Swiss Excellence.
Made in India.

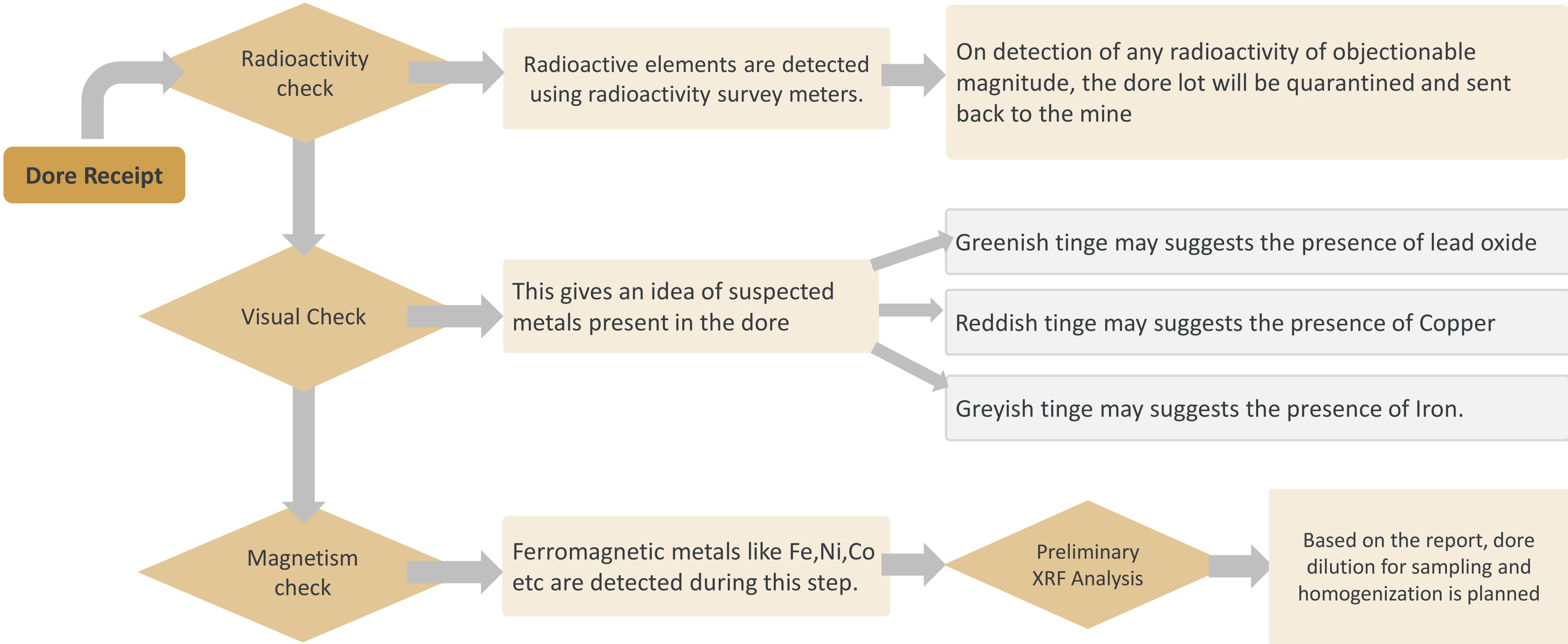
Recent Trends in refining through chemical & electrolytic method

MMTC-PAMP

Refinery

An MKS PAMP GROUP company

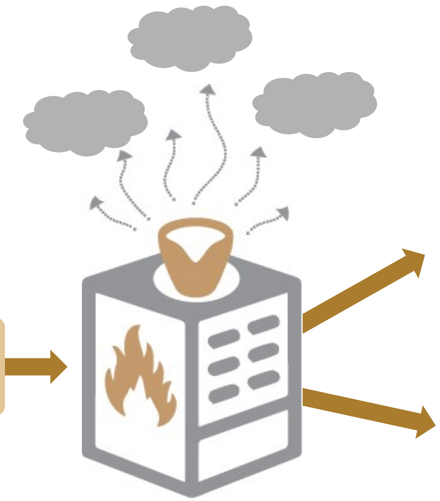
Base metal – Status at Receipt



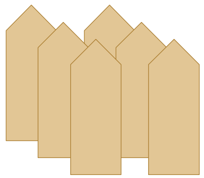
Base metal – Status in Melting operation

Volatile metals like Pb, Bi, Se, Te, As, Cd etc oxidize & escape as toxic fumes along with traces of Au and Ag 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, Zn whose melting points are similar to Gold slightly increases

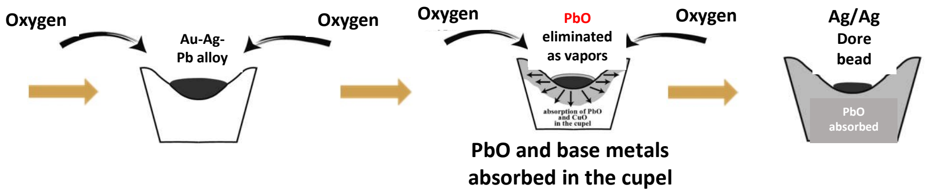
In case when **iron** is observed as the prominent impurity in the lot, care is taken to remove iron in the slag during melting

Major techniques in gold refining

TECHNIQUE | PROCESS FLOW DIAGRAM | SCOPE OF THE PROCESS

Cupellation

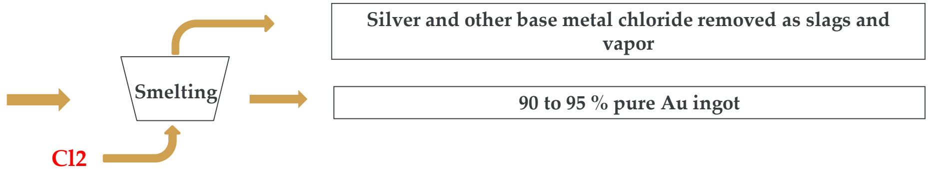
Crude gold with lead as major impurity



- Now restricted to being used only as an assaying technique and in few cases of refining due to potential lead hazard.
- The process is usually followed by nitric acid digestion which yields 95 to 99.0% Fine gold

Miller Chlorination

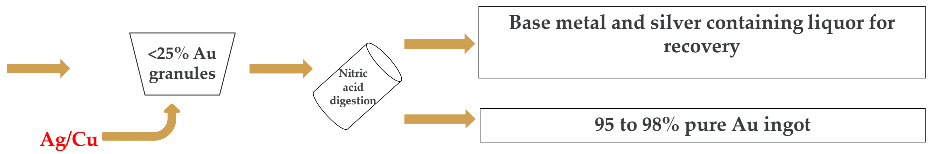
Crude gold with Silver as major impurity



- Here, chlorine gas is bubbled into the molten raw gold to remove silver as its chloride slag for later recovery.
- This process yields gold with fineness ranging from 90 to 99.5% based on the other impurities present.

Inquartation

Crude gold/jewelry scraps having all kinds of impurities



- A popular technique used predominantly by the jewelry industry.
- Raw gold alloy is made up such that the gold concentration of the resulting alloy goes below 1/4th or <25% of the original alloy.
- Here, the feed granules digested in nitric acid removes all the base metal impurities and Ag leaving behind >95 to 98% fine Au

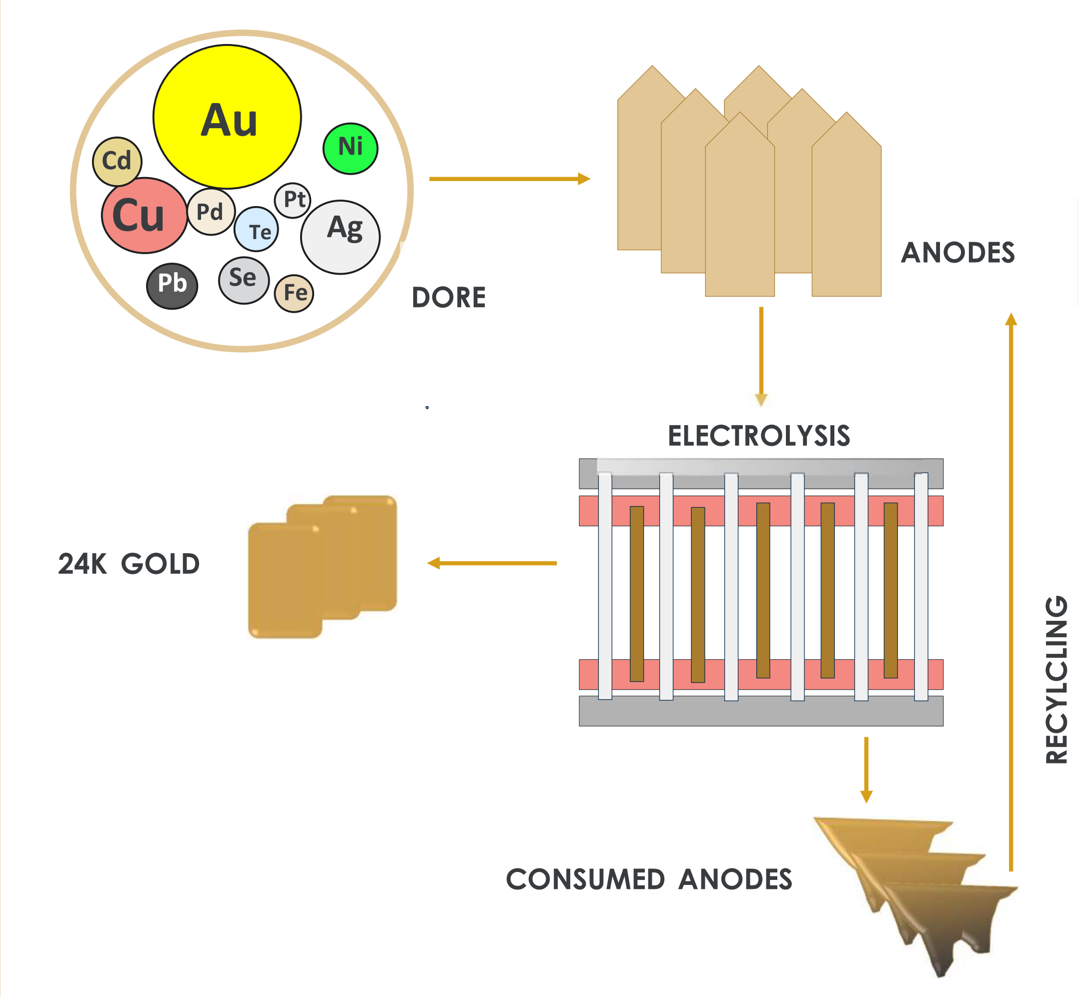
Digestion & Cementation/ Chemical refining

Electro-refining/ Wholwill's Process

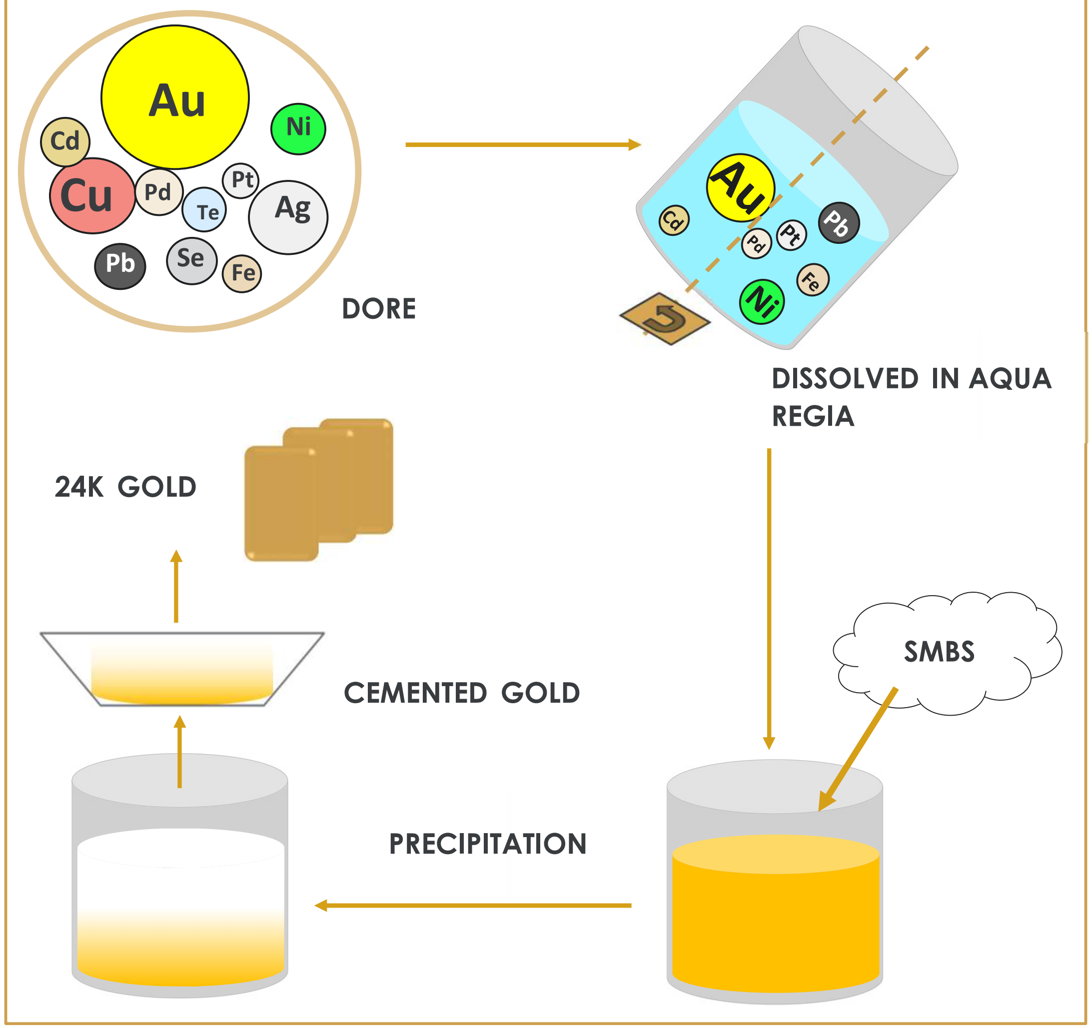
" THESES ARE MORE POPULARLY USED TECHNOLOGIES WHICH WILL BE DISCUSSED BRIEFLY IN THE PRECEEDING SECTIONS "

- These are widely used technologies for refining gold to purities >99.9%.
- While both process can be used to obtain fine gold of almost similar quality, electrorefining technique has an upper hand in terms of resource efficiency, environmental compliance and product quality

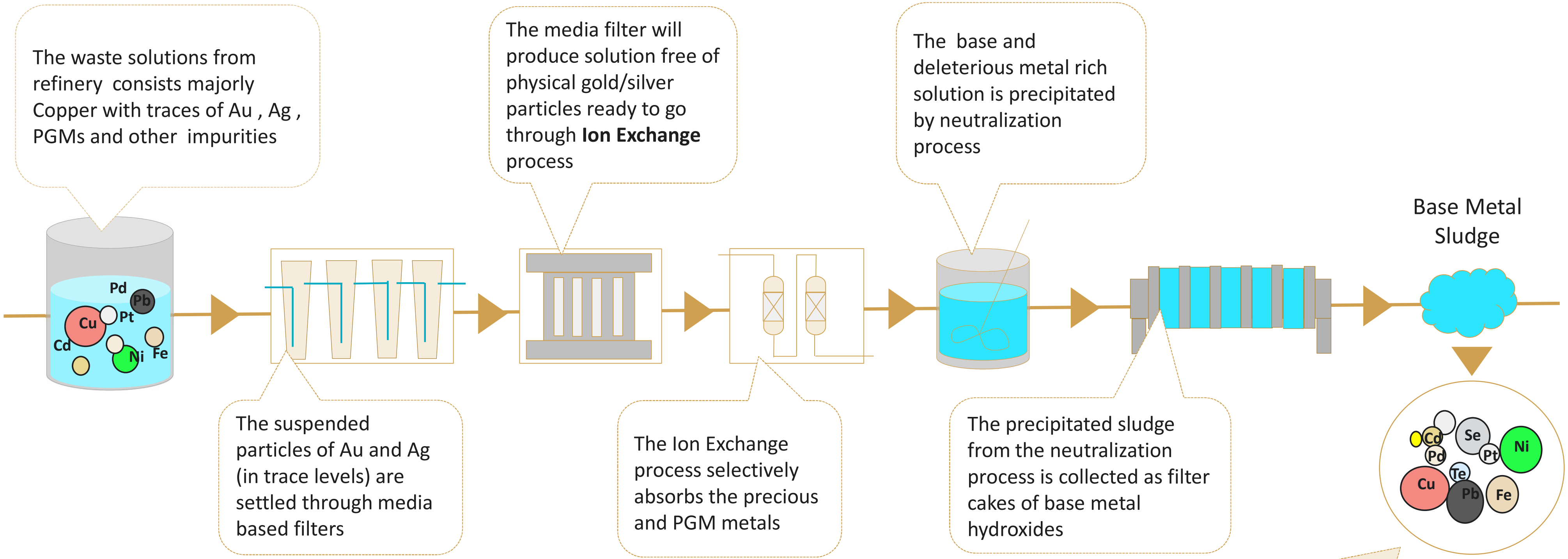
ELECTRO REFINING



CHEMICAL REFINING



Base metal – Status in Ecology operation



The base metal rich sludge so generated consists of copper as major component while all other categories of metals that had escaped the exhaustive refining process including precious and PGMs at almost undetectable traces

What are the advantages & disadvantages of both processes?

Parameters	Electro Refining	Chemical Refining
Scale of Operation	Suitable for large scale	Suitable for small scale as large scale requires big reactors
Fineness of Refined Gold	99.99% & above	99.95% maximum
Impurities in Refined Gold	Adhering to limits	Presence of deleterious elements is common
Operating cost	Low labour and chemical cost per unit of production; electricity cost is higher	Higher operating unit ; electricity cost is lower
Inventory in Process	High inventory carrying cost	Cost of inventory in WIP is much lower
Effluent Generation	Controlled generation	Consumption of chemicals is more; generates more effluent during washing and final effluent per unit of production is higher
Quality of Jewellery produced	Higher productivity and lower rejection rate due to absence of deleterious element	Manual intervention leads to presence of impurities like Fe, Pb, Cu which lead to hard spots , oxidation , brittleness in final product

Resource and energy consumption comparison (basis 200 Kg per day)

Particulars		Electro Refining		Chemical Refining	
Gold inventory required		600 Kg	**3 Times greater**	200 Kg	**As per output requirement**
Chemical consumption	HCl	2.7 L/Kg	**"approx. 350 – 400 L chemicals required to produce 200 kg of gold "**	2.7 L/Kg	**"As per stoichiometric requirement, 800 – 900 L chemicals are consumed to produce 200 kg of gold."**
	HNO3	0.7 L/Kg		0.7 L/Kg	
	NaOH	NA		0.5 l/Kg	
	SMBS	NA		1 Kg/Kg	
Equipment		1000 L, rectangular tank ; 24 V, 1000 A DC Rectifier		1500 L capacity reactor	
Manpower requirement		5		6	
Effluent generated		2.5 L/Kg raw material		11 L/Kg raw material	**4.4 times greater**
Power cost		22 Rs/Kg	**3.6 Times greater**	6 Rs/Kg	

What are the different hazards & mitigation associated with both processes?

Hazard	Mitigation
Toxic Emissions **Nox** Untreated Nitric oxide and Nitrogen dioxide fumes , contribute to the formation of smog and acid rain. **Sox** Sulfuric acid, is the main component of acid rain. Sulfur dioxide irritates the respiratory tract and aggravates conditions such as asthma and chronic bronchitis.	○ Use of efficient fume condensers to aid acid recovery from liberated fumes. ○ Use of high efficiency multistage scrubbers. ○ Use of selective catalytic reduction to convert the NOx fumes to harmless N2 and H2O (Experimental technology).
Liquid Effluents The effluent generated from above processes are highly acidic (ph. 1 or less) and also contain large quantity of deleterious metals in form of their soluble salts e.g. chlorides, nitrates, sulphates etc.	○ A series of chemical processes involving media filtration, ion absorption, neutralization and precipitation are adopted prior to sending the process effluent to ETP ensures that all the heavy metals are removed completely.
Solid Wastes Solid waste generated from the treatment of the above effluents contains Copper and traces of gold and silver	○ The solid waste generated are a rich source of base metals and must be treated for recovery .

Impurity difference

	ELECTRO REFINING			CHEMICAL REFINING			
Element	MMTC-PAMP Bullion			Indian Refiners			
	999.9 (Sponge)	999 (Conversion)	995 (Conversion)	Refiner 1	Refiner 2	Refiner 3	Refiner 4
Gold (Au) ‰	**999.96**	**999.08**	**995.08**	994.92	995.05	995.05	995.00
Silver (Ag) **(ppm)**	**29**	**900**	**4903**	4747.6	4791	4584	4872
Palladium (Pd)					5	38	35.5
Platinum (Pt)						11	
Aluminium (Al)					2		
Antimony (Sb)				5.5			
Arsenic (As)				6			
Copper (Cu)	**11.6**	**14.9**	**13.2**	161.4	98	40	14
Iron (Fe)				42	15		27
Lead (Pb)						11.5	42
Manganese (Mn)						2	
Silicon (Si)					3	4	
Tin (Sn)				89.5	15		5.8
Tellurium (Te)					5	14	3.7
Zinc (Zn)				20.8			

Impurities lead to poor finish and higher rejection

Chemical method if not controlled will add impurities to the Metal

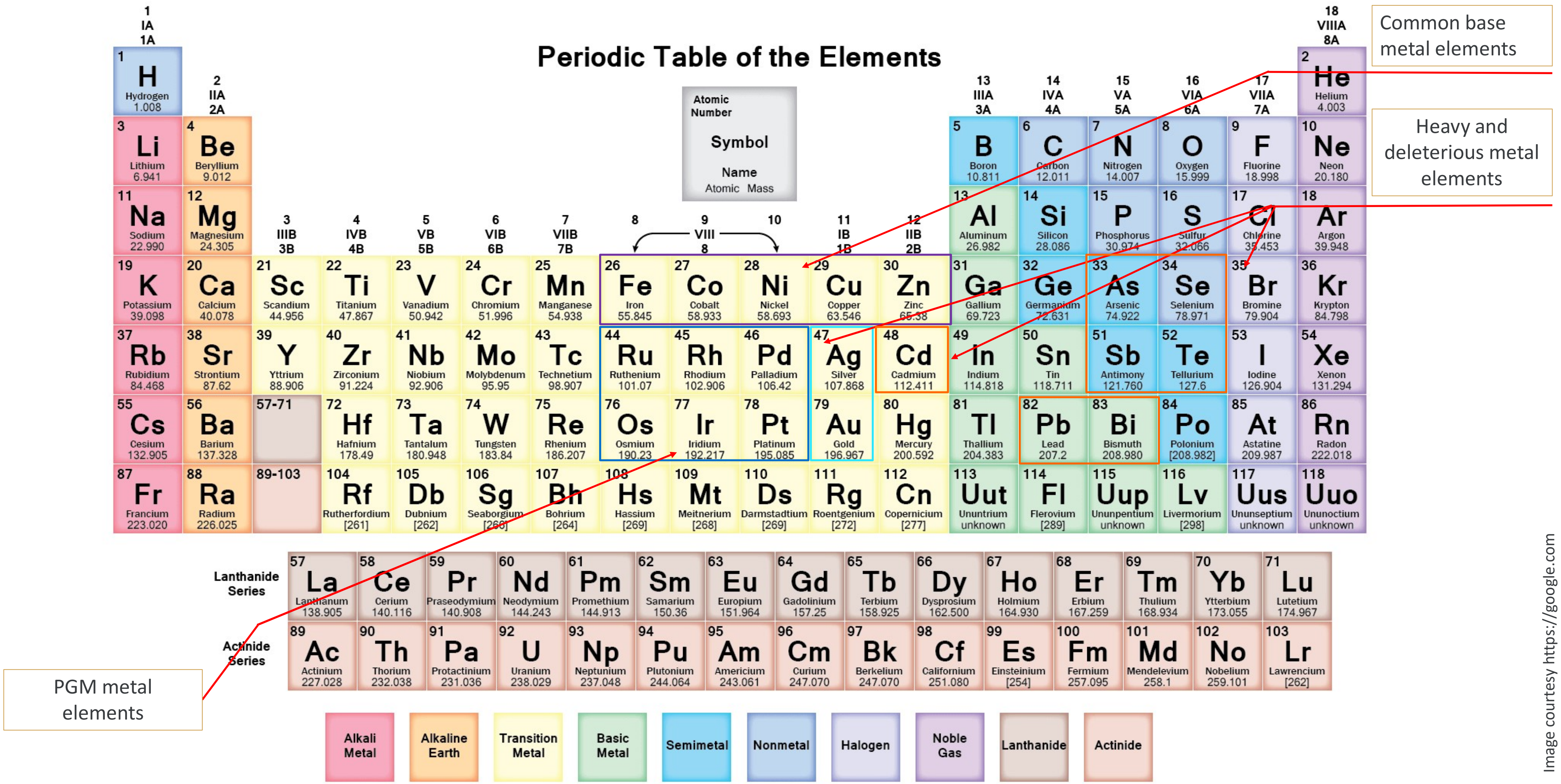


Image courtesy https://google.com

Effects of Base metal and PGM impurities in various stages of refining

Sr No	BM/PGM	Melting	Chemical/Electrochemical refining	Ecology	ASTMASTM Limits in PPM for 999.9 fine Au	Bullion
1	Silver	No effect in melting process	When in excess causes passivation of anodes/popcorns arresting the reaction.	No notable effect	90	Sulfur tarnishing , bleaches only low caratage alloys
2	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
3	Aluminium	May oxidize and separate out as dross	May precipitate as its hydroxide and accumulate on cathode if the electrolyte pH is not controlled	Precipitated as its hydroxide during effluent neutralization process	Not Specified	Strong oxide former. Results in brittleness
4	As/Sb	Generates toxic fumes that are captured by jet bag filters which are later on collected carefully and treated for recovery and safe disposal	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

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
5	Copper	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
6	Iron	Iron primarily gets removed as slags from the molten metal, generates a lot precious metal containing metallic slags that are hard to process	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 results in hardness & brittleness in cast products
7	Lead	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
8	Manganese	Has highly reducing effect when present in metallic form.	The oxides formed by the action of acids tend to precipitate and collect along with silver chloride slimes.	May escape in the effluents as permanganate salts	3	May cause stress corrosion in the final product.

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
9	Silicon	When present in large quantities can be slagged out by the addition of borax	May passivate the anodes/popcorns if present in large quantities.	No significant impact	50	Major causative of surface defects in the finished good, promotes cracking.
10	Tin	May separate out as slag when in minor quantities, when present in excess often forms alloys with gold.	Major threat in both chemical as well as electro refining , forms insoluble complexes that co-precipitates/accumulates over the product.	Precipitates and forms sludge batches that are very hard to filter.	10	May cause brittleness of the finished good.
11	Te	Generates a peculiar fume smelling like garlic toxic when inhaled	The traces that makes its way into the electrolyte are tapped out by bleeding the spent solution	The tellurium may reach the base metal sludges. Complete removal of tellurium in final discharge water is difficult	Not Specified	Rarely manifest in final product, if present may lead to embrittlement of the product.
12	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, if present may cause fire cracking of the product.

PRODUCT COMPARISON

Electrolytic refined gold

18 Y Cast tree with gold free from impurities

Chemical refined gold

Poor 18 Y tree casted using locally refined gold with high impurity

Smooth, oxidation free 18 K pink gold strip casted with gold having no impurity

18 K Strip with local gold having oxidized surface finish due to high impurity content

PRODUCT COMPARISON

Electrolytic refined gold

22 K Finished ring having high lustre and finish

Bullion bar

Chemical refined gold

22 K ring from local gold having broken shank due to impurities

Slags on bullion bar with local gold

New Technology – Acidless Separation (ALS)

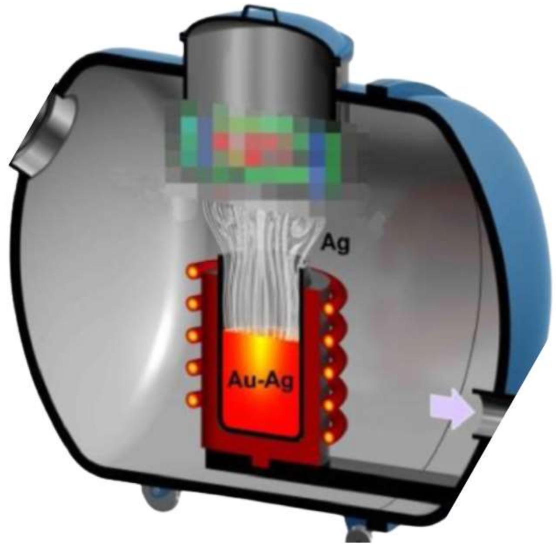
GREEN TECHNOLOGY – No use of Chemicals

LOW OPERATING COST – Very Limited manual operation

SAFE & USER FRIENDLY – Batch Process takes place in an enclosed volume & fully automated

FAST – Compared to other processes residence time of metal is low

SUSTAINABLE – No hazardous material is generated & pollution free



Acidless Separation Machine (ALS)

Consumer Testimonials

“We prefer to use MMTC-PAMP 999 gold only in our jewellery manufacturing . It has remarkable consistency in weight and purity . Due to it electrolytic origin, the gold is impurity free and when used helps us to achieve very low repairs in manufacturing compared to local gold . It is always free from Iron and we could eliminate hard spots by using this gold . On the contrary , all local gold have to be refined first to make it Ir free which adds to the production cost.”

Mr. Priyanshu Gupta , Director ,
Shri Daksh Designer Jewels Pvt Ltd

★★★★★

We at Tanvi prefer to use MMTC-PAMP 999 gold for manufacturing jewllery. MMTC-PAMP gold has amazing consistency in its weight, purity and finish . By using MMTC-PAMP gold which is electrolytically refined defects such as hard spot , colour variation , cracks etc are greatly reduced . Our productivity improves significantly when we use MMTC-PAMP 999 gold.

Mr. Bipin Viradiya , Founder and Chairman ,
Tanvi Goldcast

“We prefer to use MMTC-PAMP 999 gold only for our jewllery manufacturing . The product has remarkable consistency in weight and purity . By using this gold , we get less defects and higher productivity compared to locally refined gold .”

Mr. Amit Korat, Partner
Design Creation, Surat

★★★★★

“The gold refined from local market turns black when they melt it to make ingot while MMTC-PAMP gold is shiny. MMTC-PAMP gold is soft as mainly silver is used instead of copper and there is no problem of cracking. The gold is also higher in purity and weight.”

Mr. Ravi Khandelwal
Gold Wholesaler

★★★★★

Research team

- **Conceptualization of the paper**
- Ankur Goyal : Metallurgist
- Debasish Bhattacharjee : Metallurgist
- Praveen Kumar – Chemical Engineer
- Vishal Jodhani - Metallurgist

THANK YOU

An MKS PAMP GROUP Company