
XRF Spectrometry

X Ray Fluorescence
Spectrometry

Theremino System

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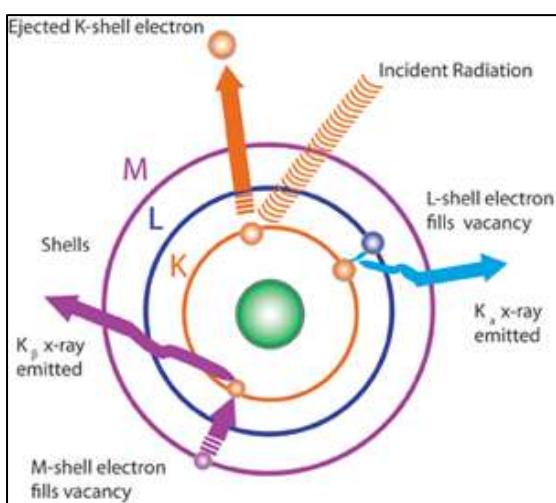
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XRF Spectrometry

Theory

X-ray fluorescence (XRF) is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays. The phenomenon is widely used for elemental analysis and chemical analysis, particularly in the investigation of metals, glass, ceramics and building materials, and for research in geochemistry, forensic science and archaeology.



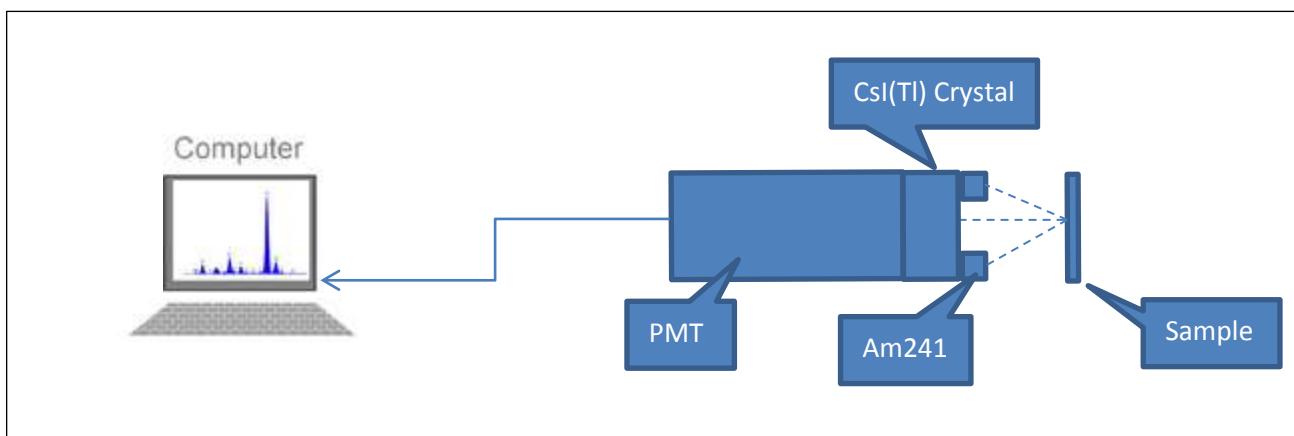
Each element has electronic orbitals of characteristic energy. Following removal of an inner electron by an energetic photon provided by a primary radiation source, an electron from an outer shell drops into its place. There are a limited number of ways in which this can happen, as shown in Figure. The main transitions are given names: an $L \rightarrow K$ transition is traditionally called $K\alpha$, an $M \rightarrow K$ transition is called $K\beta$, an $M \rightarrow L$ transition is called $L\alpha$, and so on. Each of these transitions yields a fluorescent photon with a characteristic energy equal to the difference in energy of the initial and final orbital. The wavelength of this fluorescent radiation can be calculated from Planck's Law:

$$\lambda = h \cdot c / E$$

The fluorescent radiation can be analysed either by sorting the energies of the photons (energy-dispersive analysis) or by separating the wavelengths of the radiation (wavelength-dispersive analysis). Once sorted, the intensity of each characteristic radiation is directly related to the amount of each element in the material. This is the basis of a powerful technique in analytical chemistry.

The XRF method is widely used to measure the elemental composition of materials. Since this method is fast and non-destructive to the sample, it is the method of choice for field applications and industrial production for control of materials. **Depending on the application, XRF can be produced by using not only x-rays but also other primary excitation sources like alpha particles, protons or high energy electron beams.**

Sometimes, as the atom returns to its stable condition, instead of emitting a characteristic x-ray it transfers the excitation energy directly to one of the outer electrons, causing it to be ejected from the atom. The ejected electron is called an "Auger" electron. This process is a competing process to XRF. Auger electrons are more probable in the low Z elements than in the high Z elements.



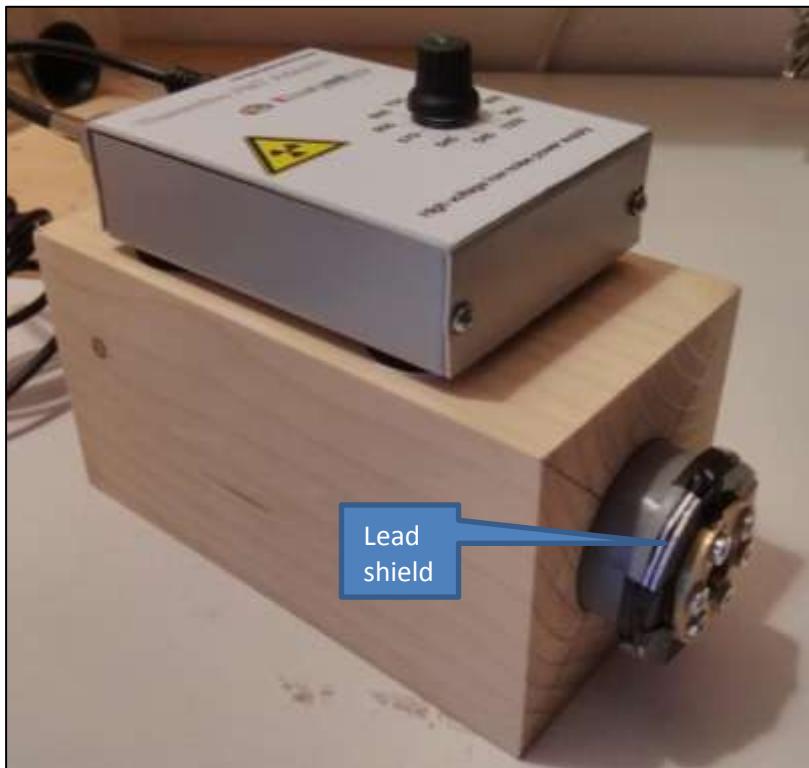
K-level and L-level emission lines in KeV

No.	Element	K α 1	K β 1	L α 1	L β 1
3	Li	0.0543			
4	Be	0.1085			
S	B	0.1833			
6	C	0.277			
7	N	0.3924			
8	O	0.5249			
9	F	0.6768			
10	Ne	0.8486			
11	Na	1.04098	1.0711		
12	Mg	1.25360	1.3022		
13	Al	1.48670	1.55745		
14	Si	1.73998	1.83594		
15	P	2.0137	2.1391		
16	S	2.30784	2.46404		
17	Cl	2.62239	2.8156		
18	Ar	2.95770	3.1905		
19	K	3.3138	3.5896		
20	Ca	3.69168	4.0127	0.3413	0.3449
21	Sc	4.0906	4.4605	0.3954	0.3996
22	Ti	4.51084	4.93181	0.4522	0.4584
23	V	4.95220	5.42729	0.5113	0.5192
24	Cr	5.41472	5.94671	0.5728	0.5828
25	Mn	5.89875	6.49045	0.6374	0.6488
26	Fe	6.40384	7.05798	0.7050	0.7185
27	Co	6.93032	7.64943	0.7762	0.7914
28	Ni	7.47815	8.26466	0.8515	0.8688
29	Cu	8.04778	8.90529	0.9297	0.9498
30	Zn	8.63886	9.5720	1.0117	1.0347
31	Ga	9.25174	10.2642	1.09792	1.1248
32	Ge	9.88642	10.9821	1.18800	1.2185
33	As	10.54372	11.7262	1.2820	1.3170
34	Se	11.2224	12.4959	1.37910	1.41923
35	Br	11.9242	13.2914	1.48043	1.52590
36	Kr	12.649	14.112	1.5860	1.6366
37	Rb	13.3953	14.9613	1.69413	1.75217
38	Sr	14.1650	15.8357	1.80656	1.87172
39	Y	14.9584	16.7378	1.92256	1.99584
40	Zr	15.7751	17.6678	2.04236	2.1244
41	Nb	16.6151	18.6225	2.16589	2.2574
42	Mo	17.47934	19.6083	2.29316	2.39481
43	Tc	18.3671	20.619	2.4240	2.5368
44	Ru	19.2792	21.6568	2.55855	2.68323
45	Rh	20.2161	22.7236	2.69674	2.83441
46	Pd	21.1771	23.8187	2.83861	2.99022
47	Ag	22.16292	24.9424	2.98431	3.15094

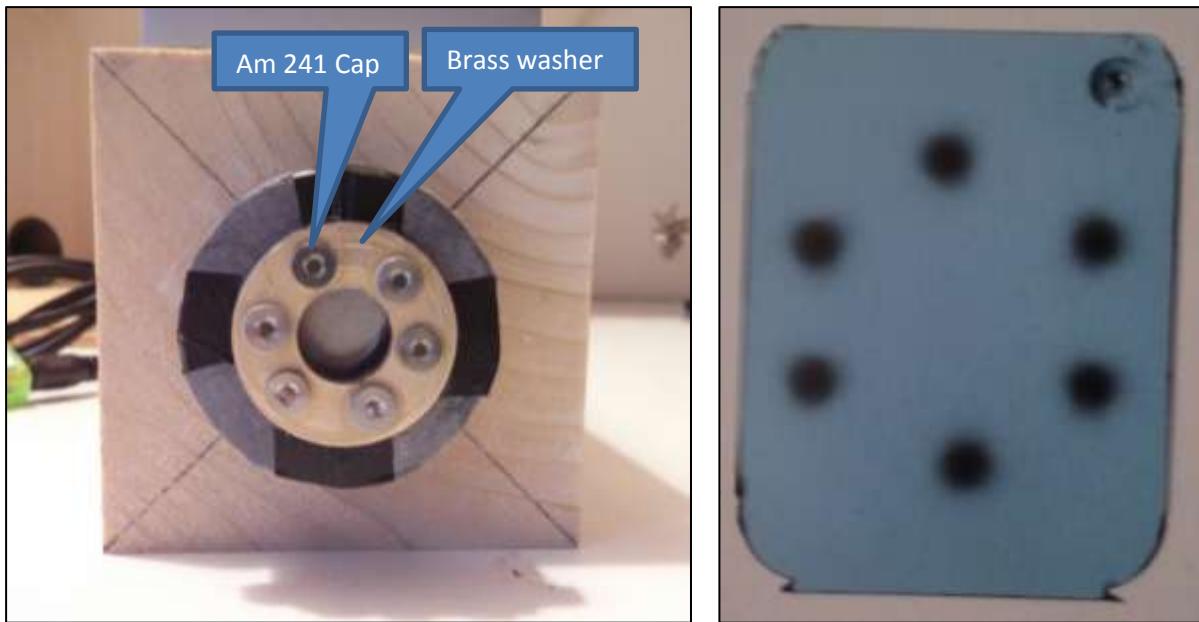
48	Cd	23.1736	26.0955	3.13373	3.31657
49	In	24.2097	27.2759	3.28694	3.48721
50	Sn	25.2713	28.4860	3.44398	3.66280
51	Sb	26.3591	29.7256	3.60472	3.84357
52	Te	27.4723	30.9957	3.76933	4.02958
53	I	28.6120	32.2947	3.93765	4.22072
54	Xe	29.779	33.624	4.1099	-
55	Cs	30.9728	34.9869	4.2865	4.6198
56	Ba	32.1936	36.3782	4.46626	4.82753
57	La	33.4418	37.8010	4.65097	5.0421
58	Ce	34.7197	39.2573	4.8402	5.2622
59	Pr	36.0263	40.7482	5.0337	5.4889
60	Nd	37.3610	42.2713	5.2304	5.7216
61	Pm	38.7247	43.826	5.4325	5.961
62	Sm	40.1181	45.413	5.6361	6.2051
63	Eu	41.5422	47.0379	5.8457	6.4564
64	Gd	42.9962	48.697	6.0572	6.7132
65	Tb	44.4816	50.382	6.2728	6.978
66	Dy	45.9984	52.119	6.4952	7.2477
67	Ho	47.5467	53.877	6.7198	7.5253
68	Er	49.1277	55.681	6.9487	7.8109
69	Tm	50.7416	57.517	7.1799	8.101
70	Yb	52.3889	59.37	7.4156	8.4018
71	Lu	54.0698	61.283	7.6555	8.7090
72	Hf	55.7902	63.234	7.8990	9.0227
73	Ta	57.532	65.223	8.1461	9.3431
74	W	59.31824	67.2443	8.3976	9.67235
75	Re	61.1403	69.310	8.6525	10.0100
76	Os	63.0005	71.413	8.9117	10.3553
77	Ir	64.8956	73.5608	9.1751	10.7083
78	Pt	66.832	75.748	9.4423	11.0707
79	Au	68.8037	77.984	9.7133	11.4423
80	Hg	70.819	80.253	9.9888	11.8226
81	Tl	72.8715	82.576	10.2685	12.2133
82	Pb	74.9694	84.936	10.5515	12.6137
83	Bi	77.1079	87.343	10.8388	13.0235
84	Po	79.290	89.80	11.1308	13.447
85	At	81.52	92.30	11.4268	13.876
86	Rn	83.78	94.87	11.7270	14.316
87	Fr	86.10	97.47	12.0313	14.770
88	Ra	88.47	100.13	12.3397	15.2358
89	Ac	90.884	102.85	12.6520	15.713
90	Th	93.350	105.609	12.9687	16.2022
91	Pa	95.868	108.427	13.2907	16.702
92	U	98.439	111.300	13.6147	17.2200
93	Np	-	-	13.9441	17.7502
94	Pu	-	-	14.2786	18.2937
95	Am	-	-	14.6172	18.8520

Equipment

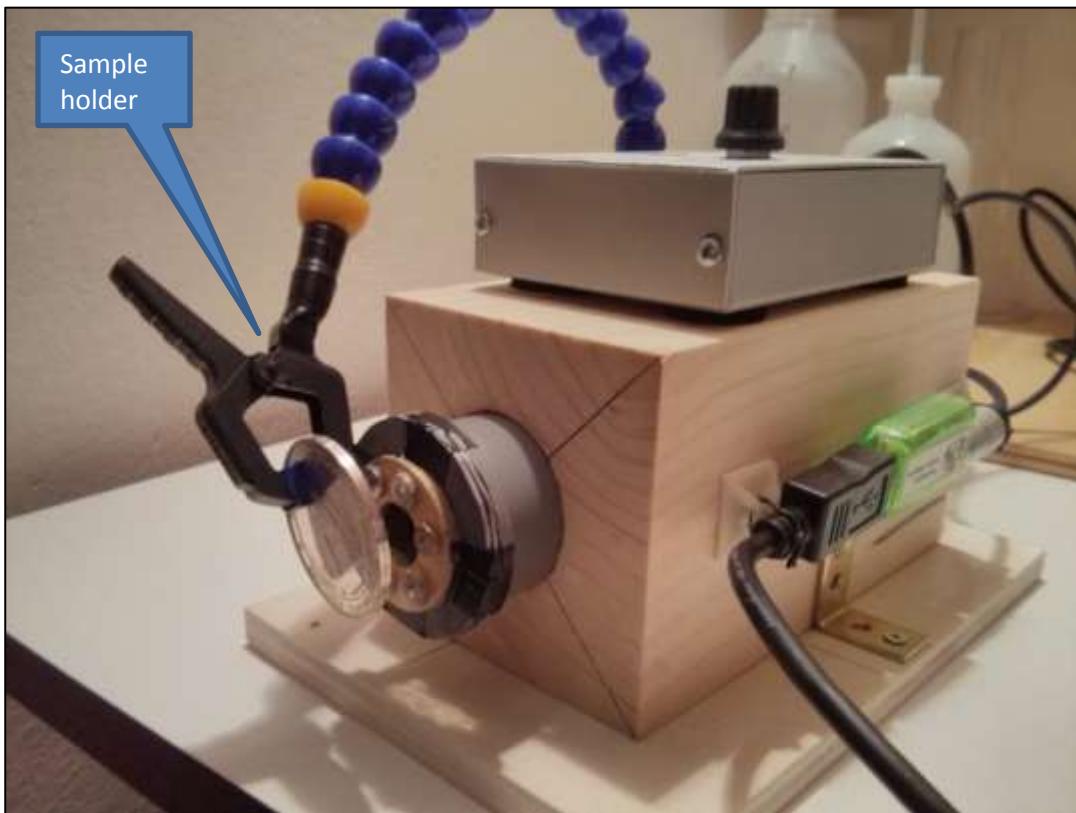
LEG RAP 47 Detector – PMT adapter



Head with Americium caps and image of the head on a radiographic film, two hours exposure time



Typical measurements setup



Measurements Parameters

Measurements Time = about 360sec

Min Energy = 0

Integration Filter = 10%

Number of bins = X10

Base-line Test

Position = 50 μ sec

Width = 300 μ sec

Max Slope = 20%

Max Noise = 15%

Resolution Compensation

Size = 20bins

Center = 20%

Left = 3%

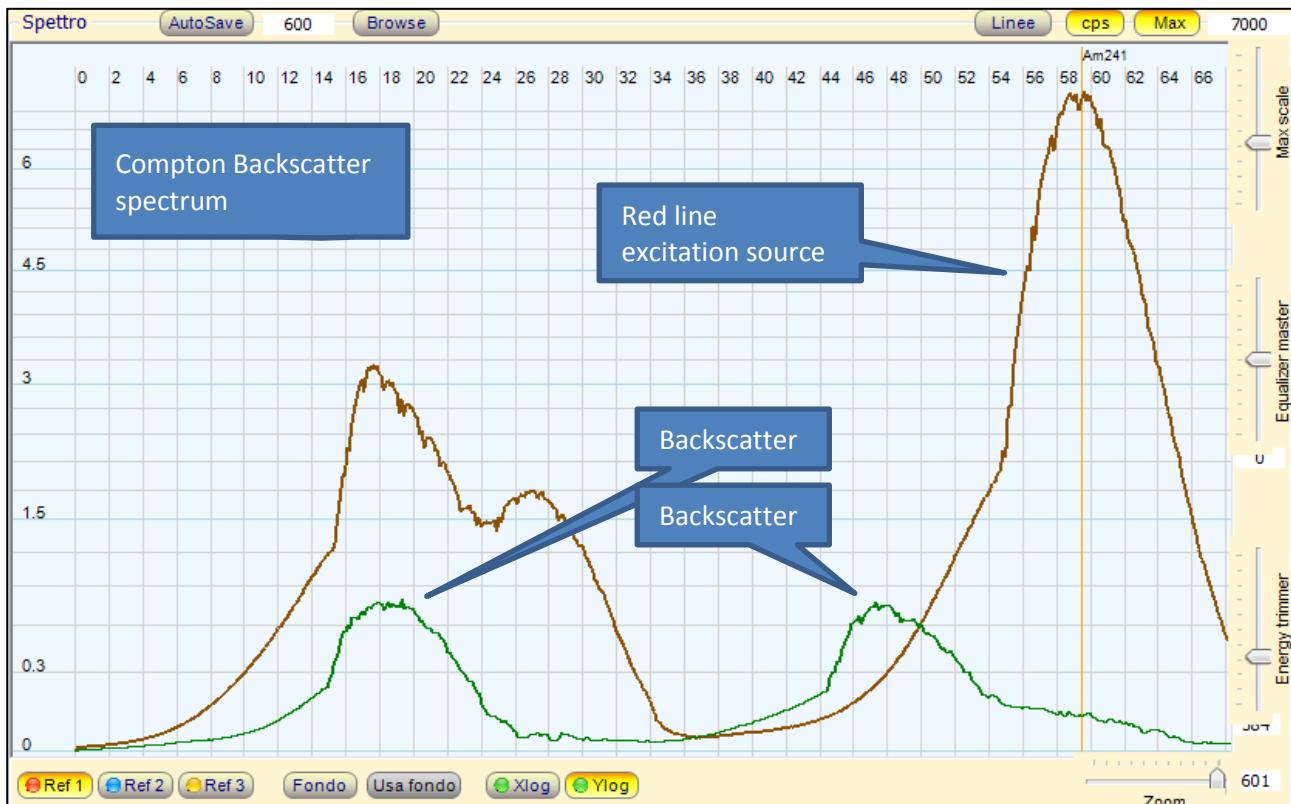
Right = 7%

Spectrum of the XRF excitation source



Americium – 241 Main emission at 59.54keV and around 20keV

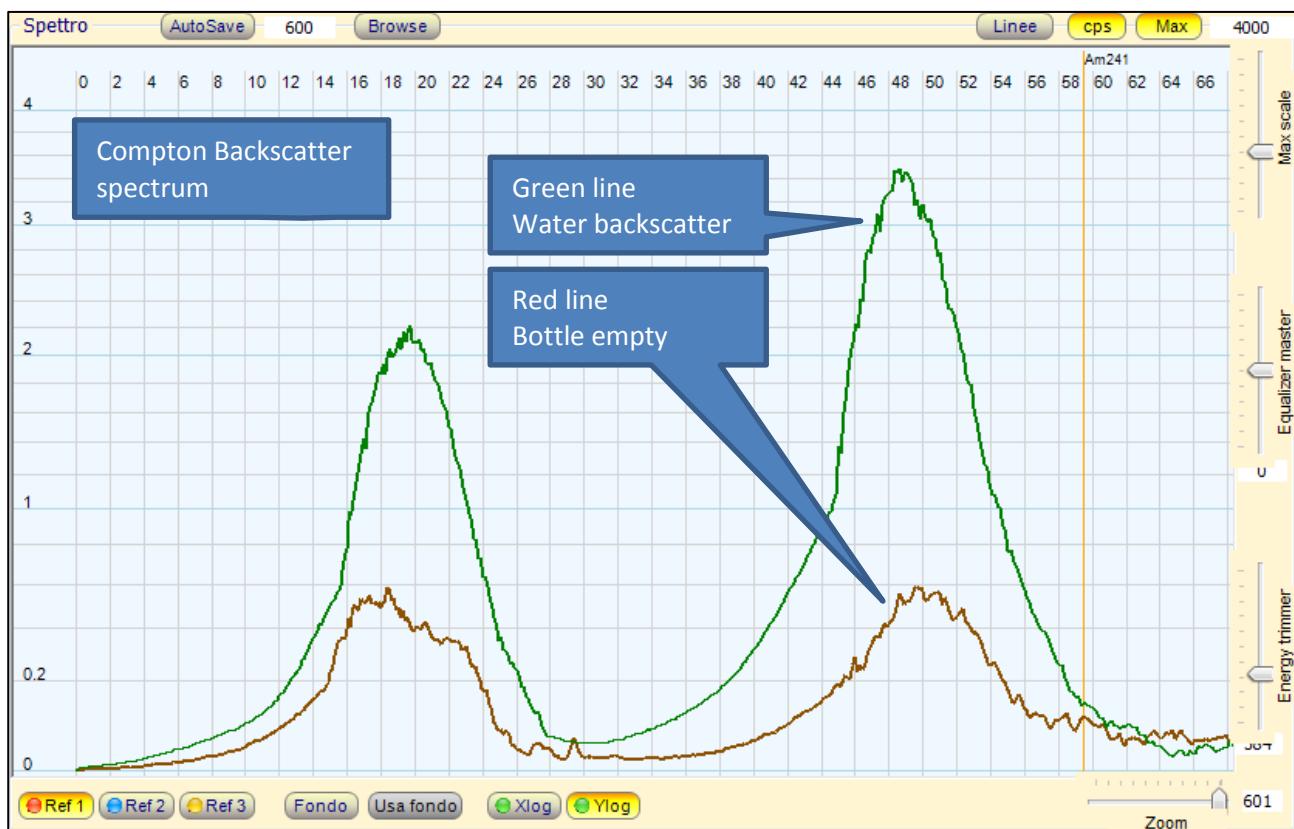
XRF spectrum of “light” materials such as wood



XRF spectrum of water



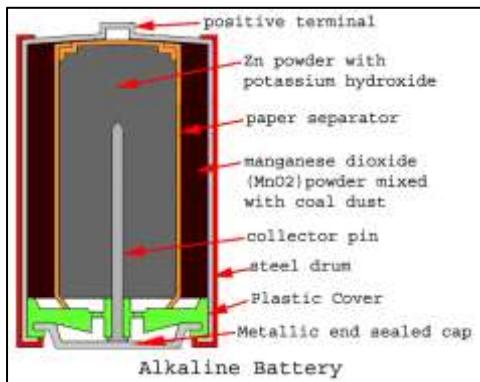
Measurements Setup



XRF Spectrometry of Chemical Elements

Manganese (Z=25) (alkaline battery)

Manganese is a chemical element with symbol **Mn** and atomic number 25. It is not found as a free element in nature; it is often found in combination with iron, and in many minerals. Manganese is a metal with important industrial metal alloy uses, particularly in stainless steels.



XRF Sample : Manganese Dioxide inside Alkaline Battery

Name / Symbol	Manganese / Mn
Atomic Number	25
Standard atomic weight	54.938044
Element category	Transition metal
Electron configuration	[Ar] 3d5 4s2
Electrons per shell	2, 8, 13, 2
K α 1	5.900 keV
K β 1	6.492 keV



Iron (Z=26)

Iron is a chemical element with symbol Fe (from Latin: ferrum) and atomic number 26. It is a metal in the first transition series. It is by mass the most common element on Earth, forming much of Earth's outer and inner core. It is the fourth most common element in the Earth's crust. Its abundance in rocky planets like Earth is due to its abundant production by fusion in high-mass stars, where the production of nickel-56 (which decays to the most common isotope of iron) is the last nuclear fusion reaction that is exothermic. Consequently, radioactive nickel is the last element to be produced before the violent collapse of a supernova scatters precursor radionuclide of iron into space.



XRF Sample : Iron wire

Name / Symbol	Iron / Fe
Atomic Number	26
Standard atomic weight	55.845
Element category	Transition metal
Electron configuration	[Ar] 3d6 4s2
Electrons per shell	2, 8, 14, 2
K α 1	6.405 keV
K β 1	7.059 keV



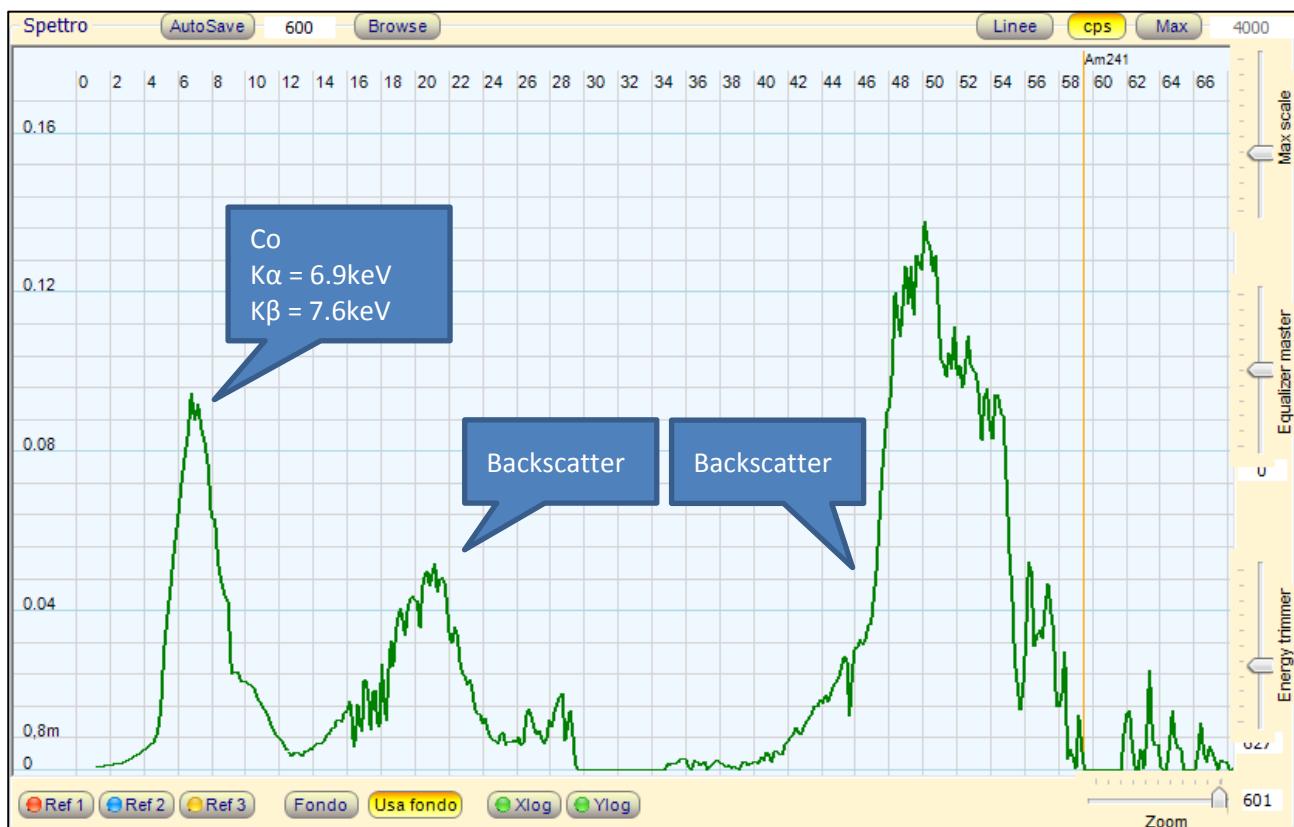
Cobalt (Z=27)

Cobalt is a chemical element with symbol **Co** and atomic number 27. Like nickel, cobalt in the Earth's crust is found only in chemically combined form, save for small deposits found in alloys of natural meteoric iron. The free element, produced by reductive smelting, is a hard, lustrous, silver-gray metal.



XRF Sample: Cobalt Sample

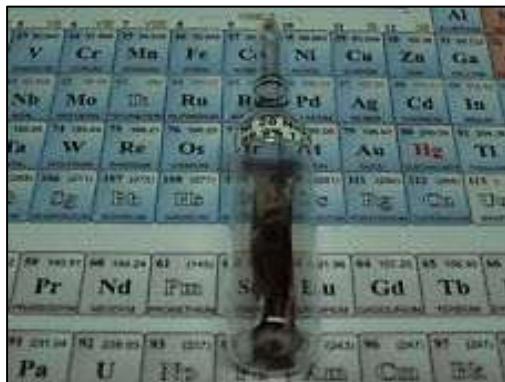
Name / Symbol	Cobalt / Co
Atomic Number	27
Standard atomic weight	58,933
Element category	Transition metal
Electron configuration	[Ar]3d74s2
Electrons per shell	2, 8, 15, 2
Kα1	6.930 keV
Kβ1	7.649 keV



Nickel (Z=28)

Nickel is a chemical element with symbol **Ni** and atomic number 28. It is a silvery-white lustrous metal with a slight golden tinge. Nickel belongs to the transition metals and is hard and ductile.

Because of nickel's slow rate of oxidation at room temperature, it is considered corrosion-resistant. Historically, this has led to its use for plating metals such as iron and brass, coating chemistry equipment, and manufacturing certain alloys that retain a high silvery polish, such as German silver. About 6% of world nickel production is still used for corrosion-resistant pure-nickel plating. Nickel-plated items are noted for provoking nickel allergy. Nickel has been widely used in coins, though its rising price has led to some replacement with cheaper metals in recent years.



XRF Sample : Nickel Sample

Name / Symbol	Nickel / Ni
Atomic Number	28
Standard atomic weight	58.6934
Element category	Transition metal
Electron configuration	[Ar] 3d9 4s1
Electrons per shell	2, 8, 16, 1
K α 1	7.480 keV
K β 1	8.267 keV



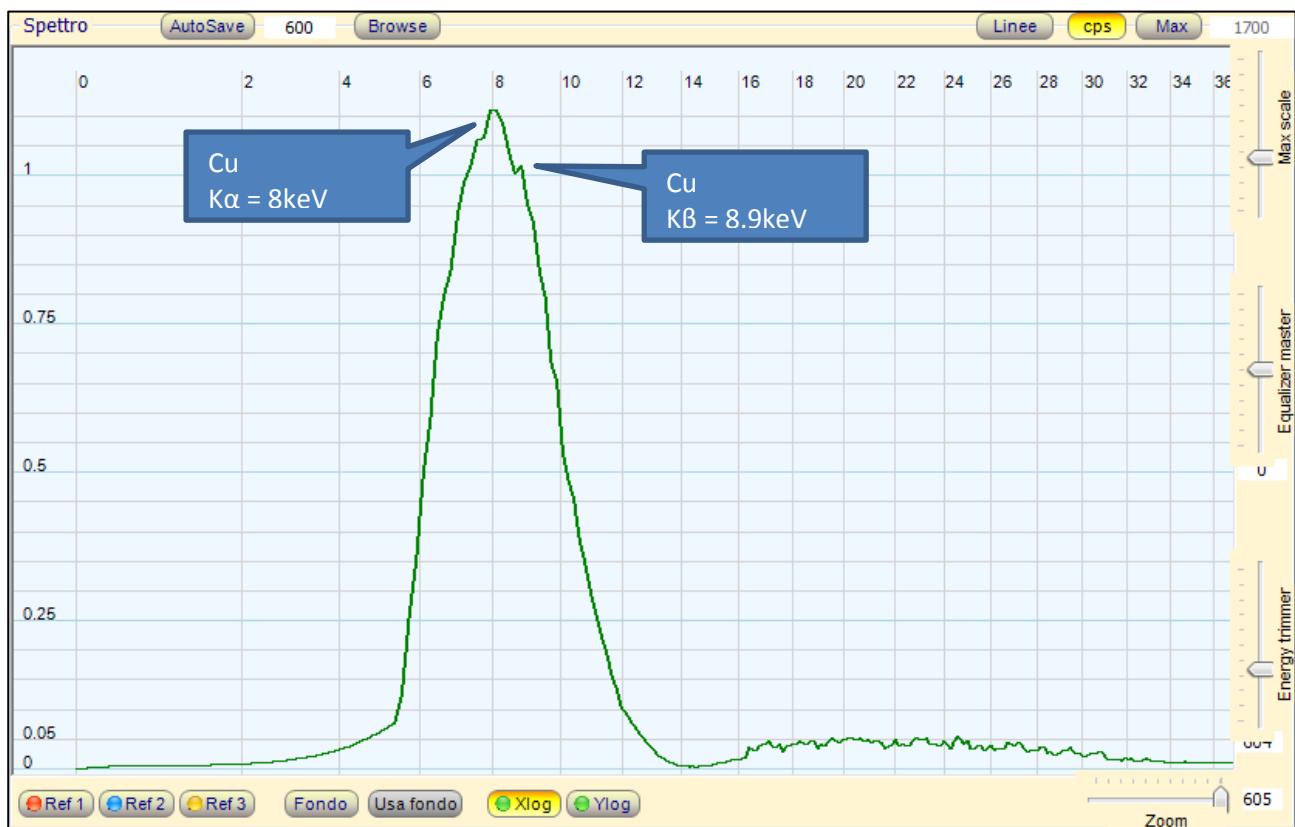
Copper (Z=29)

Copper is a chemical element with symbol Cu (from Latin: cuprum) and atomic number 29. It is a ductile metal with very high thermal and electrical conductivity. Pure copper is soft and malleable; a freshly exposed surface has a reddish-orange color. It is used as a conductor of heat and electricity, a building material, and a constituent of various metal alloys.



XRF Sample : Copper Wire

Name / Symbol	Copper / Cu
Atomic Number	29
Standard atomic weight	63.546
Element category	Transition metal
Electron configuration	[Ar] 3d10 4s1
Electrons per shell	2, 8, 18, 1
K α 1	8.046 keV
K β 1	8.904 keV



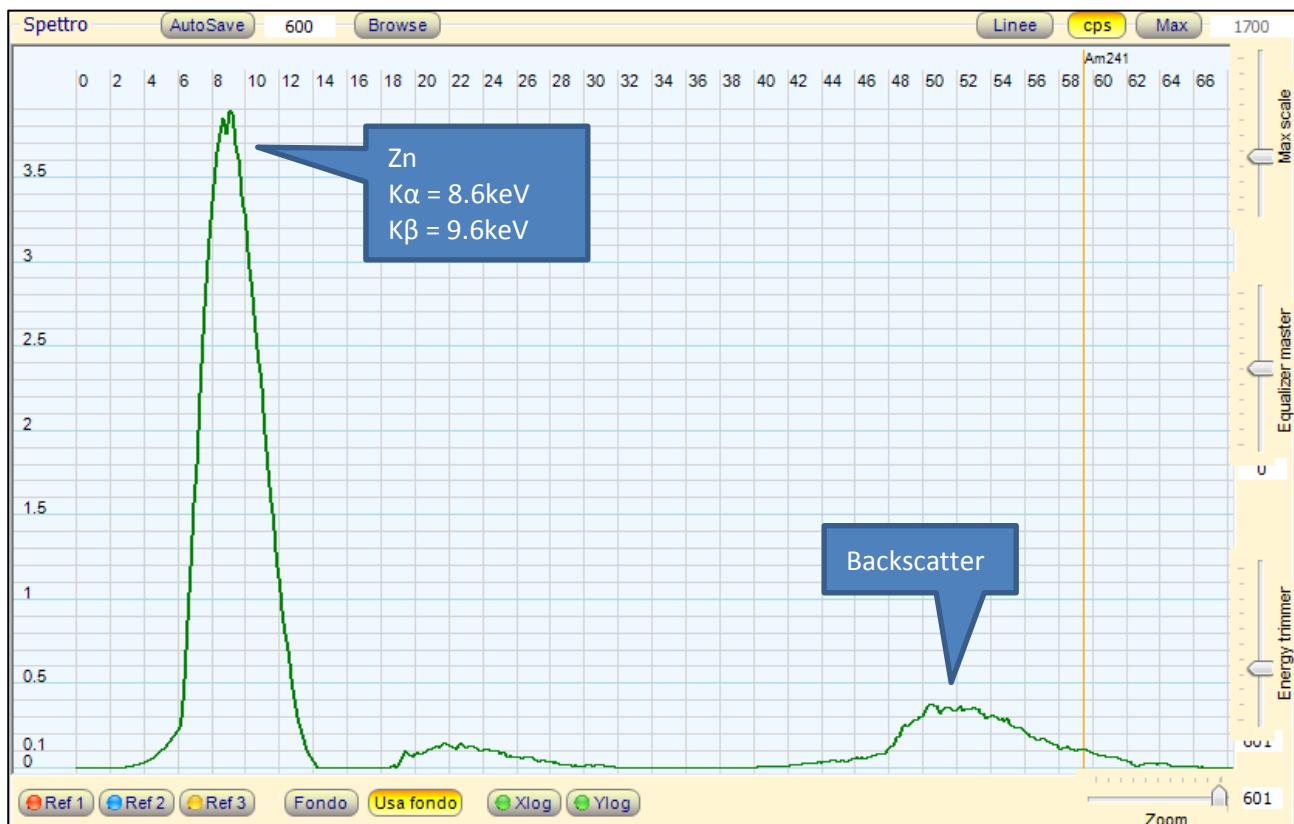
Zinc (Z=30)

Zinc, in commerce also spelter, is a chemical element with symbol **Zn** and atomic number 30. It is the first element of group 12 of the periodic table. In some respects zinc is chemically similar to magnesium: its ion is of similar size and its only common oxidation state is +2. Zinc is the 24th most abundant element in Earth's crust and has five stable isotopes. The most common zinc ore is sphalerite (zinc blende), a zinc sulfide mineral. The largest mineable amounts are found in Australia, Asia, and the United States.



XRF Sample : Zinc Sheet

Name / Symbol	Zinc / Zn
Atomic Number	30
Standard atomic weight	65.38
Element category	Transition metal
Electron configuration	[Ar] 3d10 4s2
Electrons per shell	2, 8, 18, 2
K α 1	8.637 keV
K β 1	9.570 keV



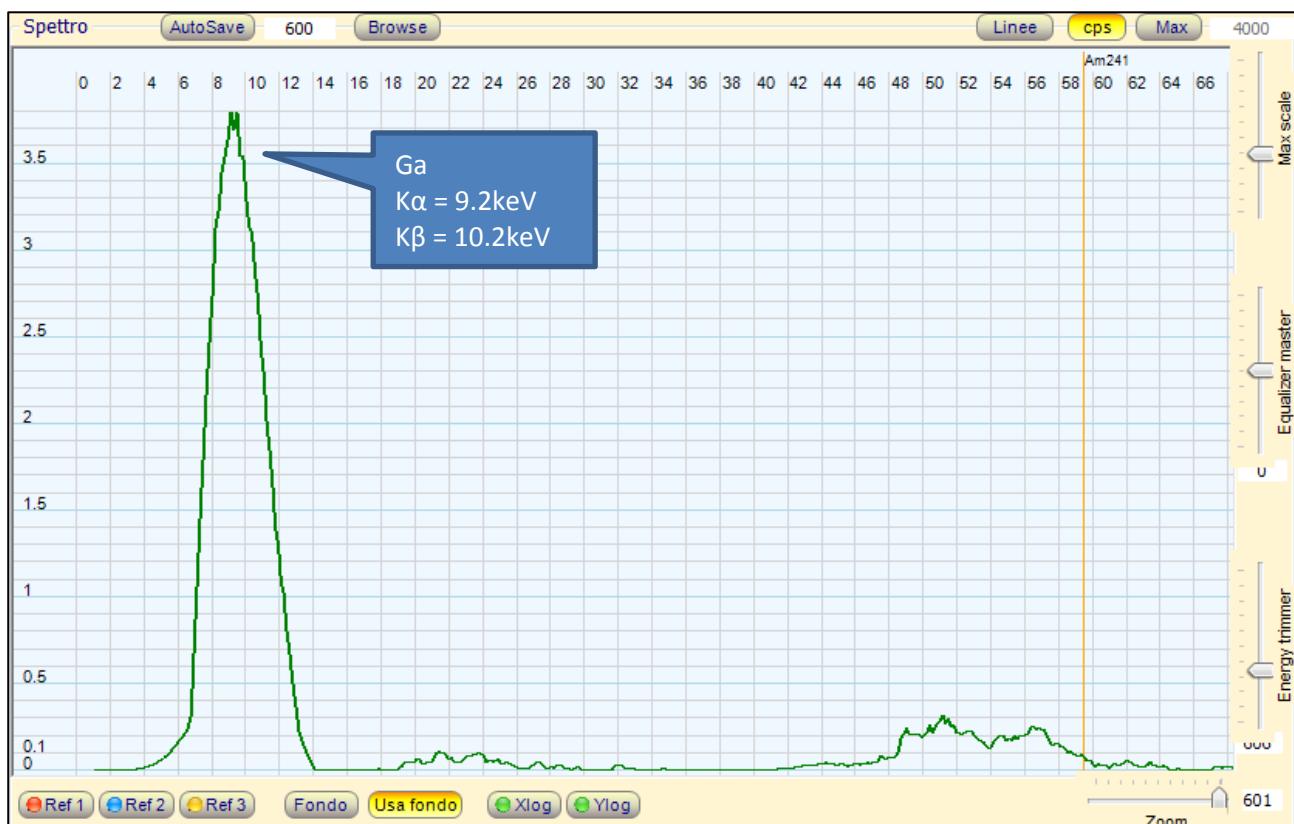
Gallium (Z=31)

Gallium is a chemical element with symbol **Ga** and atomic number 31. Elemental gallium does not occur in free form in nature, but as the gallium(III) compounds that are in trace amounts in zinc ores and in bauxite. Gallium is a soft, silvery metal, and elemental gallium is a brittle solid at low temperatures, and melts at 29.76 °C (85.57 °F) (slightly above room temperature). The melting point of gallium is used as a temperature reference point. The alloy galinstan (68.5% gallium, 21.5% indium, and 10% tin) has an even lower melting point of -19 °C (-2 °F), well below the freezing point of water. Since its discovery in 1875, gallium has been used as an agent to make alloys that melt at low temperatures. It has also been useful in semiconductors, including as a dopant.



XRF Sample: Gallium Sample

Name / Symbol	Gallium / Ga
Atomic Number	31
Standard atomic weight	69.723
Categoria Elemento	Post Transition metal
Electron configuration	[Ar]3d10 4s2 4p1
Electrons per shell	2, 8, 18, 3
K α 1	9.252 keV
K β 1	10.264 keV



Germanium (Z=32)

Germanium is a chemical element with symbol **Ge** and atomic number 32. It is a lustrous, hard, grayish-white metalloid in the carbon group, chemically similar to its group neighbors tin and silicon. Purified germanium is a semiconductor, with an appearance most similar to elemental silicon. Like silicon, germanium naturally reacts and forms complexes with oxygen in nature. Unlike silicon, it is too reactive to be found naturally on Earth in the free (native) state.



XRF Sample: Germanium Sample

Name / Symbol	Germanium / Ge
Atomic Number	32
Standard atomic weight	72,64
Element category	Metalloid
Electron configuration	[Ar]3d10 4s2 4p2
Electrons per shell	2, 8, 18, 4
K α 1	9.886 keV
K β 1	10.982 keV



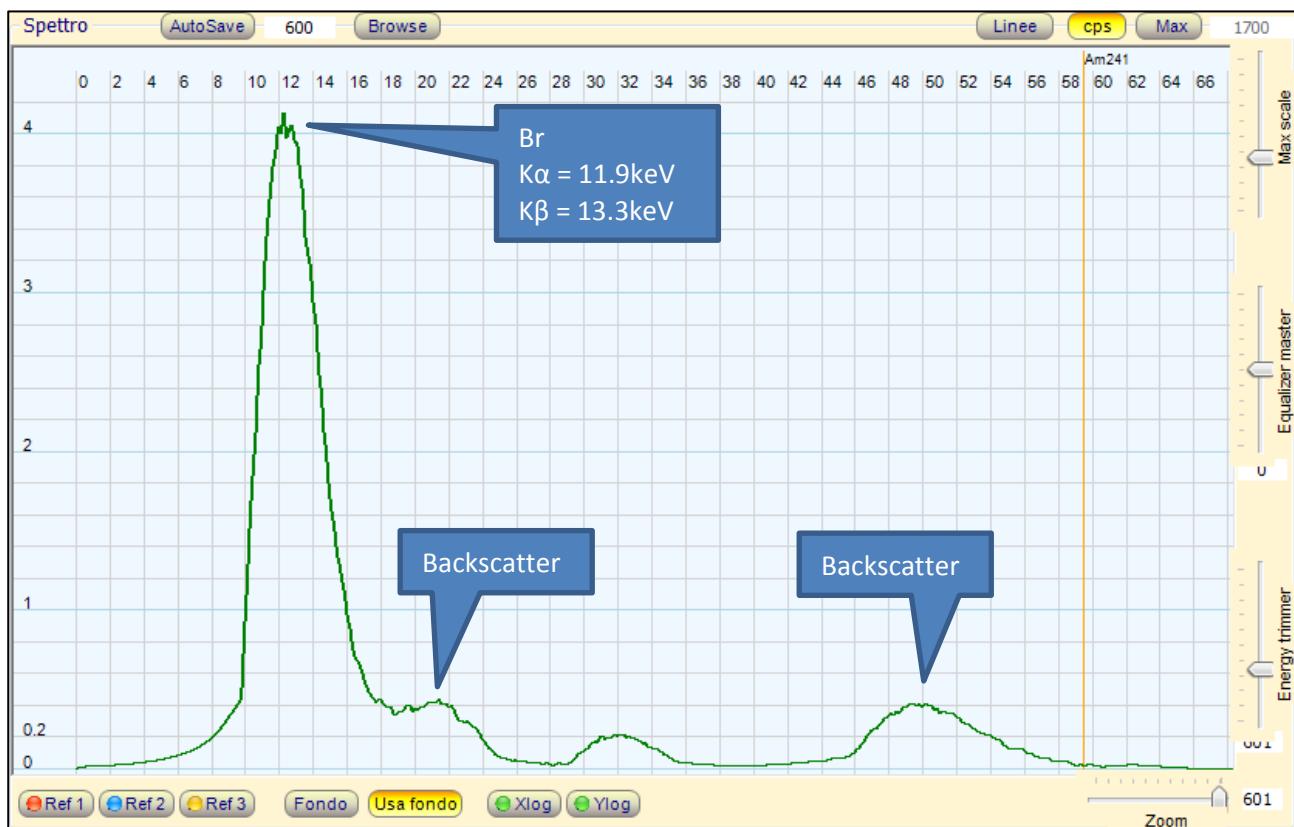
Bromine (Z=35) (Flame Retardant in PCB)

Bromine (from Greek: brómos, meaning "strong-smelling" or "stench") is a chemical element with symbol **Br**, and atomic number 35. It is a halogen. The element was isolated independently by two chemists, Carl Jacob Löwig and Antoine Jerome Balard, in 1825–1826. Elemental bromine is a fuming red-brown liquid at room temperature, corrosive and toxic, with properties between those of chlorine and iodine. Free bromine does not occur in nature, but occurs as colorless soluble crystalline mineral halide salts, analogous to table salt. It is used as flame retardant for instance inside PVCB.



XRF Sample : PCB with Bromine as Flame Retardant

Name / Symbol	Bromine / Br
Atomic Number	35
Standard atomic weight	79.904
Element category	Halogen
Electron configuration	[Ar] 3d10 4s2 4p5
Electrons per shell	2, 8, 18, 7
K α 1	11.924 keV
K β 1	13.292 keV



Rubidium (Z=37)

Rubidium is a chemical element with symbol Rb and atomic number 37. Rubidium is a soft, silvery-white metallic element of the alkali metal group, with an atomic mass of 85.4678. Elemental rubidium is highly reactive, with properties similar to those of other alkali metals, such as very rapid oxidation in air. Natural rubidium is a mix of two isotopes: ^{85}Rb , the only stable one, constitutes 72% of it. The remaining 28% is the slightly radioactive ^{87}Rb with a half-life of 49 billion years—more than three times longer than the estimated age of the universe.



XRF Sample: Rubidium Sample

Name / Symbol	Rubidium / Rb
Atomic Number	37
Standard atomic weight	85,4678
Element category	Alkali metal
Electron configuration	[Kr]5s1
Electrons per shell	2, 8, 18, 8, 1
K α 1	13.395 keV
K β 1	14.961 keV



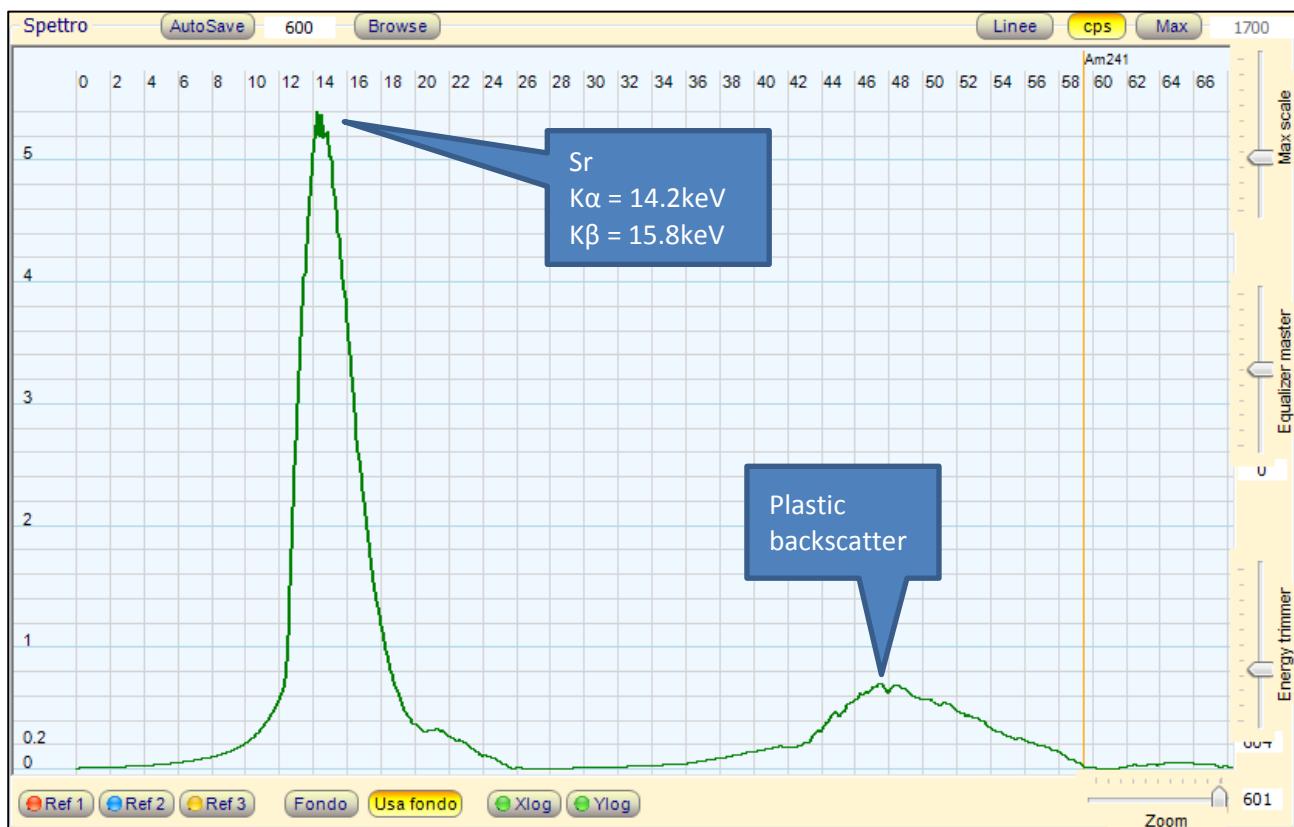
Strontium (Z=38) (Strontium Aluminate)

Strontium is a chemical element with symbol **Sr** and atomic number 38. An alkaline earth metal, strontium is a soft silver-white or yellowish metallic element that is highly reactive chemically. The metal turns yellow when it is exposed to air. Strontium has physical and chemical properties similar to those of its two neighbors calcium and barium. It occurs naturally in the minerals celestine, putnisite and strontianite. While natural strontium is stable, the synthetic ^{90}Sr isotope is present in radioactive fallout and has a half-life of 28.90 years.



XRF Sample : Strontium Aluminate

Name / Symbol	Strontium / Sr
Atomic Number	38
Standard atomic weight	87.62
Element category	alkaline earth metal
Electron configuration	[Kr] 5s2
Electrons per shell	2, 8, 18, 8, 2
K α 1	14.165 keV
K β 1	15.835 keV



Yttrium (Z=39)

Yttrium is a chemical element with symbol Y and atomic number 39. It is a silvery-metallic transition metal chemically similar to the lanthanides and it has often been classified as a "rare earth element". Yttrium is almost always found combined with the lanthanides in rare earth minerals and is never found in nature as a free element. Its only stable isotope, ^{89}Y , is also its only naturally occurring isotope.

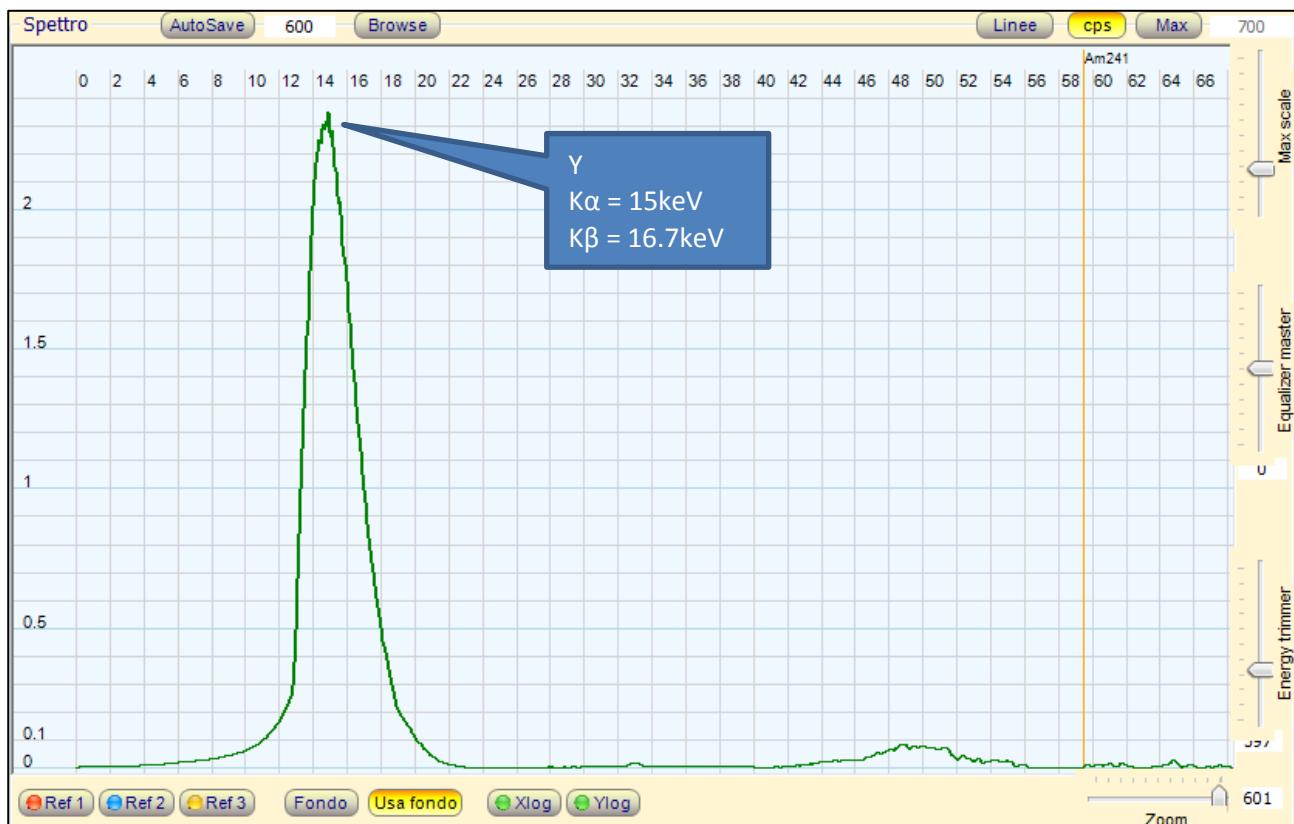
The most important use of yttrium is in making phosphors, such as the red ones used in television set cathode ray tube (CRT) displays and in LEDs. It is also used in the production of electrodes, electrolytes, electronic filters, lasers and superconductors;

As a metal, it is used on the electrodes of some high-performance spark plugs. Yttrium is also used in the manufacturing of gas mantles for propane lanterns as a replacement for thorium, which is radioactive.



XRF Sample : New type gas mantle

Name / Symbol	Yttrium / Y
Atomic Number	39
Standard atomic weight	88.90584
Element category	transition metal
Electron configuration	[Kr] 4d1 5s2
Electrons per shell	2, 8, 18, 9, 2
K α 1	14.958 keV
K β 1	16.738 keV



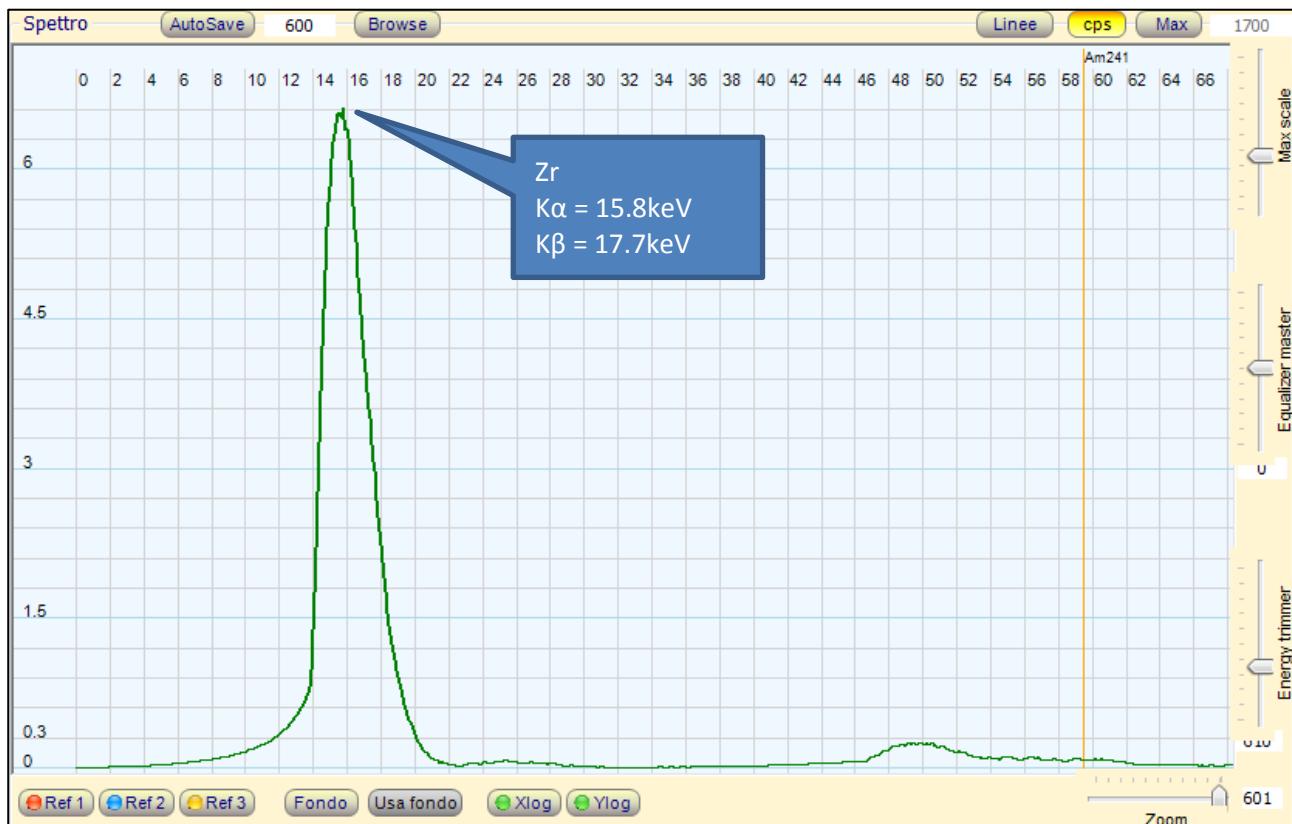
Zirconium (Z=40)

Zirconium is a chemical element with symbol **Zr** and atomic number 40. The name of zirconium is taken from the name of the mineral zircon, the most important source of zirconium. The word zircon comes from the Persian word zargun, meaning "gold-colored". It is a lustrous, grey-white, strong transition metal that resembles hafnium and, to a lesser extent, titanium. Zirconium is mainly used as a refractory and opacifier, although it is used in small amounts as an alloying agent for its strong resistance to corrosion. Zirconium forms a variety of inorganic and organometallic compounds such as zirconium dioxide and zirconocene dichloride, respectively. Five isotopes occur naturally, three of which are stable. Zirconium compounds have no known biological role.



XRF Sample : Zirconium Dioxide Knife

Name / Symbol	Zirconium / Zr
Atomic Number	40
Standard atomic weight	91.224
Element category	Transition metal
Electron configuration	[Kr] 4d2 5s2
Electrons per shell	2, 8, 18, 10, 2
K α 1	15.775 keV
K β 1	17.667 keV



Niobium (Z=41)

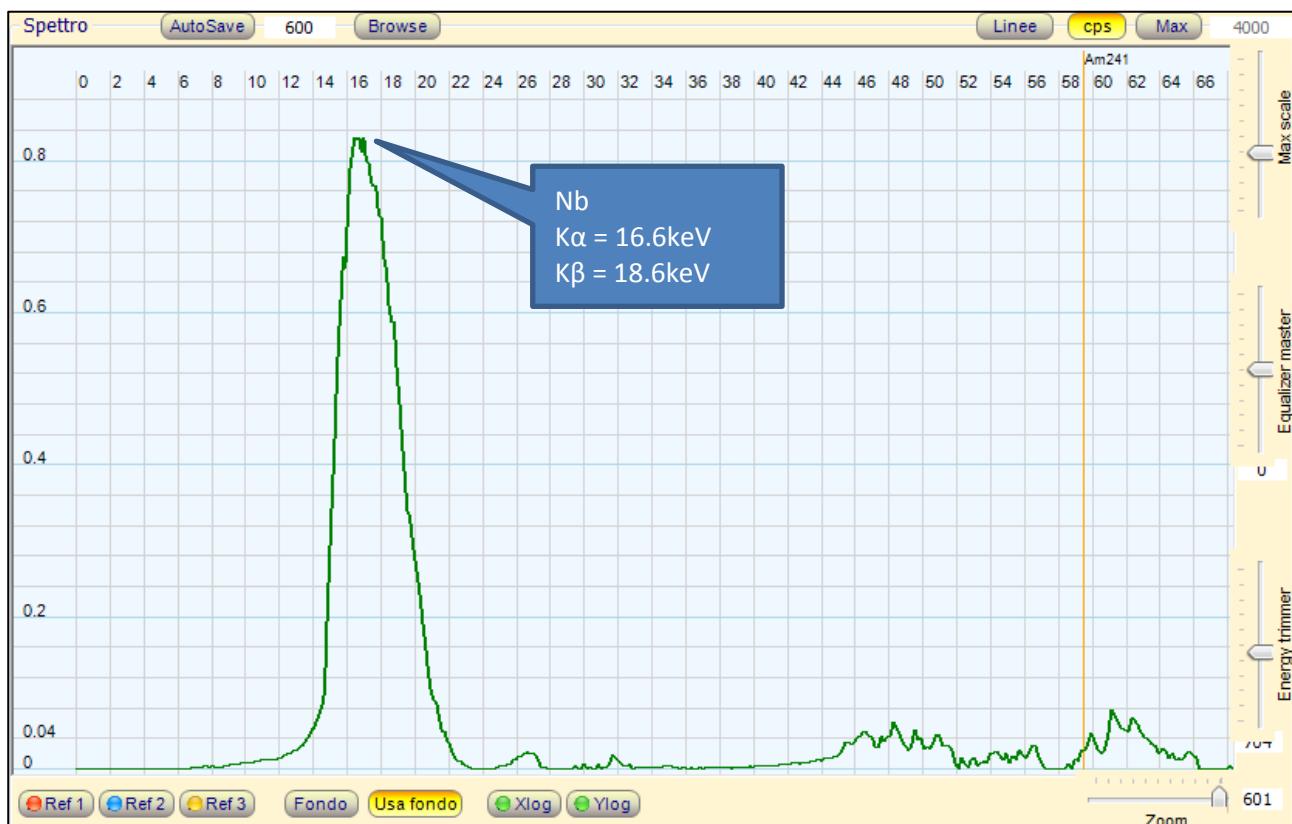
Niobium, formerly columbium, is a chemical element with symbol **Nb** (formerly Cb) and atomic number 41. It is a soft, grey, ductile transition metal, which is often found in the pyrochlore mineral, the main commercial source for niobium, and columbite.

Niobium is used in various superconducting materials. These superconducting alloys, also containing titanium and tin, are widely used in the superconducting magnets of MRI scanners. Other applications of niobium include its use in welding, nuclear industries, electronics, optics, numismatics, and jewelry. In the last two applications, niobium's low toxicity and ability to be colored by anodization are particular advantages.



XRF Sample : Niobium piercing

Name / Symbol	Niobium / Nb
Atomic Number	41
Standard atomic weight	92.90637
Element category	Transition metal
Electron configuration	[Kr] 4d4 5s1
Electrons per shell	2, 8, 18, 12, 1
K α 1	16.615 keV
K β 1	18.622 keV



Molybdenum (Z=42)

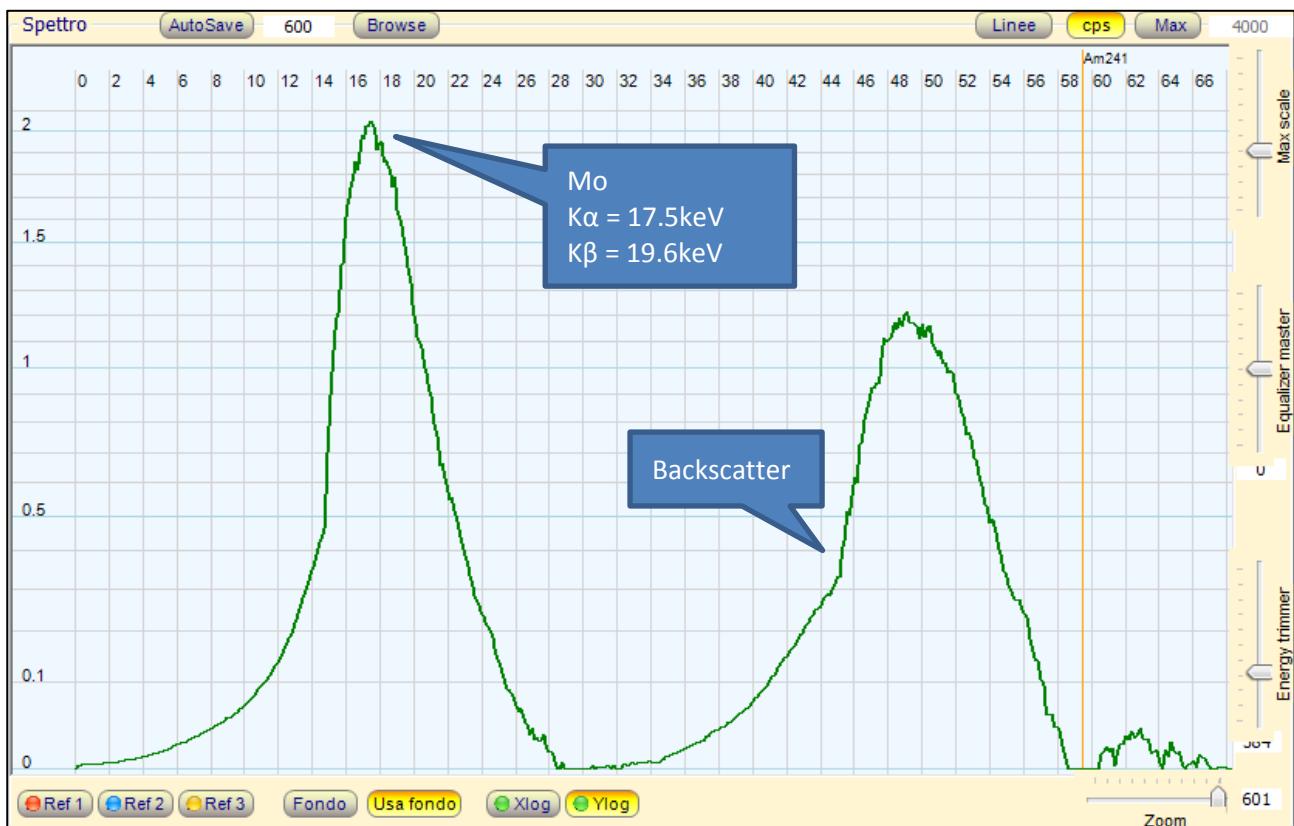
Molybdenum is a chemical element with symbol **Mo** and atomic number 42. Molybdenum does not occur naturally as a free metal on Earth, but rather in various oxidation states in minerals. The free element, which is a silvery metal with a gray cast, has the sixth-highest melting point of any element. It readily forms hard, stable carbides in alloys, and for this reason most of world production of the element (about 80%) is in making many types of steel alloys, including high strength alloys and superalloys.

Most molybdenum compounds have low solubility in water, but the molybdate ion MoO_4^{2-} is soluble and forms when molybdenum-containing minerals are in contact with oxygen and water. Industrially, molybdenum compounds (about 14% of world production of the element) are used in high-pressure and high-temperature applications, as pigments, and as catalysts.



XRF Sample : Molybdenum disulfide grease

Name / Symbol	Molybdenum / Mo
Atomic Number	42
Standard atomic weight	95.95
Element category	Transition metal
Electron configuration	[Kr] 4d5 5s1
Electrons per shell	2, 8, 18, 13, 1
K α 1	17.479 keV
K β 1	19.608 keV



Rhodium (Z=45)

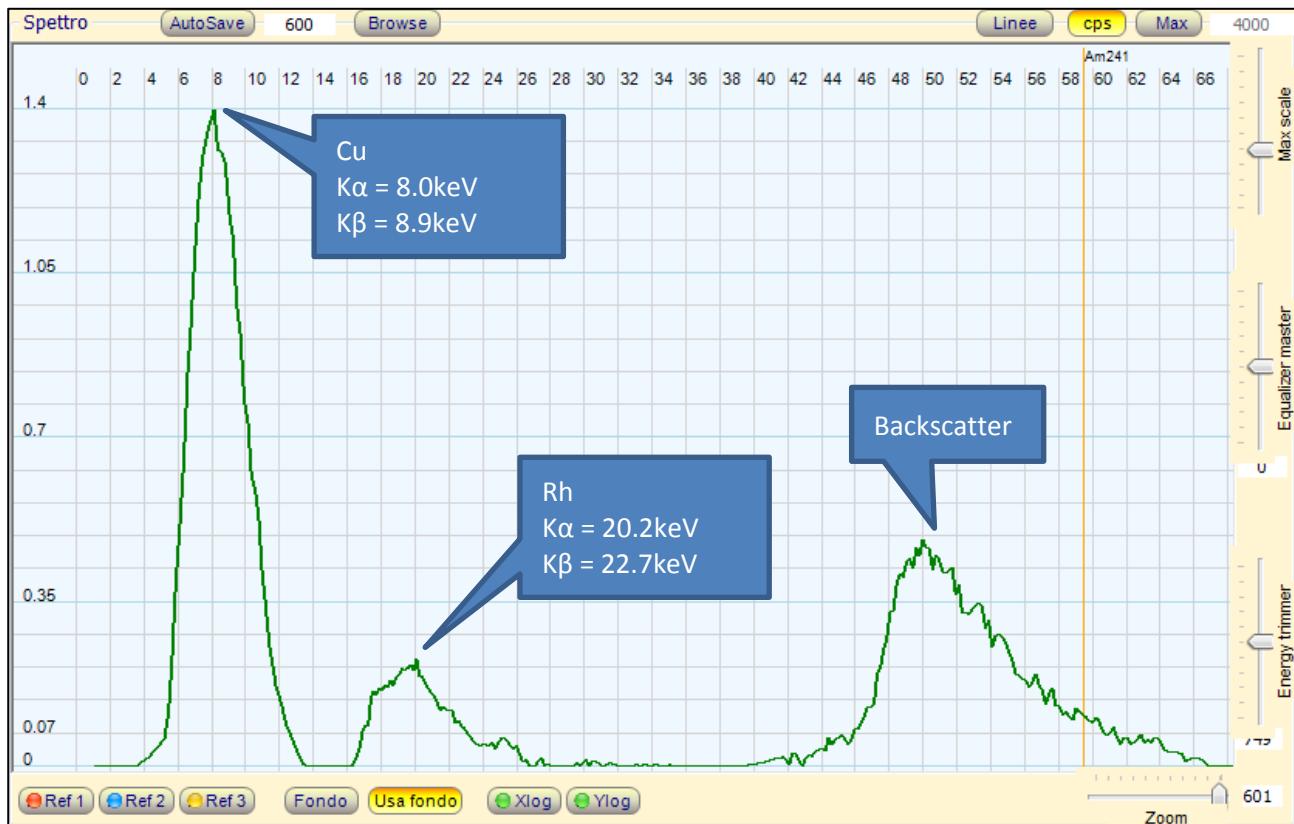
Rhodium is a chemical element with symbol **Rh** and atomic number 45. It is a rare, silvery-white, hard, and chemically inert transition metal. It is a member of the platinum group. It has only one naturally-occurring isotope, ^{103}Rh . Naturally occurring rhodium is usually found as the free metal, alloyed with similar metals, and rarely as a chemical compound in minerals such as bowieite and rhodplumsite. It is one of the rarest and most valuable precious metals.

Rhodium is a so-called noble metal, resistant to corrosion, found in platinum- or nickel ores together with the other members of the platinum group metals. It was discovered in 1803 by William Hyde Wollaston in one such ore, and named for the rose color of one of its chlorine compounds, produced after it reacted with the powerful acid mixture aqua regia.



XRF Sample: Rhodium plated copper

Name / Symbol	Rhodium / Rh
Atomic Number	45
Standard atomic weight	102,90550
Element category	Metallo di transizione
Electron configuration	[Kr]4d8 5s1
Electrons per shell	2, 8, 18, 16, 1
K α 1	20.216 keV
K β 1	22.723 keV



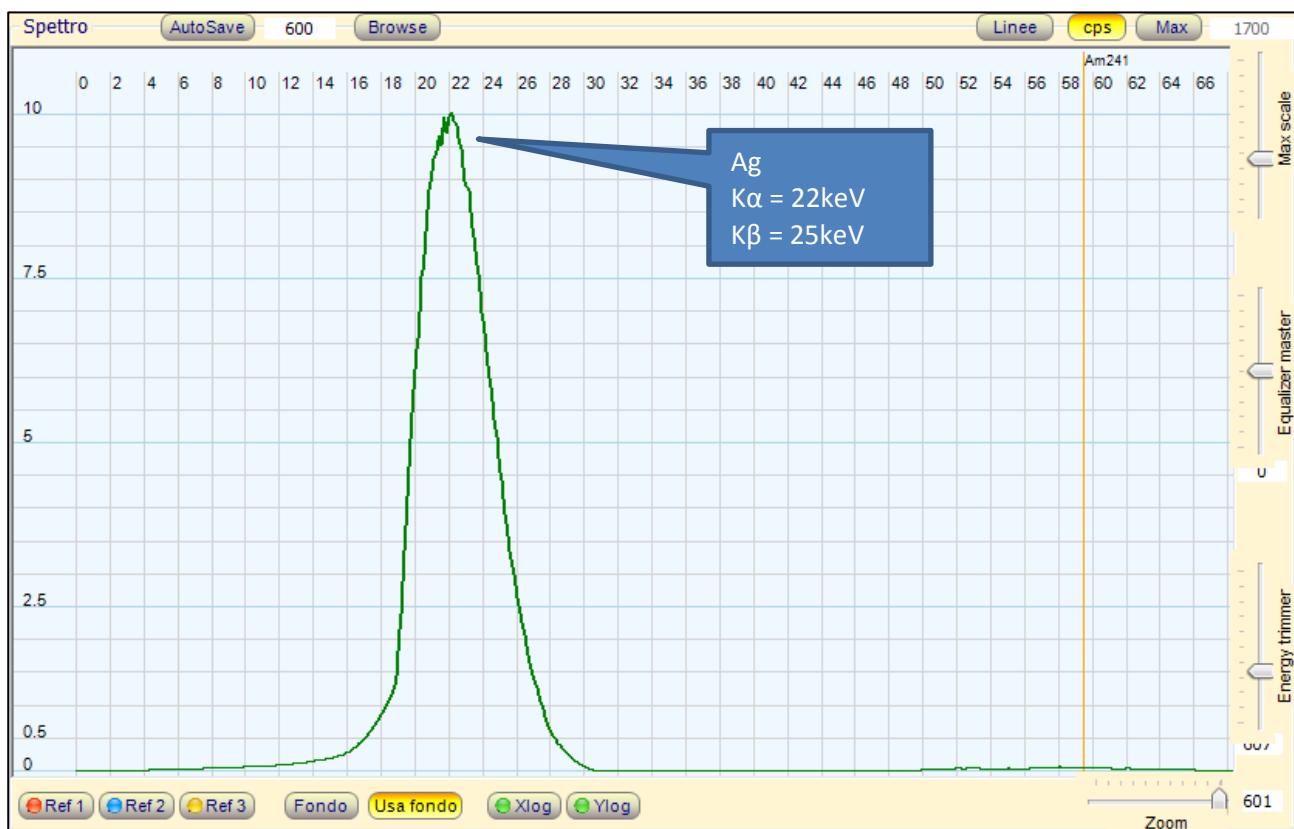
Silver (Z=47)

Silver is a chemical element with symbol Ag and atomic number 47. A soft, white, lustrous transition metal, it possesses the highest electrical conductivity of any element, the highest thermal conductivity of any metal and is the most reflective metal on the planet. The metal occurs naturally in its pure, free form (native silver), as an alloy with gold and other metals, and in minerals such as argentite and chlorargyrite. Most silver is produced as a byproduct of copper, gold, lead, and zinc refining.



XRF Sample : Silver Coin

Name / Symbol	Silver / Ag
Atomic Number	47
Standard atomic weight	107.8682
Element category	Transition metal
Electron configuration	[Kr] 4d10 5s1
Electrons per shell	2, 8, 18, 18, 1
K α 1	22.163 keV
K β 1	24.941 keV



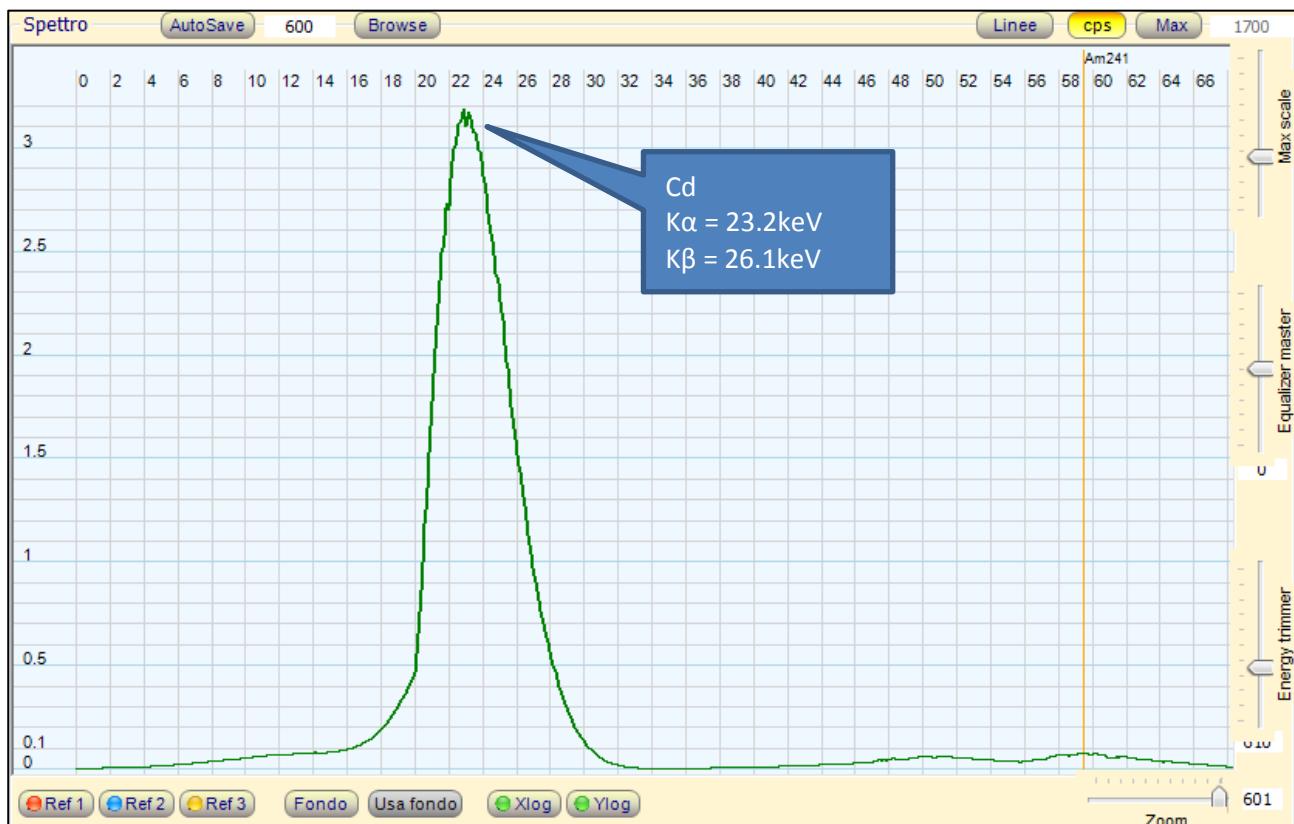
Cadmium (Z=48)

Cadmium is a chemical element with symbol **Cd** and atomic number 48. This soft, bluish-white metal is chemically similar to the two other stable metals in group 12, zinc and mercury. Like zinc, it prefers oxidation state +2 in most of its compounds and like mercury it shows a low melting point compared to transition metals. Cadmium and its congeners are not always considered transition metals, in that they do not have partly filled d or f electron shells in the elemental or common oxidation states. The average concentration of cadmium in Earth's crust is between 0.1 and 0.5 parts per million (ppm).



XRF Sample : Cadmium Yellow Pigment

Name / Symbol	Cadmium / Cd
Atomic Number	48
Standard atomic weight	112.414
Element category	Transition metal
Electron configuration	[Kr] 4d10 5s2
Electrons per shell	2, 8, 18, 18, 2
K α 1	23.173 keV
K β 1	26.095 keV



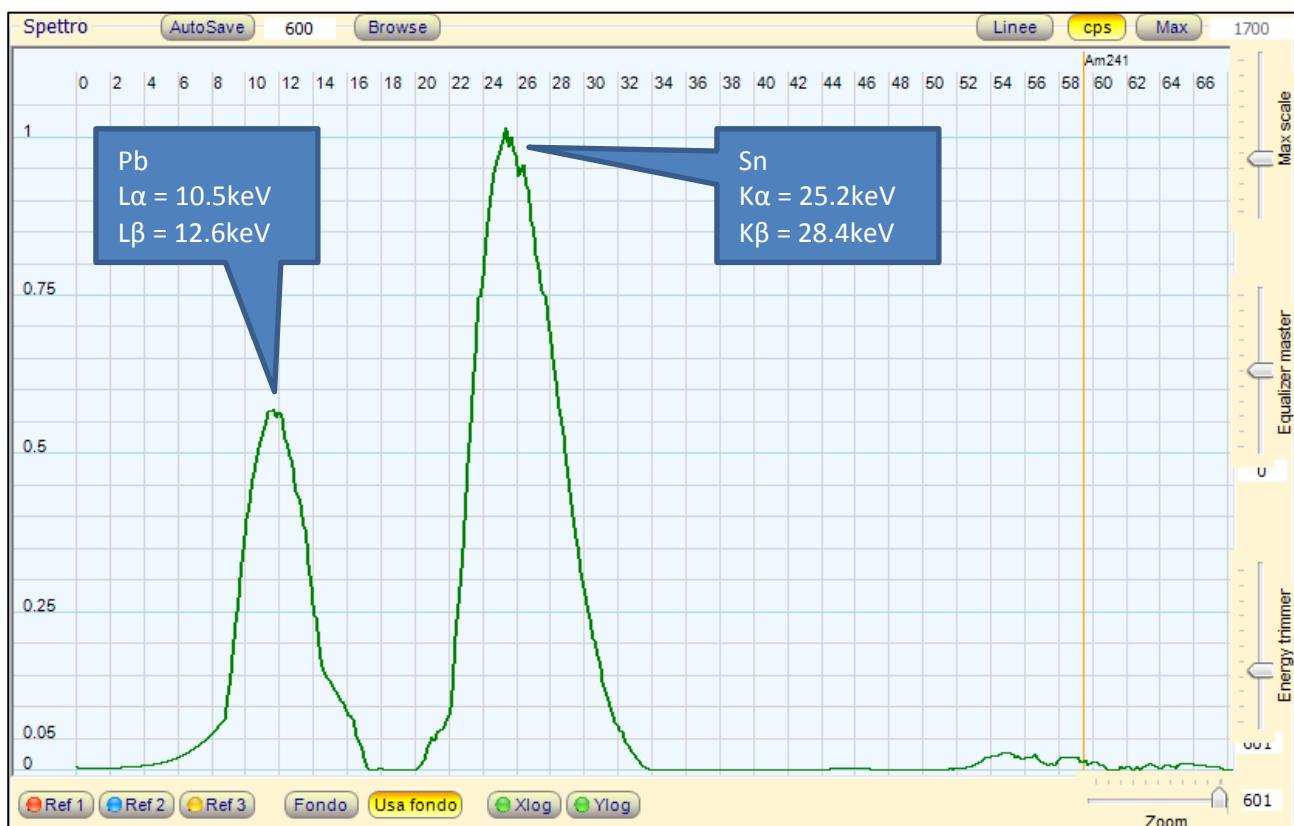
Tin (Z=50) (Soldering Alloy Tin + Lead)

Tin is a chemical element with symbol **Sn** (for Latin: stannum) and atomic number 50. It is a main group metal in group 14 of the periodic table. Tin shows chemical similarity to both neighboring group-14 elements, germanium and lead, and has two possible oxidation states, +2 and the slightly more stable +4. Tin is the 49th most abundant element and has, with 10 stable isotopes, the largest number of stable isotopes in the periodic table. It is a silvery, malleable other metal that is not easily oxidized in air, obtained chiefly from the mineral cassiterite where it occurs as tin dioxide, SnO₂.



XRF Sample : Soldering Wire

Name / Symbol	Tin / Sn
Atomic Number	50
Standard atomic weight	118.710
Element category	Post - transition metal
Electron configuration	[Kr] 4d10 5s2 5p2
Electrons per shell	2, 8, 18, 18, 4
K α 1	25.271 keV
K β 1	28.485 keV



Antimony (Z=51)

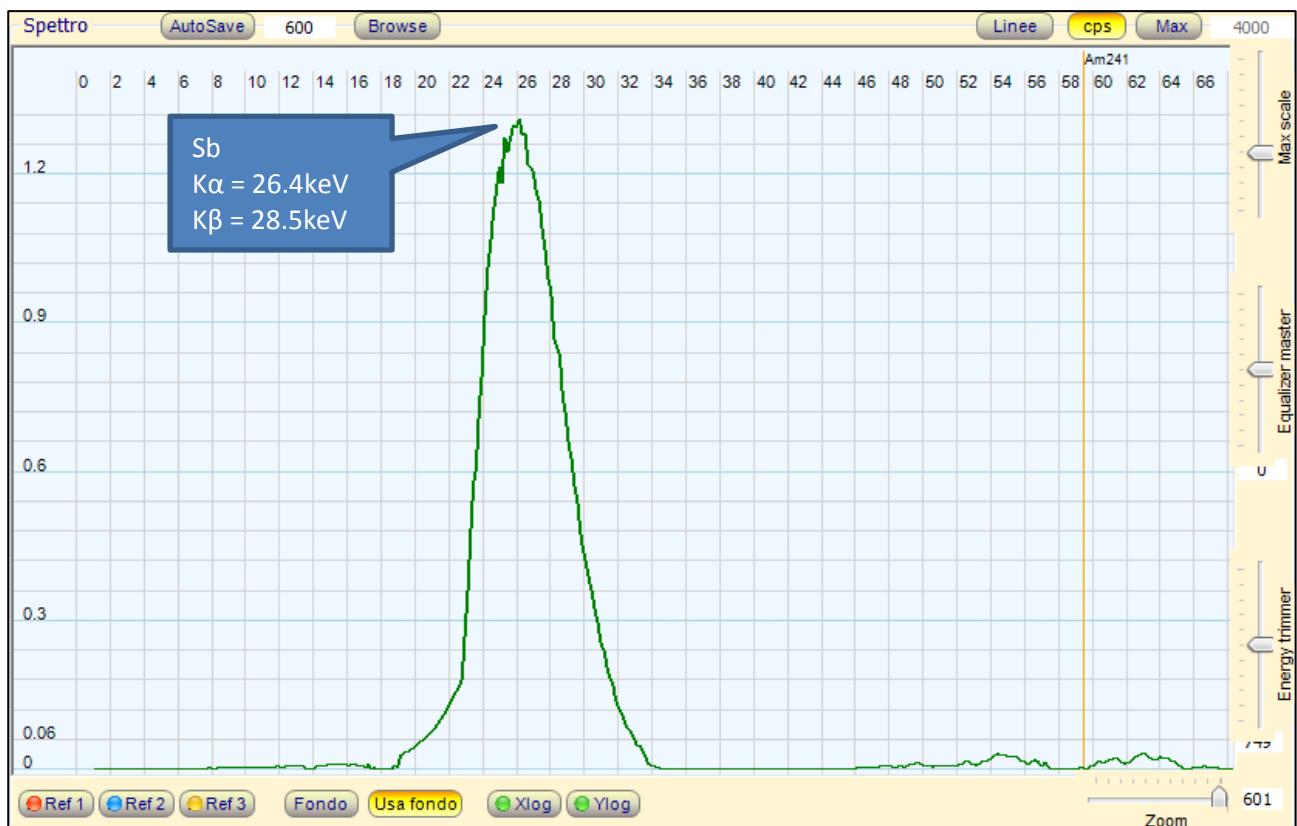
Antimony is a chemical element with symbol **Sb** (from Latin: stibium) and atomic number 51. A lustrous gray metalloid, it is found in nature mainly as the sulfide mineral stibnite (Sb_2S_3).

The largest applications for metallic antimony are as alloying material for lead and tin and for lead antimony plates in lead–acid batteries. Alloying lead and tin with antimony improves the properties of the alloys which are used in solders, bullets and plain bearings. Antimony compounds are prominent additives for chlorine and bromine-containing fire retardants found in many commercial and domestic products. An emerging application is the use of antimony in microelectronics.



XRF Sample: Antimony sample

Name / Symbol	Antimony / Sb
Atomic Number	51
Standard atomic weight	121,760
Element category	Metalloid
Electron configuration	[Kr]4d10 5s2 5p3
Electrons per shell	2, 8, 18, 18, 5
K α 1	26.359 keV
K β 1	28.486 keV



Iodine (Z=53)

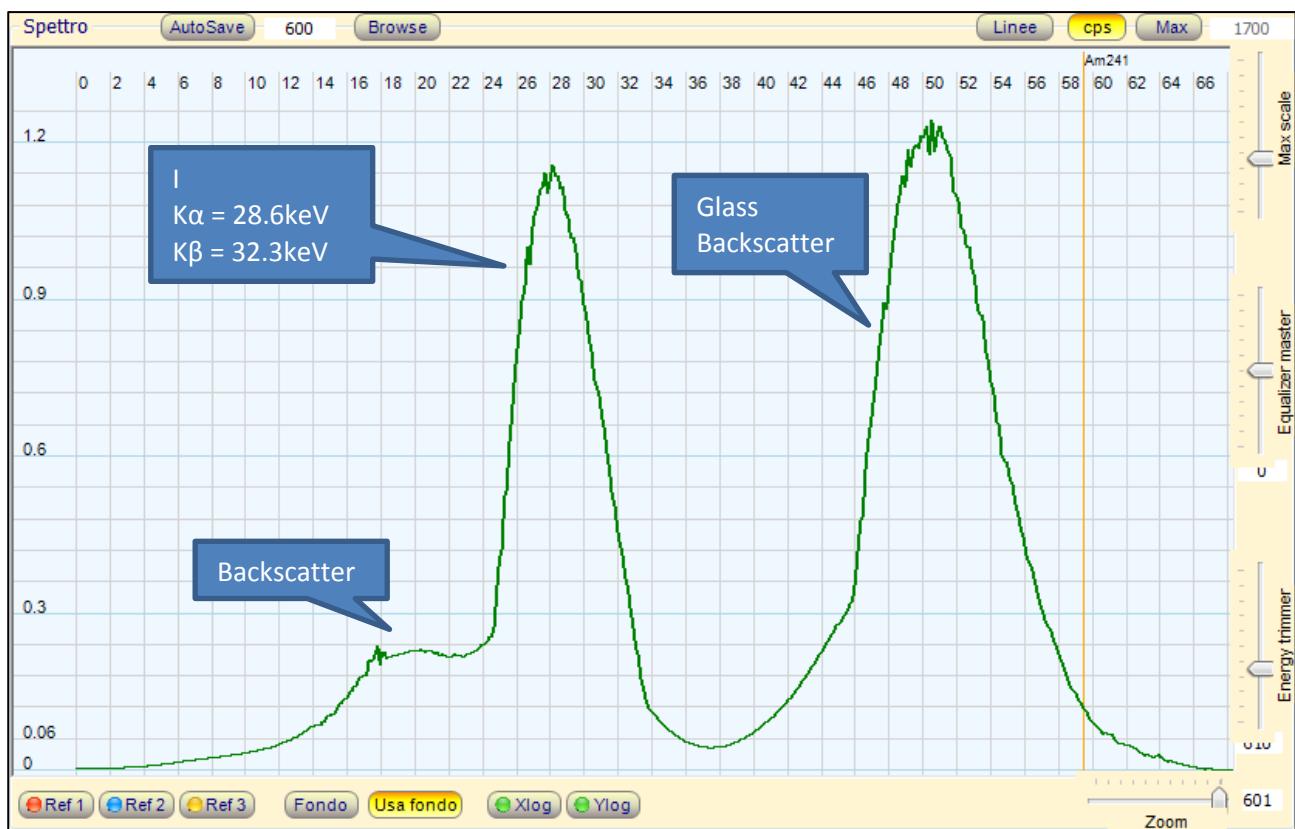
Iodine is a chemical element with symbol I and atomic number 53. The name is from Greek, meaning violet or purple, due to the color of elemental iodine vapor.

Iodine and its compounds are primarily used in nutrition, and industrially in the production of acetic acid and certain polymers. Iodine's relatively high atomic number, low toxicity, and ease of attachment to organic compounds have made it a part of many X-ray contrast materials in modern medicine. Iodine has only one stable isotope. A number of iodine radioisotopes are also used in medical applications.



XRF Sample : iodine solution

Name / Symbol	Iodine / I
Atomic Number	53
Standard atomic weight	126.90447
Element category	Halogen
Electron configuration	[Kr] 4d10 5s2 5p5
Electrons per shell	2, 8, 18, 18, 7
K α 1	28.612 keV
K β 1	32.294 keV



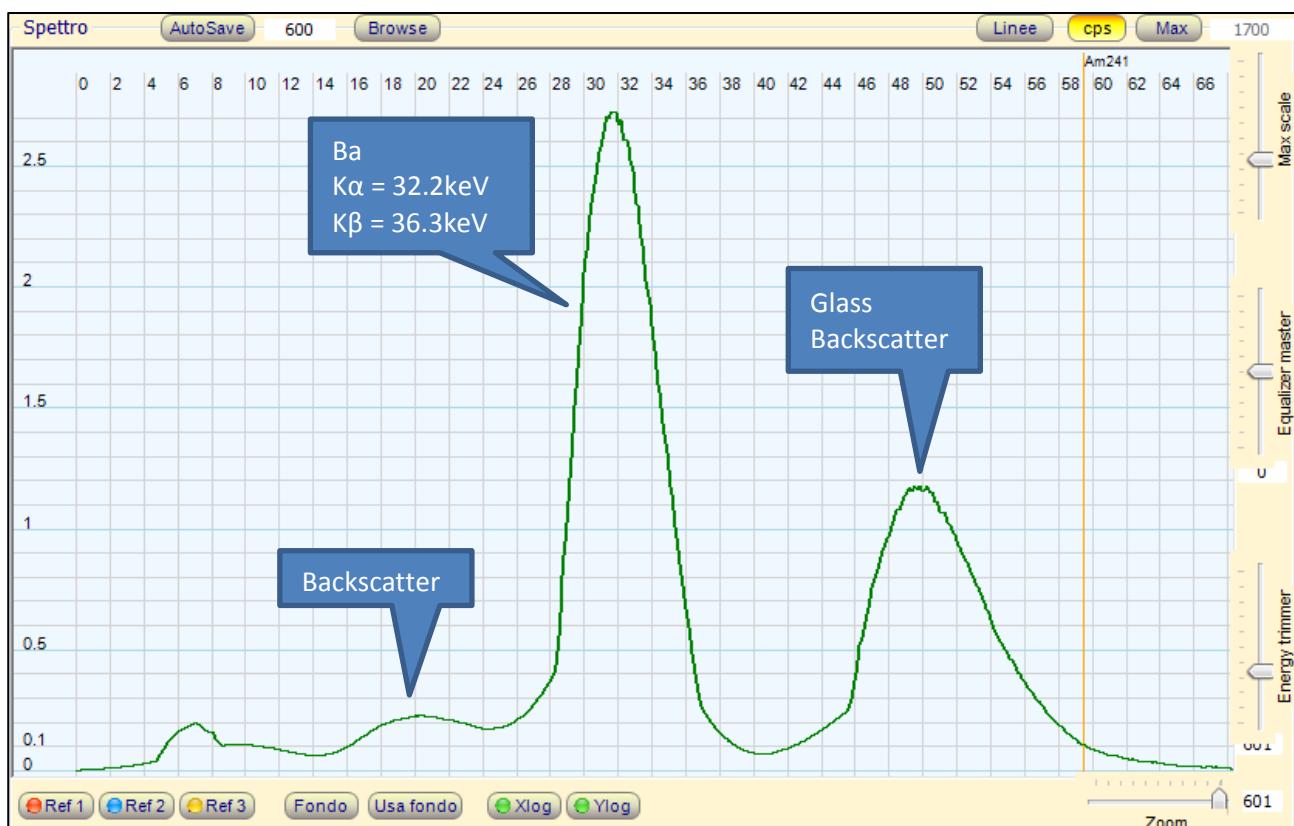
Barium (Z=56) (Glass)

Barium is a chemical element with symbol **Ba** and atomic number 56. It is the fifth element in Group 2, a soft silvery metallic alkaline earth metal. Because of its high chemical reactivity barium is never found in nature as a free element. Its hydroxide was known in pre-modern history as baryta; this substance does not occur as a mineral, but can be prepared by heating barium carbonate. It is used in glass.



XRF Sample : Glass

Name / Symbol	Barium / Ba
Atomic Number	56
Standard atomic weight	137.327
Element category	alkaline earth metals
Electron configuration	[Xe] 6s2
Electrons per shell	2, 8, 18, 18, 8, 2
K α 1	32.194 keV
K β 1	36.378 keV



Lanthanum (Z=57) Cerium (Z=58) (Ferrocerium)

Cerium is a chemical element with symbol **Ce** and atomic number 58. It is a soft, silvery, ductile metal which easily oxidizes in air. **Lanthanum** is a soft, ductile, silvery-white rare-earth metal element with symbol **La** and atomic number 57. **Ferrocerium** is a man-made metallic material that gives off hot sparks at temperatures of 1,650 °C (3,000 °F) when scraped against a rough surface (pyrophoricity), such as ridged steel. Because of this property it is used in many applications, such as clockwork toys, strikers for gas welding and cutting torches, so-called "flint-and-steel" or "flint spark lighter" fire-starters in emergency survival kits, and cigarette lighters, as the initial ignition source for the primary fuel.

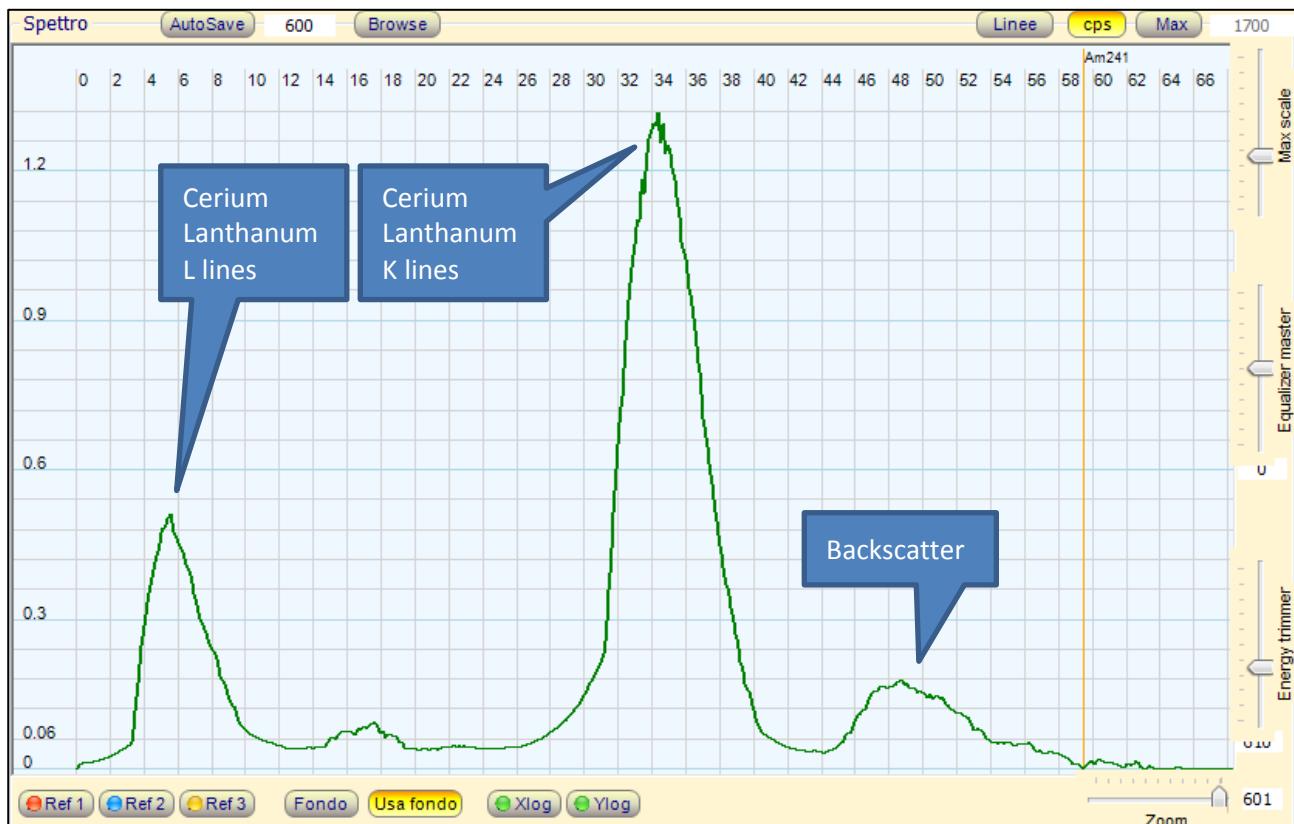
Composition of the alloy :

Element	Iron	Cerium	Lanthanum	Neodymium	Praseodymium	Magnesium
Percentage	19%	38%	22%	4%	4%	4%



XRF Sample : Ferrocium fire-starter

Cerium K α 1	34.720 keV
Cerium K β 1	39.256 keV
Cerium L α 1	4.839 keV
Cerium L β 1	5.262 keV
Lanthanum K α 1	33.442 keV
Lanthanum K β 1	37.797 keV
Lanthanum L α 1	4.647 keV
Lanthanum L β 1	5.038 keV



Gadolinium (Z=64) (X Ray Intensifying Screen)

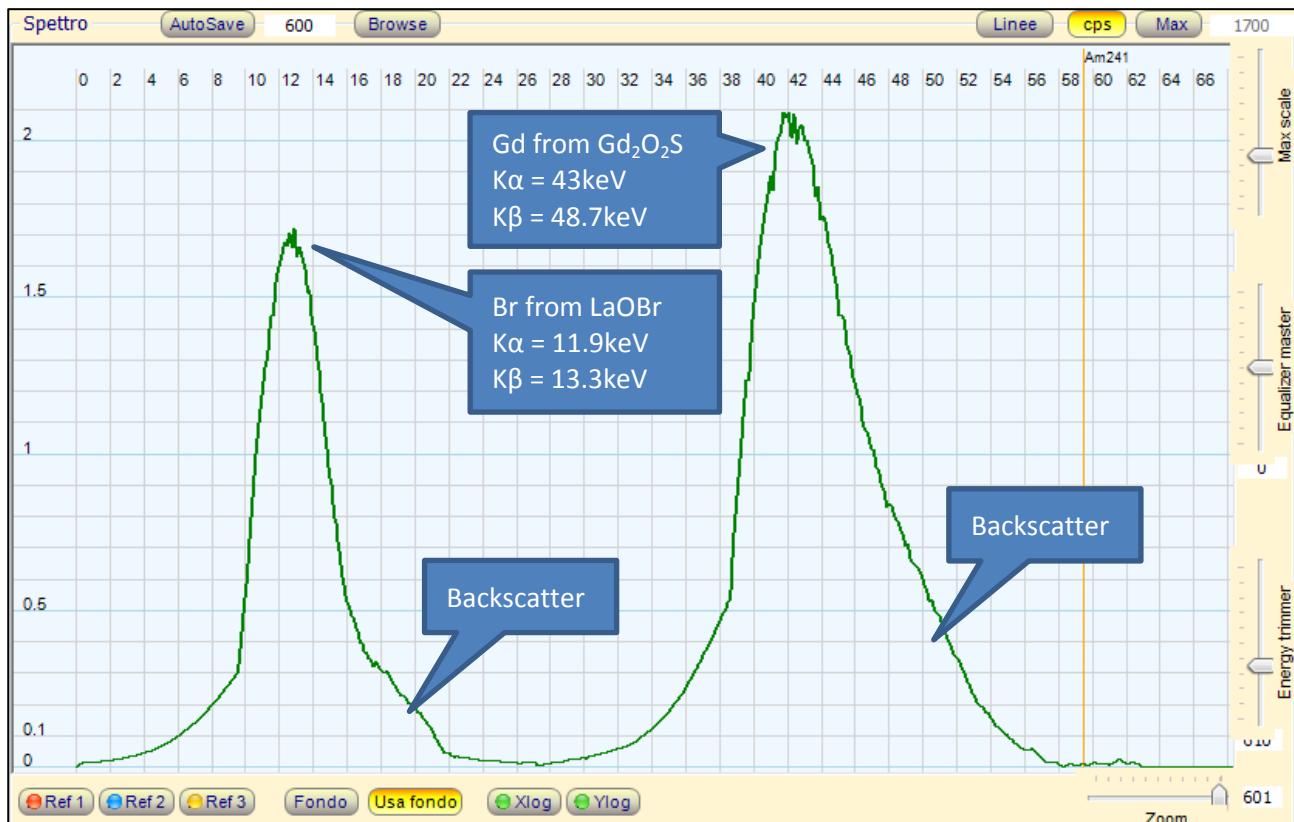
Gadolinium is a chemical element with symbol **Gd** and atomic number 64. It is a silvery-white, malleable and ductile rare-earth metal. It is found in nature only in combined (salt) form. Gadolinium was first detected spectroscopically in 1880 by de Marignac who separated its oxide and is credited with its discovery. It is named for gadolinite, one of the minerals in which it was found, in turn named for chemist Johan Gadolin.

Gadolinium metal possesses unusual metallurgic properties, to the extent that as little as 1% gadolinium can significantly improve the workability and resistance to high temperature oxidation of iron, chromium, and related alloys. Gadolinium as a metal or salt has exceptionally high absorption of neutrons and therefore is used for shielding in neutron radiography and in nuclear reactors. Like most rare earths, gadolinium forms trivalent ions which have fluorescent properties. Gadolinium(III) salts have therefore been used as green phosphors in various applications.



XRF Sample : Intensifying Screen with $\text{Gd}_2\text{O}_2\text{S}$ and LaOBr

Name / Symbol	Gadolinium / Gd
Atomic Number	64
Standard atomic weight	157.25
Element category	lanthanide
Electron configuration	[Xe] 4f7 5d1 6s2
Electrons per shell	2, 8, 18, 25, 9, 2
K α 1	42.996 keV
K β 1	48.697 keV



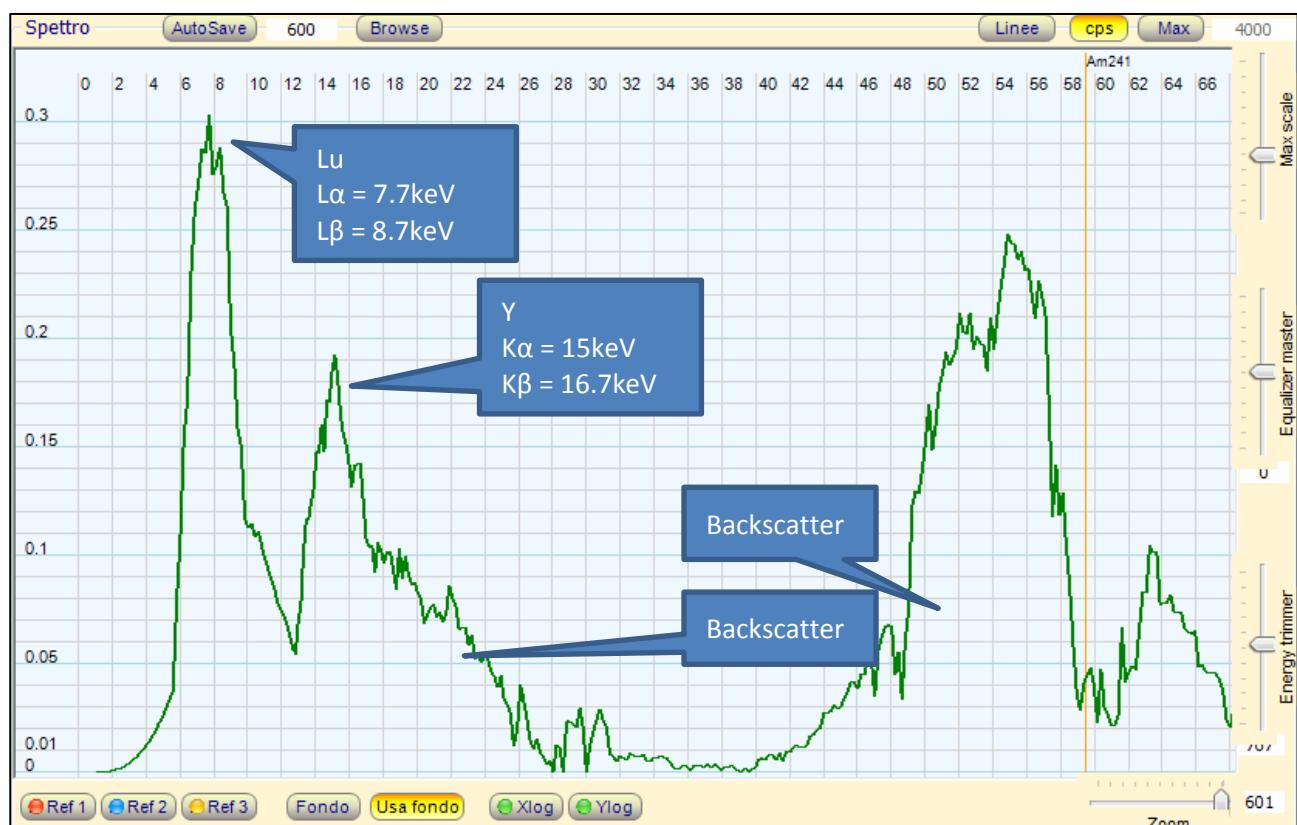
Lutetium (Z=71)

Lutetium is a chemical element with symbol **Lu** and atomic number 71. It is a silvery white metal, which resists corrosion in dry, but not in moist air. It is considered the first element of the 6th-period transition metals (or, on occasion, the last element in the lanthanide series), and traditionally counted among the rare earths. Lutetium is not a particularly abundant element, though significantly more common than silver in the earth's crust; it has few specific uses. **Lutetium-176** is a relatively abundant (2.5%) radioactive isotope with a half-life of about 38 billion years, and so used to determine the age of meteorites. Lutetium usually occurs in association with the element yttrium and is sometimes used in metal alloys and as a catalyst in various chemical reactions.



XRF Sample: LYSO crystal (lutetium, yttrium)

Name / Symbol	Lutetium / Lu
Atomic Number	71
Standard atomic weight	174,967
Element category	lanthanide
Electron configuration	[Xe]4f145d1 6s2
Electrons per shell	2, 8, 18, 32, 9, 2
L α 1	7.6555 keV
L β 1	8.7090 keV



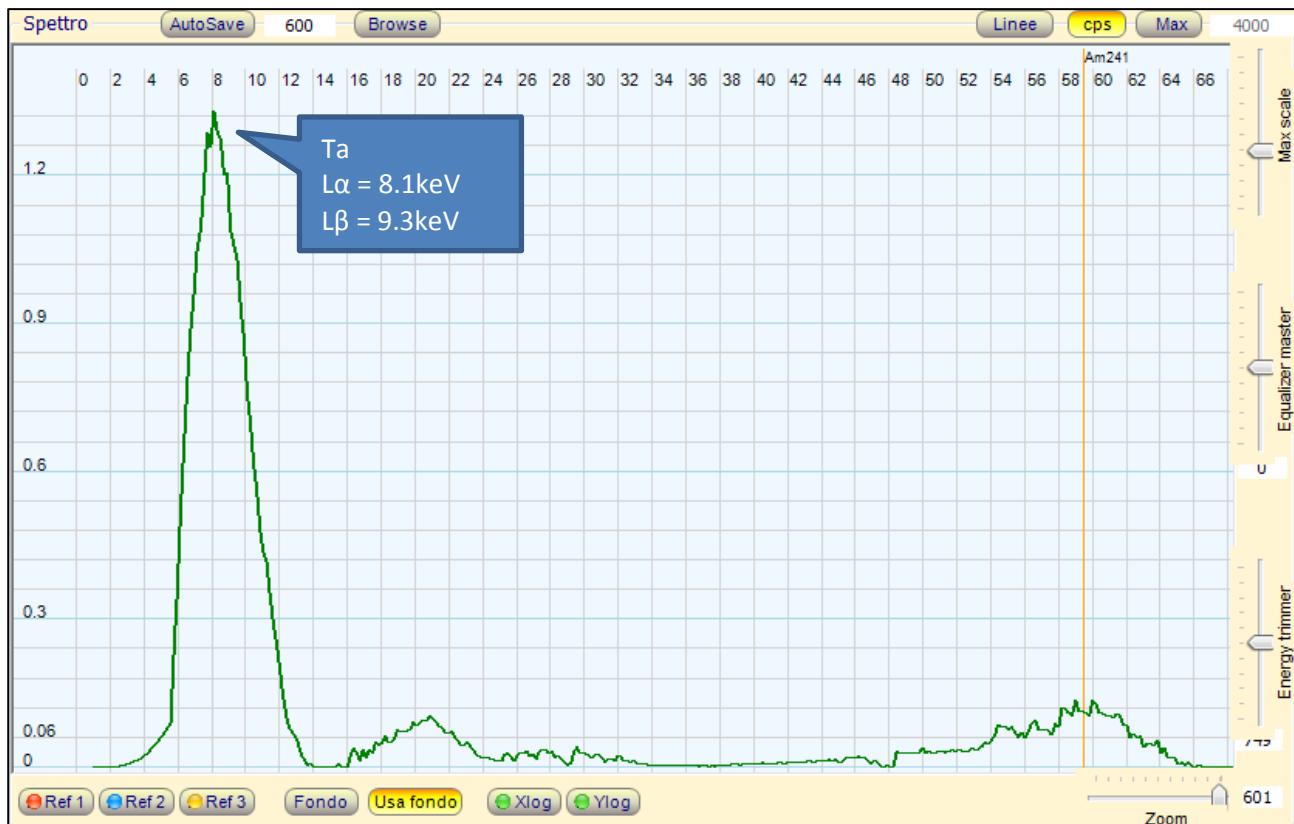
Tantalum (Z=73)

Tantalum is a chemical element with symbol **Ta** and atomic number 73. Previously known as tantalium, its name comes from Tantalus, a hero from Greek mythology. Tantalum is a rare, hard, blue-gray, lustrous transition metal that is highly corrosion-resistant. It is part of the refractory metals group, which are widely used as minor components in alloys. The chemical inertness of tantalum makes it a valuable substance for laboratory equipment and a substitute for platinum. Tantalum is also used for medical implants and bone repair. Its main use today is in tantalum capacitors in electronic equipment such as mobile phones, DVD players, video game systems and computers.



XRF Sample: Tantalum sheet

Name / Symbol	Tantalum / Ta
Atomic Number	73
Standard atomic weight	180,94788
Element category	transition metal
Electron configuration	[Xe]4f145d3 6s2
Electrons per shell	2, 8, 18, 32, 11, 2
L α 1	8.1461 keV
L β 1	9.3431 keV



Tungsten (Z=74)

Tungsten, also known as **wolfram**, is a chemical element with symbol **W** and atomic number 74.

The free element is remarkable for its robustness, especially the fact that it has the highest melting point of all the elements. Also remarkable is its high density of 19.3 times that of water, comparable to that of uranium and gold, and much higher (about 1.7 times) than that of lead.

Tungsten's many alloys have numerous applications, most notably in incandescent light bulb filaments, X-ray tubes (as both the filament and target), electrodes in TIG welding, superalloys, and radiation shielding. About half is used in the form of tungsten carbide, a durable carbon alloy. Tungsten's hardness and high density give it military applications in penetrating projectiles. Tungsten compounds are also often used as industrial catalysts.



XRF Sample : Tungsten Wire

Name / Symbol	Tungsten / W
Atomic Number	74
Standard atomic weight	183.84
Element category	transition metal
Electron configuration	[Xe] 4f14 5d4 6s2[1]
Electrons per shell	2, 8, 18, 32, 12, 2
L α 1	8.398 keV
L β 1	9.672 keV



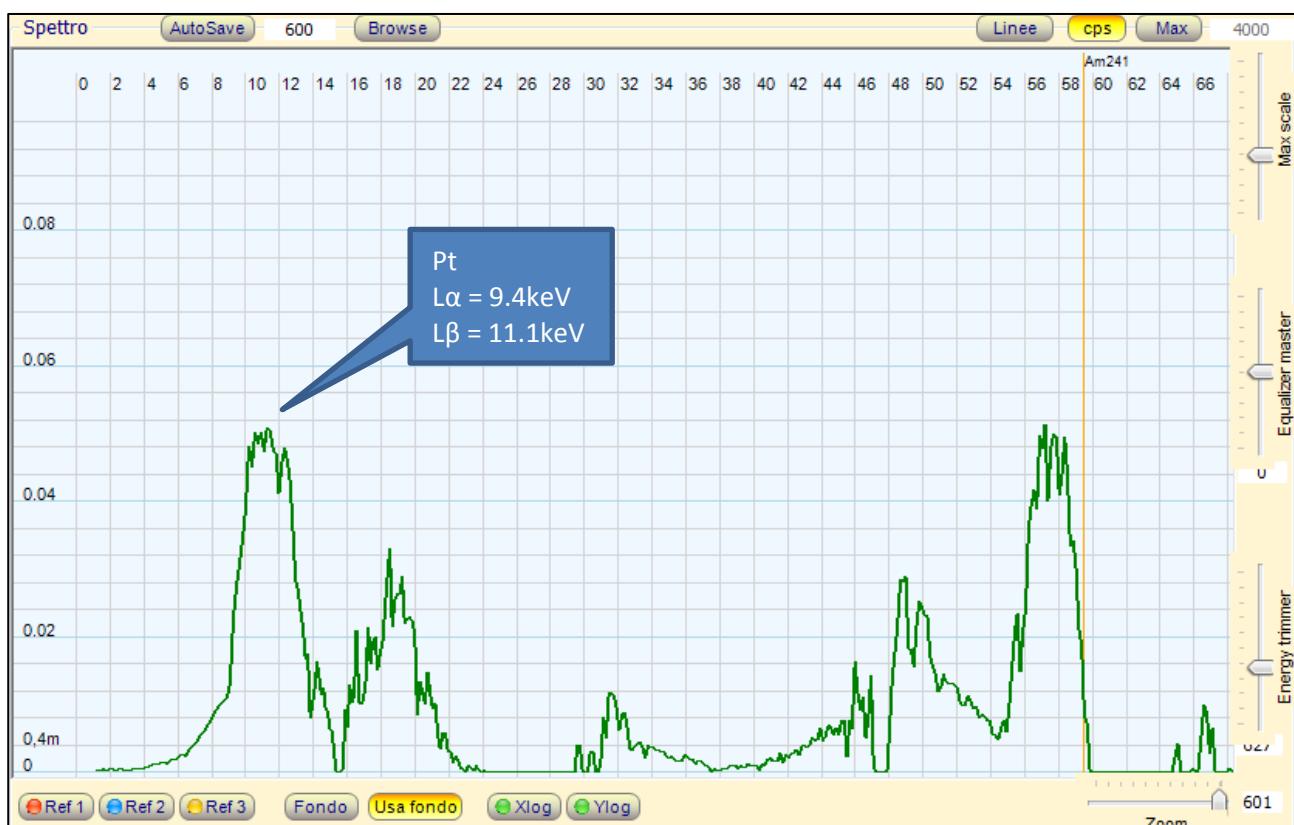
Platinum (Z=78)

Platinum is a chemical element with symbol Pt and atomic number 78. It is a dense, malleable, ductile, highly unreactive, precious, gray-white transition metal. Its name is derived from the Spanish term platina, which is literally translated into "little silver". Platinum is the least reactive metal. It has remarkable resistance to corrosion, even at high temperatures, and is therefore considered a noble metal. Consequently, platinum is often found chemically uncombined as native platinum. Platinum is used in catalytic converters, laboratory equipment, electrical contacts and electrodes, platinum resistance thermometers, dentistry equipment, and jewellery.



XRF Sample: Platinum Sample

Name / Symbol	Platinum / Pt
Atomic Number	78
Standard atomic weight	195,084
Element category	Transition metal
Electron configuration	[Xe]4f145d96s1
Electrons per shell	2, 8, 18, 32, 17, 1
L α 1	9.442 keV
L β 1	11.071 keV



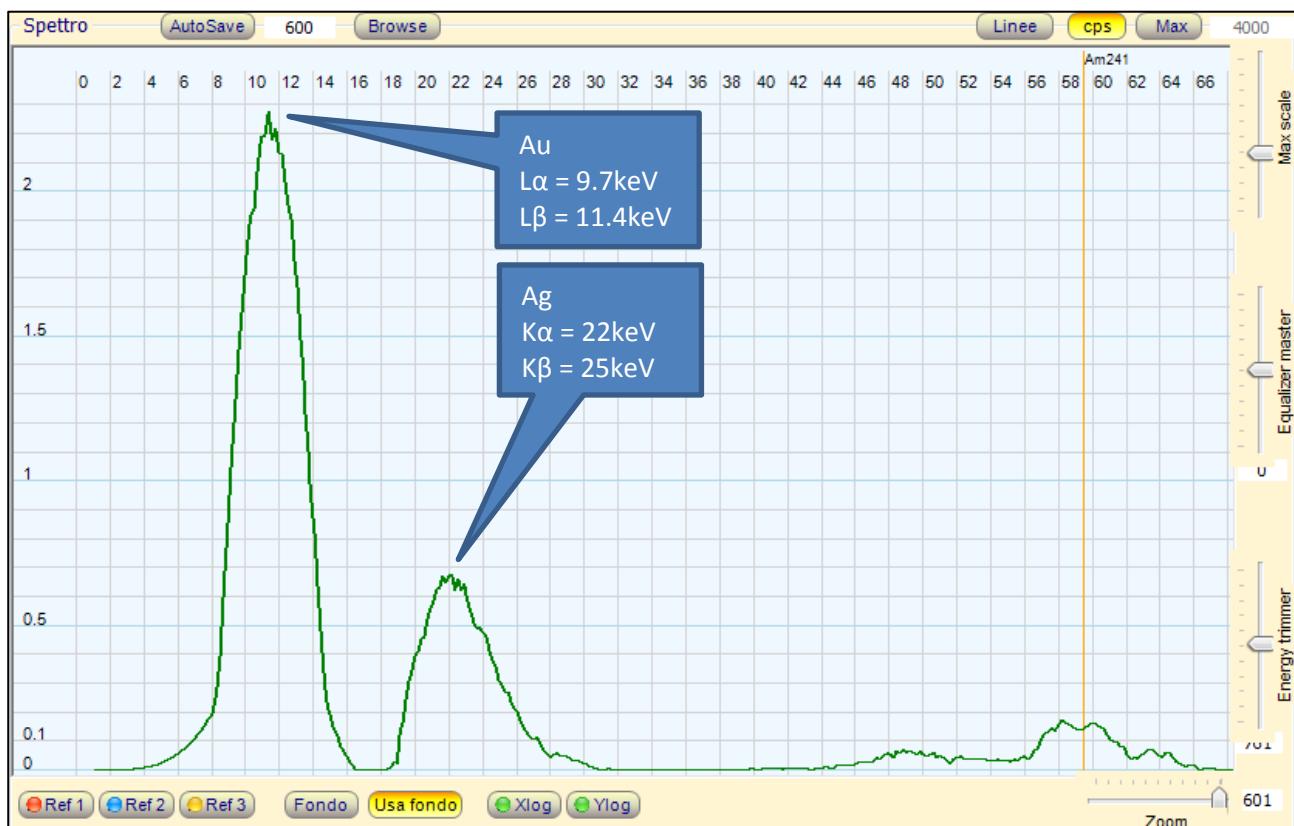
Gold (Z=79) (Alloy Gold + Silver)

Gold is a chemical element with symbol **Au** (from Latin: aurum) and atomic number 79. It is a bright yellow dense, soft, malleable and ductile metal. The properties remain when exposed to air or water. Chemically, gold is a transition metal and a group 11 element. It is one of the least reactive chemical elements, and is solid under standard conditions. The metal therefore occurs often in free elemental (native) form, as nuggets or grains, in rocks, in veins and in alluvial deposits. It occurs in a solid solution series with the native element silver (as electrum) and also naturally alloyed with copper and palladium. Less commonly, it occurs in minerals as gold compounds, often with tellurium (gold tellurides).



XRF Sample : 18k Gold Ear Ring

Name / Symbol	Gold / Au
Atomic Number	79
Standard atomic weight	196.966569
Element category	Transition metal
Electron configuration	[Xe] 4f14 5d10 6s1
Electrons per shell	2, 8, 18, 32, 18, 1
L α 1	9.713 keV
L β 1	11.443 keV



Mercury (Z=80)

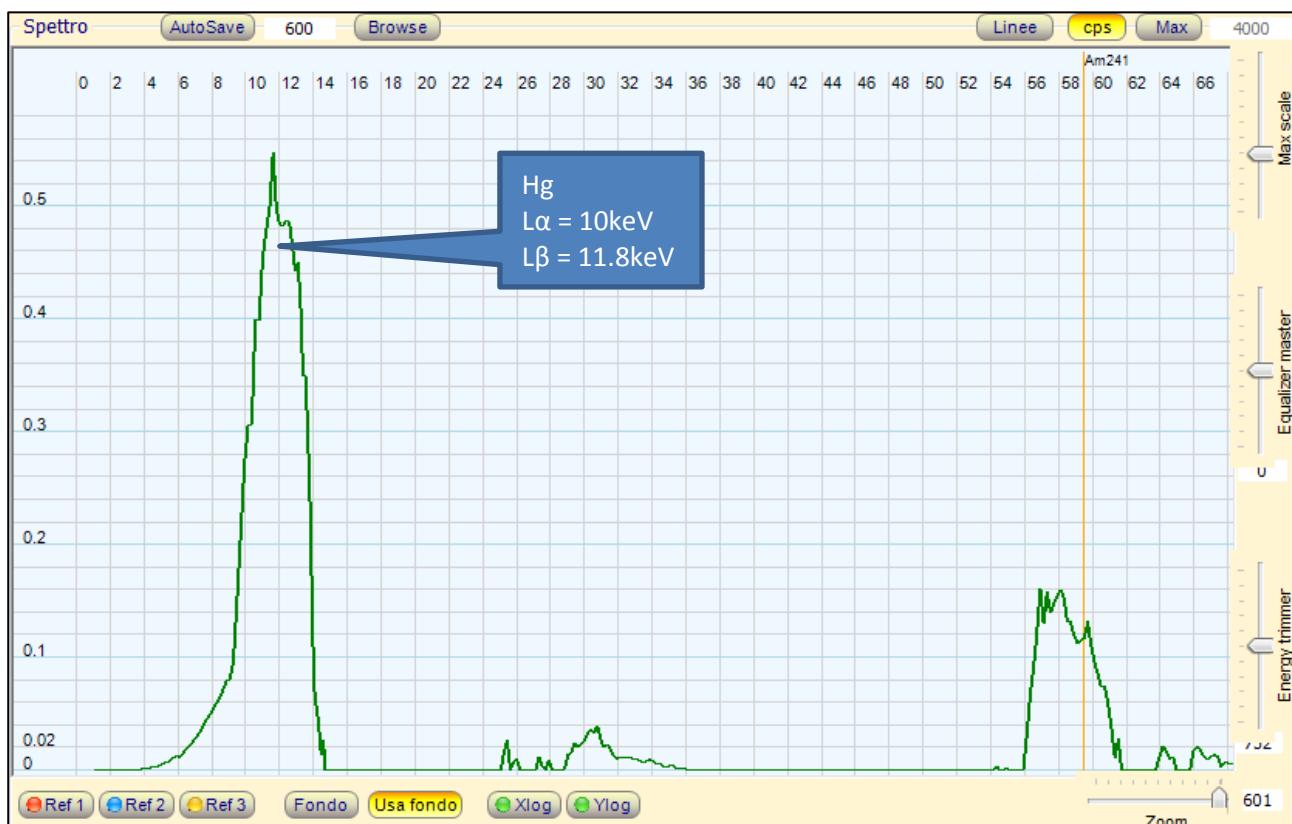
Mercury is a chemical element with symbol **Hg** and atomic number 80.

It is commonly known as quicksilver and was formerly named hydrargyrum. A heavy, silvery d-block element, mercury is the only metallic element that is liquid at standard conditions for temperature and pressure; the only other element that is liquid under these conditions is bromine, though metals such as caesium, gallium, and rubidium melt just above room temperature. Mercury is used in thermometers, barometers, manometers, sphygmomanometers, float valves, mercury switches, mercury relays, fluorescent lamps and other devices.



XRF sample: ampoule with mercury

Name / Symbol	Mercury / Hg
Atomic Number	80
Standard atomic weight	200,59
Element category	Transition metal
Electron configuration	[Xe]4f14 5d10 6s2
Electrons per shell	2, 8, 18, 32, 18, 2
L α 1	9.989 keV
L β 1	11.823 keV



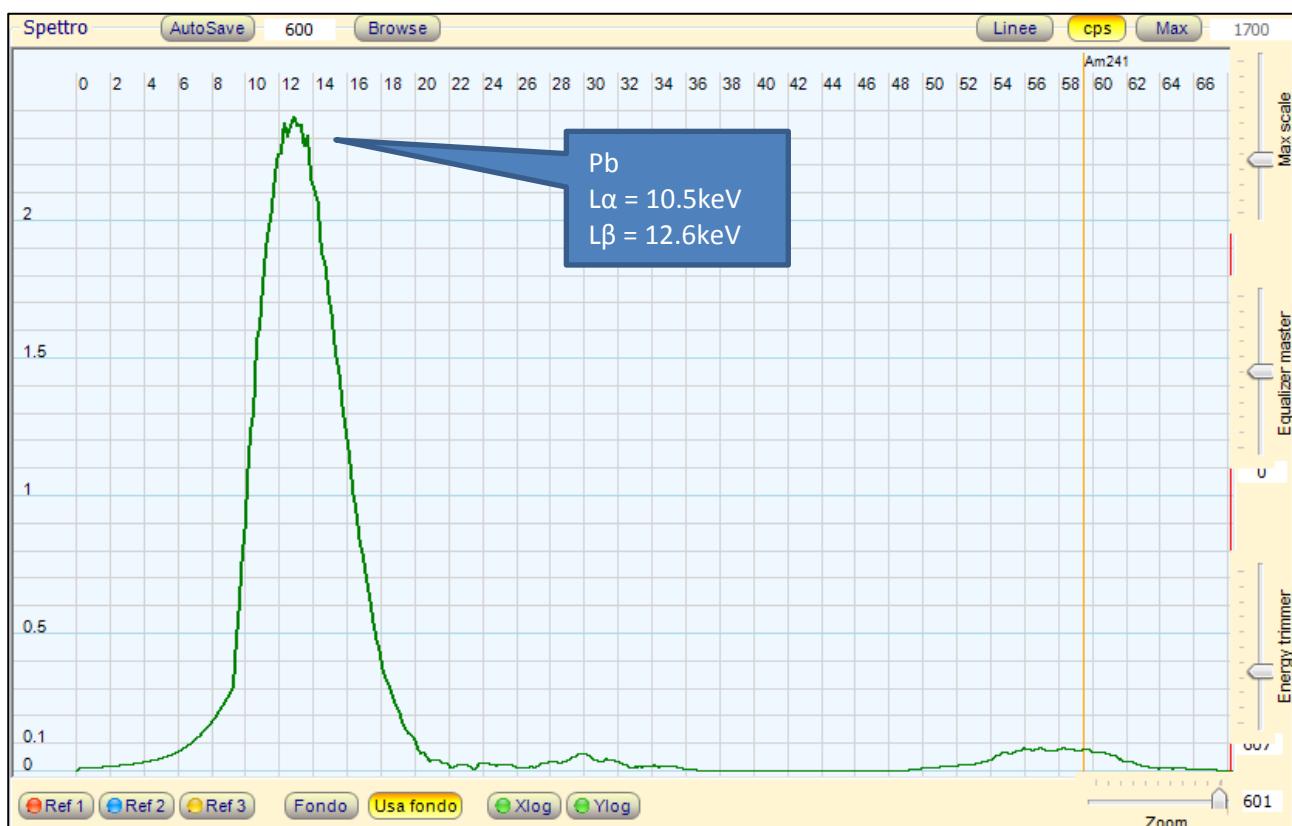
Lead (Z=82)

Lead is a chemical element in the carbon group with symbol **Pb** (from Latin: *plumbum*) and atomic number 82. Lead is a soft, malleable and heavy post-transition metal. Metallic lead has a bluish-white color after being freshly cut, but it soon tarnishes to a dull grayish color when exposed to air. Lead has a shiny chrome-silver luster when it is melted into a liquid. It is also the heaviest non-radioactive element.



XRF Sample : Lead Sheet

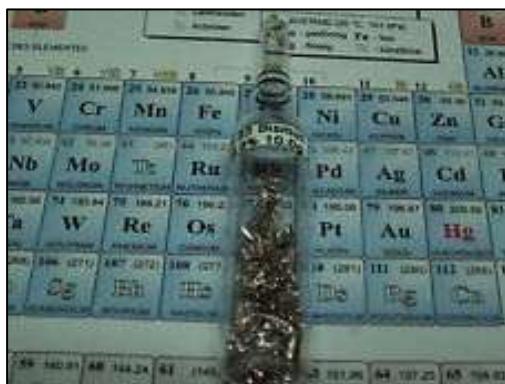
Name / Symbol	Lead / Pb
Atomic Number	82
Standard atomic weight	207.2
Element category	Post - transition metal
Electron configuration	[Xe] 4f14 5d10 6s2 6p2
Electrons per shell	2, 8, 18, 32, 18, 4
L α 1	10.551 keV
L β 1	12.614 keV



Bismuth (Z=83)

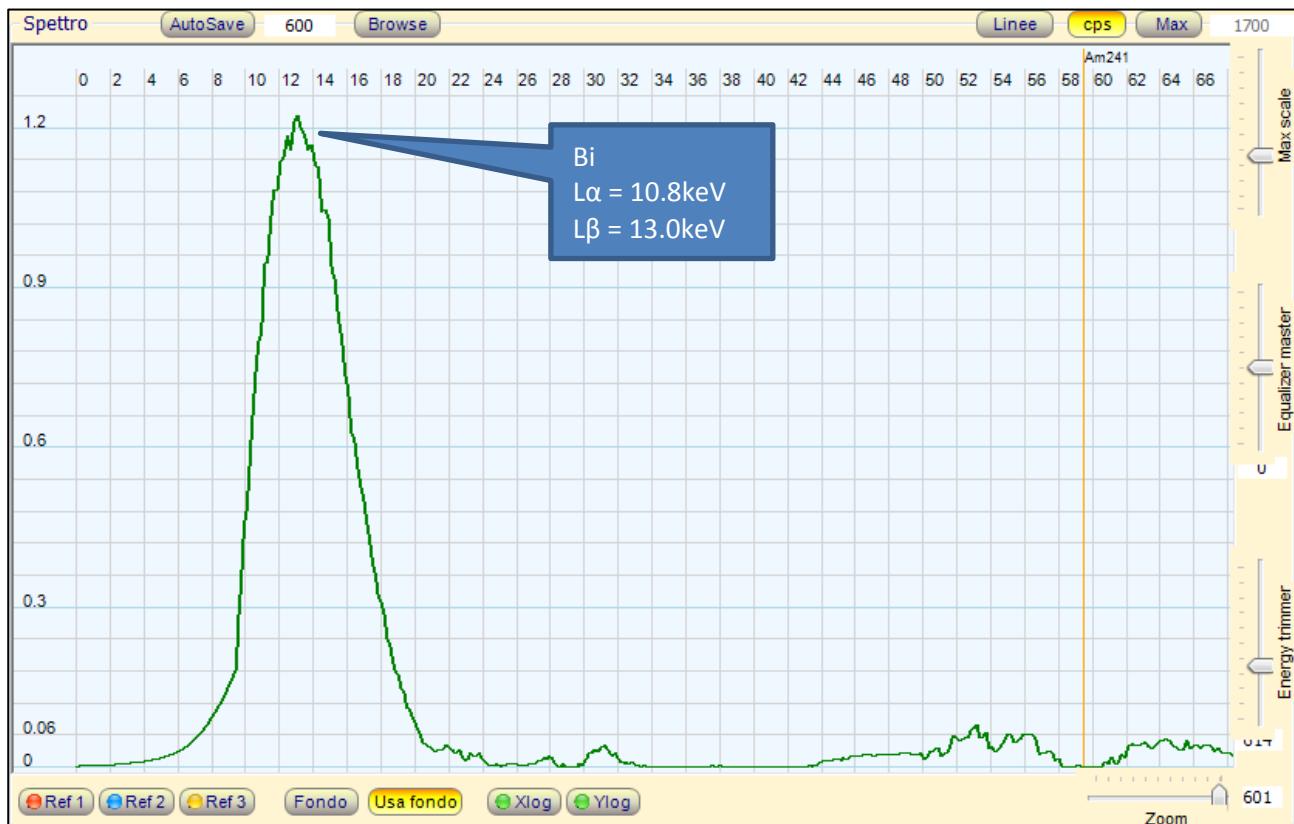
Bismuth is a chemical element with symbol **Bi** and atomic number 83. Bismuth, a pentavalent post-transition metal, chemically resembles arsenic and antimony. Elemental bismuth may occur naturally, although its sulfide and oxide form important commercial ores. The free element is 86% as dense as lead. It is a brittle metal with a silvery white color when freshly produced, but is often seen in air with a pink tinge owing to surface oxidation. Bismuth is the most naturally diamagnetic element, and has one of the lowest values of thermal conductivity among metals.

Bismuth has long been considered as the element with the highest atomic mass that is stable. However, in 2003 it was discovered to be slightly radioactive: its only primordial isotope, bismuth-209, decays via alpha decay with a half life more than a billion times the estimated age of the universe.



XRF Sample : Bismuth sample

Name / Symbol	Bismuth / Bi
Atomic Number	83
Standard atomic weight	208.98040
Element category	post-transition metal
Electron configuration	[Xe] 4f14 5d10 6s2 6p3
Electrons per shell	2, 8, 18, 32, 18, 5
L α 1	10.839 keV
L β 1	13.023 keV



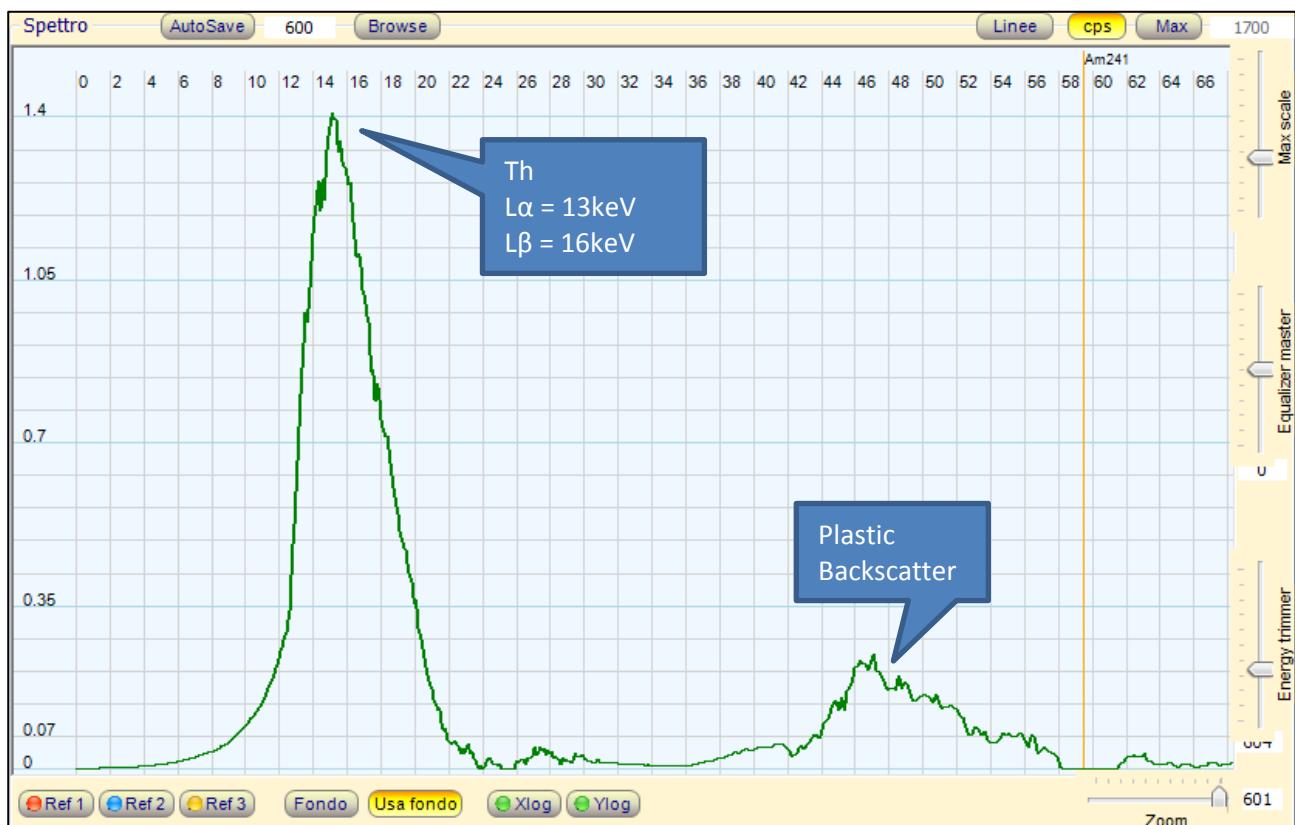
Thorium (Z=90) (Lantern Mantle)

Thorium is a chemical element with symbol **Th** and atomic number 90. A radioactive actinide metal, thorium is one of only three radioactive elements that still occurs in quantity in nature as a primordial element (the other two being bismuth and uranium).



XRF Sample : Lantern Mantle

Name / Symbol	Thorium / Th
Atomic Number	90
Standard atomic weight	232.0377
Element category	actinide
Electron configuration	[Rn] 6d2 7s2
Electrons per shell	2, 8, 18, 32, 18, 10, 2
L α 1	12.968 keV
L β 1	16.202 keV



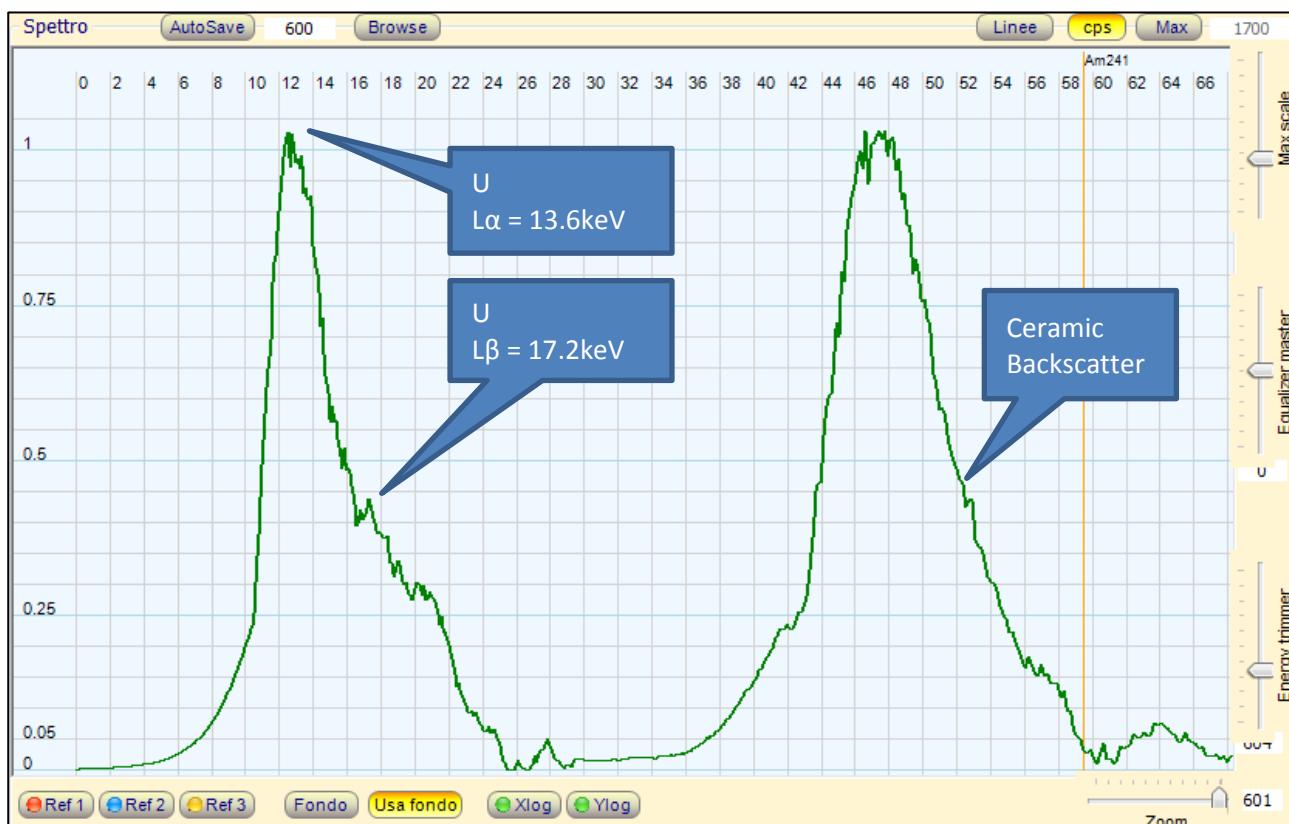
Uranium (Z=92) (Uranium Glaze)

Uranium is a chemical element with symbol **U** and atomic number 92. It is a silvery-white metal in the actinide series of the periodic table. A uranium atom has 92 protons and 92 electrons, of which 6 are valence electrons. Uranium is weakly radioactive because all its isotopes are unstable (with half-lives of the 6 naturally known isotopes, uranium-233 to uranium-238, varying between 69 years and 4.5 billion years). The most common isotopes of uranium are uranium-238 (which has 146 neutrons and accounts for almost 99.3% of the uranium found in nature) and uranium-235 (which has 143 neutrons, accounting for 0.7% of the element found naturally).



XRF Sample : Uranium Glaze

Name / Symbol	Uranium / U
Atomic Number	92
Standard atomic weight	238.02891
Element category	actinide
Electron configuration	[Rn] 5f3 6d1 7s2
Electrons per shell	2, 8, 18, 32, 21, 9, 2
L α 1	13.614 keV
L β 1	17.220 keV



Neptunium (Z=93) (americium Cap)

Neptunium is a chemical element with symbol **Np** and atomic number 93. A radioactive actinide metal, neptunium is the first transuranic element. Its position in the periodic table just after uranium, named after the planet Uranus, led to it being named after Neptune, the next planet beyond Uranus. A neptunium atom has 93 protons and 93 electrons, of which seven are valence electrons. Neptunium metal is silvery and tarnishes when exposed to air. The element occurs in three allotropic forms and it normally exhibits five oxidation states, ranging from +3 to +7.

The most stable isotope of neptunium, neptunium-237, is a by-product of nuclear reactors and plutonium production, and it and the isotope neptunium-239 are also found in trace amounts in uranium ores due to neutron capture reactions and beta decay.



XRF Sample : Americium Cap

Name / Symbol	Neptunium / Np
Atomic Number	93
Standard atomic weight	(237)
Element category	actinide
Electron configuration	[Rn] 5f4 6d1 7s2
Electrons per shell	2, 8, 18, 32, 22, 9, 2
L α 1	13.944 keV
L β 1	17.750 keV

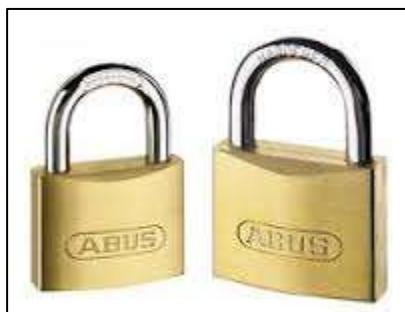


XRF Spectrometry of Alloys and Compounds

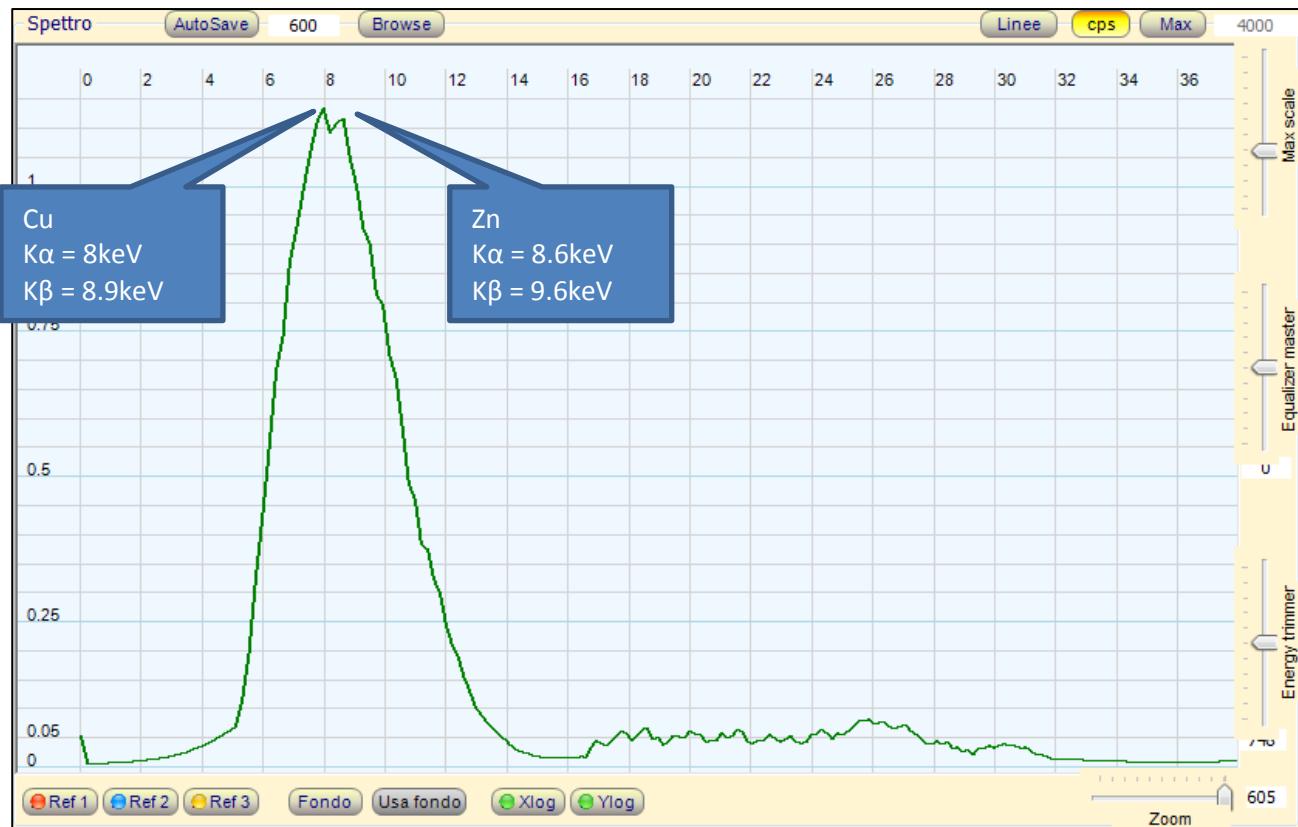
Brass (Alloy Copper + Zinc)

Brass is an alloy made of **copper** and **zinc**; the proportions of zinc and copper can be varied to create a range of brasses with varying properties. It is a substitutional alloy: atoms of the two constituents may replace each other within the same crystal structure.

By comparison, bronze is principally an alloy of copper and tin. Bronze does not necessarily contain tin, and a variety of alloys of copper, including alloys with arsenic, phosphorus, aluminium, manganese, and silicon, are commonly termed "bronze". The term is applied to a variety of brasses and the distinction is largely historical. Modern practice in museums and archaeology increasingly avoids both terms for historical objects in favour of the all-embracing "copper alloy".



XRF Sample : Locker



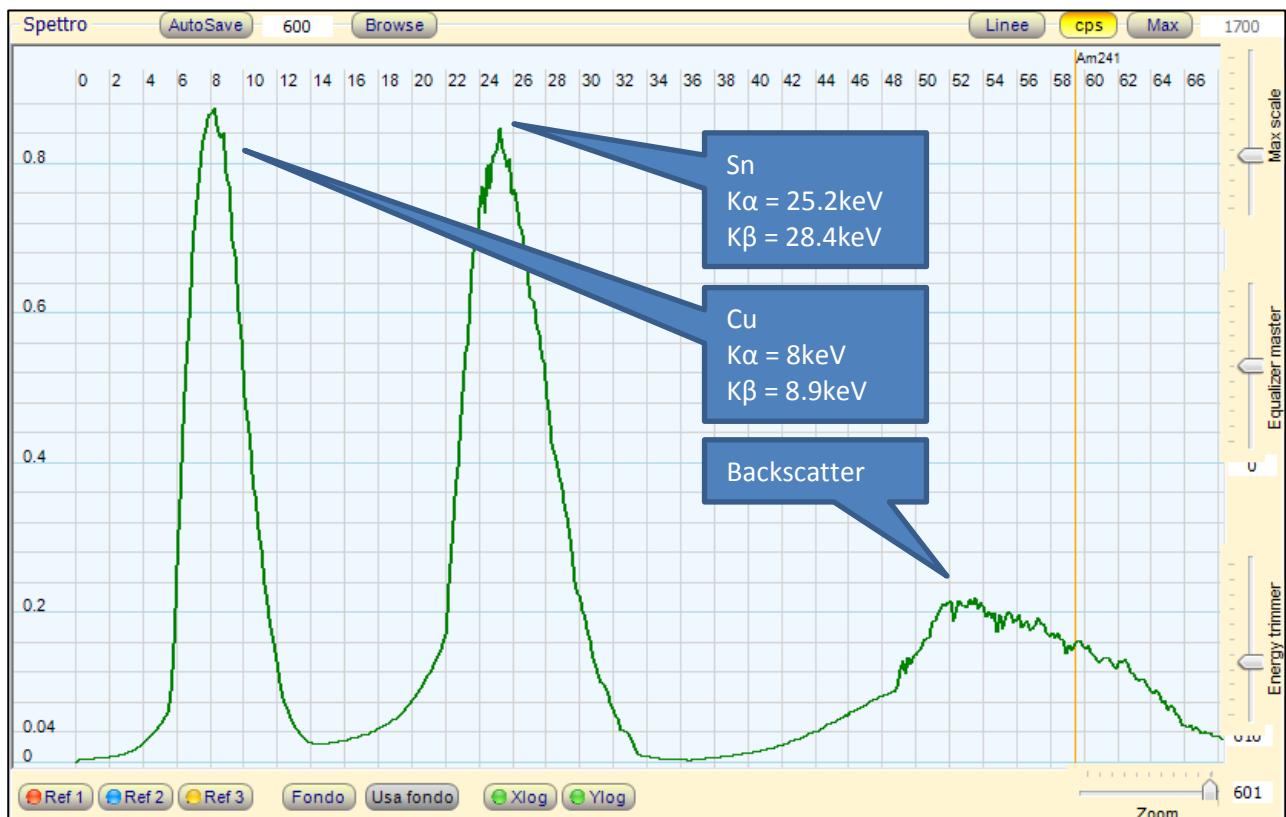
Bronze (Alloy Copper + tin)

Bronze is an alloy consisting primarily of **copper** and other metals. The addition of other metals (usually **tin**, sometimes arsenic), produces an alloy much harder than plain copper. The historical period where the archeological record contains many bronze artifacts is known as the Bronze Age.

There are many different bronze alloys, but typically modern bronze is 88% copper and 12% tin.[13] Alpha bronze consists of the alpha solid solution of tin in copper. Alpha bronze alloys of 4–5% tin are used to make coins, springs, turbines and blades.



XRF Sample : Bronze Jar

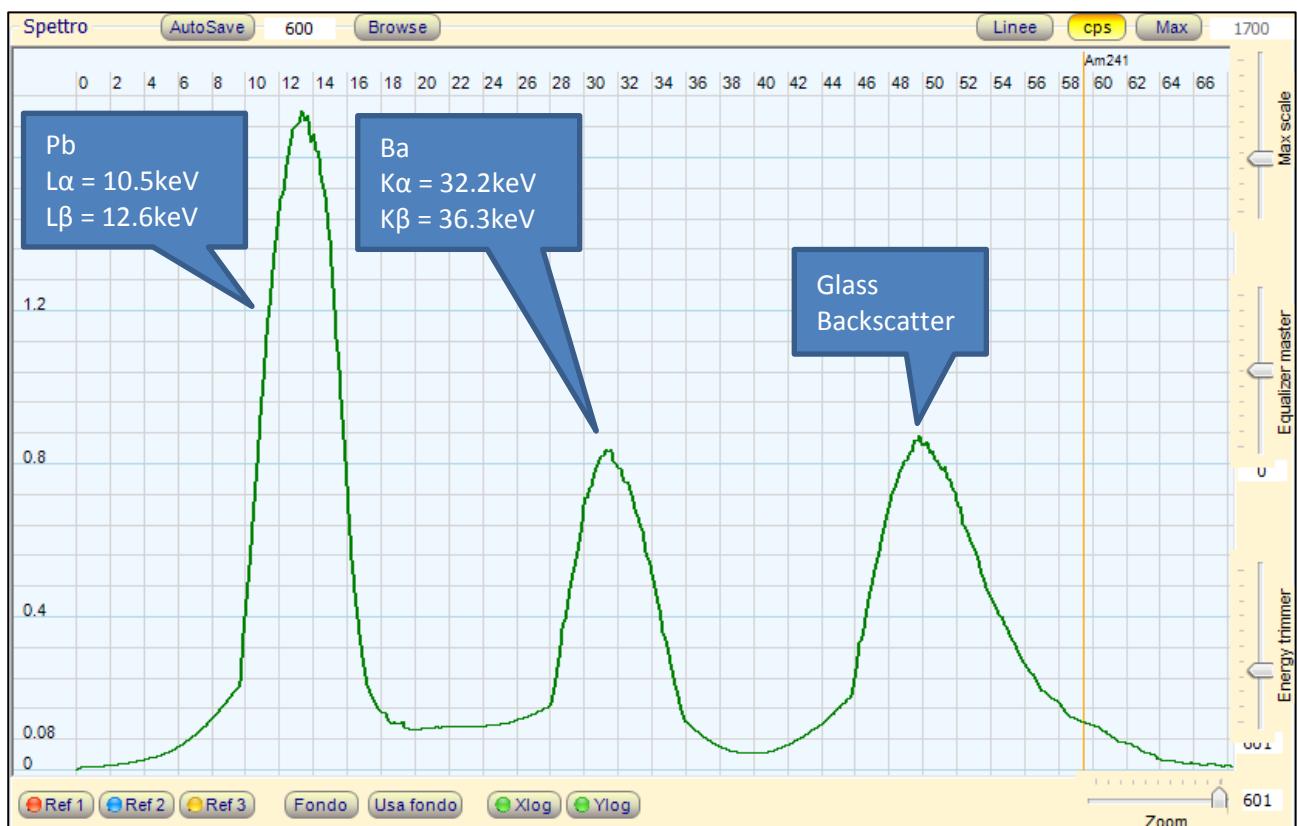


Lead Glass

Lead glass is a variety of glass in which lead replaces the calcium content of a typical potash glass. Lead glass contains typically 18–40 weight% lead(II) oxide (PbO), while modern lead crystal, historically also known as flint glass due to the original silica source, contains a minimum of 24% PbO. Lead glass is desirable owing to its decorative properties.



XRF Sample : Lead Glass

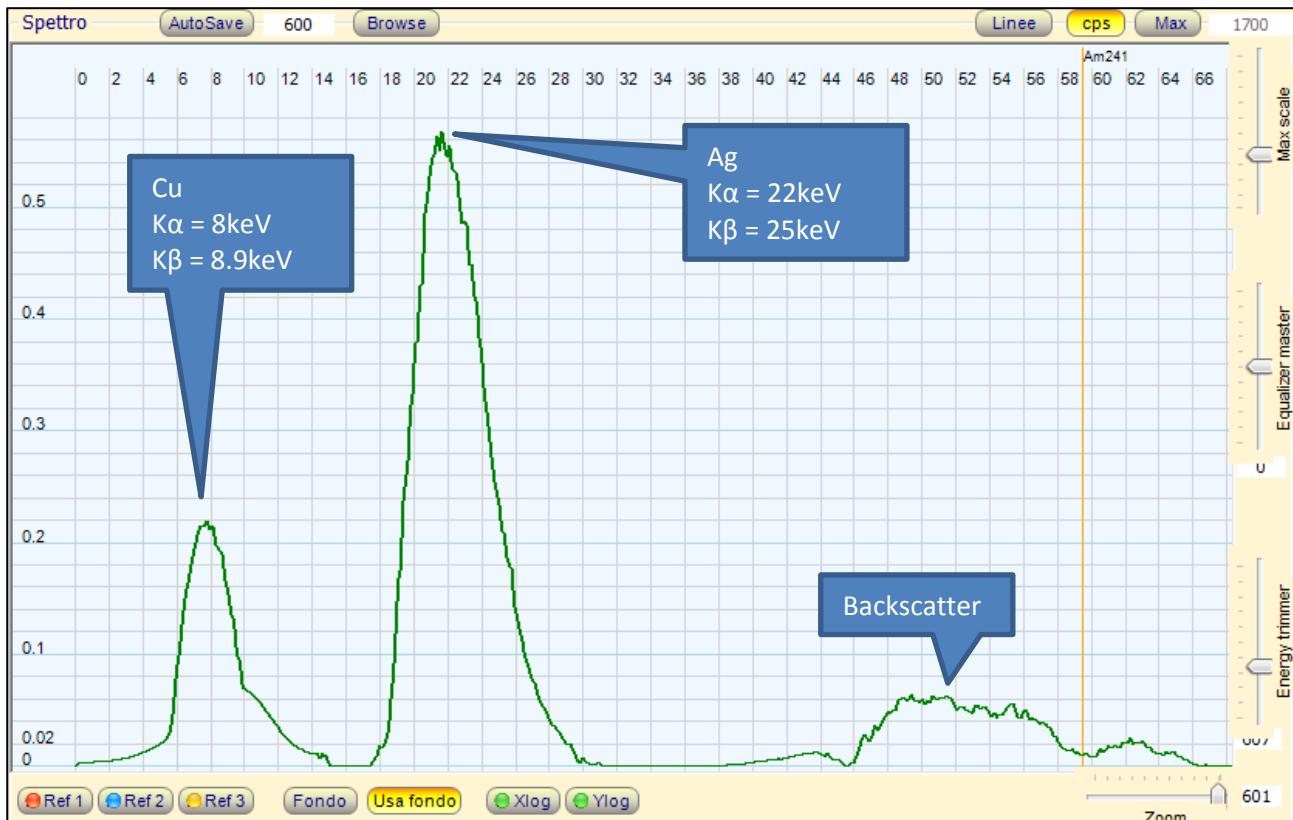


Sheffield Plate (Alloy Silver + Copper)

Sheffield plate is a layered combination of **silver** and **copper** that was used for many years to produce a wide range of household articles. These included buttons, caddy spoons, fish slices, serving utensils, candlesticks and other lighting devices, coffee and tea sets, serving dishes and trays, tankards and pitchers, and larger items such as souptureens and hot-water urns. Almost every article made in sterling silver was also crafted by Sheffield makers, who used this manufacturing process to produce nearly identical wares at far less cost.



XRF Sample : Sheffield Jar



Stainless Steel (Iron + Chromium)

In metallurgy, **stainless steel**, also known as inox steel or inox from French "inoxydable", is a steel alloy with a minimum of 10.5% **chromium** content by mass.

Stainless steel does not readily corrode, rust or stain with water as ordinary steel does. However, it is not fully stain-proof in low-oxygen, high-salinity, or poor air-circulation environments. There are different grades and surface finishes of stainless steel to suit the environment the alloy must endure. Stainless steel is used where both the properties of steel and corrosion resistance are required.

Stainless steel differs from carbon steel by the amount of chromium present. Unprotected carbon steel rusts readily when exposed to air and moisture. This iron oxide film (the rust) is active and accelerates corrosion by forming more iron oxide; and, because of the greater volume of the iron oxide, this tends to flake and fall away. Stainless steels contain sufficient chromium to form a passive film of chromium oxide, which prevents further surface corrosion by blocking oxygen diffusion to the steel surface and blocks corrosion from spreading into the metal's internal structure, and, due to the similar size of the steel and oxide ions, they bond very strongly and remain attached to the surface.



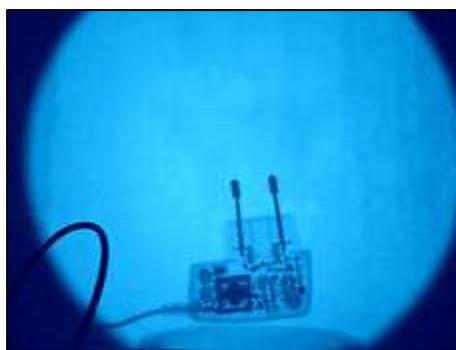
XRF Sample : Stainless Steel Knife

Iron K α 1	6.405 keV
Iron K β 1	7.059 keV
Chromium K α 1	5.415 keV
Chromium K β 1	5.947 keV

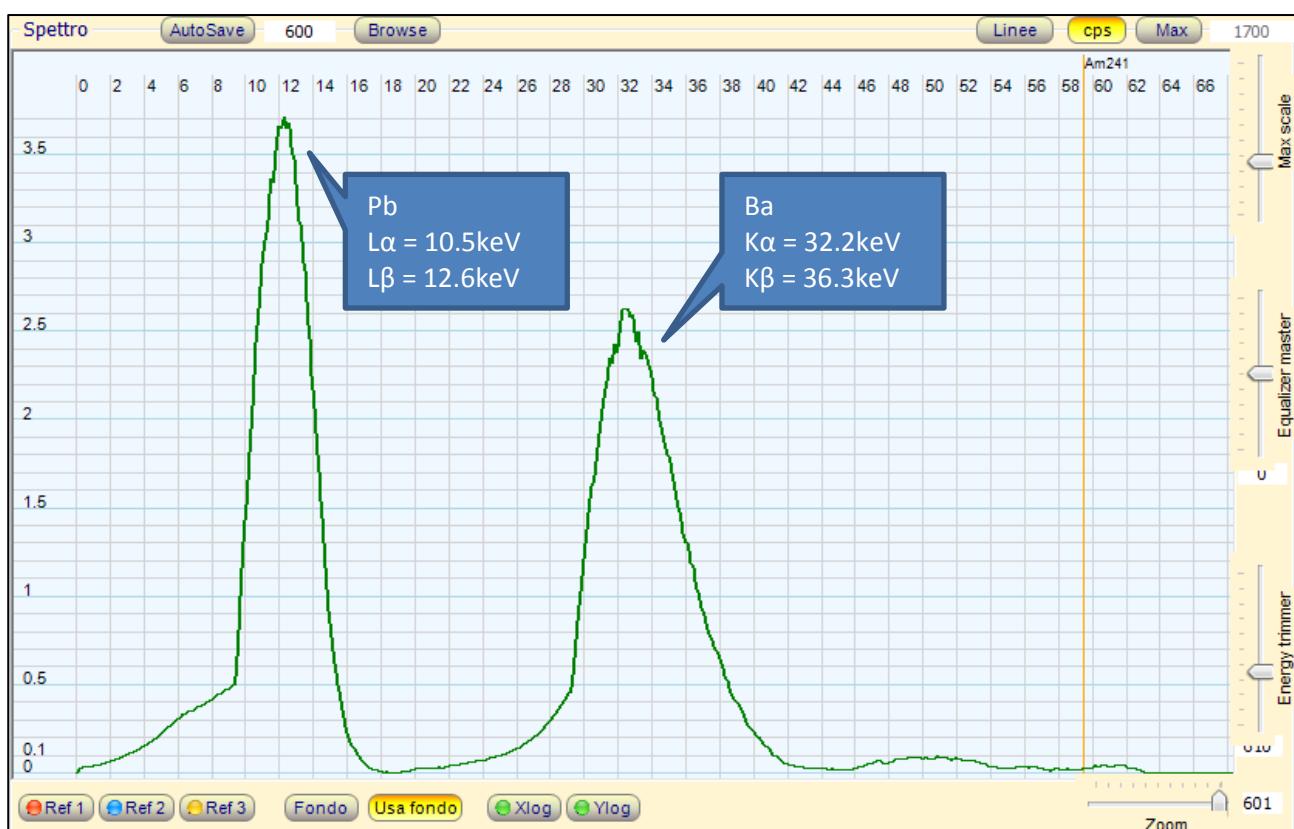


Blue X-Ray Fluorescent Screen

Intensifying and fluorescent screens consist of a thin layer of tiny phosphor crystals mixed with a suitable binder and coated in a smooth layer on a cardboard or plastic support. The coating over the layer of crystals is protected by a cleanable surface. The basic principle in the action of intensifying screen is utilization of a phosphor that converts energy carried by an x-ray photon into visible light. **Lead-activated barium sulfate(BaSO₄:Pb)** has been used in recent years in a few applications in an effort to increase speed of the screens. These phosphors emit blue light.



XRF Sample : Blue X-Ray Fluorescent Screen



Silver Halide (X Ray Film)

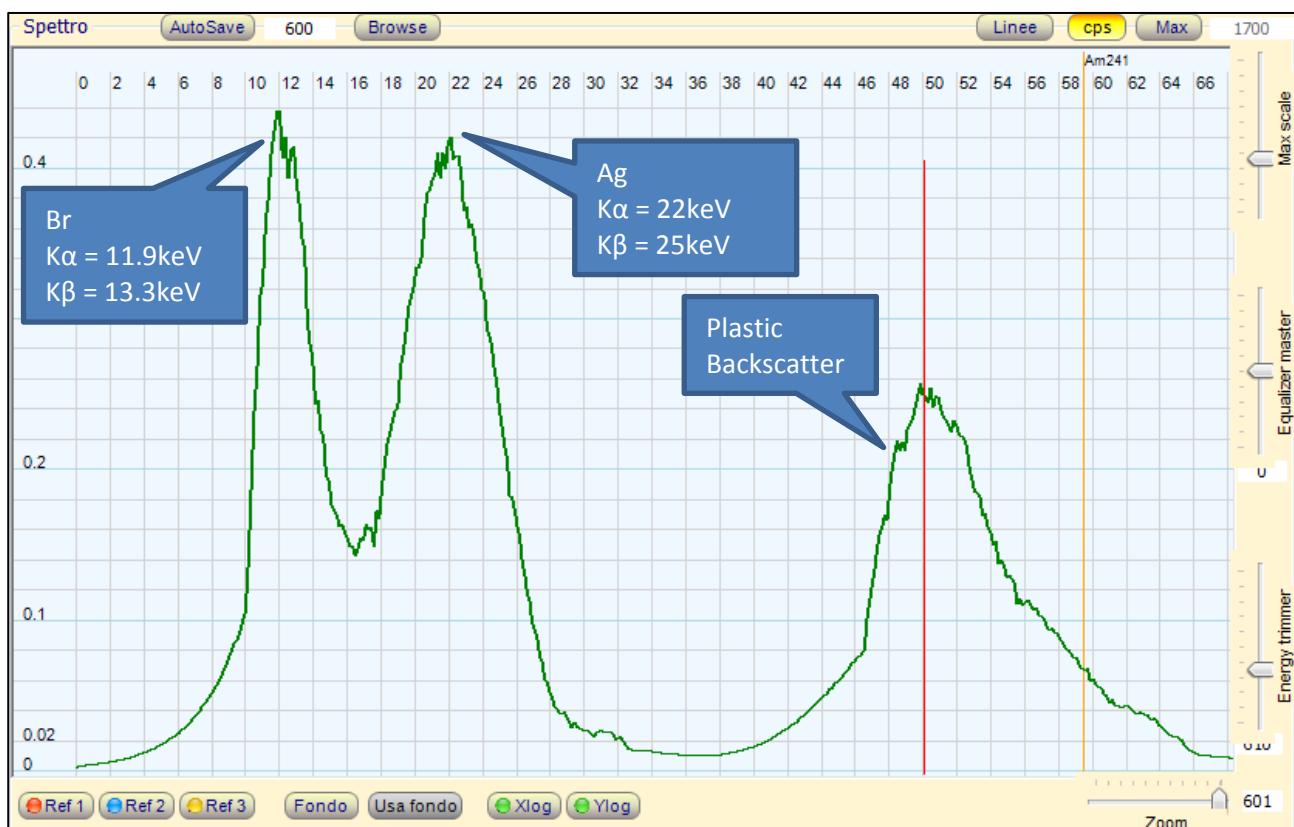
A **silver halide** (or silver salt) is one of the compounds formed between silver and one of the halogens: **silver bromide (AgBr)**, chloride (AgCl), iodide (AgI), and three forms of silver fluorides. As a group, they are often referred to as the silver halides, and are often given the pseudo-chemical notation AgX.

The light-sensitive chemicals used in photographic film and paper are silver halides.

Silver halides are used in photographic film and photographic paper, including graphic art film and paper, where silver halide crystals in gelatin are coated on to a film base, glass or paper substrate. The gelatin is a vital part of the emulsion as the protective colloid of appropriate physical and chemical properties. Gelatin may also contain trace elements (such as sulfur) which increase the light sensitivity of the emulsion, although modern practice uses gelatin without such components. When absorbed by an AgX crystal, photons cause electrons to be promoted to a conduction band (de-localized electron orbital with higher energy than a valence band) which can be attracted by a sensitivity speck, which is a shallow electron trap, which may be a crystalline defect or a cluster of silver sulfide, gold, other trace elements (dopant), or combination thereof, and then combined with an interstitial silver ion to form silver metal speck.

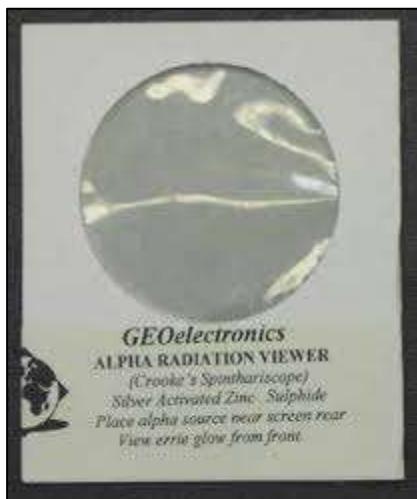


XRF Sample : X Ray Film

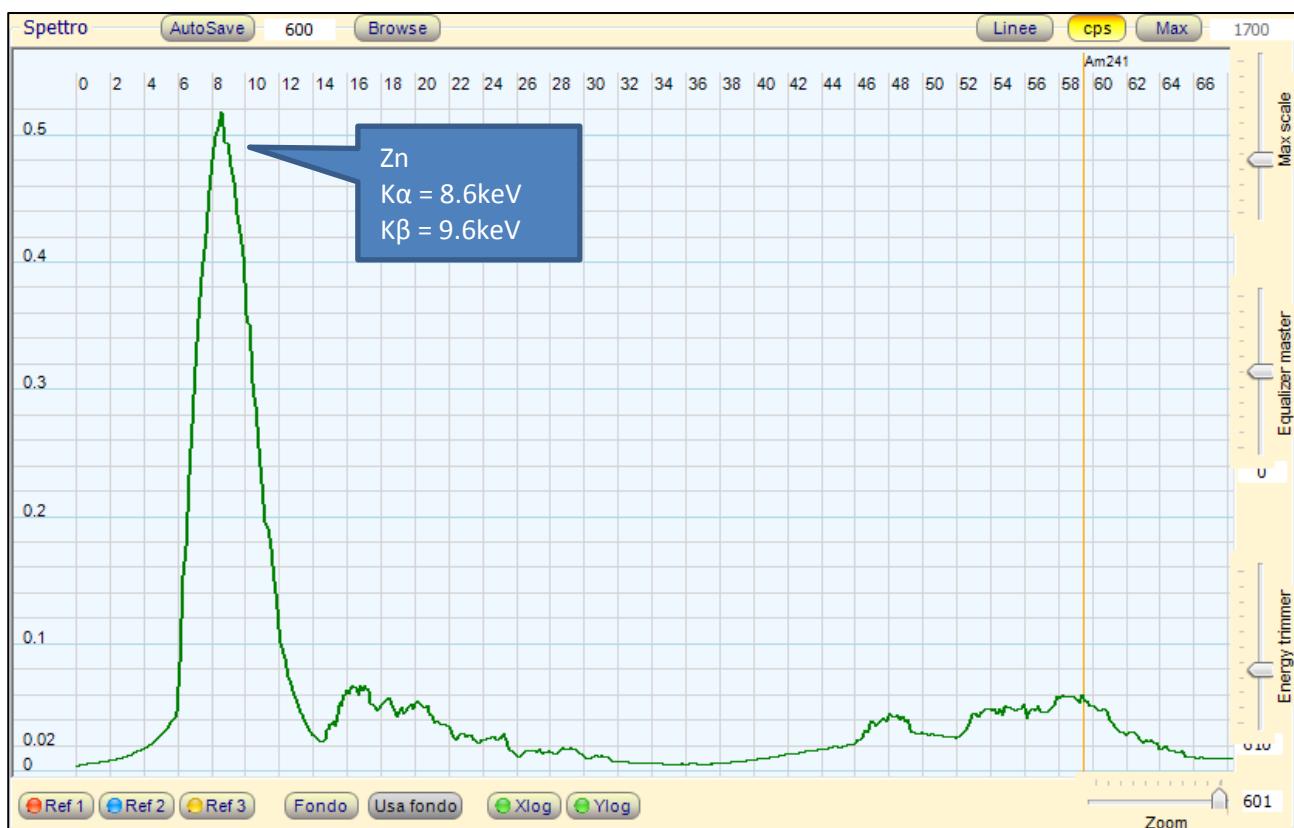


Zinc Sulfide Scintillation Screen

Zinc Sulfide (silver activated) is a polycrystalline scintillator compound used to detect alpha particle, such as in spinthariscopes.



XRF Sample : Scintillation Screen



White Gold (Gold + Palladium)

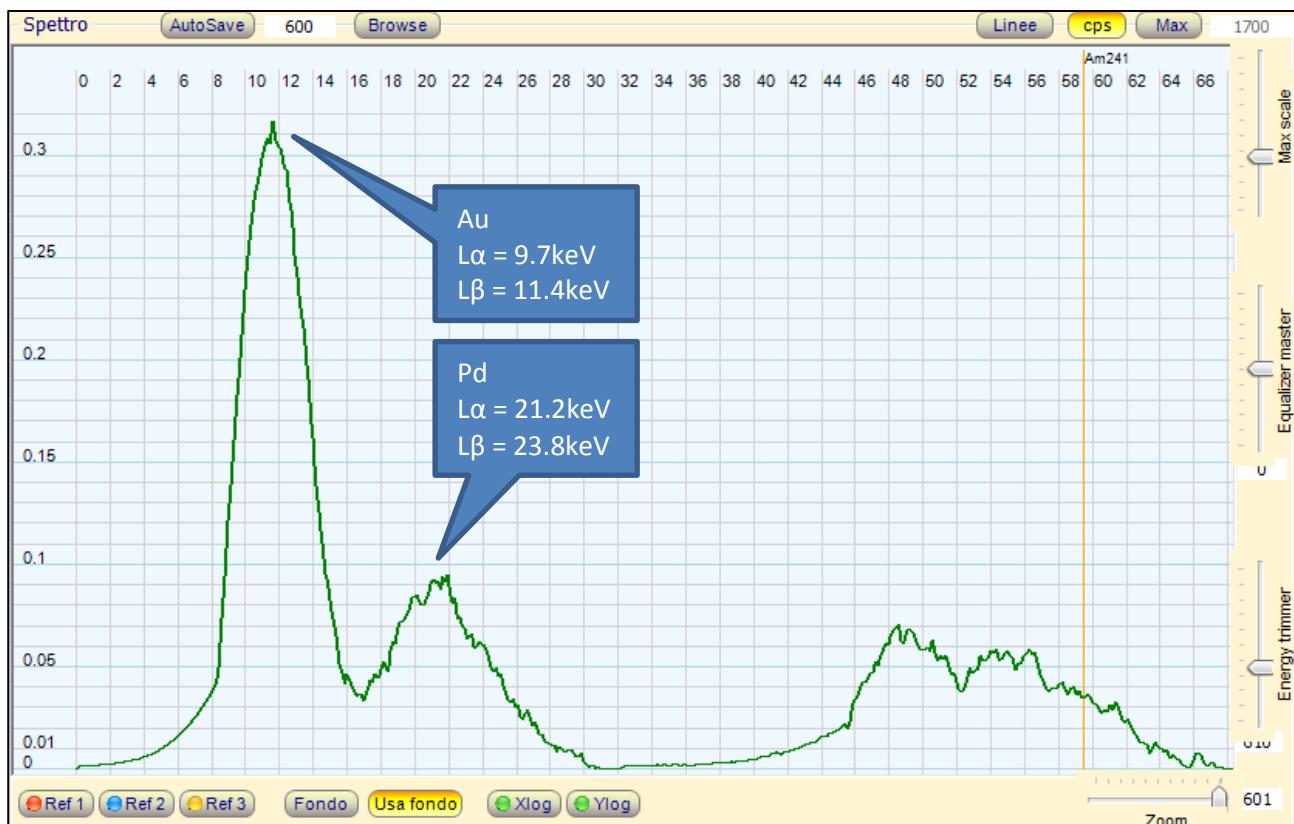
Gold and palladium are totally soluble in one another.

The primary use of gold / palladium alloys is in jewellery. The alloy is more commonly known as white gold and is an alternative to platinum. Gold / nickel alloys are also used as white gold. In both cases some other metals may be present in small amounts such as silver, zinc and copper.

The cost of palladium white golds are greater than that for nickel white golds due to palladium's higher cost and more difficult processing. Palladium white golds are also softer and more ductile compared to nickel white golds. In both cases it is not possible to have white gold with a purity greater than 21 carat.



XRF Sample : White Gold ring

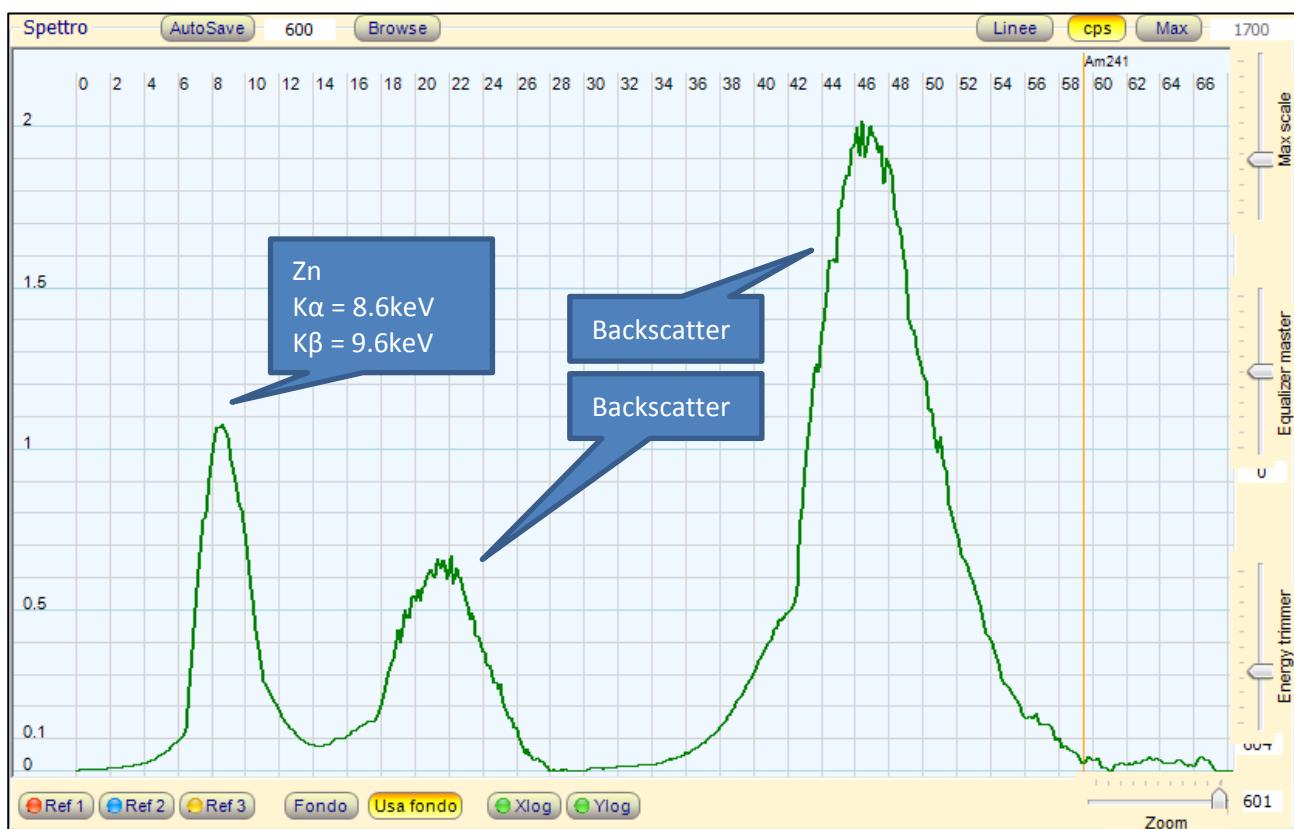


Zinc Oxide

Zinc oxide is an inorganic compound with the formula ZnO. ZnO is a white powder that is insoluble in water, and it is widely used as an additive in numerous materials and products including rubbers, plastics, ceramics, glass, cement, lubricants,[3] paints, ointments, adhesives, sealants, pigments, foods, batteries, ferrites, fire retardants, and first-aid tapes. It occurs naturally as the mineral zincite, but most zinc oxide is produced synthetically



XRF Sample : zinc oxide cream



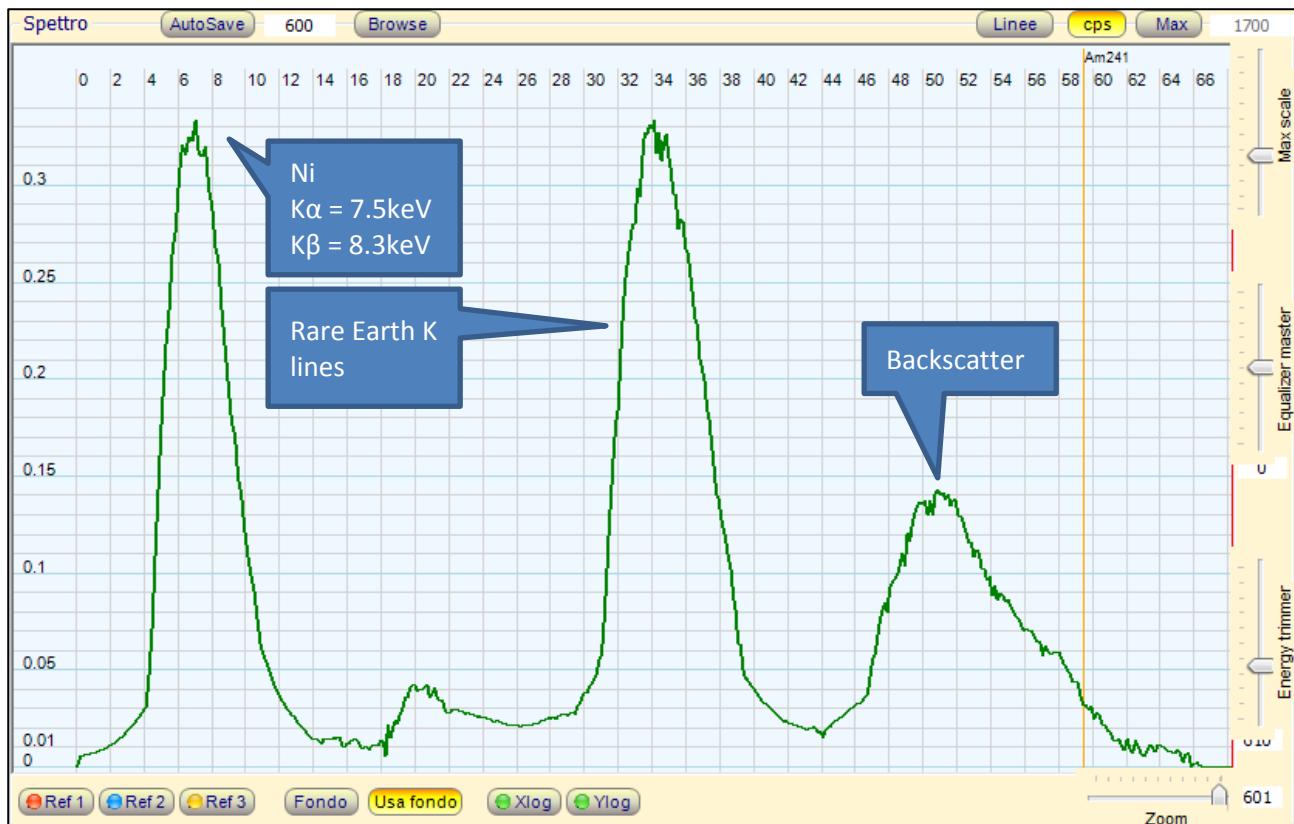
NiMH Battery

A **nickel–metal hydride battery**, abbreviated NiMH or Ni–MH, is a type of rechargeable battery. Its chemical reactions are somewhat similar to the nickel–cadmium cell (NiCd). NiMH use **positive electrodes of nickel oxyhydroxide (NiOOH)**, like the NiCd, but the **negative electrodes use a hydrogen-absorbing alloy** instead of cadmium, being in essence a practical application of nickel–hydrogen battery chemistry.

The negative electrode of a NiMH cell is actually an **intermetallic compound**. Many different compounds have been developed for this application, but those in current use fall into two classes. The most common is AB₅, where A is a rare earth mixture of **lanthanum, cerium, neodymium, praseodymium** and B is **nickel, cobalt, manganese, and/or aluminium**.



XRF Sample : NiMH Battery

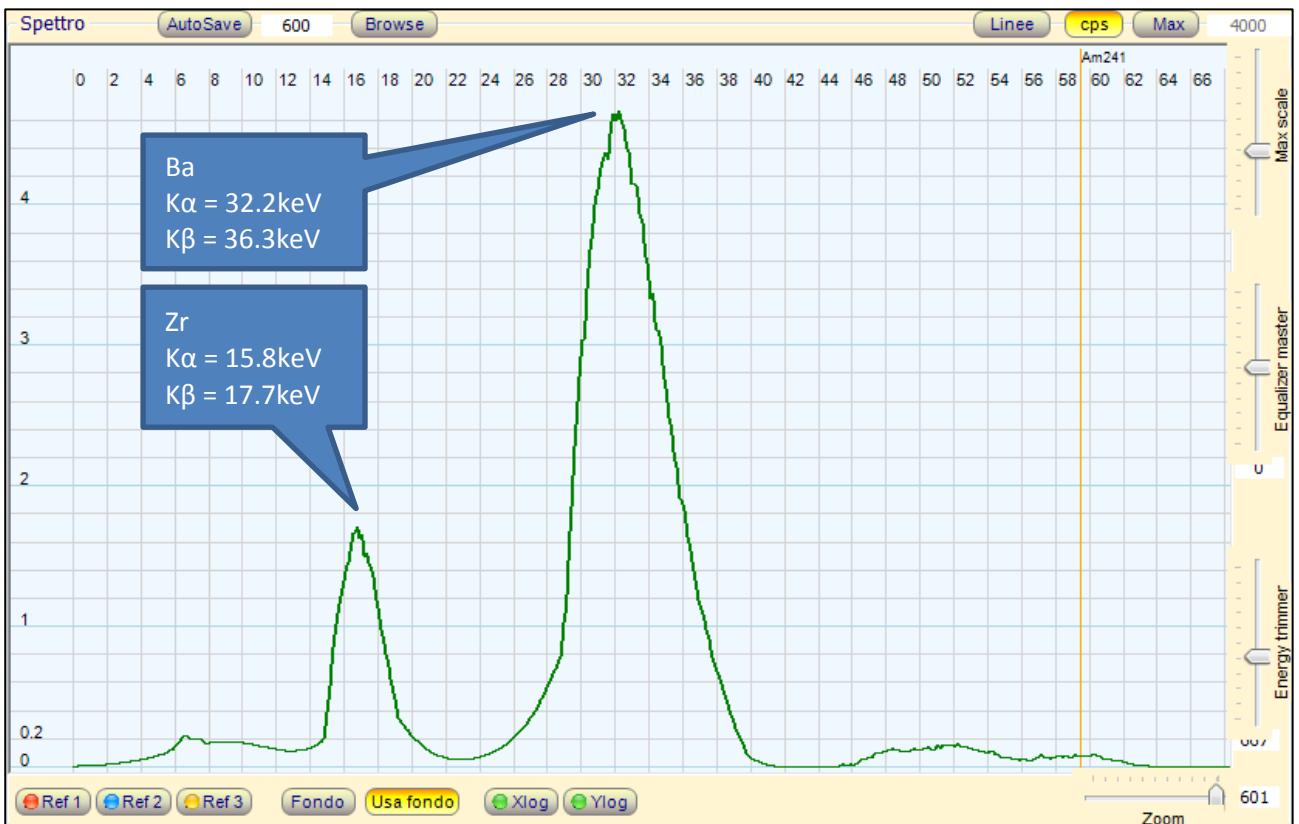


Photographic lens

The photographic lens glass contains barium in order to increase the refractive index and zirconium in order to eliminate reflections.



XRF Sample : photographic lens

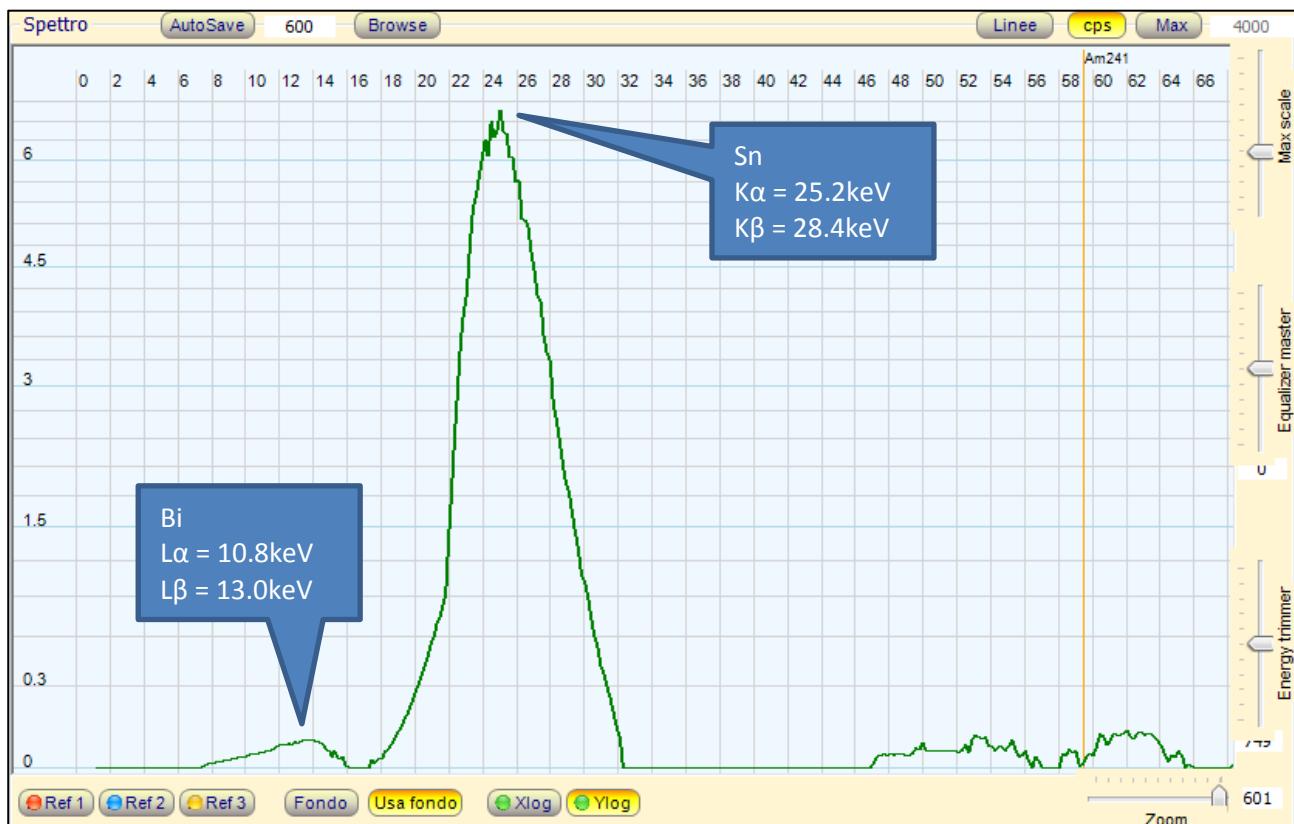


Pewter

Pewter is a malleable metal alloy, traditionally 85–99% tin, with the remainder consisting of copper, antimony, bismuth and sometimes, less commonly today, lead. Silver is also sometimes used. Copper and antimony act as hardeners while lead is common in the lower grades of pewter, which have a bluish tint. It has a low melting point, around 170–230 °C (338–446 °F), depending on the exact mixture of metals. The word pewter is likely a variation of the word spelter, a term for zinc alloys (originally a colloquial name for zinc).



XRF Sample: pewter tray



Pyrite

The mineral **pyrite**, or iron pyrite, also known as fool's gold, is an iron sulfide with the chemical formula FeS₂. This mineral's metallic luster and pale brass-yellow hue give it a superficial resemblance to gold, hence the well-known nickname of fool's gold. The color has also led to the nicknames brass, brazzle, and Brazil, primarily used to refer to pyrite found in coal.



XRF Sample: Pyrite Mineral

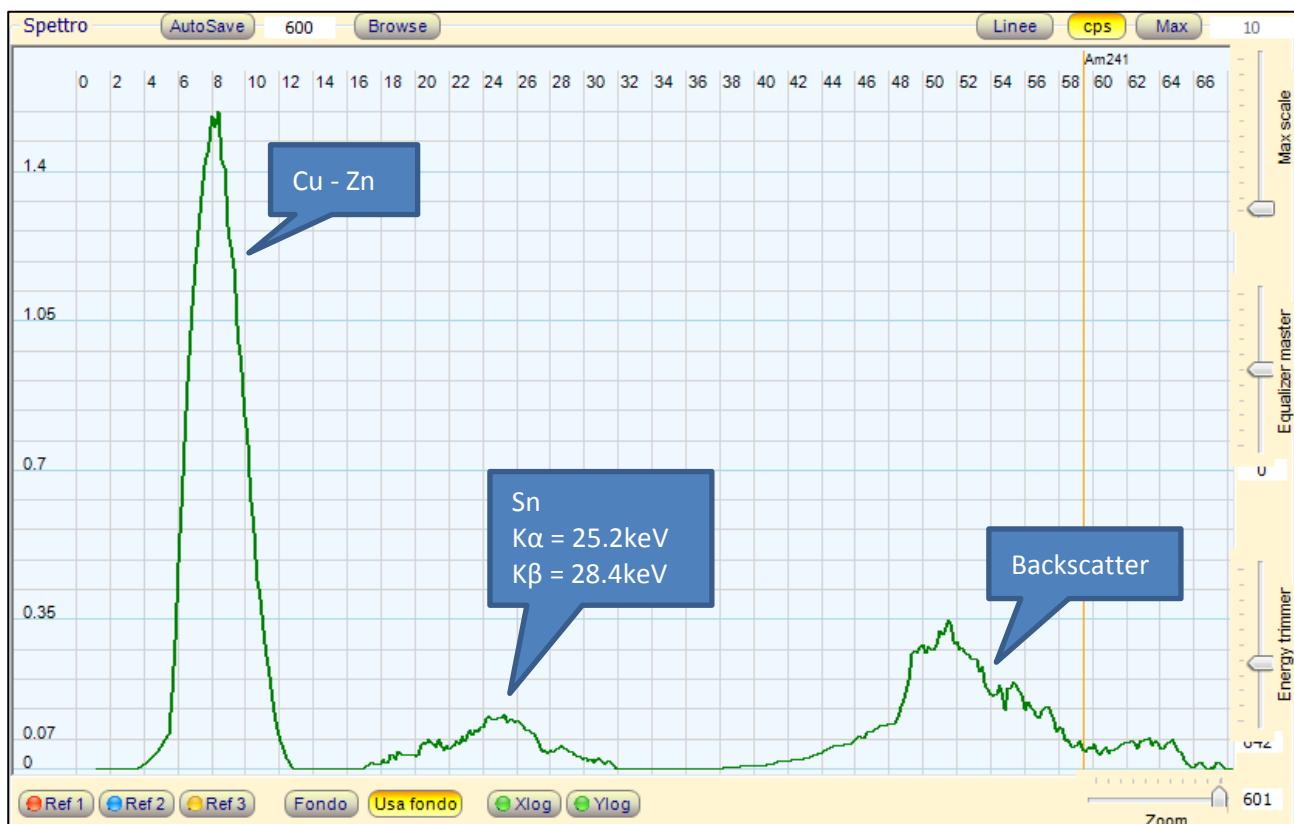


Nordic Gold

Nordic gold is the gold-coloured copper alloy from which the middle three denominations of euro coins, 50 cent, 20 cent, and 10 cent coins are made. It has also been in use for a number of years in other countries, most notably in the Swedish 10-krona coin for which it was originally developed (hence the Swedish name: nordiskt guld). Its composition is 89% copper, 5% aluminium, 5% zinc, and 1% tin.



XRF Sample: 50 cents. coin



Disclaimer and Safety Warning

- **Before using any radioactive sources:** local, national, and international regulations may restrict the purchase, storage, transport, use or disposal of radioactive sources. Please consult your local regulations to ensure your compliance before you manage any radioactive sources.
- **Never tamper with an ionization smoke detector or attempt to remove the radioactive source. Do not dismantle** smoke detector. **Do not remove** the radioactive material from any object.
- The experiments shown in this document are intended for **educational purposes** and for **testing** the measuring instruments and **should never be replicated without** proper knowledge and without the compliance with regulations.

Precautions with Radioactive Sources

Time: The simplest way to reduce exposure is to keep the time spent around a radioactive source to a minimum. If time is cut in half, so is the exposure, with all the other factors remaining constant.

Distance: Distance is another effective means to reduce radiation exposure. A formula known as the “inverse square law” relates the exposure rate to distance. Doubling the distance from a radioactive source reduces the exposure to one-fourth its original value. If the distance is tripled, the exposure is reduced by a factor of nine.

Shielding: Shielding is any material used to reduce the radiation reaching the user from a radioactive source. While a single sheet of paper may stop some types of radiation such as alpha particles, other radiation such as neutrons and photons require much more shielding. Dense materials, such as lead or steel, are used to shield photons. Materials containing large amounts of hydrogen, such as polyethylene, are used to shield neutrons.

Never wear the same rubber gloves while operating your counting instrument, as any contamination on the glove could be transferred to the instrument.

No food or drink is ever to be permitted in a radioactive laboratory.

Another good habit to acquire is **never allowing the hands to touch** any other part of the body, or another individual, while working with liquid sources.