The Forensic Analysis of Wooden Stick Matches in a Southern California Arson Case and Subsequent Examinations in Two Other Arson Cases

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Abstract

In late 1999, four arson fires were set at Joshua Tree National Park that resulted in severe damage to three government buildings. Burned and unburned wooden matches were left at the scene and a suspect was subsequently arrested and found to have similar looking matches in his pocket and vehicle. The matches from the scene and suspect were submitted to the California DOJ Riverside Criminalistics Laboratory for analyses.

Match head color, match length, stick width, stick shape and color, and the elemental and organic composition of the match heads were examined using stereomicroscopy, FTIR microscopy and SEM/EDX. The examined samples included matches from two boxes of Coleman brand matches that were found on the suspect and in his vehicle, four partially burned or unburned matches found at the scenes, six packages of different waterproof 'exemplar' matches representing four different manufacturers, and six boxes of non-waterproof 'exemplar' wooden matches from different countries/manufacturers.

The matches found at the scenes were visually and chemically similar to those found in the suspect's pocket and vehicle. They differed in match head color, and some in match head polymer type from the twelve different samples of waterproof and non-waterproof exemplar matches, thereby providing some indication as to their 'uniqueness'.

Examination results showed that match head color differs considerably among different waterproof match brands. Therefore, color is a very good discriminating tool. Although published literature discusses using elemental analysis for match comparisons, match head organic polymer coatings were also found to be useful for discrimination, especially between waterproof and non-waterproof matches. Additionally, at least in Southern California, there appears to be a limited number of waterproof match brands readily available from retailers.

Since the 1999 case, the author has analyzed some burned match heads from safety matches using SEM/EDX with some success at providing discrimination between different match brands. This presentation will cover some of this more recent casework as well as other analytical methods that have been developed and recently applied to the forensic analysis of safety matches.

Part I: 1999 Arson Case

Introduction:

On December 10, 1999, four arson fires severely damaged three government buildings at Joshua Tree National Park. Wooden stick matches were left at the scenes and a suspect was arrested with boxes of wooden matches in his possession. A National Park Service investigator requested forensic examinations and comparisons of the matches left at the scenes and the matches found in the suspect's possession. The investigator also went to various stores throughout the greater Los Angeles area to obtain additional match exemplars for comparisons and found only a limited number that were available.

Matches are generally of two varieties, the 'strike anywhere' and the 'safety' types. 'Strike anywhere' match heads contain an oxidant such as potassium chlorate mixed with an oxidizable material such as sulfur, a higher concentration of binder material such as glue, and inorganic fillers that can include glass, diatoms etc…The tips contain a large amount of a phosphorous compound, are more readily ignited than the remainder of the head, and they ignite by friction (1,2).

The 'safety matches' heads contain an oxidizing substance, an easily oxidizable material such as antimony sulfide, a binder and inorganic fillers. These matches will only ignite when struck on boxes that have striker pads containing red phosphorous, an oxidizing agent, glue, and an abrasive material such as ground glass (1,2).

The binder in match heads is usually animal glue. In some humid regions (such as Southeast Asia) casein or soya protein hydrolysates mixed with polyvinyl acetate are used as the binder to provide greater humidity resistance; however, these are not 'waterproof' matches. The humidity resistant binders are not generally used in matches from Europe or North America. Actual waterproof matches have binders that are usually nitrocellulose based lacquers (2).

Samples for Examination:

Matches from boxes of Coleman brand waterproof wooden stick matches from the suspect, partially burned or unburned wooden stick matches from the scenes, six packages of different waterproof matches representing four different manufacturers, and six boxes of non-waterproof stick matches from different countries/manufacturers were examined and compared (Figures 1-4).

Figure 1: Matches from Scenes and Suspect

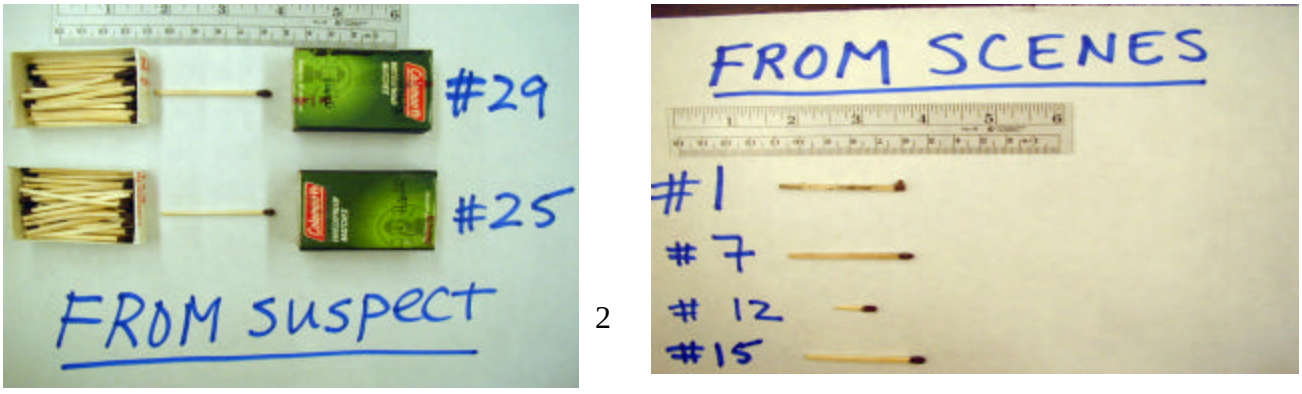


Figure 2: Exemplar Waterproof Matches

Figure 3: Brands of Waterproof Matches from Different Stores in the Greater Los Angeles Area

STORE	LOCATION	BRAND	BRAND
Adventure 16	Los Angeles	Coghlans waterproof	
Big 5	Palm Desert	Coghlans waterproof	
Jernigan Sporting Goods	Yucca Valley	Coghlans waterproof	Coghlans windproof
Kmart	Yucca Valley	Coleman	
Oshmanns	Palm Desert	Coghlans waterproof	
REI	San Dimas	REI Stormproof	
Sport Chalet	Los Angeles	Coghlans	
Sportmart	San Bernardino	Coghlans waterproof	
Supply Sergeant	Hollywood	Texsport	
Surplus Value Center	Los Angeles	Stansport waterproof	Stansport safety
Target	Corona	Coghlans waterproof	Coleman
Target	Palm Desert	Coghlans waterproof	
Western Surplus	Los Angeles	Texsport	

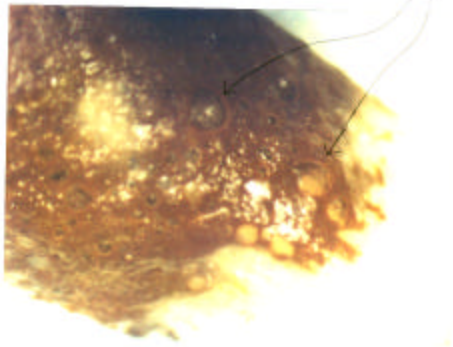
Figure 4: Exemplar Non-waterproof Matches

Methods of Analysis:

Match head color, match length, stick width, stick shape, stick color, and match head organic and inorganic components were examined using stereomicroscopy, Fourier Transform Infrared Microspectroscopy (FTIR), and Scanning Electron Microscopy - Energy Dispersive X-ray (SEM/EDX) analysis respectively.

Samples were prepared for FTIR analyses by removing thin films of binder material (Figure 5) from the match heads using a razor blade. The films were placed on a barium fluoride salt plate and analyzed using an IrPlan microscope attached to a Nicolet 5DXC infrared spectrometer. Films from each match head were analyzed more than once, and films from multiple match heads from each box were also examined.

Figure 5: Thin Film on Coleman Brand Waterproof Match Head
(Olympus SZ 40 stereomic roscope 240X)



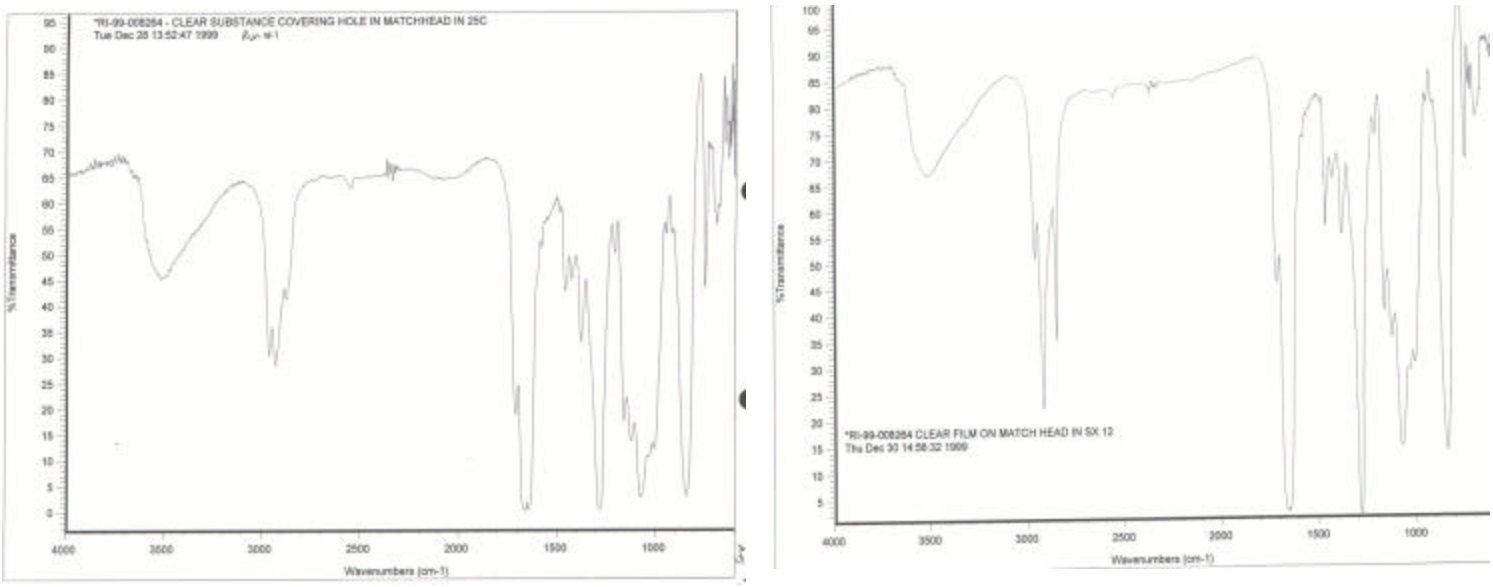
For SEM/EDX analyses a portion of the match head in each sample was cut using a razor blade and placed on carbon tape atop an aluminum sample holder. The match heads were analyzed using a Hitachi S520 SEM with a Tracor Northern 5500 EDX detector.

Examination Results:

Match head colors, match lengths, stick colors, widths and shapes for the crime scene matches and those from the suspect were similar (Tables 1A, 1B). The match head colors and lengths of the different waterproof match brands differed significantly (Table 1C).

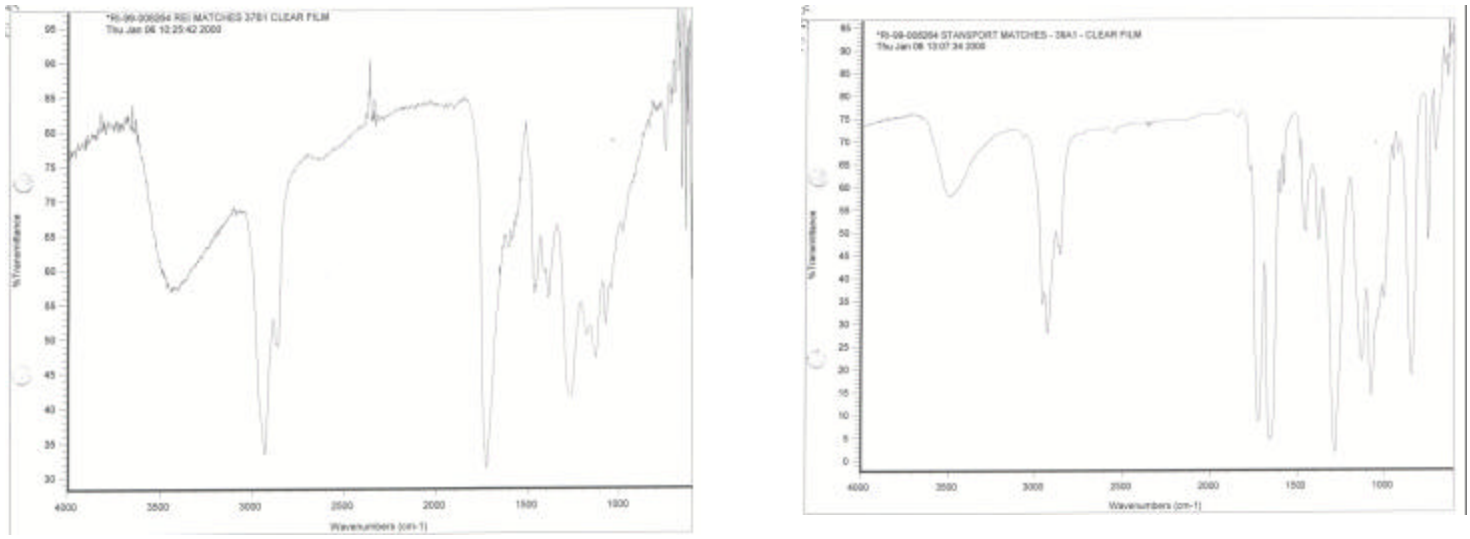
The films on the Coleman brand matches from the suspect and the thin films on the matches from the scene were similar in chemistry and they consisted of a predominantly nitrocellulose based polymer (Figure 6).

Figure 6: FTIR Spectra of Thin Film on Match heads from Suspect (#25C) and Crime Scene (#12)



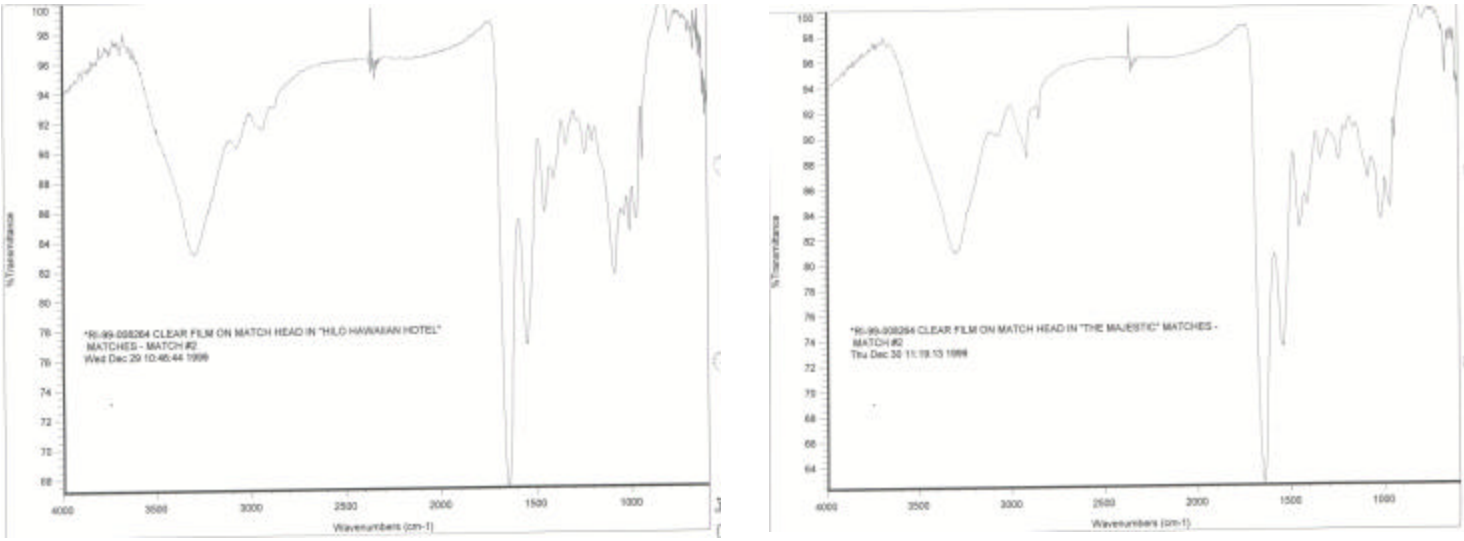
The clear films on some of the match heads in the other brands of waterproof matches differed in chemistry from the Coleman brand matches (Figure 7). Some of these match heads also had a similar binder chemistry to the Coleman brand.

Figure 7: FTIR Spectra of Clear Films from Match Heads in REI and Stansport Waterproof Matches



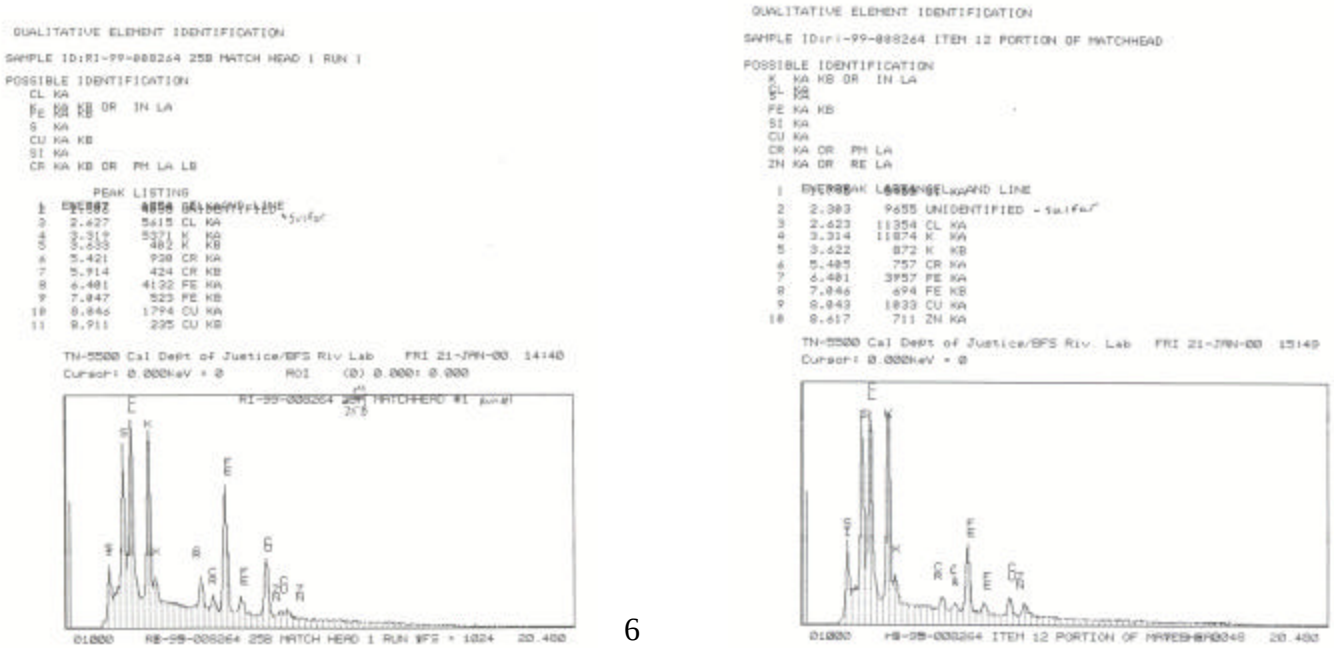
The clear films on the non-waterproof matches all differed in their FTIR spectra from the Coleman and other brands of waterproof matches (Figure 8).

Figure 8: FTIR Spectra of Clear Films in Two Non-waterproof Matches



The matches from the suspect and from the crime scenes were also similar in elemental content and they contained major elements Cl, S, K, Si, and moderate to minor elements Fe, Cr, Cu and Zn (Figure 9).

Figure 9: EDX Spectra of Matches from Suspect (25B) and from Crime Scene (12)



The following tables (Tables 1A -1D) summarize the findings from the analyses of the matches from the crime scenes, the matches from the suspect, and the exemplar matches.

Table 1

A

MATCHES FROM CRIME SCENES

Item Number	Match Head Color	Length (cm)	Stick Width (mm x mm)/ Shape	Match Head Coating – Main Polymer
1	Dark Brown	5	2 x 2 Square	Nitrocellulose
7	Dark Brown	5	2 x 2 Square	Nitrocellulose
12	Dark Brown	Match Stick Broken	----------	Nitrocellulose
15	Dark Brown	5.1	2 x 2 Square	Nitrocellulose

B

MATCHES FROM SUSPECT

Item Number	Brand Name/ Match Type	Country of Origin	Match Head Color	Length (cm)	Stick Width (mm x mm)/ Shape	Match Head Coating - Main Polymer
25B	Coleman Water Proof	China	Dark Brown	5	2 x 2 Square	Nitrocellulose
25C	Coleman Water Proof	China	Dark Brown	5	2 x 2 Square	Nitrocellulose
29A	Coleman Water Proof	China	Dark Brown	5	2 x 2 Square	Nitrocellulose

C

EXEMPLAR WATERPROOF MATCHES

Item Number	Brand Name	Country of Origin	Match Head Color	Length (cm)	Stick Width (mm x mm)/ Shape	Match Head Coating – Main Polymer
34	Texsport Safety	China	Red	3.8 to 4.0	2 x 2 Square	Nitrocellulose
35	Coghlan's Safety	Philippines	Green	4.3 to 4.4	2 x 2 Square	Nitrocellulose
36	Coghlan's Wind and Waterproof Safety	Hungary	Red	4.3 to 4.4	2 x 2 Square	Nitrocellulose (Differs in minor component from other weather-proof matches)
37	REI Storm - proof	India	Brown and Orange	7.2	2 x 2 Square	Orthopolyester (Alkyd)
38	Stansport - Waterproof	China	Brown	4.3	2 x 2 Square	Vinyl Acetate and Amide
39	Stansport Safety Waterproof	Hungary	Red	4.3 to 4.4	2 x 2 Square	Same as 36

D

OTHER EXEMPLAR MATCHES

Description	Country of Origin	Match Head Color	Match Head Coating - Main Polymer
Diamond Brand	USA	Red	Amide
Rosebud – Damp proof	USA	Red	Amide
E.S. Company ("Majestic")	Korea	Dark Gray	Amide
MD Match ("Denali")	Korea	Brown	Amide/Ester
"Hilo"	Japan	Brown	Amide
Admatch ("Residence Inn")	Korea	Brown	Amide

Conclusions:

The matches found at the crime scenes were similar visually and chemically to those from the suspect. Therefore the matches at the scenes could have come from the same source as those from the suspect.

Match head color differs considerably among different waterproof match brands and is therefore a very good discriminating tool. Polymer coatings on match heads also are variable – especially between non-waterproof and waterproof matches. Therefore, polymer coatings can provide additional information and discrimination between wooden stick matches.

Waterproof matches are highly variable and also somewhat limited in the number of available brands in Southern California (and also possibly in other areas of the country).

Part II: Additional Casework Applications:

Since 1999, more wooden stick matches have been analyzed in two additional arson cases. In one of these cases, 'strike-on-box', burned and unburned wooden stick matches representing nine different match head colors and various countries of origin/ manufacturers were analyzed for their elemental content. Portions of the match heads of each sample were placed on carbon tape atop an aluminum sample holder and analyzed using an FEI Quanta 400 variable pressure SEM with an EDAX EDX detector. The elemental compositions of the burned and unburned match heads are depicted in Table 2:

Table 2: Elemental Compositions of Burned and Unburned Wooden Stick Matches from Various Manufacturers/ Countries of Origin (Case #1)

Manufacturer And/or Country	Unburned Match head Color	Si	K	Cl	P	S	Ca	Al	Ti	Zn	Mg	Cr	Na	Fe	Cu
United Match/ Japan	Turquoise Blue	? ?	? ?	? ?		? ?	* *	? ?		? ?			*	* *	
Belgium	Blue	? ?	? ?	? ?	? ?		? ?	? ?	? ?				? ?	* *	
Japan	Purple	? ?	? ?	? ?	?	? ?	?	? ?			*		? ?		
Admatch/ Japan	Green	? ?	? ?	? ?		? ?	? ?	? ?		? ?	? ?		*		*
Canada	Red	? ?	? ?	? ?	?	? ?	*	? ?		? ?	?	* *	*		
Diamond (n=250)/ USA	Red	? ?	? ?	? ?		? ?	* *	? ?	* *		*		*	*	
Diamond (n=32)/ USA	Red	? ?	? ?	? ?	?	? ?	? ?	? ?	? ?	? ?	? ?		? ?	?	
Lastar/ Japan	Coral Red	? ?	? ?	? ?	?	? ?		? ?					? ?		
Penley/ China	Pink-Red	? ?	? ?	? ?	?	? ?	? ?	? ?		? ?	? ?	? ?	* *	? ?	
Diamond/ USA	Silver	? ?	? ?	? ?		? ?	?	? ?	? ?	* *				* *	* ?
Atlas	White	? ?	? ?	? ?		? ?	?	? ?	? ?	? ?	? ?		*	* *	
Unknown	White	? ?	? ?	? ?	?	? ?	? ?	? ?	? ?		? ?		* *	* *	
Unknown	White	? ?	? ?	? ?	?	? ?	* *	? ?	? ?	? ?	? ?		*	* *	

? Elements present in unburned match heads
? Elements present in burned match heads
* Elements possibly present in burned match heads
* Elements possibly present in unburned match heads
? Elements not present

Of the 14 elements detected in one or more of the samples, Cu and Cr were the rarest, Si, K, Cl, Al, S, and Ca were the most common, P was mostly in the burned match heads, and Ti, Zn, and Mg were in about half of the samples. Fe was present in easily detectable amounts in only a few samples, and Na may be present in more samples, but its elemental peaks may be obscured by the Zn's peaks. The elemental results are similar to those of Andrasko(3), and Glattstein, et.al.(4).

There appeared to be no particular correlation between match head color and elemental composition, and most elements present before the match heads were burned were detectable after burning.

From this limited study, it appears that the presence of Cu or Cr in wooden stick match heads could be significant for distinguishing matches from different sources. Ti, Zn, Mg and possibly Fe also appear to be relatively significant for distinguishing different matches. Cu, Cr, Ti, Zn, Mg and possibly Fe could be especially useful for

distinguishing burned match heads when original match head color is not present in burned samples.

In the second arson case, there were multiple arson scenes and a large number of burned and unburned wooden stick matches in several evidentiary items. These matches were examined and categorized based on their morphological features such as match head colors (when present), shapes and morphologies of burned and unburned match heads, lengths of matches, stick color and shape (when possible). Samples were also prepared and analyzed for their elemental content as above. The results are in Table 3.

Table 3: Table of Distinguishing Features for Different Groups of Wooden Stick Matches in Case Example #2

Group #	**Match Head Color**	**Elemental Characteristics - Significant Distinguishing Features/Relative Elemental Levels** (b=burned match head) (ub= unburned match head)
1	Red	- Ca moderate (b) - Si large (ub)
2	Red with white tips	- Ca, Zn, P moderate (b) - Si large (ub) - Zn, P, Ca, S moderate (ub)
3	Red* *(heads partially burned)	- Ca, Zn moderate
4	Red	- Do not contain Zn, Mg, Cr, or Fe
5	Burned but with yellow residue	- Ti moderate - All contain Cr - Do not contain Ca, Zn, or Fe, and little to no Mg.
6	Burned – no original color	- Does not contain Mg or Cr
7	Burned – no original color	- Contains Cr and no Fe
8	Pink-red	- Does not contain Ti

There were eight different 'groups' of matches that were defined by their morphological characteristics and the elemental contents of their unburned and/or burned match heads. Matches with similar colored heads were distinguishable when analyzed for elemental composition. Furthermore, the color and morphology of the burned residue on the match heads was also useful for distinguishing matches in Group 5 from matches in the other groups.

Part III. Newer Developments:

Farmer, et. al. recently explored the use of Isotope Ratio Mass Spectrometry (IRMS) of the wood in the sticks of wooden matches to "determine whether IRMS could be used to provide any additional information about mass-produced safety matches found at crime scenes" (5, 6).

These newer studies, combined with the traditional methods for the analysis of wooden stick matches in forensic science, allow for not only the differentiation of the matches based upon the match head compositions, but also for a more sophisticated method of possibly determining whether an individual match came from a particular box or manufacturer.

References:

1. Kirk, PL. Fire Investigation. John Wiley and Sons, NY, 1969.
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6. Farmer, NL, Meier-Augenstein, W and Kalin, RM, "Isotope Analysis of Safety Matches, *Poster Presentation*, obtained from the Internet, 2006.