Alternative Metals Study
Phase II

Technical Report

2014 Biennial Report to the Congress

United States Mint

Department of the Treasury

FINAL

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I. Executive Summary

The Coin Modernization, Oversight, and Continuity Act of 2010, Public Law 111-302 (CMOCA) authorizes the Secretary of the Treasury to conduct research and development on "possible new metallic materials or technologies for the production of circulating coins." CMOCA also specifies that before the second anniversary of its enactment, and biennially thereafter, the Secretary of the Treasury shall submit a report to Congress, analyzing production costs for each circulating coin, cost trends for such production, and possible new metallic materials or technologies for the production of circulating coins.

After Phase I concluded in December 2012, the United States Mint (Mint) delivered the first biennial report to Congress, and then continued its research into alternative metals, rejecting some of the materials recommended in that report, and identified six materials that would form the major effort for continued testing in Phase II. Beyond those six compositions, however, the Mint continued to consider and evaluate other, potential, alternative materials.

For Phase II testing, the following materials were evaluated:

	Material	Composition	Tested On
1	Copper-plated zinc (CPZ)	Copper plated on zinc (identical to current one-cent)	Five-cent
2	Tin-plated CPZ (TPCPZ)	Tin plated on copper plated on zinc	Five-cent
3	Nickel-plated steel (NPS)	Nickel plated on low-carbon steel	Five-cent Quarter-dollar*
4	Multi-ply-plated steel (MPPS)	Nickel plated on copper plated on nickel plated on low-carbon steel	Five-cent Quarter-dollar
5	Stainless steel	Austenitic (non-ferromagnetic) stainless steel, monolithic	Five-cent
6	80/20 cupronickel (80/20)	80% copper, 20% nickel, monolithic	Five-cent**

* Materials were tested on the quarter-dollar with the intent of applying those results to the dime and half-dollar.

** 80/20 was only tested on the five-cent but was expected to be clad to copper for higher denominations if it passed.

The Mint chose the top five listed as "co-circulate" materials, meaning the Mint recognized that the material would not have the same electromagnetic signature (EMS) or piece weight as the material of same-denomination coins that are currently in circulation (current material). The Mint chose 80/20 as a "seamless" material, meaning the Mint expected the material to match the current material's EMS and weight, and have no appreciable impact on the coin-accepting industry.

The Mint purchased all materials except stainless steel in variability lots, which were laboratory-produced and contained 500–2,000 pieces made to specifications to provide the expected range of material properties in production. The supplier provided multiple configurations, typically modifying the key variable such as plating thickness, to provide the Mint with samples that would span the normal variation to be expected in production material. Those materials that passed the variability lot testing were then purchased in pre-production lots, which were much larger, typically about 2 million pieces. Pre-production lots were produced on the supplier's normal manufacturing lines over separate production runs to evaluate material that would be representative of actual production.

During variability testing, materials were processed through progression strikes to show how varying strike force (in metric tons, or tonnes) would affect the material's detail ("fill") as compared with the current coins. The Mint also put test pieces through a two-week accelerated wear test, a steam test designed to test the material's resistance to color change, and various other tests, such as conductivity, hardness, and EMS. Then, the materials had to pass a Go/No-Go determination on seven criteria.

TPCPZ and CPZ both failed their Go/No-Go determinations because of poor results on the wear test. NPS and MPPS passed their Go/No-Go criteria for both the five-cent and the quarter-dollar and the Mint purchased those materials for pre-production testing. As the Mint had not finalized security requirements of the quarter-dollar at that time, it purchased NPS and MPPS for the quarter-dollar. Stainless steel was the subject of a Feasibility Study at the time, and had not yet reached the Variability stage as the other co-circulate materials had.

The original 80/20 material's EMS did not match the current material. However, a slightly modified version of the 80/20 material, which substituted manganese for some of the nickel to achieve the conductivity and EMS of the current material, showed promise. Accordingly, the Mint procured about 500 pieces of this modified 80/20 to run it through the progression strikes, wear test, and steam test. The Mint also tested the modified 80/20's EMS at three different external coin acceptor manufacturers that all confirmed an EMS match with the current material. The Mint determined that modified 80/20 passed its Go/No-Go criteria and, accordingly, it purchased additional quantities for pre-production testing.

The Mint purchased NPS and MPPS in five-cent and quarter-dollar configurations and the modified 80/20 (from this point on in the Executive Summary, referred to as "80/20") in five-cent configuration for the pre-production testing. Initially, NPS and MPPS proved to have poor striking qualities in the variability testing. However, the Mint consulted with The Royal Mint (RM) and the Royal Canadian Mint (RCM), both of which have experience with these cold-rolled[1], low-carbon, plated-steel materials, and identified various changes to mitigate these issues. In addition, the Mint had to send nonsense dies (some polished to ascertain the effects of die surface preparation on striking) to RM and RCM for physical vapor deposition (PVD) coating to enable dies to withstand the severe abrasion associated with nickel plating on both of these products.

The RM and RCM sent to the Mint quantities of both materials, which showed improvement, but the Mint still had problems with die life and fill. After more interaction with the RM and RCM, the Mint received pre-production lots and conducted full tests on both plated-steel materials. The die life still proved significantly less than with the current material. The Mint determined that noticeable changes to the coin aspects (including adjustment to the height of relief/crown, smoothing design features, softening letters, and less-detailed images in general) would be needed to improve coinability. In addition, planchet profiles and blank lubrication would need optimization. The tests suggest that the plated-steel materials will not surpass or even match the current material in coinability.

The Mint also investigated stainless steel as a co-circulate option, either as a monolithc material for the five-cent, or as a clad material for the dime, quarter-dollar, and half-dollar. The security requirements of the quarter-dollar (and higher denominations) make this easily-counterfeited material unsuitable for those denominations, though it would be feasible for the five-cent. Further testing would be required to determine its feasibility for cladding the dime.

The Mint is still researching other alternatives to the ones already tested in this report. Of note are coins made of a variation on "nickel silver," a material composed of copper, nickel, and zinc that has a silver appearance. The variation, alloy C77000, is expected to yield a coin that has the same EMS as current coins, and (similar to the 80/20 alloy) has a weight that falls into the acceptable variation on current coins. The Mint is partnering with the National

[1] Rolling is a metal process in which metal stock is pressed through one or more pairs of rollers to reduce the thickness of the metal. Cold-rolled indicates that the rolling was at a temperature in which the metal grains do not recrystallize; the absence of recrystallization reduces the material's ability to deform under stress (ductility).

Institute of Standards and Technology (NIST), a bureau of the Department of Commerce, to pursue an alloy development project.

The Mint is also investigating plated coins that use a silicon-steel core, not used elsewhere in the world, that could have a unique EMS. Silicon steel is commonly referred to as "electrical steel" and has a similar price to low-carbon steel.

Tables I-1 and I-2, on pages vii and viii, provide a performance summary of the co-circulate materials in the Down Selection, first for the five-cent, and then for the quarter-dollar.

The charts show that MPPS and NPS have superior durability compared with the current material. However, MPPS and NPS were less coinable than the current material; were not as recyclable; were more vulnerable to counterfeiting and fraud; and MPPS is only available from the RCM, unlike the other candidate materials and the current material, which all have multiple suppliers. This makes NPS and MPPS feasible for the five-cent, but (due to security requirements) not feasible for the quarter-dollar.

External Studies

During the course of Phase II, the Mint contracted Concurrent Technologies Corporation (CTC), which had conducted Phase I of the Alternative Metals Study in 2010–2012, to evaluate the potential use of bi-metallic coin construction for U.S. coins, and to study the feasibility of stainless steel for use in U.S. coins. The Mint also contracted Fraunhofer USA, a company that specializes in applied research for government and industry customers, to research laser-blanking as a production improvement at United States mints.

All three reports are attached to this report, and their executive summaries are in Sections 7 (Bi-Metallic Coins), 8 (Stainless Feasibility), and 9 (Laser-Blanking).

Findings and Conclusions

Two separate types of alternatives were considered during Phase II testing/evaluation. The first was a material with an EMS and piece weight that was potentially seamless with the current material. The second were co-circulate alternatives in which the EMS differed from the current material and the piece weight would vary from the current material by 4 percent or more.

Potentially seamless alternatives would not require changes to the coin acceptors, but would only offer modest annual savings (approximately 3 percent). Co-circulate alternatives provide much greater annual savings (up to approximately 20 percent), but would require significant stakeholder conversion costs to accommodate the different EMS and piece weight.

- Potentially seamless alternative evaluated: 80/20
- Co-circulate alternatives evaluated: Nickel-plated steel (NPS)
Multi-ply-plated steel (MPPS)
Stainless steel
Copper-plated zinc (CPZ)
Tin-plated CPZ (TPCPZ)

Seamless Material

1. A variant of today's current cupronickel composition, termed 80/20, which has a lower nickel content with higher manganese, was found to be seamless when tested by three separate coin-acceptor manufacturers.[2] The Mint estimated this material would provide approximately $5.25M annual savings ($3.2M for the five-cent, $0.8M for the dime, $1.25M for the quarter-dollar) with no impact on the public or on stakeholders.

2. 80/20 matches the current material in both EMS and in piece weight, having a weight that falls within legally accepted variances for the current material.

3. Initial testing of other, potentially seamless, leaner-copper alternatives shows potential for further incremental material savings.

[2] In testing, treated 80/20 five-cent pieces were 100% accepted by all three coin-acceptor manufacturers.

Co-Circulate Materials

4. Plated-steel materials are a viable option for the five-cent and potentially the dime, and offer up to approximately $29M in savings annually over current materials. However, plated-steel materials have increased risks of fraud and counterfeit, and are used in low-value foreign coins, all of which make the materials not feasible for use in the quarter-dollar. They also have a significantly lower die life, which, if not mitigated (see #6, below), could increase production and labor costs, and reduce the savings the materials might offer.

5. Stainless steel, while resistant to corrosion, has a hardness that can negatively impact its coinability. Control of cold-rolling reduction and proper annealing of the right grades demonstrated the ability to mitigate this factor, and improves the coinability of stainless steel. (See attached Stainless Feasibility Study and its Executive Summary in Section 8.)

Production Improvement

6. The Mint explored options of adjusting the height of the relief and crown on the current coin design to address unacceptable fill on some materials. However, this change introduced other issues, such as outer elements (e.g., the border) filling before inner ones, or the flow of the material changing. It became clear that changes to the coin features—including adjustments to the height of relief/crown, planchet profile, smoothing of design, softening of the letters, and less-detailed images in general—must be treated as a collective system. This system involves not only the items mentioned here, but also matching planchet-die geometry, strike force, die lubrication/coating/polishing, and other variables.

Terminated Materials

7. Testing of plated zinc alternatives (copper-plated zinc (CPZ) and tin-plated copper-plated zinc (TPCPZ)) showed insufficient wear and durability properties for consideration on denominations other than the current one-cent CPZ application. Additionally, TPCPZ exhibited galvanic corrosion when copper and tin, two dissimilar metals, were exposed to the environment during wear, rendering this construction unsuitable for any U.S. coins.

Table I-1. Five-Cent Down-Select Summary

5-Cent Down-Select Summary				
Factor	**Description**	**Material Composition & Unit Cost**		
		NPS	**MPPS**	**Stainless 3XX**
	Current Unit Cost $0.0787 (FY14 Unit Costs through March 2014)	**$ 0.0611**	**$ 0.0550**	**$ 0.0583**
Environmental Impact	No change or better compared to current for internal operations and external fabricator	Comparable or Better	Comparable or Better	Comparable or Better
Supply Chain	There is future availability of the metal and a competitive supply chain - more than one fabricator/supplier	Comparable or Better	Less than Current	**TBD**
Coinability	Crack/piece-out incidences are less than or equal to our current, die life is acceptable	Less than Current	Less than Current	**TBD**
Recyclability	Ease of recycling and value of metal recovery	Less than Current	Less than Current	Comparable or Better
Durability	Tarnish and corrosion resistance; acceptable durability/wear	Comparable or Better	Comparable or Better	Comparable or Better
Counterfeit/Slug Vulnerability	Uniqueness among world coins, limited use of lesser value foreign coins, tokens or easily produced counterfeit devices	Less than Current	Less than Current	Less than Current
Applicability for U.S. Circulating Coinage		**Feasible**	**Feasible**	**TBD**

Table I-2. Quarter-Dollar Down-Select Summary

Quarter-Dollar Down-Select Summary			
Factor	Description	Material Composition & Unit Cost	
		NPS	MPPS
	Current Unit Cost $0.0912 (FY14 Unit Costs through March 2014)	$ 0.0676	$ 0.0651
Environmental Impact	No change or better compared to current for internal operations and external fabricator	Comparable or Better	Comparable or Better
Supply Chain	Future availability of the metal and a competitive supply chain - more than one fabricator/supplier	Comparable or Better	Less than Current
Coinability	Crack/piece-out incidences are less than or equal to our current, die life is acceptable	Less than Current	Less than Current
Recyclability	Ease of recycling and value of metal recovery	Less than Current	Less than Current
Durability	Tarnish and corrosion resistance; acceptable durability/wear	Comparable or Better	Comparable or Better
Counterfeit/Slug Vulnerability	Uniqueness among world coins, limited use of lesser value foreign coins, tokens or easily produced counterfeit devices	Less than Current	Less than Current
Applicability for U.S. Circulating Coinage		**Not Feasible**	**Not Feasible**

Technical Recommendations for Further Study

1. Continue 80/20 Testing and Evaluation
    a. Continue larger-scale testing of 80/20 and develop a final specification that can be utilized by current and other strip suppliers.
    b. Conduct feasibility, variability, and pre-production testing on cladding 80/20 to a copper core as an alternative for the clad denominations of dime, quarter-dollar, and half-dollar. The primary benefit of this is the streamlining of the material production.
2. Pursue seamless alloy development

    Continue alloy development of other, potentially seamless, leaner-copper alternatives to provide opportunity for additional incremental materials savings without impacting coin acceptors and coin processors. Initial testing indicates further opportunity for incremental material cost reductions with a composition evolving over several progressive steps.
3. Continue stainless steel R&D
    a. Continue larger-scale variability and pre-production testing on the two stainless steel grades identified in the attached Stainless Feasibility Study: Rittenhouse 52 and 18-9LW.
    b. Conduct testing and evaluation of monolithic stainless steel as a clad outer layer as a co-circulate material. Engineering calculations indicate this combination could exhibit a similar EMS to the current clad coins and enable the copper core thickness to be reduced, providing incremental material savings and a reduction in the use of the more-expensive and price-volatile nickel. Its piece weight, however, would be lighter.
4. Explore production improvements
    a. Investigate push-back blanking and determine if that is a technically feasible and cost-effective production method that would enable elimination of internal annealing on strip material (see attached Laser-Blanking Study).
    b. Pursue more-structured test strikes on different coin materials, modified design aspects, and upset profile configurations to increase the Mint's understanding of the overall coin manufacturing system. These results can be utilized to improve production efficiencies on current coin materials and provide for quicker evaluation of future materials. Results from structured trials can be used to support predictive model development and reduce the need for time-consuming iterative test strikes.

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1. Introduction

The United States Mint (Mint) is a bureau of the United States Department of the Treasury. Established in 1792, the Mint is the world's largest coin manufacturer. The principal mission of the Mint is to mint and issue circulating coins in amounts that the Secretary of the Treasury decides are necessary to meet the needs of the United States. Current coins in circulation are the one-cent, five-cent, dime, quarter-dollar, half-dollar, and dollar. The half-dollar and dollar are not currently in production for circulation, though the coins remain legal tender.

The Mint is a self-funded agency that issues circulating coins to the Federal Reserve Banks at face value and distributes numismatic products—including collectible coins and sets, bullion coins, medals, and related accessories—at prices established to fully recover their costs.

1.1. Background

Prior to 1965, the four higher denomination coins (dime, quarter-dollar, half-dollar, and dollar) were made of a 90% silver-10% copper (Ag-10%Cu) alloy; the five-cent has been a monolithic[3] copper-nickel (Cu-25%Ni) alloy (also known as "cupronickel") since 1866 (except for a brief change to the composition during World War II).

In 1965, in response to dwindling supplies of silver in the U.S. Treasury, Congress passed legislation that required the Mint to replace silver coins with coins made of the five-cent's cupronickel alloy that was clad to a commercially pure (99.9%) copper core. The Mint recommended these two materials and their relative thickness in the clad formulation because this configuration provided electromagnetic properties that matched current coins in coin acceptors at that time. The weight of the coins was slightly different, but the new coins' lighter piece weight had no appreciable effect on their use in vending.

The one-cent was made of a copper-zinc (Cu-5%Zn) alloy before it was changed to a copper-plated zinc core in 1982, in response to the rising price of copper. Since 1983, the one-cent

[3] Metals are mixed together and are inseparable without smelting.

has been composed of a zinc-copper (Zn-0.8%Cu) alloy core, electroplated with 8 microns[4] (8μm) of pure copper.

In 2006 and 2007, the prices of nickel and copper both rose high enough to make the one-cent and five-cent cost more than their face values. Because of this, since 2007, the United States Mint has maintained regulations, approved by the Secretary of the Treasury under 31 U.S.C. § 5111(d), prohibiting the melting, exportation or treatment of one-cent and five-cent coins.

1.2. Public Law

On November 30, 2010, the U. S. Congress passed Public Law 111-302, the Coin Modernization, Oversight, and Continuity Act of 2010 (CMOCA), which authorized the Mint to research and develop alternative metals for U.S. coins. The President subsequently approved this legislation on December 14, 2010. The intent of CMOCA is to reduce the expense of minting coins while still keeping them secure from fraud and counterfeiting. The act also specifies that, in recommending new metals, the Secretary of the Treasury must consider their impact on the public and stakeholders (vending machine and other coin acceptor manufacturers, vending machine owners and operators, transit officials, municipal parking officials, depository institutions, coin and currency handlers, armored-car operators, car wash operators, laundromats, and American-owned manufacturers of commercial coin-processing equipment). A copy of CMOCA can be found in Section 1.9 of this report.

1.3. Costs

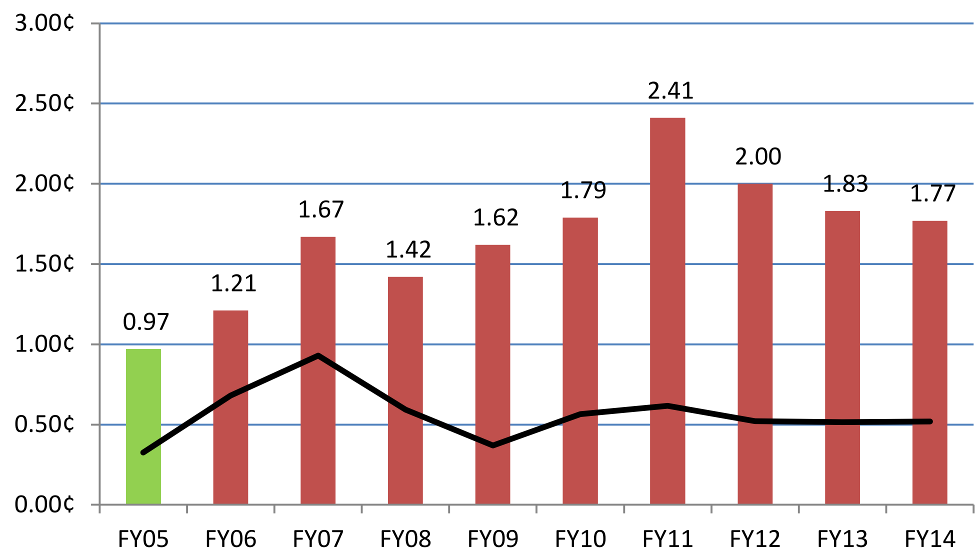
Since 2006, both the one-cent and five-cent have cost more to produce than their face value, as shown in Figures 1-1 and 1-2, below. Rising costs of raw materials (shown as the black line in Figures 1-1 and 1-2) have combined with rising fabrication[5] costs to contribute to that imbalance. Conversely, the dime and the quarter-dollar cost less than half their face value to produce as of March 2014, though the costs of their raw materials (cupronickel clad to copper) have also risen. Two reasons these coins' costs are not yet above face value are their

[4] One one-millionth of a meter, or one-thousandth of a millimeter; also called a micrometer; 1μm is roughly equivalent to 0.00003937 inches; for comparison, an average piece of paper is 75μm thick.

[5] Fabrication is the process by which the material is produced by the supplier and may include plating, cladding, and/or alloying, and can also include the cost of rolling.

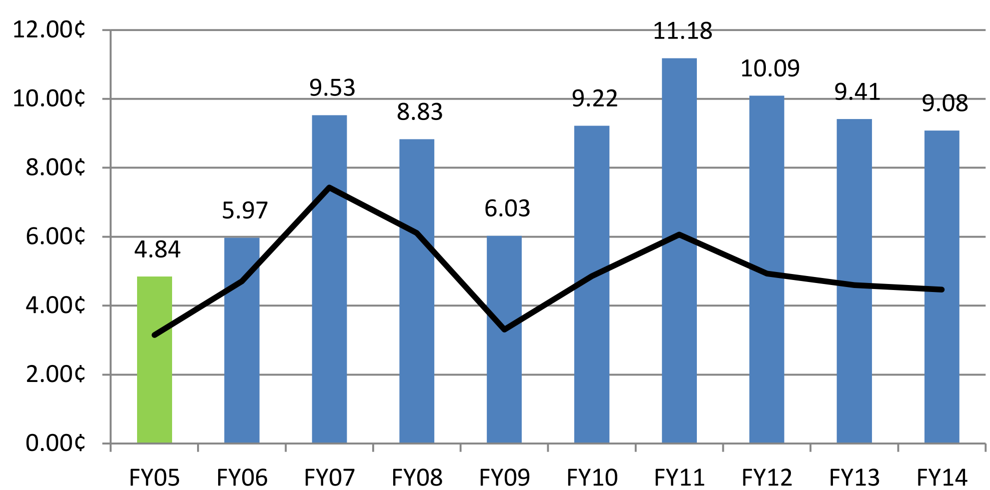
relative size vs. face value and the fact that the majority of the coins' material (two-thirds) is the lower-cost copper core.

Figure 1-1. Historical Unit Cost of the One-Cent



General and Administrative costs were not figured into the one-cent's cost until 2011.
Raw metal costs are the black line; FY14 costs are through March 2014.

Figure 1-2. Historical Unit Cost of the Five-Cent



Raw metal costs are the black line; FY14 costs are through March 2014.

The costs of the one-cent and five-cent coins include more than just the material cost because the Mint does not manufacture materials, but buys them either in rolls of metal strip or as ready-to-strike planchets.

When the material is received in strip form, the Mint first punches out "blanks," or coin-sized discs from the sheet. These blanks are then sent through a furnace in a process called "annealing," which softens the material. After this, blanks are cleaned before the "upsetting" step, which raises the edges of the blank. At this point, the blank is called a "planchet" and is ready to be struck into a coin. All of these steps cost the Mint resources (electricity, water, and tools), time, and money (wages, supplies, etc.).

When the material arrives in planchet form, the supplier has handled all those previous steps, and all that remains for the Mint is to strike the planchets into coins (as is the case with the one-cent). In this case, supplier fabrication costs tend to be slightly higher than coins made from strip, as they include labor and other costs of fabrication to deliver the material in ready-to-strike form.

Mint production costs reflect the amount of work the Mint does to produce each coin; the least amount of work is performed on the one-cent planchets which are received ready to strike (stamp, count, and package). The five-cent, dime, and quarter-dollar all have to be blanked, annealed, cleaned, and upset before they can be struck into coins, and their direct Mint production costs per coin are correspondingly higher, per unit.

In all cases, though, plant overhead costs (heating, electricity, etc.) must be considered. All of these costs add up to what is known as the Cost of Goods Sold (COGS).

Table 1-1. FY2014[6] Unit Cost of Producing and Distributing Coins, by Denomination

	One-Cent	Five-Cent	Dime	Quarter-Dollar
Metal Cost	0.96	4.97	2.39	5.83
Mint Production	0.54	1.51	0.99	1.72
Cost of Goods Sold	***1.50***	***6.48***	***3.38***	***7.55***
General and Administrative	0.28	1.34	0.65	1.46
Distribution to FRB	0.02	0.05	0.04	0.11
Total Unit Cost	**1.80**	**7.87**	**4.07**	**9.12**

Costs are shown in cents.

In addition to the COGS, the Mint incurs costs in simply running the day-to-day operations of Mint offices in support of the coin-making process (general and administrative costs).

[6] Unit costs are FY2014 YTD through March 2014

Finally, the cost of distributing sold coins to the Federal Reserve Banks (FRBs) is also the Mint's responsibility.

1.4. Summary of Phase I

In July 2011, the Mint awarded Concurrent Technologies Corporation (CTC) a competitively bid contract to investigate various alternative compositions for all U.S. circulating coins. The half-dollar, dime, and quarter-dollar all have identical compositions, and of those three denominations, only quarter-dollar nonsense pieces were struck. In addition, testing was performed on the one-cent and five-cent.

1.4.1. Alternative Metals Considered but Eliminated

In determining what materials are suitable for replacing the current ones, the study considered many factors, including:

- U.S. industrial base ability to supply material
- Material availability, now and in the future
- Process consistency at mints and metal producers
- Process capabilities and current capitalization at Mint facilities
- Material prices
- Material price trends
- Available fabrication methods
- Fabrication costs
- Coin die life
- Electromagnetic signature (EMS)
- Wear resistance
- Corrosion resistance
- Color and circulation-based color change
- Coinability (i.e., low flow stress, adequate ductility)[7]
- Work hardening[8]
- Density
- Environmental impact
- Toxicity
- Worker health and safety
- Recyclability
- Construction (plated vs. clad vs. monolithic)
- Security (i.e., counterfeit and fraud resistance)
- Coin-processing equipment (hardware and software)
- Blind and visually-impaired recognition and acceptance
- General public recognition and acceptance
- Co-circulation of current and new coins.

[7] Flow stress is a measure of the force required to permanently deform a metal during forming operations. Ductility is a metal's ability to be worked without cracking, shattering or breaking.

[8] Work hardening is a material response in which the strength of metallic minerals increases due to permanent deformation.

Consideration of all these issues makes the design and selection of a coinage material and the associated production methods a complex, challenging task.

The periodic table contains 91 metals within it (out of 118 total elements). Very early in the project, CTC rejected the majority of those metals from consideration as an alternative coin material for a variety of reasons. The most common reasons were the metal's radioactivity (uranium, plutonium, and thorium) or toxicity (lead, cadmium, and chromium). Of the remaining metals, CTC rejected most for their softness, potentially negative environmental impacts, and/or negative health and safety impacts.

This early review then resulted in CTC eliminating even more potential metals, primarily for high cost, as shown in Table 1-2.

Table 1-2. Eliminated Candidate Metals for Coinage

Element	Element Symbol	Reasons for Elimination
Beryllium	Be	Too expensive; toxic
Bismuth	Bi	Too expensive; multi-colored oxidation
Cobalt	Co	Too expensive; toxic if ingested
Molybdenum	Mo	Too expensive; health issues when metalworking
Niobium	Nb	Too expensive
Tantalum	Ta	Too expensive; rare
Titanium	Ti	Too expensive
Vanadium	V	Too expensive; environmental issues
Tungsten	W	Too expensive; too hard
Zirconium	Zr	Too expensive
Silver	Ag	Too expensive*
Gold	Au	Too expensive*

* - Ag and Au are used for commemorative coins and for bullion.

CTC then considered the London Metal Exchange, other sources of metal prices, and global metal supplies to determine the best possible candidate metals and alloys from those metals that remained (iron, aluminum, zinc, tin, manganese, etc.). They determined steel, zinc, and aluminum alloys to be the leading candidates to reduce the cost of coinage by replacing nickel and copper, either partially or wholly.

In this process, CTC selected candidate metals for each circulating denomination. Low cost was the clear driver for the one-cent. Security and ease of transition were minor concerns because that denomination is not typically used in vending machines or in other, non-attended, automated points of sale. For all other denominations, two general categories identified the metals and fabrication concepts: potential for seamless transition, with modest cost savings; and potential for non-seamless co-circulation, with significant cost savings.

The candidates for seamless transition had a similar electromagnetic signature (EMS) as the current coins, so disruption of or cost to the vending and coin-processing industries would be minimal. Those candidate materials for the non-seamless transition did not match the EMS of the current materials, but were designed to have an identifiable, unique EMS of their own, whenever possible. This was to prevent fraudulent coins from being easily produced from readily-available metals with an EMS like the new material. The introduction of non-seamless EMS coins would also result in higher conversion costs incurred by the vending industry and other stakeholders to accommodate co-circulation. Those impacts were discussed extensively in Chapter Four of the CTC Final Report.

1.4.2. Alternatives to Production

In addition to the alternative metals, CTC investigated alternatives to the production methods used by the Mint. They found that the Mint's production techniques have been substantially the same for the last 75 years, and, through continuous improvement, remain quite efficient. Although newer processes exist for producing volumes of small parts (such as plastic injection molding), there are no proven ways to more economically produce the quantity and quality of metal stampings such as those produced by the Mint at this time. All other mints in the world use variants of the United States Mint's processes in making their own coins, and the Mint remains the world's largest producer of coined products. With respect to production methods and processes, CTC recommended no major changes to production, and for the Mint to continue to focus on improvement.

As a result, CTC determined that significant production or equipment changes did not need to be considered as part of the proposed action. Instead, they focused on cost-saving changes to the composition of the coins themselves, with any subsequent changes to production dependent on the materials selected (such as eliminating blanking, annealing, washing, and upsetting).

1.4.3. Proposed Action

Based on the testing and research performed in this phase (Phase I) of the Alternative Metals Study, CTC found that there was no more-cost-effective alternative material for the one-cent, and thus recommended that it remain unchanged.

In addressing the seamless[9] alternative options, CTC recommended that the composition of the five-cent be replaced with one of three copper-based options: 669z, G6, or unplated 31157, or a broader material specification that focused on EMS and had broader ranges of compositions to enable more flexibility in sourcing. They also included a recommendation to complete additional testing on 669z-clad C110 copper for use in the dime, quarter-dollar, and half-dollar for seamless transition.

Regarding co-circulation options, CTC found that stainless steel provided a low-cost, silver-white choice for the 5 cent that does not require further treatment for corrosion protection. But while ferritic stainless has a lower material cost, it requires higher striking loads (which can lead to shorter die life) and is ferromagnetic (is attracted to magnets), which is not suitable for most coin-processing sensors. Austenitic stainless is a better candidate as it requires lower striking loads and is not ferromagnetic.

Stainless steel options, however, have lower security, given the relatively cheaper material available. For austenitic stainless steels, their common EMS and conductivity readings do not vary much by grade, and so, are prone to fraud. For ferritic stainless steels, their inconsistent EMS associated with ferritic stainless makes them less secure and the acceptor windows have to be widened to accommodate the variation.

The following tables, 1-3 and 1-4, list the materials identified as potential replacements for all circulating denominations except for the one-cent. CTC recommended that further testing and evaluation be conducted on these materials, which formed the basis for Phase II of the Alternative Metals Study.

[9] In Phase I, "seamless" meant a material with an EMS that matched the current coin's EMS, to allow the new coin to be used in vending machines without changes to the coin acceptor. Diameter and thickness remained unchanged and weight was not a consideration.

Table 1-3. CTC-Recommended Five-Cent Alternatives

Candidate	Composition and Notes
Multi-ply-plated steel	10µm Ni plated on 23µm Cu plated on 4µm Ni plated on low-carbon steel core; provided in planchet form
TPCPZ-plated zinc	3µm Sn plated on 7µm Cu plated on Zn core; provided in planchet form
669z	Cu-10%Zn-5%Ni-10%Mn[10]; lower nickel content than current material; provided in sheet form
G6 mod	Cu-22%Zn-10%Ni-2%Mn; lower nickel content than current material; provided in sheet form
Unplated 31157	Cu-31%Zn-0.5%Ni-6.5%Mn; low-nickel content; provided in planchet form
Stainless steel	Stainless steel; provided in sheet form
Nickel-plated steel	25µm Ni plated on low-carbon steel; provided in planchet form

Sn=tin, Zn=zinc, Mn=manganese

Table 1-4. CTC-Recommended Dime, Quarter-Dollar, and Half-Dollar Alternatives

Candidate	Composition and Notes
Multi-Ply-plated steel	10µm Ni plated on 23µm Cu plated on 4µm Ni plated on low-carbon steel core; provided in planchet form
TPCPZ-plated zinc	5µm Sn plated on 12µm Cu plated on Zn core; provided in planchet form
TPCPZ-plated zinc	7.7µm Sn plated on 12.7µm Cu plated on Zn core; provided in planchet form
TPCPZ-plated zinc	10.2µm Sn plated on 11.2µm Cu plated on Zn core; provided in planchet form
669z-clad C110	Cu-10%Zn-5%Ni-10%Mn cladding; lower nickel content than current cladding; provided in sheet form
G6-mod-clad C110	Cu-22%Zn-10%Ni-2%Mn clad to copper (C110) core; provided in sheet form
Unplated 31157-clad C110	Cu-31%Zn-0.5%Ni-6.5%Mn clad to copper (C110) core; provided in planchet form
302HQ	Stainless steel; glued to copper as "clad" material for limited testing
Nickel-plated steel	25µm Ni plated on low-carbon steel; provided in planchet form

[10] Throughout this report, chemical element percentages are in weight percent; the balance of the composition is the first element listed.

1.5. Phase II

1.5.1. Introduction

In Phase II of the Mint's Alternative Metals Study, the Mint tested five-cent and quarter-dollar alternatives. The dime, quarter-dollar, and half-dollar have an identical composition. The Mint determined that testing of either the dime or the quarter-dollar could be extrapolated to the other (the half-dollar could also be extrapolated), so the Mint only struck quarter-dollar nonsense test pieces in addition to the five-cent pieces in Phase II. The dollar coin was not addressed in Phase II.

The Mint concentrated its efforts on six materials:

- Copper-plated zinc (**CPZ**)
- Multi-ply-plated steel (**MPPS**)
- Nickel-plated steel (**NPS**)
- Stainless steel
- Tin-plated CPZ (**TPCPZ**)
- Cupronickel (**80/20**)[11]

CTC's recommended "potentially seamless" materials (G6 mod, 669z, and 31157) had a distinctly yellow cast to them and did not have significant cost savings, so the Mint rejected those for further consideration. Instead, it chose to pursue a cupronickel alloy similar to that used in the current five-cent, dime, quarter-dollar, and half-dollar (75/25)[12], but with slightly less nickel (80/20), to provide higher cost savings with no discernible color change.

The Mint considered CPZ and monolithic stainless, but only for use in the five-cent. The other compositions were intended for potential use in the five-cent and the quarter-dollar (along with the dime and half-dollar). Out of all the materials tested in Phase II, only the 80/20 alloy was a potentially seamless alternative to the current materials.

1.5.2. Objective

Section 2(a)(1) of Public Law 111-302 authorizes the Secretary of the Treasury to "conduct any appropriate testing of appropriate coinage metallic materials within or outside of the Department of the Treasury." The Mint designed the Alternative Metals Study with several

[11] While the composition is not exactly 80% copper and 20% nickel, this is an approximation and is used as the material's term.

[12] Composition is 75% copper, 25% nickel.

goals in mind. In Phase II of that Study, the Mint's primary goal was to conduct larger scale testing and evaluation of the materials identified in Phase I, using the quantitative measures developed to define the ability of identified alternative material candidates to meet the requirements of coinage production and circulation. Ultimately, the Mint's goal is to compare the performance of alternative material candidates with known characteristics and properties of current coinage materials to determine suitable replacements for those current materials.

1.5.3. Testing

The Mint tested the candidate materials in two groups during Phase II. The first group, the "variability" lots, was a laboratory-produced, limited run intended to identify any shortcomings in the materials and establish the variation expected in EMS before the larger "pre-production" lots were run. The Mint purchased these "variability lots" of the selected material in quantities at the minimum, nominal, and maximum of the supplier's production control band. During the variability testing, the Mint struck 500 pieces, minimum, for each metal; this was not enough to determine die life or modes of failure, but it was more than sufficient to determine wear, steam corrosion, external EMS characteristics, hardness, conductivity, and coin-sorting/verification (CSV)[13] results.

Later, in the pre-production testing, the Mint tested multiple die pairs for each candidate, and ran those either until die failure, or when a die pair reached 500,000 strikes, whichever came first. The purpose of the pre-production stage was to determine the materials' production viability and provide a relative indication of expected die life, not a statistical die-life projection. To estimate actual die life would require many more test runs. The Mint chose 500,000 strikes per die pair—as that is considered a representative die life for the five-cent and quarter-dollar denominations currently minted—and four die pairs, so as to not pose an undue burden from a testing productivity perspective. Extended runs were conducted on the current material with nonsense dies to validate the baseline of 500,000 strikes.

Table 1-5, below, depicts current-material, five-cent, die-life performance in Philadelphia and supports the targeted level of 500,000 strikes as reasonable, although actual performance averages vary.

[13] CSV machines test many variables of coins that pass through their sensors, including ferromagnetism, permeability, EMS, diameter, and thickness. CSVs are common in the vending-machine industry.

Table 1-5. Average Die-Life Performance (Five-Cent) – Philadelphia

	CY2011	CY2012	CY2013	CY2014TD
Obverse	521	435	537	527-704
Reverse	490	577	488	560-755

Die life is shown in thousands of strikes per die.

Table 1-6, below, shows die-life performance for the quarter-dollar in Philadelphia and supports the targeted level of 500,000 strikes as reasonable.

Table 1-6. Average Die-Life Performance (Quarter-Dollar) – Philadelphia

	CY2011	CY2012	CY2013	CY2014TD
Obverse	503	431	640	481
Reverse	497	413	647	470

Die life is shown in thousands of strikes per die.

There is more variability in quarter-dollar die life than in the five-cent's as each year there are five new reverse designs for the America the Beautiful (ATB) series which affects both the reverse and the obverse die life.

1.6. Other Research and Development

In addition to testing and evaluating the metals above, the Mint continued researching and considering additional alternative materials. The Mint performed secondary research with the National Institute of Standards and Technology on another potentially seamless material, C77000, and researched co-circulate alternatives such as zinc-aluminum alloy, silicon steel, and plated steel provided in sheets with an exposed edge. This secondary research was intended to continue the broader search for lower-cost alternatives, and to ensure a more thorough and ongoing approach to the Alternative Metals Study.

C77000

C77000 is a monolithic copper alloy (Cu-27%Zn-18%Ni) that the Mint identified for its lower nickel content compared with the current alloy and for its potentially similar EMS signature, which can make it a seamless candidate. Also known as "nickel silver," C77000 does not exhibit the "yellowing" tendency shown by the other copper-based alloys identified in Phase I, which was another factor in its favor. The Mint will perform more extensive testing on this alloy and on alloys based on it to better characterize its potential.

Plated Steel

The Mint looked at plated steel in sheet form. Steel is much less expensive than any other substrate in Phase II, and the use of plated strip is a more cost-effective coating method than plating planchets. It also has a more uniform layer which would yield more consistent EMS readings. The principal negative is the exposed edge, which would be untreated steel and subject to corrosion.

Silicon Steel

Silicon steel, commonly called "electrical steel," exhibited different electromagnetic signatures from normal or stainless steel during initial testing and the Mint regarded it as a potential alternative to the plain steel core used in the plated materials under consideration (MPPS and NPS). Also, if its corrosion resistance could be improved, it could be considered as a monolithic material in lower-denomination coins.

Zinc-Aluminum

The Mint pursued zinc-aluminum alloys because test pieces made solely of zinc or of aluminum had limitations in Phase I (zinc showed poor corrosion resistance unless coated or plated, and aluminum was very light and presented handling issues), but a combination of the two showed initial promise. However, in testing, the combined material still showed a lack of acceptable corrosion resistance through various metallurgical phases that created areas of acceptable and unacceptable corrosion on the surface. This corrosion tendency could not be controlled with a binary zinc-aluminum alloy.

Nickel-Plated CPZ

The CPZ supplier has recently developed this alternative to its CPZ, and the Mint plans on testing this plated material to see if it will prove to be more durable than the other zinc-based materials.

1.7. Testing Facilities

In 2011, the Mint constructed a highly secure research and development (R&D) facility inside the Philadelphia Mint and isolated from regular circulating production. This facility's security ensures that materials are tested thoroughly on the same type of equipment as that used in production, and then crushed and/or stored under U.S. Mint Police oversight until the materials can be properly (and securely) destroyed and recycled. In this way, test pieces were isolated from normal production material and proper controls were maintained. Later in 2013/2014, the Mint supplemented the production capabilities of the R&D room with a secure diagnostic lab for conducting metallurgical tests and evaluating alternative materials.

1.8. Independent Peer Review

The Mint proactively elected to have an independent, outside authority review the Mint's research methods and processes, testing methods, and data. The Mint subsequently entered into an Interagency Agreement (IA) with the U.S. Department of Energy (DOE), which owns the facilities that house Argonne National Laboratory (Argonne). Under the IA, Argonne was to conduct an independent verification and validation (IV&V) of the Alternative Metals Study, Phase II. In this independent peer review (IPR), Argonne ensured that the Mint's processes, tests, and evaluations were valid and that the findings and conclusions were supportable.

During the course of testing, the Mint provided documentation of all procedures, test data, and analyses to the Argonne IPR team for their input. Argonne responded in timely fashion to all data sent to them over the course of the R&D effort and identified potential gaps and concerns that were satisfactorily answered by the Mint. In every case, Argonne verified and validated the Mint's efforts. In late 2014, Argonne issued their official report. The following page contains its executive summary.

1.8.1. Argonne Report Executive Summary

Argonne National Laboratory provided IV&V services to the US Mint for its Alternative Metals Study – Phase II. Services includes (1) validation of project plans, (2) review testing and evaluation, (3) review down-selection plan, and (4) validation of the US Mint's final recommendations. This report is the final deliverable of IV&V service contract.

Validation of project's plans included an initial on-site visit to the US Mint R&D facilities in Philadelphia. Testing capabilities were reviewed and found to be adequate for performing the planned work. Documentation relating to the experimental work was reviewed and any deficiencies were corrected by the US Mint.

Project performance was reviewed during weekly conference calls, as well as review of US Mint experimental data documentation provided by secure file transfer. Data generated and provided was consistent with expectations. In addition, a second site visit was performed to review and witness on-site testing, including wear testing.

The down-selection plan was reviewed and found to be sound. The testing regimen was sufficient to provide discriminating data amongst the various alternative metal candidates.

The US Mint's final recommendations are documented in its 2014 Biennial Report to Congress. Six alternative metal compositions were evaluated. The findings and recommendations are:

1. Continue the 80/20 alloy testing and evaluation
2. Pursue seamless alloy development
3. Continue stainless steel R&D
4. Explore production improvements

The US Mint also concluded that plated zinc metal alternatives (CPZ and TPCPZ) should be eliminated from further consideration.

IV&V Findings Statement

The US Mint followed established protocols in performing the R&D work. The work plan was sound and addressed the key metal physical and chemical properties. The tests revealed positive and negative aspects of the alternative metals under consideration. The findings, conclusions, and recommendation made by the US Mint are supported by the work performed in this project.

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1.9. Public Law 111-302

Public Law 111–302
111th Congress

An Act

To provide research and development authority for alternative coinage materials to the Secretary of the Treasury, increase congressional oversight over coin production, and ensure the continuity of certain numismatic items.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the ''Coin Modernization, Oversight, and Continuity Act of 2010''.

SEC. 2. AUTHORITY TO CONDUCT RESEARCH AND DEVELOPMENT ON ALL CIRCULATING COINS.

(a) IN GENERAL.—To accomplish the goals of this Act and the requirements of subchapter II of chapter 51 of title 31, United States Code, the Secretary of the Treasury may—

(1) conduct any appropriate testing of appropriate coinage metallic materials within or outside of the Department of the Treasury; and

(2) solicit input from or otherwise work in conjunction with entities within or outside of the Federal Government including independent research facilities or current or potential suppliers of the metallic material used in volume production of circulating coins,

to complete the report referred to in this Act and to develop and evaluate the use of new metallic materials.

(b) FACTORS TO BE CONSIDERED.—In the conduct of research, development, and the solicitation of input or work in conjunction with entities within and outside the Federal Government, and in reporting to the Congress with recommendations, as required by this Act, the Secretary of the Treasury shall consider the following:

(1) Factors relevant to the potential impact of any revisions to the composition of the material used in coin production on the current coinage material suppliers.

(2) Factors relevant to the ease of use and ability to cocirculate of new coinage materials, including the effect on vending machines and commercial coin processing equipment and making certain, to the greatest extent practicable, that any new coins work without interruption in existing coin acceptance equipment without modification.

(3) Such other factors that the Secretary of the Treasury, in consultation with merchants who would be affected by any change in the composition of circulating coins, vending machine and other coin acceptor manufacturers, vending machine owners and operators, transit officials, municipal parking officials, depository institutions, coin and currency handlers, armored-car operators, car wash operators, and American-owned manufacturers of commercial coin processing equipment, considers to be appropriate and in the public interest, after notice and opportunity for comment.

SEC. 3. BIENNIAL REPORT TO THE CONGRESS ON THE CURRENT STATUS OF COIN PRODUCTION COSTS AND ANALYSIS OF ALTERNATIVE CONTENT.

(a) REPORT REQUIRED.—Before the end of the 2-year period beginning on the date of the enactment of this Act, and at 2-year intervals following the end of such period, the Secretary of the Treasury shall submit a report to the Committee on Financial Services of the House of Representatives and the Committee on Banking, Housing, and Urban Affairs of the Senate analyzing production costs for each circulating coin, cost trends for such production, and possible new metallic materials or technologies for the production of circulating coins.

(b) DETAILED RECOMMENDATIONS.—In preparing and submitting the reports required under subsection (a), the Secretary of the Treasury shall include detailed recommendations for any appropriate changes to the metallic content of circulating coins in such a form that the recommendations could be enacted into law as appropriate.

(c) IMPROVED PRODUCTION EFFICIENCY.—In preparing and submitting the reports required under subsection (a), the Secretary of the Treasury shall include recommendations for changes in the methods of producing coins that would further reduce the costs to produce circulating coins, and include notes on the legislative changes that are necessary to achieve such goals.

(d) MINIMIZING CONVERSION COSTS.—In preparing and submitting the reports required under subsection (a), the Secretary of the Treasury, to the greatest extent possible, may not include any recommendation for new specifications for producing a circulating coin that would require any significant change to coin-accepting and coin-handling equipment to accommodate changes to all circulating coins simultaneously.

(e) FRAUD PREVENTION.—The reports required under this section shall make no recommendation for a specification change that would facilitate or allow the use of a coin with a lesser value produced, minted, or issued by another country, or the use of any token or other easily or regularly produced metal device of minimal value, in the place of a circulating coin produced by the Secretary.

(f) RULE OF CONSTRUCTION.—No provision of this Act shall be construed as requiring that additional research and development be conducted for any report under this Act but any such report shall include information on any such research and development during the period covered by the report.

SEC. 4. MEETING DEMAND FOR SILVER AND GOLD NUMISMATIC ITEMS.

Subsections (e) and (i) of section 5112 of title 31, United States Code are each amended by striking ‘‘quantities’’ and inserting ‘‘qualities and quantities that the Secretary determines are’’.

SEC. 5. TECHNICAL CORRECTIONS.

Section 5112(u)(1) of title 31, United States Code is amended—

(1) by striking ‘‘exact duplicates’’ and inserting ‘‘likenesses’’;

(2) by striking subparagraph (C);

(3) by redesignating subparagraphs (D) and (E) as subparagraphs (C) and (D), respectively; and

(4) in subparagraph (A), by striking ‘‘of 3.0 inches’’ and inserting ‘‘determined by the Secretary that is no less than 2.5 inches and no greater than 3.0 inches’’.

SEC. 6. BUDGETARY EFFECT.

The budgetary effects of this Act, for the purpose of complying with the Statutory Pay-As-You-Go Act of 2010, shall be determined by reference to the latest statement titled ‘‘Budgetary Effects of PAYGO Legislation’’ for this Act, submitted for printing in the Congressional Record by the Chairman of the House Budget Committee, provided that such statement has been submitted prior to the vote on passage.

Approved December 14, 2010.

2. Materials

2.1. Introduction

Several alloys the Mint chose to research in Phase II include similar metals. Those metals are nickel, copper, zinc, and steel. Other metals are present in some alloys (such as manganese, aluminum or tin), but in smaller percentages.

2.1.1. Raw Metals

The following are price histories and basic facts on the major raw metals that were a part of Phase II of this study, from most expensive to least.

Nickel

Figure 2-1. Commodity Price History of Nickel, 1999 to 2014[14]

The Mint began using nickel in its coins in 1857, and in 1866, the five-cent gained its 25 percent nickel composition/appearance and its popular moniker, the "nickel." Its silver-white color has made it a popular metal for coining since the 19th century, but its rising price has made many countries replace it with less-expensive iron (steel) alloys in recent years.

[14] USGS information was only available through 2010, so was not used in this section.

Nickel's price of just under $7/lb as of January 2014 was barely one-third that of its peak in 2007 and was about the same as it briefly was in 2004. However, its price in January 2014 was still over three times higher than it was in 1999, and it has seen fluctuations over the last five years that pushed it as high as six times the 1999 price. The five-cent has borne the brunt of this rising price as there is more nickel in that coin (1.20g) than in any other U.S. coin (0.944g in the half-dollar, 0.472g in the quarter-dollar, 0.189g in the dime), because of its construction and size.

Copper

Figure 2-2. Commodity Price History of Copper, 1999 to 2014

Copper has been in use in U.S. coins since the Mint was founded. It is also the most conductive non-precious metal, and is used in electrical, plumbing, and food-service industries, in addition to coining.

Copper's price saw a similar percentage increase up to 2007 as most other metals did, but it started earlier, and had more fluctuations. Copper is quickly rising in industrial use worldwide, and as a result, its price rebounded after the drop in 2008, increasing back to or above its 2007 levels. Copper's price is still relatively low in spite of the percentage increase, barely above $3/lb at the start of 2014. The quarter-dollar contains more copper (5.198g) than any other U.S. coin produced for circulation (3.75g in the five-cent, 2.079g in the dime). Two-thirds of the quarter-dollar's construction is its pure-copper core, and its cladding is 75 percent copper.

Manganese

Manganese is the ninth-most-abundant metal on Earth, and is used mainly in steel production. It has been used in American coins as far back as 1942, when it and silver were added to the five-cent to replace the nickel content and some of the copper content during World War II. It has also been used in the dollar coin since 2000.

Manganese is not traded on the commodities market, but pricing history from 2005 to present is available. This pricing history is based on weekly average sales prices that are averaged out from the multiple companies that have reported their sales figures.

The price of manganese increased to a high of more than $2.30/lb in 2007. In 2008, the price fell to $1.42/lb. Prices fell further in 2009 to $1/lb., and while they have fluctuated over the past five years, at the start of 2014, prices were just over $1/lb.

Zinc

Figure 2-3. Commodity Price History of Zinc, 1999 to 2014

Zinc is the fourth-most-common metal in use (behind iron, aluminum, and copper), and world resources are estimated at 1.9 billion tonnes, with major deposits and several mines in the United States.

Its price graph is quite similar to that of nickel, but at a far smaller scale (nickel reached a peak price over $23/lb vs. barely over $2/lb for zinc). The percentage changes in both zinc and nickel over the last 15 years, however, are remarkably similar. As of January 2014, zinc was trading at just over $0.90/lb.

In spite of increasing demand for zinc, its price has remained relatively stable over the last three years, thanks in large part to increasing production levels, worldwide.

Aluminum

Figure 2-4. Commodity Price History of Aluminum, 1999 to 2014

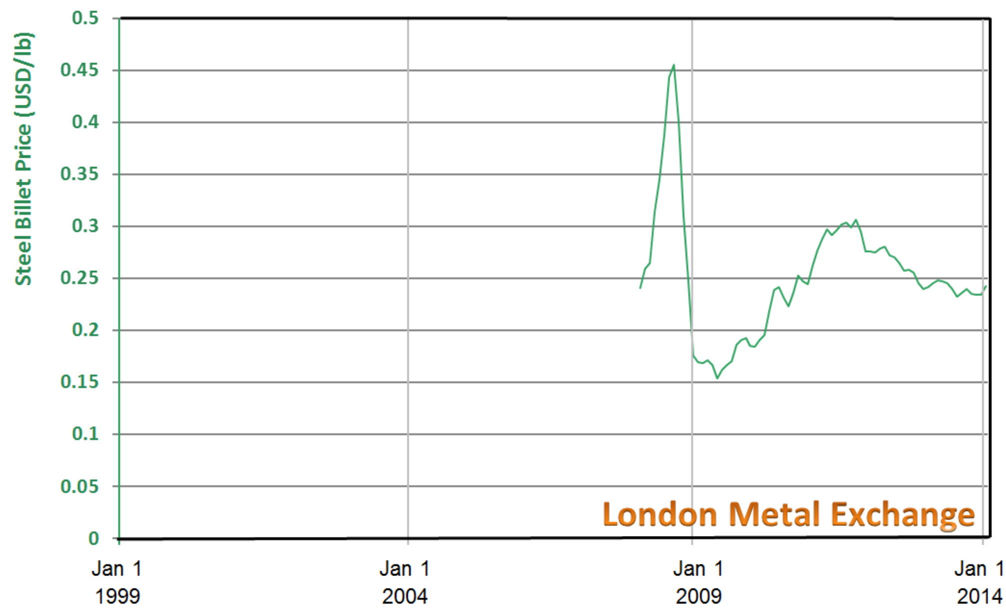
Aluminum is the second-most-abundant metallic element on Earth. Found primarily in the form of bauxite, aluminum is cheaply extracted through the Hall-Héroult Process invented in 1886.

Its price more than doubled between 1999 and 2007, reaching nearly $1.40/lb just before the drop in 2008 took it to $0.60/lb. Prices recovered, peaking at about $1.25/lb in 2011, but as of the start of 2014, its price was just under $0.80/lb.

Aluminum is still in high demand in multiple industries, so its price remains somewhat higher than less-abundant materials, such as steel.

Steel

Figure 2-5. Commodity Price History of Steel Billet, 2008 to 2014



Steel was not openly traded before 2008

Technically an alloy rather than a raw metal, steel is iron mixed with 0.002% to 2.1% carbon. Stainless steel adds more materials for corrosion resistance (including chromium and nickel), and can be ferritic (4XX series, which is drawn to magnets) or austenitic (3XX and 2XX series, not drawn to magnets).

Steel began trading on the London Metal Exchange in 2008 at just under $0.25/lb. After a brief surge in its price to an all-time high of over $0.45/lb, prices fell in 2008 until they hit their low of slightly more than $0.15/lb in May 2009. In the five years since, its price has recovered, but decreasing demand has kept its price relatively low; it was still just over $0.24/lb at the start of 2014.

These are commodity prices for common grades of steel and are provided for illustrating price trends; the steel used in plated-coin materials is a cold-rolled, low-carbon grade and is higher in actual cost than "mild" steel. Stainless steel, with its additional alloying elements, is higher yet in cost per pound.

The supply of each of the raw metals seen in Phase II is both stable and of sufficient supply sources to warrant consideration as use in replacement candidates for current coins.

2.1.2. Other Considerations

Security and fraud prevention play a key role in this study; medium- to high-denomination[15] coins made of inexpensive, easily-accessed metals (or those that also make up washers and other, cheap, coin-sized items) are at a high security risk, as "slugs" can pass for those coins in automated transactions. Plating such coins may not provide enough security from slugging or counterfeiting, as plating facilities, methods, and equipment are plentiful and relatively inexpensive.

Lastly, in reporting to Congress with recommendations on alternative metals, CMOCA requires the Secretary of the Treasury to consider as a factor that, to the greatest extent practicable, any new coins work without interruption in existing coin acceptance equipment without modification, and, to the greatest extent possible, include no recommendation for new specifications for producing circulating coins that would require any significant change to coin-accepting and coin-handling equipment to accommodate changes to all circulating coins simultaneously (Public Law 111-302, Sections 2(b)(2) and 3(d)).

No single (or elemental) metal known, however, can provide a truly seamless interaction with current coins and still provide cost savings. As a result, alloys, plated metals, and clad configurations were the best approach to cost savings while still ensuring a smooth transition.

The candidate materials' density (and therefore the individual piece weight) often varied from the current material, and were usually lighter as heavier alternatives tended to be more costly. The weight variance was difficult to avoid, because in Phase I, CTC recommended the Mint maintain the current physical dimensions (the same diameter and edge thickness), as changing those created a significant impact on shareholders.

CTC further estimated that the costs associated with piece weight changes would be associated predominantly with armored car carriers and bulk coin processors. A weight change would not eliminate a material from technical consideration, but if the candidate material's weight varied too much from the current coin weight, the material would be considered a "co-circulate" option, and not a "seamless" one.

[15] According to the European Vending Association's Handbook (used by mints worldwide as the reference for coins and coin security), "medium" value is approximately 27-68 cents and "high" value is above 68 cents. (See Section 4.)

The Mint chose the Phase II candidate alloys and metals with these considerations in mind, along with availability, sources of proprietary alloys, and key features of the materials, including the material's color and expected durability and recyclability.

2.2. Approach

For all materials in Phase II, the Mint purchased a "variability" lot, and then for all materials except TPCPZ, CPZ, and an 80/20 cupronickel alloy[16], the Mint purchased a "pre-production" lot. Variability lots were lab-produced and small, usually about 500–2,000 pieces of the material. The intent was to provide material that was suitable for characterizing key attributes such as coining, wear, electromagnetic signature (EMS), and corrosion resistance, and to establish the expected composition variation to better characterize the EMS of each alternative material. The pre-production lots were mass-produced and representative of the properties and characteristics that would be seen in actual Mint coining. The Mint processed upwards of approximately 2 million pieces for the material/denomination combinations.

Figure 2-6. Quarter-Dollar Nonsense Test Pieces

For the variability lots, the Mint asked suppliers to give a range of production for the materials' construction. In the case of plated metals, for example, the variability was on the minimum, nominal, and maximum levels of plating. This provided the Mint an understanding of the variability in the materials and allowed the Mint to test alternative materials before spending more money on them. In some cases, materials were rejected from further testing during the variability lot steps (see below).

[16] Optimization of this composition is still on-going with one of the suppliers.

The Mint ran the pre-production lots through the same evaluation tests to which the metals were subjected in the variability lots, but with added tests on die life and planchet dimensions. (The short runs in the variability lots were sufficient to determine proper die-striking force, and to get an indication of die wear, but were too small to test actual die life, or to get a true indication of planchet-size variances.)

The tests run during pre-production testing also gave the Mint a larger, more representative sample of material results than in the variability lots, enabling an assessment of the potential supply chain. With a broader range of test results, more accurate analysis was possible, and the Mint gained a deeper understanding of the feasibility of candidate materials.

Table 2-1. Phase II Test Program Summary

ALTERNATIVE METAL TEST AND EVALUATION STATUS

Material			Variability Lots				Pre-Production Lots					Updated as of July 21, 2014
Potentially Seamless			Mat'l Rec'd	Test Strikes	Wear Test	EMS Test	Mat'l Ordered	Mat'l Due	Pre-Prod Strikes	Wear Test	EMS Test Local	Used by other countries
80/20	A 5¢	Mn 0.2-0.6%		Jun 2013	Passed	Failed	Canceled - failed EMS Test					Yes – US 75/25, Canada 75/25, UK 84/16
	B 5¢	Mn approx 3.0%		Nov 2013	Passed	Complete	Yes	Jun 2014	Jul 2014	Complete	Complete	
							Wear and EMS test on pilot material					
Co-Circulate												
Copper-Plated Zinc (CPZ) 5¢			May 2013	Jun 2013	Failed	Complete	Yes	Rec'd	Jan 2014	Failed	Complete	Yes – US 1¢, Singapore
							Canceled - failed wear test					
Tin-Plated CPZ 5¢ and 25¢			May 2013	Jun 2013	Failed	Complete	Canceled - failed wear test					No
Nickel-Plated Steel 5¢ and 25¢			Jun 2013	Jul 2013	5¢ Passed	Complete	Yes	Jun 2014	Jun 2014	Complete	Complete	Yes – UK, China, and a number of commonwealth countries
					25¢ Passed			Jun 2014	Jul 2014	Complete	Complete	
Multi-Ply-Plated Steel 5¢ and 25¢			Oct 2013	Oct 2013	5¢ Passed	Complete	Yes	Apr 2014	May 2014	Complete	Complete	Yes – Canada and a number of other countries
					25¢ Passed			Apr 2014	May 2014	Complete	Complete	
			Status									
Stainless Monolithic 5¢			CTC Stainless Feasibility Study final report received July 2014. Ten compositions tested, two identified for further testing.									Yes - Mexico, India and several smaller countries

2.3. Key Features

2.3.1. EMS

The electromagnetic signature (EMS) of a coin is extremely important. Most coin-accepting machines use the coin's EMS to verify the coin's value and accept or reject coins on this basis. The security of a unique EMS serves to prevent nearly-worthless discs of cheap metal (slugs) from being passed off as genuine coins in these machines. It also prevents counterfeiters from manufacturing their own coins from cheaper materials.

Plating provides some security and yields an EMS that is more difficult to match with common metals, but plating can be easily replicated.

Cladding[17], on the other hand, can provide a coin with an EMS that is more difficult to match inexpensively, and is not easily copied, effectively deterring counterfeiting and fraud.

2.3.2. Weight

The new coins should weigh as close as possible to the weight of current coins, as some commercial stakeholders rely on weight to facilitate commerce. Currently, there is a +/- 2.1–3.2 percent variance seen[18] in U.S. coinage. This variation is accepted by coin handlers and armored car companies as it is very minor and goes both up and down, so it tends to balance out, overall. The Mint considers matching-EMS candidate materials with weight that falls within this variance to be seamless.

Historically, the dime, quarter-dollar, and half-dollar have shared a direct relation between their values and their weights. The quarter-dollar (2.5 times the value of the dime) weighs precisely 2.5 times the weight of the dime (5.670g v. 2.268g) and the half-dollar (2.0 times the value of the quarter-dollar) weighs exactly 2.0 times the weight of the quarter-dollar (11.340g v. 5.670g). As a result, carriers have been able to bag dimes and quarters together and accurately estimate their value very quickly.

If there is only a minor difference in piece weight between a candidate material and the current material, it could be accepted as the present variation is, or the Mint could mitigate it by making small changes in the features of the coin, and the Mint kept this in mind as testing proceeded.

According to CTC's report from Phase I, a change in piece weight carried a lower cost to coin stakeholders than did a change to either the EMS or ferromagnetism of the current coin (given that dimensions of diameter and thickness need to remain the same), but it is a per-year cost.

2.3.3. Color

Since the 19th century, the five-cent, dime, and quarter-dollar have had a silver-white appearance. When these coins were changed to their current cupronickel composition in 1965, color was a factor in the material chosen, to allay any public concerns about the new coins.

[17] Cladding is defined in Section 2.3.4.

[18] Actual figures from Philadelphia Mint production from June 2013 to June 2014.

CPZ was the only metal examined in the primary testing and evaluation of Phase II that is not gray- or silver-white, and was considered solely for the five-cent based on potential cost savings. Several alternative metal candidates in Phase I were rejected from Phase II because they were too yellow.

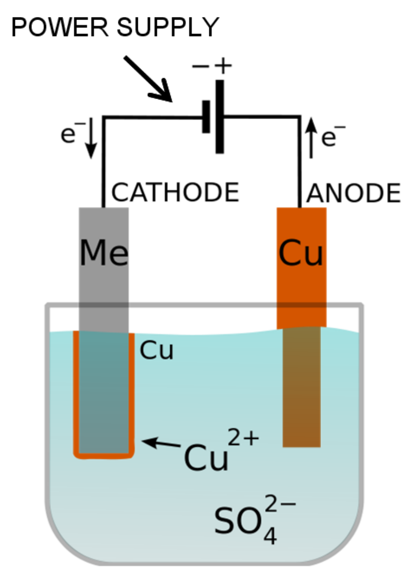
2.3.4. Construction

In Phase II, the Mint examined alternative metals in three basic composition types: plated, monolithic, and clad. No material tested in this phase was a simple elemental metal.

Plating

Plated metals have a metal core plated with one or more other metals in thin layers. The reason for this plating can be for color, security, EMS, corrosion/wear protection, or a combination thereof. Plating is performed in many ways, with multiple variations, but only electroplating was seen in plated candidate metals of Phase II.

Figure 2-7. Electroplating



"Me" in this figure is a stand-in for any metal.

Electroplating uses an electric current to move metal from an anode (such as copper) in an electrolytic solution onto a metal cathode (for example, zinc discs) in the solution. As shown in Figure 2-7, when the anode is positively charged, its metal atoms are oxidized, creating metal ions (Cu^{2+}) that dissolve in the electrolytic solution. At the negatively-charged cathode, the dissolved metal ions in the electrolytic solution are reduced to elemental metal

(Cu) at the solution/cathode interface. The cathode is sometimes referred to as a “core” or “substrate.”

Plating thickness varies over the surface of the piece with heavier thicknesses on the edge, as a function of the plating physics. This variation in plating thickness contributes to a varying (“wider”) EMS on plated coins. When plating thicknesses are given, they refer to a measurement in the center of the plated piece.

Monolithic

A monolithic alloy is a homogeneous (evenly mixed) blend of a metal and at least one other material. This is different from plating or cladding in that there are no layers; the materials are melted down and mixed together into a single alloy that is the same, through and through.

Cladding

Clad metals can use either, both, or none of the above constructions. Cladding bonds dissimilar metals together. The clad material could then be plated, but this is not usually done in coining.

Typically, clad coinage metals are “roll clad,” a process in which the layers of metal (for coins, this is usually a symmetrical “sandwich” of an odd number of layers) are thoroughly cleaned and passed through a series of rollers under sufficient mechanical pressure to bond the layers together. The high force serves to permanently deform the metals and to reduce their combined thickness in the process.

2.3.5. Hardness

Rockwell 15T hardness tests determine a material’s hardness relative to other materials. Planchets made from harder materials will typically require more force to strike or form a coin. More force to strike can also mean more stress-induced cracking and chipping on the die (tooling) surfaces, which creates defects on the resultant coin and can shorten the die’s life.

Figure 2-8. Damaged Die

Die 00581A (obverse), with a hairline crack at the top of Martha Washington's bonnet.

A material that is too soft, however, can excessively deform when it is blanked (cupping)[19] or upset. Beyond the impact to production, coins made of material that is too soft can cause significant damage to automatic coin handling/processing equipment (for example, if the coins can cold-weld together or if they fail to convey through coin acceptors). They may also not stand up to the wear a coin experiences in normal circulation, and can rapidly become too damaged to circulate.

Another consideration with regards to hardness is a material's ductility and tensile strength. A ductile material "flows" in the striking process, allowing it to more easily fill in the peaks and valleys in the die's design.

While a material that shattered upon striking would have been eliminated from consideration, no such conditions existed in Phase II, and hardness itself was not a basis in

[19] See attached Laser-Blanking Study for section on "push-back blanking" as a counter to cupping.

determining a material's feasibility. Ductility was, however, indirectly a factor, as it affected how well a material achieved proper detail ("filled") on strikes during progression strikes (the first step in testing). As a result, the Mint considered hardness as a property to test, but not as a precursor to success in coining a material.

2.4. The Materials

Following are the current material used in U.S. coins, and the six candidate materials from Phase II. These entries show only the five-cent and the quarter-dollar, as the quarter-dollar served as the proxy for the three clad denominations (dime, quarter-dollar, and half-dollar which use the same composition of material, just rolled to different thicknesses) for this study.

2.4.1. Current

The Mint performed identical tests on the current material and the alternative candidates.

Table 2-3. Current Material Specifications

Coin	Material	Construction	Weight
Five-Cent	Cu-25%Ni (cupronickel)	Monolithic	5.000g
Quarter-Dollar	Cupronickel clad to copper core	Clad (cupronickel over C110 copper)	5.670g

2.4.2. 80/20 Cupronickel

The 80/20 candidate is very similar to the current 75/25 material, with 20 percent less nickel in its composition. In the five-cent, this is a significant change, though for the quarter-dollar, it only comes to 20 percent of 8.33 percent, or only 1.67 percent of the coin's overall makeup. As a result, while 80/20 is a seamless alternative, cost savings with that material are small compared with other alternatives.

The two "80/20" material samples were ordered in two different compositions; 80/20A was Cu/20%Ni with a minor amount of manganese (which tested as having an EMS too different from the current material), while 80/20B contained more manganese, replacing some of the copper and nickel, for a final composition of Cu-19.7%Ni-3.3%Mn.

Table 2-4. 80/20B Specifications

Coin	Material	Construction	Weight
Five-Cent	Cu-20%Ni-3%Mn	Monolithic (cupronickel)	4.96g

2.4.3. Copper-Plated Zinc (CPZ)

The planchets used in the current U.S. one-cent are zinc discs plated with 8µm of copper, known as copper-plated zinc, or CPZ. The Mint examined this material as a potential alternative for the five-cent, but after it failed the variability lot wear test, it was dropped from consideration.

Table 2-5. CPZ Specifications

Coin	Material	Construction	Weight
Five-Cent	8µm Cu plated on Zn-.8%Cu core	Zinc plated with copper	4.06g

2.4.4. Multi-Ply-Plated Steel

Multi-Ply-Plated Steel (MPPS) is a process developed and patented by the Royal Canadian Mint (RCM) in which RCM takes a core of cold-rolled, low-carbon steel and first plates it with nickel, then copper, and then nickel again. MPPS is used in over 60 countries; Canada supplies approximately half of those countries with MPPS, and the other half manufacture it under license.

The multiple layers of plating allow RCM to alter the EMS of the coin by changing the thickness of the plating layers. The Mint struck this candidate in five-cent and quarter-dollar nonsense pieces.

MPPS has significant vulnerabilities to fraud and counterfeiting, and is used in lower-value world coins that are a similar size as the quarter-dollar, and is therefore not feasible for use in the quarter-dollar. It is, however, feasible for use in the five-cent and potentially in the dime.

Table 2-6. MPPS Specifications

Coin	Material	Construction	Weight
Five-Cent	4µm Ni on 5µm Cu on 10µm Ni on Steel core	Plated (nickel-copper-nickel over steel)	4.37g
Quarter-Dollar	4µm Ni on 23µm Cu on 10µm Ni on Steel core	Plated (nickel-copper-nickel over steel)	5.03g

2.4.5. Nickel-Plated Steel

Nickel-plated steel (NPS) can be legally manufactured by anyone with the means to plate nickel on steel. Currently, it is used on coins in the UK and a number of other countries around the world (in 2013, the RM produced 2.29 billion NPS coins and blanks for 38 customers). NPS is made from cold-rolled, low-carbon steel planchets plated nominally with 25µm of nickel, which is thick enough to generate a clearly discernable EMS, though it is a different EMS from current U.S. coins. The Mint struck this candidate in five-cent and quarter-dollar nonsense pieces.

NPS has significant vulnerabilities to fraud and counterfeiting, and is used in lower-value world coins that are a similar size as the quarter-dollar, and is therefore not feasible for use in the quarter-dollar. It is, however, feasible for use in the five-cent and potentially in the dime.

Table 2-7. NPS Specifications

Coin	Material	Construction	Weight
Five-Cent	25µm Ni plated on Steel core	Plated (nickel over steel)	4.40g
Quarter-Dollar	25µm Ni plated on Steel core	Plated (nickel over steel)	5.03g

2.4.6. Stainless Steel

Stainless steel is more expensive than carbon steels, but it does not need surface treatment for corrosion protection and is still priced lower than most other metals and alloys. By definition, stainless steel contains more than 12 percent chromium, though it can contain other elements—most notably, nickel.

Ferritic (i.e., drawn to magnets) stainless steel has relatively low or no nickel content, which makes it a low-cost option over austenitic (i.e., not drawn to magnets) stainless that contains significant quantities of nickel.

The makeup of stainless steel, while imparting the desired corrosion resistance, also makes the material more difficult to strike. The focus of CTC's study was to identify a composition and thermal mechanical practice[20] that provided the desired balance between the two.

The Mint, working with CTC, evaluated this easily counterfeited material solely for the low-denomination five-cent.

Table 2-8. Stainless Steel Specifications

Coin	Material	Construction	Weight
Five-Cent	Fe-C-Mn-Si-Ni-Cr	Monolithic Stainless Steel	4.37g

2.4.7. Tin-Plated Copper-Plated Zinc (TPCPZ)

TPCPZ is a copper-plated zinc planchet that is further plated in tin for the silver-white color the public expects on the five-cent, dime, and quarter-dollar. The Mint struck this candidate in five-cent and quarter-dollar nonsense pieces. TPCPZ failed the wear test, and the Mint eliminated it from further consideration.

Table 2-9. TPCPZ Specifications

Coin	Material	Construction	Weight
Five-Cent	Zn-Cu-Sn	Sn plated on Cu plated on Zn	4.1g
Quarter-Dollar	Zn-Cu-Sn	Sn plated on Cu plated on Zn	4.54g

2.5. Cost

As has been stated, the driving factor behind Public Law 111-302 was lowering the cost of U.S. coins. Production, fabrication, and metal costs all add up, but recycling options have also been a factor, including web scrap recycling options, in the case of material sent to the

[20] Thermal mechanical practice refers to the cold-rolling reduction and annealing practices which control the mechanical properties of the material.

Mint as coiled roll. The cost of minting coins is defrayed when old coins and condemned material are directly recycled by the supplier into new material for coins. When this is not an option, however, the Mint can still see some returns if there is another recycler interested in buying the scrap metal or if the supplier has other uses for the metal. This recycling then introduces another security factor (ensuring the coins are melted down by the recycler) and generally gains the Mint less money than if the material can be returned directly to the coin material supplier and reused as stock for future coin material.

Stainless steel, CPZ, and 80/20 have direct recycling options with the coin material supplier. These are figured into the metal costs of these materials, shown in Tables 2-10 and 2-11, below. The cost breakdown includes estimations of fabrication costs in some cases, as the actual numbers were not supplied.

Table 2-10. Estimated Unit Costs of Five-Cent Candidates

<table>
<tr><th>Candidate Material</th><th>Metal Cost</th><th>Supplier Fabrication</th><th>U.S. Mint Direct Production</th><th>Metal +Fabrication +Production</th><th>Overhead +G&A +Distribution</th><th>Est. TOTAL</th></tr>
<tr><td>Current (FY2014)</td><td>4.21</td><td>0.76</td><td>0.42</td><td>5.39</td><td>2.48</td><td>7.87</td></tr>
<tr><td>80/20 Cupronickel</td><td>3.88</td><td>0.76</td><td>0.42</td><td>5.07</td><td>2.48</td><td>7.54</td></tr>
<tr><td>3XX Stainless Steel</td><td>2.11</td><td>0.76</td><td>0.49</td><td>3.35</td><td>2.48</td><td>5.83</td></tr>
<tr><td>Multi-Ply Plated Steel</td><td colspan="2">2.81</td><td>0.21</td><td>3.02</td><td>2.48</td><td>5.50</td></tr>
<tr><td>Nickel-Plated Steel</td><td colspan="2">3.42</td><td>0.21</td><td>3.63</td><td>2.48</td><td>6.11</td></tr>
<tr><td>Copper-Plated Zinc</td><td colspan="2">1.70</td><td>0.21</td><td>1.91</td><td>2.48</td><td>4.39</td></tr>
<tr><td>Tin-Plated CPZ</td><td colspan="2">1.97</td><td>0.21</td><td>2.18</td><td>2.48</td><td>4.66</td></tr>
</table>

Green indicates a "seamless" alternative and red, a canceled alternative. All costs are in cents.
Plated materials' Metal Cost and Supplier Fabrication are supplier quotes from October 2013.
All other figures are from FY2014 (YTD through March 2014).

Table 2-11. Estimated Unit Costs of Quarter-Dollar Candidates

Candidate Material	Metal Cost	Supplier Fabrication	U.S. Mint Direct Production	Metal +Fabrication +Production	Overhead +G&A +Distribution	Est. TOTAL
Current (FY2014)	4.08	1.75	0.48	**6.31**	**2.81**	**9.12**
80/20 Cupronickel	3.88	1.75	0.48	**6.19**	**2.81**	**9.00**
Multi-Ply Plated Steel	3.46		0.24	**3.70**	**2.81**	**6.51**
Nickel-Plated Steel	3.71		0.24	**3.95**	**2.81**	**6.76**
Tin-Plated CPZ	3.79		0.24	**4.03**	**2.81**	**6.84**

Green indicates a "seamless" alternative and red, a canceled alternative. All costs are in cents.
Plated materials' Metal Cost and Supplier Fabrication are supplier quotes from October 2013.
All other figures are from FY2014 (YTD through March 2014).

Table 2-12, below, shows the cost breakdown of the current coins and their alternatives with estimated savings.

Table 2-12. Estimated Cost Breakdown – Current and Alternative Metals

5¢	Annualized Volume	Weight (grams)	Metal Cost	Metal + Supplier Fab + USM Direct Production	USM O/H+ G&A + Distribution	Total Unit Cost	% Savings	Savings Compared to YTD FY-14 5¢ through March 2014 984 M Coins	Notes
FY13 5¢ 1,123 M Coins		5.00	$0.0530	$ 0.0662	$ 0.0279	$ 0.0941		$ -	a
FY14 5¢ (75-25) -->3/31/14 492M coins	984 M	5.00	$0.0421	$ 0.0539	$ 0.0248	$ 0.0787	-16.4%	$ 15,189,203	b
80-20Cu-Ni Solid		4.96	$0.0388	$ 0.0507	$ 0.0248	$ 0.0754	-4.1%	$ 3,211,103	e
Multi-Ply plated steel (p)		4.37	$0.0281	$ 0.0302	$ 0.0248	$ 0.0550	-30.1%	$ 23,335,468	q
3XX Stainless steel (s)		4.46	$0.0211	$ 0.0335	$ 0.0248	$ 0.0583	-25.9%	$ 20,097,771	e
Nickel plated steel (p)		4.40	$0.0342	$ 0.0363	$ 0.0248	$ 0.0611	-22.3%	$ 17,310,451	q
CPZ (p) 8 µm		4.06	$0.0094	$ 0.0191	$ 0.0248	$ 0.0439	-44.2%	$ 34,254,534	q
Tin plated CPZ (p)		4.10	$0.0197	$ 0.0218	$ 0.0248	$ 0.0466	-40.8%	$ 31,614,856	q
10¢	**Annual Volume**	**Weight (grams)**	**Metal Cost**	**Metal + Supplier Fab + USM Direct Production**	**USM O/H+ G&A + Distribution**	**Total Unit Cost**	**% Savings**	**Savings Compared to YTD FY-14 10¢ through March 2014 1,650 M Coins**	
FY13 10¢		2.27	$0.0204	$ 0.0307	$ 0.0149	$ 0.0456		$ -	a
FY14 10¢ (92-8) -->3/31/14 825M coins	1,650 M		$0.0169	$ 0.0267	$ 0.0140	$ 0.0407	-10.7%	$ 8,027,772	b
80-20 Cu-Ni Clad		2.27	$0.0165	$ 0.0262	$ 0.0140	$ 0.0403	-1.2%	$ 791,839	e
Multi-Ply plated steel (p)		2.00	$0.0217	$ 0.0231	$ 0.0140	$ 0.0371	-8.9%	$ 5,956,892	e
Nickel plated steel (p)		2.00	$0.0225	$ 0.0238	$ 0.0140	$ 0.0379	-7.0%	$ 4,735,956	e
25¢	**Annual Volume**	**Weight (grams)**	**Metal Cost**	**Metal + Supplier Fab + USM Direct Production**	**USM O/H+ G&A + Distribution**	**Total Unit Cost**	**% Savings**	**Savings Compared to YTD FY-14 25¢ through March 2014 1,062 M Coins**	**Notes**
FY13 25¢ 1,062 M Coins		5.67	$0.0465	$ 0.0714	$ 0.0336	$ 0.1050		$ -	a
FY14 25¢ (92-8) -->3/31/14 592.2M coins	1,062 M	5.67	$0.0408	$ 0.0631	$ 0.0281	$ 0.0912	-13.2%	$ 14,715,198	b
80-20 Cu-Ni Clad		5.66	$0.0396	$ 0.0619	$ 0.0281	$ 0.0900	-1.3%	$ 1,252,998	e
Multi-Ply plated steel (p)		5.03	$0.0346	$ 0.0370	$ 0.0281	$ 0.0651	-28.6%	$ 27,718,074	q
Nickel plated steel (p)		5.03	$0.0371	$ 0.0395	$ 0.0281	$ 0.0676	-25.8%	$ 25,020,594	q
Tin plated CPZ (p)		4.54	$0.0379	$ 0.0403	$ 0.0281	$ 0.0684	-25.0%	$ 24,171,079	q

Notes:
a = FY13 Actuals
b = FY2014 10/1/13–3/31/14
e = Estimate
q = Supplier quote

Key:
(cs)=clad strip
(p)=plated
(s)=strip
Green=seamless alternative and Red=cancelled alternative

Assumptions:
> FY13 unit cost data is from FY13 Annual Report
> Mint Production, G&A, and distribution costs are FY14 YTD through March
> Volumes are annualized FY14 (YTD through March) volumes.
> Savings are calculated based on FY14 YTD through March total unit costs and volumes

2.6. Sourcing

The Mint requires a consistent supply of metal for its coins and medals. Successful candidate materials must therefore be made of metals that are readily available and in good supply. This was evident when the U.S. Treasury saw its silver reserves drop to dangerously low levels in the early 1960s.

Competition among suppliers can help the Mint keep costs down if the Mint uses materials with multiple suppliers over those with a single, proprietary supplier. The availability and ease of sourcing, though, must be balanced with concerns over broad access and security.

Currently, the Mint orders its materials from domestic suppliers. Suppliers get the best quality metal at the best prices, which often means foreign sources. Those foreign sources usually have friendly relations with the U.S., but domestic suppliers are preferable, not only for the lower risk, but also for lower shipping costs and a shorter supply chain.

Cupronickel (80/20)

The two cupronickel suppliers for Phase II obtain their nickel and copper from many of the same sources globally. These foreign and domestic sources have been consistent, and more sources, including a potential domestic nickel source, are appearing.

Copper-Plated Zinc and TPCPZ

The CPZ supplier obtains its zinc primarily from Canada, but also through recycling. Its copper and tin come from domestic and foreign sources, depending on price levels and availability, and also from recycling.

Multi-Ply-Plated Steel

The Mint bought this material from the Royal Canadian Mint, which patented and manufactures this material for their own and other nations' coins.

Nickel-Plated Steel

The Royal Mint obtains their nickel and steel from sources in Wales (UK) and supplied this material to the Mint for Phase II.

Stainless Steel

The suppliers obtain their raw materials from multiple sources, both domestic and foreign, and in major part from recycling. Depending on which grade would be selected, there may be sourcing limitations posed by intellectual property rights.

3. Testing

The Mint purchased the candidate materials first in small variability lots, typically 500 to 2,000 pieces produced in a lab environment spanning the expected range of composition/ construction anticipated in normal production processes, and tested each for the feasibility of their use as U.S. coins. After evaluation and passing a "Go/No-Go" determination, materials were tested in pre-production lots, typically 2 million pieces, for a final determination.

Stainless steel, however, was not run through variability or pre-production, though CTC and the Mint tested and evaluated various, preliminary grades until two were recommended (see the attached Stainless Feasibility Study; the Executive Summary is in Section 8). Future testing on the two, identified, stainless-steel materials would conform to the control plan for variability lots, and—if justified—pre-production testing.

In all cases, these materials were struck as "nonsense" pieces that, at first glance, looked like U.S. coins with accurate dimensions, but with Martha Washington's profile on the obverse and had the letters in all the words (like "Liberty" or "United States of America") scrambled. After testing, nonsense pieces that were no longer required were crushed and either sent back to the supplier (current baseline pieces), or securely melted (alternative metal pieces).

3.1. Control Plan and Procedures

3.1.1. Control Plan

Before testing in Phase II began, the Mint prepared a plan by which testing would progress. The Control Plan detailed each step in testing, the criteria "Go/No-Go," and the assumptions, risks, and roles and responsibilities. By creating a detailed plan, the Mint prepared a guide by which Argonne National Lab (Argonne) could follow the Mint's progress easily for its Independent Peer Review (IPR) (see Section 1.8).

3.1.2. Procedures

To ensure consistent test results, the Mint established quality assurance Standard Operating Procedures (SOPs) for each step in the testing. These SOPs established test objectives and clearly defined, possible-result parameters. Each SOP established what kind of instrument would be used, how long the test would last, how many pieces would be tested, and what (if any) criteria there would be for Go/No-Go or for down selection. Throughout Phase II, the Mint followed the SOPs, documented their progress, and provided copies of the progress documentation and the SOPs to Argonne for its IPR.

3.2. Steps

3.2.1. Progression Strikes

Each material needed to first go through "progression" strikes. The Mint first struck five planchets of the material at a low tonnage (press force) and then examined the struck pieces for dimensions and for image detail. The Mint then struck five more planchets at each progressively higher tonnage, and continued to examine the dimensions and detail until it was determined to be sufficient for a U.S. circulating coin. At each step in this process, for each metal, the Mint recorded the tonnage, dimensions, and the level of detail.

Figure 3-1. R&D Coining Press

The horizontal press at the testing facilities.

When the correct level of detail was reached, or when the maximum tonnage for that material was reached, the rest of the material was struck at that tonnage for that stage of testing.

Determining "acceptable" detail fill was subjective, but was consistent throughout the testing process. Mint engineers who were assigned to the technical team routinely conduct progression strikes in the course of their day-to-day duties, and their extensive experience enabled the subjective R&D assessments to be consistent.

3.2.2. Testing Results

Before variability testing began, the Mint set up an electronic database with minimum and maximum acceptable dimensional results to make it easier to see if a material passed or failed the test, and by how much. The setup also enabled the Mint to readily see the variances within each material and judge if the material were too inconsistent. For each material, the Mint used calibrated micrometer gauges connected to a computer to enter the relevant data into the database where the Mint could analyze it.

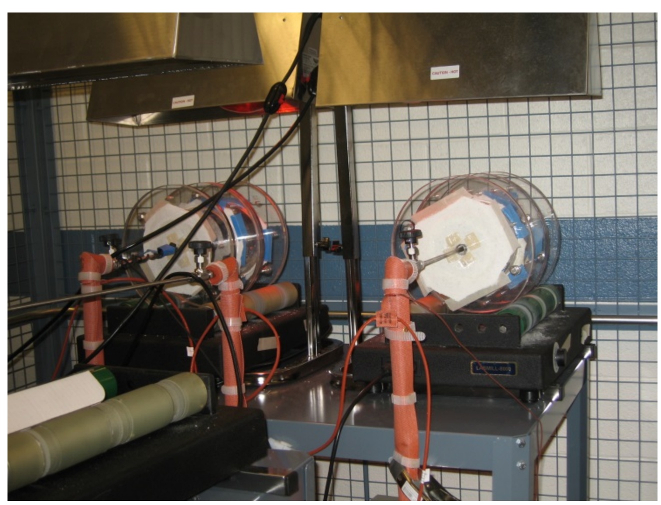
For the variability lots, the Mint used a specific dimensional data system, which generated reports for each material that showed the minimum and maximum acceptable numbers; the average, low, and high scores for each test; and a bar chart that showed the variances in the tests (typically a bell curve was seen).

For pre-production lots, the Mint used a software spreadsheet program to record results from micrometers connected to the computer and generate reports that made individual points of data easier to access.

3.2.3. Wear Test

For each material, the Mint took either one group (variability) or four groups (pre-production) of five random pieces from test strikes and put them through a two-week-long comparative wear test. Nonsense pieces were placed in a towel-lined tumbler with current coins and then tumbled with a light application of artificial sweat at 40–52 °C in a humidified environment.

Figure 3-2. Steam Test Tumblers



The facility had multiple tumblers, each with two test compartments which were lined with pleated towels. The towels overlapped slightly, introducing an occasional flip in the movement of the pieces and coins in the tumbler. Large, infrared lamps were placed above each tumbler to heat the tumblers above the condensation point of the humidified air.

Into each compartment went five sample nonsense pieces (five-cent or quarter-dollar) of a test material, along with one each of a current one-cent, five-cent, quarter-dollar, and dollar, for a total of nine pieces in each compartment. All coins and test pieces were thoroughly cleaned before testing, and were subsequently cleaned before each measurement. Testers wore powder-free rubber gloves when handling the cleaned coins and test pieces.

The Mint measured the weight of each test piece before the wear test, once during the test, and finally at the end of the test. Edge thickness of test pieces was measured before the wear test and at the end of the test to judge deformation as compared with current material coins of the same denomination. Those same-denomination coins had been put through the same test previously to provide a baseline for weight loss and edge deformation. The Mint measured weight and thickness to the fourth decimal point, in grams for the weight and in inches for the thickness.

This was an accelerated wear test that replaced an earlier test the Mint used in Phase I. In the earlier test, there were various other materials (leather, cork, cloth) co-mingled with the test pieces and a larger amount of artificial sweat. The Mint determined the earlier test was too aggressive and not representative of actual use, especially when wear-testing plated materials. The Mint developed this optimized test procedure to address the aggressiveness noted in Phase I of the original test.

Note that this wear test was designed to be comparative (evaluate an alternative material as either better, the same or worse than the current material) and not to predict actual coin life.

To pass the Go/No-Go determination for the variability lot stage, candidate materials could only lose up to twice as much weight on a percent basis as the current material lost after the two weeks were up (i.e., exhibited at least half the life), and had to show as much dimensional durability (keep the same edge thickness), with no more than a 0.010" difference with the current coins tested previously.

3.2.4. Steam Test

The Mint took a small number of random blanks for each material and measured the color (brightness and hue) with a spectrophotometer that gave a positive "L" value for the brightness, and then an "a" value (positive for red, negative for green) and a "b" value (positive for yellow, negative for blue) for the hue.

Figure 3-3. Steam Test Autoclave

When those scores were recorded, the Mint steamed the blanks in an autoclave at 100 °C, atmospheric pressure, and 100 percent humidity to accelerate the oxidation rate compared with ambient conditions.

After this, the Mint measured the color again and recorded the difference. Note that this method was only used to evaluate the properties of the chemical layer formed during the blank preparation process. In the a and b color plan, less change meant a better protective chemical layer.

The Mint examined the tested samples under appropriate lighting for discoloration or spots.

3.2.5. Coin Sorter/Validator (CSV) Test

Many retail, public transit, financial institutions, and other industries that handle large numbers of coins use coin sorter/validator systems from numerous manufacturers. These systems take many different readings of a coin to determine the coin's diameter, edge thickness, conductivity, and permeability, among other characteristics. For Phase II, the Mint obtained a high-speed CSV for its R&D program.

Figure 3-4. High-Speed CSV

During variability lots, for each material, the Mint chose random samples of no less than 100 nonsense pieces at each of the supplier's minimum, maximum, and nominal platings, thicknesses, etc. During pre-production lots, the Mint chose at least two large samples of approximately 30,000 pieces for each material and selected at least 100 pieces from each subsequent sampling of 30,000 pieces.

The Mint then sent these pieces through the CSV to determine the material's measurements and electromagnetic characteristics, consistency across batches, and match with the current material.

To ensure that the data was accurate and reliable, the Mint kept the CSV properly calibrated at all times.

3.2.6. Hardness Test

The Mint tested a random sample of each material using a hardness tester. Blanks that were not yet annealed and ready-to-strike planchets were both tested, and so, there are "pre-annealed" and "annealed" results from this test, though some materials only have a score in one of the fields (i.e., a material that could not be annealed, or a material that came already annealed). The Mint used the Rockwell 15T scale for this test.

Figure 3-5. Hardness Tester

The test involved putting a planchet in the hardness tester, and applying a minor load to the material, which established the "zero position." A major load was then applied and removed, leaving the minor load in place. The tester then showed the depth of penetration from the zero position, on a readout in which harder materials have a higher number. For small lots (30 or fewer), each piece was tested in five different points, with the highest and lowest of the five readings disregarded. The Mint then averaged the remaining three readings for that piece's reading. For larger lots (over 30 pieces), the Mint took one reading per piece, and performed statistical analysis on the data sets, using them for comparison and evaluation.

Nominal hardness values for current materials are between 62 and 72[21], and this was the target for the candidate materials, but hardness was not a consideration for Go/No-Go.

[21] The Rockwell hardness number is relative, with no unit.

3.2.7. Electrical Conductivity Test

Conductivity is the measure of how well a material carries an electrical charge. Copper is the most conductive non-precious metal, and is used as the standard for conductivity. In 1913, due to a lack of uniformity in the value of annealed copper in various countries, the U.S. National Bureau of Standards (now the National Institute of Standards and Technology) developed the International Annealed Copper Standard (IACS) which was quickly adopted by the International Electrotechnical Commission. This standard was accepted by 1914 and is still used.

The IACS uses a percentage score to represent the conductivity of a metal. A score of 100 percent IACS translates to 58 million siemens[22] per meter at 20 °C[23], which was the conductivity of commercially pure, annealed copper when the standard was set.[24]

The Mint used a conductivity meter to test each material as blank planchets in variances of construction (minimal, nominal, and maximal). Each planchet was tested at two to four different frequencies. This test is suitable only for non-ferromagnetic materials.

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[22] 1 siemens (S) is equivalent to the reciprocal of 1 ohm (1/ohm) in the International System of Units; also referred to as the “mho”; the ohm is a measure of electrical resistance, the siemens is a measure of electrical conductivity.

[23] Equates to 68 °F, or room temperature.

[24] Commercially pure, annealed copper at 20 °C today has a higher IACS than 100% because of better methods for removing impurities from the metal.

3.3. Material Tests – Variability Lots

3.3.1. CPZ (Variability Lot)

CPZ failed the wear/durability requirement, and as a result, the Mint eliminated the material from further consideration.

Progression Strikes

The Mint struck CPZ planchets at strike forces from 33 to 54 tonnes; the detail became acceptable[25] at 54 tonnes, the same tonnage as the current material, which indicated a potential for similar die life with this material.

Figure 3-6. CPZ Test Piece

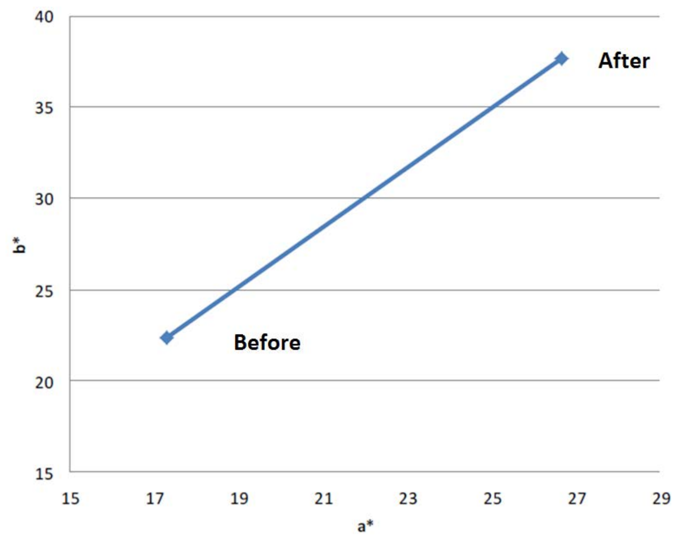
CPZ: 54 tonnes

Steam Test

The color change shown by the CPZ blanks in the variability lot steam test was noticeable, and was determined to be inferior to the current five-cent material. However, the change was within acceptable parameters set by the Mint. (The full test results are available in Appendix 10.2.1.)

[25] "Acceptable" meant sharp, square, level lettering, and fine detail that matched up visually with that in the dies.

Figure 3-7. Five-Cent CPZ Blank Color Change—Variability Lot



CPZ's color changed to a darker hue, with more yellow (higher b) and more red (higher a).

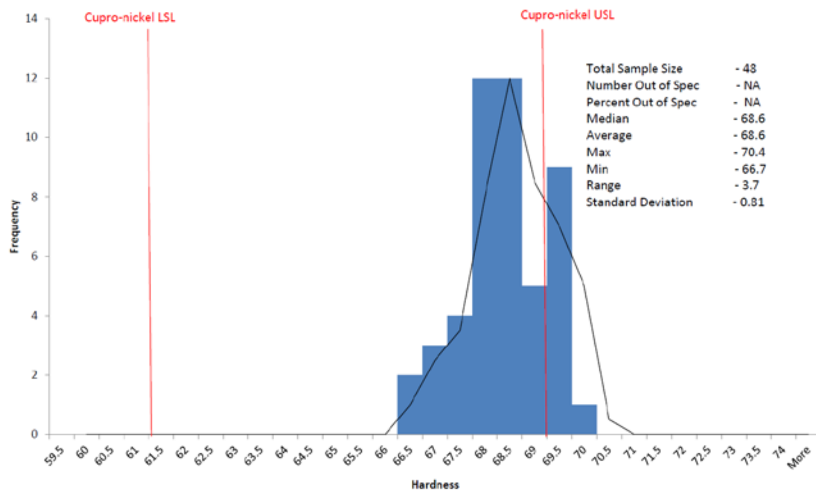
CSV Test

The CSV scans showed acceptable size and EMS measurements for a co-circulate material. (The full test results are available in Appendix 10.3.1.)

Hardness Test

The Mint tested 48 blank planchets for their hardness, using the Rockwell HR 15T scale. CPZ showed a hardness range of 66.7 to 70.4, with an average of 68.6. The range of the samples showed a hardness level slightly higher than that of the current cupronickel.

Figure 3-8. Five-Cent CPZ Planchet Hardness Test—Variability Lot



Conductivity

The Mint tested 20 random CPZ blanks each at minimal and nominal plating for their conductivity. From the lowest to the highest frequencies, CPZ yielded IACS readings of 28.36% to 29.55% and deviations among the pieces tested at each frequency were well within acceptable parameters.

Copper-Plated Zinc Go/No-Go Determination

Security

Go. CPZ was solely being considered for use in the five-cent, so security needs were minimal, given the five-cent's value and the standards in the European Vending Agency (EVA) Handbook regarding low-denomination coinage. The Mint produced nonsense pieces and tested them internally and at Coin Acceptor Manufacturers. The material yielded a unique EMS with respect to other world coins, but it did not match the current material, so it was considered a co-circulate alternative.

Recyclability

Go. Any condemned or recycled CPZ would be sent directly to the supplier for re-melting and use in future coin materials. The data suggested this would be relatively cost-neutral, with the recovered metal's value offsetting the cost of processing and melting.

Public Health/Toxicity

Go. CPZ presents no unique hazards such as radioactivity or toxicity, and is not a known allergen. Copper and zinc are used in bathroom and kitchen fixtures as well as current U.S. coinage (one-cent), so there is significant public exposure and experience with the metals in this material. As such, the Mint was able to state that there are no unique or special hazards to humans associated with CPZ.[26] Its main hazard would be ingestion/aspiration of the material, which could cause gastro-intestinal or respiratory issues; this is unrelated to the material or its use, and so is not a greater or lesser risk for this than any other coin.

Wear Test

No Go. CPZ performed acceptably in one aspect of the wear test, weight loss. During the two-week test, it lost 3.6mg of its material compared with the 12.9mg lost by the current material, but the durability of CPZ was insufficient, causing the edges to deform 0.0165", more than the 0.010" maximum allowed. Also, the 8μm copper plating was too thin to withstand the wear, and the high points of the nonsense pieces had worn down to the zinc substrate, as shown in the photo, below. This was also evident on the pieces subjected to multiple runs through the CSV to simulate a life of wear in automated CSVs.

Figure 3-9. CPZ After Wear Test

Note the zinc exposure at edges of high points.

As a result of CPZ's low durability and the weakness of the plating, the Mint determined that the material failed this test. While plating thickness could be increased to compensate for the automated coin sorter wear test, the inherent weakness of the zinc substrate when used for the heavier five-cent (vs. the smaller/lighter one-cent) resulted in the excessive edge deformation and would not be improved by thicker plating layers. The material supplier has indicated in technical discussions that there is limited ability to improve the inherent

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[26] Dogs and cats that swallow zinc-based coins may be poisoned by the zinc. (Source: CBS News http://www.cbsnews.com/news/dog-fatally-poisoned-by-one-penny/)

mechanical properties of the zinc substrate without trading off hardness for ductility. Stated differently, increasing the hardness and resistance to deformation would significantly impact the ductility and ability to strike a coin. (The full test results are available in Appendix 10.1.1.)

Co-Circulate

No-Go. CPZ showed a unique EMS, acceptable color change in its steam test, and proved to have the proper size, weight, edge thickness, and conductivity to co-circulate as a five-cent. However, CPZ failed the two-week wear test, showing worse edge deformation than the current material, and the zinc substrate began to show through at the high points on the design. As a result of this test, CPZ was dropped from consideration and was not evaluated further.

Go/No-Go Recommendation

No-Go.

3.3.2. Tin-Plated Copper-Plated Zinc (Variability Lot)

Tin-plated copper-plated zinc (TPCPZ) failed the wear requirement, and as a result, the Mint eliminated the material from further consideration.

Progression Strikes

The Mint struck five-cent TPCPZ planchets at strike forces from 50 to 66 tonnes; the detail became acceptable at 54 tonnes, the same tonnage as the current material, which indicated a potential for similar die life with this material. Then it struck quarter-dollar planchets at strike forces from 59 to 67 tonnes; the detail was acceptable at 59 tonnes, well below the current 62-tonne striking force.

TPCPZ's dimensional and design fill was superior to the current five-cent and quarter-dollar materials for the entire range of the progression strikes.

Steam Test

There was almost no color change shown by the TPCPZ blanks in the variability lot steam test, and the Mint determined TPCPZ to be superior to the current five-cent and quarter-dollar materials for this test. As shown in Figures 3-10 and 3-11, below, the "before" and "after" points are so close, marking them yields no significant data. (The full test results are available in Appendix 10.2.2.)

Figure 3-10. Five-Cent TPCPZ Blank Color Change—Variability Lot

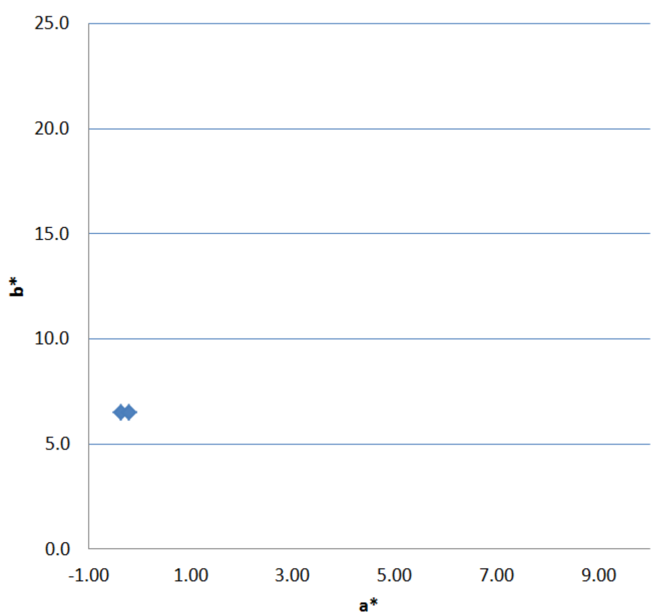
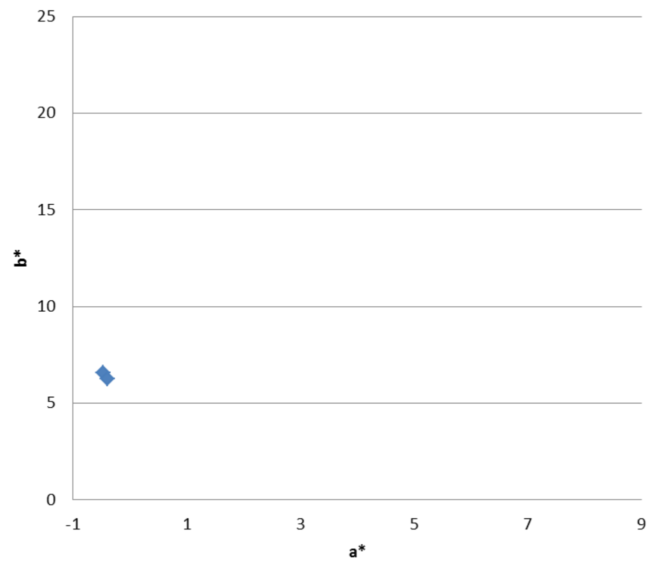


Figure 3-11. Quarter-Dollar TPCPZ Blank Color Change—Variability Lot



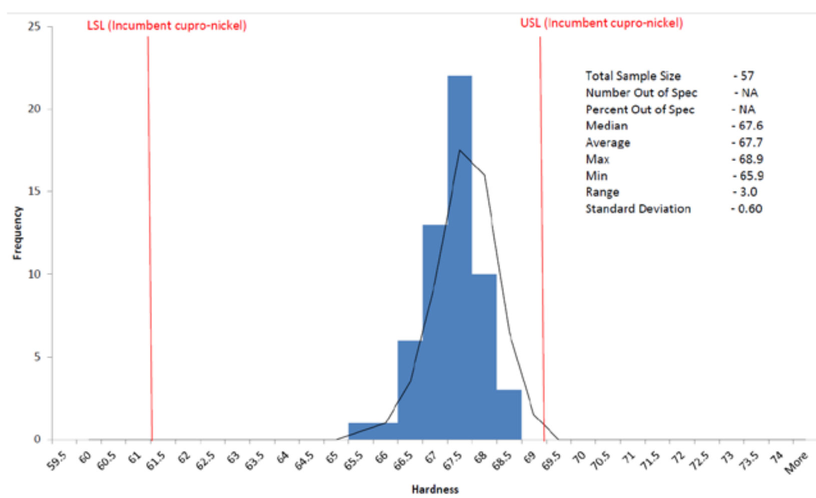
CSV Test

The CSV scans showed acceptable size and EMS measurements for a co-circulate material. (The full test results are available in Appendix 10.3.2.)

Hardness Test

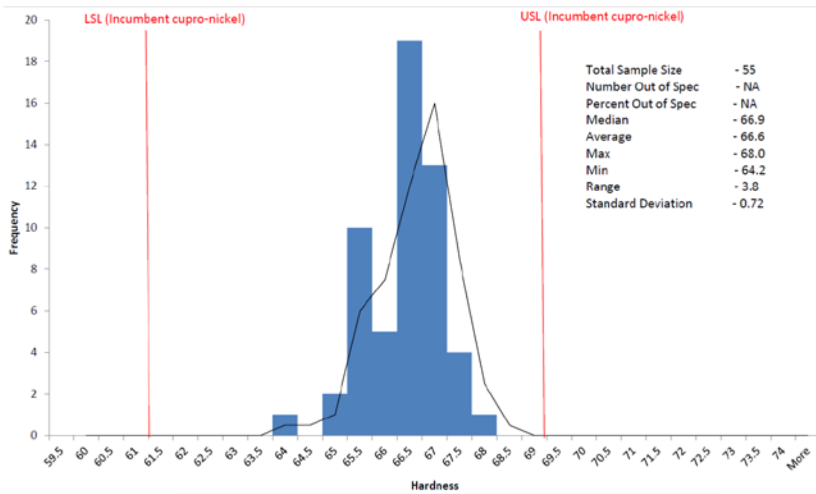
The Mint tested 57 blank five-cent planchets of the for their hardness, using the Rockwell HR 15T scale. As shown in Figure 3-12, below, TPCPZ showed a hardness range of 65.9 to 68.9, with an average of 67.6. The range of the samples showed a similar hardness level as the current cupronickel, but slightly harder.

Figure 3-12. Five-Cent TPCPZ Planchet Hardness Test—Variability Lot



Next, the Mint tested 55 blank quarter-dollar TPCPZ planchets for their hardness. As shown in Figure 3-13, below, the quarter-dollar configuration TPCPZ showed a hardness range of 64.2 to 68.0, with an average of 66.9, which was slightly harder than the current material's hardness.

Figure 3-13. Quarter-Dollar TPCPZ Planchet Hardness Test—Variability Lot



Conductivity

The Mint tested random five-cent and quarter-dollar TPCPZ blanks at minimum, nominal, and maximum plating for their conductivity. For the five-cent blanks, from the lowest to the highest frequencies, TPCPZ yielded IACS readings of 28.50% to 30.71% and deviations among the pieces tested at each frequency were well within acceptable parameters. The IACS readings for the quarter-dollar blanks were 28.48% to 30.78% with deviations well within acceptable parameters.

TPCPZ Go/No-Go Determination

Security

Go. For the five-cent, the security requirements are minimal given its value and the standards in the EVA Handbook. However, for the quarter-dollar, the security requirements are more extensive as the coin is near the breakpoint for medium-value coins in the EVA Handbook. The appropriate level of security for the quarter-dollar was still to be determined, so the material was rated as "Go" for security.

Test pieces were produced and tested both internally and at Coin Acceptor Manufacturers. The material yielded a unique EMS with respect to other world coins, but its EMS did not match the current material so it was considered a co-circulate candidate material.

Recyclability

Go. Any condemned or recycled material would go to a brass supplier for re-melting and use on future brass (non-coin) materials. Zinc and copper are the main constituents in brass which also has a tin as an additive. The data suggests that this would be relatively cost-neutral with the recovered metal units offsetting the costs of processing and melting.

Public Health/Toxicity

Go. TPCPZ has no unique hazards such as radioactivity or toxicity, and is not a known allergen. Tin, copper, and zinc are all commonly used materials and the zinc core with copper plating is currently used as U.S. coinage (one-cent) and there are no unique or special hazards to humans associated with it.[27] Its main hazard would be ingestion/aspiration of the material, which could cause gastro-intestinal or respiratory issues; this is unrelated to the material or its use, and so is not a greater or lesser risk for this than any other coin.

Wear Test

No Go. After only two days in the tumbler, the tin plating and copper plating on the TPCPZ pieces had worn almost completely away from the zinc substrate, as shown in the picture, below. The Mint conducted a second round of wear testing, which confirmed the earlier failure. The material failed this test. (The full test results are available in Appendix 10.1.2.)

Figure 3-14. TPCPZ After Wear Test

Note the fragments of plating remaining around the edge of the piece.

[27] Dogs and cats that swallow coins with a zinc core may be poisoned by the zinc. (Source: CBS News.)

Co-Circulate

No-Go. TPCPZ showed a unique EMS, acceptable color change in its steam test, and proved to have the proper size, weight, edge thickness, and conductivity to co-circulate. Unfortunately, it failed the two-week wear test, with the plating wearing away nearly completely in only two days. As a result of this test, TPCPZ was dropped from consideration and was not tested further in the pre-production lots.

Go/No-Go Recommendation

No-Go.

3.3.3. Multi-Ply-Plated Steel (Variability Lot)

Multi-Ply-Plated Steel (MPPS) passed all of its Go/No-Go criteria for both the five-cent and the quarter-dollar, except security levels needed for the quarter-dollar were still being evaluated. Testing continued through the pre-production lots for this material at that denomination. As its EMS signature and weight differ significantly from the current coins, MPPS is considered a co-circulation option.

Progression Strikes

The Mint struck five-cent and quarter-dollar MPPS planchets at strike forces from 30 to 60 tonnes. The current five-cent tonnage is 54 tonnes; at 54 and 60 tonnes, MPPS fill was poor. The Mint observed abrasive wear scratches in the progression strikes, attributed to the abrasive nature of the pure-nickel surface coating. For any extensive striking such as pre-production lots, PVD-coated dies[28] would be required.

Figure 3-14. MPPS Five-Cent Test Piece

Red arrows indicate areas of poor fill.

[28] Physical vapor deposition is a vacuum deposition method involving plasma sputter bombardment of target material to deposit thin films of that material onto surfaces (i.e., coining dies). PVD coatings are generally used to improve hardness and wear resistance. The RCM routinely uses this coating process on their numismatic and circulating dies; for further testing, the Mint sent dies to the RCM for PVD coating.

The current quarter-dollar tonnage is 62 tonnes, but the MPPS quarter-dollar nonsense pieces needed 65 tonnes to see acceptable fill in the lettering along the edge.

Figure 3-15. MPPS Quarter-Dollar Test Piece

Steam Test

There was almost no color change shown by the MPPS blanks in the variability lot steam test, and the Mint determined MPPS to be superior to the current five-cent and quarter-dollar materials for this test. As shown in Figures 3-16 and 3-17, below, the “before” and “after” points are so close, marking them yields no significant data. (The full test results are available in Appendix 10.2.4.)

Figure 3-16. Five-Cent MPPS Blank Color Change—Variability Lot

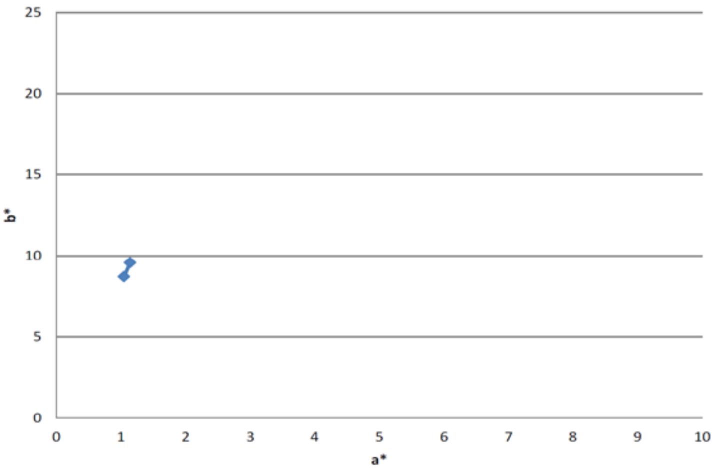
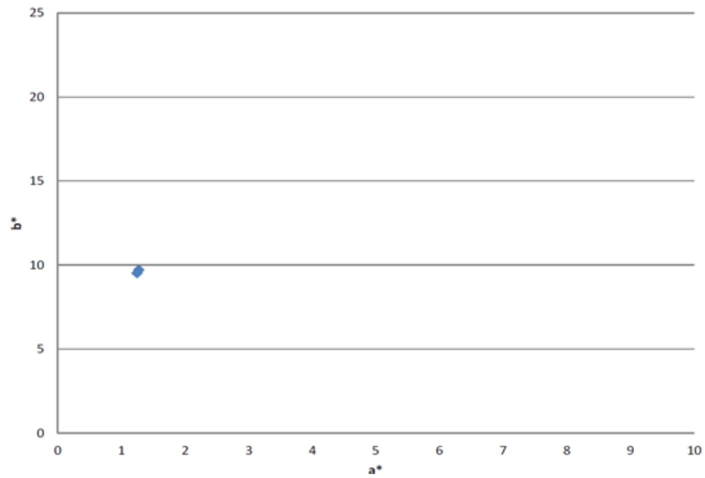


Figure 3-17. Quarter-Dollar MPPS Blank Color Change—Variability Lot



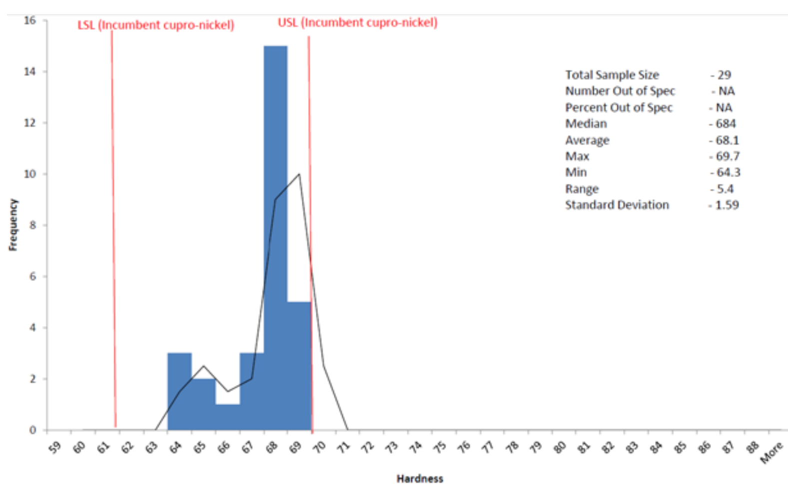
CSV Test

The CSV scans showed acceptable size and EMS measurements for a co-circulate material. (The full test results are available in Appendix 10.3.4.)

Hardness Test

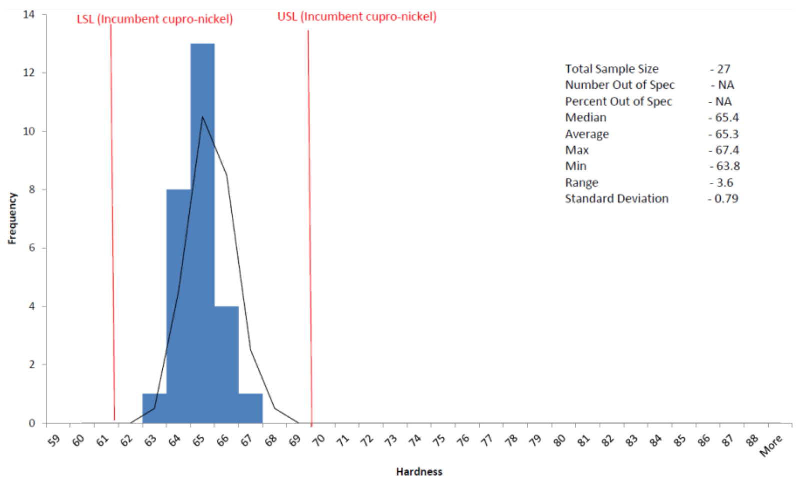
The Mint tested 29 blank MPPS five-cent planchets for their hardness, using the Rockwell HR 15T scale. As shown in Figure 3-18, below, MPPS showed a hardness range of 64.3 to 69.7, with an average of 68.1. The range of the samples showed a similar hardness level as the current cupronickel, but slightly harder.

Figure 3-18. Five-Cent MPPS Planchet Hardness Test—Variability Lot



Next, the Mint tested 27 blank quarter-dollar MPPS planchets for their hardness. As shown in Figure 3-19, below, MPPS showed a hardness range of 63.8 to 67.4, with an average of 65.3, which was almost identical to the current material's hardness.

Figure 3-19. Quarter-Dollar MPPS Planchet Hardness Test—Variability Lot



Conductivity

The conductivity test is appropriate for measuring non-ferromagnetic metals and alloys. The construction of the MPPS planchet makes this test not applicable due to the combination of non-ferromagnetic plating and ferromagnetic steel substrate, so it was not performed.

Conductivity was measured in the CSV test (see above), which uses sensors capable of measuring the relative electromagnetic properties of both ferromagnetic and non-ferromagnetic metals.

MPPS Go/No-Go Determination

Security

Go. For the five-cent, the security requirements are minimal given its value and the standards in the EVA Handbook. At the time of variability testing, no security determination had been established for the quarter-dollar, so the material was approved for pre-production testing.

Nonsense pieces were tested both internally and at coin acceptor manufacturers. MPPS exhibits a distinguishable EMS, but has a broader conductivity band that can overlap with other world coins. The steel core also makes MPPS more easily counterfeited, which has a greater potential impact on the quarter-dollar, as it is more widely used in vending.

Recyclability

Go. Any condemned or recycled material would go to a stainless steel supplier for re-melting and use on other non-coin materials. The data suggests that this would be relatively cost-neutral with the recovered metal units offsetting the cost of processing and melting. However, with the presence of copper, the ability to absorb large quantities of MPPS as stainless scrap is limited and may impact the recyclability of the larger quantities that would be generated if the material was used for U.S. coinage. The Mint contacted two domestic stainless steel mills that reported that the percentage of stainless material containing copper was 40 percent of one supplier's volume and only 15 percent of the other's. Depending on the volume and timing, then, recycling could be limited.

Public Health/Toxicity

Go. MPPS has no unique hazards such as radioactivity or toxicity, and is not a significant allergen. It is a material used in a number of applications worldwide, including coinage. There are no unique or special hazards associated with it. The nickel coating can cause skin rashes in some small portion of the population with an occurrence possibly higher than the current five-cent or quarter-dollar material which has been acceptable. Its main hazard would be ingestion/aspiration of the material, which could cause gastro-intestinal or respiratory issues; this is unrelated to the material or its use, and so is not a greater or lesser risk for this than any other coin.

Wear Test

Go. MPPS performed exceptionally well in the two-week wear test, as the five-cent nonsense pieces lost an average of 14.1mg of the material compared with the 19.0mg lost by the current material. The quarter-dollar nonsense pieces performed even better, losing only an average of 4.4mg compared with the 27.2mg lost by the current material. In the five-cent configuration, MPPS' edge deformation was less than the current material, and in the quarter-dollar configuration, MPPS deformed only 0.005" more than the current material, well within the 0.01" allowed. (The full test results are available in Appendix 10.1.4.)

Figure 3-20. MPPS Quarter-Dollar After Wear Test

Co-Circulate

Go. MPPS showed acceptable color change in its steam test, and proved to have the proper size, weight, edge thickness, and conductivity to co-circulate. It also showed a superior resistance to wear, but needed more tonnage to strike and caused wear to the dies. The Mint determined that this likely could be mitigated with further testing. Security for the quarter-dollar was still being determined, so the team considered MPPS a valid candidate for co-circulation in pre-production testing for both the five-cent and the quarter-dollar.

Go/No-Go Recommendation

Go.

3.3.4. Nickel-Plated Steel (Variability Lot)

Nickel-Plated Steel (NPS) passed all of its Go/No-Go criteria for both the five-cent and the quarter-dollar, except the Mint was still evaluating the security levels needed for the quarter-dollar. Testing continued through the pre-production lots for this denomination. As its EMS signature and weight differ significantly from the current coins, NPS is considered a co-circulation option.

Progression Strikes

The Mint struck five-cent NPS planchets at strike forces from 30 to 65 tonnes. The current five-cent tonnage is 54 tonnes, and at this tonnage, NPS fill matched the current material's, but edge thickness was insufficient until 58 tonnes. Abrasive wear scratches in the progression strikes were attributed to the abrasive nature of the pure-nickel surface layer. For any extensive striking such as pre-production runs, PVD-coated dies would be required.

Figure 3-21. NPS Five-Cent Test Piece

Red arrows indicate abrasive wear scratches

The Mint then struck quarter-dollar planchets at strike forces from 36 to 73 tonnes. NPS fill and coin diameter were unacceptable across the entire range of progression strikes.

Figure 3-22. NPS Quarter-Dollar Test Piece

Red areas indicate insufficient fill.

Steam Test

The NPS blanks showed a slight color change in the variability lot steam test, making the blanks darker, but the change was small. The Mint determined NPS to be superior to the current five-cent and quarter-dollar materials for this test. As shown in Figures 3-23 and 3-24, below, the five-cent and quarter-dollar saw nearly identical color changes, with the hue going slightly more yellow and more red. (The full test results are available in Appendix 10.2.3.)

Figure 3-23. Five-Cent NPS Blank Color Change—Variability Lot

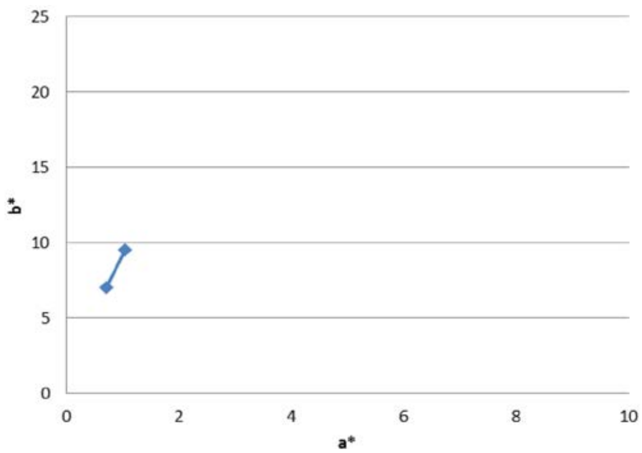
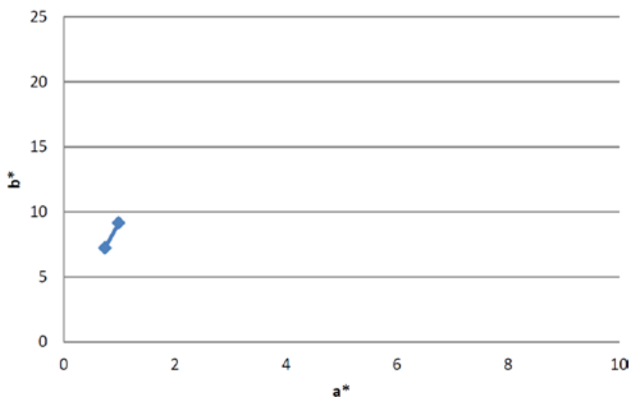


Figure 3-24. Quarter-Dollar NPS Blank Color Change—Variability Lot



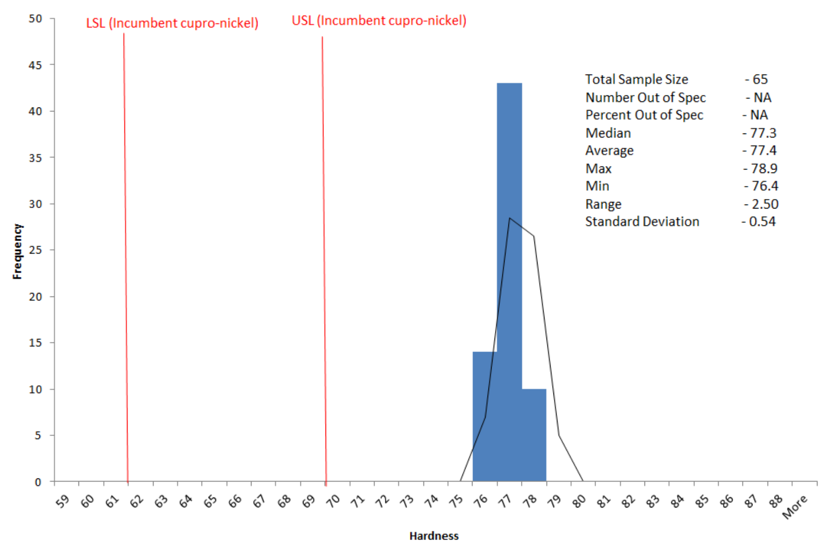
CSV Test

The CSV scans showed acceptable size and EMS measurements for consideration as a co-circulate material. (The full test results are available in Appendix 10.3.3.)

Hardness Test

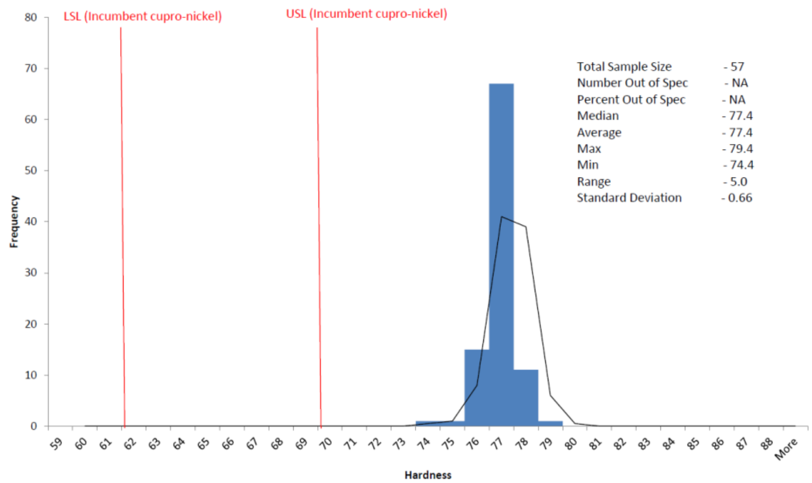
The Mint tested 65 blank NPS five-cent planchets for their hardness, using the Rockwell HR 15T scale. As shown in Figure 3-25, below, NPS showed a hardness range of 76.4 to 78.9, with an average of 77.3, well above the upper limit for the current cupronickel.

Figure 3-25. Five-Cent NPS Planchet Hardness Test—Variability Lot



Next, the Mint tested 57 blank NPS quarter-dollar planchets for their hardness. As shown in Figure 3-26, below, NPS showed a hardness range of 74.4 to 79.4, with an average of 77.4. The range of the samples showed a similar hardness level to the five-cent pieces, well above the upper limit for the current cupronickel.

Figure 3-26. Quarter-Dollar NPS Planchet Hardness Test—Variability Lot



Conductivity

The conductivity test is appropriate for measuring non-ferromagnetic metals and alloys. The construction of the NPS planchet makes this test not applicable due to the combination of non-ferromagnetic plating and ferromagnetic steel substrate, so it was not performed.

Conductivity was measured in the CSV test (see above), which uses sensors capable of measuring the relative electromagnetic properties of both ferromagnetic and non-ferromagnetic metals.

NPS Go/No-Go Determination

Security

Go. For the five-cent, the security requirements are minimal given its value and the standards in the EVA Handbook. However, for the quarter-dollar, the security requirements are more extensive as the coin is near the breakpoint for medium-value coins in the EVA Handbook. At the time of variability testing, no security determination had been established for the quarter-dollar, so the material was approved for pre-production testing.

Recyclability

Go. The recycle path for any condemned or recycled material would be directly to a stainless steel supplier for re-melting and for use on other, non-coin materials. The data suggests that this would be relatively cost-neutral with the recovered metal units offsetting the costs of processing and melting. As iron (steel) and nickel are both present in all stainless steel grades, there would not be any limitation on accepting the scrap for remelting.

Public Health/Toxicity

Go. NPS has no unique hazards such as radioactivity or toxicity, and is not a significant allergen. It is a material used in a number of applications worldwide, including coinage. There are no unique or special hazards associated with it. The nickel coating can cause skin rashes in some small portion of the population with an occurrence possibly higher than the current five-cent or quarter-dollar material which has been acceptable. Its main hazard would be ingestion/aspiration of the material, which could cause gastro-intestinal or respiratory issues; this is unrelated to the material or its use, and so is not a greater or lesser risk for this than any other coin.

Wear Test

Go. NPS performed supremely well in the two-week wear test, as the five-cent nonsense pieces lost an average of 7.7mg of the material compared with the 24.5mg lost by the current material. The quarter-dollar nonsense pieces performed equally well, losing only an average of 5.8mg compared with the 27.2mg lost by the current material. In the five-cent configuration, NPS' edge deformation was less than the current material; in the quarter-dollar configuration, NPS' edge deformation was identical to the current material. (The full test results are available in Appendix 10.1.3.)

Figure 3-27. NPS Quarter-Dollar After Wear Test

NPS quarter-dollar nonsense piece after wear test

Co-Circulate

Go. NPS showed acceptable color change in its steam test, and proved to have the proper size, weight, edge thickness, and conductivity to co-circulate. It also showed a superior resistance to wear, but needed more tonnage to strike and caused wear to the dies. The Mint determined that this could be mitigated with further testing. Security for the quarter-dollar was still being determined, so the team considered NPS a valid candidate for co-circulation in pre-production testing for both the five-cent and the quarter-dollar.

Go/No-Go Recommendation

Go.

3.3.5. Cupronickel 80/20 from Supplier A (80/20A) (Variability Lot)

Cupronickel 80/20 from Supplier A (80/20A) passed all of its Go/No-Go criteria for the five-cent except for the EMS test. 80/20A was intended to be a seamless alternative, but its EMS was too far out of the current material's range. The Mint pursued an alternative composition for 80/20 from Supplier B (see 3.3.6), and 80/20A was deferred from further testing during Phase II to allow the Mint to focus on refining the B composition, which was closer to the current material's EMS.

Progression Strikes

Due to a limited number of blanks available for testing, the Mint did not conduct progression strikes for 80/20A. Instead, the Mint struck five-cent planchets at the current five-cent tonnage of 54 tonnes. At this tonnage, 80/20A achieved acceptable design and dimensional fill that was similar to those of the current five-cent. The Mint observed no difficult-to-fill areas.

Figure 3-28. 80/20A Test Piece (54T Strike)

Steam Test

The 80/20A blanks showed random, large, water stains in the variability lot steam test, making the blanks' test results exceedingly variable and rendering the test inconclusive. (The full test results are available in Appendix 10.2.5.)

CSV Test

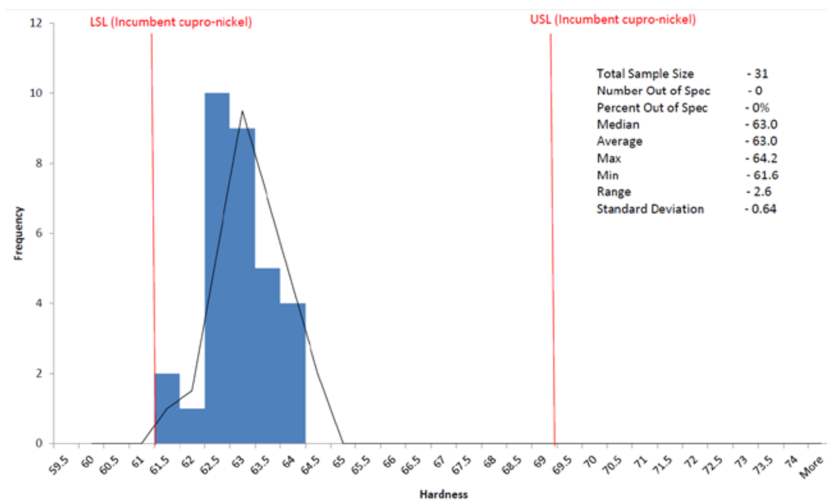
The CSV scans showed acceptable size measurements but unacceptable EMS results for consideration as a seamless material. (The full test results are available in Appendix 10.3.5.)

Hardness Test

The Mint tested 31 blank 80/20A five-cent planchets for their hardness, using the Rockwell HR 15T scale. As shown in Figure 3-29, below, 80/20A showed a hardness range of 61.6 to

64.2, with an average of 63.0. The range of the samples showed a hardness level well within the range of the current cupronickel but slightly softer on average. For cupronickel, the hardness was not a function of just the composition, but also the annealing. These pieces were subject to a laboratory anneal which contributed to the lower hardness observed.

Figure 3-29. Five-Cent 80/20A Planchet Hardness Test—Variability Lot



Conductivity

The Mint tested six batches of five random 80/20A blanks each at minimal and nominal composition for their conductivity. From the lowest to the highest frequencies, 80/20A yielded IACS readings of 5.61% to 6.93% and deviations among the pieces tested at each frequency were well within acceptable parameters.

80/20A Go/No-Go Determination

Security

Go. For the five-cent, the security requirements are minimal given its value and the standards in the EVA Handbook. 80/20A proved to have the same level of security as the current material, with a unique EMS, an uncommon alloy, and no use in other mints.

Recyclability

Go. The recycle path for any condemned or recycled material would be directly to the coin material supplier for re-melting and for use on coin materials. The data suggests that this would be cost-positive with the recovered metal units more than offsetting the costs of processing and melting.

Public Health/Toxicity

Go. As a cupronickel alloy, there are no unique hazards such as radioactivity or toxicity, and it is not a significant allergen. The nickel content can be a cause for skin rashes in some small portions of the population with an occurrence similar to the current five-cent material. Its main hazard would be ingestion/aspiration of the material, which could cause gastro-intestinal or respiratory issues; this is unrelated to the material or its use, and so is not a greater or lesser risk for this than any other coin.

Wear Test

Go. 80/20A performed well in the two-week wear test, as the five-cent nonsense pieces lost an average of 19.5mg of the material compared with the 20.3mg lost by the current material. Edge deformation in the five-cent configuration was only 0.005" more than the current cupronickel, half of the 0.010" allowable deformation. (The full test results are available in Appendix 10.1.5.)

Figure 3-30. 80/20A After Wear Test

Seamless

No-Go. 80/20A showed staining in its steam test, but proved to have the proper size, weight, edge thickness, and conductivity for a seamless candidate. It also showed good resistance to wear, and comparable strike tonnage. Its EMS, however, was too far out of the acceptable range for a seamless candidate. The team therefore deferred 80/20A as a candidate.

Go/No-Go Recommendation

No-Go.

3.3.6. Cupronickel 80/20 from Supplier B (80/20B) (Variability Lot)

Cupronickel 80/20 from Supplier B (80/20B) passed all of its Go/No-Go criteria for the five-cent as a seamless alternative. The Mint requested this material as a development step in conjunction with the 80/20A, and had the supplier change the material to 77% Cu/19.7% Ni/3.3% Mn, which showed a promising EMS match.

Progression Strikes

Due to a limited number of blanks available for testing, the Mint did not conduct progression strikes for 80/20B. Instead, the Mint struck five-cent planchets at the current five-cent tonnage of 54 tonnes. At this tonnage, 80/20B achieved acceptable design and dimensional fill that was similar to those of the current five-cent. The Mint observed no difficult-to-fill areas.

Figure 3-31. 80/20B Test Piece (54T Strike)

Steam Test

The 80/20B blanks showed random, large, water stains in the variability lot steam test, making the blanks' test results exceedingly variable and rendering the test inconclusive. (The full test results are available in Appendix 10.2.6.)

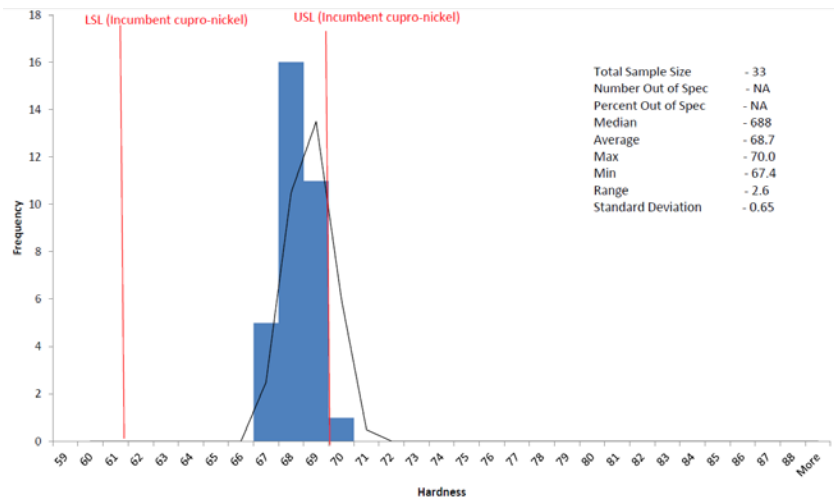
CSV Test

The CSV scans showed acceptable size measurements and acceptable EMS results for consideration as a potentially seamless material with minor adjustments to the composition. (The full test results are available in Appendix 10.3.6.)

Hardness Test

The Mint tested 33 blank 80/20B five-cent planchets for their hardness, using the Rockwell HR 15T scale. As shown in Figure 3-32, below, 80/20B showed a hardness range of 67.4 to 70.0, with an average of 68.7. The range of the samples showed a hardness level well within the range of the current cupronickel but slightly harder on average. Whether this was related to composition changes, use of a laboratory anneal or both could not be determined.

Figure 3-32. Five-Cent 80/20B Planchet Hardness Test—Variability Lot



Conductivity

The Mint tested three batches of 25 random 80/20B blanks each at minimal and nominal composition for their conductivity. From the lowest to the highest frequencies, 80/20B yielded IACS readings of 5.00% to 5.99% and deviations among the pieces tested at each frequency were well within acceptable parameters.

80/20B Go/No-Go Determination

Security

Go. For the five-cent, the security requirements are minimal given its value and the standards in the EVA Handbook. 80/20B proved to have the same level of security as the current material, with a unique EMS, an uncommon alloy, and no use in other mints.

Recyclability

Go. Any condemned or recycled material would go directly to the coin material supplier for re-melting and for use on coin materials. The data suggests that this would be cost positive with the recovered metal units more than offsetting the costs of processing and melting.

Public Health/Toxicity

Go. As a cupronickel alloy, there are no unique hazards such as radioactivity or toxicity, and it is not a significant allergen. The nickel content can be a cause for skin rashes in some small portions of the population with an occurrence similar to the current five-cent material, which has been acceptable. Its main hazard would be ingestion/aspiration of the material, which could cause gastro-intestinal or respiratory issues; this is unrelated to the material or its use, and so is not a greater or lesser risk for this than any other coin.

Wear Test

Go. 80/20B performed well in the two-week wear test, as the five-cent nonsense pieces lost an average of 16.8mg of their material compared with the average of 19mg that the current pieces lost. Edge deformation in the five-cent configuration was measured at the 0.010" allowable deformation. (The full test results are available in Appendix 10.1.6.)

Figure 3-33. 80/20B After Wear Test

Seamless

Go. 80/20B showed staining in its steam test, but proved to have the proper size, weight, edge thickness, and conductivity for a potentially seamless candidate. It also showed good resistance to wear, and comparable strike tonnage. The material has an EMS that can be read by vending machines and other coin handling equipment. Its signature is very similar to that of the current material and could potentially be seamless with further composition changes.

Go/No-Go Recommendation

Go.

3.4. Pre-Production Testing

The materials that passed Go/No-Go—nickel-plated steel, multi-ply-plated steel, and 80/20B—were subjected to many of the same tests in pre-production as they saw in variability. The materials were purchased in their standard configurations (not purchased in minimum, maximum, and nominal variances) expected to be seen in normal production.

Die life and die wear were not tested in variability lots, but both were considerations in pre-production testing. Other tests that had been performed in variability lots (wear, steam color change, CSV) were applied to the pre-production lots to determine how well the materials performed at their standard configurations.

Materials in pre-production testing were put through a down-selection process at the end of testing, in which they each were measured against current coinage materials to determine their feasibility for use in U.S. coinage.

Both nickel-plated steel and multi-ply-plated steel were tested in five-cent and quarter-dollar configurations while 80/20B was tested only in the five-cent configuration (with the understanding that it could replace the current clad material in the dime, quarter-dollar, and half-dollar if it passed as a seamless alternative for the cupronickel five-cent).

3.4.1. CPZ Pre-Production Data

The Mint purchased CPZ for pre-production and the pre-production tests were completed before the Mint had finalized the optimization of the wear test. Therefore, when CPZ failed its Go/No-Go determination (due to durability of plating thickness and substrate), even though the Mint had already run the pre-production tests, CPZ was not put through a down-selection process. (CPZ's pre-production test data is included in this report only as reference through Appendix 10.4.)

3.4.2. Down-Selection Matrices

The following tables summarize the down-selection process for the co-circulate materials that passed Go/No-Go. In all cases, criteria were rated in two tiers: Comparable or Better, and Less than Current.

Multi-Ply-Plated Steel (Five-Cent)

Alternative Metals Viability					
Factor	Description	Rating Comparable or Better Less than Current	Justifications & Comments		Judging Rubric
Cost (per unit)	Total unit cost including consideration for capital expenditures vs. anticipated material savings	$0.0547	Estimated cost is $0.0547/unit, $0.0262 less (32% lower) than current.	X	Over 11% lower than current ($0.0809)
					Up to 10% lower than current
Environmental Impact	No change or better compared to current for internal operations and external fabricator	Comparable or Better	Operation of plating should be considered major change to waste stream, but can be effectively mitigated.	X	No changes, or changes to waste stream that can be effectively mitigated
					Unmitigated environmental impacts
Supply Chain	Future availability of the metal and a competitive supply chain - more than one fabricator/supplier	Less than Current	All materials are in adequate supply; Royal Canadian Mint holds patent for fabrication process which controls supplier base.		Adequate raw metal supply available; at least two established suppliers
				X	Adequate raw metal supply available; one supplier or supplier(s) is not proven
Coinability	Crack/piece-out incidences are less than or equal to our current, die life is acceptable	Less than Current	Plated steel die failure proved significantly higher than current. Experience at other mints suggests design changes could improve performance.		Considering the number of strikes before die retirement, die surface crack/piece-out incidence rates are similar or less than standard crown/relief test dies (current)
				X	Considering the number of strikes before die retirement, die surface crack/piece-out incidence rates are greater than standard crown/relief test dies (current)
Recyclability	Ease of recycling and value of metal recovery	Less than Current	Material recyclable, for non-coin use only; issue with volume of coins recycled; market limited due to copper content.		Similar or higher metal value recoverable in recycling, including handling costs
				X	Disposed of with reduced or no metal value in recovery, no handling cost to US Mint
Durability	Tarnish and corrosion resistance Acceptable durability/wear	Comparable or Better	Wear rate 82% lower than current; minimal discoloration.	X	Minimal or no discoloration and same or reduced wear
					Significant discoloration and increased wear
Counterfeit/Slug Vulnerability	Uniqueness among world coins, limited use of lesser value foreign coins, tokens or easily produced counterfeit devices	Less than Current	Commonly used, readily available material; ferromagnetic core; plating easily replicated; no unique EMS found.		Discrete or unique EMS, using common or uncommon materials and fabrication process
				X	No unique EMS, using common material and fabrication processes; easily counterfeited

Nickel-Plated Steel (Five-Cent)

Alternative Metals Viability					
Factor	Description	Rating (Comparable or Better / Less than Current)	Justifications & Comments	Judging Rubric	
Cost (per unit)	Total unit cost including consideration for capital expenditures vs. anticipated material savings	$0.0611	Estimated cost is $0.0611/unit, $0.0176 less (22% lower) than current.	X	Over 11% lower than current ($0.0787)
					Up to 10% lower than current
Environmental Impact	No change or better compared to current for internal operations and external fabricator	Comparable or Better	Operation of plating should be considered major change to waste stream, and can be effectively mitigated.	X	No changes, or changes to waste stream that can be effectively mitigated
					Unmitigated environmental impacts
Supply Chain	Future availability of the metal and a competitive supply chain - more than one fabricator/supplier	Comparable or Better	All materials are in adequate supply; two existing suppliers of this material.	X	Adequate raw metal supply available; at least two established suppliers
					Adequate raw metal supply available; one supplier or supplier(s) is not proven
Coinability	Crack/piece-out incidences are less than or equal to our current, die life is acceptable	Less than Current	Plated steel die failure proved significantly higher than current. Experience at other mints suggests design changes could improve performance.		Considering the number of strikes before die retirement, die surface crack/piece-out incidence rates are same or less than standard crown/relief test dies (current)
				X	Considering the number of strikes before die retirement, die surface crack/piece-out incidence rates are greater than standard crown/relief test dies (current)
Recyclability	Ease of recycling and value of metal recovery	Less than Current	Material recyclable, but only for non-coin use. Material sees flexible use in recycling with only nickel in its plating.		Similar or higher metal value recoverable in recycling, including handling costs
				X	Disposed of with reduced or no metal value in recovery, no handling cost to US Mint
Durability	Tarnish and corrosion resistance; Acceptable durability/wear	Comparable or Better	Wear rate 85% lower than current; no significant discoloration.	X	Minimal or no discoloration and same or reduced wear
					Significant discoloration and increased wear
Counterfeit/Slug Vulnerability	Uniqueness among world coins, limited use of lesser value foreign coins, tokens or easily produced counterfeit devices	Less than Current	Commonly used, readily available material; ferromagnetic core; plating easily replicated; no unique EMS found.		Discrete or unique EMS, using common or uncommon materials and fabrication process
				X	No unique EMS, using common material and fabrication processes; easily counterfeited

Stainless Steel (Five-Cent)

Alternative Metals Viability					
Factor	**Description**	**Rating** (Comparable or Better / Less than Current)	**Justifications & Comments**		**Judging Rubric**
Cost (per unit)	Total unit cost including consideration for capital expenditures vs. anticipated material savings	$0.0583	Estimated cost is $0.0583/unit, $0.0204 less (26% lower) than current.	X	Over 11% lower than current ($0.0787)
					Up to 10% lower than current
Environmental Impact	No change or better compared to current for internal operations and external fabricator	Comparable or Better	Similar to current waste stream.	X	No changes, or changes to waste stream that can be effectively mitigated
					Unmitigated environmental impacts
Supply Chain	Future availability of the metal and a competitive supply chain - more than one fabricator/supplier	TBD	Raw materials in good supply; one of two recommended materials is patent pending, which could impact supply chain.		Adequate raw metal supply available; at least two established suppliers
					Adequate raw metal supply available; one supplier or supplier(s) is not proven
Coinability	Crack/piece-out incidences are less than or equal to our current, die life is acceptable	TBD	Limited testing. Larger scale test warranted on two 3XX series grades.		Considering the number of strikes before die retirement, die surface crack/piece-out incidence rates are similar or less than standard crown/relief test dies (cupronickel baseline)
					Considering the number of strikes before die retirement, die surface crack/piece-out incidence rates are greater than standard crown/relief test dies (cupronickel baseline)
Recyclability	Ease of recycling and value of metal recovery	Comparable or Better	Monolithic material that can be 100% recycled into future coin use.	X	Any metal value recoverable in recycling, including handling costs
					Disposed of with no metal value in recovery, no handling cost to US Mint
Durability	Tarnish and corrosion resistance Acceptable durability/wear	Comparable or Better	18-9 LW—Wear rate 98% lower than current; Rittenhouse 52—Wear rate 95% lower than current; No discoloration in either	X	Minimal or no discoloration and same or reduced wear
					Significant discoloration and increased wear
Counterfeit/Slug Vulnerability	Uniqueness among world coins, limited use of lesser value foreign coins, tokens or easily produced counterfeit devices	Less than Current	Commonly used, readily available material; no unique EMS found.		Discrete or unique EMS, using common or uncommon materials and fabrication process
				X	No unique EMS, using common material and fabrication processes; easily counterfeited

Multi-Ply-Plated Steel (Quarter-Dollar)

Alternative Metals Viability					
Factor	Description	Rating Comparable or Better Less than Current	Justifications & Comments	Judging Rubric	
Cost (per unit)	Total unit cost including consideration for capital expenditures vs. anticipated material savings	$0.0651	Estimated cost is $0.0651/unit, $0.0261 less (29% lower) than current.	X	Over 11% lower than current ($0.0912)
					Up to 10% lower than current
Environmental Impact	No change or better compared to current for internal operations and external fabricator	Comparable or Better	Operation of plating should be considered major change to waste stream, but can be effectively mitigated.	X	No changes, or changes to waste stream that can be effectively mitigated
					Unmitigated environmental impacts
Supply Chain	Future availability of the metal and a competitive supply chain - more than one fabricator/supplier	Less than Current	All materials are in adequate supply; Royal Canadian Mint holds patent for fabrication process which controls supplier base.		Adequate raw metal supply available; at least two established suppliers
				X	Adequate raw metal supply available; one supplier or supplier(s) is not proven
Coinability	Crack/piece-out incidences are less than or equal to our current, die life is acceptable	Less than Current	Plated steel die failure proved significantly higher than current. Experience at other mints suggests design changes could improve performance.		Considering the number of strikes before die retirement, die surface crack/piece-out incidence rates are similar or less than standard crown/relief test dies (cupronickel baseline)
				X	Considering the number of strikes before die retirement, die surface crack/piece-out incidence rates are greater than standard crown/relief test dies (cupronickel baseline)
Recyclability	Ease of recycling and value of metal recovery	Less than Current	Scrap market limited due to copper content. Material recyclable, for non-coin use only; issue with volume of coins recycled.		Similar or higher metal value recoverable in recycling, including handling costs
				X	Disposed of with reduced or no metal value in recovery, no handling cost to US Mint
Durability	Tarnish and corrosion resistance Acceptable durability/wear	Comparable or Better	Wear rate 84% lower than current; minimal discoloration.	X	Minimal or no discoloration and same or reduced wear
					Significant discoloration and increased wear
Counterfeit/Slug Vulnerability	Uniqueness among world coins, limited use of lesser-value foreign coins, tokens or easily produced counterfeit devices	Less than Current	Commonly used, readily available material; ferromagnetic core; plating easily replicated; no unique EMS found; lesser-value foreign coins (e.g., Philippine 1-peso coin, worth $0.02) match material and size.		Discrete or unique EMS, using common or uncommon materials and fabrication process
				X	No unique EMS, using common material and fabrication processes; easily counterfeited

Nickel-Plated Steel (Quarter-Dollar)

Alternative Metals Viability

Factor	Description	Rating Comparable or Better Less than Current	Justifications & Comments		Judging Rubric
Cost (per unit)	Total unit cost including consideration for capital expenditures vs. anticipated material savings	$0.0676	Estimated cost is $0.0676/unit, $0.0236 less (26% lower) than current.	X	Over 11% lower than current ($0.0912)
					Up to 10% lower than current
Environmental Impact	No change or better compared to current for internal operations and external fabricator	Comparable or Better	Operation of plating should be considered major change to waste stream, and can be effectively mitigated	X	No changes, or changes to waste stream that can be effectively mitigated
					Unmitigated environmental impacts
Supply Chain	Future availability of the metal and a competitive supply chain - more than one fabricator/supplier	Comparable or Better	All materials are in adequate supply; two existing suppliers of this material.	X	Adequate raw metal supply available; at least two established suppliers
					Adequate raw metal supply available; one supplier or supplier(s) is not proven
Coinability	Crack/piece-out incidences are less than or equal to our current, die life is acceptable	Less than Current	Plated steel die failure proved significantly higher than current. Experience at other mints suggests design changes could improve performance.		Considering the number of strikes before die retirement, die surface crack/piece-out incidence rates are similar or less than standard crown/relief test dies (cupronickel baseline)
				X	Considering the number of strikes before die retirement, die surface crack/piece-out incidence rates are greater than standard crown/relief test dies (cupronickel baseline)
Recyclability	Ease of recycling and value of metal recovery	Less than Current	Material recyclable, but only for non-coin use. Material sees flexible use in recycling with only nickel in its plating.		Similar or higher metal value recoverable in recycling, including handling costs
				X	Disposed of with reduced or no metal value in recovery, no handling cost to US Mint
Durability	Tarnish and corrosion resistance Acceptable durability/wear	Comparable or Better	Wear rate 72% lower than current; no significant discoloration.	X	Minimal or no discoloration and same or reduced wear
					Significant discoloration and increased wear
Counterfeit/Slug Vulnerability	Uniqueness among world coins, limited use of lesser value foreign coins, tokens or easily produced counterfeit devices	Less than Current	Commonly used, readily available material; ferromagnetic core; plating easily replicated; no unique EMS found; lesser-value foreign coins (e.g., Nigerian 50-Kobo coin, worth $0.003) match material and size.		Discrete or unique EMS, using common or uncommon materials and fabrication process
				X	No unique EMS, using common material and fabrication processes; easily counterfeited

3.4.3. Multi-Ply-Plated Steel (Pre-Production Lot)

For pre-production testing, the upset profiles of the Multi-Ply-Plated Steel (MPPS) planchets were modified from those used in variability lots. MPPS passed its down-selection criteria for the five-cent, with Comparable or Better in half of its criteria, but it rated Less than Current in four of the six criteria for the quarter-dollar, including for coinability and counterfeit/slug vulnerability. MPPS showed insufficient fill in both five-cent and quarter-dollar denominations in the progression strikes, only seeing complete fill above the current strike force, and seeing a significantly greater rate of die failure than seen with the current material.

The RCM PVD-coated the dies for pre-production testing, and the coating worked to prevent abrasive wear when striking the nickel surface of the planchets. Polishing the dies before PVD coating extended the die life, but the dies still failed in under 250,000 strikes (less than half the baseline of 500,000 strikes).

Progression Strikes

The Mint struck five-cent MPPS planchets at strike forces from 20 to 60 tonnes. The current five-cent tonnage is 54 tonnes, and at this and 56 tonnes, MPPS fill was poor. The PVD coating on the dies succeeded in preventing abrasive wear scratches from appearing in struck pieces.

Figure 3-34. MPPS Five-Cent Test Piece (56T Strike)

The top of Martha's bonnet, near the upper-left edge, shows insufficient fill

The Mint struck quarter-dollar MPPS planchets at strike forces from 36 to 64 tonnes. The current quarter-dollar tonnage is 62 tonnes; design/border fill was acceptable at 55 tonnes, but the MPPS nonsense pieces needed 64 tonnes to see acceptable fill in the lettering along the edge. The early fill at the border likely "locked" the metal at the border of the planchets, preventing the material in the center of the planchet from flowing out to the border and filling in the letters in the die. This necessitated the increase in strike force that may have contributed to die failure.

Figure 3-35. MPPS Quarter-Dollar Test Piece (64T Strike)

The Mint determined that five-cent and quarter-dollar MPPS pieces struck with polished, PVD-coated dies performed worse than with the current material in terms of strike force and die life.

The Mint also observed a greater rate of crack/piece-out incidents and a higher die-life-failure rate than the current material, seeing die pairs last an average of 200,000 strikes before they had to be replaced (as compared to the nominal 500,000). Two sets of unpolished, PVD-coated dies saw cracks form at just over 20,000 strikes, illustrating that polishing of the die would be necessary.

Further research will be needed to determine what the optimized die life will be, but it is anticipated to be fewer than 500,000 strikes. RCM's current average die life, after years of producing MPPS coins, is 350,000 strikes. A financial analysis can be done on how the loss in productivity impacts the anticipated material cost savings.

Steam Test

There was little color change shown by the MPPS blanks in the pre-production lot steam test, and the Mint determined MPPS to be superior to the current five-cent and quarter-dollar materials for this test. The results are shown in Figures 3-36 and 3-37, below, with the "before" point lower and to the left of the "after" point in each graph. (The full test results are available in Appendix 10.5.2.)

Figure 3-36. Five-Cent MPPS Blank Color Change—Pre-Production Lot

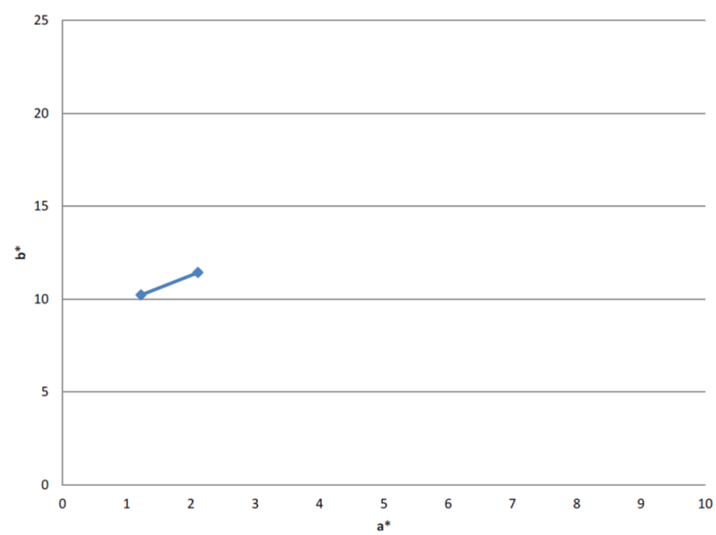
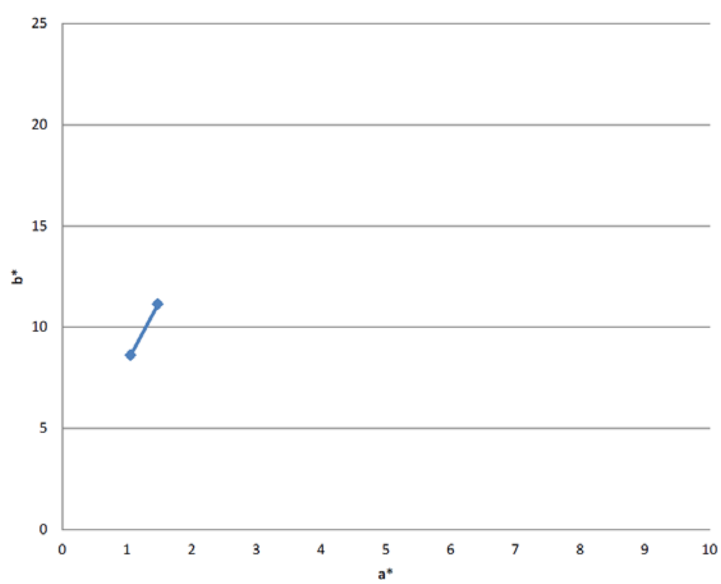


Figure 3-37. Quarter-Dollar MPPS Blank Color Change—Pre-Production Lot



CSV

The CSV tests showed acceptable conductivity, size, and EMS measurements for a co-circulate material, though the EMS was not unique among world coins, contributing to a security concern about the application of this material to the quarter-dollar. (The full test results are available in Appendix 10.6.2, at the end of this report.)

Hardness Test

The Mint tested two lots of 255 blank MPPS five-cent planchets and two lots of 255 blank MPPS quarter-dollar planchets for their hardness, using the Rockwell HR 15T scale. MPPS showed a hardness range of 65.4 to 69.9 with an average of 67.9 in the five-cent, and a range of 65.3 to 73.6 with an average of 68.8 in the quarter-dollar, almost identical to the hardness shown in the variability lots. The range of the samples showed a slightly harder level than the current cupronickel.

Wear Test

MPPS performed even better in the two-week wear test for pre-production than it had in variability. The five-cent and quarter-dollar nonsense pieces both lost an average of 3.4mg of the material compared with the 19.0mg lost by the current five-cent material and the 27.2mg lost by the current quarter-dollar material. Edge deformation in the five-cent and quarter-dollar MPPS was less than the deformation shown by the current material. (The full test results are available in Appendix 10.4.2.)

3.4.4. MPPS Down-Selection

Environmental Impact

Comparable or Better. As MPPS is a plated material being tested as a replacement for the monolithic five-cent and the three clad denominations, data suggests that the use of this material would have a negative impact on the waste stream. However, this impact could be effectively mitigated.

Supply Chain

Less than Current. All the raw materials in MPPS are in adequate supply, but the Royal Canadian Mint has a pending U.S. patent extension application on this material, effectively reducing the number of established suppliers to one, as compared to the current two suppliers for both the five-cent and the quarter-dollar.

Coinability

Less than Current. Pre-production strikes of standard-crown dies at comparable tonnage to the current strike force saw a significantly greater rate of failure to the dies than seen with current materials. The Mint also observed inferior fill rates at comparable tonnage to the current material. More testing will be needed to see if these issues can be mitigated.

Recyclability

Less than Current. MPPS sees an inferior recycling option compared with current materials. While steel and nickel are both sought by stainless steel manufacturers, the inclusion of copper in this material limits its scrap market. Copper-bearing stainless steel grades made up only 40 percent and 15 percent at two domestic stainless steel plants, illustrating the limitations presented by the copper plating. The material is recyclable, for non-coin use only, but there is a potential land-fill issue with the volume of coins the Mint would likely recycle (based on the number of coins currently sent back to suppliers by the Mint).

Durability

Comparable or Better. The Mint observed a superior wear rate after the wear test and minimal discoloration after the steam test with MPPS. MPPS showed a wear rate 82 percent lower than the current material.

Counterfeit/Slug Vulnerability (Quarter-Dollar Only)

Less than Current. MPPS has a ferromagnetic core made of a very common material. The plating of this material is easily replicated and easily counterfeited (in testing, a steel slug plated for a few minutes in a copper solution (using only a battery) and another steel slug with aluminum foil taped to it were both accepted by two different coin acceptors as MPPS quarter-dollars). MPPS' EMS was also found to vary far more than the current quarter-dollar and was not unique among world coins. (The Philippine one-peso coin, for example, is approximately the same size as the quarter-dollar and is made of MPPS, but is only worth about $0.02.) The Mint determined that MPPS' security was lesser than the current quarter-dollar's.

Feasibility

Five-Cent – **Feasible**

Quarter-Dollar – **Not Feasible**

3.4.5. Nickel-Plated Steel (Pre-Production Lot)

Nickel-Plated Steel (NPS) rated as Comparable or Better for half of its Down Selection criteria as a co-circulate option for the five-cent and the quarter-dollar, but it rated as Less than Current in coinability, recyclability, and counterfeit/slug vulnerability (which did not apply to the five-cent).

After the variability testing was complete, the Mint provided feedback to The Royal Mint (RM) technical representatives and subsequently RM revised the upset profiles and sent small quantities of planchets (five-cent and quarter-dollar) called "Pilot lots." The RM also PVD-coated the dies to alleviate the abrasion of the blanks' nickel surface, but the Mint still observed a significantly greater rate of die failure than seen with the current material. Some die pairs were polished before PVD coating and others were not, to determine what difference, if any, polishing would make.

The Mint conducted further progression strikes, and quarter-dollar progression strikes demonstrated improvements from the previous strike, but required 66 tonnes to achieve acceptable design fill and coin dimensions. The border achieved fill at only 58 tonnes, which likely "locked" the metal at the border of the planchets, preventing the material in the center of the planchet from flowing out to the border and filling in the detail in the die.

Figure 3-38. NPS Quarter-Dollar Test Piece (66T Strike)

Revised-upset five-cent planchets produced test pieces with worse design fill and coin edge thickness than those of the previous progression strikes. Again, feedback was provided to RM for improvement to the five-cent upset profile prior to receiving pre-production quantities. Changes were also requested for the quarter-dollar to counter the die-failure rate.

The revised-upset quarter-dollar NPS planchets arrived in late July. In spite of the changes requested for the quarter-dollar planchets, design fill and coin edge thickness were still worse than those of the previous progression strikes. Die-life failure rates were also drastically higher with this material than with the current material. The data suggests that this material will continue to have issues with strike force and die-life failure regardless of changes made to the coining system.

Figure 3-39. NPS Five-Cent Test Piece (Detail)

NPS five-cent: edge lettering showing poor letter fill

Progression Strikes

After receiving the pre-production lots, the Mint struck five-cent NPS planchets at strike forces from 20 to 60 tonnes. The current five-cent tonnage is 54 tonnes, and at this and 56 tonnes, NPS fill was acceptable. The PVD coating on the dies succeeded in preventing abrasive wear scratches from appearing in struck pieces.

The Mint struck quarter-dollar NPS planchets at strike forces from 36 to 64 tonnes. The current quarter-dollar tonnage is 62 tonnes; design/border fill was acceptable at 55 tonnes, but the NPS nonsense pieces needed 64 tonnes to see acceptable fill in the lettering along the edge.

The rates of die failure with NPS were greater than that seen with the current material, as PVD-coated die pairs failed on an average of 261,000 strikes, below the baseline level of the current material and standard dies, which was 500,000. Dies that were not polished before PVD coating failed on an average of 77,000 strikes. Cracks presented on both the obverse (bonnet area) and reverse (building top corner to coin edge) of the dies.

The Mint determined the coating failures were related to metal oxides on the dies' surfaces. PVD coatings typically do not adhere as well to metal oxides as they do to elemental metal. The RM dies were relatively free of surface oxides after heat treatment and their follow-on polishing operation removed what thin oxide layer may have been present. U.S. Mint dies have much thicker oxide layers and limited post-finishing operation to remove these layers. The significant difference in die life seen between the non-polished and polished dies indicated that future dies would need to be polished to provide a more-uniform surface and one that was free of oxides.

The five-cent planchets and struck pieces further exhibited indications of poor lubrication, a condition that needs to be investigated further. The team saw unacceptable, excessive wear on the press parts, especially the press's mechanical "fingers" that move the planchets into position at the dies and the conveyor belts that take struck coins away. The excessive wear must be resolved to support sustained coining operations.

Improved coinability and die life could be achieved with an optimization of the die designs to be more compatible with the NPS material. The hardness check on the retained planchets showed NPS to be approximately 20 percent harder than the current material. Also, the upset profile of the planchets appeared sharper than the current material's flatter configuration. Both of these, along with the poor lubrication, could also have contributed to the excessive equipment wear.

While it is possible to double the die life with changes in coin features and lubrication, it is not likely that these changes alone will improve the die-life gap. Some reduction in die life is to be expected with this alternative material. The die life achieved by RM is around 600,000 strikes for the 5-pence and 10-pence coins. Other countries that RM has supplied with NPS have an average of 447,000 strikes with a range from 215,000 to 800,000. This average is on coins with differing features, and the quality standards for those mints are unknown. Given the need for coin changes and the lower anticipated die life, this material is considered as Less than Current for coinability and die wear.

Further research will be needed to determine what the optimized die life will be, but it is anticipated to be less than 500,000 strikes. A financial analysis can be performed on how the loss in productivity impacts the anticipated material cost savings.

Steam Test

There was little color change shown by the NPS blanks in the pre-production lot steam test, and the Mint determined NPS to be superior to the current five-cent and quarter-dollar materials for this test. The results are shown in Figures 3-40 and 3-41, below, with the "before" point lower and to the left of the "after" point in each graph. (The full test results are available in Appendix 10.5.1.)

Figure 3-40. Five-Cent NPS Blank Color Change—Pre-Production Lot

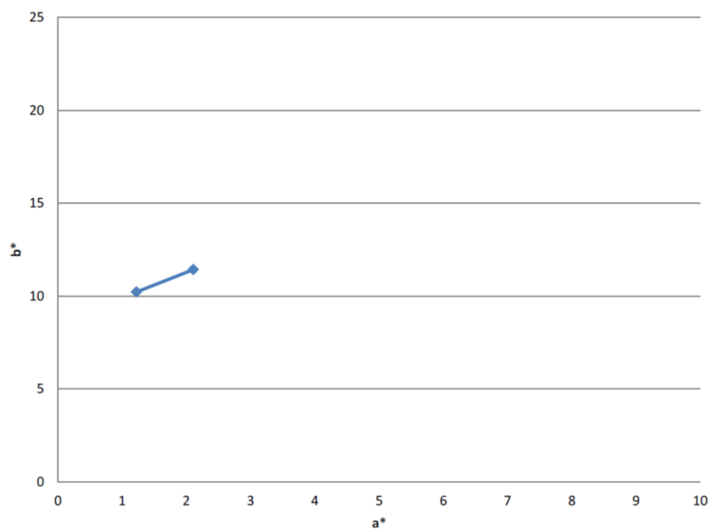
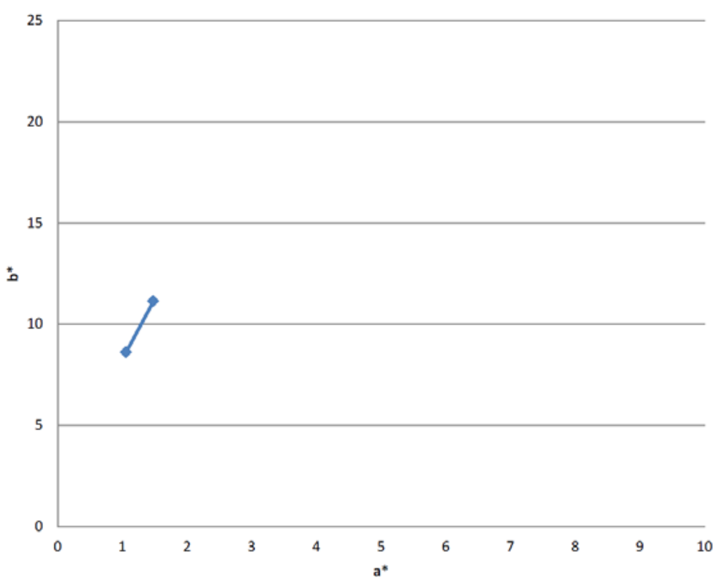


Figure 3-41. Quarter-Dollar NPS Blank Color Change—Pre-Production Lot



CSV

The CSV tests showed acceptable conductivity, size, and EMS measurements for a co-circulate material, though the EMS was not unique among world coins, contributing to this material's security failure for the quarter-dollar. (The full test results are available in Appendix 10.6.1.)

Hardness Test

The Mint tested two lots of 255 blank NPS five-cent planchets and two lots of 255 blank NPS quarter-dollar planchets for their hardness, using the Rockwell HR 15T scale. NPS showed a hardness range of 65.4 to 69.9 with an average of 67.9 in the five-cent, and a range of 65.3 to 73.6 with an average of 68.8 in the quarter-dollar, almost identical to the hardness seen in the variability lots. The range of the samples showed a higher hardness level than the current cupronickel.

Wear Test

As in the variability lot wear test, NPS performed exceptionally well, with a wear rate 72 percent lower than the current material (4.6mg v. 19mg for five-cent and 7.5mg v. 27.2mg for the quarter-dollar). In addition, the five-cent and the quarter-dollar NPS pieces showed an average edge deformation lower than that shown by the current material. (The full test results are available in Appendix 10.4.1.)

3.4.6. NPS Down-Selection

Environmental Impact

Comparable or Better. As NPS is a plated material being tested as a replacement for the monolithic five-cent and the three clad denominations, the data suggests that the use of NPS would have a negative impact on the waste stream. However, that impact could be effectively mitigated.

Supply Chain

Comparable or Better. All the raw materials in NPS are in adequate supply. There are at least two established suppliers, which is identical to the current two suppliers for both the five-cent and the quarter-dollar.

Coinability

Less than Current. Pre-production strikes of standard-crown dies at comparable tonnage to the current material had a significantly greater rate of die failure than with current materials. The Mint also observed that changes The Royal Mint made to the upset profile between the Pilot lot and the pre-production lot improved the fill on progression strikes dramatically.

The Mint also saw more wear on the press machinery, from the feed bowl, the mechanical "fingers" that move planchets into the press, and the conveyor belt that carries the new coins away. In some of these cases, parts that normally would last weeks required changing every eight hours or less.

Recyclability

Less than Current. NPS sees an inferior recycling option compared with current materials. While steel and nickel are both sought by stainless steel manufacturers, the recyclability would be for non-coin use only.

Durability

Comparable or Better. The Mint observed a superior wear rate and minimal discoloration with NPS. NPS showed a wear rate of only 18 percent, below the maximum 20 percent set by the Mint.

Counterfeit/Slug Vulnerability (Quarter-Dollar Only)

Lesser than Current. NPS has a ferromagnetic core and is made of commonly used, readily available materials. NPS' plating is easily replicated (many web sites have simple instructions on how to nickel-plate objects such as coins). The EMS was wider than the current quarter-dollar and was not unique among world coins. (The Nigerian 50-Kobo coin, for example, is approximately the same size as the quarter-dollar and is made of NPS, but is only worth $0.003.) The Mint determined that NPS' security was lesser than the current quarter-dollar's.

Feasibility

Five-Cent – **Feasible**

Quarter-Dollar – **Not Feasible**

3.4.7. Cupronickel 80/20B (Pre-Production Lot)

Cupronickel 80/20 supplied by Supplier B (80/20B) rated as Comparable or Better for all of its Down Selection criteria as a seamless option for the five-cent, and is expected to perform equally well as cladding for the dime, quarter-dollar, and half-dollar (testing to begin in Phase III).

Progression Strikes

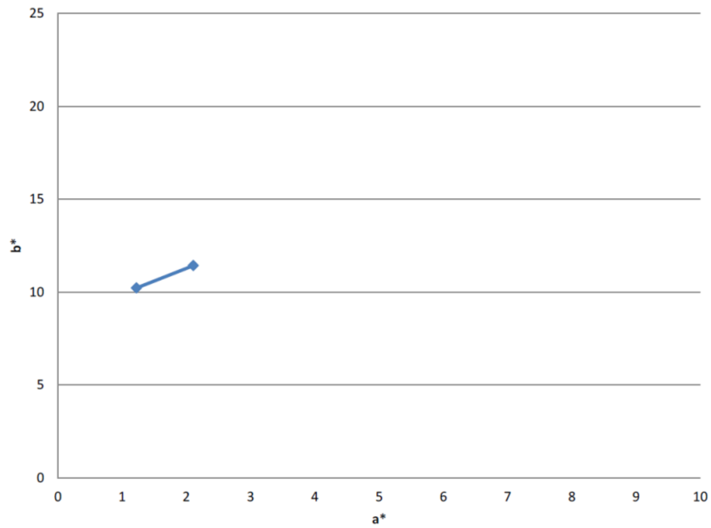
The Mint struck five-cent 80/20B planchets at strike forces from 20 to 60 tonnes. The current five-cent tonnage is 54 tonnes, and at this and 56 tonnes, 80/20B fill was acceptable.

Figure 3-44. 80/20B Test Piece (54T Strike)

Steam Test

There was little color change shown by the 80/20B blanks in the pre-production lot steam test, and the Mint determined 80/20B to be comparable to the current five-cent material for this test. The results are shown in Figure 3-43, below, with the "before" point lower and to the left of the "after" point in the graph. (The full test results are available in Appendix 10.5.3.)

Figure 3-45. Five-Cent 80/20Blank Color Change—Pre-Production Lot



CSV

The CSV tests showed acceptable size measurements for a seamless material, and an EMS that matched the current five-cent. (The full test results are available in Appendix 10.6.3.)

Hardness Test

The Mint tested two lots of 255 blank 80/20B five-cent planchets, using the Rockwell HR 15T scale. 80/20B showed a hardness range of 65.4 to 69.9 with an average of 67.9 in the five-cent, almost identical to the current cupronickel.

Conductivity

The Mint tested six batches of five random 80/20B planchets for their conductivity. The planchets were tested at four different frequencies, and from the lowest to the highest frequencies, 80/20B yielded IACS readings of 5.61% to 6.93%. Deviations among the pieces tested at each frequency were well within acceptable parameters. The readings were very similar to current conductivity measurements.

Wear Test

As in the variability lot wear test, 80/20B wear rate was comparable to the current material, losing 7 percent less material (17.6mg v. 19mg). In addition, the five-cent pieces showed an average edge deformation lower than that shown by the current material. (The full test results are available in Appendix 10.4.3.)

3.4.8. 80/20B Down-Selection

Environmental Impact

Comparable or Better. 80/20B has nearly the same configuration as the current five-cent, and the addition of manganese does not cause any significant environmental impact.

Supply Chain

Comparable or Better. All the raw materials in 80/20B are in adequate supply. The number of established suppliers is identical to the current two suppliers for the five-cent.

Coinability

Comparable or Better. Pre-production strikes of standard-crown dies at comparable tonnage to the current strike force saw a slightly lesser rate of failure to the dies than seen with current materials. The Mint also observed acceptable fill rates at comparable tonnage to the current material.

Recyclability

Comparable or Better. 80/20B sees a comparable recycling option compared with current materials for the five-cent. If this material is also chosen to replace the cladding in the clad denominations, then the inclusion of manganese may impact the recycling options.

Durability

Comparable or Better. The Mint observed a comparable wear rate and minimal discoloration with 80/20B. 80/20B showed a wear rate of only 18 percent, below the maximum 20 percent set by the Mint.

Counterfeit/Slug Vulnerability (Quarter-Dollar Only)

Comparable or Better. If 80/20B is chosen to replace the cladding on U.S. clad coins, its unique EMS will combine with the clad configuration to provide a similar level of security as that found in the current materials.

Feasibility

Five-Cent – **Feasible**

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4. U.S. Coin Security

4.1. Threats

In coinage, there are two threats: counterfeiting and fraud. Both can create problems for vendors and shop owners, as well as public mistrust in coins.

4.1.1. Counterfeiting

Counterfeit coins are imitations that are passed off fraudulently or deceptively as genuine coins. In practice, they are easily rejected by mechanical coin validators as the EMS is incorrect, but in person-to-person commerce, they can be easily mistaken for genuine coinage. The fake coin is almost always of little or no value.

Sometimes, coins from other countries, which look similar to U.S. coins, enter circulation. Canadian quarter-dollars are one example. This becomes problematic when legitimate coins (with a low value) from one country are accepted in another country as a higher-value coin. In 2006, the Philippine 1-peso (value of 2.4 U.S. cents) was discovered to be passing for the 1-dirham coin in the United Arab Emirates (value of 27.2 U.S. cents).[29] In another case in 2013, Amsterdam discovered that over 10,000 Thailand 10-baht coins (value of 23 euro cents) had been passing for 2-euro coins in that city alone.[30]

4.1.2. Fraud

Fraud involves deceitfully and purposefully replacing coinage with slugs or tokens that are accepted by mechanical coin validators as genuine. Mechanical coin acceptors rely on dimensions and electromagnetic signature (EMS) rather than visual recognition. In a fraudulent scenario, the readout of the fake coin matches a genuine coin, but it may not have the same appearance. The fraud is recognized after the fact when the vending machine is serviced, but by then it is too late to prevent the theft. As with counterfeit coins, fraudulent tokens are usually of little or no value. In 2004, a man in Atlanta was arrested and convicted for defrauding the U.S. Postal Service (USPS) with 150,000 fake dimes he had made and used in USPS stamp machines over the course of several weeks.[31]

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[29] Source: http://gulfnews.com/news/gulf/uae/general/hey-presto-a-peso-s-as-good-as-a-dirham-1.38628 (Aug. 1, 2006)

[30] Source: http://www.dutchamsterdam.nl/2375-amsterdam-flooded-with-thai-currency (Dec. 11, 2013)

[31] Source: internal communication between the defrauded Atlanta Post Office and the U.S. Mint HQ (2004-2006).

Figure 4-1. Slugs and Tokens

U.S. quarter-dollar above slugs and tokens collected from vending machines

The absence of a cashier to visually authenticate a coin enables an individual (commonly called a "fraudster") to substitute lower-value foreign coins or other non-genuine items (tokens or slugs) without risk. Given the anonymous nature of vending transactions, fraud is a very real concern with coin design and materials.

4.2. Security Features of U.S. Coinage

Coin security is based on overt and covert features. Overt features are those easily determined through visual or quick dimensional or weight check. A cashier would look at the coin to determine if it looks (design and color), feels (weight), and sounds like a real coin when deposited into the cash register. A vending machine would check the diameter or thickness and possibly the weight. Covert features, which cannot be easily validated visually, rely on material composition or makeup. Measurement of covert features is done through electrical circuitry or other instrumentation. As coins increase in value, more covert features are incorporated to deter fraud.

4.2.1. Background

Vending equipment facilitates commercial transactions without a human to handle and validate the payment. The coin acceptor mechanism that validates the authenticity of the payment is called a discriminator. Vending equipment prior to 1963 contained rudimentary discriminators based primarily on the physical attributes of the coinage, (size, density, weight, etc.).

Common construction items like washers and conduit knockouts could be modified to trick these rudimentary discriminators; thus, magnets were incorporated in vending equipment to reject steel-based materials. As product costs in vending machines increased, industry required improved methods, and discriminators needed more sophistication and complexity. The application of miniaturization, electronic transducers, and sensing technology created an opportunity to take coin validation to the next level in vending. Such technology led to the development of systems to detect a coin's EMS or conductivity, both of which can uniquely identify a particular coin type.

Vending discriminators now vary in complexity, depending on the value of the product served or service rendered. For example, a "canteen operation," where product values often exceed one dollar, allows bills, coins, and sometimes stored-value or credit card transactions. The coin discriminators in this system will employ more advanced features. In contrast, a laundromat, car wash or other low-value product/service vending application relies on overt coin characteristics and may only contain a physical check of the coin (thickness and diameter).

4.2.2. Variances in Conductivity/EMS

Conductivity is the percent IACS (International Annealed Copper Standard) for non-ferrous alloys (see section 3.2.7). It is a ratio of a particular alloy's conductivity compared to pure copper at 20 degrees Celsius. EMS is a measure of a material as an "eddy current" is passed through it, providing unique values for various metallic compositions. Both EMS and conductivity are measured at various frequencies. Unfortunately, there is no established industry standard for what frequency to use and conductivity/EMS readings on materials differ from frequency to frequency. This means two materials' readings may match at one frequency, but be different at another.

The lack of a standard frequency creates challenges in identifying a material that can display the same EMS across the range of frequencies used in coin acceptors. For ferromagnetic products, an additional property (material permeability) also impacts the EMS. Other components of coin acceptor discriminators relate to coins' physical dimensions, specifically, inductive thickness, an electrical reading based on the actual thickness of a specific alloy.

Vending discriminators must also accept a range of coin properties and conditions but also screen out foreign coins, tokens, and slugs. However, the physical properties of coins can vary based on age, use, and manufacturing tolerances. Coins with more wear have less material and this affects the coins' measurements. A coin that is used, for example, in vending or casino operations will see more physical wear than one that is cycled through the banking system or a coin that sits in a consumer's jar for years. A tolerance band is set up for the various properties being measured and periodically adjusted to accommodate the coins in circulation. Many coin acceptors can be adjusted through software or a programming service call, but older ones still require physical modification. A change in composition or physical dimensions will affect the various vending segments differently and the impact will be immediately felt by industry.

4.2.3. Coin Construction

Up to 1964, U.S. coinage for the dime and higher denominations were 90 percent silver. As silver supplies dwindled and metal costs rose, the U.S. government changed the metal composition. The new coinage material consisted of a pure copper core with a silver-colored nickel/copper alloy skin. The skin was applied to the core through a mechanical process called cladding in which the different materials were rolled and reduced in thickness under pressure, bonding the materials together. The Mint punches coin blanks or planchets from sheets of clad material and presses (cold forms or "coins") the planchets into coins with the appropriate dies. The result are clad coins with multiple layers.

By applying different signals through the sensing circuits in the coin acceptor discriminator, sensors can see through the cladding layer and detect the core composition yielding two separate and distinct signals for use in discrimination. Thus, the new clad material provided increased security in coinage, both from the physical dimensions (diameter and thickness) and from the metallic composition (skin and core metallic makeup).

The rising cost of raw materials is creating a challenge for world mints, driving them to use lower-cost metals. Sensitive to the needs of commerce (banking and vending), national governments must weigh the benefit of making the material change versus the impact to industry. Some have gravitated to using iron or steel as a substrate which complicates the security of discriminators in vending equipment. Magnets, which were used to screen out common items, cannot be used if coins themselves are ferromagnetic. Also, due to the abundance of steel items that can be modified to fit into vending equipment (conduit knockouts, washers, etc.), steel is considered to present a higher level of fraud in vending. As such, most countries consider steel viable for use in low-value coinage only.

4.2.4. Coin Security Evolution

As world mints evolve and introduce higher-value coinage systems, fraud potential increases, and more sophisticated security systems are necessary to deter fraudsters. New technologies are being developed by, or in conjunction with, world mints incorporating acoustical, optical or micro-text signatures. These technologies are generally proprietary and are just being considered for use in major coinage systems.

For example, The Royal Mint has developed and patented a technology termed "iSIS." The technology is based on introducing a fluoroluminescent compound into the plated layer that is detected by a proprietary sensor. The measured density of the compound particles is used to validate the coin. Another advanced technology developed by the Mint of Finland is called "CoinTune." This proprietary technology is based on developing a unique acoustical signature of a coin and subsequently reading this signature in vending to validate the coin. Finally, the Royal Canadian Mint has developed a micro-text/engraving process that provides a unique and difficult to reproduce optical signature on the coin face. It also has developed what it terms "DNA Mapping," which maps and stores the unique morphology on a specific location of the coin surface for future reference and validation. This "signature" is unique on each coin produced and enables RM to verify or authenticate the coin.

The viability of incorporating such technologies into vending equipment has yet to be quantified and is subject to factors such as cost, complexity, and maintenance requirements. In discussions with various coin acceptor manufacturers, there is no active program to incorporate any of these new technologies into existing coin acceptors. With time to be allotted for design, marketing, and transition by the vending industry, this would place any change in the sensor base on a five-year or greater horizon. Until such a time that these new technologies are proven cost-effective and reliable in application, the electromagnetic signature of clad and non-ferrous materials represents the security benchmark for coinage alloys in automated vending operations.

4.3. Steel-Based Coin Security

During the course of Phase II, the Mint worked closely with several, large coin acceptor manufacturers—Cummins Allison, MEI, SCAN COIN and Coinstar—to test and analyze struck pieces. The Mint also communicated with U.S.-based manufacturer CoinCo and obtained its feedback.[32] These are the main companies that produce the coin-accepting mechanisms used in vending machines within the United States and worldwide.

[32] CoinCo tested materials in Phase I, but did not have the available time or resources to support testing in Phase II.

As a primary reference document, the Mint used The Coin Design Handbook, version 2 (2012) prepared by the European Vending Association (EVA).[33] This document was written by the following EVA member companies: CoinCo, MEI Conlux, NGZ, NRI (part of Crane Payment Solutions), and SCAN COIN. In addition, it was endorsed by a number of the EVA Coin Group member companies including Cummins Allison. Given the extensive international involvement, it was considered a valuable reference document in evaluating coin materials and designs for both compatibility with coin accepting mechanisms and also security.

In the Handbook, the EVA defines Security as, "A coin that does not **misvalidate**, is able to be **differentiated** correctly, is not **easy** to **fraud**, and has a low **fraud** risk, is regarded as being more secure and suitable for higher value coins."[34] Key considerations include the similarity to other, lesser-valued, world coins and the ease of creating fraudulent coins, including knowledge of techniques, and availability of equipment and materials. Complex machining, unique or expensive equipment, and materials that are more difficult to obtain provide increased protection against fraud. According to the EVA, "Fraud coins that are very simple to manufacture and use widely available materials can present a very real **fraud risk** to relatively low value **coins**."[34]

The EVA further defines coins by their value using the Euro as the basis. Coins are characterized in Table 4-1, below.

Table 4-1. EVA Coin Value Categories

Category	Value
Very Low Value	up to 2 cents Euro or equivalent (up to approx. 2.7¢ U.S.)[35]
Low Value	>2 cents Euro to 20 cent Euro or equivalent (>2.7¢ to approx. 27¢ U.S.)
Medium Value	>20 cents Euro to 50 cents Euro or equivalent (>27¢ to approx. 68¢ U.S.)
High Value	>50 cents Euro or equivalent (>68¢ U.S.)

[33] Previously known as the World Vending Association, founded by the U.S.-based National Automatic Merchandising Association and the EVA.
[34] Emphasis EVA's.
[35] Using an exchange rate of 1 Euro = $ 1.357.

The level of a coin's security is directly related to its value. Stated differently, the level of security (and cost associated) should be commensurate with the coins value to effectively support commerce. Fraudsters and counterfeiters are drawn to higher-value coins, with a greater return for their effort.

Steel-based coinage materials considered in Phase II include plated steel and stainless steel. The Mint tested plated steel in two versions: nickel-plated steel obtained from The Royal Mint and multi-ply-plated steel obtained from the Royal Canadian Mint. These are single or multiple layers of nickel and copper/nickel plated on a cold-rolled, low-carbon steel core. They are used in coinage worldwide. The Mint worked with an external research firm to test different grades of stainless steel.

4.3.1. Plated Steel

When discussing coin security vs. construction, the EVA Handbook notes:

Single Layer (i.e. Nickel-Plated Steel)

> *Plated coins that have a single plated layer on a solid steel core are effected by the variability in the manufacturing process and the dominant effects of the core.* (page 28)
>
> *The risk from fraud is high due to the ready availability of round steel discs. As well as widespread availability of Copper and Nickel plating facilities worldwide.* (page 28)
>
> *Single layer plated coins should only be used for low value coins because of the ease of and risk from fraud.* (page 28)

Multi-Layer Plated Coins

> *The risk from fraud is high due to the ready availability of round steel discs. As well as widespread availability of Copper and Nickel plating facilities worldwide.* (page 30)
>
> *Although multilayer plated coins enable other single layer plated steel coins that have a similar diameter and thickness to be differentiated, they have a high risk from fraud because of their steel and copper/nickel plated construction. Overall they offer no improvements in security using inductive material sensors in today's coin validators when compared to single plated layer.* (page 30)

Multilayer plated coins should only be used for low value coins because of the ease of and risk from fraud. (page 30)

Ferromagnetism

Steel is ferromagnetic (attracted by a magnet), which presents several problems in coin acceptor security. Phase I identified vending machines and laundromat facilities as being the dominant shareholders for automated point-of-sale transactions. These machines have a magnetic discriminator intended to capture steel slugs, which would need to be removed or disabled to accommodate steel coins.

Foreign Coins

Although plated-steel coins would cost less to produce, they are also more vulnerable to fraud. Several examples of foreign plated-steel coins show the relationship between construction, coin value, the EVA guidelines, and equivalent U.S. values.

Table 4-2. Foreign Plated-Steel Coins

Country/Region	Denominations	EVA Coin Value	U.S. Equivalent
Canada	5-cent	low value	4.6 cents
	10-cent	low value	9.2 cents
	25-cent	low value	23 cents
	50-cent	medium value	46 cents
	1-dollar	high value	92 cents
	2-dollar	high value	184 cents
United Kingdom	5-pence	low value	8.5 cents
	10-pence	low value	17 cents
	Note: 20-pence through 1-pound are monolithic alloy construction (non-steel). Higher is non-steel bi-metallic.		
European Union	1-cent	very low value	1.36 cents
	2-cent	very low value	2.74 cents
	5-cent	low value	6.8 cents
	Note: 10-cent through 50-cent are monolithic alloy construction (non-steel). Higher are non-steel bi-metallic.		

The majority of mints conform to the EVA guidelines and only use plated coins for low-value denominations (i.e., below approximately 27¢ U.S.). The Royal Canadian Mint, however, utilizes plated materials for low-, medium- and high-value denominations. In separate discussions, neither The Royal Mint nor the Royal Canadian Mint claims to experience fraud with their plated coins, though the RCM employs many security features (such as laser-etching a micro-engraved image of a maple leaf on their one-dollar coin). The Royal Canadian Mint and The Royal Mint (as well as other international mints) also have active research programs in anti-fraud techniques to improve the security of their plated-steel coins.

While the UK and Canada claim not to experience significant counterfeiting with their plated-steel coins, many examples of counterfeiting are reported in China, which uses nickel-plated steel coins. In 1991, China began to use nickel-plated steel on its one-Yuan coins. The core is low-carbon steel and surface is plated with pure nickel. Because the common core materials cost very little, and nickel plating is an inexpensive, simple process, there have been tens of millions of counterfeit one-Yuan coins circulating since the coins' release. The total cost for making a single, fake, one-Yuan coin is about 3 U.S. cents.

The following table shows a partial list of seized counterfeit one-Yuan coins; these were published in Chinese newspapers. More counterfeit coins are still circulating, and as a result, many small shops in China no longer accept one-Yuan coins in commerce.

Table 4-3. Counterfeit Seizures in China

Date	Location	Quantity
2006 May	Nanchang	10,000,000
2006 August	Heibei Province	10,520,000
2007 December	Nanjin	30,000,000
2008 November	Fuzhou	700,000
2009 August	Feishan	220,000
2009 August	Zhengzhou	100,000
2009 September	Hefei	1,000,000

4.3.2. Stainless Steel

Stainless steel is being considered as an alternative metal for U.S. coinage. It is termed monolithic or homogeneous since it consists solely of one alloy and exhibits the same chemical composition throughout. Stainless steel is produced in two forms: ferritic (400 series) and austenitic (200 and 300 series), both of which are an alloy of iron and chromium.

Ferritic stainless steel has very little nickel and therefore has lower material costs. It is ferromagnetic, which means it is attracted by a magnet. This presents several problems in vending security. First, many coin acceptors used in vending and the laundromat industry have a magnetic discriminator intended to capture steel slugs; this would need to be removed or disabled to accommodate ferritic steel coins. Second, the ferritic steel's EMS is highly variable and influenced by manufacturing inconsistencies and by the handling of a coin over time. This requires coin acceptors to undergo modifications to have a wider acceptance band, making the material less secure when used in coin validators.

Austenitic stainless steel has a significant quantity of nickel (which makes it non-ferromagnetic), so it has a higher material cost. The EMS of austenitic steel does not vary much from alloy to alloy, though, which means a coin validator cannot effectively discriminate between one austenitic stainless steel grade and another.

4.3.3. Homogeneous Materials

For both ferritic and austenitic stainless steels, the EVA Handbook notes that:

> *Non-magnetic homogeneous coins are generally to be considered for low to medium value denominations; however the security of the coin depends significantly on the choice of material.*

If the homogeneous material is commonly available and/or cheap, the risk of fraud is greater because there is no unique construction in homogeneous coins or special EMS to help discriminate real coins from frauds. Stainless steel's readily available material and solid construction enables someone to easily manufacture a disc that could be used in vending. For low-value coins, this is not a significant risk as the return on investment does not offset the fraudster's time and costs in manufacturing the fakes. Risk becomes greater at higher denominations, where there is more return on investment.

4.3.4. Coin Sorter/Validator Testing

Although each coin acceptor manufacturer has a different algorithm and frequency in their mechanisms, each measures the conductivity of coins. The "accept" range of these mechanisms' sensors (the "band width," or "window") is of particular concern in coin security. If two compositions of the same coin/denomination have very different EMSs, the mechanism needs to be set to accept both, which means its window of acceptance opens very wide, leaving it more vulnerable to being defrauded by slugs and tokens that could easily fall inside the window.

The Mint used an industry-standard coin sorter/validator (CSV) to capture data of various materials being tested and considered. The Mint compared the internal test results of various materials which compared the spread in both the Outer Conductivity (OC) and Inner Conductivity (IC).

The CSV sensors change their frequency to read the coin only partially under the surface, and then read the same coin more deeply, to gather the entire EMS of the material. As coins pass through, some variability is seen. In testing, for the current cupronickel, the sensor readings and their variability was recorded, giving an average value for each of the criteria with the variance on each criterion.

The CSV was programmed with acceptance windows pre-set for each EMS parameter. The acceptance window width was based on the variance of actual coins, either newly minted or pulled from circulating coinage. The Mint's coin validation involved comparing the measured value of each EMS parameter to the acceptance windows for coin validation.

The plated-steel materials' criteria for the five-cent pieces differed drastically from the current material, having some scores 12 percent higher, and others over 50 percent lower than the current material. Most of the criteria had a variance at least 10 percent higher than the average score. For inner and outer conductivity, the variance for NPS and MPPS was over 33 percent of the average score, as compared with just over 10 percent variance on the current material.

The Mint made the following findings from this test:

1. Plated-steel EMS ranges are wider than those of the current material, necessitating wider acceptance windows and therefore less security.
2. Plated-steel and monolithic EMS ranges tend to overlap at multiple frequencies, diminishing the enhanced security of dual-frequency coin validation.
3. Clad construction offers high security, as evidenced by the low incidence of EMS overlap with MPPS and NPS. These findings are in line with EVA's Coin Design Handbook's rating of clad construction being more secure than plated.
4. Clad constructions may have relatively large EMS range widths, but security is not compromised because EMS average values are widely separated when validated using dual-frequency acceptors.

The complete readings are available in Appendix 10.9.

4.4. Steel-Based Coin Security Conclusions

Given the EVA guidelines, it is clear that steel coin construction would present acceptable risks for application on the United States five-cent and dime (low-value denominations). While the quarter-dollar is technically below the EVA-recommended threshold, it is very close, and that status is sensitive to variations in the exchange rate (since the EVA guidelines are based on the Euro). Of greater consideration in the United States is the fact that the quarter-dollar is the highest-value coin used regularly in vending transactions. This means that the risk of fraud on this denomination needs to be seriously considered in this country more so than others. While ultimately a policy decision (risk vs. return), the application of plated-steel material to the quarter-dollar is not advisable from a technical perspective. The material gains must be weighed against the impact of fraud and its effect on the confidence of the monetary system in supporting commerce.

Use of stainless steel for the five-cent or the dime (not both) would be acceptable from a security standpoint; use of stainless steel would not be acceptable for the quarter-dollar. One unique consideration with homogeneous coin construction is the relative size of the denominations. In most of the world's coin sets, the size of the coin increases as the value does. This means a lower-valued coin could not be made into a higher-valued one by rolling or resizing. In the U.S., the larger size of the five-cent vs. the dime (a legacy of the relative value of cupronickel vs. silver) would allow this practice, and so precludes the use of the same monolithic material on both the five-cent and the dime.

5. Coinability

Coinability is a subjective characteristic, but a critical one when evaluating potential materials for coining. It is the term associated with how readily a material can be struck into a coin and encompasses a number of elements including material mechanical properties, blank preparation/lubrication, upset profile[36], level of details in the coin design, height of details in the design (i.e. height of relief[37] and crown[38]), and die surface finish. Each of these elements contributes in varying degrees to the performance of a material during high-speed stamping. Throughout testing, the Mint expended significant effort to keep these elements consistent from material to material.

When evaluating a potential material, a balance must be achieved between keeping the elements consistent with other material testing (to attribute the outcome to the alternative material) and optimizing the above elements for each material (as they act as a "system" coming together to produce a result). For the purposes of consistency, the main focus was on using the same die design, stamping press, and quality standard.

5.1. Testing Methods

Two methods were used to evaluate coinability: progressions strikes[39] and extended striking trials (pre-production runs) in which die pairs were run to failure. Acceptable quality was determined through initial progression strikes on the material in which coin fill and dimensions were evaluated with increasing striking force and an aim striking tonnage set that provided acceptable visual and dimensional results.

Over the course of pre-production runs, the dimensions and appearance of the struck pieces were checked frequently with the quality standards being the same as those used in normal production operations for circulating coins. Circulating coins are not free from defects, but the coins must be within dimensional tolerances and observed defects must be limited in

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[36] Upset refers to movement of metal on the edge to pre-form the rim.

[37] Height of relief is dimension of highest part of the artwork as referenced from the lowest part of the field adjacent to the artwork.

[38] Crown is the dimension that characterizes the depth of the basin before the artwork is overlaid.

[39] Progression strikes are a controlled test where the striking force is incrementally increased and the development of the design fill, edge profile, and coin dimensions are closely examined to evaluate a material. In addition, an aim striking force (tonnage) is established that provides an acceptable level of visual quality and dimensional compliance.

size. The resultant average for die life and the level/degree of defects observed in the die and struck piece were the basis for determining coinability. A rating of Comparable or Better (than the current material) or Less than Current was determined and used as one of the down-select criteria.

The Martha Washington nonsense design was patterned exactly after the current designs used for circulating coins with similar images (Martha Washington instead of Thomas Jefferson on the five-cent or George Washington on the quarter-dollar obverse and Mount Vernon vs. Monticello on the reverse of the five-cent) and similar inscriptions (same letters, but jumbled). As it was known that U.S. coin designs have more detail and relief than most circulating world coins, two alternatives were developed to the standard-crown nonsense dies. These were half-crown and flat-crown in which the nonsense design details were kept identical, but the height of relief and crown were reduced by half (half-crown) and then again by half (flat-crown) to provide dies that more closely approximated international coinage. Pre-production runs were performed on the current material for both the standard and the modified dies so there would be a valid baseline.

5.2. Baseline Results

Obtaining a statistically valid die life for alternative materials would require a significant number of runs. To evaluate coinability on candidate materials, the Mint decided to run at least four die pairs to failure or 500,000 strikes, whichever came first. A target of 500,000 strikes was established because that represented an acceptable productivity threshold for die life and was representative of past results on the five-cent and quarter-dollar circulating coins (see section 1.5).

Tables 5-1 and 5-2, below, respectively show the results of the baseline run on the current five-cent and quarter-dollar materials. Each die pair consisted of an obverse die and a reverse die. If one die in a pair failed, both were then replaced.

Table 5-1. Baseline Die-Life Determination (Five-Cent)

Die Pair	Crown	Die Life (strikes)	Failure Mode
1st	Standard	365,672	Crack and piece out on reverse
2nd	Standard	500,003	No objectionable defects
3rd	Standard	500,031	Crack observed on bonnet and weakness in steps on reverse; was borderline to continue
4th	Standard	641,116	No objectionable defects ran until 641,116 and retired dies
5th	Half	500,000	No objectionable defects noted
6th	Half	500,003	Slight crack developing at top of bonnet
7th	Half	500,350	No objectionable defects noted
8th	Half	503,256	No objectionable defects noted
9th	Flat	500,037	No objectionable defects noted
10th	Flat	458,247	Piece out noted on reverse before 200,000, not significant enough to pull the die. 2nd piece out noted on reverse still acceptable for circulating quality. 3rd piece out observed and dies pulled.
11th	Flat	500,126	No objectionable defects noted
12th	Flat	467,655	Piece out noted on reverse (letter S)
Overall		5,936,496	Average 494,708

These results validated that the Martha Washington nonsense dies were representative of the normal circulating dies in that they displayed similar defect patterns and life.

The results of the baseline run on current quarter-dollar material with half- and standard-crown dies are in the following table.

Table 5-2. Baseline Die-Life Determination (Quarter-Dollar)

Die Pair	Crown	Die Life (strikes)	Failure Mode
1st	Standard	500,028	No objectionable defects noted
2nd	Standard	500,004	No objectionable defects noted
3rd	Standard	459,075	Crack on obverse near base of Martha's bust
4th	Standard	500,002	No objectionable defects noted
5th	Half	500,000	No objectionable defects noted
6th	Half	501,856	No objectionable defects noted
7th	Half	500,000	No objectionable defects noted
8th	Half	311,601*	Defect noted on obverse, die retired. Under further examination, "defect" was an impression from debris stamped into the surface; no actual defect in die.
Overall		3,460,965	Average 494,424

* - Die retired prematurely; not counted toward overall or average.

Again, the results both validated the use of the Martha Washington nonsense dies as representative of circulating results and the use of 500,000 as a target threshold.

5.2.1. 80/20B Five-Cent

The upset profile on the material provided for the pre-production run was similar to that used for the circulating five-cent. Procedures for annealing and blank preparation (including chemicals currently used) were provided to the vendor. The Mint does not have any large capacity capability for annealing or preparing blanks without risking contamination with current material, so external processing was necessary. Progression strikes set aim tonnage at 54 tonnes.

Table 5-3. Initial 80/20B Die Life (Five-Cent)

Die Pair	Die Life (strikes)	Failure Mode
1st	<100,000, but ran to 500,000	Significant wear noticed on both sides before 20,000, would have retired before 100,000 but continued run to 500,000. Engraver initials worn on the obverse around 200,000. Cracks noticed in the bonnet area around 400,000 strikes. Cracking more prevalent, especially on the obverse letters.
2nd	<100,000, but ran to 255,274	Wear noticed on reverse starting at 12,000 strikes. Cracking noticed in the bonnet area around 200,000 strikes. Excessive die wear seen, but elected to continue to observe other defects.
3rd	67,413	Wear observed on outer perimeter of struck piece by 10,000 strikes. Noticeable wear at 20,000 strikes on both sides. Wear marks developing near nose on the obverse at 40,000. Dies retired when wear was deemed excessive visually.
4th	116,130	Same pattern of wear developing by 20,000 strikes including the nose area. Retired dies due to excessive wear.
5th	64,574+	Material burnished using standard circulating chemicals. Ran available material, no noticeable wear and die pair could have been run much longer.
Overall	1,005,391 (603,391)	Average 120,678

The 80/20 material is very close in composition to the current cupronickel (75% copper, 25% nickel). There is a larger quantity of manganese in the 80/20 to match the EMS of the five-cent, approximately 4% Mn vs. less than 0.6% in the current material. The manganese level is similar to the level in the dollar coin material which does not exhibit excessive die wear, so the difference in manganese is not felt to be a contributor to the excessive die wear. Given that, the material's performance was not considered representative. The Mint associated the premature wear issue with the blank cleaning/lubrication being significantly different than that on our standard cupronickel.

On a conference call with the supplier, the Mint learned the desired lubricant chemical had not been applied and, in fact, there was only a tarnish inhibitor applied to the blanks, no lubrication. This was confirmed when a small quantity of the 80/20B blanks were burnished in the small-volume burnishing machine in the R&D room. The Mint then struck the newly burnished material with normal appearance through over 60,000 strikes (see 5th die pair in

Table 5-3, above). Wear had been noticed consistently before 20,000 strikes on the untreated material.

Coinability and die life of the 80/20B cannot be definitively assessed on these results. The excessive die wear is considered to be related to the inadequate blank preparation, specifically no lubrication. The remaining material was returned for proper blank preparation and the pre-production run resumed on July 14, 2014.

Testing resumed when the Mint received the treated material. There were some issues with the feed fingers during the tests, but this was unrelated to the material, and was not counted against the material. On the two die pairs that did not have problems with the feed fingers, die life was comparable to the current material, although when the dies failed with 80/20B, it was the reverse die that failed, as opposed to the current material seeing die failure on the obverse.

Table 5-3. Treated 80/20B Die Life (Five-Cent)

Die Pair	Die Life (strikes)	Failure Mode
1st	454,000	No objectionable defects noted
2nd	1,095*	Die clash on fingers; retired and installed die pair #3
3rd	470,000	No objectionable defects noted
4th	---*	Die clash on fingers before start; replaced with die pair #5
5th	47,931*	Problems continued with fingers; ended pre-production run and emptied the feed hopper
Overall	924,000	Average 462,000

* - Die retired prematurely; not counted toward overall or average.

5.2.2. Multi-Ply-Plated Steel (Five-Cent)

The Mint used the Canadian-standard upset profile provided by RCM. Due to the abrasive nature of the nickel surface, protective die coatings were required. This is not a practice the Mint uses except for numismatic coins, so the dies were sent to the RCM for coating with their Physical Vapor Deposition (PVD) process and recipe. As their practice was to polish the die surface before coating, some dies were coated without polishing and others with to provide results that would guide future practices. For the pre-production runs, the Mint only used the polished dies which were buffed after PVD coating.

Blank surfaces were prepared per the standard practice the RCM uses on its coinage and the material they provide to other world mints. Progression strikes of standard-crown test dies showed non-fill in high-relief areas (i.e., Martha's bonnet) at up to 60 tonnes, well above the normal circulating strike tonnage of 54 tonnes. The decision was made to use 54 tonnes as the aim tonnage for standard-crown dies. Aim tonnage for the half-crown dies was set at 52 tonnes.

Table 5-4. MPPS Die Life (Five-Cent)

Die Pair	Crown	Die Life (strikes)	Failure Mode
1st	Standard Not Polished	125,779	Crack noticed on bonnet on obverse at 100,000. Crack started at 20,000 strikes. Die retired due to obverse crack.
2nd	Standard Not Polished	67,121	Crack on obverse
3rd	Half Polished	267,000 (500,146)	At 194,000 strikes, noticed defect on the nose (Obverse). At 267,000 strikes the defect was significant enough that the die should have been retired. Continued running to see what additional defects would manifest. At 442,000 piece-outs seen on reverse near the letter F. Ended run after 500,000 strikes.
4th	Half Polished	138,568	Retired die due to crack in nose area of the obverse
5th	Half Polished	103,310	At 40,000 strikes noticed the die coating starting to fail, continued run until crack or piece out. Pulled die at 103,310 for excessive tool marks and coating failure on the obverse.
6th	Half Polished	108,517	Crack on nose seen at 89,000. Stopped run at 108,517 due to crack on obverse.
Overall		810,295 (1,043,441)	Average of 135,049 strikes

Pre-production strikes of standard crown dies were conducted at tonnage comparable to that used for the current material, although given that the features were not optimized for this material and lack of fill was observed in high-relief areas on the obverse design. Pre-production strikes using half-crown dies were conducted at lower tonnage than current strike tonnage.

Coin edge thickness was within specifications, but measurably greater than current coins struck at higher tonnage. Multi-Ply Plated Steel five-cent exhibited premature die retirements as compared to the baseline. Defects seen included cracks, tool marks, and die coating failures. The coating failures are felt to be related to metal oxides on the dies surfaces. PVD coatings typically do not adhere as well to metal oxides as elemental metal. The cracks were present on both the Standard Crown and Half-Crown Martha Washington designs, which illustrates that the feature changes necessary to accommodate plated-steel material would not just be a lowering of the relief/crown.

More feature changes would be required. Improvement in coinability and die life could be possible with an optimization of the Martha Washington designs to be more compatible with the MPPS. This would include a softening of detail, adjustments in the height and degree of image detail, as well as adjustments to the lettering. These changes would not affect the public recognition, but would diminish the aesthetics of the circulating coin appearance.

There is a significant gap though between the averages of 135K and the desired baseline performance of 500K so it is unlikely that the design and/or upset profile changes alone will close the die-life gap fully; therefore, some reduction in die life is to be expected with this alternative material. This is confirmed by RCM's experience of 350K die life on their five-cent coin. Given the feature changes and lower anticipated die life, this material should be considered as feasible, but Less than Current in coinability and die wear.

5.2.3. Multi-Ply Plated Steel Quarter-Dollar

The upset profile provided was RCM 3M with angle A[40] moved closer to the blank edge to address the concentric ring observed on test pieces stamped from previous variability lot planchets. As with the five-cent, the nonsense dies were sent to the RCM for coating to protect against the increased wear encountered from the nickel. Blank surface preparation was per the standard practice the RCM uses on its coinage and the material they provide to other world mints. Progression strikes set aim tonnage at 64 tonnes for the standard crown and 62 tonnes for the half-crown.

[40] Angle of the top edge of the upset with respect to the flat surface on a drawing that shows the exact upset profile from a side-view.

Table 5-5. MPPS Die Life (Quarter-Dollar)

Die Pair	Crown	Die Life (strikes)	Failure Mode
1st	Standard Not Polished	152,179	Noticed crack on bonnet at 20,000 under microscope, continue to run, retired from service due to coating failure.
2nd	Standard Not Polished	242,682	At 180,000 noticed small mark on obverse chin and start of crack on bonnet. Retired dies due to crack on bonnet.
3rd	Half Polished	106,036	Noticed a “glow” appearance on both sides of the pieces soon after start-up. Noticed crack on reverse in the rhino’s body at 76K. At 80K, rev crack getting larger and crack starting in obverse bonnet area. Retired dies due to cracks on both sides.
4th	Half Polished	155,957	Still see a “glow” on both sides of the pieces after start-up. Defect starting on the obverse chin area at 27K. Crack developing on reverse in the rhino body. Retired dies due to cracks on both sides.
5th	Half Polished	318,986	Crack starting on obverse in the bonnet area at 215K, cracks noticed on the reverse in the mountain field at 250K. Retired dies due to crack on obverse bonnet area.
6th	Standard not polished	231,344	Crack starting in obverse bonnet area at 102K. Retired dies due to obverse crack and delaminated coating.
7th	Standard not polished	150,030	Noticed coating peeling at 125K lower bust area, retired dies due to coating failure.
8th	Half not polished	140,304	Retired due to coating failure in the obverse field area.
Overall		776,235 (721,283)	Standard Crown 194,059 (Half-Crown 180,321)

Tonnage was comparable to that used for the current material, although given the features were not optimized for this material, a balancing was needed between desired coin fill and dimensions. Multi-Ply Plated Steel exhibited premature die retirements as compared to the baseline. Defects seen included cracks, tool marks, and die coating failures. The coating failures are felt to be related to metal oxides on the dies surfaces. PVD coatings typically do not adhere as well to metal oxides as elemental metal. The cracks were present on both the

Standard Crown and Half-Crown Martha Washington designs, which illustrates that the design changes necessary would not just be a lowering of the relief/crown. Improvement in coinability and die life could be possible with an optimization of the Martha Washington designs to be more compatible with the MPPS.

The current circulating coin design will need to be modified if this material is to be used. This would involve a lowering and softening of details in the image and lettering. This would not affect the public recognition, but would diminish the aesthetics of the circulating coin.

There is a significant gap between the averages of 188K and the baseline performance of 500K, so it is unlikely that the design and/or upset profile changes alone will close the die life gap and some reduction in die life is to be expected with this alternative material. This is confirmed by RCM's experience of 350K on their 25-cent coin. Given the need for feature changes and lower anticipated die life, this material should be considered as feasible, but Less than Current in coinability and die wear.

5.2.4. Nickel-Plated Steel Five-Cent

The pre-production upset profile provided was modified based on feedback provided to The Royal Mint after striking variability lots. Earlier variability lots exhibited premature edge fill, which was not observed during pre-production strikes. As with the MPPS, the five-cent nonsense dies were sent to The Royal Mint for coating to protect against the increased wear encountered from the nickel surface. Blank surface preparation was per the standard practice the RM uses on its coinage and the material they provide to other world mints. Progression strikes set aim tonnage at 54 tonnes for the standard crown.

Table 5-6. NPS Die Life (Five-Cent)

Die Pair	Die Prep	Die Life (strikes)	Failure Mode
1st	Standard; Not polished	75,542	Wear seen within the first 20,000 strikes, especially on the reverse at the 10 and 2 position. Checked die height and was ok, polished the die and resumed striking. Wear marks continued and losing detail on the reverse. Secured run due to crack on reverse left side of building to coin edge.
2nd	Standard; Polished	252,515	28,000 strikes finger smashed and others severely worn requiring change. Continued feed finger and blank feeding issues. Retired die pair due to die clash.
3rd	Standard; Polished	270,218	Feed finger and blank feed issues encountered from the start. Coins show wear, especially around the lettering. Crack staring at 100,000 strikes on Obv top of bonnet, scattered small die coating failures. Started practice of changing fingers every 80,000 strikes. Retired die pair due to crack on obverse in the bonnet and PVD coating failures.
4th	Standard; Not polished	80,001	Oilers were turned on as a trial, obverse becoming shiny; reverse still shows a matte finish. Widespread wear noted at 67,000 strikes on obverse and increasing wear on reverse. Numerous coating failures and crack starting in nose. Retired die due to excessive wear.
5th	Standard; Not polished	76,953	Conducted strikes with oilers off. Obverse die worn in a manner similar to the 1st "not polished" die pair and did not become shiny as the 4th die pair with oilers on. Dies retired due to excessive wear.
Overall		755,229	Overall average of 151,046 strikes Not Polished 77, 499 strikes Polished 261,367 strikes

Tonnage was comparable to that used for the current material with both fill and dimensions acceptable. Nickel-plated steel exhibited premature die retirements though as compared to the baseline. Defects seen included cracks, excessive wear, tool marks and die coating failures. The coating failures are felt to be related to metal oxides on the dies surfaces. PVD coatings typically do not adhere as well to metal oxides as elemental metal.

The cracks were present on both the Obverse (bonnet area) and Reverse (building top corner to coin edge). A significant difference was seen between the Not Polished and Polished die life indicating that going forward circulating dies would need to be polished to provide a more uniform surface and one that was free of oxides.

The planchets and struck pieces exhibited indications of poor lubrication (severe bridging in the feed hopper and Kuster Cart) and that needs to be investigated further with the RM. The excessive wear on the press parts, is unacceptable and must be resolved to support sustained coining operations. Improvement in coinability and die life could be possible with an optimization of the Martha Washington designs to be more compatible with the NPS.

The hardness check on the retained planchets showed the NPS material to be about 20 percent harder than the current material and harder than the RCM plated steel. Also the upset profile appeared sharper vs. the current material's flatter configuration. Both of which, along with the poor lubrication, could also have contributed to the excessive wear. Most definitely there would need to be some accommodation with the current circulating coin design images and features if this material was to be used. The design changes would not affect the public recognition, but would diminish the circulating coin's aesthetics. The blank lubrication and part wear also needs to be addressed to make the material viable.

Since the material is utilized in the United Kingdom and many other countries this is possible, but will require optimization trials. There is a significant gap though between the averages of 261K on the polished coated dies and the baseline performance of 500K so while it is possible to double the die life with changes in features and lubrication; it is not likely that these changes alone will close the die life gap and some reduction in die life is to be expected with this alternative material. The experience of the RM is around 600K strikes for the 5-pence and 10-pence. Experience with other countries they have supplied reflected an average of 447K strikes with a range from 215K to 800K. This average is on coins with very differing designs and the quality standards for those Mints are not known.

Given the need for feature changes and lower anticipated die life, this material should be considered as feasible, but Less than Current in coinability and die wear.

5.2.5. Nickel-Plated Steel Quarter-Dollar

The pre-production upset profile provided was modified based on feedback provided to The Royal Mint after striking variability lots. Strike tonnage was higher than the current material and die life on both standard and half crown was noticeably less. Use of coated and polished dies was necessary. While improvement could be expected with further optimization of coinage system; obtaining a die life comparable to the current material is not likely. Coinability should be considered Less than Current.

Table 5-7. NPS Die Life (Quarter-Dollar)

Die Pair	Die Prep	Die Life (strikes)	Failure Mode
1st	Standard Polished	145,919	Crack on obv, bottom of bust, was noticed early at 20,000 strikes and later progressed to objectionable (larger, more visible). Cracks on obv (bottom and top of bust) and rev (lettering). Pulled for crack at bottom of bust.
2nd	Standard Polished	105,236	Coating delamination noticed early on, not objectionable. Crack on obverse at 7 o'clock position, radiating out to edge.
3rd	Standard Polished	54,264	Die clash with feed fingers damaged dies so curtailed run. (Not counted toward total, as material was not cause of failure.)
4th	Standard Polished	57,907	Feed finger clash at 961 strikes, dies were inspected and OK – switched to plastic fingers. Retired die later due to crack on obverse radiating out to border.
5th	Half Crown Polished	86,240	Coating delamination noticed after 4,000 strikes, not objectionable. Crack noticed at top of bonnet and bottom of bust at 52K. Retired die due to crack on bottom of the bust getting more pronounced.
6th	Half Crown Polished	101,000	Observed crack starting on bottom of bust around 22,000 strikes. Retired die due to cracks at bottom of bust, also noticed crack on Rhino body on the reverse.
7th	Half Crown Polished	102,600 (127,991)	At 60,000 strikes noticed crack on the bottom of the bust (Obv) and Rhino body (rev), continued to run. A second crack observed developing on the Rhino body at 102,600 strikes, would have been cause for retirement, but elected to run further. At 113,200 strikes noted crack on obv through the letters PROJECT that ran to the border. At 122,300 strikes noted crack in more lettering on the obverse and decided to run out the rest of the feed hopper.
Overall		309,062 (289,840)	Standard Crown average: 103,021 (Half Crown average: 96,613)

Progression strikes were performed on the pilot pre-production material received earlier; performed abbreviated progression strikes to confirm correct tonnage, fill and dimensions, aiming for 66T, but settling on 68T after observing unacceptable diameter at 66T. This was related to the thicker upset profile which caused the border to completely fill before achieving nominal coin diameter (locked border).

No excessive wear on the coated dies was noted throughout the run and there was less wear on the feed fingers and press parts than experienced on the five-cent. The Mint encountered feed issues throughout the run which required adjustments to the press to accommodate (had to dress up the swivel plate and feed bowl on multiple occasions).

The Mint consistently observed cracks at the bottom of the bust on both the standard and half-crown designs. Also encountered cracks in lettering on both sides and the body of the rhino on the reverse. The cracks in the lettering were not observed during the baseline strikes or on other 25-cent material struck. Ran four die pairs with standard design (one pair clashed so wasn't counted) average of the other three was 101,021 strikes. On the half crown, 3 die pairs were run with an average of 96,613 strikes.

5.3. Conclusions

Table 5-9. Pre-Production Average Die Life

Material	Denomination	Aim Tonnage	Number Die Pairs	Average Die Life
Current Standard Crown	Five-cent	54 tonnes	4	501,706
Current Half Crown	Five-cent	54 tonnes	4	501,627
Current Flat Crown	Five-cent	54 tonnes	4	481,516
80/20B No Lubrication	Five-cent	54 tonnes	5	120,678
80/20B With Lubrication	Five-cent	54 tonnes	2	462,000
Multi-Ply Plated Steel – Standard Crown	Five-cent	54 tonnes	2	96,450
Multi-Ply Plated Steel – Half Crown	Five-cent	52 tonnes	4	154,349
Nickel Plated Steel	Five-cent	54 tonnes	5	Overall 151,046 Not Polished 77,499 Polished 261,367
Current Standard Crown	Quarter-dollar	62 tonnes	4	489,777
Current Half Crown	Quarter-dollar	62 tonnes	3	500,618
Multi-Ply Plated Steel Standard Crown	Quarter-dollar	64 tonnes	4	194,059
Multi-Ply Plated Steel Half Crown	Quarter-dollar	64 tonnes	4	180,321
Nickel Plated Steel Standard Crown	Quarter-dollar	68 tonnes	3	103,021
Nickel Plated Steel Half Crown	Quarter-dollar	68 tonnes	3	96,613

Results from the pre-production testing support the following findings:

- 80/20 tonnage (54T) was comparable to that used for the current material, with fill and dimensions good. Die life was also comparable as was the mode of failure (cracks). One difference was that the reverse exhibited cracks, while on the current material the obverse is the normal side to fail. The slight difference in composition did not affect the coinability once proper blank treatment was applied.
- Nickel-plated material will require polished and coated dies for circulating coin production.

- Wear resistance of press components in contact with nickel-plated materials must be increased.
- Plated-steel material will require changes in the design, specifically a softening of image and lettering and lowering of detail height. These changes should not affect the public recognition of coins, but could diminish the aesthetics of the circulating coin.

6. Findings/Conclusions and Recommendations

Two separate types of alternatives were considered during Phase II testing/evaluation. The first was a material with an EMS and piece weight that was potentially seamless with the current material. The second were co-circulate alternatives where the EMS differed from the current material and the piece weight would vary from the current material by 4 percent or more.

Potentially seamless alternatives would not require changes to the coin acceptors, but would only offer modest material savings (approximately 3 percent). Co-circulate alternatives provide much greater materials savings (20-35 percent), but would require significant stakeholder conversion costs to accommodate the different EMS.

- Potentially seamless alternative evaluated: 80/20
- Co-circulate alternatives evaluated: Nickel-plated steel (NPS)
Multi-ply-plated steel (MPPS)
Stainless steel
Copper-plated zinc (CPZ)
Tin-plated CPZ (TPCPZ)

6.1. Findings and Conclusions

Seamless Material

1. A variant of today's current cupronickel composition, termed 80/20, which has a lower nickel content with higher manganese, was found to be seamless when tested by three separate coin acceptor manufacturers.[41] The Mint estimated this material would provide approximately $5.25M annual savings ($3.2M for the five-cent, $0.8M for the dime, $1.25 for the quarter-dollar) with no impact on the public or on stakeholders.

2. 80/20 matches the current material in both EMS and in piece weight, having a weight that falls within legally accepted variances for the current material.

[41] In testing, 80/20 was 100% accepted by all three coin acceptor manufacturers.

3. Initial testing of other, potentially seamless, leaner-copper alternatives shows potential for further incremental material savings without presenting any color changes or corrosion-resistance changes.

Co-Circulate Materials

4. Plated-steel materials are a viable option for the five-cent (further testing will determine feasibility for the dime), and offer up to approximately $29M in savings annually over current materials. However, plated-steel materials have increased risks of fraud and counterfeit, and are used in low-value foreign coins, all of which make the materials not feasible for use in the quarter-dollar. They also have a significantly lower die life, which, if not mitigated (see #6, below), could increase production and labor costs, and reduce the savings the materials might offer.

5. Stainless steel, while resistant to corrosion, has a hardness that can negatively impact its coinability. Control of cold-rolling reduction and proper annealing of the right grades demonstrated the ability to mitigate this factor, and improves the coinability of stainless steel, warranting further testing and evaluation. (See attached Stainless Feasibility Study and its Executive Summary in Section 8.)

Production Improvement

6. Adjusting the height of relief/crown on our current coin designs by a fixed percentage introduced other issues, such as outer elements (e.g., the border) filling before inner ones, or the flow of the material changing. It became clear that changes to the coin features—including adjustments to the height of relief/crown, planchet profile, smoothing of design, softening of the letters, and less-detailed images in general—must be treated as a collective system. This system involves not only the items mentioned here, but also matching planchet-die geometry, strike force, die lubrication/coating/polishing, and other variables.

7. Striking of coins with an outer nickel layer (whether single-layer NPS or multilayer MPPS) will require that circulating dies be polished (to provide a uniform and smooth surface) and coated (to provide sufficient abrasion resistance). PVD coatings on U.S.-Mint-manufactured dies demonstrated poor adherence to die surfaces (coating delamination).

8. To accommodate the abrasive outer nickel plating on NPS and MPPS, coating and/or replacement of parts that contact the planchet/coin will be required in production

equipment (conveyors, material handling, press feed/takeaway parts and coin counters). This will reduce identified material savings by an estimated $6M[42] per year. A similar accommodation will be required by all external coin processors and handlers to address the increased wear associated with nickel surfaces.

9. Variability and Pre-production trials indicate planchet lubrication is a critical, but not-yet-optimized variable impacting coining performance with alternative materials. The application of Carboshield BTX to our current cupronickel-based material significantly improved die life and effectively raised the bar for alternatives. However, it took the Mint over three years to develop and implement this lubricant/anti-tarnish material. The Mint will need to develop a similar development process for alternative materials.

10. The inclusion of more than just nickel and copper in leaner-copper-based alloys impacts hardness and more critically conductivity. This will require development of the annealing practices and also slight changes to the coin designs' relief/crown.

11. Test strikes with different material, die designs, and planchet upset profiles confirm that collectively these factors need to be treated as a complete system when making changes. Results seen from changing one variable cannot be interpreted as solely related to that one factor. This means changes to die designs, planchet upset, and material composition will require structured trials to gain a broader understanding and effectively interpret results.

Terminated Materials

12. Testing of plated zinc alternatives (copper-plated zinc (CPZ) and tin-plated copper-plated zinc (TPCPZ)) showed insufficient wear and durability properties for consideration on heavier denominations than the current one-cent CPZ application. Additionally, TPCPZ exhibited galvanic corrosion when copper and tin, two dissimilar metals were exposed to the environment during wear, rendering this construction unsuitable for U.S. coins.

[42] According to Schuler, the manufacturer of the presses in the Mint.

6.2. Recommendations for Further Study

1. Continue 80/20 Testing and Evaluation
    a. Continue larger-scale testing of 80/20 and develop a final specification that can be utilized by current and other strip suppliers.
    b. Conduct feasibility, variability and pre-production testing on cladding 80/20 to a copper core as an alternative for the clad denominations of dime, quarter-dollar and half-dollar. Direct cost savings from this change would be limited, but continuing to clad these coins with the same alloy used in the five-cent would streamline material production.
2. Pursue seamless alloy development

    Continue alloy development of other, potentially seamless, leaner-copper alternatives to provide opportunity for additional incremental materials savings without impacting coin acceptors and coin processors. Initial testing indicates further opportunity for incremental material cost reductions with a composition evolving over several progressive steps.
3. Continue stainless steel R&D
    a. Continue larger-scale variability and pre-production testing on the two stainless steel grades identified in the attached Stainless Feasibility Study.
    b. Conduct testing and evaluation of monolithic stainless steel as a clad outer layer as a co-circulate material. Engineering calculations indicate this combination could exhibit a similar EMS to the current clad coins and enable the copper core thickness to be reduced, providing incremental material savings and a reduction in the use of the more-expensive and price-volatile nickel. Its piece weight, however, would be lighter.
4. Explore production improvements
    a. Investigate push-back blanking and determine if that is a technically feasible and cost-effective production method that would enable elimination of internal annealing on strip material (see attached Laser-Blanking Study).
    b. Pursue more-structured test strikes on different coin materials, modified design aspects, and upset profile configurations to increase the Mint's understanding of the overall coin manufacturing system. These results can be utilized to improve production efficiencies on current coin materials and provide for quicker evaluation of future materials. Results from structured trials can be used to support predictive model development and reduce the need for time-consuming iterative test strikes.

7. Bi-Metallic Coin Study

Concurrent Technologies Corporation (CTC) performed the study on bi-metallic coins, and recommended against the proposal to make bi-metallic five cents from current one-cent coins as the center and five-cent coins as the outer ring. CTC also determined that bi-metallic construction would be advisable for coin denominations above the dollar. Below is the Executive Summary.

7.1. Executive Summary

The Mint sought to leverage CTC's recent experience in the *Alternative Metals Study* to identify and quantify many of the issues associated with material selection, supply, production, manufacturing and public use of bi-metallic coins.

CTC provided a tabular database entitled "World Bi-Metallic Coins" that includes countries where the bi-metallic coins are issued, along with their denomination, images of the obverse and reverse (when available), materials of construction, total coin weight and coin dimensional specifications (thickness and diameter of the outer ring and core), inside-diameter-to-outside-diameter (ID/OD) ratio, approximate United States (U.S.) equivalent monetary value, Web site for images and other details, and the country's mint or government Web site. A total of 194 countries (including the United States) populate the World Bi-Metallic Coins database. Of the 194 total countries surveyed, 92 countries have one or more bi-metallic coins in their nation's coin set. From the World Bi-Metallic Coins database, CTC observed that the ID/OD ratio of bi-metallic coins throughout the world varied between a minimum of 0.56 and a maximum of 0.78. A mean ID/OD ratio of 0.68 was found.

CTC also investigated the feasibility and estimated unit cost of creating a circulating bi-metallic coin using the current one-cent coin/planchet as an insert to an outer ring made from a current five-cent coin/planchet. Demonstration pieces were fabricated (i.e., not struck) and provided to the United States Mint to illustrate the placement of an already circulated one-cent coin/planchet inside an outer ring made from an already circulated five-cent coin/planchet. These demonstration pieces also illustrated the effects of using an ID/OD ratio of 0.90 (full diameter of a one-cent coin) and 0.68 (world mean ID/OD ratio); the outer rim of material was removed from the one-cent coin to achieve an ID/OD ratio of 0.68. Estimated unit costs were calculated for each possible one-cent coin/planchet in a five-cent coin/planchet scenario.

CTC investigated the feasibility and cost effectiveness of utilizing a bi-metallic coin for circulating coin denominations other than the five-cent coin. Manufacturing equipment needed to produce bi-metallic coinage and production changes necessary to support producing a bi-metallic coin for the United States in circulating coin quantities was documented. Factors considered in the selection of potential metal alloys included color, electrical conductivity, tarnish and corrosion resistance, wear resistance, electrochemical compatibility with other alloys, cost, mechanical properties, coefficient of thermal expansion, recyclability and environmental impact. By their nature, bi-metallic coins require metals of differing colors. Of the many alternative alloys considered, the majority of those selected for further evaluation was either already being used or were similar to alloys already being used in production of world circulating bi-metallic coins. This included copper-nickel alloys, various brasses and stainless steels.

Hypothetical two- and five-dollar circulating coins were contemplated and several constructions were evaluated. This investigation was motivated by the discovery that at least six bi-metallic world circulating coins, whose value exceeds $2 U.S. dollars, are currently in circulation throughout the world. The hypothetical two- and five-dollar United States coins were assumed to be 28 millimeters (mm) and 29.2 mm in diameter and 2.45 mm and 2.75 mm in rim height, respectively. These diameters fall between those of the legacy one-dollar and half-dollar coins. The thickness of these two hypothetical coins is greater than any current U.S. coin, but is less than other coins, including the United Kingdom one-pound coin, circulated throughout the world. These hypothetical bi-metallic coins could be produced by the United States Mint for 0.22 to 0.27 $/coin, depending upon the materials used in their construction. Additional development, beyond the engineering cost analysis described here, must be completed prior to selecting any of these designs for production.

Changes to the size and construction of the half-dollar coin were contemplated. A bi-metallic construction was evaluated having an inside diameter of 14.8 mm, an outside diameter of 22.73 mm and a rim height of 2.31 mm. The core of this hypothetical half-dollar coin was made of homogeneous 75Cu-25Ni cupronickel while the outer ring was made of Nordic gold. The projected unit cost for this coin was 0.143 $/coin (using FY2014 metal cost and FY2013 United States Mint indirect costs for the quarter-dollar coin). The unit cost to produce legacy 75Cu-25Ni-clad copper half-dollar coins for circulation in FY2006—the last year that circulating half-dollar coins were produced—was 0.1749 $/coin; the projected cost to produce legacy 75Cu-25Ni-clad copper half-dollar coins for circulation in FY2014 was

0.19132 $/coin. Therefore, the hypothetical bi-metallic half-dollar circulating coin would offer a 25 percent reduction in unit cost compared to the legacy construction.

CTC performed a regulatory analysis of the applicable environmental issues, including those related to air pollutant emissions, solid and/or hazardous waste management, water use and wastewater discharges. CTC did not undertake a formal National Environmental Policy Act (NEPA) environmental assessment as that was beyond the scope of the current project. Recyclability of individual metal components prior to assembly was considered for the materials considered as potential bi-metallic coin candidates. Two methods of recycling bi-metallic coins were considered: 1) separation of the two metal constituents into two unique streams and 2) blending of both metal constituents into a single recycle stream.

Based upon the information gathered from each of the above factors, CTC offers the following recommendations for consideration and implementation by the United States Mint. Detailed descriptions of the study's findings and conclusions can be found in the body of the report.

- **A bi-metallic five-cent coin, utilizing any materials for coin construction, will need to co-circulate with the existing homogeneous cupronickel five-cent coin.** If all materials in a newly introduced bi-metallic five-cent circulating coin are non-ferromagnetic, then a one-time investment of $277M is required by the United States coin stakeholder community to accept the new coin construction. However, if any of the components are ferromagnetic, then a one-time investment of $532M to upgrade or replace existing coin-acceptance equipment will be needed. If a bi-metallic five-cent coin of different weight than the legacy five-cent coin was introduced into circulation, additional sorting and handling would be required by United States coin and currency handlers; the cost associated with this additional handling was estimated to be $3.75M per year.
- **Do not pursue concept of one-cent core in five-cent outer ring using either previously circulated coins or unstruck planchets.** Significant technical and cost issues have been identified with this bi-metallic coin construction.
    - Technical issues, which cannot be overcome and therefore preclude the use of either previously circulated coins or unstruck planchets, include the following.
        - A full-diameter one-cent coin/planchet placed inside a five-cent coin/planchet outer ring would yield an inside-to-outside diameter ratio of 0.90, which is well beyond the ratio of all other known bi-metallic coins in circulation throughout the world. An outer ring of such narrow width will be subject to warping, denting, crushing and

other damage during normal handling operations. In addition, maintaining stability during assembly and striking will be problematic and options for locking mechanisms between the one-cent coin/planchet core and five-cent coin/planchet outer ring will be severely limited with such a narrow outer ring.

    - Use of a reduced-diameter, previously circulated one-cent coin/planchet will expose the zinc core, which would quickly corrode during normal handling and exposure to the environment. This will lead to decreased coin life and public confusion.
    - A full-diameter five-cent coin will not fit into the striking press collar unless the outside diameter of the five-cent coin is first reduced by upsetting or machining. This adds another processing step to the production of such bi-metallic coins.
    - The approximately 0.3-mm thickness mismatch between the one-cent and five-cent coins/planchets violates a recommendation by the leading supplier of bi-metallic coin presses to keep such thickness mismatches to less than 0.1 mm. Thickness mismatches greater than 0.1 mm would tend to wear unevenly, collect debris along the corner formed by the thinner component at the junction of the two components, likely induce stress concentrations in the striking dies thereby shortening useful die life and potentially require larger acceptance windows in automated coin-acceptance devices due to inconsistencies associated with placement of the two components in the thickness direction.
    - The one-cent's date of striking, Lincoln's profile, the shield and "ONE CENT" are clearly visible on those demonstration pieces based on the use of a previously circulated one-cent coin. During striking of the resulting bi-metallic five-cent coin, a "double strike" condition would occur as the original images would appear behind the newly struck image. Furthermore, the alignment of the two images would be random leading to wide variations in the final struck image and potentially leading to increased variability in finished coin quality.

- Introduction of such a bi-metallic five-cent coin into circulation, would not offer the same amount of unit cost savings as other alternative five-cent coin constructions as identified in the *Alternative Metals Study*. Furthermore, additional sorting and handling of this construction, which would require co-circulation, would require an estimated increase of $3.75M/year by the coin and currency handlers. Also, less expensive options consisting of homogeneous non-ferromagnetic stainless steel construction were identified in the *Alternative Metals Study*.

    - An option to use a full-thickness copper-plated zinc core was considered. Of the three constructions evaluated, only one provided any significant unit cost savings. However, this construction relied on nickel-plated steel for the outer ring resulting in a complex metal mixture that:
        - Is susceptible to rapid corrosion
        - Requires upgrades or replacements for many coin-acceptance devices by domestic coin stakeholders at a cost of $532M since the associated steel alloys are ferromagnetic
        - Requires additional sorting and handling by the coin and currency handlers at an annual cost of $3.75M.
- **Consider use of a clad core for any bi-metallic coins with a face value greater than or equal to one dollar to increase security and visual uniqueness.** According to the guidelines defined in the European Vending Association (EVA) <u>Coin Design Handbook</u>, bi-metallic coins are suitable for higher-value coins, which are defined as those whose value is approximately greater than 50 Euro cents (approximately 68 United States cents). Security features, such as clad core bi-metallic construction, are highly recommended to deter counterfeits—the clad-core bi-metallic construction is the highest security feature commonly available in circulating coins according to the EVA <u>Coin Design Handbook</u>. The added cost for a clad core bi-metallic coin was found to be between 0.02 and 0.03 $/coin more than a homogeneous core design. Therefore, the added security offered by a clad core was judged to be worth the additional cost for coins that typically can be produced in circulation quantities for 0.18 to 0.27 $/coin depending on material selection and coin dimensions.
- **Use an ID/OD ratio between 0.60 and 0.75 for bi-metallic coins.** Maintaining this ID/OD ratio is consistent with the majority of bi-metallic circulating coins in the world. This ratio is consistent with a recommendation by the manufacturer of the overwhelming majority of the world's coin striking presses to keep the exposed areas of the two components (i.e., the core and outer ring) approximately equal. Deviations from equal areas sometimes occur to minimize the quantity of the more expensive of the two components of a bi-metallic coin. The unit cost of bi-metallic coins did not vary widely over an ID/OD ratio between 0.60 and 0.75 indicating that other factors, including artistic appeal, may play an important role in selecting the desired ID/OD ratio for any given bi-metallic coin.
- **Use a minimum outer ring width (i.e., the difference between the outside radius and inside radius) of 4.0 mm.** A leading coin striking press manufacturer recommends that the width of the outer ring be a minimum of 3.5–4.5 mm to ensure that high-quality outer rings are delivered to, and maintained during operations within, the bi-metallic coining presses. A range in widths is given since the recommended value for

any given coin depends on the thickness and outside diameter of the outer ring; larger widths apply to outer rings of larger diameter.

- **Prior to introducing any circulating coin of new construction, including bi-metallic construction, engage the coin-acceptor community to test for uniqueness from other circulating coins used throughout the world.** The United States Mint should provide manufacturers of automated coin-processing equipment samples of the final coins (made from the new materials of construction) at least 18 months in advance of the expected date for introducing these coins into circulation. Doing so will provide the coin-processing industry time to respond to changes in the construction of coins. These samples are expected to be used to design the necessary changes to the manufacturer's equipment and to get their clients prepared for the introduction of these coins into circulation.
- **Within the sizes of the current United States coin set, use of piercings from high-denomination bi-metallic coins is not practical for low-value coins of smaller diameter.** In no cases were the thickness and diameter of such piercings (within the bounds of acceptable ID/OD ratios for bi-metallic coins) acceptable for striking. In all cases, the piercing size violated the thickness and diameter tolerances required of planchets used to produce these low-denomination coins.
- **The capital cost required by the United States Mint to produce bi-metallic coins would increase the unit cost of coins by approximately 0.0066 \$/coin.** This assumes the use of piercing presses, new vertical coin striking presses, additional upsetting mills and inspection of outer rings. A 10-year return on investment was used for this calculation.

Production of bi-metallic coins at the United States Mint will require additional process steps and production equipment compared to the legacy coin production. Compared to the production of homogeneous or clad coins, bi-metallic coins require the following additional processing steps: one additional blanking operation, one additional upsetting operation, a piercing operation and inspection of the outer ring. Two options exist for production of bi-metallic coins: 1) processing of materials from rolled coils to finished bi-metallic coins at the United States Mint and 2) striking pre-assembled bi-metallic planchets produced by a supplier. Both options will require purchase of additional vertical presses and support equipment; a similar number of additional vertical presses and support equipment would be required for either option to meet the production demands of the United States Mint. In the first option, the United States Mint would purchase the equipment directly; in the second option, the bi-metallic planchet supplier would purchase the equipment (and indirectly pass the cost onto the United States Mint). In the first option, the United States Mint could retire their current horizontal striking presses (or use them for production of non-bi-metallic coins). However, if the second of these options is exercised, then the United States Mint must still use its existing horizontal striking presses to strike the bi-metallic pre-assembled planchets. In effect, an additional, and costly processing step will be required for this option: the assembled components must be compressed with a flat die to lock them together and to ensure they remain intact during subsequent handling, shipping and loading into the horizontal striking presses at the United States Mint. As a result, CTC expects the cost impact to the United States Mint for this second production option to be higher than having the United States Mint complete all production steps in-house.

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8. Stainless Steel Feasibility Study

Concurrent Technologies Corporation (CTC) performed the study on Stainless Steel alternatives, and published that report to the Mint in early July 2014. Below is the Executive Summary, formatted for this report.

8.1. Executive Summary

The United States Mint sought to leverage CTC's recent experience in the *Alternative Metals Study* and CTC's broad understanding of metals, manufacturing and coin production to identify and quantify many of the issues associated with material selection, supply, production, manufacturing and public use of stainless steel coins. Key to the success of the current effort was the willingness of the suppliers to provide laboratory heats (each weighing approximately 50 pounds) of down selected stainless steel alloys for evaluation. Stainless steel alloys having low hardness, strength and work hardening behavior, while achieving complete die fill and the ability to upset blanks in a softened, annealed state to minimize striking loads and die fatigue, were down selected for this project. The results of this study include the following.

- A material change from cupronickel to a stainless steel alloy for the existing five-cent coin would require co-circulation (although non-seamless) with the legacy coin; non-seamless alternative candidates having a different, possibly unique, EMS and/or a different weight than the incumbent coinage.
- Stainless steel alloys would provide a lower-cost candidate for the five-cent circulating coin.
- Based upon the United-States-Mint-approved cost analysis methodology used, all stainless steel alloys evaluated offer a unit cost saving to the United States Mint for five-cent circulating coins.
- While the unit cost saving to the United States Mint for ferromagnetic alloys were found to be higher than that for non-ferromagnetic alloys, use of ferromagnetic stainless steel coins would have approximately twice the cost impact to the domestic coin stakeholders (including the vending industry, laundromats and others) than would the use of non-ferromagnetic stainless steel coins.
- Rittenhouse and Modified 18-9 LW appeared to offer good striking performance at striking loads that were comparable to those used to manufacture the legacy cupronickel five-cent circulating coins. However, validation of production parameters using production equipment (as opposed to the laboratory-scale heats and equipment evaluated and discussed in this report) at the suppliers need to be

evaluated; therefore, larger scale tests are recommended before attempting a preproduction run.

Based upon these findings, the following recommendations are offered.

- Complete additional technical assessments of Rittenhouse 52 and Modified 18-9 LW stainless steel alloys. Striking of these alloys during tests completed at the United States Mint Research and Development Center in Philadelphia showed complete die fill with reduced coining loads as compared to the incumbent cupronickel five-cent circulating coin.
- Consider only non-ferromagnetic stainless steel alloys for use in five-cent coins to minimize the impact to the domestic coin stakeholders.
- Confirm unit cost estimates by obtaining updated cost quotes from material vendors for production volumes of stainless steel five-cent coins and completing preproduction runs to validate striking die life.
- Apply numerical methods (such as finite element analysis) to predict blanking shear stresses, die fill, die stress and die life for various materials, die shape and process conditions. Doing so will improve the understanding of how these factors interact in advance of actual pre-production trials. The virtual trials will allow for relatively inexpensive investigations of many process design scenarios, which will enhance the probability of achieving successful and meaningful pre-production trials.

9. Laser-Blanking Study

Fraunhofer USA performed the study on laser blanking, and published that report to the Mint in July 2014. Below is the Executive Summary, formatted for this report.

9.1. Executive Summary

In support of the Coin Modernization, Oversight, and Continuity Act of 2010, the U.S. Mint is seeking ways to reduce the cost of producing circulating coins. One potential idea is to replace the current mechanical die blanking and on-site annealing with laser blanking and off-site bulk annealing. A second scenario is to retain the on-site annealing and exchange die-blanking with laser blanking. The U.S. Mint contracted with Fraunhofer USA to investigate the technical and financial feasibility of these ideas.

Fraunhofer conducted a thorough review of the technical issues and found no significant concerns. The review involved laser cutting nine different materials and making sample coin blanks. The sample blanks were characterized for diameter, burr, knit-line, edge condition, grain structure, and hardness in the area adjacent to the laser cutting. Laser cutting of the monolithic 5-cent material was found to be faster and at better edge quality than with any of the clad materials (dime, quarter, and dollar). Sample lots of 100 pieces of 5-cent, dime, quarter, and dollar blanks were sent to the U.S. Mint for evaluation.

A conceptual design was developed along with 3D CAD images showing how multiple lasers working in parallel could meet the production needs of the U.S. Mint. Also an Environmental Assessment was performed which yielded no significant concerns.

Several economic analyses were performed using a range of assumptions and **none of the analyses showed a strongly favorable economic outcome for laser blanking**. When considering laser blanking machines with production capacity equal to the current die blanking machines, laser blanking looks economically unfavorable. When lower production capacity was considered, the economics of laser blanking are roughly equivalent to die blanking within the margin of error of the analysis, making laser blanking not a very compelling avenue for pursuing cost reduction efforts. Perhaps in the future, if lasers cut faster or become less expensive, that situation might change; but currently the financial feasibility of laser blanking looks challenging.

In the course of this study, Fraunhofer identified a promising alternative to laser blanking called die blanking with a push-back system, which could eliminate the expense of on-site annealing. This system is very similar to the current die blanking and the capital investment looks to be low. Fraunhofer recommends that a study be conducted of a push-back die blanking system for the U.S. Mint.

If the U.S. Mint decides that a lower production capacity meets its needs, then the economics of laser blanking are estimated to be roughly equal with die blanking and laser blanking might be pursued by the U.S. Mint for some of the benefits it offers. Fraunhofer has developed a logical multiphase development process to continue the effort into laser blanking that will address some of the design and production questions while minimizing development expenses.

Circulating coins are manufactured with three successive metal forming steps. 1) Punch out a flat circular disk, called a blank, from a flattened coil of "hard" sheet metal. 2) Raise a ridge along the outer circumference of the blank (known as upsetting the blank) to create what is known as a planchet. 3) Coin the planchet by stamping the top and bottom surfaces with artwork such as the faces of U.S. Presidents and required inscriptions associated with U.S. coinage. The first step in this sequence, blanking, is the subject of the current cost reduction effort.

Mechanical die blanking is a simple process that works like a paper hole-punch with the punch positioned above the sheet metal and the die below. The die sets are constructed with multiple punches so that each time the die closes, as many as 20 blanks are created. The die press runs at 550 strokes per minute which means that over 5 million blanks can be produced in a single 8 hour shift.

In order to punch out a clean flat blank, the coils of sheet metal must be in a so called work-hardened state rather than a soft, or annealed, state. Unfortunately, the final metal forming step (stamping) requires the metal to be in an annealed state. This means that the U.S. Mint must run large and expensive rotary retort furnaces to anneal all the coin blanks on site.

The proposed laser blanking process, however, is capable of directly cutting annealed sheet material. Thus if laser blanking is technically and financially feasible, it would be possible to eliminate the rotary retort furnaces at the U.S. Mint facilities. The responsibility of annealing the coiled sheet metal material would then be shifted to the metal suppliers who are believed to be able to anneal the metal in bulk coil form at a lower cost compared to the U.S. Mint's rotary retort furnaces.

The work performed by Fraunhofer was structured into four areas

1) Technical feasibility
2) Conceptual design
3) Environmental assessment
4) Economic feasibility

Technical feasibility was performed by cutting out sample blanks using a 6KW Trumpf laser and quantifying the quality of the resulting blanks. In total, nine different materials were cut. Naturally the five existing coin materials were cut, 5-cent[43], Dime, Quarter, Half-Dollar, and Dollar (note that the penny was not tested because it is not blanked at the U.S. Mint). Also, four possible future alternative materials were cut: 304 stainless steel, 430 stainless steel, brass, and silicon steel.

Once the samples were cut, various pieces of metrological equipment were used to quantify six different areas of concern: 1) diameter, 2) burr, 3) edge condition (chamfer), 4) knit-line, 5) grain structure, and 6) hardness in the heat affected zone (HAZ).

The diameter data raised no concerns since the blank diameter is easily adjusted in the machine and the range of diameters (sample to sample variation) was within acceptable limits, less than ±0.002" (±50μm). Some samples were found to be excessively elliptical, a problem that was mostly resolved with improved sample fixturing and would likely be completely resolved by switching to a rotary actuator from the X-Y actuator used in the test setup.

The edge burrs raised no concerns as they were typically around 0.001" (25μm) or less once the laser process parameters were optimized.

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[43] The word "nickel" is ambiguous as it can mean either a five cent coin or a silver metallic material. Both the coin and the metal are discussed in this document leading to possible confusion. To reduce the chance of confusion, the term "five-cent" is used in this document to refer to the coin whereas "nickel" is used in reference to the metal.

The edge condition (chamfers) of some of the laser cut blanks raised some initial concerns but ultimately the chamfers were deemed acceptable. Edge chamfers on some of the clad copper blanks (e.g. quarters) were as large as 0.004" (100μm), which raised the initial concerns. However, two additional studies removed the concerns. Firstly, die blanked samples (the current process) were found to have edge chamfers of a similar size (particularly on the quarter blanks). Secondly, a set of die-cut 5-cent blanks were modified to have 0.002", 0.004", and 0.008" chamfers (50, 100, and 200μm) and then processed into coins at the U.S. Mint. The samples were found to produce acceptable coins even with as much as 0.008" (200μm) chamfer on one edge.

Knit-line is a term chosen to describe a small bump at the edge of the coin blank at the location where the laser starts and stops cutting. This bump can be as large as 0.008" (200μm) and is a concern because it could cause problems in feeding the blanks into the upsetting machine or in actually upsetting the blanks. If the knit-line does cause a problem, Fraunhofer is confident that a laser cutting machine could be designed to hold the blank while it is being cut which would eliminate the knit-line.

Grain structure within the HAZ did not raise any concern. Prior to testing, there were concerns that the heat from the laser would create edge hardening which might make upsetting or stamping difficult with laser cut blanks. However, the only observable change was some signs of grain growth when hard samples were cut which indicates the material is softening rather than hardening.

Hardness measurements did not raise any concern, with one exception. When hard samples were laser cut, the material hardness frequently decreased, which is not a concern. When annealed samples were laser-cut, no change in hardness was measured. One exception was 304 stainless steel which showed a significant increase in hardness in the HAZ which might cause difficulties when trying to upset blanks or stamp planchets made from that material. The hardness at the edge of the laser cut 304 blanks increased to 250 (HV100) which is about twice as hard as the current, annealed cupronickel materials being processed at the Mint. A previous alternative metals study performed for the U.S. Mint showed this material was difficult to strike due to its hardness, so any increase in hardness would only make this situation worse.

Overall, laser cutting of blanks appears to be technically feasible. Some careful engineering design might be needed for the laser blanking machine, but no fundamental problems with laser cutting were identified.

While producing high quality laser cut blanks was shown to be possible, it was known that they would need to be cut very quickly. The current mechanical die blanking system cuts metal at the equivalent of 600 linear meters per minute. Testing with the lasers showed that the cutting speed for current coin materials is between 14 and 35 meters per minute. To have a laser machine match the performance of the die blanking machine would require a machine design with multiple lasers, and immediately raised concerns about the cost of the machine.

In order to make an estimate of the cost of laser blanking, it was necessary to have a conceptual design of a laser blanking machine. The overall concept is to have multiple lasers cutting blanks at the same time to improve the throughput of the machine. A number of lasers (perhaps 4) would be mounted side by side across the width of the strip. These lasers would each be mounted on rotary stages that would move in a circular motion. The stages would be actuated with individual actuators or, as a secondary option, with a mechanism that drives them together as a group. The group of stages would also be mounted on a stage that allowed the laser cutting to start (the pierce) slightly to the side of the coin blank. Additional groups of lasers (perhaps 4 rows of 4 lasers, total 16) would be located downstream of the first group to cut more blanks. This layout is actually similar to the punch and die positions in the current blanking machine, although the lasers would likely need more space than punches and dies.

The footprint of the laser machine would be more than the current die-blanking press, but significantly less than the space made available by the elimination of the rotary retort furnace. If the rotary retort furnace is retained, Fraunhofer believes the laser blanking system could still be made to fit within the current footprint, but the engineering design would be more difficult. A laser blanking machine requires a significant amount of support equipment including the lasers themselves, chillers, air handlers, and nitrogen generators which will consume significant floor area. It is recommended that a mezzanine be constructed above the laser cutting machine to hold the various pieces of support equipment. The laser blanking system (with mezzanine) should easily fit within the available floor space of the U.S. Mint. Lower ceiling heights in Denver might require an alternative placement of support equipment.

The environmental assessment raised no concerns. Eliminating the annealing furnaces at the U.S. Mint would eliminate potential sources of both air and water pollution (though neither are really a serious concern as they are carefully managed by the U.S. Mint). Laser cutting will use additional electricity and the bulk annealing at the suppliers might shift environmental concerns from the U.S. Mint facility to supplier locations, but there is no significant cause for concern.

The financial feasibility study, however, cast significant doubt about the proposed savings from the laser based blanking system. On the positive side, laser blanking of 5-cent coins might be slightly less expensive than the current die blanking owing to the relatively high speed cutting that is possible on the cupro-nickel material that the 5-cent is made from. On the negative side, the slower laser cutting on the clad copper materials (dime, quarter, half-dollar, and dollar) make laser cutting significantly more expensive than the current die blanking. Slower cutting means that more lasers working in parallel are needed, increasing both the cost of the machine and the electricity to run it and also the cost of consumables (e.g. filters). Furthermore, designing a machine that would potentially require over 30 lasers would be a challenge. Fraunhofer is aware of commercial laser cutting machines with 2 lasers, but no more than that. But it is worth noting that current commercial machines are sold based on their flexibility, whereas the U.S. Mint does not need geometric flexibility which greatly simplifies the design and control of multiple lasers.

The economic analysis that looked most favorable for laser blanking was replacing all ten production lines with laser blanking machines with lower production capacity, either half-speed or annealing speed[44]. For this analysis, the economics of laser and die blanking were roughly equal, at least within the uncertainty of the analysis. This analysis could be used as justification to further pursue laser blanking, however, the switch to laser blanking does not look to be a promising venue for significant cost savings and carries some development risks.

One of the key findings from the economic analyses is that the savings from off-site bulk annealing of the coin material proved to be less than expected. This meant that it was not as easy to use the savings from the annealing costs to help cover the cost of laser blanking.

Given that laser blanking appears to be technically feasible but financially uncompelling, there are a few options that can be considered:

1) Take no further action.

[44] A half speed machine is one that has a production capacity of half the current die blanking machine. An annealing speed machine has a production capacity that is equal to the current annealing furnace production capacity. Both are capable of delivering FY2013 production volumes, despite having lower production capacity.

2) Undertake a prototype development effort to make a single laser blanking machine to address issues such as knit-line, rotary stage cutting, and practical cutting speeds. Experience gained from the prototype development would decrease the risks associated with laser blanking, decrease economic uncertainty, and allow the U.S. Mint to gain valuable experience with this new blanking technology.
3) Undertake a study of non-laser based blanking alternatives such as die-blanking with a push-back station that might be able to directly blank annealed material without distorting the blanks.
4) Undertake a study of waterjet cutting blanks.

It is Fraunhofer's recommendation to proceed with option 3 and possibly option 2 above. Die-blanking with a push-back station is viewed as a strong candidate for cost-reducing the blanking operation at the U.S. Mint and laser blanking might be useful as well, although the current analysis suggests it is likely not a strong candidate. Waterjet cutting is believed to be slow and somewhat messy and not likely to be a good fit for the U.S. Mint's application.

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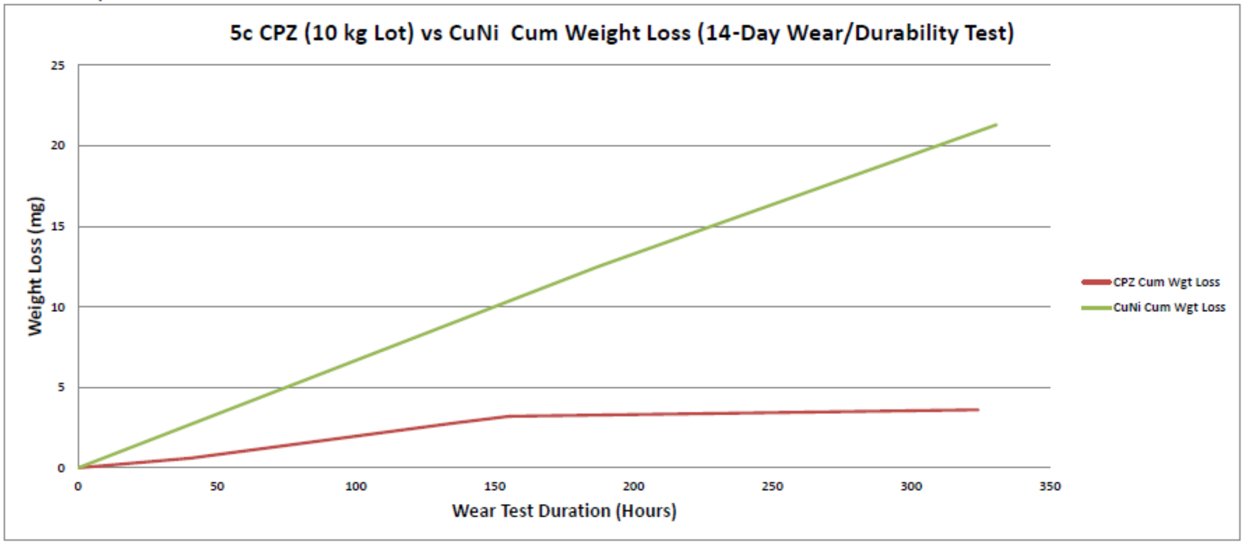
10. Appendices

10.1. Wear Test Results – Variability Lots

10.1.1. Copper-Plated Zinc (CPZ)

WEAR AND DURABILITY TESTING (October 1 - 15, 2013)

Performed by: Uvon Tolbert



Average Weight Loss (per piece): CPZ = 3.6 miligrams
Current 5 cent = 21.3 miligrams

Durability (Edge Deformation): Ending CPZ Edge Thickness = 0.0855"
Ending Current 5-cent Edge Thickness = 0.069"
Deformation = 0.0855 - 0.069 = **0.0165"**

Durability Rating: 5-cent CPZ is rated No Go for durability because edge deformation difference between it and the current 5-cent coin from the same wear chamber exceeded the maximum allowable of 0.010". The soft zinc core is judged to be too soft to reliably withstand impacts and handling (i.e., repeated mechanical coins sorting/counting) expected during circulation. Additionally, the 8-micron copper plating was not thick enough to prevent breakthrough and exposing the zinc core after cycling test pieces 100 times through the coin sorter/validator.

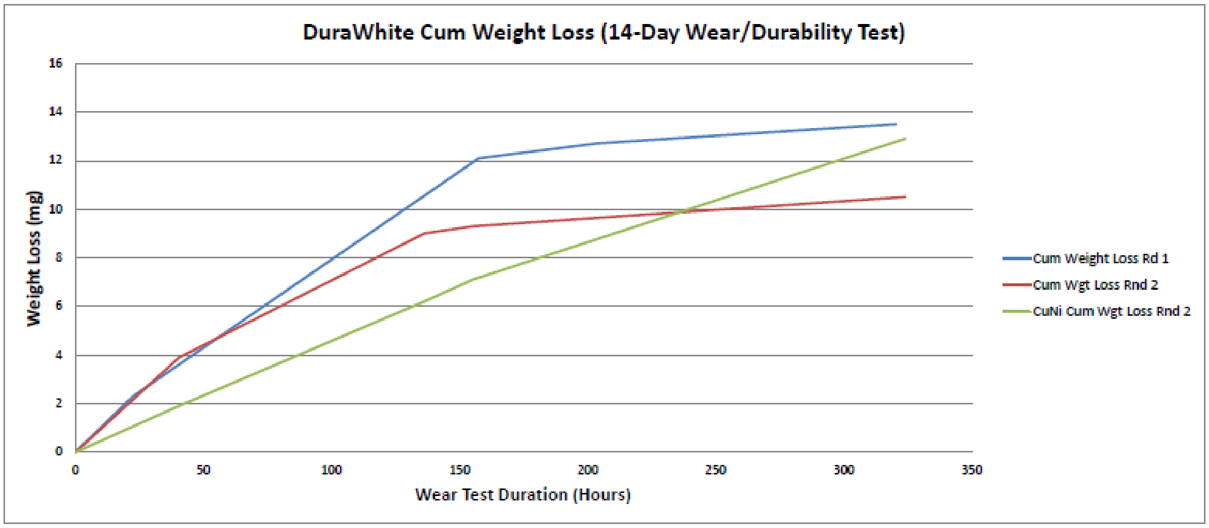
Wear Rating: 5-cent CPZ is rated **Go** for wear resistance based on the first week's weight loss results (see graph above). However, increasing edge thickness as wear testing continued (edge deformation) served to reduce sliding wear to obverse/reverse designs (see graph above) and reducing weight loss.

Overall Rating: No Go

10.1.2.Tin-Plated CPZ (TPCPZ)

TPCPZ Five-Cent (Variability)

WEAR AND DURABILITY TESTING



Average Weight Loss (per piece): DuraWhite Round 1 = 13.5 miligrams
DuraWhite Round 2 = 10.5 miligrams
Cupro-nickel = 12.9 miligrams

Durability (Edge Deformation): Ending DuraWhite Edge Thickness = 0.0867" for Round 1 and 0.089" for Round 2
Ending Cupro-nickel Edge Thickness = 0.070"
Round 1 Deformation = 0.0867 - 0.070 = 0.0167" Round 2 Deformation = 0.089 - 0.070 = 0.0190"

Durability Rating: 5-cent DuraWhite is rated No Go for durability because edge deformation difference between it and cupro-nickel 5-cent coin from the same wear chamber exceeded the maximum allowable of 0.010". The soft zinc core is judged to be too soft to reliably withstand impacts and handling (i.e., repeated mechanical coins sorting/counting) expected during circulation. Additionally, the tin/copper plating did not prevent breakthrough and exposure of the zinc core during 14-day wear testing.

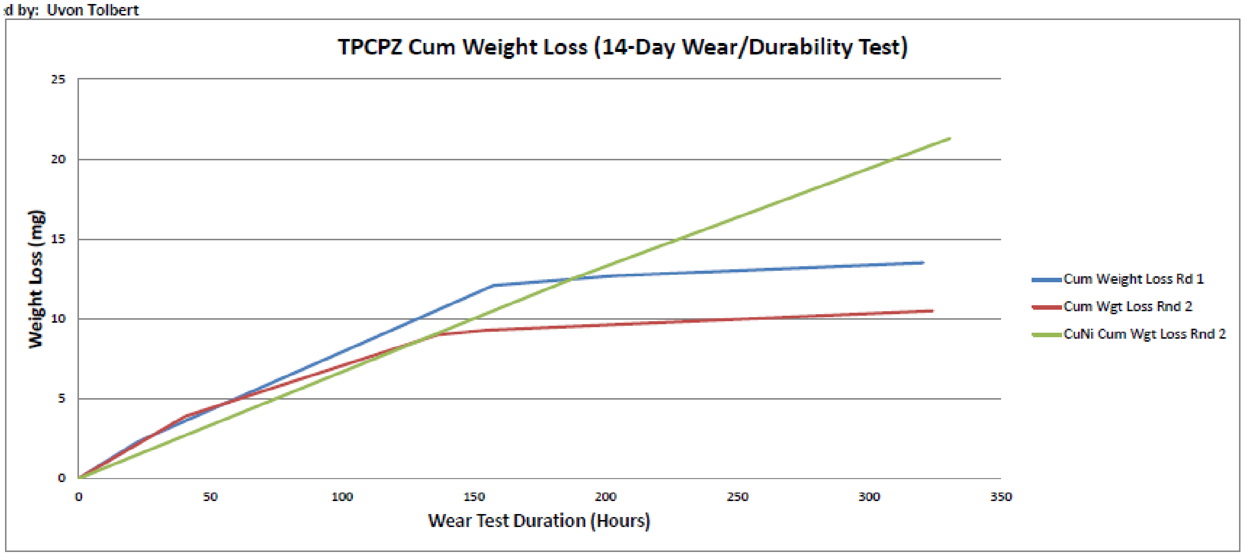
Wear Rating: 5-cent DuraWhite is rated No Go for wear resistance based on the first 2-day weight loss results. These wear rates were higher than the maximum acceptable theshold rate of two times that of cupro-nickel 5-cent (see graph above). During this initial two days of wear testing, tin/copper plating was worn through to the zinc core. Wear rates moderated as wear testing continued due to increasing edge thickness with wear test duration. Increasing edge thickness served to reduce sliding wear to obverse/reverse designs, reducing weight loss.

Overall Rating: No Go

TPCPZ Quarter-Dollar (Variability)

WEAR AND DURABILITY TESTING (Sep 17 - Oct 1 and Oct 1 - Oct 15, 2013

d by: Uvon Tolbert



Average Weight Loss (per piece): TPCPZ Round 1 = 13.5 miligrams
TPCPZ Round 2 = 10.5 miligrams
Current 5 Cent = 21.3 miligrams

Durability (Edge Deformation): Ending TPCPZ Edge Thickness = 0.0867" for Round 1 and 0.089" for Round 2
Ending Current 5-cent Edge Thickness = 0.070"
Round 1 Deformation = 0.0867 - 0.070 = **0.0167"** Round 2 Deformation = 0.089 - 0.070 = **0.0190"**

Durability Rating: 5-cent TPCPZ is rated No Go for durability because edge deformation difference between it and the current 5-cent coin from the same wear chamber exceeded the maximum allowable of 0.010". The soft zinc core is judged to be too soft to reliably withstand impacts and handling (i.e., repeated mechanical coins sorting/counting) expected during circulation. Additionally, the tin/copper plating did not prevent breakthrough and exposure of the zinc core during 14-day wear testing.

Wear Rating: 5-cent TPCPZ is rated No Go for wear resistance based on the first 2-day weight loss results. During this initial two days of wear testing, tin/copper plating was worn through to the zinc core. Wear rates moderated as wear testing continued due to increasing edge thickness with wear test duration. Increasing edge thickness served to reduce sliding wear to obverse/reverse designs, reducing overall weight loss.

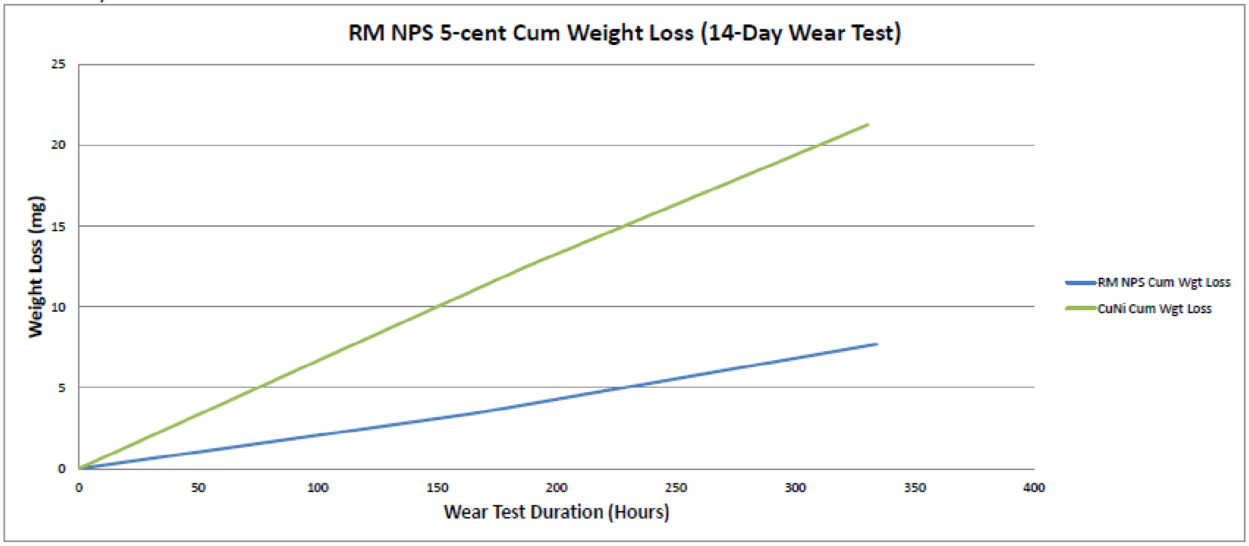
Overall Rating: No Go

10.1.3.NPS

NPS Five-Cent (Variability)

WEAR AND DURABILITY TESTING (Nov 5 - 19, 2013)

Performed by: Uvon Tolbert



Average Weight Loss (per piece):	RM NPS 5 cent = 7.7 miligrams Current 5 cent = 21.3 miligrams
Durability (Edge Deformation):	Ending RM NPS 5-cent Edge Thickness = 0.0770" Ending Current 5-cent Edge Thickness = 0.0790" Deformation = 0.0770 - 0.0790 = **-0.0020"**

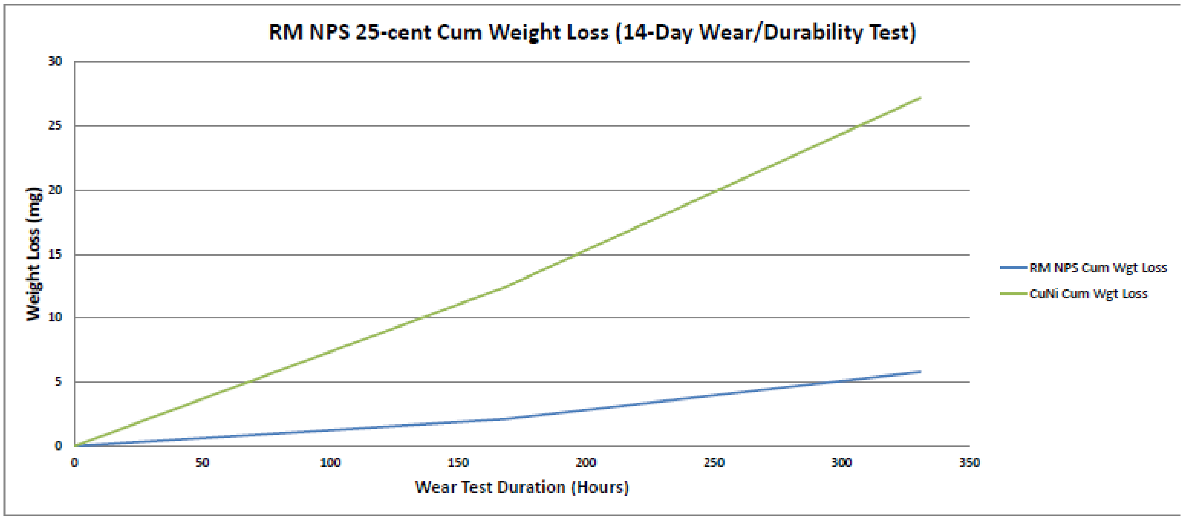
Durability Rating: 5-cent RM NPS rated Go for durability because edge deformation difference between it and the current 5-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010". In fact, MPPS deformation was less than that of the current 5 cent (-0.0020"). This significantly lower deformation is likely due to the relatively thick nickel plating. Nickel plating is much harder than the current cupronickel.

Wear Rating: 5-cent RM NPS is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of the current 5-cent (see graph above). The wear rate of NPS was significantly less than that of the current 5-cent.

Overall Rating: Go

NPS Quarter-Dollar (Variability)

WEAR AND DURABILITY TESTING



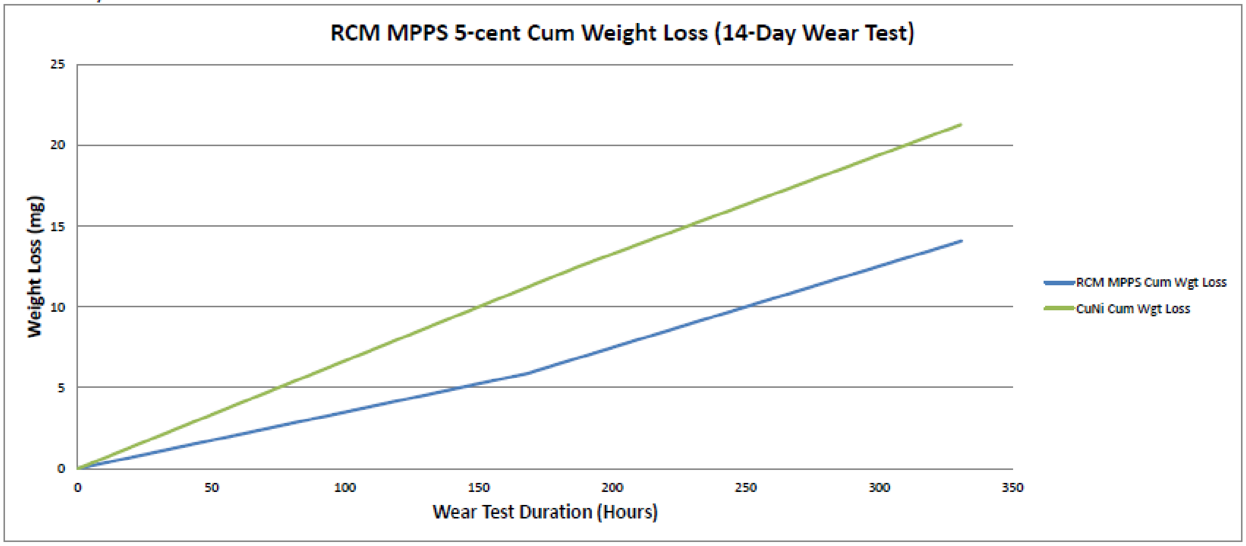
Average Weight Loss (per piece):	RM NPS = 5.8 miligrams Cupro-nickel = 27.2 miligrams
Durability (Edge Deformation):	Ending RM NPS Edge Thickness = 0.0695" Ending Cupro-nickel Edge Thickness = 0.0695" Deformation = 0.0695 - 0.0695 = 0"
Durability Rating:	25-cent RM NPS rated Go for durability because edge deformation difference between it and cupro-nickel 25-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010". NPS deformation was the same as that of cupro-nickel 25-cent.
Wear Rating:	25-cent RM NPS is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of cupro-nickel 25-cent (see graph above). The wear rate of NPS was significantly less than that of cupro-nickel 25-cent, especially during week one of testing. This reduced wear rate was due to exceptional low wear along reeded edges of nickel plated test pieces.
Overall Rating:	Go

10.1.4.MPPS

MPPS Five-Cent (Variability)

WEAR AND DURABILITY TESTING (Dec 9 - 23, 2013)

Performed by: Uvon Tolbert



Average Weight Loss (per piece):	RCM MPPS = 14.1 miligrams Current 5 Cent = 21.3 miligrams
Durability (Edge Deformation):	Ending RCM MPPS Edge Thickness = 0.0795" Ending Current 5-cent Edge Thickness = 0.0800" Deformation = 0.0795 - 0.0810 = **-0.0005"**

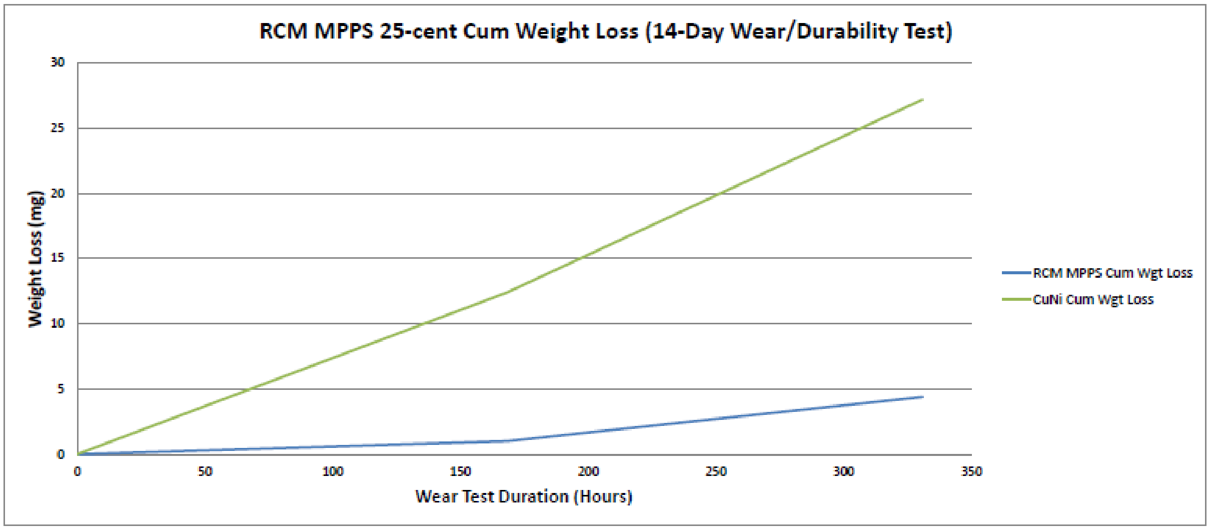
Durability Rating: 5-cent RCM MPPS rated Go for durability because edge deformation difference between it and current 5-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010". In fact, MPPS deformation was less than that of the current 5 cent (-0.0005").

Wear Rating: 5-cent RCM MPPS is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of the current 5-cent (see graph above). The wear rate of MPPS was significantly less than that of the current 5-cent.

Overall Rating: Go

MPPS Quarter-Dollar (Variability)

WEAR AND DURABILITY TESTING



Average Weight Loss (per piece): RCM MPPS = 4.4 miligrams
Cupro-nickel = 27.2 miligrams

Durability (Edge Deformation): Ending RCM MPPS Edge Thickness = 0.0740"
Ending Cupro-nickel Edge Thickness = 0.0690"
Deformation = 0.0795 - 0.0810 = 0.0050"

Durability Rating: 25-cent RCM MPPS rated Go for durability because edge deformation difference between it and cupro-nickel 25-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010". MPPS deformation was 0.0050" greater than that of cupro-nickel 25-cent.

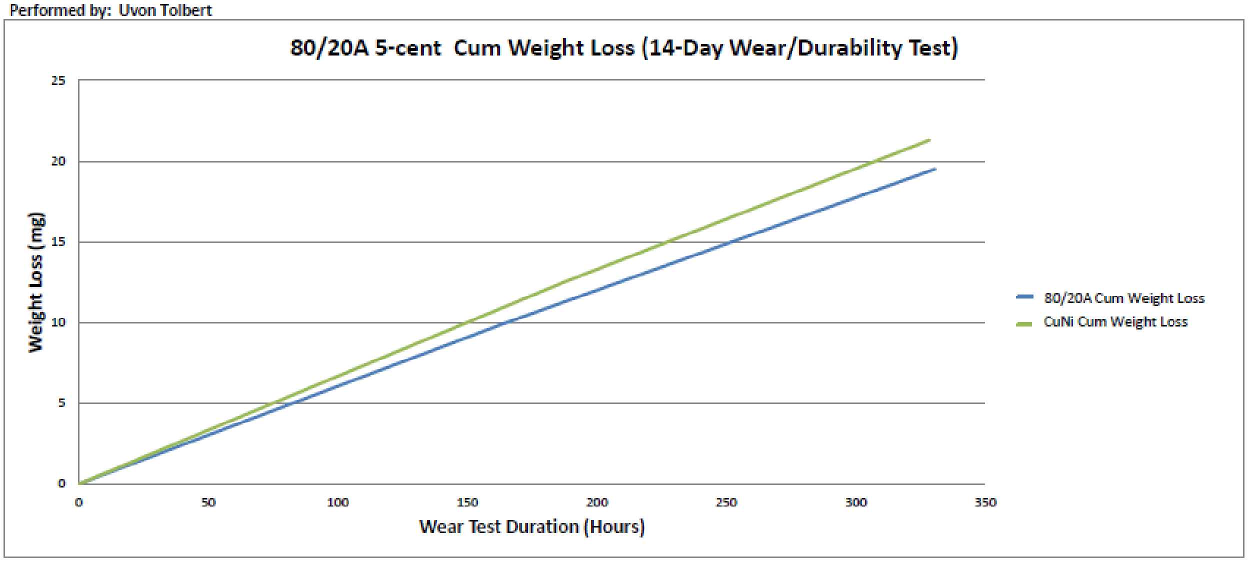
Wear Rating: 25-cent RCM MPPS is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of cupro-nickel 25-cent (see graph above). The wear rate of MPPS was significantly less than that of cupro-nickel 25-cent, especially during week one of testing. This reduced wear rate was due to exceptional low wear along reeded edges of nickel plated test pieces.

Overall Rating: Go

10.1.5.80/20A (Variability)

WEAR AND DURABILITY TESTING (Oct 15 - Oct 29, 2013)

Performed by: Uvon Tolbert



Average Weight Loss (per piece): 80/20A 5 cent = 19.5 miligrams
Current 5 cent = 21.3 miligrams

Durability (Edge Deformation): Ending 80/20A 5-cent Edge Thickness = 0.0800"
Ending Current 5-cent Edge Thickness = 0.0795"
Deformation = 0.0800 - 0.0795 = **0.0005"**

Durability Rating: 5-cent 80/20A rated Go for durability because edge deformation difference between it and the current 5-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010".

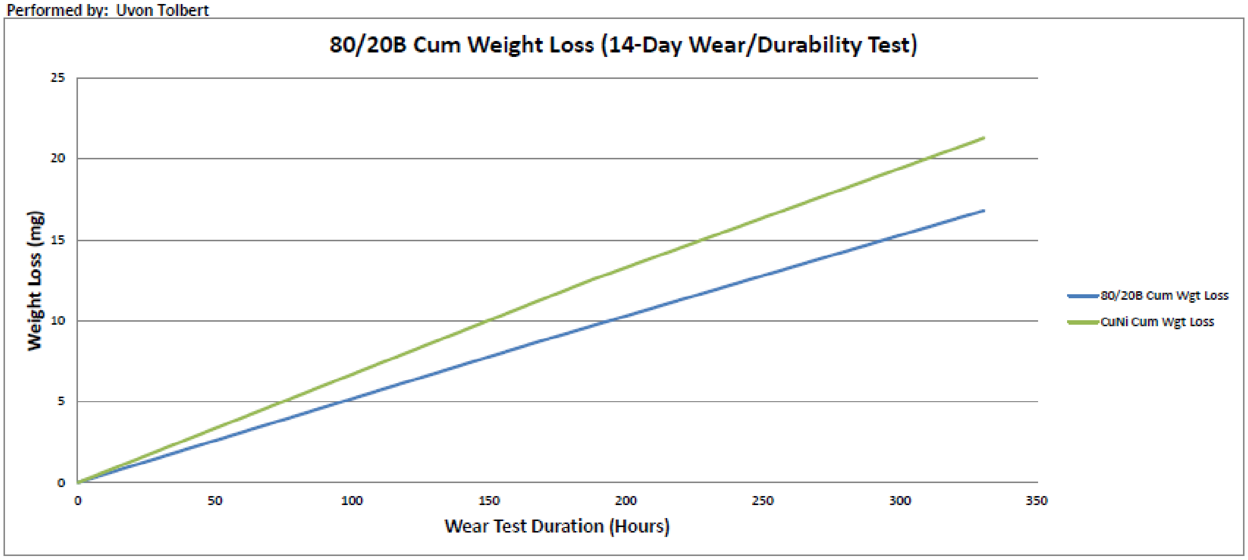
Wear Rating: 5-cent 80/20A is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of the current 5 cent (see graph above). In fact, the wear rates of 80/20A was comparable to that of the current 5 cent.

Overall Rating: Go

10.1.6. 80/20B (Variability)

WEAR AND DURABILITY TESTING (Dec 9 - 23, 2013)

Performed by: Uvon Tolbert



Average Weight Loss (per piece): 80/20B 5 Cent = 16.8 miligrams
Current 5 Cent = 21.3 miligrams

Durability (Edge Deformation): Ending 80/20B 5-cent Edge Thickness = 0.0810"
Ending Current 5-cent Edge Thickness = 0.0820"
Deformation = 0.0820 - 0.0810 = **0.0010"**

Durability Rating: 5-cent 80/20B rated Go for durability because edge deformation difference between it and the current 5-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010".

Wear Rating: 5-cent 80/20B is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of the current 5-cent (see graph above). The wear rates of 80/20B was less than that of the current 5-cent.

Overall Rating: Go

10.2. Steam Test Results – Variability Lots

10.2.1. CPZ Steam Test

CPZ 5 Cent Blanks Variability Tests Color Change Before and After Steam Test

Test Date: 04/01/14
Operator: Tony Ying
The average measured values of 5 CPZ 5 cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the envelope. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of CPZ blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	76.20	17.29	22.31	1.30	0.94	0.92
After steam test	60.18	26.69	37.67	3.03	2.09	2.70

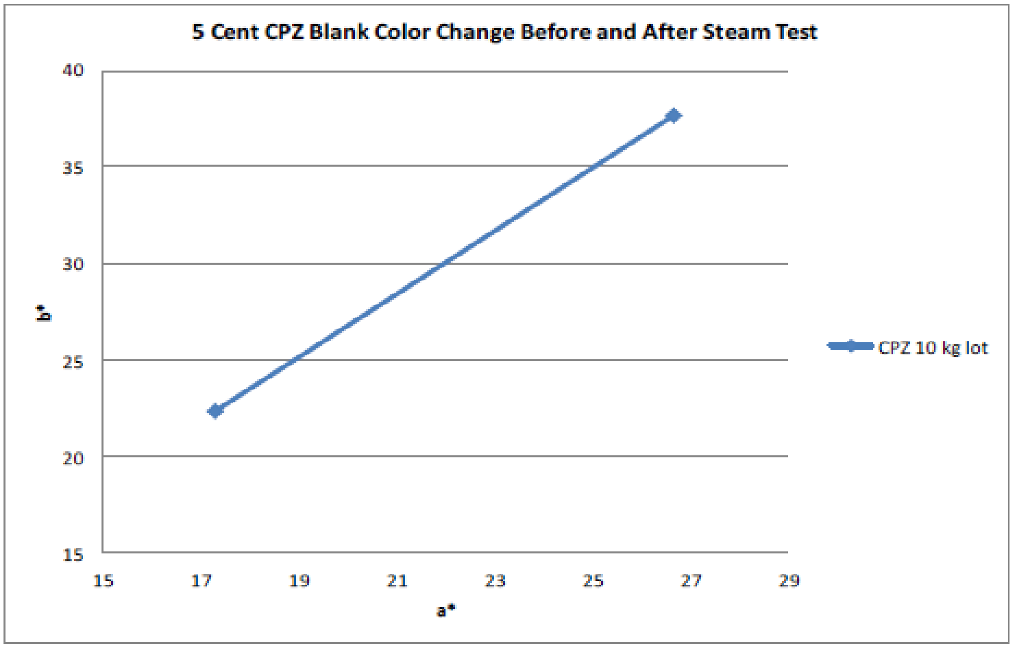


Figure 1: The color change of CPZ blanks.

Overall Assessment: When the other batch of the blanks was tested, the color change was much less. No conclusion was made.

10.2.2.TPCPZ Steam Test

TPCPZ (Five-Cent) (Variability)

TPCPZ 5 Cent Blanks Variability Tests Color Change Before and After Steam

Test Date: 04/03/14

Operator: Tony Ying

The average measured values of 5 TPCPZ 5-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the envelope. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of TPCPZ 5-cent blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	88.10	-0.37	6.51	0.74	0.07	0.59
After steam test	87.90	-0.21	6.48	0.48	0.07	0.38

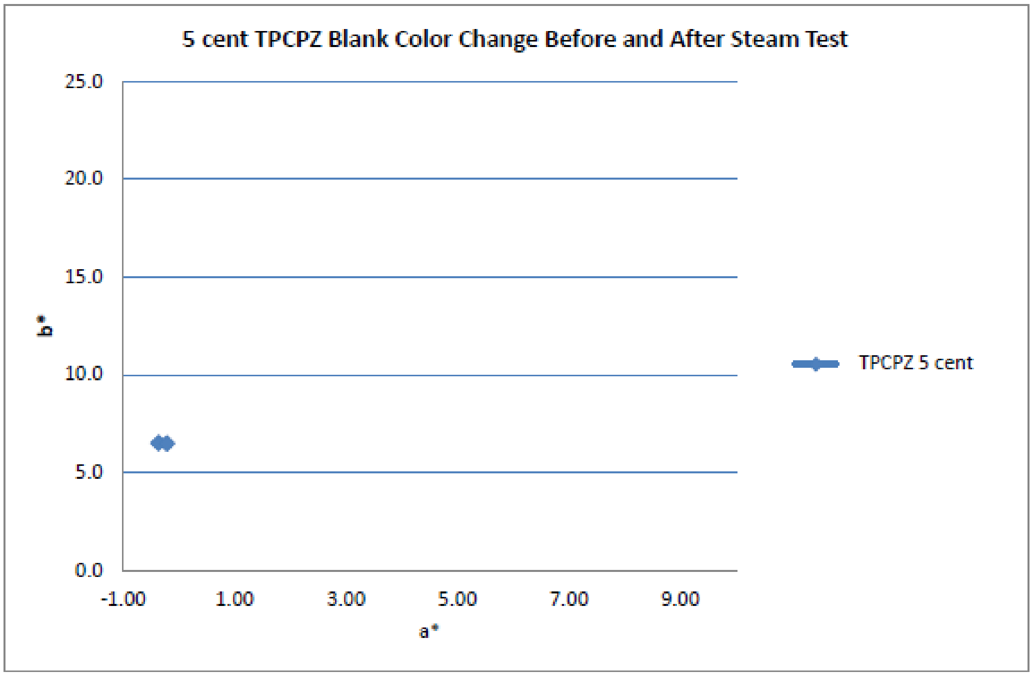


Figure 1: The color change of TPCPZ 5-cent blanks.

Overall Assessment: better than the current cupronickel material.

TPCPZ (Quarter-Dollar) (Variability)

TPCPZ 25 cent blanks Variability Tests Color Change Before and After Steam Test

Test Date: 04/03/14

Operator: Tony Ying

The average measured values of 5 TPCPZ 25-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the envelope. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of TPCPZ 25-cent blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	87.73	-0.46	6.56	1.78	0.13	0.58
After steam test	88.20	-0.39	6.24	1.06	0.13	0.52

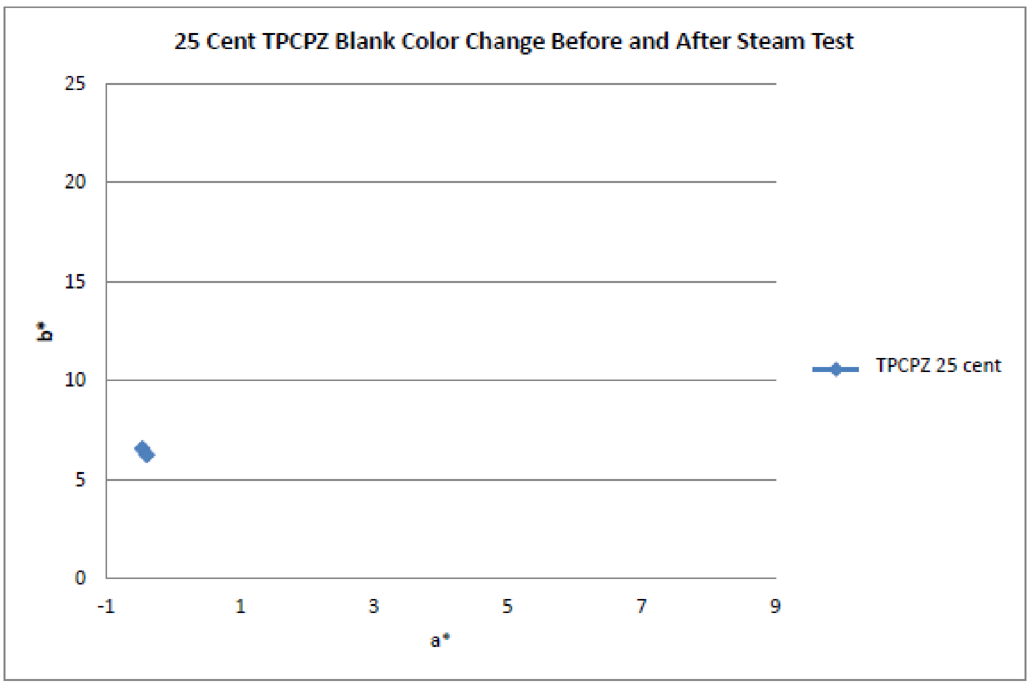


Figure 1: The color change of TPCPZ 25-cent blanks.

Overall Assessment: better than the current cupronickel material.

10.2.3.NPS Steam Test

NPS Five-Cent (Variability)

RM NPS 25 µm 5 Cent Blanks Variability Tests Color Change Before and After Steam Test

Test Date: 04/09/14
Operator: Tony Ying
The average measured values of 5 Royal Mint Nickel Plated Steel 25 µm thick plating layer 5-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the envelope. The standard deviations of the measurement are also listed in the same table. There are three different coating thickness for the nickel plated steel, they are 18 µm, 25 µm, and 32 µm thick, respectively. Since the oxidation only appears on the surface, only 25 µm thick plated samples were tested.

Table 1: The average and deviation of RM NPS 25 µm 25-cent blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	81.65	0.70	7.03	0.54	0.02	0.15
After steam test	79.56	1.04	9.55	1.07	0.12	0.46

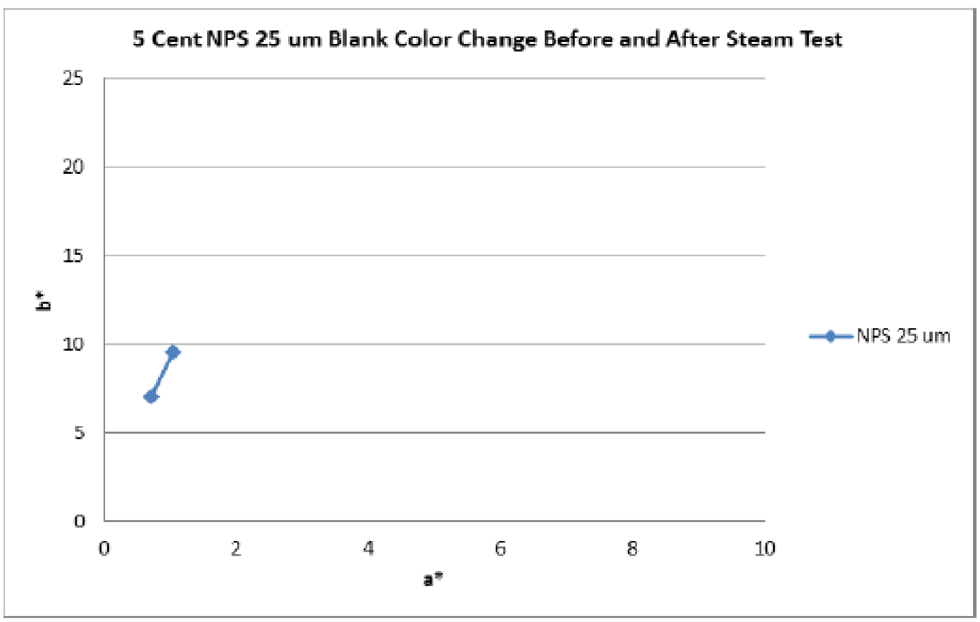


Figure 1: The color change of RM NPS 25 µm 5-cent blanks.

Overall Assessment: better than the incumbent Cupronickel material.

NPS Quarter-Dollar (Variability)

RM NPS 25 µm 25 Cent Blanks Variability Tests Color Change Before and After Steam Test

Test Date: 04/09/14
Operator: Tony Ying
The average measured values of 5 Royal Mint Nickel Plated Steel 25 µm thick plating layer 25-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the envelope. The standard deviations of the measurement are also listed in the same table. There are three different coating thickness for the nickel plated steel, they are 18 µm, 25 µm, and 32 µm thick, respectively. Since the oxidation only appears on the surface, only 25 µm thick plated samples were tested.

Table 1: The average and deviation of RM NPS 25 µm 25-cent blank colors.

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	81.39	0.74	7.22	1.17	0.17	0.74
After steam test	79.74	0.99	9.15	1.72	0.25	0.95

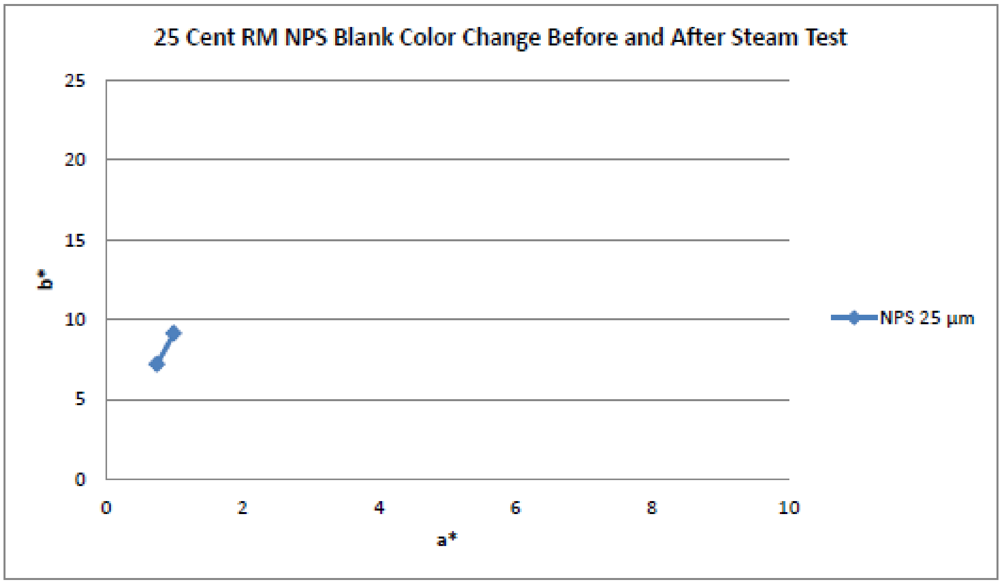


Figure 1: The color change of RM NPS 25 µm 25-cent blanks.

Overall Assessment: better than the incumbent Cupronickel material.

10.2.4.MPPS Steam Test

MPPS Five-Cent (Variability)

RCM MPPS Sample B 5 Cent Blanks Variability Tests Color Change Before and After Steam Test

Test Date: 04/17/14

Operator: Tony Ying

The average measured values of 5 Royal Canadian Mint Multi-Plyl Plated Steel sample B 5-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the envelope. The standard deviations of the measurement are also listed in the same table. There are three different coating thickness for the multi-ply plated steel, they are sample A, B and C, respectively. Since the oxidation only appears on the surface, only sample B was tested.

Table 1: The average and deviation of RCM MPPL Sample B 5-cent blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	78.45	1.05	8.71	0.96	0.10	0.53
After steam test	77.96	1.14	9.58	0.21	0.05	0.46

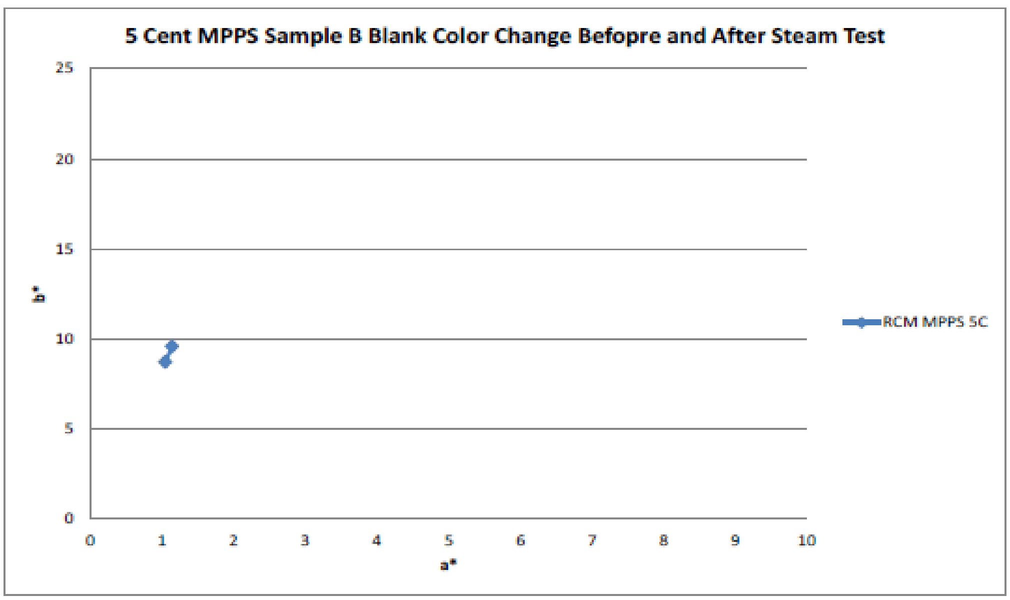


Figure 1: The color change of RCM MPPS sample B 5-cent blanks.

Overall Assessment: better than the incumbent Cupronickel material.

MPPS Quarter-Dollar (Variability)

RCM MPPS Sample B 25 Cent Blanks Variability Tests Color Change Before and After Steam Test

Test Date: 04/17/14

Operator: Tony Ying

The average measured values of 5 Royal Canadian Mint Multi-Plyl Plated Steel sample B 25-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the envelope. The standard deviations of the measurement are also listed in the same table. There are three different coating thickness for the multi-ply plated steel, they are sample A, B and C, respectively. Since the oxidation only appears on the surface, only sample B was tested.

Table 1: The average and deviation of RCM MPPL Sample B 25-cent blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	77.14	1.27	9.71	1.41	0.17	0.76
After steam test	77.13	1.25	9.52	1.12	0.16	0.34

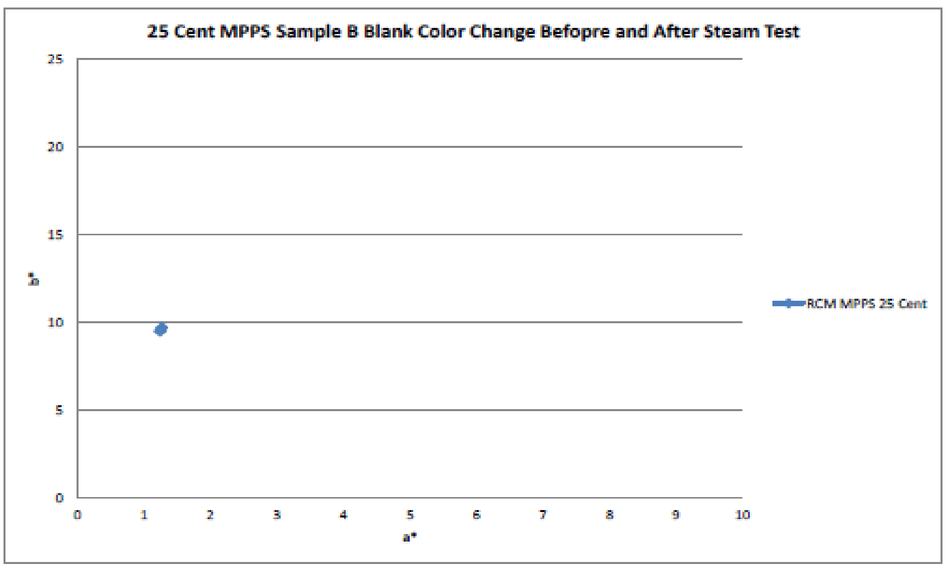


Figure 1: The color change of RCM MPPS sample B 25-cent blanks.

Overall Assessment: better than the incumbent Cupronickel material.

10.2.5.80/20A Steam Test (Variability)

80/20A Cupronickel 5 Cent Blanks Variability Tests Color Change Before and After Steam Test

Test Date: 04/09/14

Operator: Tony Ying

The average measured values of 5 80/20A 5-cent cupronickel blanks made by group #1, #2, #3, #4, #5 and #6 alloys before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the envelope. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of colors of different groups of 80/20A 5-cent blanks

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
#1 Before	83.15	1.73	9.24	0.62	0.08	0.65
#1 After	70.88	3.75	26.85	5.58	1.62	9.91
#2 Before	81.65	2.24	11.38	0.84	0.17	0.86
#2 After	77.84	2.75	16.24	1.88	0.45	1.86
#3 Before	82.57	1.70	8.56	0.96	0.17	0.93
#3 After	76.64	2.52	18.03	0.56	0.42	2.05
#4 Before	81.93	1.62	9.12	1.00	0.18	0.89
#4 After	77.23	2.20	16.48	1.04	0.14	2.23
#5 Before	81.80	1.75	9.03	1.32	0.26	0.83
#5 After	73.96	2.93	21.39	2.34	0.66	6.78
#6 Before	82.67	1.33	8.45	0.32	0.04	0.31
#6 After	78.34	1.83	14.86	0.66	0.15	1.32

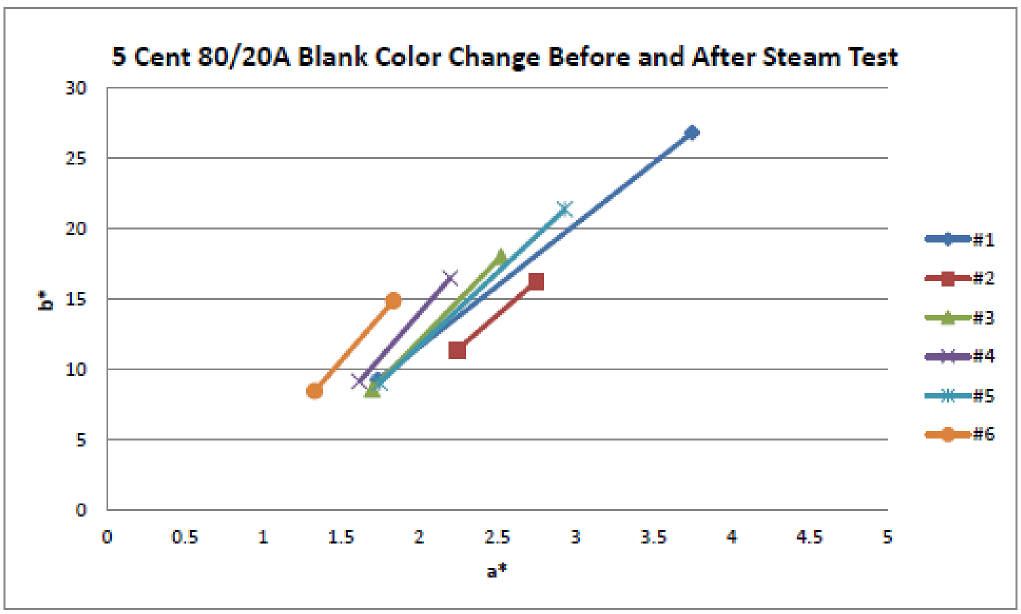


Figure 1: The color change of 6 groups of 80/20A 5-cent blanks.

Overall Assessment: Cannot get conclusion, because large water stain marks randomly appeared on the initial blanks.

10.2.6. 80/20B Steam Test (Variability)

80/20B Cupronickel 5 Cent Blanks Variability Tests Color Change Before and After Steam Test

Test Date: 04/10/14

Operator: Tony Ying

The average measured values of 5 80/20B 5-cent cupronickel blanks made by group 81000, 82000, and 83000 alloys before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the envelope. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of color of different groups of 80/20B 5-cent blanks

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
81000 Before	75.57	1.79	7.86	2.87	0.20	0.94
81000 After	70.54	3.30	16.57	3.41	0.63	2.13
82000 Before	76.17	2.23	9.38	1.92	0.11	0.66
82000 After	68.33	3.29	16.37	4.19	0.63	2.12
83000 Before	76.97	1.64	7.93	1.23	0.20	0.70
83000 After	64.47	3.50	19.18	4.56	1.41	3.71

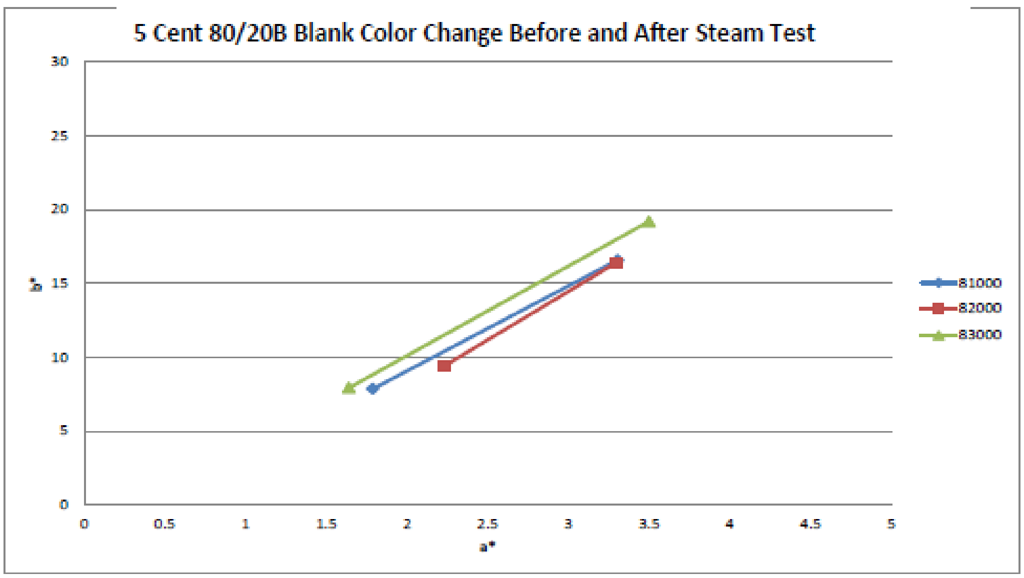


Figure 1: The color change of 3 groups of 80/20B 5-cent blanks.

Overall Assessment: Cannot get conclusion, because large water stain marks randomly appeared on the initial blanks.

10.3. Conductivity and CSV Test Results – Variability Lots

10.3.1.CPZ Conductivity and CSV

Conductivity – Nominal CPZ (Variability)

Electrical Conductivity (% IACS)

Date:	4-Feb-14	**Page _1_of_1__**
Conductivity Meter:	Sigma Test D 2.068 Foerster (Cert: 20130200-51386) Due March 25, 2014	
Operator:	Barry Claybrook	
Material:	CPZ 5c Nominal Plating	
Form:	Planchets (10 Kg)	

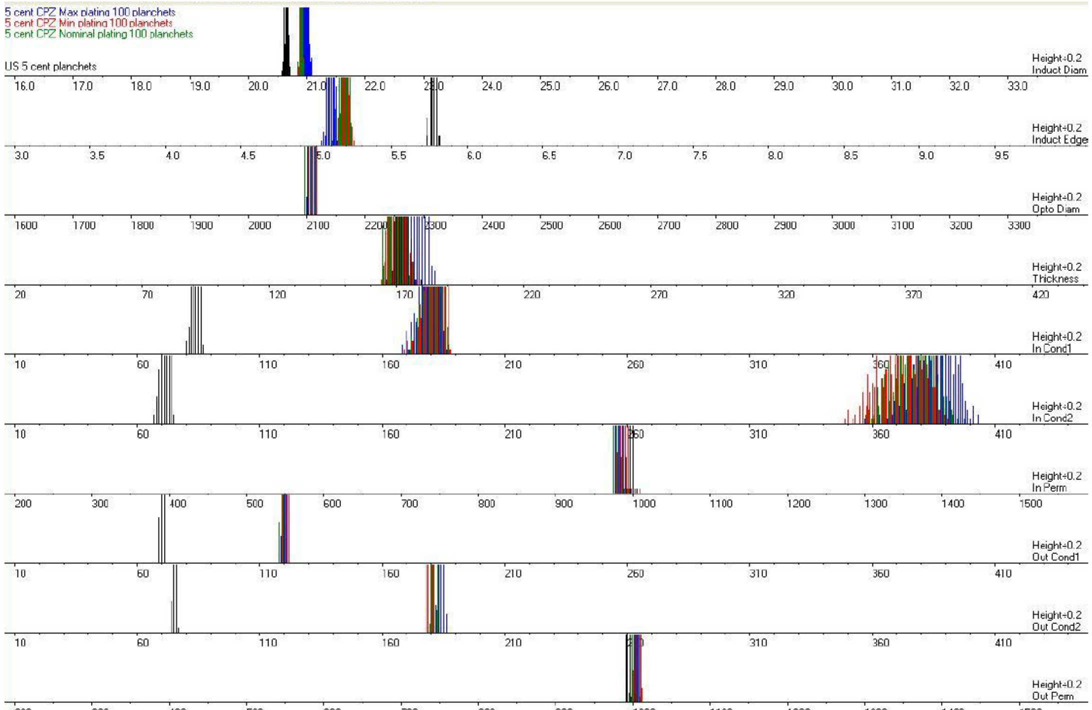
	FREQUENCY			
	1 = ___60__kHz	**2 = __120__kHz**	**3 = __240__kHz**	**4 = __480__kHz**
1	28.47	28.62	28.93	29.21
2	28.41	28.64	28.930	29.28
3	28.43	28.53	28.97	29.34
4	28.380	28.64	28.930	29.22
5	28.47	28.62	28.91	29.24
6	28.410	28.590	28.970	29.22
7	28.36	28.59	28.86	29.31
8	28.43	28.55	28.88	29.24
9	28.450	28.66	28.97	29.26
10	28.45	28.64	28.91	29.47
11	28.48	28.69	28.95	29.36
12	28.47	28.64	29	29.26
13	28.450	28.660	28.910	29.19
14	28.47	28.66	29	29.47
15	28.5	28.67	28.95	29.36
16	28.47	28.69	29.02	29.55
17	28.47	28.72	28.78	29.33
18	28.48	28.66	28.86	29.20
19	28.4	28.62	28.97	29.34
20	28.450	28.640	28.900	29.34
Average	**28.45**	**28.64**	**28.93**	**29.31**
Median	**28.45**	**28.64**	**28.93**	**29.30**
SD	**0.037**	**0.046**	**0.057**	**0.099**
Min	**28.36**	**28.53**	**28.78**	**29.19**
Max	**28.50**	**28.72**	**29.02**	**29.55**

Electrical Conductivity (% IACS)

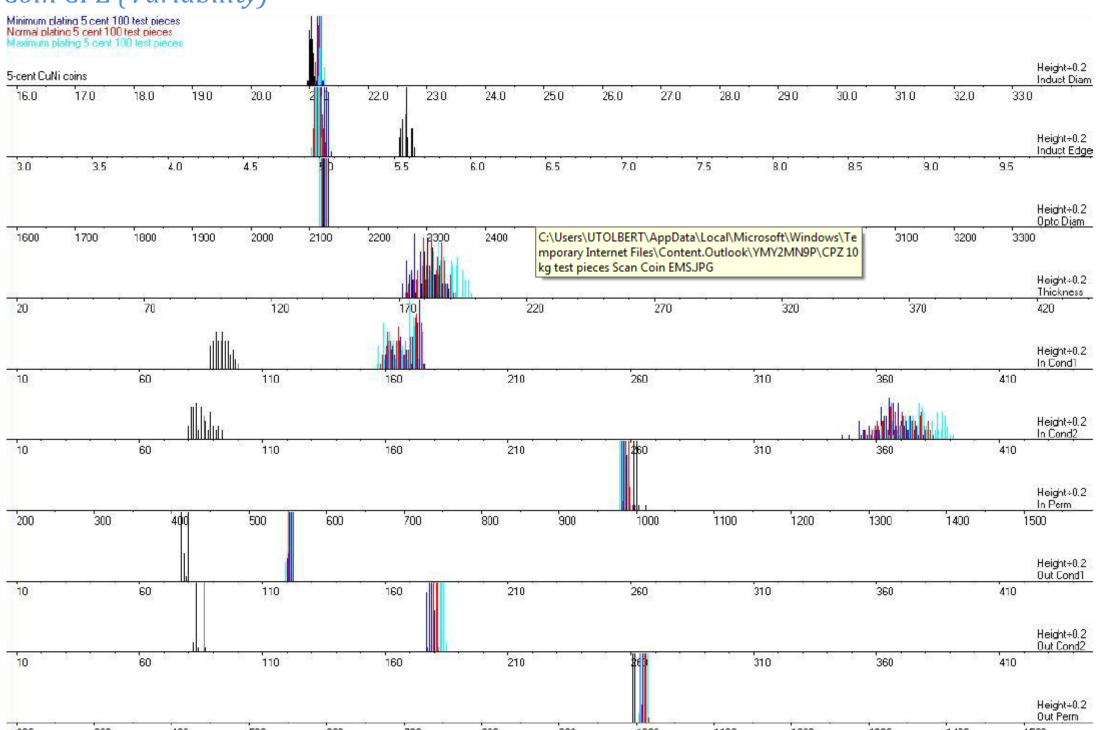
Date:	4-Feb-14	**Page _1_of_1__**
Conductivity Meter:	Sigma Test D 2.068 Foerster (Cert: 20130200-51386) Due March 25, 2014	
Operator:	Barry Claybrook	
Material:	CPZ 5c Minimum Plating	
Form:	Planchets (10 Kg)	

	FREQUENCY			
	1 = _____60__kHz	**2 = ____120__kHz**	**3 = ____240__kHz**	**4 = ___480__kHz**
1	28.17	28.22	28.53	28.83
2	28.02	28.22	28.450	28.79
3	28.12	28.29	28.48	28.79
4	28.000	28.21	28.500	28.76
5	28.12	28.26	25.5	28.84
6	28.120	28.240	28.520	28.86
7	28.12	28.31	28.53	28.72
8	28.22	28.22	28.57	28.76
9	28.170	28.28	28.57	28.84
10	28.12	28,28	28.56	28.78
11	28.21	28.24	28.5	28.76
12	28.21	28.31	28.53	28.74
Average	**28.13**	**28.25**	**28.25**	**28.79**
Median	**28.12**	**28.24**	**28.52**	**28.79**
SD	**0.069**	**0.034**	**0.912**	**0.044**
Min	**28**	**28.21**	**25.5**	**28.72**
Max	**28.22**	**28.31**	**28.57**	**28.86**

CSV –Planchet CPZ (Variability)



CSV – Coin CPZ (Variability)



10.3.2.TPCPZ Conductivity and CSV

Conductivity – Max TPCPZ (Five-Cent) (Variability)

Electrical Conductivity (% IACS)

Date:	4-Feb-14	**Page _1_of_1__**
Conductivity Meter:	Sigma Test D 2.068 Foerster (Cert: 20130200-51386) Due March 25, 2014	
Operator:	Barry Claybrook	
Material:	TPCPZ 5c Horizontal Max Plating	
Form:	Planchets (10 Kg)	

	FREQUENCY			
	1 = _____60__kHz	**2 = ____120__kHz**	**3 = ____240__kHz**	**4 = ___480__kHz**
1	28.53			30.57
2	28.55			30.38
3	28.59			30.4
4	28.6			30.64
5	28.53			30.38
6	28.62			30.53
7	28.55			30.31
8	28.5			30.71
9	28.53			30.55
10	28.62			30.43
11				
Average	**28.56**			**30.49**
Median	**28.55**			**30.48**
SD	**0.042**			**0.129**
Min	**28.5**			**30.31**
Max	**28.62**			**30.71**

Electrical Conductivity (% IACS)

Date:	4-Feb-14	**Page _1_of_1__**
Conductivity Meter:	Sigma Test D 2.068 Foerster (Cert: 20130200-51386) Due March 25, 2014	
Operator:	Barry Claybrook	
Material:	TPCPZ 25c Horizontal Max Plating	
Form:	Planchets (10 Kg)	

	FREQUENCY			
	1 = _____60__kHz	**2 = ____120__kHz**	**3 = ____240__kHz**	**4 = ___480__kHz**
1	28.57			30.66
2	28.79			30.6
3	28.71			30.78
4	28.9			30.72
5	28.81			30.38
6	28.84			30.64
7	28.86			30.41
8	28.81			30.64
9	28.74			30.57
10	28.88			30.6
11	28.86			30.64
12				
Average	**28.80**			**30.60**
Median	**28.81**			**30.64**
SD	**0.095**			**0.119**
Min	**28.57**			**30.38**
Max	**28.90**			**30.78**

Electrical Conductivity (% IACS)

Date:	4-Feb-14	**Page _1_of_1__**
Conductivity Meter:	Sigma Test D 2.068 Foerster (Cert: 20130200-51386) Due March 25, 2014	
Operator:	Barry Claybrook	
Material:	TPCPZ 5c Oblique Nom Plating	
Form:	Planchets (10 Kg)	

	FREQUENCY			
	1 = _____60__kHz	**2 = ____120__kHz**	**3 = ____240__kHz**	**4 = ___480__kHz**
1	28.48			30.48
2	28.57			30.4
3	28.53			30.62
4	28.52			30.53
5	28.57			30.76
6	28.59			30.97
7	28.55			30.379
8	28.53			30.78
9	28.55			30.79
10	28.57			30.76
11	28.59			30.57
12				
Average	**28.55**			**30.64**
Median	**28.55**			**30.62**
SD	**0.033**			**0.187**
Min	**28.48**			**30.379**
Max	**28.59**			**30.97**

Electrical Conductivity (% IACS)

Page _1_of_1__

Date:	4-Feb-14
Conductivity Meter:	Sigma Test D 2.068 Foerster (Cert: 20130200-51386) Due March 25, 2014
Operator:	Barry Claybrook
Material:	TPCPZ 25c Oblique Nom Plating
Form:	Planchets (10 Kg)

	FREQUENCY			
	1 = _____60__kHz	**2 = ____120__kHz**	**3 = ____240__kHz**	**4 = ___480__kHz**
1	28.66			29.88
2	28.6			30.41
3	28.57			30.12
4	28.62			30.07
5	28.66			30.21
6	28.72			30.41
7	28.62			30.22
8	28.69			30.17
9	28.66			30.33
10	28.76			30.29
11	28.71			30.31
12				
Average	**28.66**			**30.22**
Median	**28.66**			**30.22**
SD	**0.056**			**0.157**
Min	**28.57**			**29.88**
Max	**28.76**			**30.41**

Electrical Conductivity (% IACS)

Date:	4-Feb-14	**Page _1_of_1__**
Conductivity Meter:	Sigma Test D 2.068 Foerster (Cert: 20130200-51386) Due March 25, 2014	
Operator:	Barry Claybrook	
Material:	TPCPZ 5c Horizontal/Oblique Min Plating	
Form:	Planchets (10 Kg)	

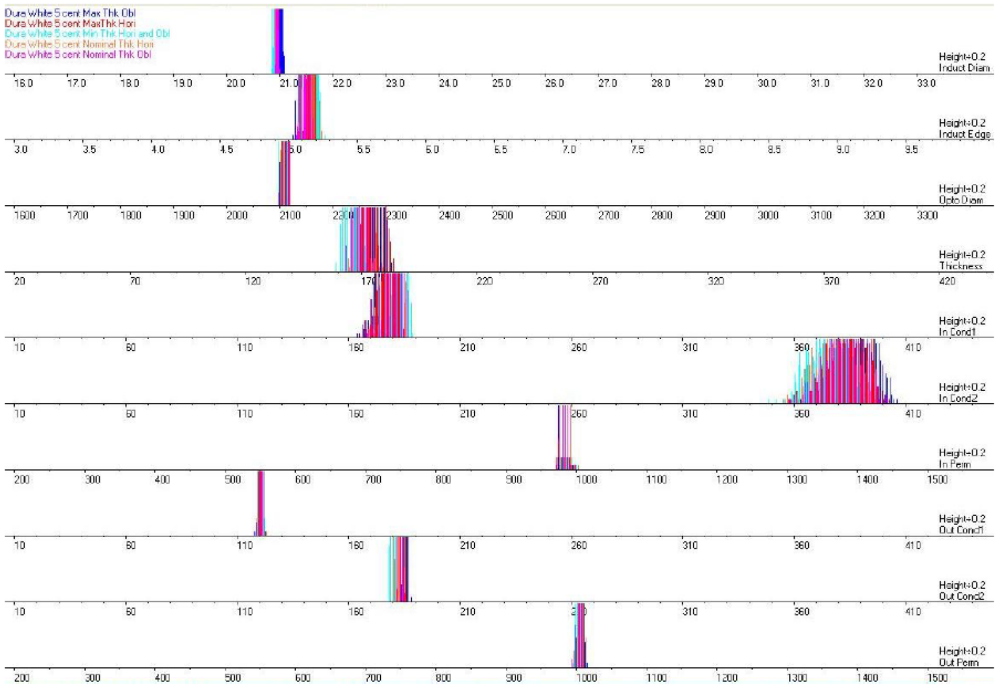
	FREQUENCY			
	1 = _____60__kHz	**2 = ____120__kHz**	**3 = ____240__kHz**	**4 = ___480__kHz**
1	28.19			29.22
2	28.4			29.12
3	28.38			29.02
4	28.24			29.17
5	28.21			29.12
6	28.38			29.38
7	28.38			29.09
8	28.28			29.14
9	28.34			29.07
10	28.36			29.16
11	28.38			28.98
12	28.33			29.22
13	28.29			29.1
14	28.33			29.22
15	28.36			29.31
16	28.29			29.19
17	28.33			29.1
18	28.34			29.31
19	28.33			29.38
20	28.31			29.4
	28.28			29.31
Average	**28.32**			**29.13**
Median	**28.36**			**29.12**
SD	**0.077**			**0.106**
Min	**28.19**			**28.98**
Max	**28.40**			**29.40**

Electrical Conductivity (% IACS)

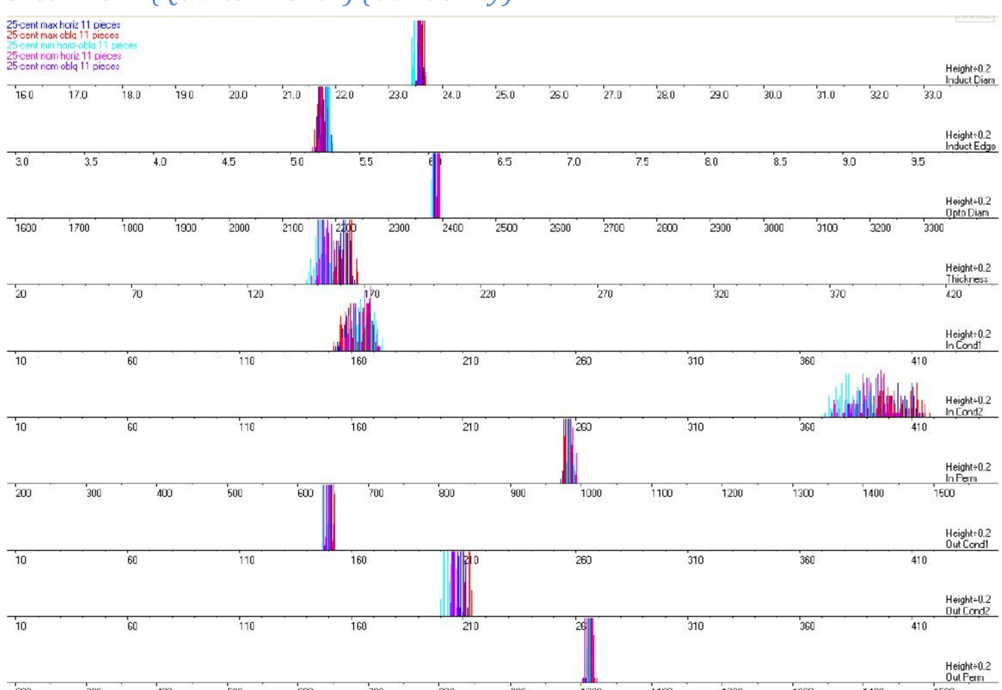
Date:	4-Feb-14	**Page _1_of_1__**
Conductivity Meter:	Sigma Test D 2.068 Foerster (Cert: 20130200-51386) Due March 25, 2014	
Operator:	Barry Claybrook	
Material:	TPCPZ 25c Horizontal/Oblique Min Plating	
Form:	Planchets (10 Kg)	

	FREQUENCY			
	1 = _____60__kHz	**2 = ____120__kHz**	**3 = ____240__kHz**	**4 = ___480__kHz**
1	28.48			29.26
2	28.52			29.22
3	28.62			29.09
4	28.55			29.03
5	28.53			29.14
6	28.59			29.16
7	28.52			29.17
8	28.55			29.34
9	28.6			29.12
10	28.64			29.33
11	28.62			29.38
12				
Average	**28.57**			**29.20**
Median	**28.55**			**29.17**
SD	**0.051**			**0.112**
Min	**28.48**			**29.03**
Max	**28.64**			**29.38**

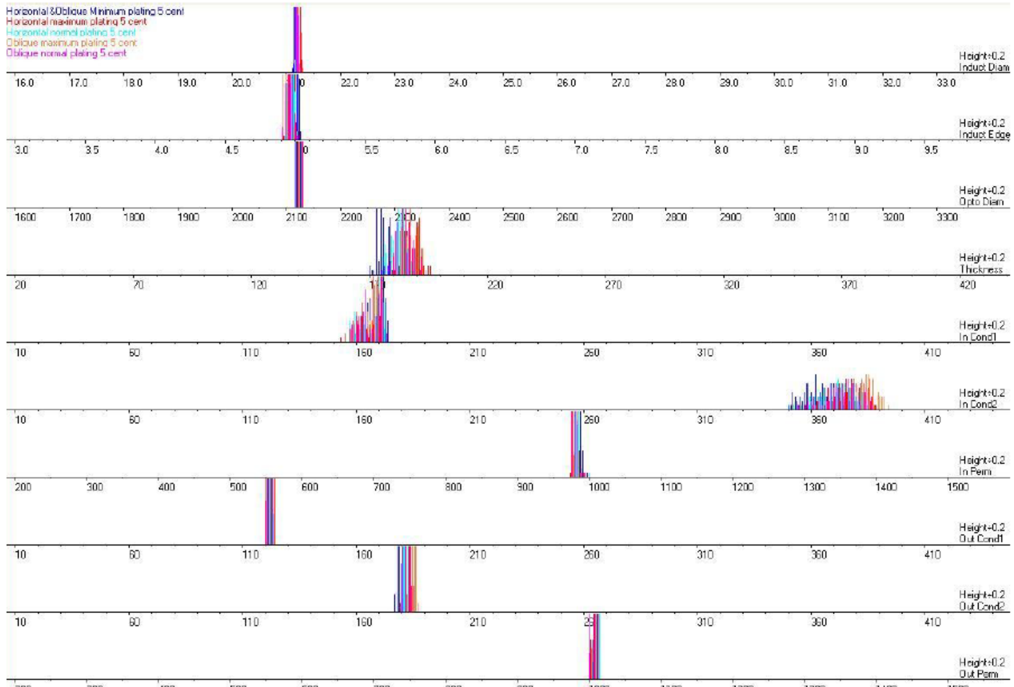
CSV – Planchet TPCPZ (Five-Cent) (Variability)



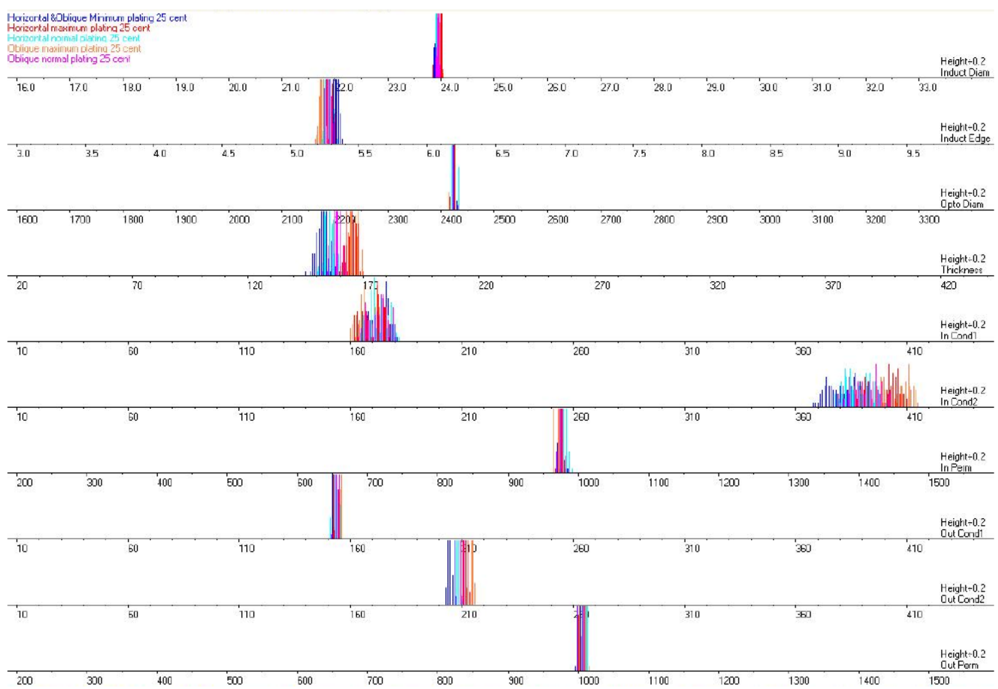
CSV – Planchet TPCPZ (Quarter-Dollar) (Variability)



CSV – Coin TPCPZ (Five-Cent) (Variability)

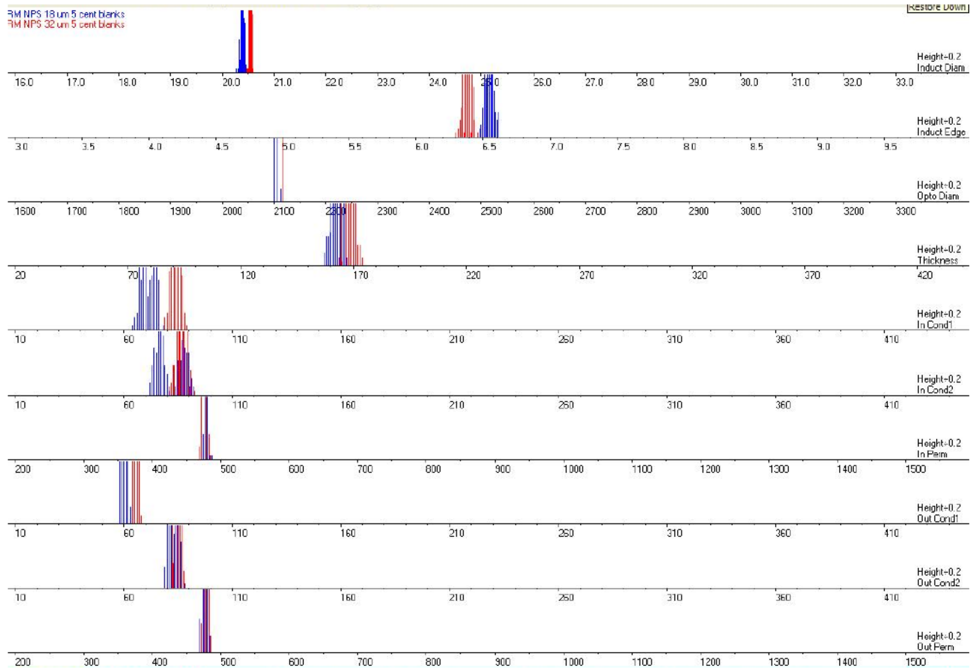


CSV – Coin TPCPZ (Quarter-Dollar) (Variability)

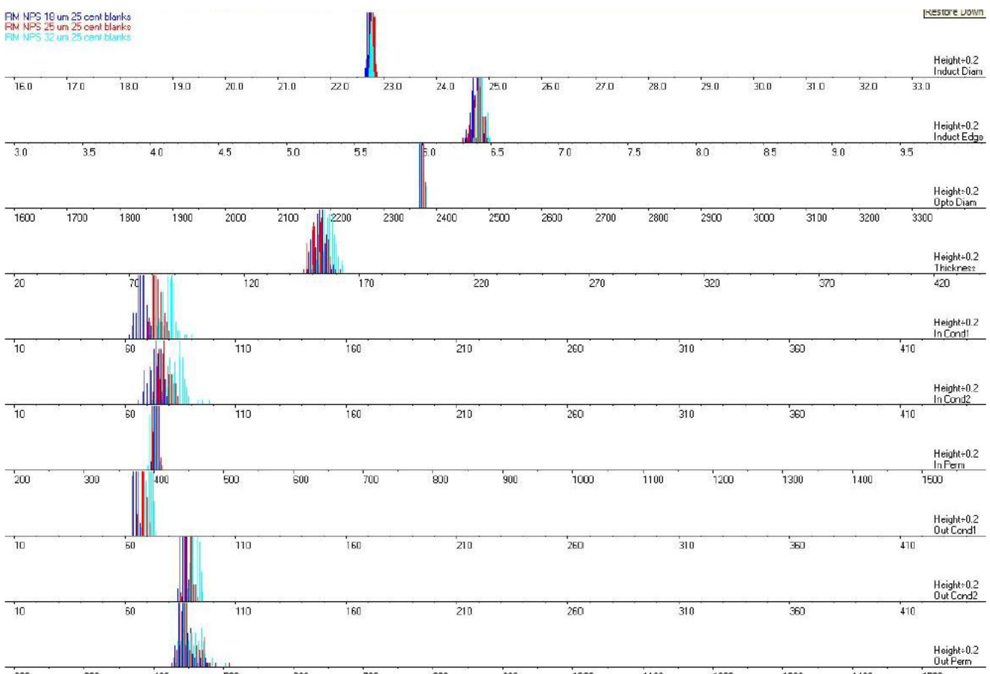


10.3.3.NPS (Conductivity Test Not Applicable)

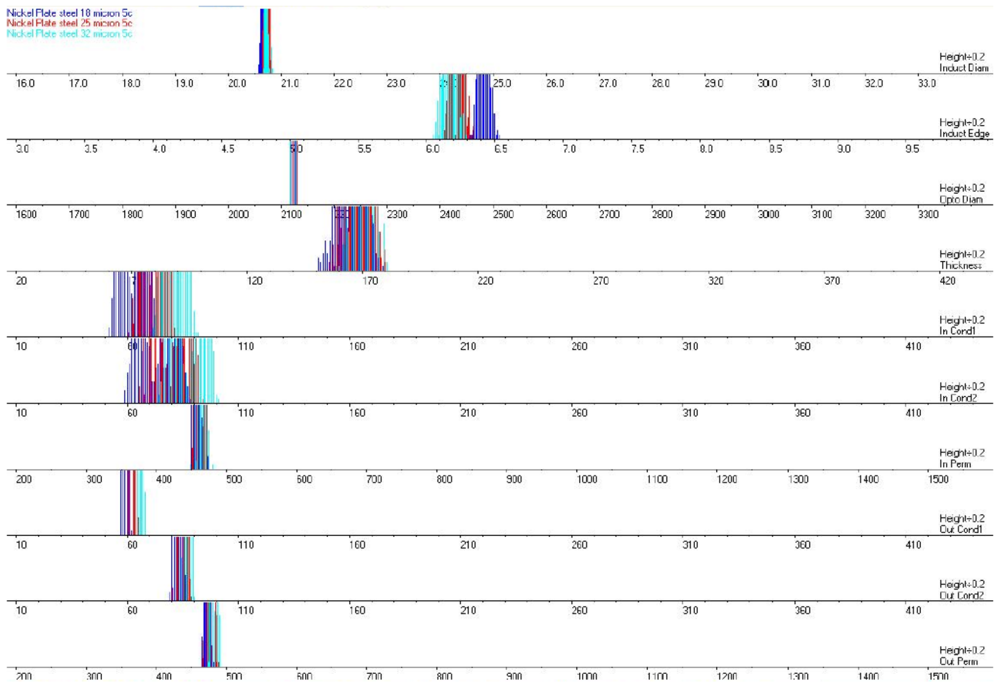
CSV – Planchet NPS (Five-Cent) (Variability)



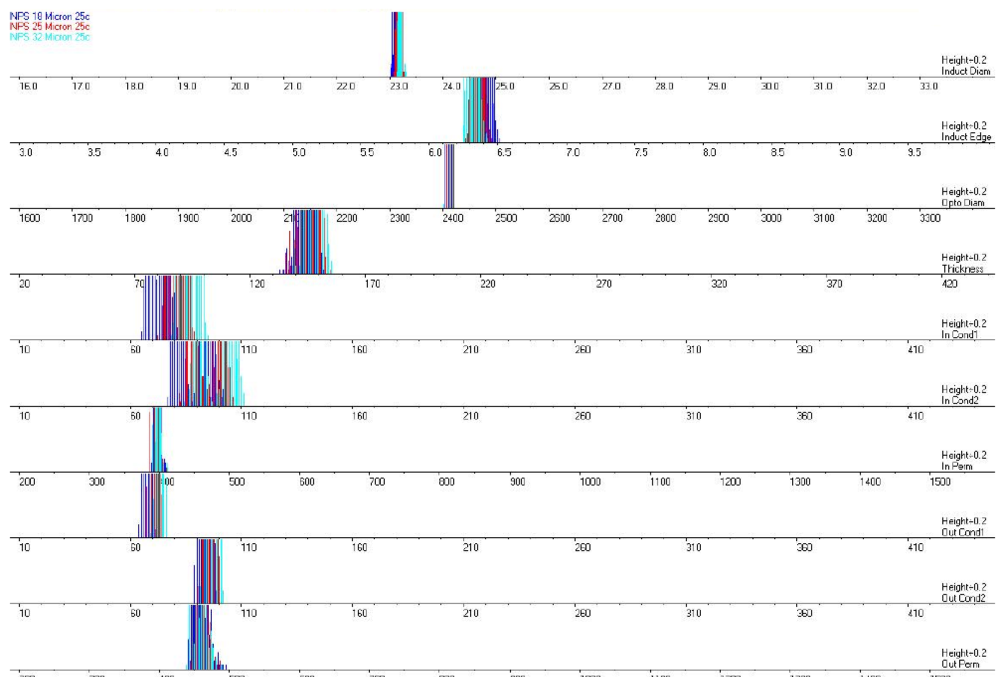
CSV – Planchet NPS (Quarter-Dollar) (Variability)



CSV – Coin NPS (Five-Cent) (Variability)

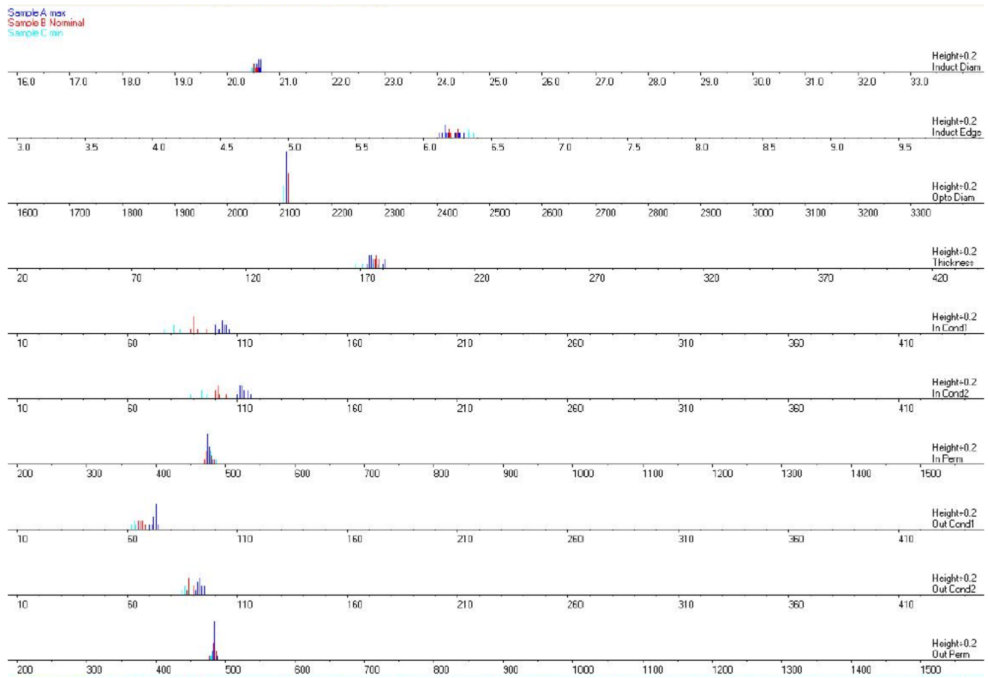


CSV – Coin NPS (Quarter-Dollar) (Variability)

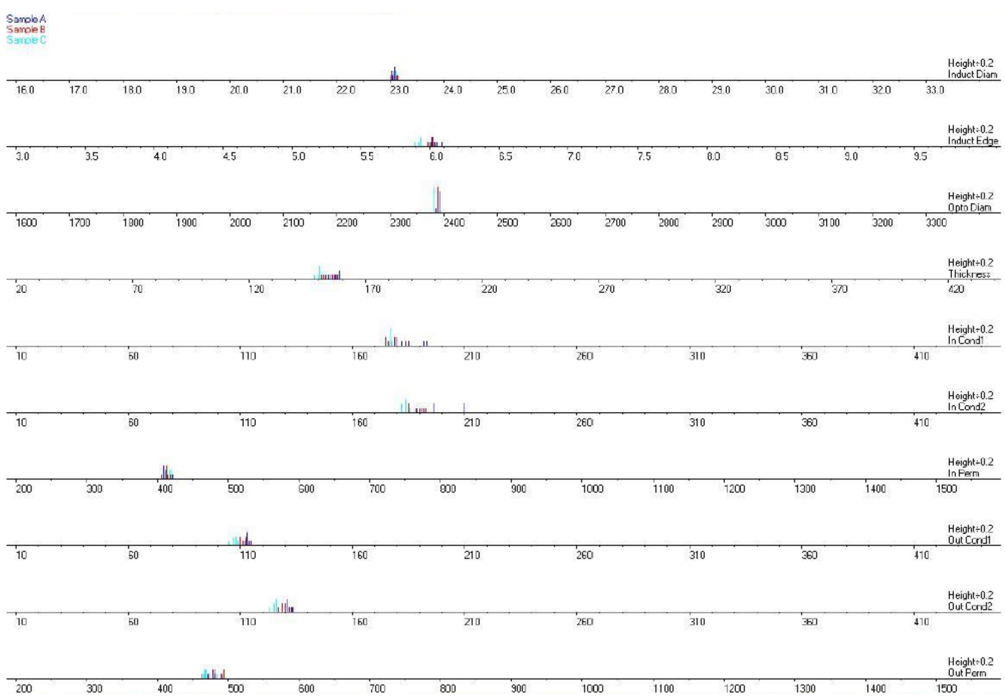


10.3.4.MPPS (Conductivity Test Not Applicable)

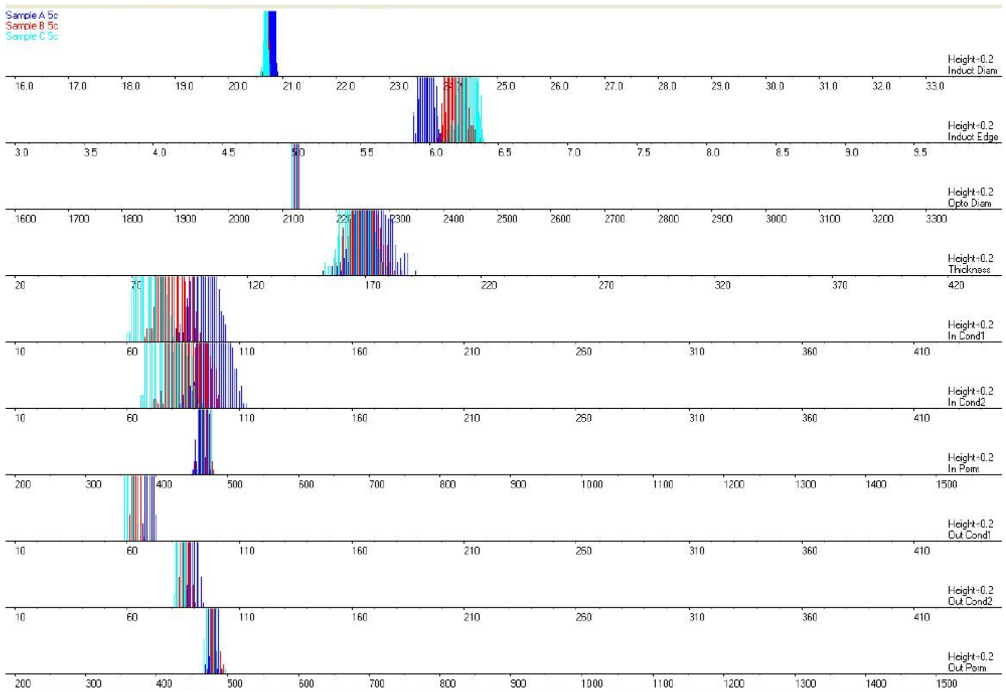
CSV – Planchet MPPS (Five-Cent) (Variability)



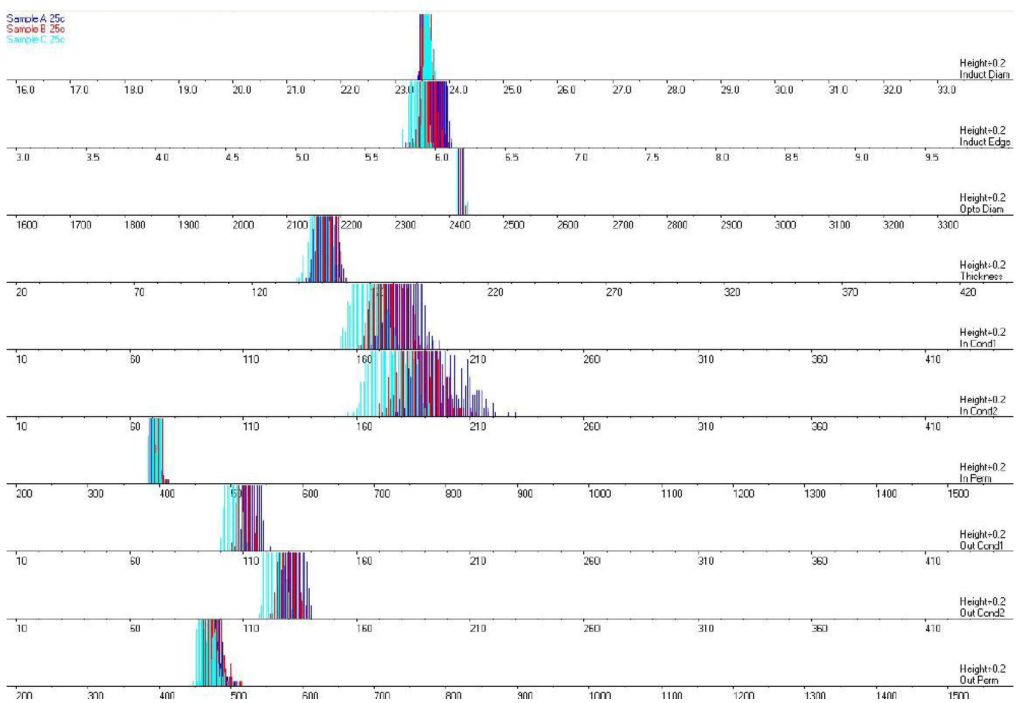
CSV – Planchet MPPS (Quarter-Dollar) (Variability)



CSV – Coin MPPS (Five-Cent) (Variability)

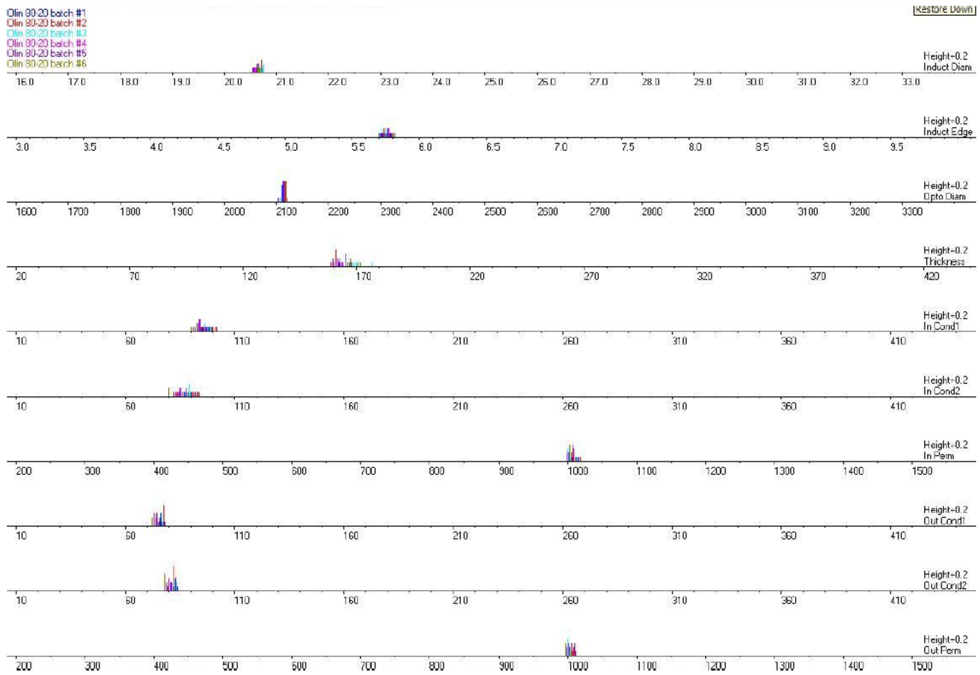


CSV – Coin MPPS (Quarter-Dollar) (Variability)

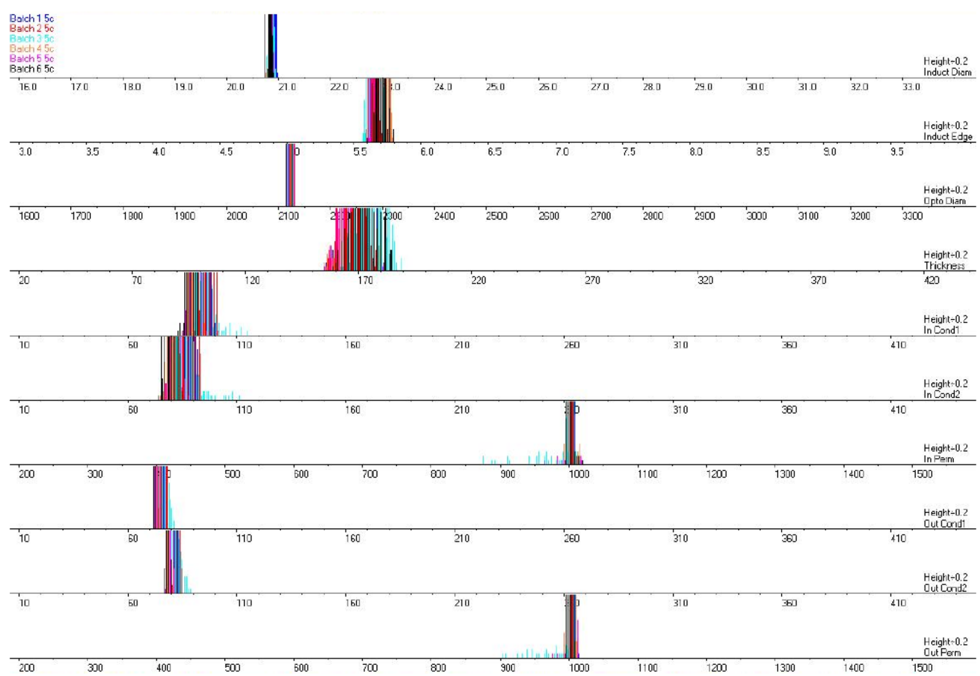


10.3.5.80/20A (Conductivity Results Unavailable)

CSV – Planchet 80/20A (Variability)

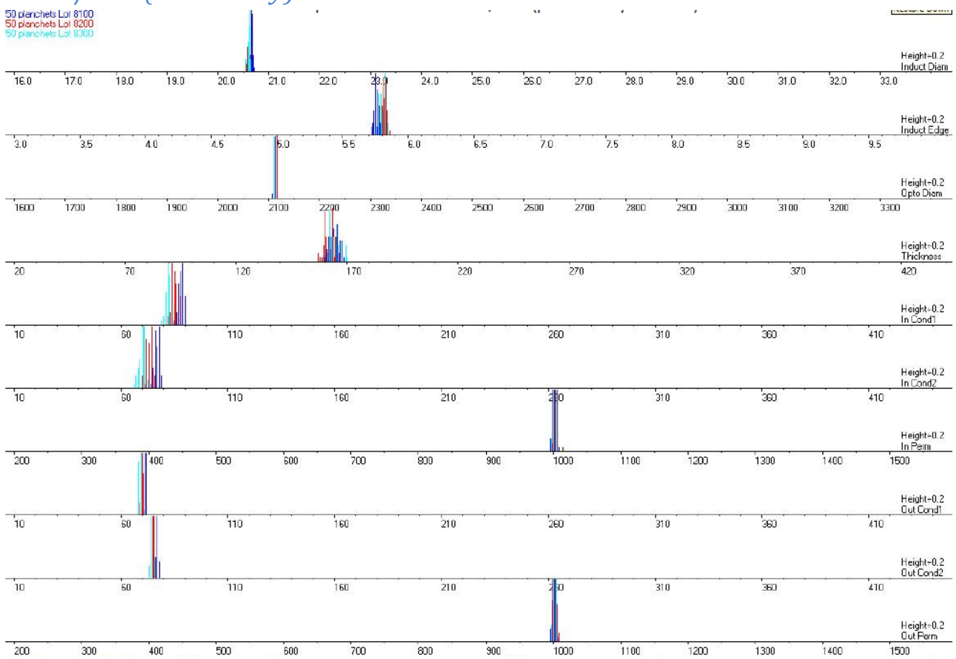


CSV – Coin 80/20A (Variability)

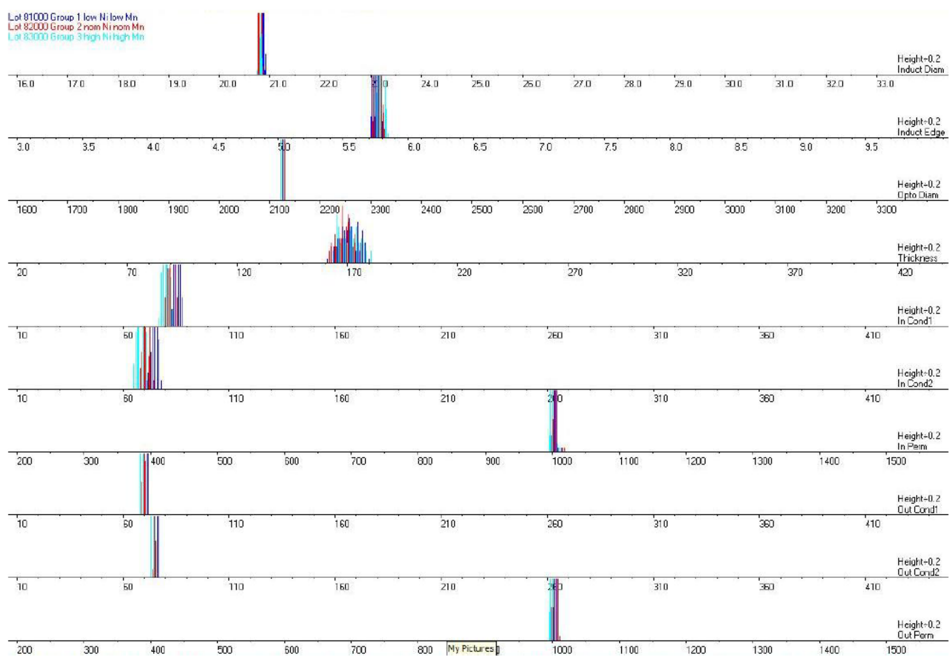


10.3.6.80/20B (Conductivity Results Unavailable)

CSV – Planchet 80/20B (Variability)



CSV – Coin 80/20B (Variability)



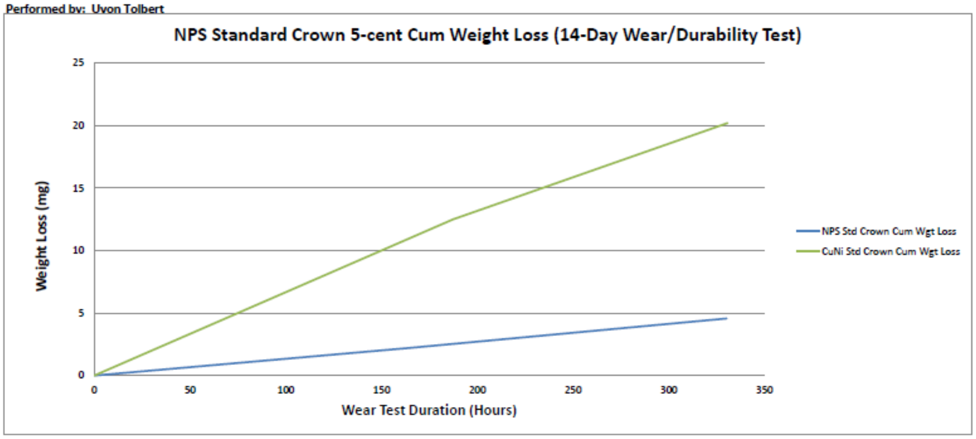
10.4. Wear Test Results – Pre-Production

10.4.1.NPS

NPS Pilot Material (Five-Cent)

WEAR AND DURABILITY TESTING (May 22 - June 5, 2014)

Performed by: Uvon Tolbert



Average Weight Loss (per piece): NPS 5-cent = 4.6 miligrams
Cupro-nickel = 19 miligrams

Durability (Edge Deformation): Ending NPS 5-cent Edge Thickness = 0.0780"
Ending Cupro-nickel Edge Thickness = 0.0820"
Deformation = 0.0780 - 0.0820 = **- 0.0040"**

Durability Rating: 5-cent NPS 5-cent rated Go for durability because edge deformation difference between it and cupro-nickel 5-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010". In fact, NPS 5-cent demonstrated less deformation than baseline cupro-nickel.

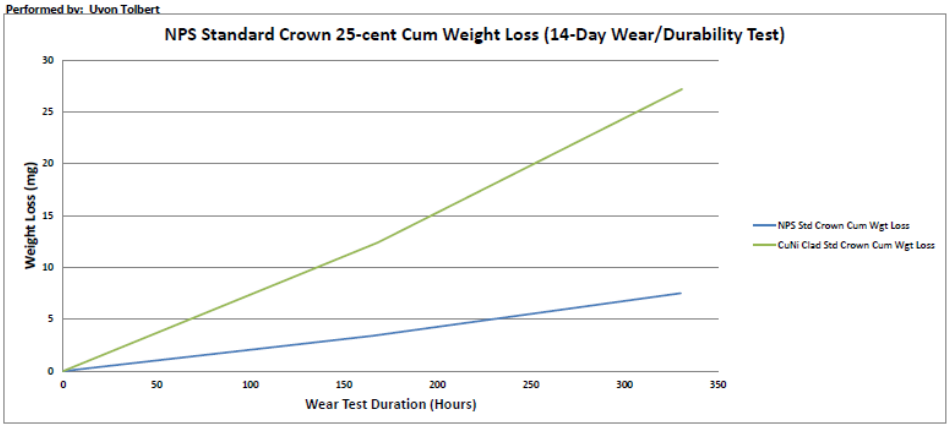
Wear Rating: 5-cent NPS 5-cent is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of cupro-nickel 5-cent (see graph above). The wear rate of NPS 5-cent was 24% that of cupro-nickel 5-cent.

Overall Rating: Go

NPS Pilot Material (Quarter-Dollar)

WEAR AND DURABILITY TESTING (May 22 - June 5, 2014)

Performed by: Uvon Tolbert



Average Weight Loss (per piece): NPS 25-cent = 7.5 miligrams
Cupro-nickel clad = 27.2 miligrams

Durability (Edge Deformation): Ending NPS 25-cent Edge Thickness = 0.0685"
Ending Cupro-nickel Edge Thickness = 0.0740"
Deformation = 0.0685 - 0.0740 = - 0.0055"

Durability Rating: NPS 25-cent rated Go for durability because edge deformation difference between it and cupro-nickel clad 25-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010". In fact, NPS 25-cent demonstrated less deformation than baseline cupro-nickel clad.

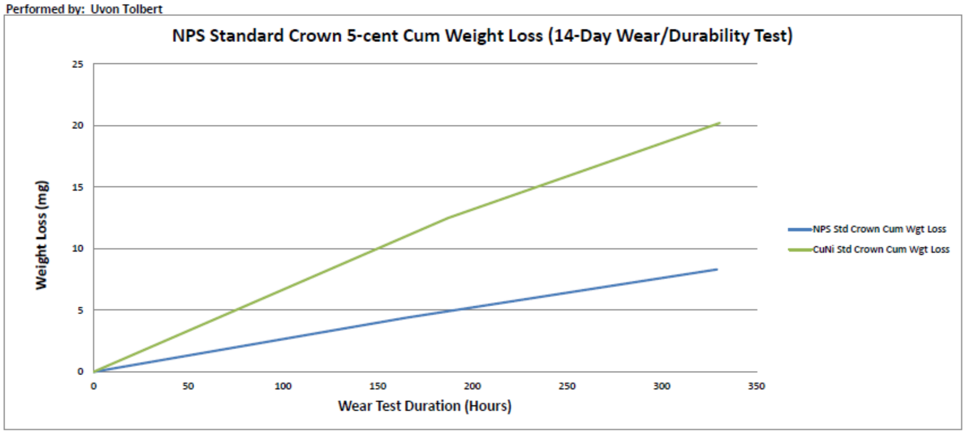
Wear Rating: NPS 25-cent is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of cupro-nickel clad 25-cent (see graph above). The wear rate of NPS 25-cent was 28% that of cupro-nickel clad 25-cent.

Overall Rating: Go

NPS Pre-production (Five-Cent)

WEAR AND DURABILITY TESTING (Pre-production: June 25 to July 9, 2014)

Performed by: Uvon Tolbert



Average Weight Loss (per piece): NPS 5-cent = 8.3 miligrams
Cupro-nickel = 20.2 miligrams

Durability (Edge Deformation): Ending NPS 5-cent Edge Thickness = 0.0768"
Ending Cupro-nickel Edge Thickness = 0.0820"
Deformation = 0.0780 - 0.0820 = **- 0.0052"**

Durability Rating: 5-cent NPS 5-cent rated Go for durability because edge deformation difference between it and cupro-nickel 5-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010". In fact, NPS 5-cent demonstrated less deformation than baseline cupro-nickel.

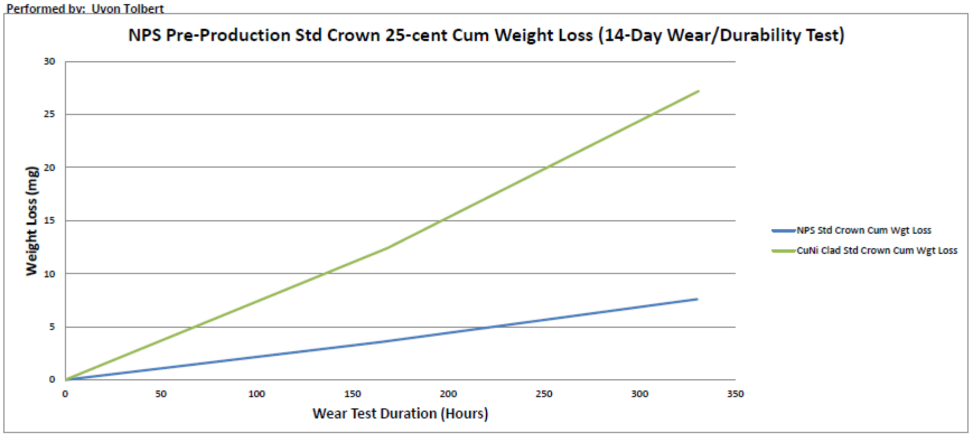
Wear Rating: 5-cent NPS 5-cent is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of cupro-nickel 5-cent (see graph above). The wear rate of NPS 5-cent was 41% that of cupro-nickel 5-cent.

Overall Rating: Go

NPS Pre-production (Quarter-Dollar)

WEAR AND DURABILITY TESTING (July 16 - July 30, 2014)

Performed by: Uvon Tolbert



Average Weight Loss (per piece): NPS 25 cent = 7.6 miligrams
Current 25 cent = 27.2 miligrams

Durability (Edge Deformation): Ending NPS 25-cent Edge Thickness = 0.0735"
Ending Current 25-cent Edge Thickness = 0.0730"
Deformation = 0.0735 - 0.0730 = **0.0005"**

Durability Rating: NPS 25-cent rated Go for durability because edge deformation difference between it and the current 25-cent coin from the same wear chamber did not exceed the maximum allowable 0.010".

Wear Rating: NPS 25-cent is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of the current 25-cent (see graph above). The wear rate of NPS 25 cent was 30% that of the current 25 cent.

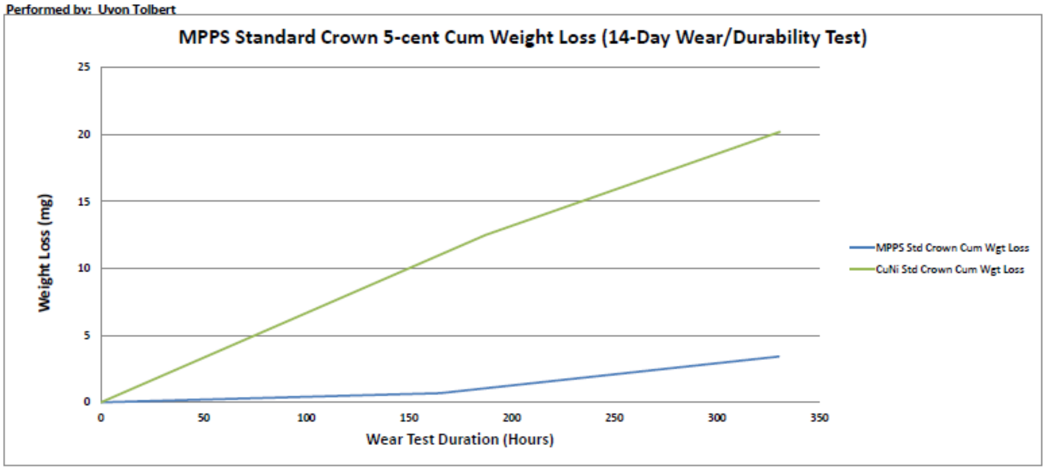
Overall Rating: Go

10.4.2.MPPS

MPPS (Five-Cent) (Pre-Production)

WEAR AND DURABILITY TESTING (Apr 23 - May 21, 2014)

Performed by: Uvon Tolbert



Average Weight Loss (per piece): MPPS 5-cent = 3.4 miligrams
Cupro-nickel = 19 miligrams

Durability (Edge Deformation): Ending MPPS 5-cent Edge Thickness = 0.0795"
Ending Cupro-nickel Edge Thickness = 0.0820"
Deformation = 0.0820 - 0.0810 = - **0.0025"**

Durability Rating: 5-cent MPPS 5-cent rated Go for durability because edge deformation difference between it and cupro-nickel 5-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010". In fact, MPPS 5-cent demonstrated less deformation than baseline cupro-nickel.

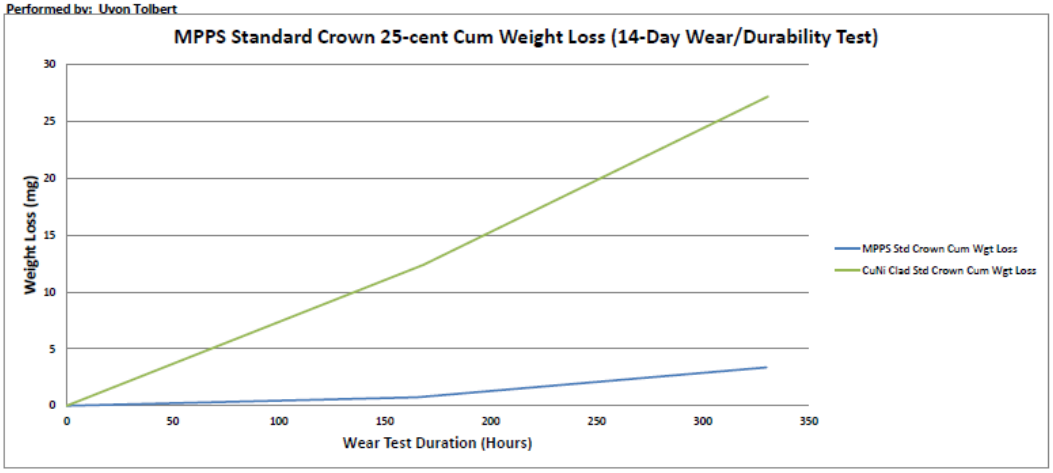
Wear Rating: 5-cent MPPS 5-cent is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of cupro-nickel 5-cent (see graph above). The wear rate of MPPS 5-cent was 18% that of cupro-nickel 5-cent.

Overall Rating: Go

MPPS (Quarter-Dollar) (Pre-Production)

WEAR AND DURABILITY TESTING (Apr 23 - May 21, 2014)

Performed by: Uvon Tolbert



Average Weight Loss (per piece):	MPPS 25-cent = 3.4 miligrams Cupro-nickel clad = 27.2 miligrams	
Durability (Edge Deformation):	Ending MPPS 25-cent Edge Thickness = Ending Cupro-nickel Edge Thickness = Deformation = 0.0690 - 0.0740 = **- 0.0050"**	0.0690" 0.0740"

Durability Rating: MPPS 25-cent rated Go for durability because edge deformation difference between it and cupro-nickel clad 25-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010". In fact, MPPS 25-cent demonstrated less deformation than baseline cupro-nickel clad.

Wear Rating: MPPS 25-cent is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of cupro-nickel clad 25-cent (see graph above). The wear rate of MPPS 25-cent was 16% that of cupro-nickel clad 25-cent.

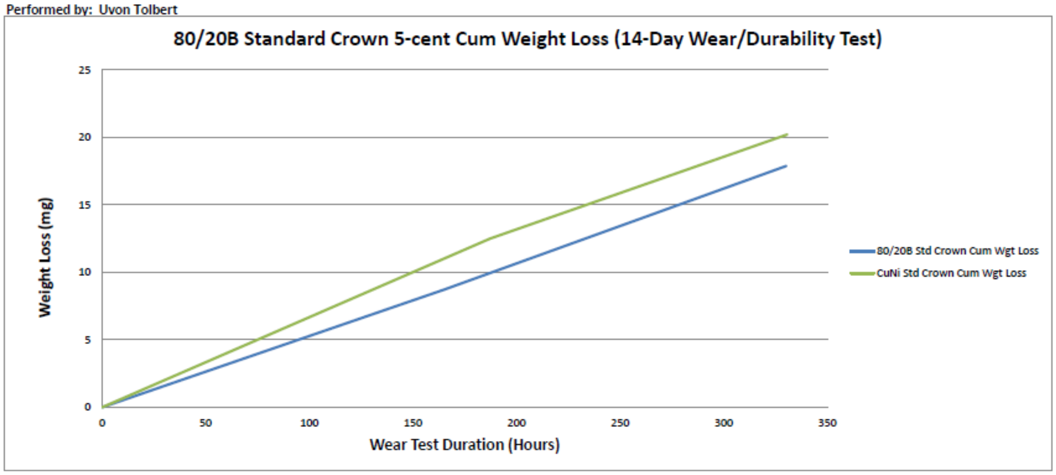
Overall Rating: Go

10.4.3. 80/20B

Initial 80/20B Five-Cent (Pre-Production)

WEAR AND DURABILITY TESTING (Apr 23 - May 7, 2014)

Performed by: Uvon Tolbert



Average Weight Loss (per piece): 80/20B 5 cent = 17.9 miligrams
Current 5 cent = 21.0 miligrams

Durability (Edge Deformation): Ending 80/20B Edge Thickness = 0.0827"
Ending Current 5-cent Edge Thickness = 0.0820"
Deformation = 0.0827 - 0.0820 = **0.0007"**

Durability Rating: 5-cent 80/20B rated Go for durability because edge deformation difference between it and the current 5-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010".

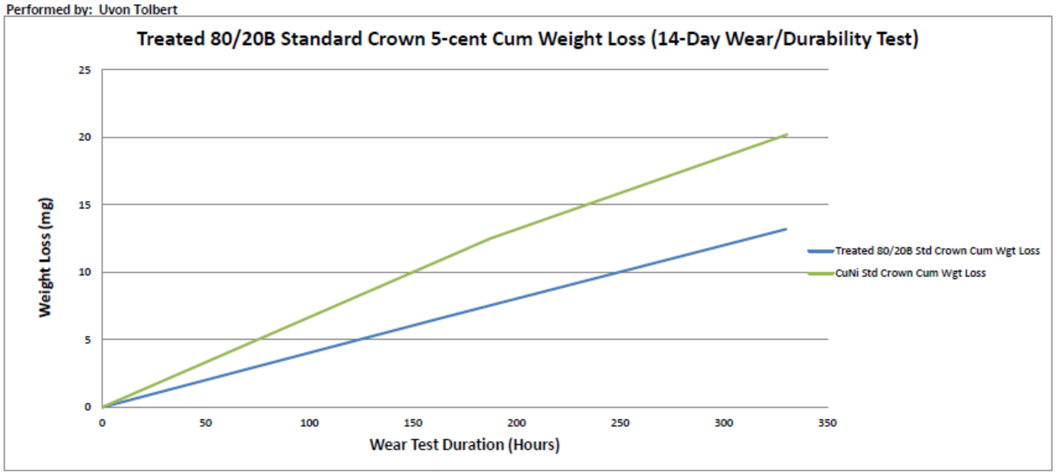
Wear Rating: 5-cent 80/20B is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of the current 5 cent (see graph above). The wear rates of 80/20B was less than that of current 5 cent.

Overall Rating: Go

Treated 80/20B Five-Cent (Pre-Production)

WEAR AND DURABILITY TESTING (Jul 23 - Aug 6, 2014)

Performed by: Uvon Tolbert



Average Weight Loss (per piece): Treated 80/20B 5-cent = 13.2 miligrams
Cupro-nickel = 20.2 miligrams

Durability (Edge Deformation): Ending 80/20B Edge Thickness = 0.0790"
Ending Cupro-nickel Edge Thickness = 0.0812"
Deformation = 0.0790 - 0.0812 = **-0.0022"**

Durability Rating: 5-cent 80/20B rated Go for durability because edge deformation difference between it and cupro-nickel 5-cent coin from the same wear chamber did not exceed the maximum allowable of 0.010". In fact, 5-cent 80/20B deformed less than cupro-nickel tested under the same conditions.

Wear Rating: 5-cent 80/20B is rated Go for wear resistance based on the 14-day weight loss results. The wear rate was not greater than the maximum acceptable theshold rate of two times that of cupro-nickel 5-cent (see graph above). The wear rates of 80/20B was 65% that of cupro-nickel 5-cent.

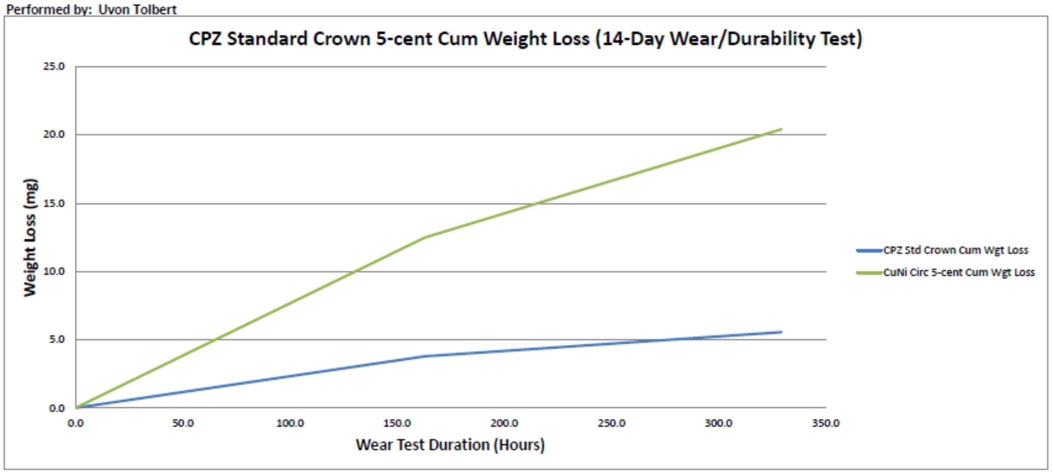
Overall Rating: Go

10.4.4.CPZ

CPZ Five-Cent (Pre-Production)

WEAR AND DURABILITY TESTING (Apr 9 to Apr 23, 2014)

Performed by: Uvon Tolbert



Average Weight Loss (per piece):	CPZ = 5.6 miligrams Cupro-nickel = 20.1 miligrams	
Durability (Edge Deformation):	Ending CPZ Edge Thickness = Ending Cupro-nickel Edge Thickness = Deformation = 0.0845 - 0.070 = **0.0145"**	0.0845" 0.070"

Durability Rating: 5-cent CPZ is rated No Go for durability because edge deformation difference between it and cupro-nickel 5-cent coin from the same wear chamber exceeded the maximum allowable of 0.010".

Wear Rating: 5-cent CPZ is rated **Go** for wear resistance based on the first week's weight loss results, which suggests a wear rate comparable to cupro-nickel 5-cent (see graph above). However, increasing edge thickness as wear testing continued (edge deformation) served to reduce sliding wear to obverse/reverse designs (see graph above), reducing weight loss.

Overall Rating: No Go

10.5. Steam Test Results – Pre-Production

10.5.1. Nickel-Plated Steel

NPS Pilot Material (Five-Cent)

RM NPS 5 Cent Blanks Pre-Production Tests Color Change Before and After Steam Test

Test Date: 05/20/14

Operator: Tony Ying

The average measured values of 40 RM NPS 5-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the tanks. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of RM NPS 5-cent blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	82.24	0.69	6.97	0.58	0.03	0.14
After steam test	79.08	1.01	9.96	0.73	0.07	0.48

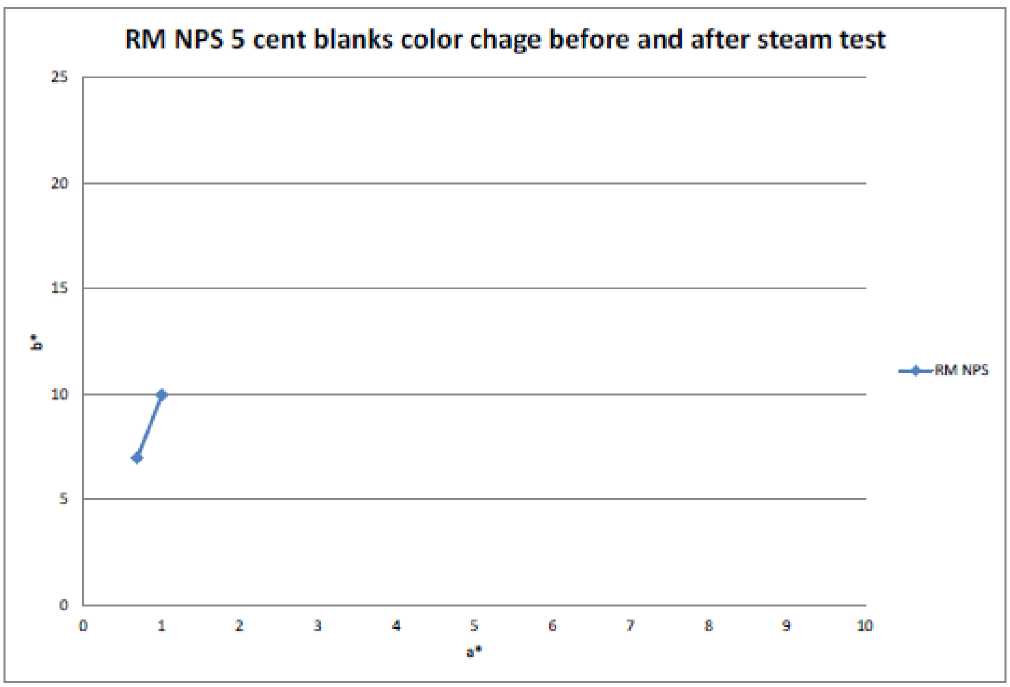


Figure 1: The color change of RM NPS 5-cent blanks.

NPS Pilot Material (Quarter-Dollar)

RM NPS 25 Cent Blanks Pre-Production Pilot Tests Color Change Before and After Steam Test

Test Date: 06/05/14

Operator: Tony Ying

The average measured values of 20 RM Pilot NPS 25-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the tanks. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of RM NPS Pilot 25-cent blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	81.57	0.72	7.19	0.68	0.03	0.21
After steam test	78.23	1.09	10.10	1.31	0.16	2.23

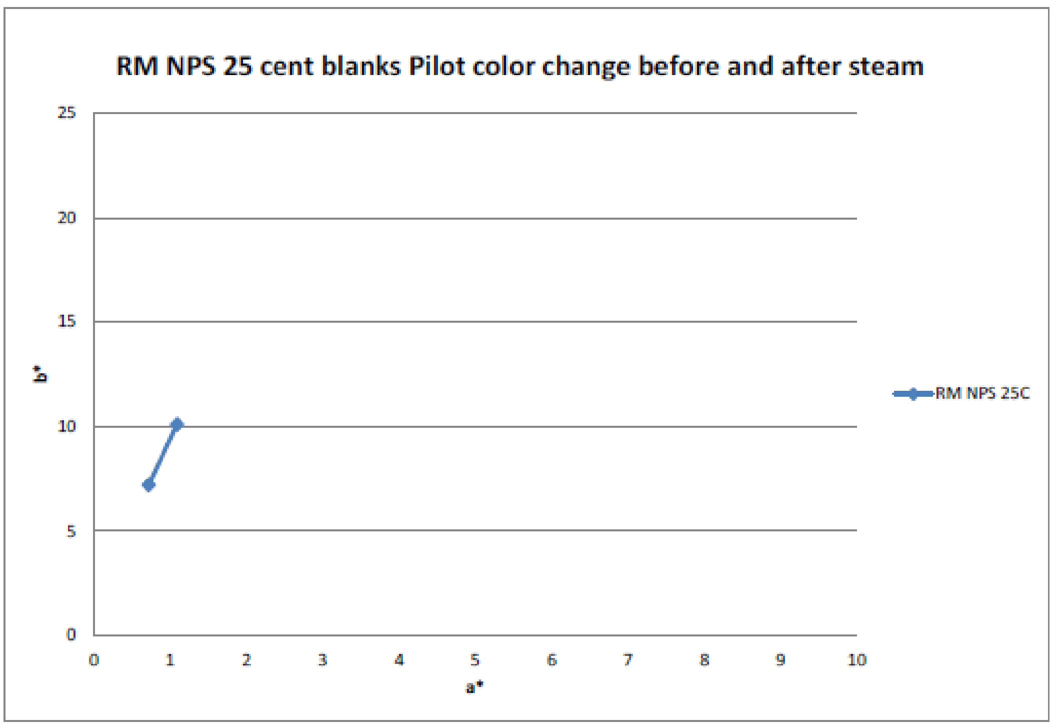


Figure 1: The color change of RM NPS Pilot 25-cent blanks.

NPS Pre-production (Five-Cent)

RM NPS 5 Cent Blanks Pre-Production Tests Color Change Before and After Steam Test

Test Date: 06/19/14

Operator: Uvon Tolbert

The average measured values of 20 RM NPS 5-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the tanks. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of RM NPS 5-cent blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	81.46	0.74	7.20	1.13	0.05	0.29
After steam test	78.86	1.09	10.45	2.47	0.12	0.78

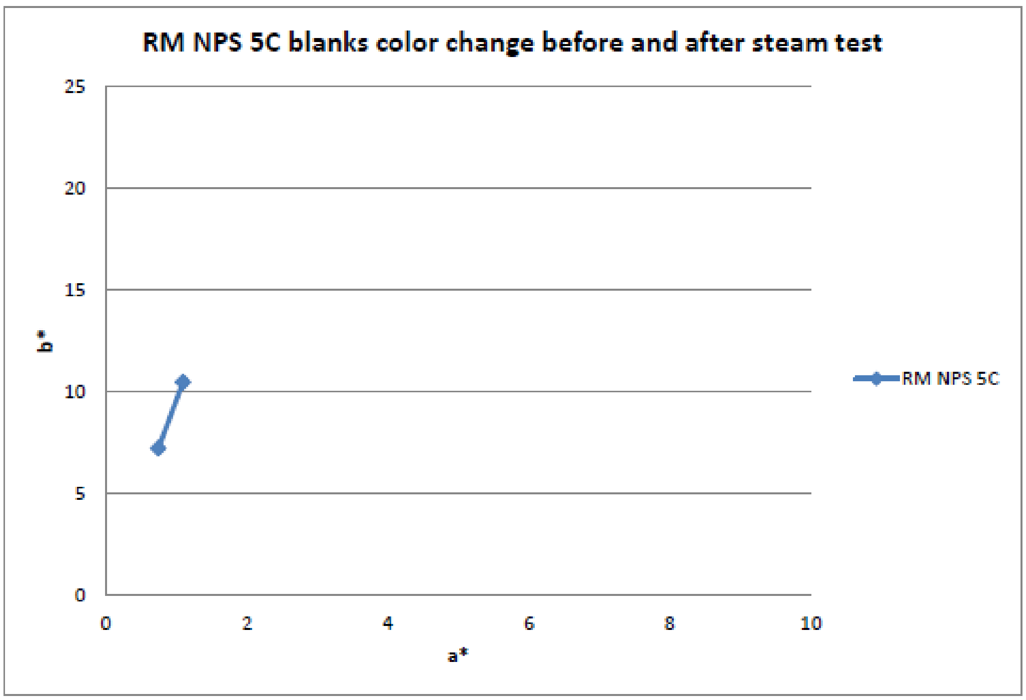


Figure 1: The color change of RM NPS 5-cent blanks.

NPS Pre-production (Quarter-Dollar)

RM NPS 25 Cent Blanks Pre-Production Tests Color Change Before and After Steam Test

Test Date: 07/23/14

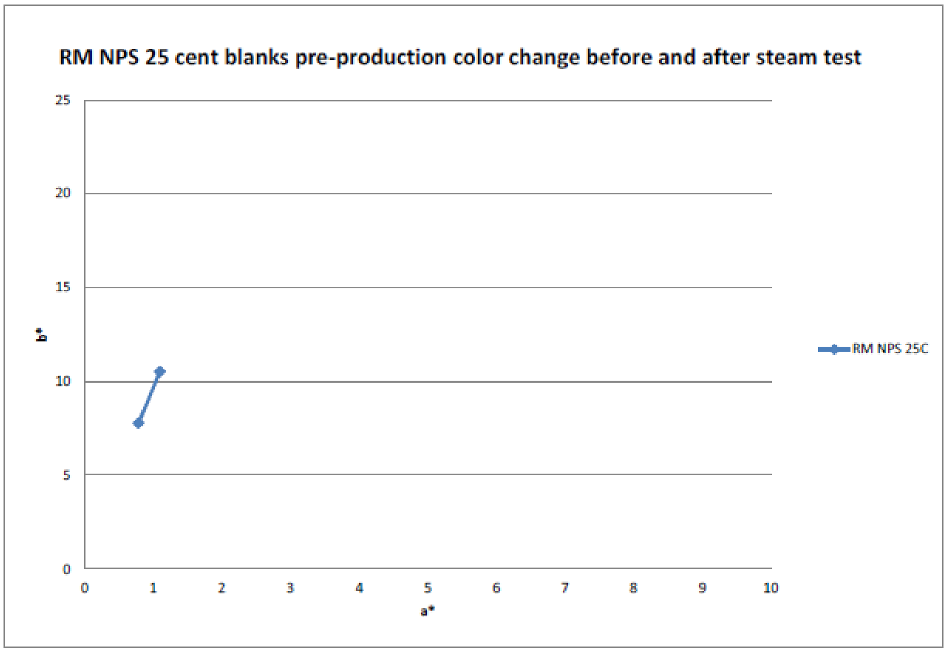
Operator: Tony Ying

The average measured values of 20 RM NPS 25-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the tanks. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of RM NPS cent blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	80.87	0.79	7.76	1.06	0.07	0.40
After steam test	78.22	1.10	10.51	1.35	0.15	0.95



10.5.2.MPPS

MPPS (Five-Cent) (Pre-production)

RCM MPPS 5 Cent Blanks Pre-Production Tests Color Change Before and After Steam Test

Test Date: 04/28/14

Operator: Uvon Tolbert

The average measured values of 20 RCM MPPS 5-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the tanks. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of RCM MPPS 5-cent blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	85.56	1.22	10.22	0.96	0.12	0.42
After steam test	74.90	2.11	11.42	1.03	2.22	0.30

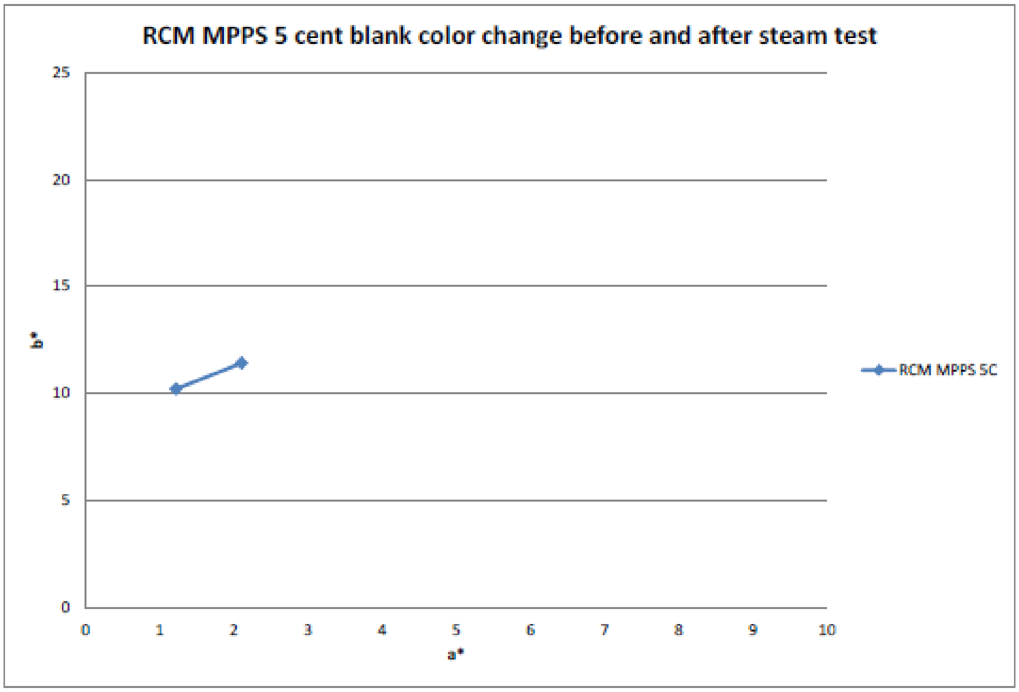


Figure 1: The color change of RCM MPPS 5-cent blanks.

MPPS (Quarter-Dollar) (Pre-production)

RCM MPPS 25 Cent Blanks Pre-Production Tests Color Change Before and After Steam Test

Test Date: 05/01/14

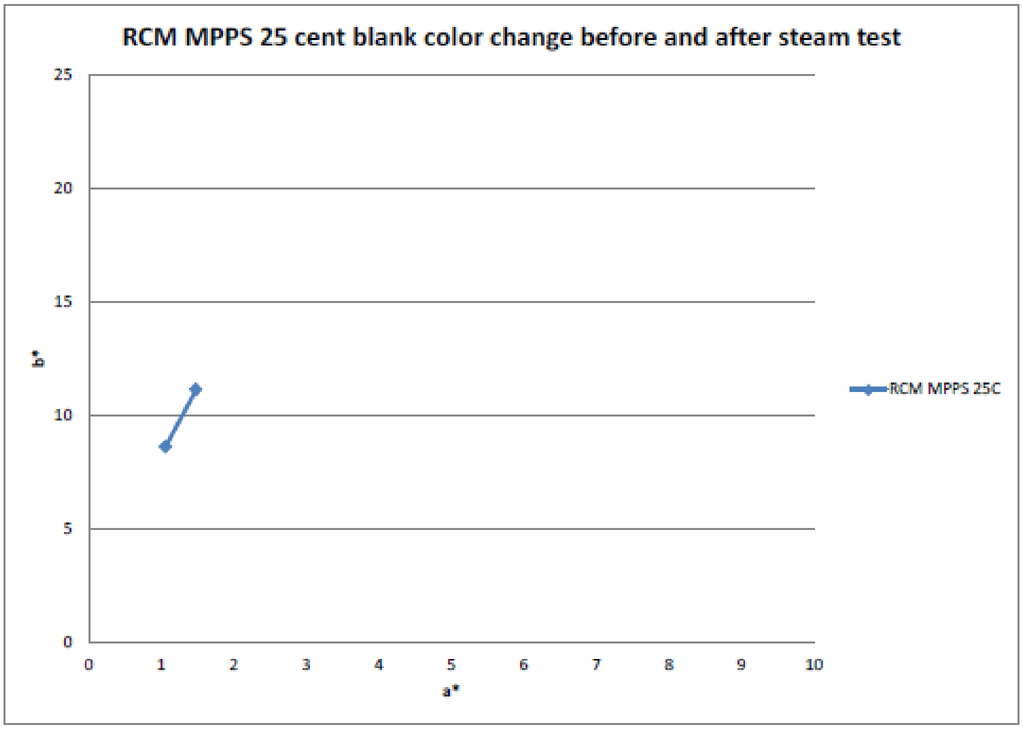
Operator: Uvon Tolbert

The average measured values of 20 RCM MPPS 25-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the tanks. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of RCM MPPS 25-cent blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	77.93	1.06	8.60	1.11	0.11	0.40
After steam test	75.00	1.48	11.13	1.60	0.15	0.67



10.5.3.80/20B

80/20B Five-Cent (Pre-Production)

80/20B CuNi 5 Cent Blanks Pre-Production Tests Color Change Before and After Steam Test

Test Date: 05/20/14

Operator: Tony Ying

The average measured values of 40 80/20B CuNi 5-cent blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the tanks. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of 80/20B CuNi 5-cent blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	82.23	1.82	8.78	0.63	0.10	0.27
After steam test	75.04	2.64	16.59	1.70	0.33	1.33

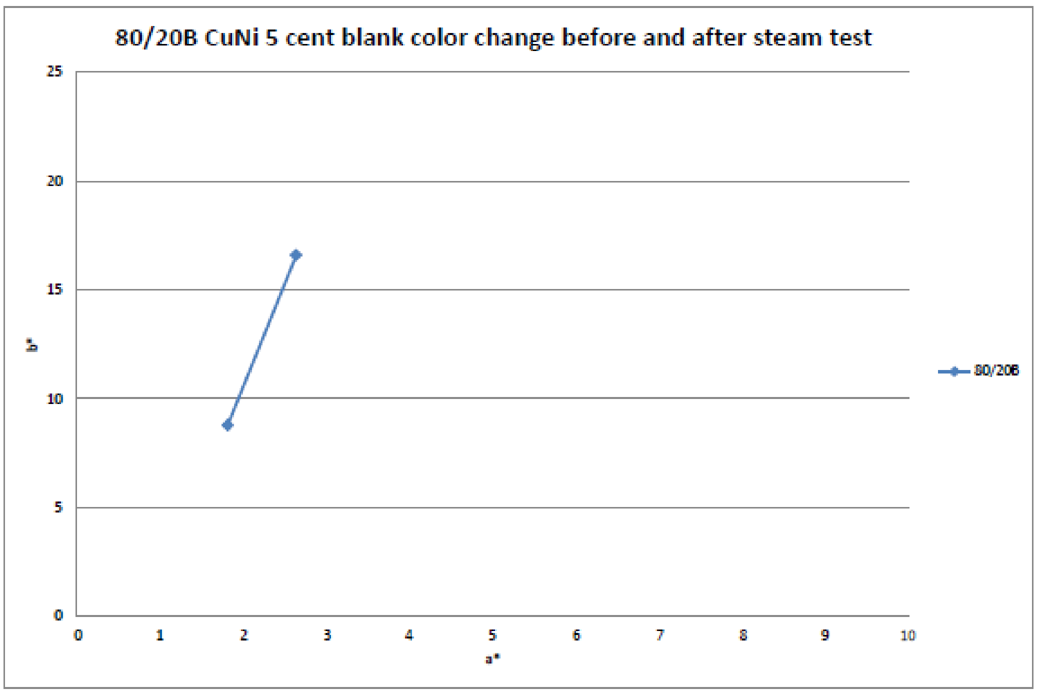


Figure 1: The color change of 80/20B CuNi 5-cent blanks.

Overall Assessment: comparable to the current cupronickel material.

80/20B Five-Cent Lubricated (Pre-Production)

80/20B CuNi 5 Cent Lubricated Blanks Pre-Production Tests Color Change Before and After Steam Test

Test Date: 07/08/14

Operator: Tony Ying

The average measured values of 20 80/20B CuNi 5-cent lubricated blanks before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the tanks. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of 80/20B CuNi 5-cent lubricated blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	81.88	1.91	8.96	0.37	0.07	0.25
After steam test	71.84	4.01	19.91	3.46	0.90	3.04

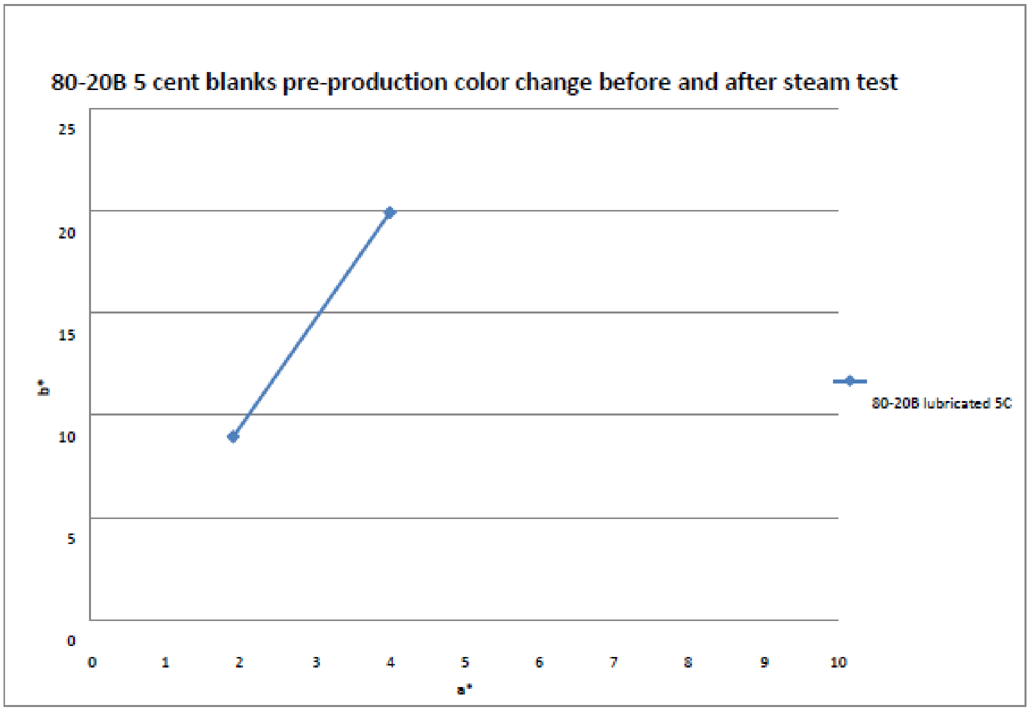


Figure 1: The color change of 80/20B CuNi 5-cent lubricated blanks.

Overall Assessment: Comparable to the current cupronickel material.

10.5.4.CPZ

CPZ Five-Cent (Pre-Production)

CPZ 5 Cent Blanks Pre-Production Tests Color Change Before and After Steam Test

Test Date: 04/01/14

Operator: Tony Ying

The average measured values of 20 CPZ 5 cent blanks for pre-production before and after 2-hour steam test are listed in table 1.

These blanks are randomly collected from the envelope. The standard deviations of the measurement are also listed in the same table.

Table 1: The average and deviation of CPZ blank colors

	L* average	a* average	b* average	L* standard deviation	a* standard deviation	b* standard deviation
Before steam test	80.09	16.90	20.80	1.08	0.69	0.70
After steam test	77.70	17.67	23.08	1.44	0.62	0.65

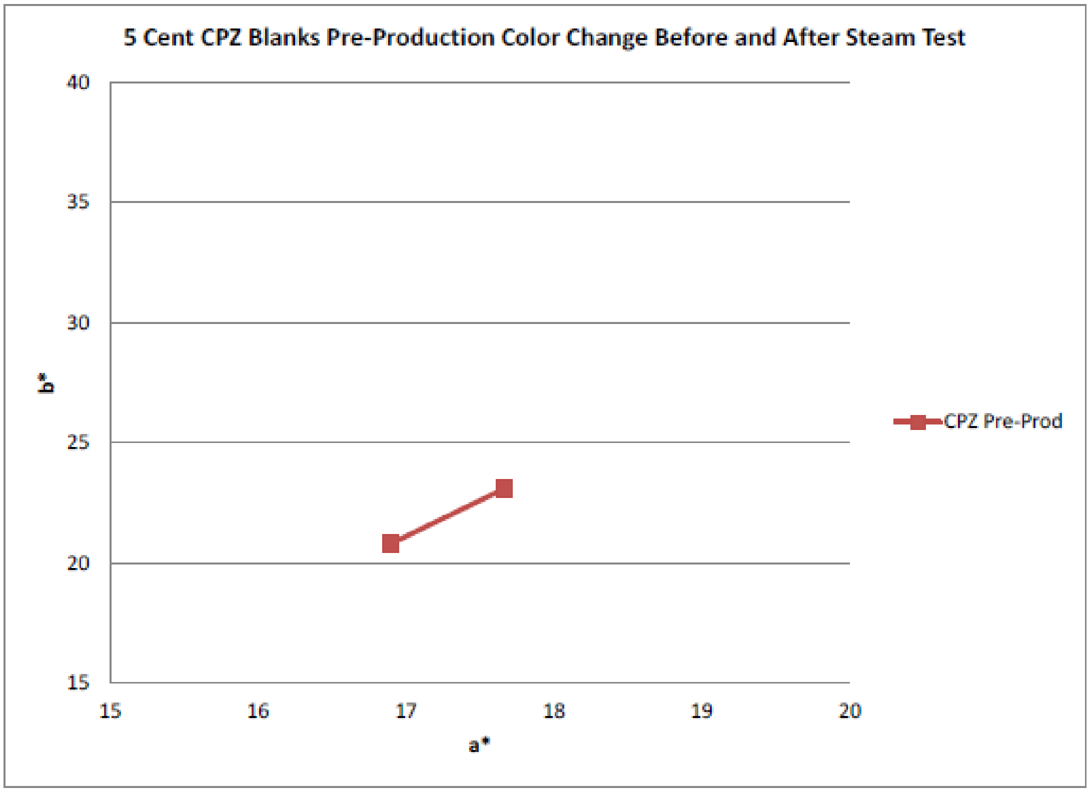
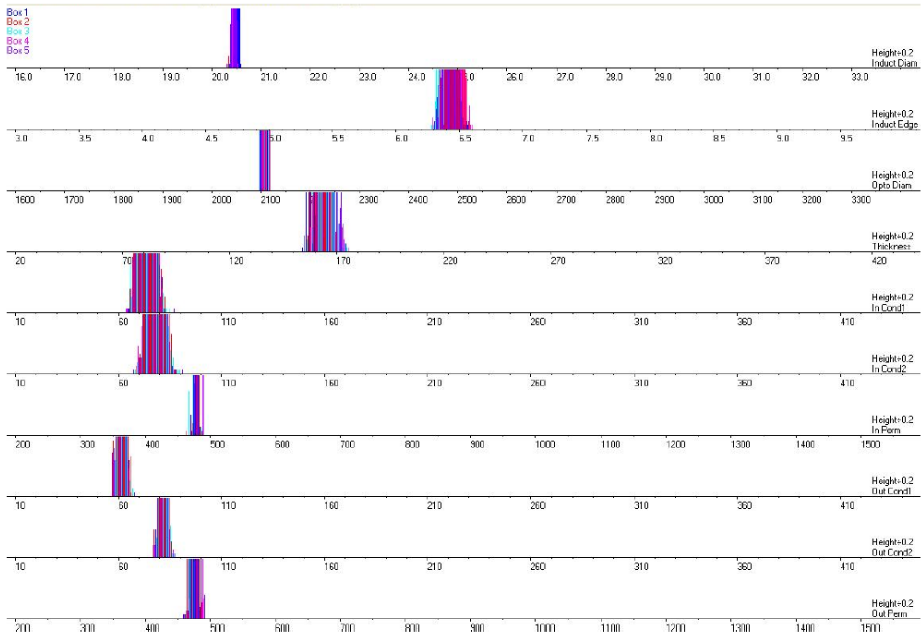


Figure 1: The color change of CPZ blanks.

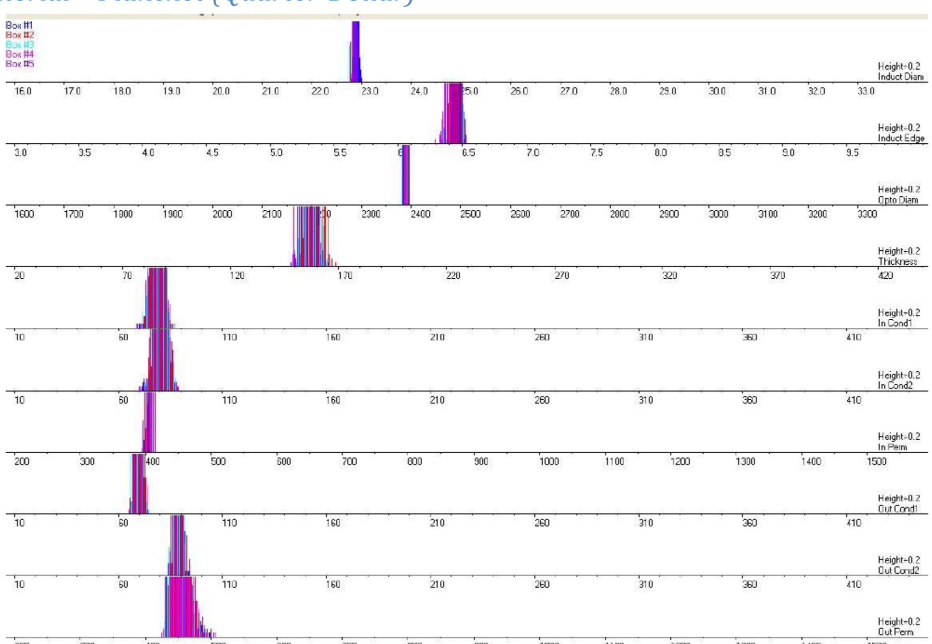
10.6. CSV Test Results – Pre-Production

10.6.1.NPS

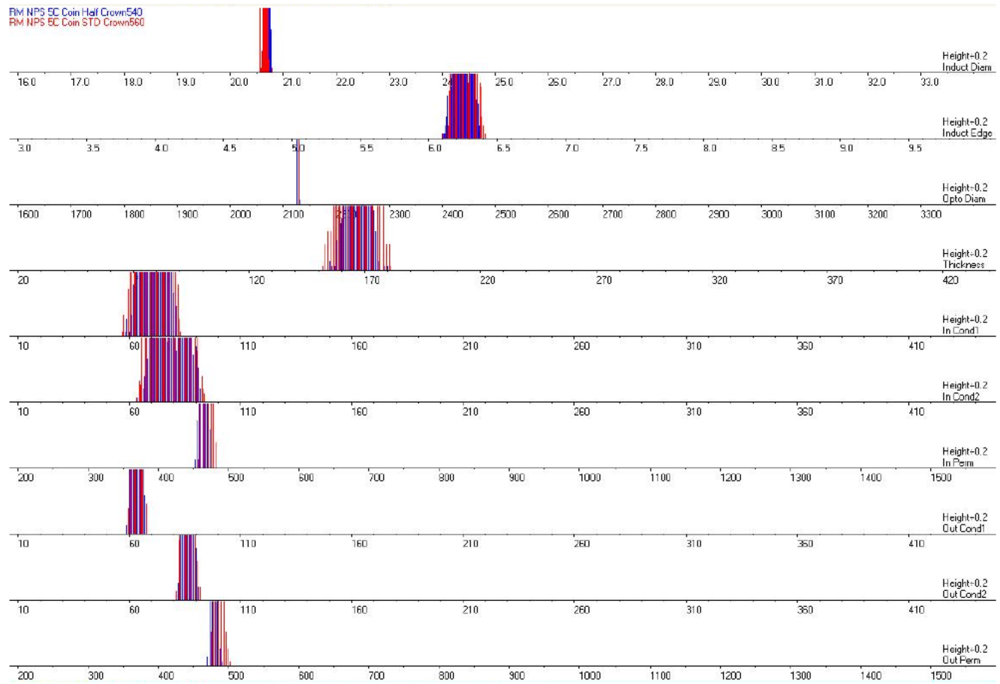
NPS Pilot Material – Planchet (Five-Cent)



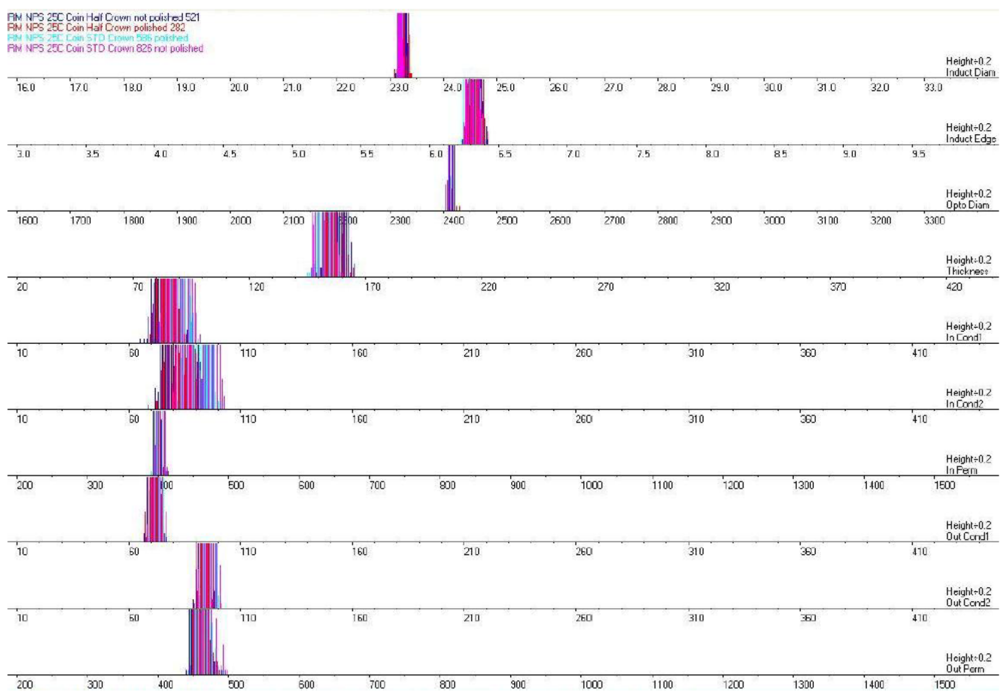
NPS Pilot Material – Planchet (Quarter-Dollar)



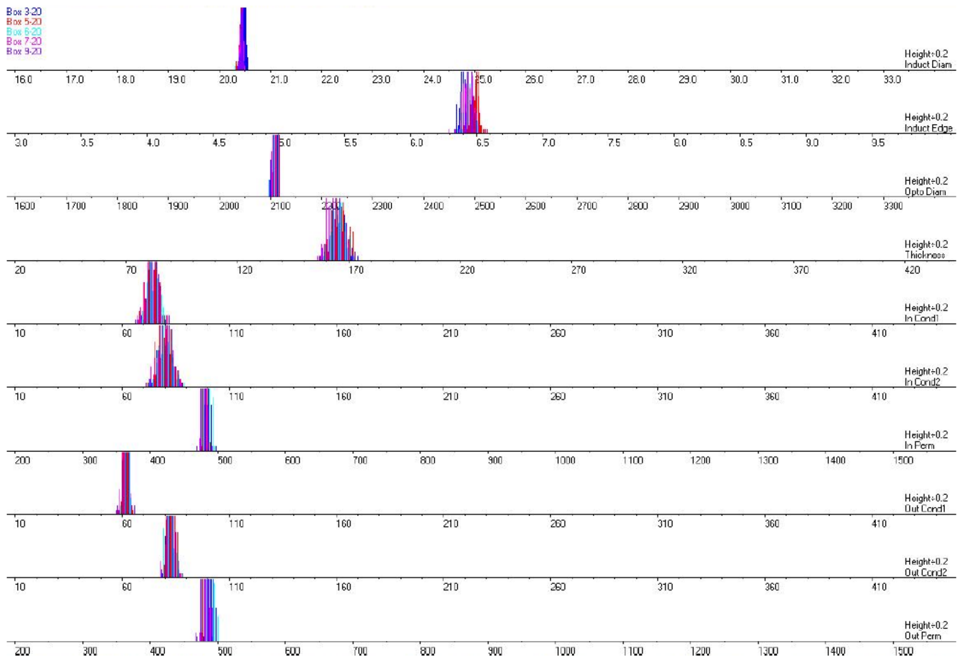
NPS Pilot Material – Coin (Five-Cent)



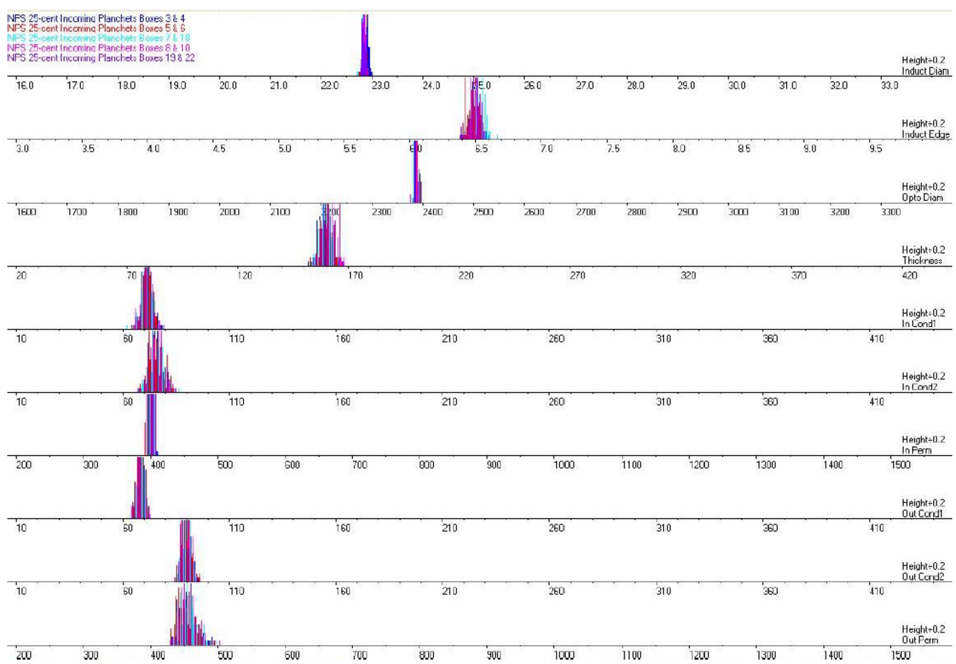
NPS Pilot Material – Coin (Quarter-Dollar)



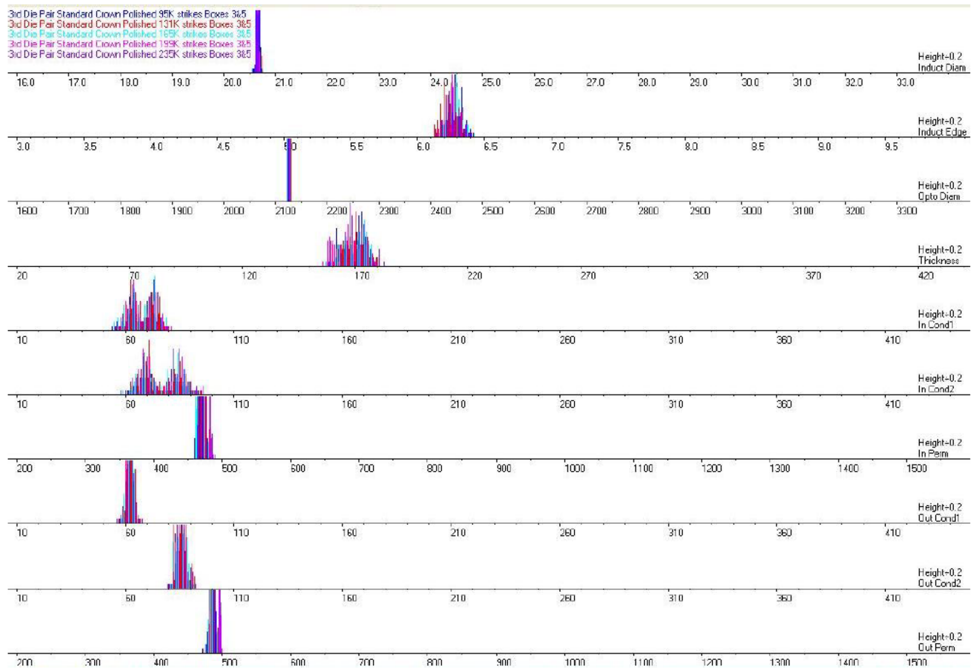
NPS Pre-production – Planchet (Five-Cent)



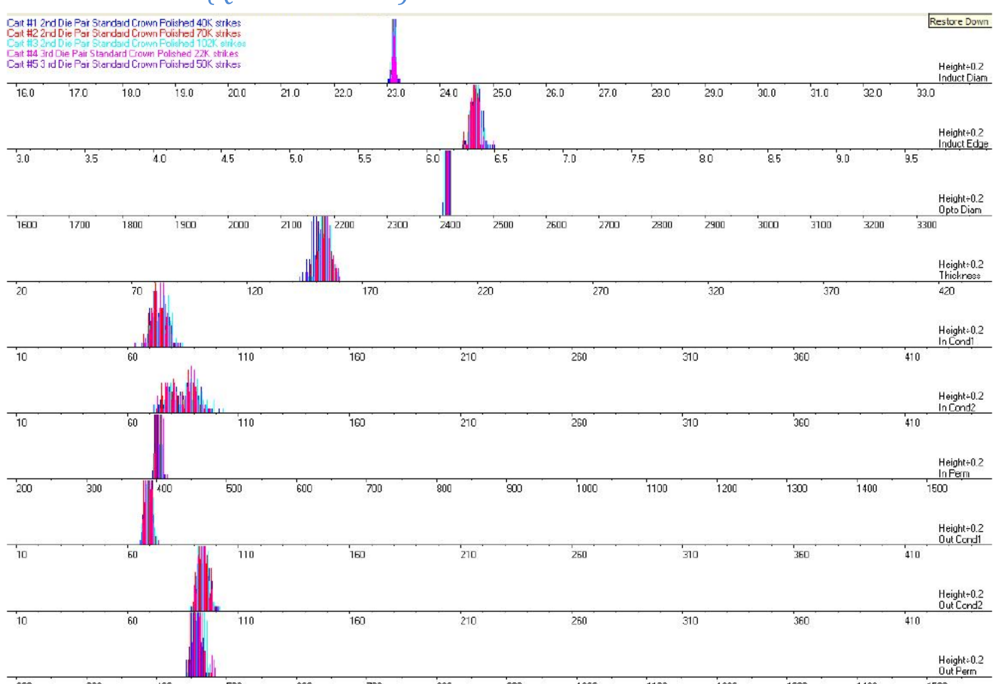
NPS Pre-production – Planchet (Quarter-Dollar)



NPS Pre-production – Coin (Five-Cent)

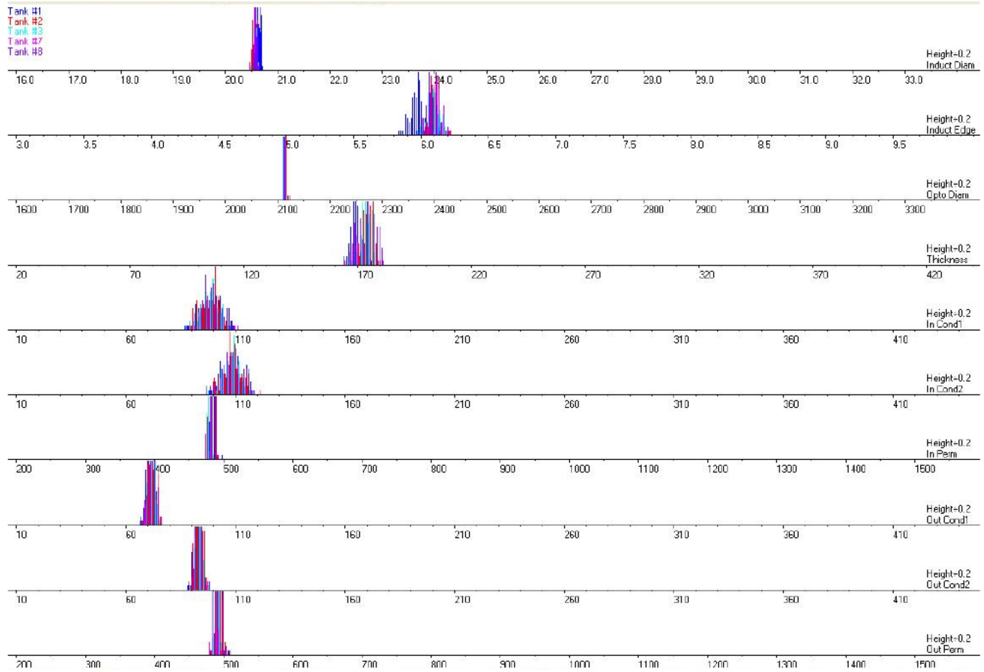


NPS Pre-production – Coin (Quarter-Dollar)

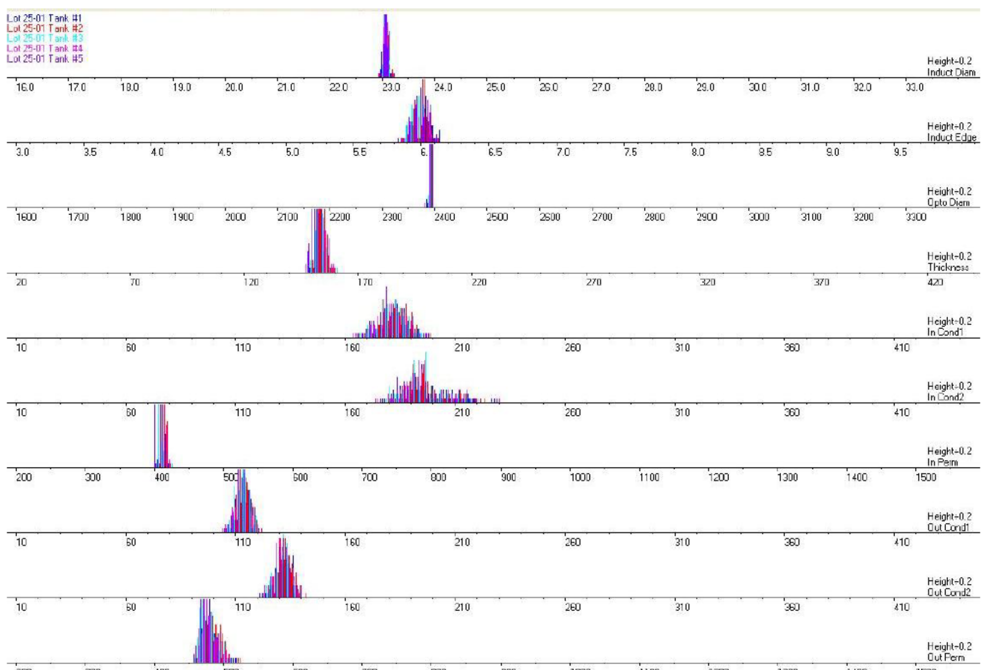


10.6.2.MPPS

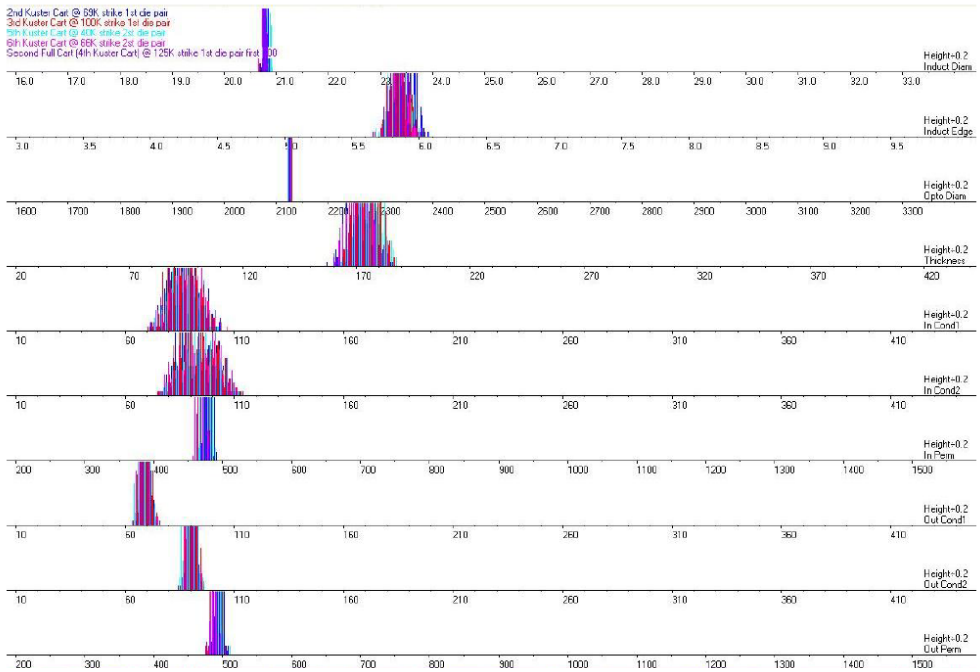
MPPS Pre-production – Planchet (Five-Cent)



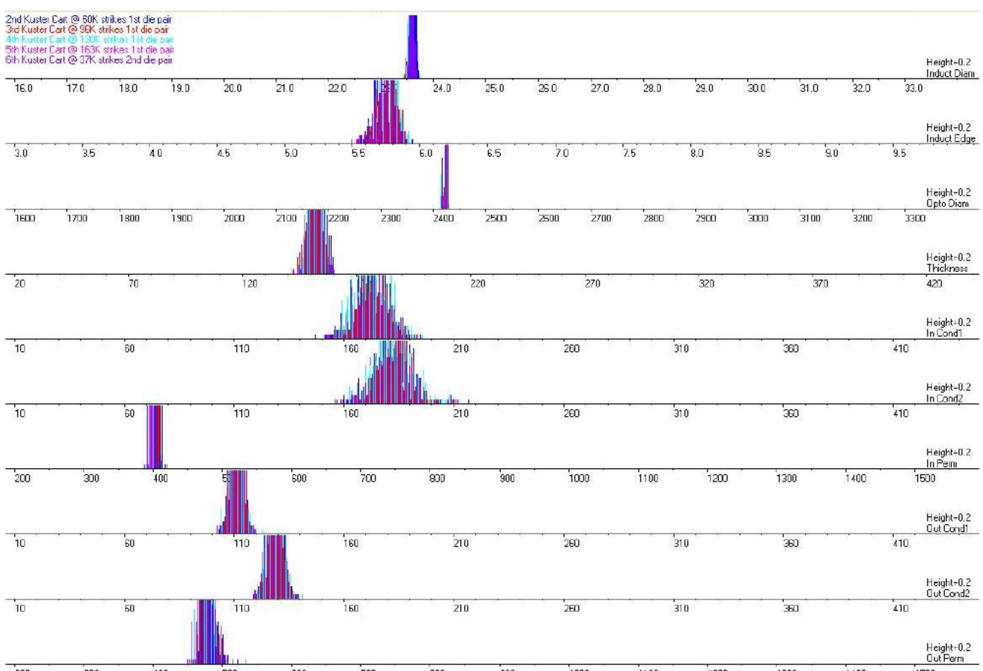
MPPS Pre-production – Planchet (Quarter-Dollar)



MPPS Pre-production – Coin (Five-Cent)

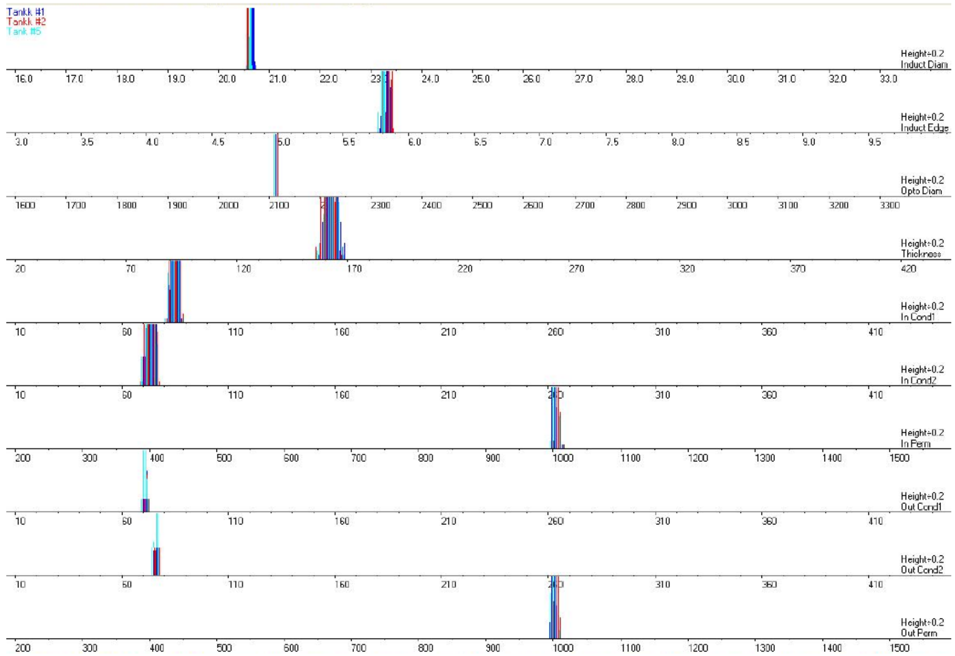


MPPS Pre-production – Coin (Quarter-Dollar)

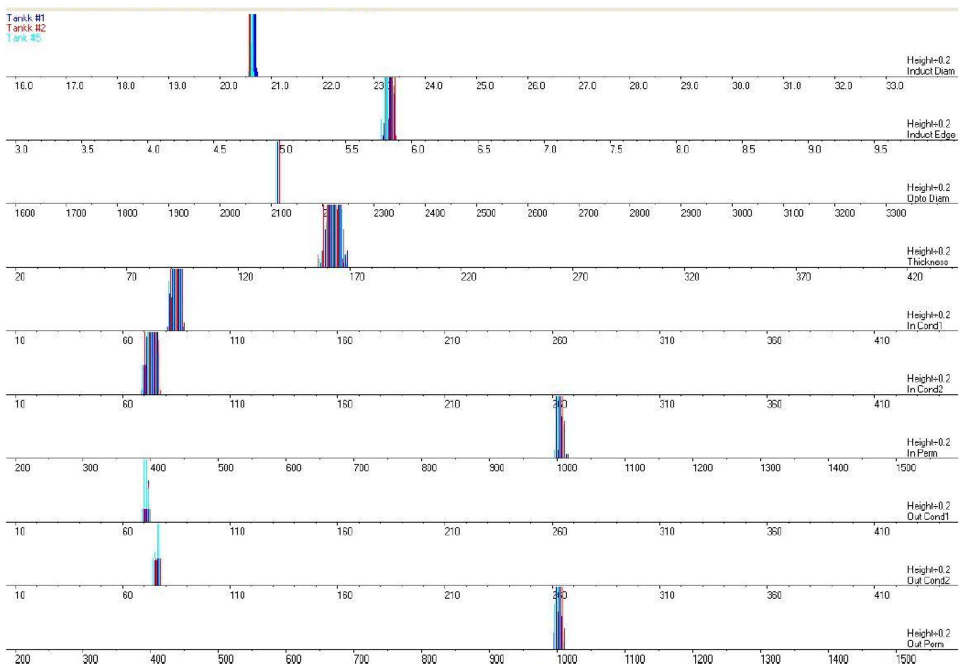


10.6.3.80/20B

80/20B Pre-production – Planchet (Five-Cent)

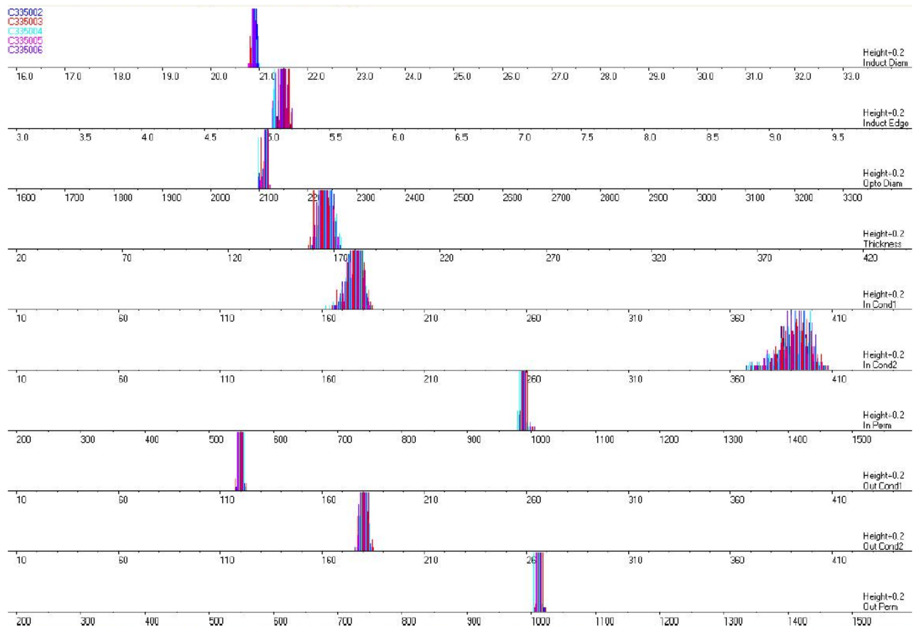


80/20B Pre-production – Coin (Five-Cent)

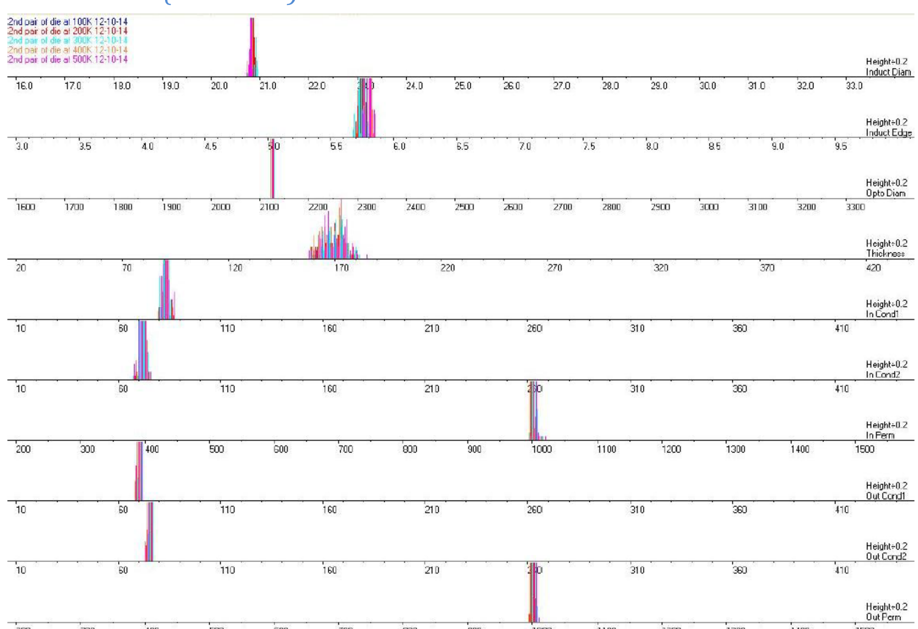


10.6.4.CPZ

CPZ Pre-production – Planchet (Five-Cent)



CPZ Pre-production – Coin (Five-Cent)



10.7. CSV Comparison—Plated Steel v. Current Material

MATERIAL (Five-Cent))	CSV ELECTROMAGNETIC SIGNATURES AVERAGE / RANGE WIDTH						COMMENTS
	Inner Conductivity 1	Inner Conductivity 2	Inner Permeability	Outer Conductivity 1	Outer Conductivity 2	Outer Permeability	
Current Cu-Ni	**82 / 9.7**	**71 / 9.8**	**1004 / 14.5**	**70 / 3.4**	**75 / 3.4**	**1003 / 13.9**	**Current**
80/20	84 / 9.6	73 / 9.4	1007 / 12.2	71 / 2.9	76 / 2.7	1007 / 10.1	Seamless
MPPS	91 / 35.8	99 / 44.9	485 / 24.4	70 / 9.9	91 / 10.2	501 / 20.9	
NPS	68 / 32.5	76 / 43.5	472 / 27.8	62 / 8.8	85 / 8.6	488 / 20.9	
Stainless (302HQ)	31 / 6.0	11 / 5.5	997 / 12.4	47 / 3.0	56 / 3.0	995 / 11.6	

The first number is the average for that material. The second number is how much variance is seen in that material. The larger the second number, the wider the coin acceptor's "window" of acceptance must open to accept both.

MATERIAL (Quarter-Dollar)	CSV ELECTROMAGNETIC SIGNATURES AVERAGE / RANGE WIDTH						COMMENTS
	Inner Conductivity 1	Inner Conductivity 2	Inner Permeability	Outer Conductivity 1	Outer Conductivity 2	Outer Permeability	
Current Cu-Ni Clad	**68 / 18.9**	**550 / 62.5**	**825 / 21.0**	**115 / 12.9**	**287 / 7.2**	**1006 / 15.5**	**Current**
MPPS	176 / 44.9	189 / 60.7	400 / 17.5	113 / 16.5	131 / 18.1	475 / 37.2	Not Feasible
NPS	82 / 23.3	90 / 36.6	398 / 16.5	72 / 9.1	95 / 11.4	457 / 49.4	Not Feasible

1. EMS ranges that overlap those of the current are highlighted in yellow.
2. Plated-steel EMS ranges are wider than those of the current, necessitating wider acceptance windows and less security.
3. Plated-steel and monolithic EMS ranges tend to overlap at multiple frequencies, diminishing the enhanced security of dual-frequency coin validation.
4. Cupronickel clad construction offers high security, as evidence by the low incidence of EMS overlap with MPPS and NPS.

11. Acronym List

°C	degrees Celsius
μm	micrometer, micron, 1 millionth of a meter
COGS	cost of goods sold
CPZ	copper-plated zinc
CSV	coin sorter/validator
DOE	Department of Energy
EMS	electromagnetic signature
EVA	European Vending Association
FRB	Federal Reserve Bank
IA	interagency agreement
IACS	International Annealed Copper Standard
IPR	independent peer review
IV&V	independent verification and validation
MPPS	multi-ply-plated steel
NIST	National Institute of Standards and Technology
NPS	nickel-plated steel
PL	public law
PVD	physical vapor deposition
R&D	research and development
RCM	Royal Canadian Mint
RM	The Royal Mint (UK)
SOP	standard operating procedures
TPCPZ	tin-plated, copper-plated zinc
USPS	United States Postal Service