UNDERKARAT JEWELRY: THE PERFECT CRIME?
INVESTIGATIONS AND ANALYSIS OF JEWELRY USING XRF

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ABSTRACT

Underkarating of jewelry is a silent crime that often goes unnoticed, yet it can be effectively detected through XRF screening. It has become increasingly common in the last 15 years for XRF to be used in a preemptory fashion by jewelry manufacturers for process control and by industry oversight organizations for checking for compliance to karat fineness regulations. XRF has now also been successfully used for investigation and enforcement of underkarat jewelry fraud resulting in criminal prosecution and fines. Jewelry XRF applications and regulations are briefly reviewed and several cases of crime investigation and enforcement are presented.

INTRODUCTION

Retail gold jewelry is a $16B industry in the United States, consuming approximately 400 tons of gold per year (1). Federal law, created in 1906 and amended in 1976, defines the guidelines for gold jewelry and falls under the jurisdiction of the FTC. It requires that all gold jewelry be either labeled / tagged with the karat fineness value, or the karat value be stamped into the jewelry with an accompanying registered trademark. No less than 10K (1 karat = 1/24 part gold) can be sold in the U.S. as 'gold' jewelry. The law grants small negative tolerances for fineness (3ppt for cast or 7ppt for soldered jewelry). The actual gold content of a piece of gold jewelry must be at or above the indicated karat fineness value, minus the allowed negative tolerance, or the jewelry is considered to be *underkarat*. For example, 14K equates to 58.33 wt% gold and cast jewelry indicated to be 14K can be 58.03 wt% gold or above.

Whether done intentionally or by accident, underkarating is fraudulent misrepresentation to the consumer. This crime usually goes undetected and is not actively enforced by any government agency. The loss to the unsuspecting consumer can be viewed several ways. The simplest viewpoint is that a small marginal amount of gold is missing from the item which amounts to only a few dollars. However, the 'missing margin' integrated over large quantities of jewelry amounts to millions of dollars. A more comprehensive approach is to recognize that the entire retail value of the underkarat item is forfeit because illegal underkarat jewelry is, by definition, not gold jewelry - worth only its intrinsic scrap gold value. Hence, a gold ring that retailed for $100 and is underkarat retains only the intrinsic scrap gold content of perhaps $20, representing an $80 loss to the consumer. Using this model, a level of 10% underkarating represents a $1.2B consumer loss and at a 1% level the loss is $120M. Estimates vary as to the amount of underkarating that is experienced in the jewelry industry from less than 1% to as much as 50% depending upon the location and the outlet. This is not to impugn the jewelry industry – in most reputable high end and chain retail outlets underkarating is much less likely to occur than in ‘bargain’ gold exchanges and jewelry marts. However one approaches this, there is a substantial loss to the consumer every year from underkarating that goes largely undetected and un-enforced.

XRF AND THE JEWELRY APPLICATION

A number of different techniques are used to fabricate jewelry which results in samples that vary considerably in homogeneity, and hence their suitability for accurate XRF analysis. Lost wax investment casting, extrusion - rolling - stamping, pressed powder, and electroforming processes are all used. Each of these methods results in jewelry samples that possess unique XRF measurement characteristics due in part to the macroscopic metallurgical properties of the alloy being used. One can study the phase diagram for the Au – Cu system to understand that the gold-rich fraction of higher melting point will solidify first that in some cases, creates a gold-rich ‘skin’ on the outside surface of the sample. In addition, a piece of jewelry may have areas of solder, electro-plating, or multiple colored alloys juxtaposed with the parent alloy. Since XRF is essentially a surface analysis technique with an effective depth of approximately 10um for typical jewelry alloys, it is possible for ‘sample - prep’ errors to be introduced into the measurement due to heterogeneity. Generally, the observed effect is an XRF assay that is biased often in the gold-rich direction. (2).

Since the legal tolerances require jewelry to be no less than 3ppt or 7ppt below plumb karat, the gold assay accuracy must be commensurate with these requirements. The incumbent referee analysis technique in the jewelry industry is the *fire assay***.** This is a destructive gravimetric technique whereby a sizeable portion (fraction of a gram to a gram) is cut from the sample and scorified in a bone-ash cupel in a furnace to separate the base metals from the precious metals. The process, also termed cupellation, can be accurate to within 0.02wt% Au, but in practice it is typically about 0.1wt%. Like any analytical technique, it is vulnerable to system and statistical errors, however, XRF measurements are always compared to fire assay values to gauge accuracy.

Under the most ideal conditions, XRF can achieve remarkably close parity to fire assay. In production casting, these conditions can be met with successful results as shown in Table 1. Through careful calibration, sample preparation, and measurement technique, parity to fire assay was maintained to 1ppt or better over a period of 7 months of collected data. Production casting represents perhaps the best application of XRF to jewelry analysis and application of the technique to ‘finished goods’ will be explored in the following four investigations.

Table 1. Casting Site: XRF Vs. Fire Assay (FA)

Test Duration	7 Months
No. Of Assays	191
Average Difference Between XRF and FA	0.03 wt% Au
Maximum Difference Between XRF and FA	0.10 wt% Au

XRF JEWELRY INVESTIGATIONS

As mentioned above, the fire assay technique has always been used in the jewelry industry as the accepted referee method for determining karat content of jewelry. Its main drawback, however, is that it is destructive which leads to a quandary: destroy the jewelry (evidence) to determine its value, or retain the jewelry intact without assurance of its karatage. In many countries outside the US, assay laboratories employ 'micro-fire assays' whereby a small amount of sample is scraped from the surface and assayed. This is also somewhat vulnerable to sample heterogeneity, as is XRF. The next most suitable solution is karat screening using XRF, and this is actually a listed procedure with US Customs laboratories. Over the last 15 years, XRF has gained considerable use and acceptance within the manufacturing industry as well as industry oversight organizations. The following four examples chronicle the use and characteristics of XRF jewelry analysis as it was used in 'forensic mode' for investigations of underkarating.

San Francisco District Attorney Vs. IPI Gold 1990

The Consumer Protection Division of the San Francisco District Attorney's (SFDA) office conducted three raids on IPI Gold, San Francisco, starting in 1989 (3). The owners were arrested and charged with selling underkarated and untrademarked gold jewelry. 15,000 pieces of jewelry were seized from IPI Gold as suspect underkarat merchandise and the total civil exposure could have amounted to $80M in fines. The SFDA and IPI stipulated the use of a benchtop EDXRF instrument for purposes of efficiently sorting the jewelry after the SFDA tested the XRF instrument and determined it to have the requisite characteristics: "relevant, reliable and trustworthy" (3).

A summary of the SFDA's test results is given in Table 2 that compares XRF and Fire Assay (FA) results on a set of samples from the confiscated merchandise. The XRF agreed with 80 to 90% of the fire assay judgments and the instrument was used to sort thousands of pieces of jewelry. The presence of solder or plating on the elephant chain in Table 1 most likely biased the XRF result. Nevertheless, this was a landmark case for XRF and jewelry analysis that established the technique as a viable and useful tool in criminal prosecution of an underkarating case.

Table 2. SFDA Test: XRF Vs. Fire Assay

Description	XRF, Karat	Fire Assay, Karat
Crucifix	8.71	8.45
Cadillac Charm	13.59	13.57
Nugget Charm	13.86	13.89
Rope Chain	9.42	9.38
Crucifix	10.12	10.00
Pinky Ring	8.67	8.66
Ring	12.17	12.21
Butterfly Charm	14.03	13.86
Elephant Chain	15.05	13.38
Chain Necklace	14.24	14.51

SFDA Test Parameters: Seiko SEA-2001 benchtop EDXRF; SiLi detector / LN2; 50KV; 13Watt Rh tube; 3mm beam; 300sec measurement; ~30% deadtime; Rel. Std. Dev. 0.13% Au 1-sigma; FP calibration / one standard.

Dateline NBC: "All That Glitters" 1995

Tabloid TV has conducted and aired numerous investigations on underkarating over the last 15 years. Dateline NBC conducted such an investigation in 1995. They 'shopped' a number of retail outlets undercover and assayed the merchandise by fire assay and XRF. Some very surprised and unwitting 'participants' were confronted on national TV with very damaging results (4).

In this investigation, we used a small-spot 'micro-EDXRF' instrument to screen the jewelry samples and Dateline also had the samples fire assayed. A 'scorecard' of XRF Vs. fire assay is tabulated in Table 3. XRF agreed with the fire assay judgments 41 out of 46 times for a parity of 89%. In all, 16 of the samples were found to be underkarat by fire assay and XRF found 11 samples to be underkarat. All of the underkarat samples that XRF failed to detect were bracelets. As in the SFDA case above, the plating and soldering typical in fabrication of these particular items most likely biased the XRF measurements in the gold-rich direction and this was unaccounted for in our methodology. The screening reliability could have been reduced by the shorter 50-second (livetime) measurement time, which yielded poorer relative precision than was possibly needed.

Table 3. Dateline NBC Test: XRF Vs. Fire Assay

Number of Comparisons	46
No. of Agreements on Assay Judgments	41
% Parity	89
No. Underkarat Detections, Fire Assay	16
No. of Underkarat Detections, XRF	11

It is interesting to note that when the sample population for this test excludes samples that most likely contained solder and plating and includes only solid cast samples, the parity increases to 96% as shown in Table 4, below. Thus, the improved 'sample-prep' qualities of the more homogenous cast jewelry indicate that very high parity and measurement reliability approaching that of Table 1 can be achieved with XRF on finished goods.

Table 4. Dateline NBC Test: Solid Cast Samples Only

No. of Comparisons	25
No. of Agreements on Assay Judgments	24
% Parity	96
No. Underkarat Detections, Fire Assay	10
No. of Underkarat Detections, XRF	9

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Dateline opted to defer only to the fire assay results as a basis for their publicized confrontations, since they could not have assurance of '100% accuracy' using XRF. Though no analysis – fire assay included – is guaranteed to be 100% accurate, this investigation confirmed the observations of the earlier SFDA test, above, and further validated the scope and value of XRF as a screening tool for detection of underkarat jewelry.

Dateline Test Parameters: Kevex Omicron 'Micro-EDXRF'; SiLi detector / LN2; 50KV / 50W mini-focus tube; 500UM beam size; 50sec livetime; Rel. Std. Dev. 0.5% Au 1-sigma; 2 -standard FP calibration.

US Customs Field Test 1999

The US Customs is responsible for inspecting jewelry to ensure the 10K minimum has been met and to check for copyright infringement of trademark. In addition, they also levy duties on imported goods such as jewelry. A visit to the US Customs website will reveal XRF is one of several listed procedures for evaluation of incoming jewelry. To evaluate XRF screening, a field test was set up at a major port-of-entry known for importing high volumes of jewelry which was under US Customs jurisdiction.

For this test, we used a small spot 'micro-EDXRF' instrument. Customs agents produced samples from a parcel of jewelry that was a candidate for duty assessment and importation. A large gold ring from the parcel, which was declared to be 14K with a large solitaire cubic zirconia (CZ) gemstone, was analyzed (CZ is a form of yttria-stabilized zirconia.). The XRF assay of the ring shank was 18K with a high degree of confidence. When the X-Ray beam was directed on the center of the CZ stone, the resulting X-Ray spectrum did not reveal any zirconium or yttrium K-alpha or K-beta characteristic peaks, but rather a broad scatter-continuum of the tube's Bremsstrahlung output plus the characteristic Rayleigh and Compton lines from the Mo tube anode. The instrument, typically extremely sensitive to even very small quantities of Zr, showed an absence of this and any other element above its detection limit from Ti – U. The spectrum was typical of the scatter pattern one obtains off of a low-Z material such as glass, plastic - or diamond! The diamond could then be positively identified by other means.

In this case, the XRF screening exposed fraud and smuggling by helping to identify the true quality of merchandise whose value had been intentionally under-declared to avoid higher assessment of duty. In a sense, this might be considered a case of ‘overkarating’.

Test Parameters: CMI 950 benchtop ‘Micro-EDXRF’; sealed Xe gas proportional counter; 45KV 0.8ma; Mo anode mini-focus tube; 300um beam size; 90sec measurement time; Rel. Std. Dev. 0.13% Au one-sigma; multiple-standard FP calibration.

New York State Attorney General Vs. New York City Jewelers, 2001

This is the precedent - setting case for XRF jewelry screening for forensic purposes. Based upon X-Ray evidence alone, the New York State Attorney General executed legal action against 18 retailers and two distributors of jewelry in New York City and levied fines totaling $125,000. In addition, the guilty parties’ names were well publicized, damaging the crucial reputation upon which jewelers do business. The Jeweler’s Vigilance Committee (JVC), the industry-sponsored oversight organization, conducted the investigation and shopped a number of jewelry vendors in New York City. The merchandise was tested with a benchtop EDXRF and some was found to be less than 10K, whereupon, they turned the evidence over to the State Attorney’s office.

This example shows the complete and effective use of XRF in a forensic application and marks the arrival and maturation of XRF as an accepted jewelry screening tool. The JVC maintains that XRF data provides the “clear and convincing evidence” that is requisite for such work.

Test Parameters: Seiko SEA-2010 benchtop EDXRF; SiLi detector / LN2; 50KV; 3mm beam; Rel. Std. Dev. 0.13% Au 1-sigma; FP calibration / one standard.

CONCLUSION

Underkarating is a substantial and costly crime that generally goes undetected and un-enforced. The forensic application of XRF jewelry screening typically delivers accuracy almost as high as 90% and above. This has proven mostly efficacious for forensic work and XRF has established itself as “relevant, reliable and trustworthy” and providing “clear and convincing evidence.” This had a positive impact on the jewelry industry and improved consumer protection.

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