Effect and Origin of Base metal – Deleterious elements in Gold Refining and Melting

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An MKS PAMP GROUP Company

1. Objectives

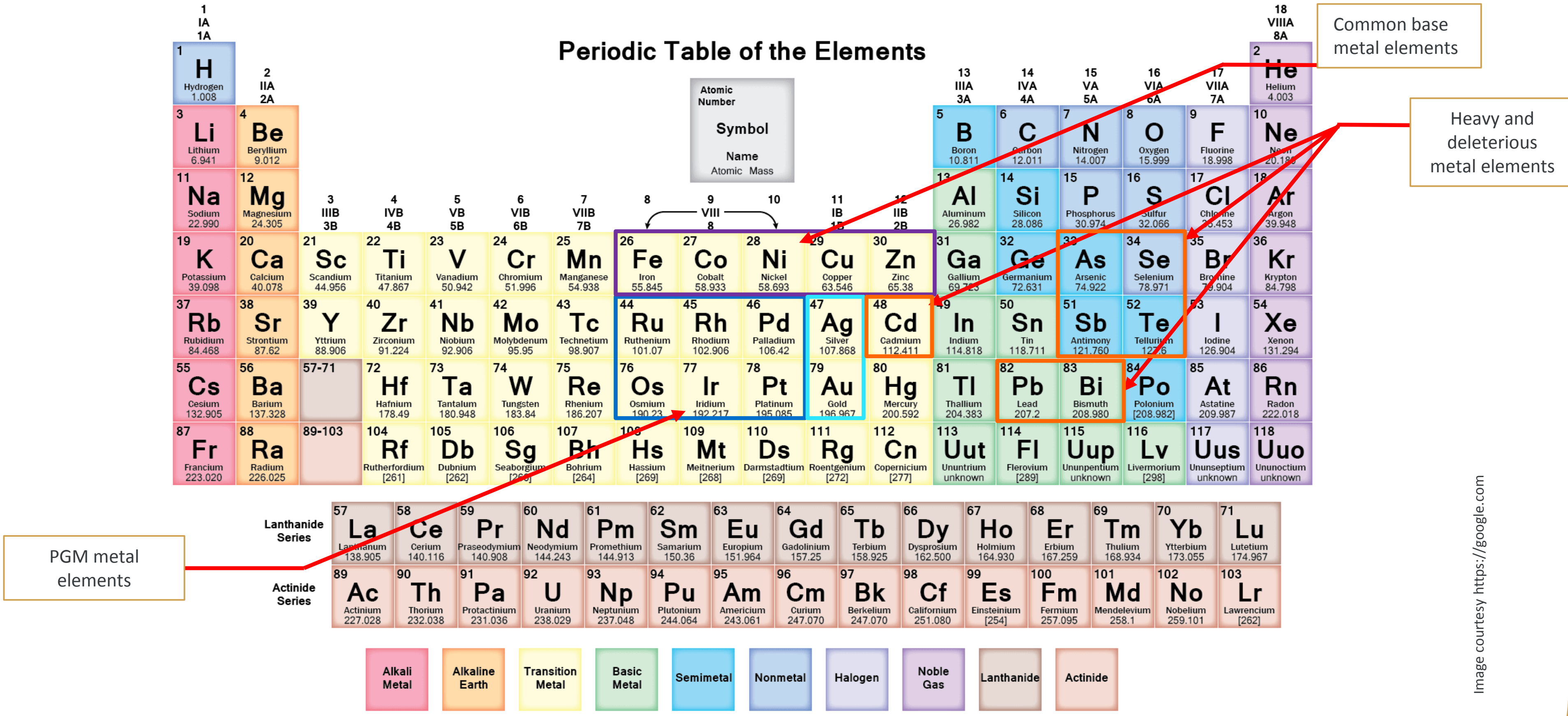


Image courtesy https://google.com

2. Properties – Occurrence and Behaviour of Base Metal and Deleterious elements

Properties of Base and other Deleterious Metals

Element	Atomic Mass	Atomic number	Melting point (Deg C)	Boiling point (Deg C)	Heat of fusion (KJ/mol)	Heat of vaporisation (KJ/mol)	Density (g/cm3)	Thermal Conductivity (W/m.K)	Thermal Expansion (µ.m/mK @ 25deg)	Crystal Structure
Copper	63.54	29	1084	2562	13.26	300.4	8.96	401	16.5	F.C.C.*
Nickel	58.69	28	1455	2730	17.48	379	8.90	90.9	13.4	F.C.C
Iron	55.84	26	1538	2862	13.8	349.6	7.87	94	12	B.C.C
Lead	207.2	86	327.4	1749	4.77	179.5	11.34	35.3	28.9	F.C.C
Cadmium	112.4	48	321.07	767	6.21	99.87	8.65	96.6	30.8	H.C.P
Arsenic	74.92	33	615(Sub)	NA	24.44	34.76	5.72	50.2	5.6	Rh.C***
Bismuth	208.9	83	271.5	1564	11.30	179	9.78	7.97	13.4	Rh.C
Antimony	121.76	51	630.63	1635	19.79	193.43	6.697	24.4	11	Rh.C
Selenium	78.97	34	221	685	6.69	95.48	4.81	0.519	37	H****

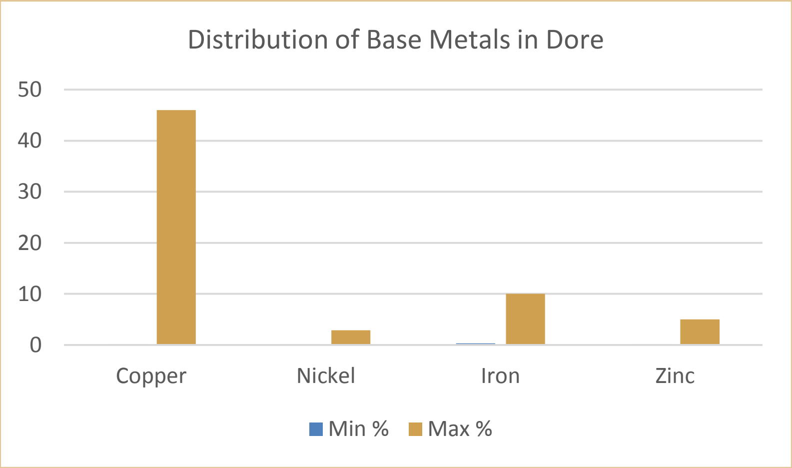
* Face centered Cubic system
** Hexagonal closed packed *** Rhombohedral ****Hexagonal

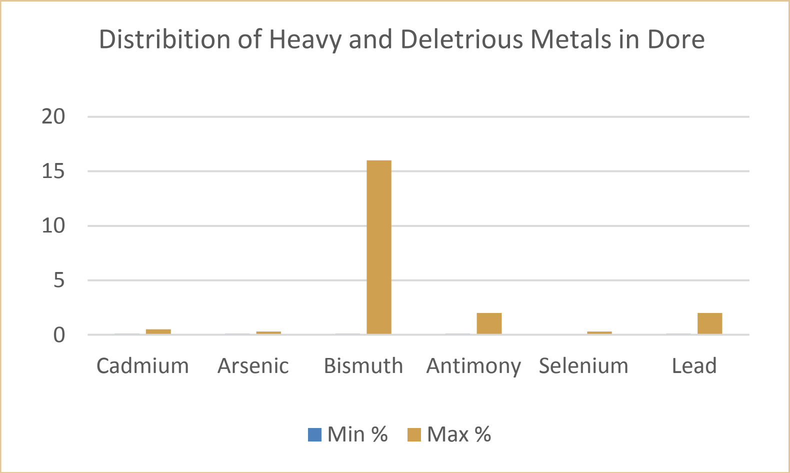
Properties of Precious Metal and PGM's

Element	Atomic Mass	Atomic number	Melting point (Deg C)	Boiling point (Deg C)	Heat of fusion (KJ/mol)	Heat of vaporisation (KJ/mol)	Density (g/cm3)	Thermal Conductivity (W/m.K)	Thermal Expansion (µ.m/mK @ 25deg)	Crystal Structure
Gold	196.96	79	1064.18	2970	12.56	342	19.3	318	14.2	F.C.C.*
Silver	107.86	47	961.78	2163	11.28	254	10.49	429	18.9	F.C.C.*
Iridium	77	77	2446	4130	41.12	564	22.56	147	6.4	F.C.C.*
Osmium	190.23	76	3033	5012	31	378	22.59	86.75	5.1	H.C.P**
Ruthenium	101.7	44	2334	4150	38.59	619	12.45	117	6.4	H.C.P**

* Face centered Cubic system
** Hexagonal closed packed

Occurrence of base, deleterious and heavy metals





Behavior of base metals

Sr No	Base Metal	Typical Range in Dore	Typical Behavior
1	Copper	0.1 – 46%	• Copper is one of the common metallic elements that easily alloys with gold hence their high probability in the raw materials like Dore and Jewellery Scrap. • Copper is a soluble impurity in the electrolysis process, hence has probability of co-deposition in to the cathode.
2	Iron	0.03 – 10%	• Iron may be present in dore in substantial quantity based on different mines • Iron is often removed as slag.
3	Nickel	0.1 – 2.83%	• Nickel is usually found lower in concentration in dore. It's a soluble impurity and easily removed by chemical treatment
4	Cobalt	Rarely observed	• The properties of Co are similar to that of Nickel in terms of its melting point and alloying ability
5	Zinc	0.11-5%	• Less in Dore but mainly in Jewellery scrap. The metal with the lowest melting point in this category, • Zinc gets oxidized during melting and is removed as Zn0 vapors • Zinc alloys well with Gold, Silver and Copper hence usually a trace level of the same always manages to get inside the system.

Behavior of Heavy & Deleterious Metals

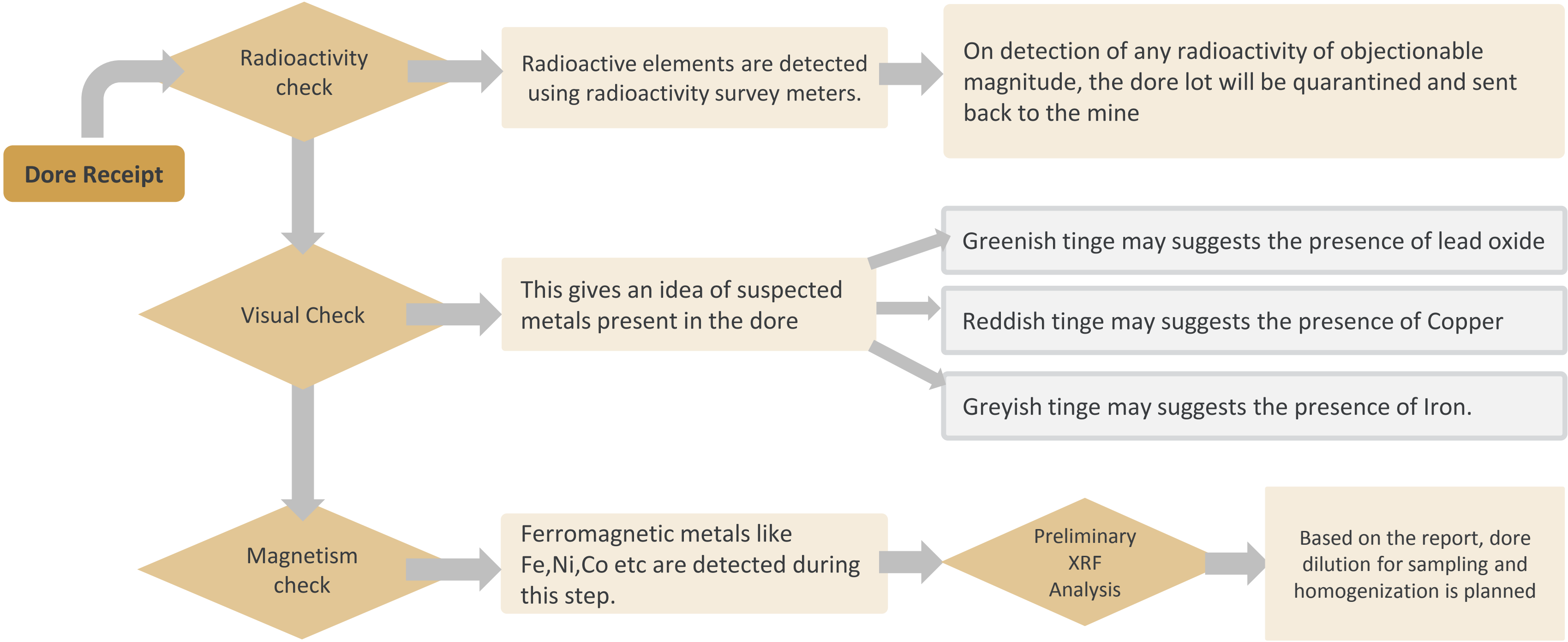
Sr No	Metal	Typical range in Dore	Properties
6	Cadmium	0.1 – 1.1%	• Cadmium is mostly found in the jewelry scrap but its use is declining as its carcinogenic
7	Lead	0.1 – 2.0%	• Lead is a volatile metal. • It can be separated out by increased holding time and also by oxygen lancing that drives away all the lead as their oxide fumes.
8	Bismuth	0.1 – 16%	• Bismuth generally comes from Dore with High copper or in Anode Slimes. • Its Volatile and is normally refined through Silver refining
9	Arsenic	0.1 – 0.4%	• Any Dore having high Copper is likely to have Arsenic. • It is considered as a deleterious impurity as it leads to serious health hazards while processing
10	Selenium	0.02-0.3%	• Selenium is a low melting heavy metal with a very high affinity for oxidation. • Se usually vaporizes as metal vapor and metal oxides. • Selenium also has the affinity of precipitating as its mono-chloride during dissolution in aqua regia.
11	Antimony	0.1 – 2%	• A deleterious element that generates toxic oxides upon melting.

Behavior of PGMs

Sr No	PGMs	Properties
12	Platinum	• Platinum is noble metal. • During processing Gold dore, Platinum is removed by Ion exchange method or by selective precipitation
13	Palladium	• Its a is noble metal. • During processing Gold dore, Palladium is removed by Ion exchange method or by selective precipitation
14	Iridium	• It forms a heterogeneous system with gold, as it distributes itself in unpredictable manner.
15	Ruthenium	• It distributes itself irregularly in the metal.
16	Osmium	• Being densest of the metals, osmium usually distributes itself in unpredictable manner • Its highly volatile and gets removed during melting. Its oxide is highly toxic

3. Effect of Base Metal and Deleterious Elements in Refining Process

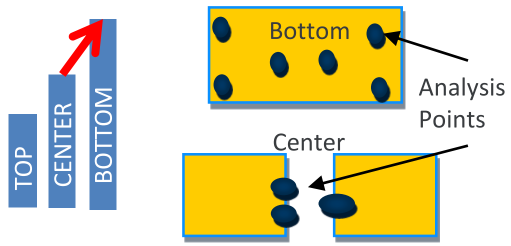
Base metal – Status at Receipt



Detection probability for Iridium – Ruthenium and Osmium

Only Iridium

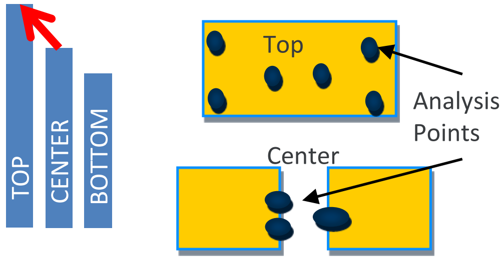
- When only Iridium is present in sample, the trend for qualitative analysis of iridium is in **ascending order from Center towards Bottom side.**
- When samples contains only iridium, the no. of **analysis spots at bottom side must be increased** to enhance detection probability.



High value detection predominantly towards Bottom and center.

Iridium-Ruthenium

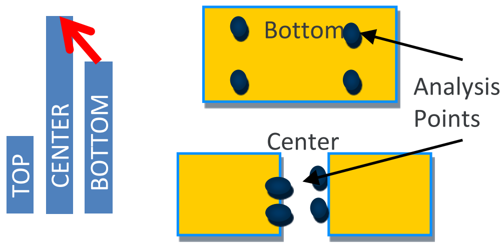
- When Iridium-Ruthenium is present in sample, then the trend for qualitative analysis of iridium is in **ascending order from Center towards Top side.**
- When samples contains iridium/ruthenium, **the no of spots of analysis at Top side must be increased** to enhance detection probability.



High value detection predominantly towards Top and center.

Iridium-Osmium

- When Iridium-Osmium is present in sample, then the trend for qualitative analysis of iridium-osmium is in **ascending order from bottom towards Center side**.
- When samples contains iridium-osmium, the **no of spots of analysis at Center side must be increased** to enhance detection probability



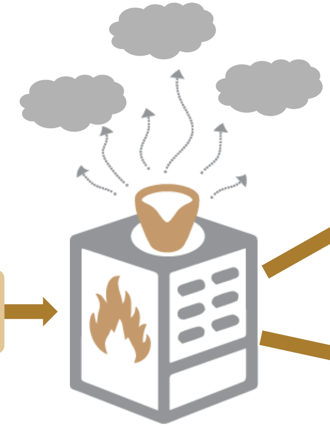
High value detection predominantly towards Center and bottom.

Base metal – Status in Melting operation

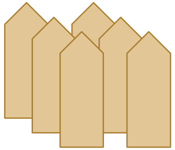
Volatile metals like Cd, Pb, Bi, As, Se, Sb and Te oxidize & escape as toxic fumes along with traces of Au and Ag. They are captured by Jet Bag Filters for later treatment, recovery and disposal

Analyzed Metal lot

Dilution with calculated amounts of Ag/Au



Melting of the blend

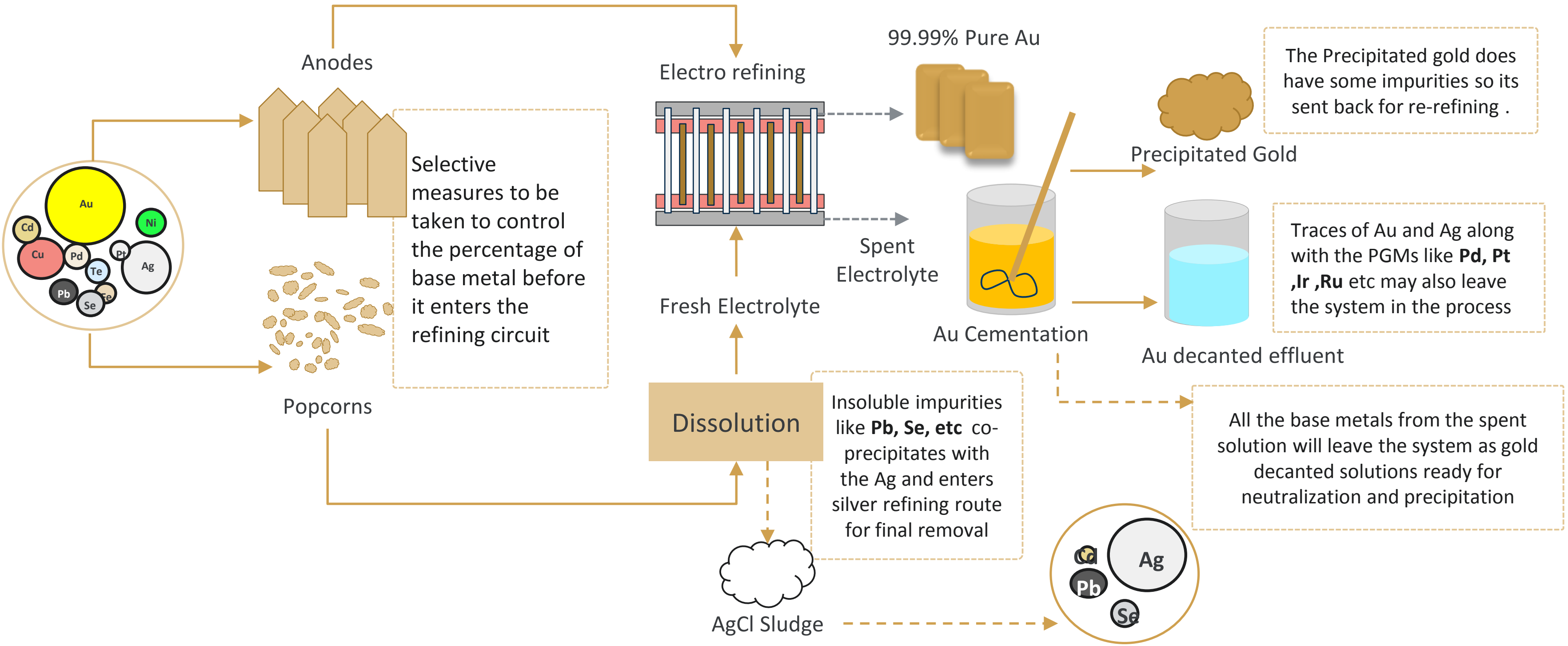


Anodes and Popcorns are rid of major deleterious and heavy metal impurities as the major volatile elements get removed during melting.

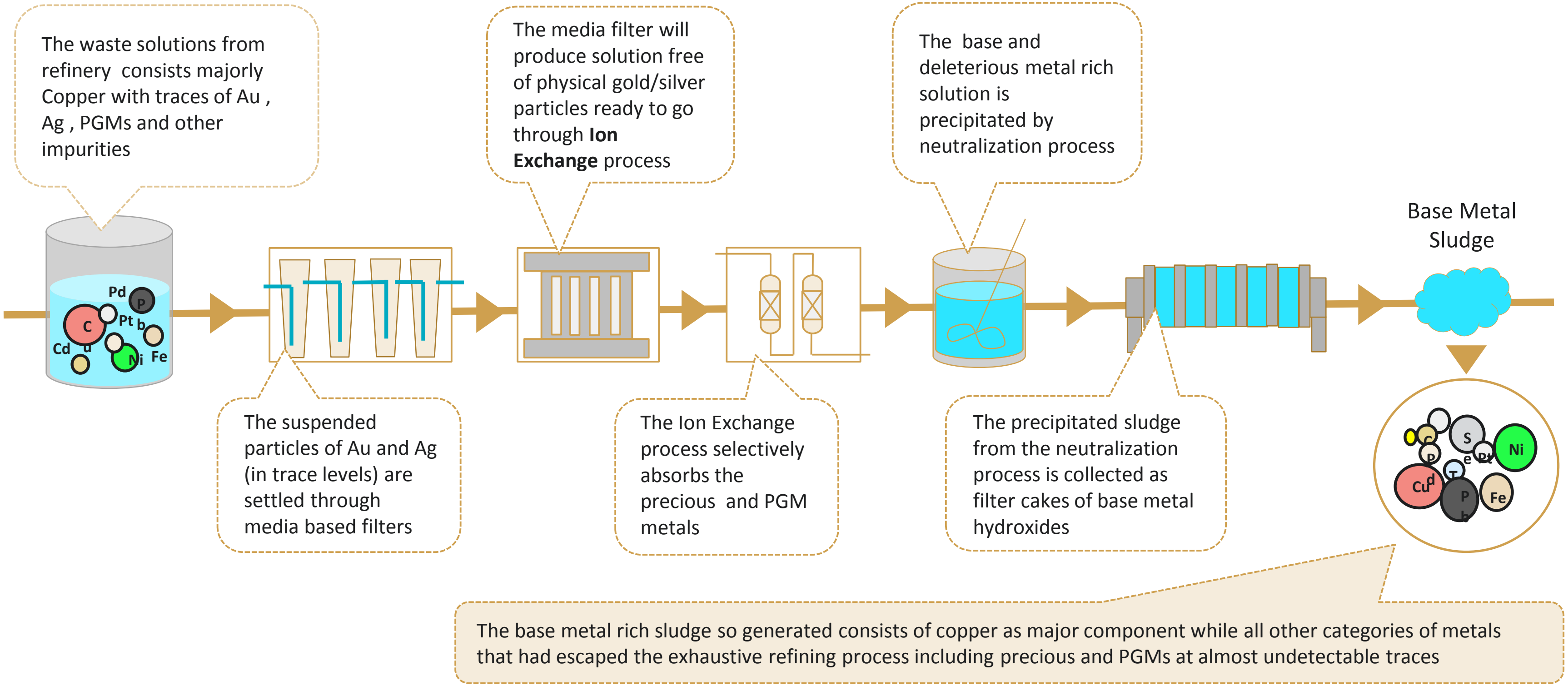
Concentration of base metals like Cu, Ni whose melting points are similar to Gold slightly increases

In case when iron is observed as the prominent impurity in the lot, care is taken to remove iron in the slag during melting

Base metal – Status in Chemical and Electrochemical Refining



Base metal – Status in Ecology operation



Effects of Base Metals in various stages of refining

Sr No	Base Metal	Melting	Chemical/Electrochemical Refining	Ecology	ASTM Limits in PPM for 999.9 fine Au	Bullion
1	Cu	No severe impact on melting due to its lower toxicity and miscibility with gold	Cu helps in electrolysis as it improves ionic conductivity. Excess Cu built up in electrolyte affects gold purity through co-deposition. Its removed periodically by bleeding and replenishment	Copper gets precipitated as hydroxide which is sent for recycling	50	Cu may manifest into to finished product as trace impurity
2	Fe	Iron primarily gets removed as slags from the molten metal	Its removed periodically by bleeding and replenishment	Iron joins the final base metal sludge stream as chloride or nitrate	Not Specified	Trace Iron levels in the product may result into brittleness in cast products
3	Ni/Co	May cause inhomogeneity issues due to its higher melting point.	Its removed periodically by bleeding and replenishment	It gets removed as hydoxides in the sludge	3/Not Specified	Rarely manifests in final bullion
4	Zn	Zinc is oxidized and removed as ZnO2 fumes that are collected by the jet bag filters along with other deleterious elements	Zinc does not co-deposit due to its high reduction potential. Its easily get removed in the impaired electrolyte	It gets removed as chlorides, nitrates and hydroxide in the sludge	Not Specified	Rarely manifests in final bullion

Effects of Heavy & Deleterious Metals in various stages of refining

Sr No	H & D Metals	Melting	Chemical/Electrochemical refining	Ecology	ASTM Limits in PPM for 999.9 fine Au	Bullion
5	Cd	Generates toxic fumes that are captured by jet bag filters which are later on collected carefully and treated for recovery and safe disposal	Normally treated in nitric medium and removed by periodically bleeding the spent electrolyte	Need to be separated out by selective treatment	Not Specified	Not allowed in bullion product
6	Bi		Bi has to be treated in the Nitric media for multiple times to achieve ASTM quality	Bi traces also reach base metal sludge	20	Bi traces may cause casting issues
7	As/Sb		The traces that makes its way into the electrolyte are tapped out by bleeding the spent solution	The accumulated As in the effluent concentrates into the base metal sludge	30/Not Specified	Rarely manifest in final product
8	Se		The traces that makes its way into the electrolyte are tapped out by bleeding the spent solution	The selenium may reach the base metal sludges. Selenium is difficult to be completely removed in the final discharge water	Not Specified	Rarely manifest in final product
9	Pb	Lead primarily gets removed as oxides during various melting stages	Removed as chlorides and nitrates with help of chemicals	The Lead also reach base metal sludge	20	Not allowed in Bullion product

Effects of PGMs in various stages of refining

Sr No	PGMs	Melting	Chemical/Electrochemical refining	Ecology	ASTMASTM Limits in PPM for 999.9 fine Au	Bullion
10	Platinum and Palladium	No effect in melting process	Selective precipitation or ion exchange to separate this from Gold and Silver at suitable stage	Traces of this metal goes into the filter press sludge and to be recovered by recycling	Pt– Not Specified Pd - 50	Comply ASTM
12	Iridium/ Ruthenium/ Osmium	Due to high melting point and due to density difference, it distributes irregularly	Can be separated out by chemical refining prior to entering the main circuit	Traces of this metal goes into the filter press sludge	Not Specified	Presence may effect casting and improper assay.

Research team

Conceptualization of the paper

Ankur Goyal : Metallurgist

Debasish Bhattacharjee : Metallurgist (Main contributor to this paper)

Pankaj Deshmukh : Analytical chemistry

Compilation of the data

Praveen Kumar – Chemical Engineer

4. Q and A

THANK YOU

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