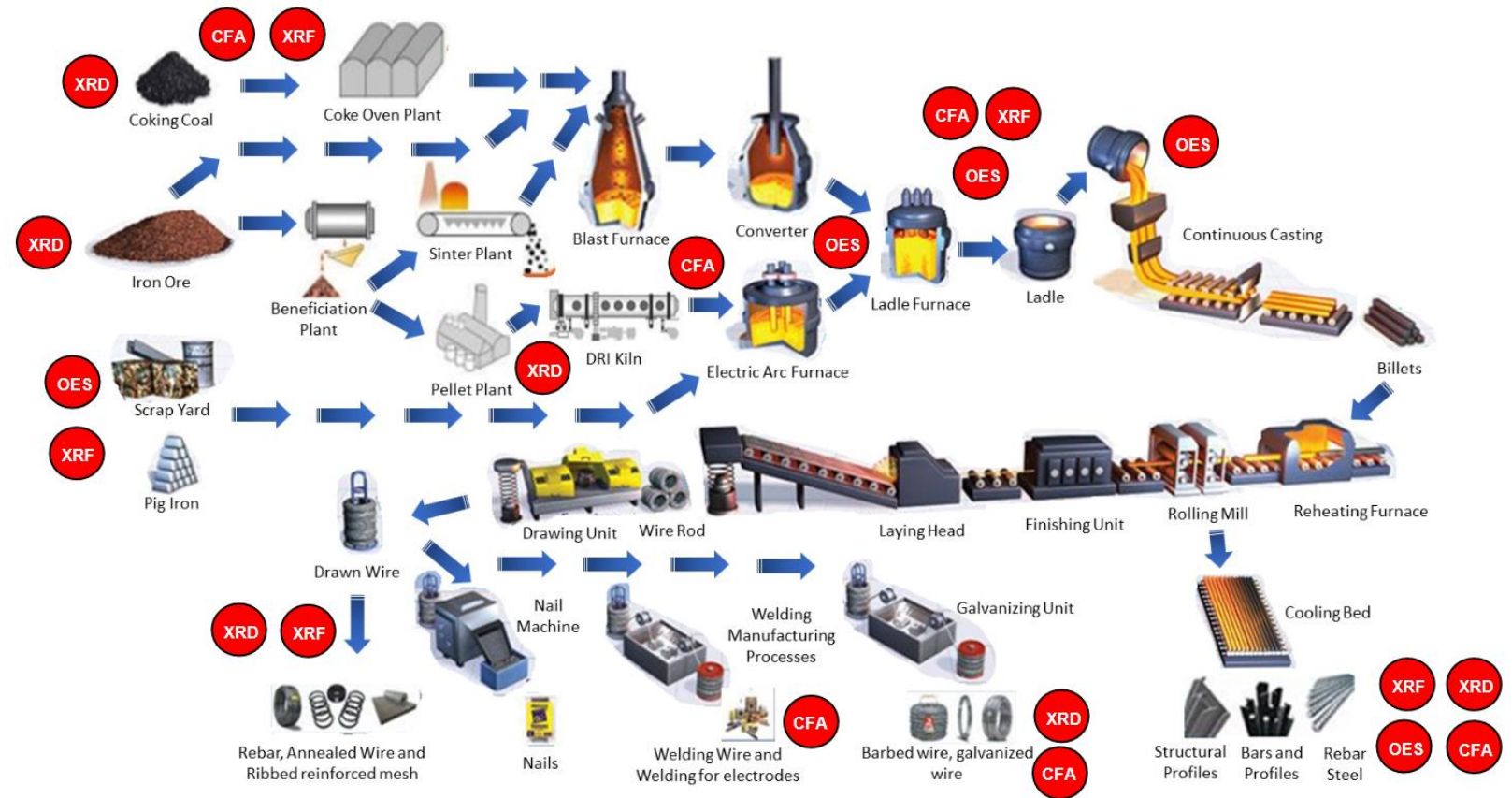
Iron/Steel/Stainless Steel Blast Furnace – Electric Arc

- Iron ore, coke, limestone, flux (CaF_2), scrap metal
- Process control:
 - Starter: Sinter
 - Intermediates: Pig Iron, cast Iron
 - Slags (furnace status)
- Quality Control in steel: Majors with XRF (Fe, Ni, W, Cr), traces by OES

XRF, OES, CS/ONH

Applications of Elemental Analysis in Steel Production

- Raw material analysis by XRF
- Furnace / Process analysis by XRF and OES
- Product quality control by OES, XRF and CS/ONH



*Note: CS/ONH analysis Combustion Fusion/Gas Analysis is often referred to (CFA),

X-ray Fluorescence Analysis (XRF) Capabilities

- Qualitative Analysis
 - Quick identification of all elements in a sample
- Quantitative Analysis
 - Precise and accurate analysis of concentrations
- Semi-Quantitative Analysis
 - Estimation of concentrations in completely unknown samples
 - Applications in R&D with demands for **ANALYTICAL FLEXIBILITY**
 - Applications in PC and QC with demands for **PRECISION, ACCURACY** and **SPEED**
- Solid and liquid samples can be analyzed directly with little or no sample preparation required
- Non-destructive analysis to the sample
- Sampling-to-analysis result time is relatively short (~3 to ~10 min)
- Accuracy and long-term stability
- Elemental range: (Be) Na to U
- Linearity from ppm to 100%



EDXRF has advanced over the past decade due to new detector technology offering:

- 20 times better count rate capabilities
- Enhanced spectral resolution close to theoretical physical limit of Si- detector technology
- Peltier cooling instead of liquid nitrogen

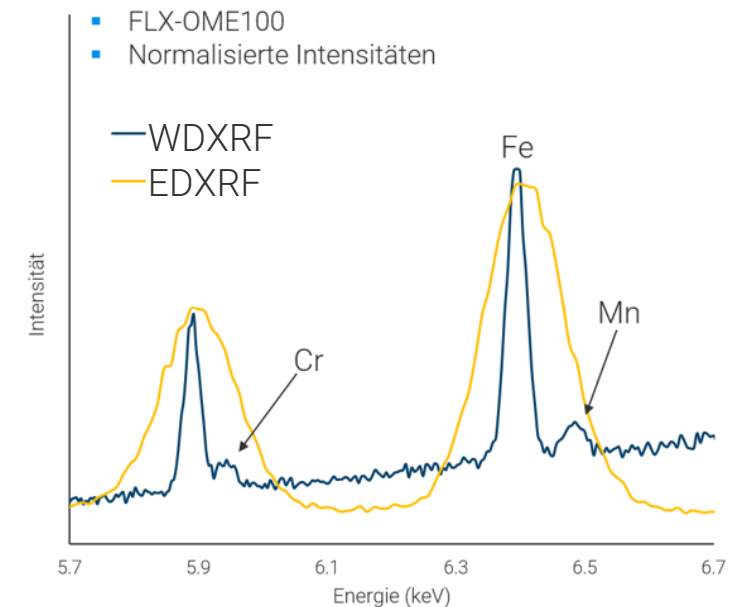
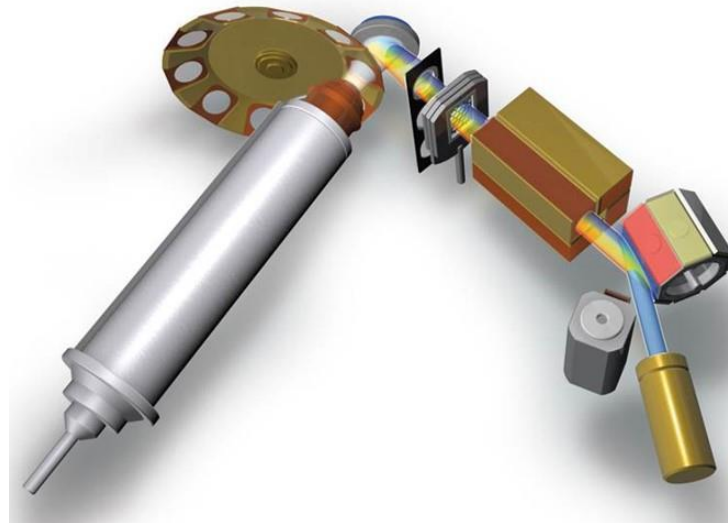
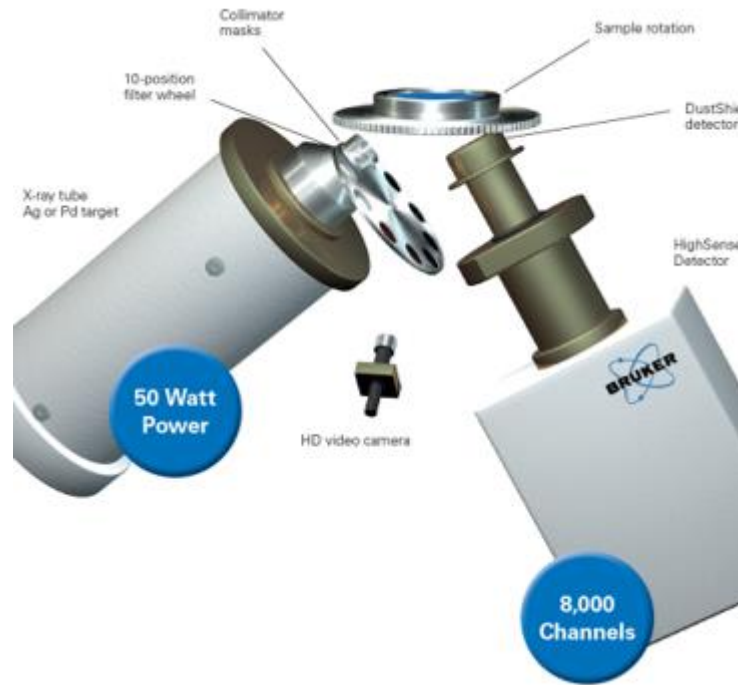
HOW TO MAKE BETTER WDXRF APPLICATIONS IN MINERALS & MINING ?

Which Technology to Choose: Energy-dispersive XRF (EDXRF) or Wavelength-dispersive XRF (WDXRF)

EDXRF – Direct or Polarized
Typical < 100 W

WDXRF – Seq. Or Sim
50 W – 4.2 kW

Resolution
Typical factor of 10 times better



Work in metallurgical central labs: Deliver timely and best data for all raw materials, intermediates and final products

- Incoming inspection of raw materials (iron ore, limestone, coal,...)
- Intermediates (sinter, iron, slags)
- Alloys

Crucial:

- Accuracy for incoming materials (commercial value)
- Analyzing speed for process control (energy)
- Accuracy and flexibility for final products
 - Vast range of alloys (low alloy steels versus tool and stainless steel, e.g. Ni, Mo, W at very low and high concentrations)



Data Quality depends on the Optimal Strategy: It's all about sample preparation!

Material to be analyzed must be

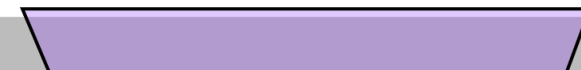
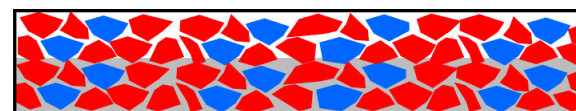
- Representative
- Homogeneous
- Small enough in particle size so that several layers will be measured
- Flat on surface without irregularities
- Compatible with the sample geometry (fit in cups or rings)
- Thick enough to be infinitely thick for X-rays to be measured (analyzed layers)



Pressed Powders



Fused Beads



} Analyzed Layer

XRF X-ray Fluorescence Analysis

Precision and Counting Statistics

Precision limited by counting statistical error

$$\text{CSE}(\%) = 100\% / \text{SQRT}(N)$$

$$\Delta c / c = \text{SQRT}(N) / N = 1 / \text{SQRT}(N)$$

N =	100	SQRT(N) =	10	3*SQRT(N) / N =	30 %
N =	1000	SQRT(N) =	30	3*SQRT(N) / N =	10 %
N =	10 000	SQRT(N) =	100	3*SQRT(N) / N =	3 %
N =	100 000	SQRT(N) =	300	3*SQRT(N) / N =	1 %
N =	1000 000	SQRT(N) =	1000	3*SQRT(N) / N =	0.3 %
N =	10 000 000	SQRT(N) =	3000	3*SQRT(N) / N =	0.1 %

Grade Control in Mining:

- Trueness is vital to compare data between different labs (and CRMs)
 - Sample preparation and calibration
- Precision is important, especially for process control
 - Sample preparation and number of collected counts per element in a sample

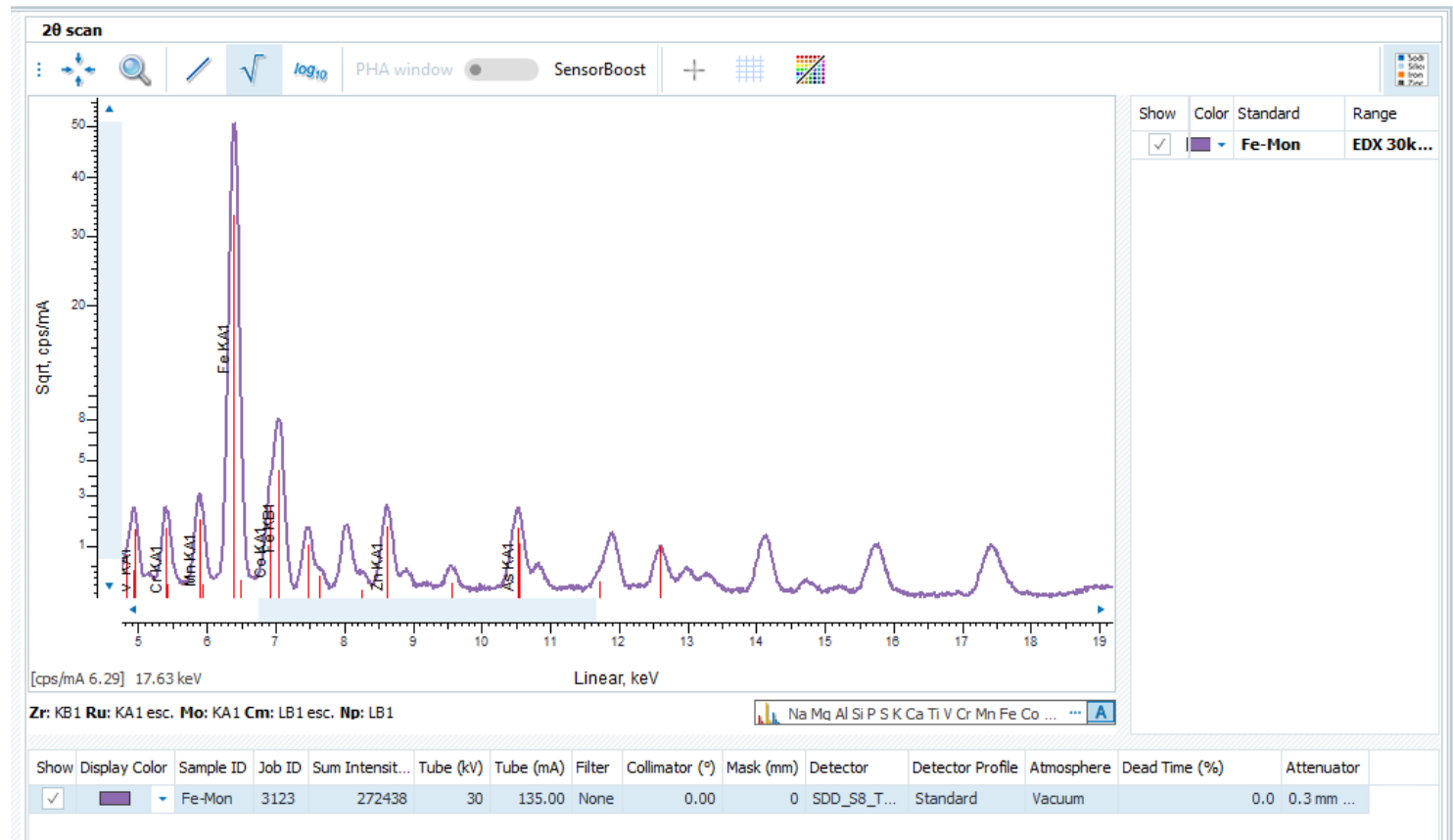
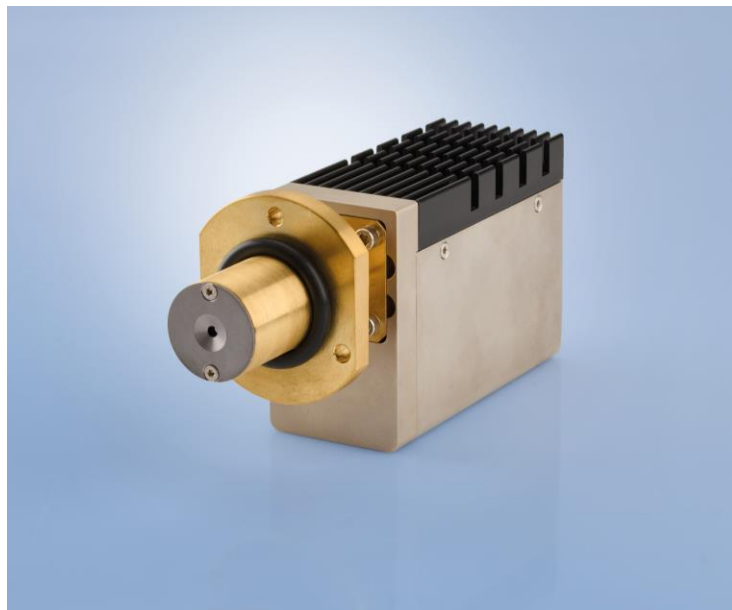
Optimize by:

Time → Capacity of an instrument
Intensity → Power, optics, detection

Simultaneous Detection with WDXRF and EDXRF Whenever Excitation is similar

Multi Element Channel:

- Based on Silicon-Drift Detector with fast signal processing
- E.g. HighSense XP detector with up to 2.4 M cps total counts and up to 132 eV resolution



Spectrum of a geological sample, recorded parallel to the sequential WDXRF

- saves typically 30 to 40% measurement time in geology, minerals and metals



Iron Ore Analysis

Precision test

Sample ID	Fe ₂ O ₃ (%)	SiO ₂ (%)	CaO (%)	Mn ₃ O ₄ (%)	Al ₂ O ₃ (%)	TiO ₂ (%)	MgO (%)	P ₂ O ₅ (%)	SO ₃ (%)	K ₂ O (%)	SnO ₂ (%)	V ₂ O ₅ (%)	Cr ₂ O ₃ (%)
1	63.60	7.01	4.21	1.921	4.892	1.497	4.900	2.631	2.120	1.821	0.197	0.190	0.216
2	63.61	7.03	4.21	1.920	4.887	1.487	4.888	2.638	2.126	1.816	0.187	0.188	0.214
3	63.67	7.05	4.21	1.919	4.881	1.498	4.899	2.643	2.126	1.826	0.190	0.193	0.213
...
10	63.86	7.04	4.22	1.932	4.892	1.496	4.897	2.637	2.113	1.821	0.193	0.195	0.215
Min	63.600	7.010	4.210	1.919	4.866	1.482	4.888	2.623	2.109	1.815	0.187	0.188	0.212
Max	63.860	7.050	4.220	1.932	4.892	1.498	4.924	2.643	2.126	1.826	0.200	0.195	0.216
Average	63.685	7.026	4.216	1.923	4.883	1.492	4.900	2.631	2.119	1.819	0.192	0.193	0.214
Std.Dev	0.073	0.014	0.005	0.004	0.008	0.006	0.011	0.006	0.006	0.004	0.004	0.002	0.001
Rel.Std.Dev	0.11%	0.20%	0.12%	0.21%	0.17%	0.38%	0.22%	0.24%	0.28%	0.20%	2.21%	1.18%	0.77%

Measurement time reduction by 50 % down to app. 5 minutes:

- **SIMULTANEOUS DETECTION**
- **OPTICS WITH HIGHER INTENSITY**

Steel Works Process Control

Process Control Tasks of S8 TIGER Series 3 at line:

- Pig iron: Reduction of iron ore to iron, high carbon concentrations
- Cast iron: Increase iron concentration
 - Analysis of Fe, some traces plus C and Si, Traces with OES; Fe, C and Si with XRF
- Slags as pressed pellets (Blast furnace)

Analysis of majors and minors:

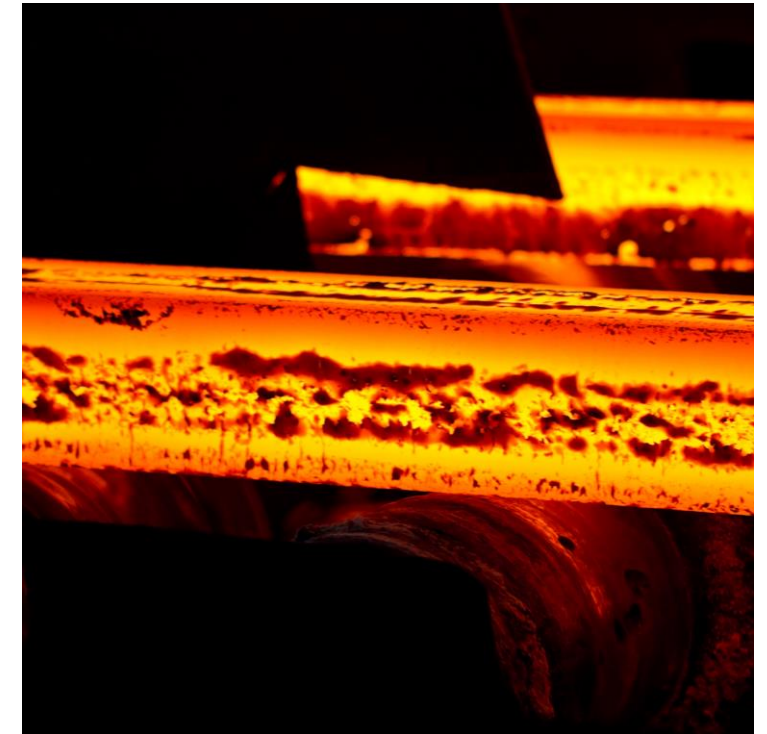
- CaF_2/MgO Ratio: Efficiency of fluorspar additions as an additive in ladle treatment
- MnO/MgO Ratio: Dissolution of furnace refractory materials into the slag
- CaO/SiO_2 Ratio: Determining the hydraulic potential of slag, used in concrete
- Fe/P Ratios: Enriching the slag with iron and phosphorus for recovery

SPEED, SPEED, SPEED

Time means energy consumption



High Power excitation in combination with fast sample preparation and speed options in detection: fast return of results for process control



Better understanding of the process related intermediates (pig iron, cast iron, slags) leads to efficient production

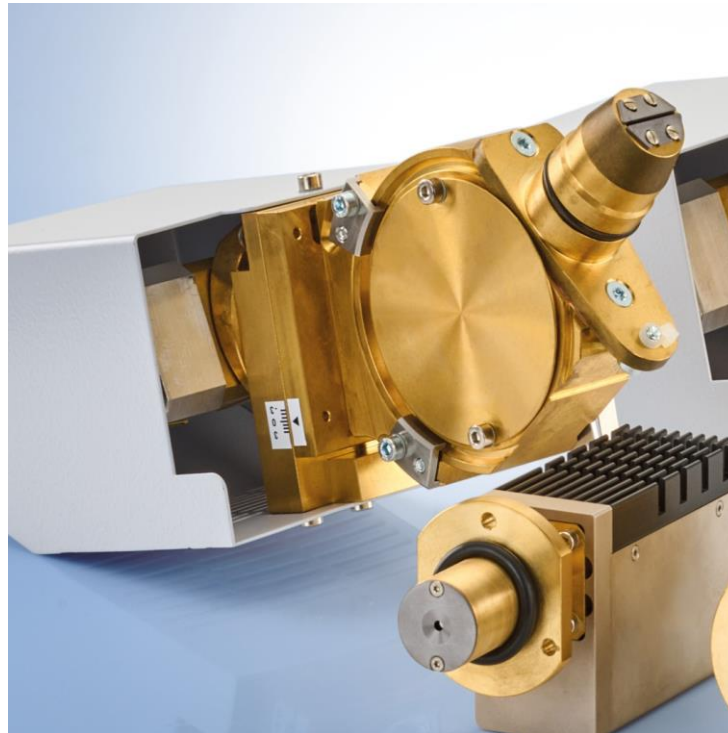
XRF Application Example

Cast iron

Process Control (CAST IRON) with the S8 TIGER Series 3, 4 kW:

- 15 elements:
- C, Si, P, S, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Sn, Pb
- Time-to-result:
- Typical: 1 min 40 sec. per sample
- Sample throughput:
- 30 samples/h

- Fast, accurate and precise process and quality control of cast iron, including Carbon analysis



Carbon single element channel for parallel measurement of C in cast iron

Speed gain of ~ 20 s



Sampling, cooling, surface milling:
XRF analysis



UNLOCK THE POWER OF XRF IN METAL PRODUCTION

Quality Control of Metals Alloy composition and Impurities

How to improve maximum count rates for light elements? Better linearity for higher count rates by eliminating artefacts

Flow counters often limited to 1.5 – 2 M cps max.
at higher concentrations proportional counters saturate:

- Higher dead time
- Broader peaks in PHA

Signal is lost to (whenever readout is too slow)

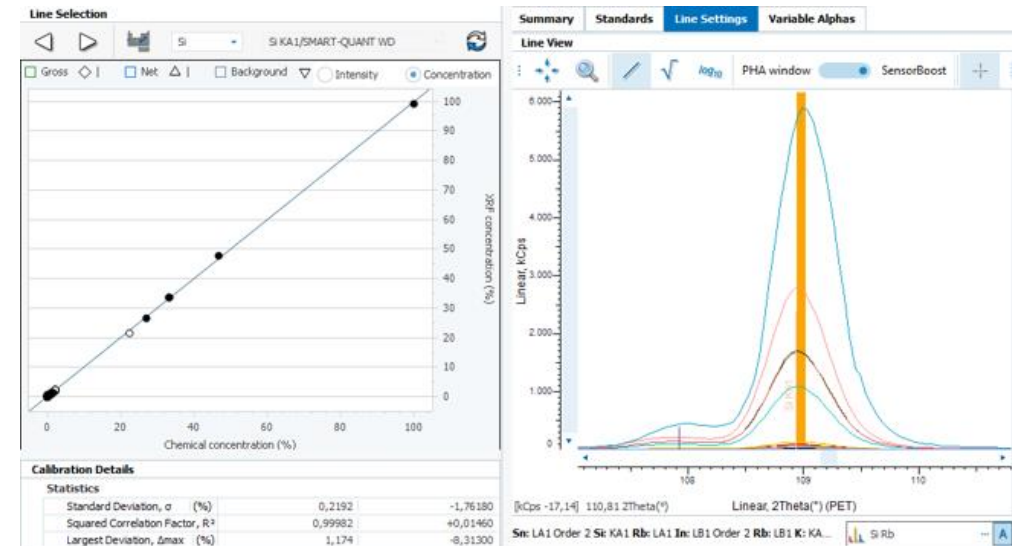
- Escape Peaks
- Sum peaks



New signal processing

Stabilizes PHA peak position at optimum

- Reduces background noise
- Eliminates effects of escape and sum peaks
- Doubles effective linear count rate compared to traditional systems
- Reduction of measurement time or enhancing precision for minor and major elements



Heavy Element Detection

Scintillation Counter for heavy elements

- for higher count rate
- more than **2 M cps** (linear)
- with multi channel analyzer



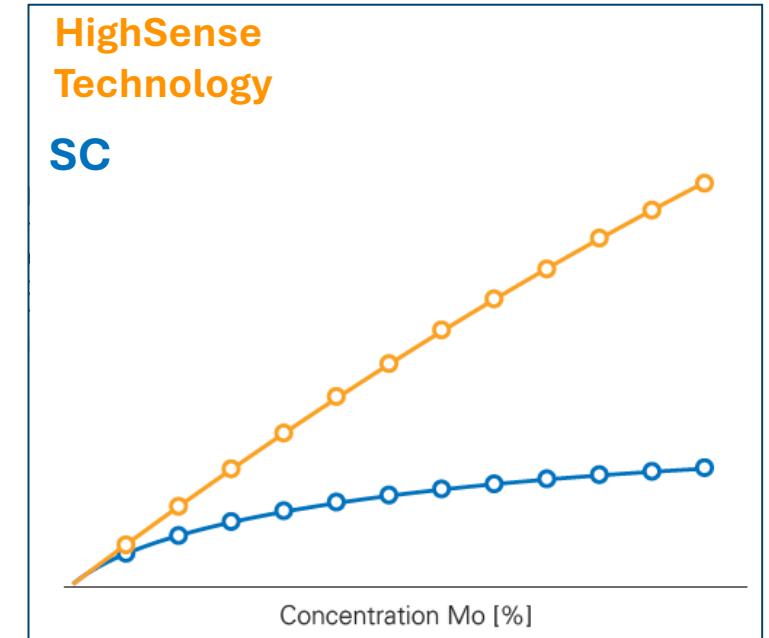
New silicon based heavy element detector

- higher sample throughput
- faster measurements
- In metals and ores



Performance ratings

- 12 Mcps linearity of 0.9999
- 23 Mcps linearity of 0.9996
- no dead time



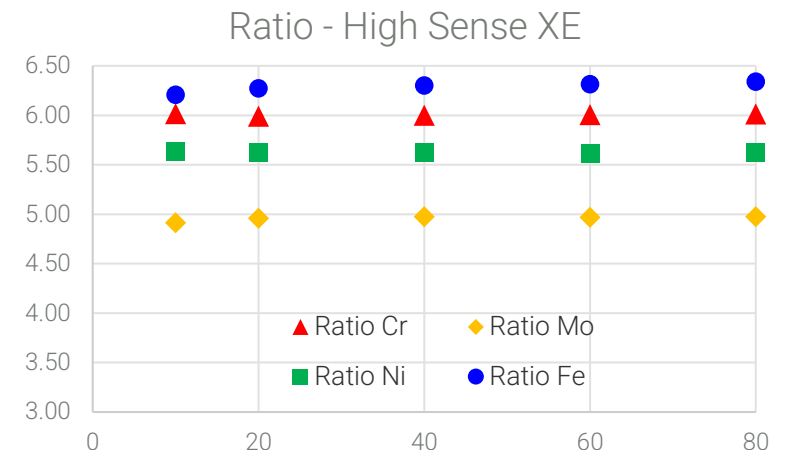
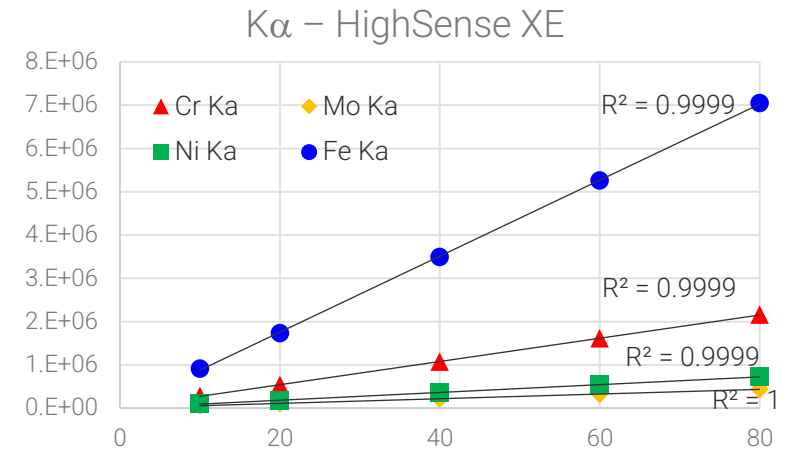


Quality Control of Metals

How to test the linearity of your system

303	CERT	Accuracy	
		AVG	SD
Mn (%)	1.68	1.75	0.20%
Si (%)	0.58	0.62	0.21%
Cu (%)	0.36	0.37	0.19%
Ni (%)	8.14	8.18	0.17%
Cr (%)	17.21	17.27	0.11%
Mo (%)	0.55	0.57	0.13%
Co (%)	0.16	0.163	0.88%
V (%)	0.07	0.07	0.58%
Nb (%)	0.01	0.01	1.50%
Al (%)	0.003	0	12.50%
Ti (%)	T	0	T
W (%)	0.07	0.07	2.68%
Sn (%)	0.01	0.011	2.97%
Fe (%)	70.8	70.83	0.10%
P (%)	0.03	0.03	0.80%
S (%)	0.309	0.31	0.22%

- High linearity is vital, esp. for valuable elements such as Mo, Ni, W:
 - Analyze the ratio of $K\alpha$ line (high count rate) with $K\beta$ line (low count rate) as indicator for high linearity
- This enables to create calibrations covering wider concentration ranges from low to high grades
 - Aluminum alloys with variation of Mg, Si
 - Steel alloys (low alloys, tool and stainless steel)
 - Copper alloys (brass, bronze)



Bruker's Elemental Analysis Solutions for the Metal Industry

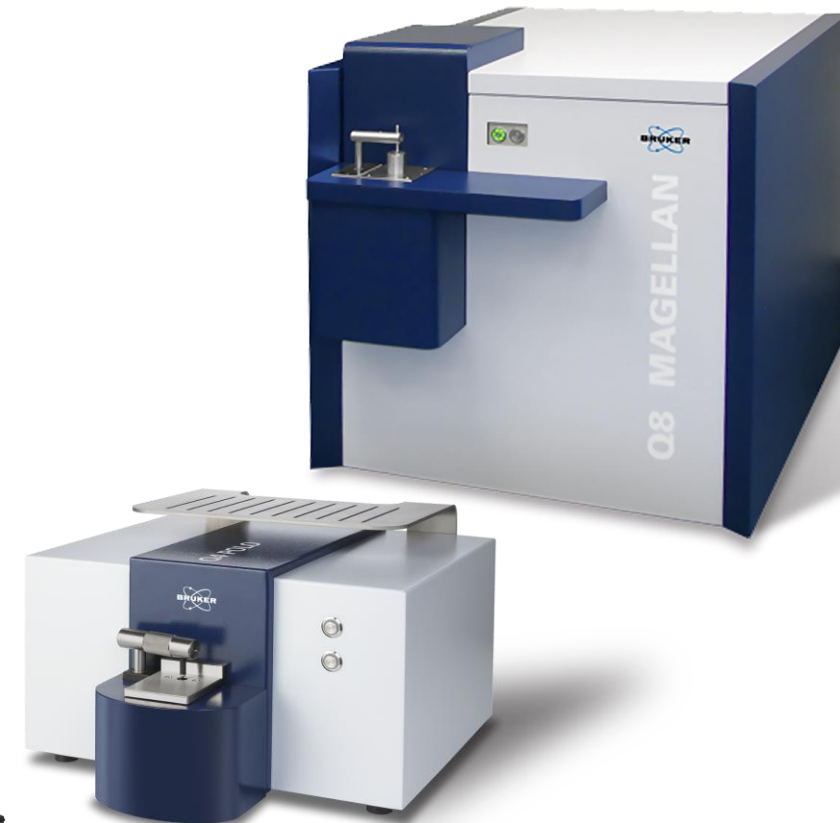
CS/ONH Analysis



X-Ray Fluorescence (XRF)



Optical Emission Spectroscopy (OES)



Elemental Analysis of Steel Metal Slags requires Accuracy & Speed

- Slag is an important agent in high temperature metallurgical processes.
- It is tuned to an equilibrium condition for maximum action on the metal purity, least attack on the refractory lining, and optimal physical properties.
- Dosage of slag enhancing additives – such as lime and dolomite – is performed based on the chemical composition of the slag.
- For cost-efficient steel production, it is essential to monitor the slag composition accurately and fast.



Elemental Analysis of Steel Metal Slags requires Accuracy & Speed

There are different types for slags in steel production, e.g.:

- Electric Arc Furnace (EAF) Slag
- Ladle Metallurgy Furnace (LMF) Slag

The difference in steel production procedure results in different slag compositions and, thus, in different requirements for analytical solutions.



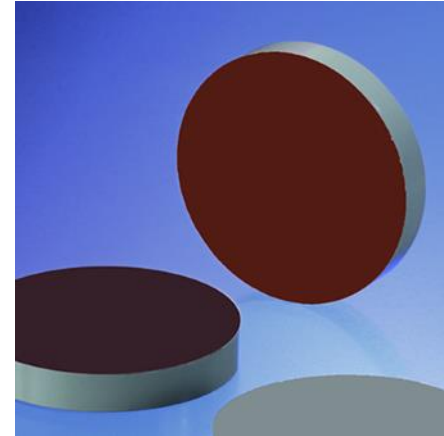
Fast and reliable slag analysis with the S2 PUMA Series 2

Sample Preparation

- samples were crushed and the remaining metallic iron was removed with a magnet before grinding.
- Pressed to pellets by using 15 g of sample material and 1 g grinding aid.

The key advantage of pressed pellets when compared to fused beads is the fast and simple procedure.

Careful pellet preparation enables high repeatability and reliability, in particular for minor and trace element analysis.



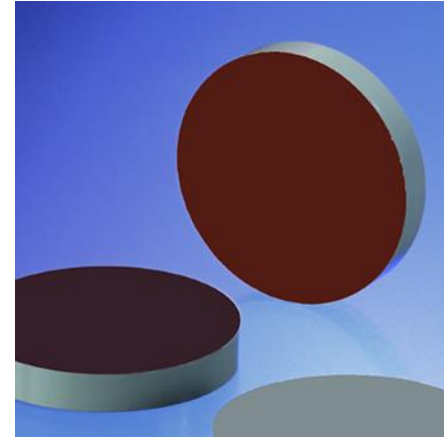
Fast and reliable slag analysis with the S2 PUMA Series 2

Analytical Conditions and Calibration

Elements	Voltage [kV]	Current [mA]	Measurement time [s]	Beam Filter	Mode
F, Mg, Al, Si, P, S, Ca, Ti, Mn, Fe	20	automatic*	120	none	Vacuum

*Current is maximized automatically for best count statistics.

- A set of 30 certified and secondary reference materials



Fast and reliable slag analysis with the S2 PUMA Series 2

EAF Slags

Compositional range

Compound	EAF Slags [wt%]
MgO	2.4 – 23.5
Al ₂ O ₃	0.5 – 10.2
SiO ₂	4.7 – 48.7
P ₂ O ₅	0.01 – 16.7
S	0.03 – 0.2
CaO	1.2 – 42.9
TiO ₂	0.15 – 2.3
Cr ₂ O ₃	0.5 – 53.8
MnO	2.0 – 28
FeO	9.1 – 48.1

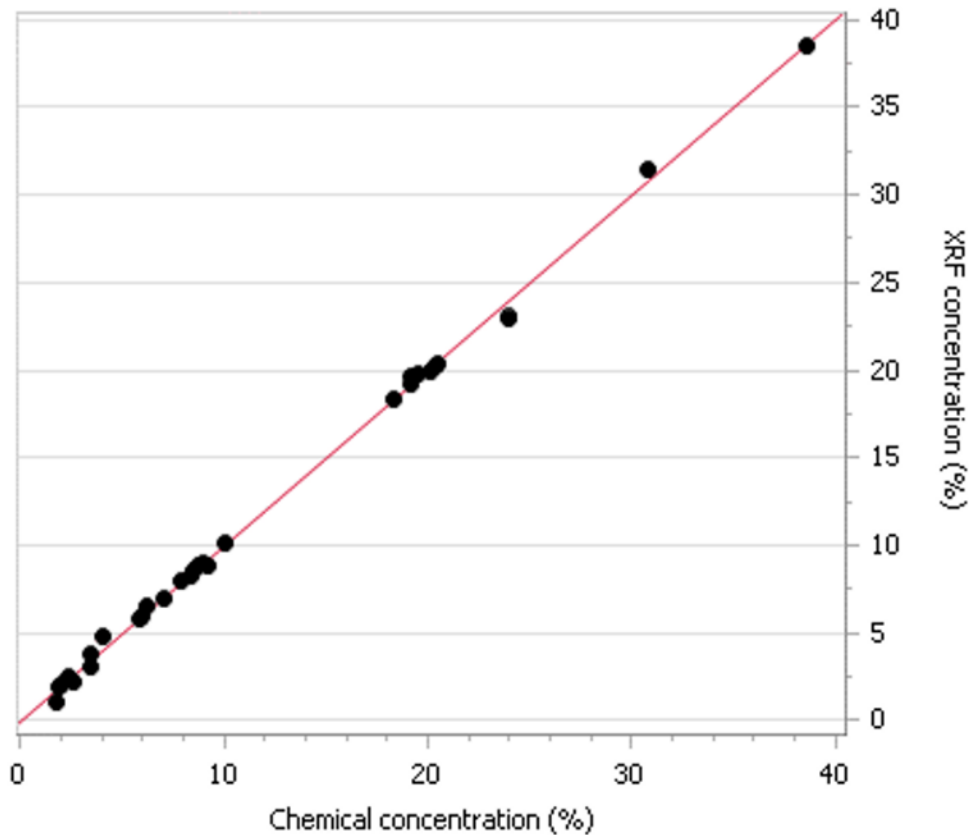
LMF Slags

Compositional range

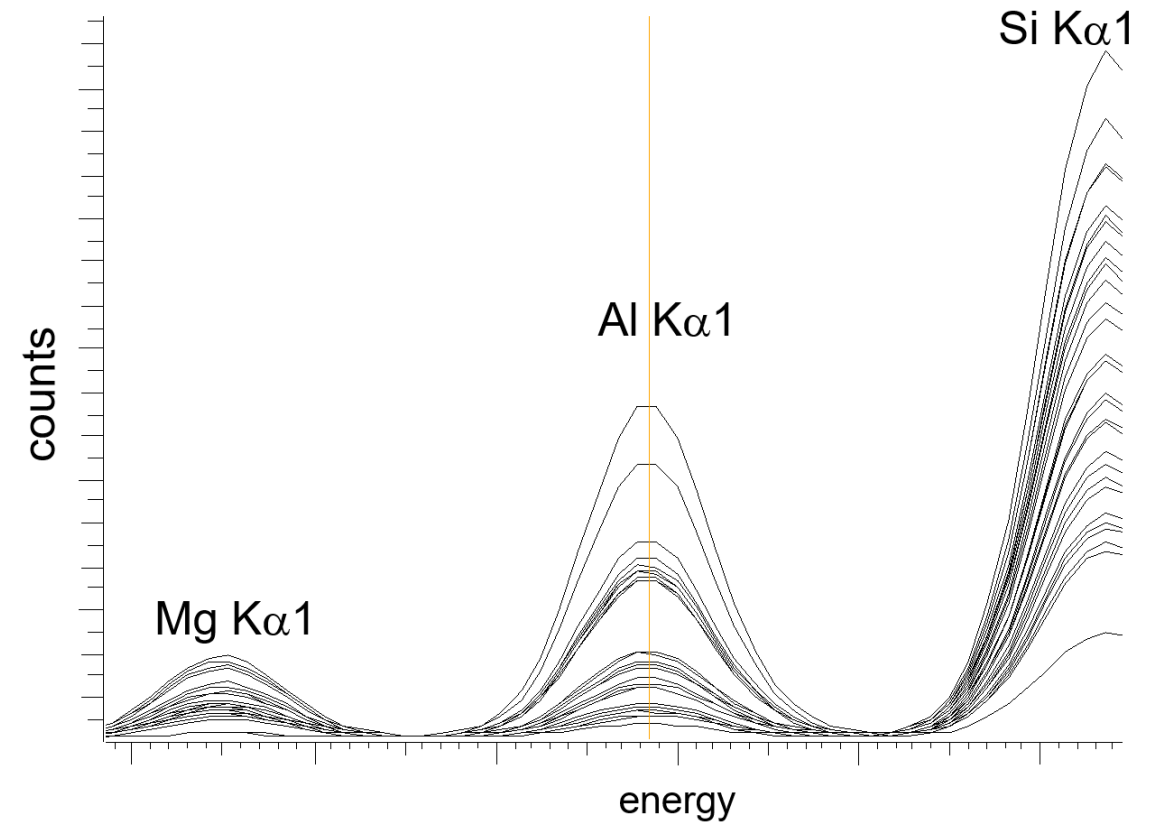
Compound	LMF Slags [wt%]
F	0.03 – 7.9
MgO	0.2 – 21.2
Al ₂ O ₃	1.8 – 38.6
SiO ₂	7.4 – 51.4
P ₂ O ₅	0 – 1.6
S	0 – 1.2
CaO	0.6 – 60.4
TiO ₂	0.01 – 2.2
MnO	0.06 – 14.9
FeO	0.1 – 17.2

Fast and reliable slag analysis with the S2 PUMA Series 2

Calibration curve for MgO



Calibration peaks for Mg K α 1, Al K α 1 and Si K α 1





Fast and reliable slag analysis with the S2 PUMA Series 2

[wt.%]	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	S	CaO	TiO ₂	Cr ₂ O ₃	MnO	FeO	V-Ratio	B3-Ratio
Rep-1	13.53	6.36	14.20	0.240	0.130	26.97	0.36	2.16	5.59	29.84	1.90	1.29
Rep-2	13.61	6.38	14.20	0.240	0.130	26.97	0.37	2.16	5.59	29.84	1.90	1.29
Rep-3	13.63	6.37	14.27	0.240	0.130	27.01	0.37	2.16	5.59	29.78	1.89	1.29
Rep-4	13.56	6.36	14.21	0.240	0.120	27.00	0.37	2.17	5.58	29.85	1.90	1.29
Rep-5	13.61	6.36	14.26	0.240	0.120	27.01	0.37	2.16	5.56	29.79	1.89	1.29
Rep-6	13.55	6.38	14.18	0.240	0.130	27.00	0.37	2.17	5.58	29.85	1.90	1.29
Rep-7	13.56	6.38	14.27	0.230	0.130	27.01	0.37	2.16	5.58	29.79	1.89	1.28
Rep-8	13.55	6.37	14.24	0.240	0.130	27.01	0.37	2.17	5.60	29.81	1.90	1.29
Rep-9	13.69	6.39	14.24	0.240	0.120	27.04	0.37	2.16	5.56	29.76	1.90	1.29
Rep-10-101	...	...	...	...	...	...	...	...	...	...	...	...
Rep-102	13.75	6.54	14.41	0.240	0.130	27.03	0.37	2.17	5.56	29.62	1.88	1.26
Average [wt.%]	13.69	6.44	14.34	0.244	0.126	27.02	0.37	2.17	5.57	29.70	1.89	1.28
Abs. Std. Dev. [wt.%]	0.10	0.05	0.07	0.005	0.005	0.03	<0.01	0.01	0.01	0.07	0.01	0.01
Rel. Std. Dev. [%]	0.7	0.7	0.5	2.3	3.8	0.1	0.9	0.3	0.2	0.2	0.5	0.5
Certified	13.40	6.58	14.24	0.250	0.13	26.66	0.35	2.17	5.63	29.49	1.87	1.26
Difference	0.29	0.14	0.10	0.006	0.004	0.36	0.02	<0.01	0.06	0.21	0.02	0.02

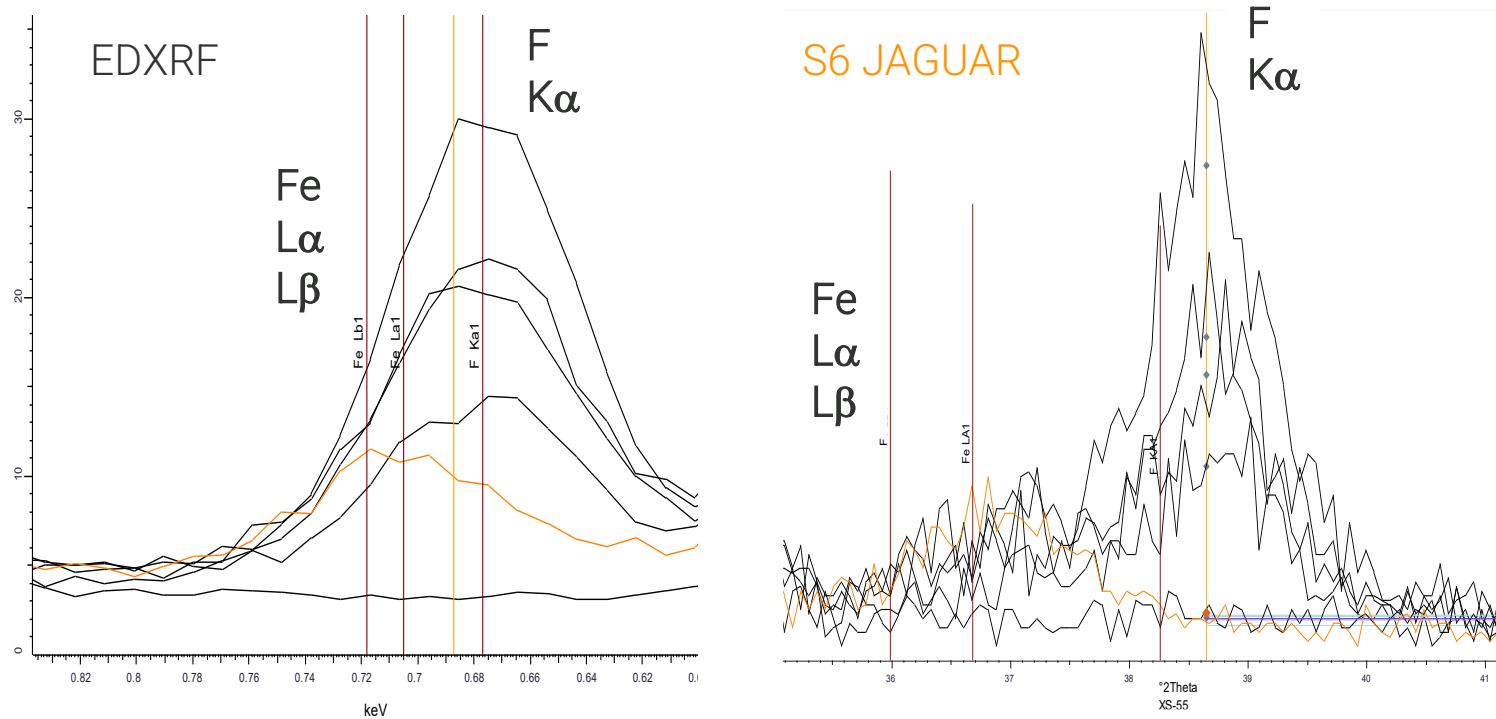
Repetition test (samples were loaded and unloaded between the analyses)

- Results for EAF slag
- Viscosity (V) and Basicity (B) are critical monitoring parameters
- Excellent precision and accuracy for Slag analysis thanks to the HighSense Technology of the S2 PUMA Series 2

Viscosity (V) Ratio: CaO / SiO₂; Basicity (B3) Ratio = CaO / (SiO₂ + Al₂O₃ + TiO₂)

S6 JAGUAR benchtop WDXRF

For enhanced light element performance



- Strong overlap of F K α and Fe L α with EDXRF leads to medium accuracy and precision:
Min 3.59 % \rightarrow 3.78 % \leftarrow Max 4.07 %
- S6 JAGUAR: Optimal resolution, clear separation of both lines, high sensitivity with 400 W power:
Min 3.97 % \rightarrow 4.03 % \leftarrow Max 4.07 %

S6 JAGUAR HighSense™ Goniometer: Impressive Versatility & Performance



- 400 W excitation
 - 20 – 50 kV
 - 1 – 17 mA
 - Optimal settings for every single element at full power
- 5 position beam filter (optional) for improved peak-to-background ratio
- 4 sample masks (optional for different sample sizes)
- Vacuum seal for low-cost-of-operation
- Up to 4 analyzer crystals for the entire element range and specific demands
- Flow counter and HighSense XE detector for 2 Mcps countrates for high calibration ranges

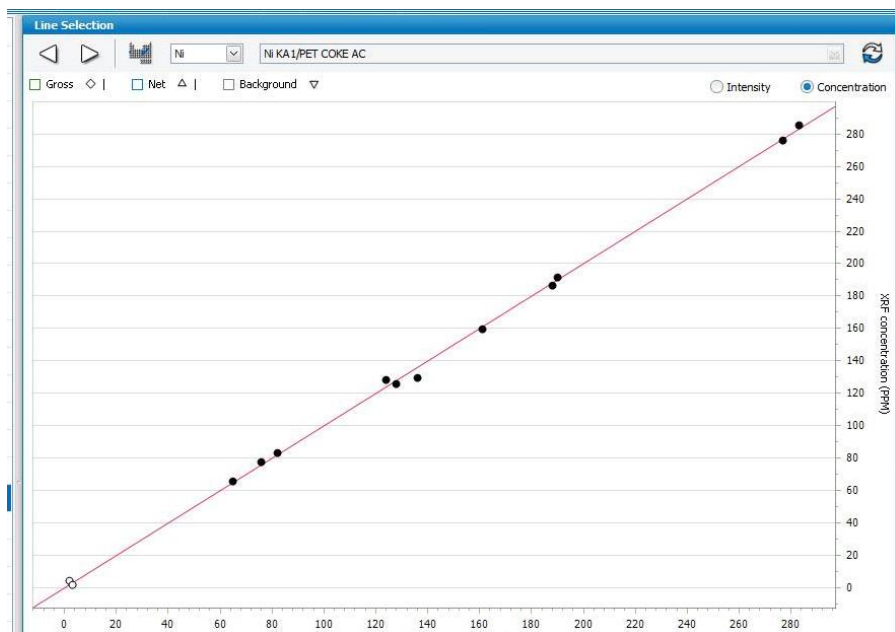
Coal, Coke and Carbon Analysis with the S6 JAGUAR

- Coal is widely used in metal making (aluminum, steel) and power generation (electricity)
- Analysis of coal, coke and carbon products is vital:
 - Prevent contamination of metals (impurities)
 - Inhibit corrosion (monitoring of Cl)
 - Reduce environmental impact (reducing S conc.)



Coal, Coke and Carbon Analysis with the S6 JAGUAR

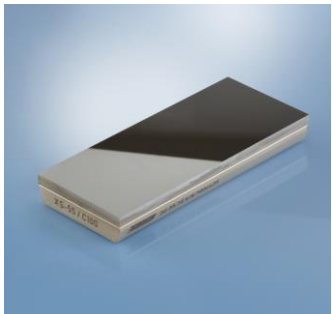
Nickel trace calibration
R²: 0.99853, LOD: 0.4 ppm



Optimal accuracy for minor elements, such as S traces, e.g., Si, Cl, Fe

Element	XRF conc.	Certified conc.	Std.Dev.	Rel.Std.Dev.
S [%]	3.40	3.30	0.02	0.72%
Ni [ppm]	128	124	4.48	3.50%
Si [ppm]	24	28	1.15	4.80%
Fe [ppm]	276	266	2.65	0.96%
Na [ppm]	623	645	43.61	7.00%
Al [ppm]	153	150	5.66	3.70%
Ca [ppm]	112	107	2.35	2.10%
K [ppm]	17	17	1.84	10.80%
Cl [ppm]	100	n.a.	--	--
Ti [ppm]	5	4	0.31	6.10%
Zn [ppm]	40	41	0.10	0.25%
V [ppm]	302	300	2.33	0.77%

Summary



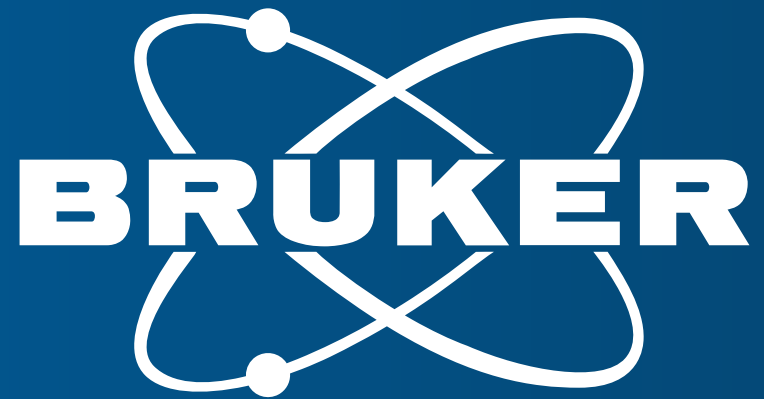
WDXRF is the optimal choice for industrial applications:

1. Configurations for higher intensity – providing better counting statistics
2. Better spectral resolution to resolve neighboring lines, esp for minerals and mining: Cr, Mn, Fe, Co – $K\alpha$ and $K\beta$ overlays in EDXRF
3. Benchtop ED and WDXRF instruments for applications at line or smaller labs: Slags, incoming raw materials
4. Faster measurements with new detector technology for simultaneous detection
5. New software developments for faster signal processing and matrix handling

Tips:

- In process control fast sample preparation instead of perfect trueness – fast decision making
- Fused beads typically better data quality – Dilution of matrix, removal of mineral effects
- Define required analytical precision: This will lead to optimal measurement time (counting statistics)
- Whenever possible, configure instrument for higher intensity when precision counts (process control)





Innovation with Integrity