HOW DO I INTERPRET THE DATA?
This is a question frequently asked by customers. Normally one should not have to interpret test data as PAL provides this important function. The data is presented primarily to let the customer know which of the values if any, triggered maintenance recommendations. Following are some of PAL's considerations.

1. WEAR METALS
One of the least understood concepts to the layman is "wear metals". They are the first ten metals we list on our report (anti, occasionally, Zinc or Magnesium and they simply represent the amount of each metal detected in the lube at sampling time, though not in its chemical form. As an example, when iron is reported from the plasma emission spectrometer (the instrument used to detect and quantify metallic elements), we do not know if it is in an oxide form (rust) or if it represents relatively recent erosion of an iron containing part in the system.

Within reason, the amount of each metal detected is irrelevant as long as the amount deposited in the lube remains at a constant, stable rate with respect to time or mileage on the lube from sample to sample. For example, it is possible that metal quantities will climb the longer a lube remains in the unit. Under extended drains the values may become further elevated, but may still be indicating a "normal" wear pattern for the particular unit. It is when the wear rate established for a given unit increases significantly that corrective action or inspection may be advisable.

Each unit make exhibits particular tendencies. Some tend to show metals increases at constant rate, while others tend to stabilize after various time mileage plateaus. There are numerous reasons why this is so, even between models of the same manufacturer. Among them are lube consumption rate (probably the most significant), sump capacity relative to surfaces lubricated, standard original equipment filtration, whether the unit is supercharged or not, and the BMEP {Brake Mean Effective Pressure; applicable to reciprocating engines) rating. Even identical units may show quite a variance from age difference (lube consumption), special after-market filtration, application, and type of lube. The moral is: Don't assume that a given unit must have a predetermined threshold value for wear metals, even for a specific interval, let its trend serve as an indicator.

2. ADDITIVE .METALS
Magnesium, Barium, Calcium, Phosphorous, Zinc
These metals tend to remain fairly stable, but can easily fluctuate 20% as a normal circumstance. Drastic changes, or elimination or emergence of an element that was or was not formerly present usually indicates the addition of make-up lube whose additives differ from the supplier's. It could also indicate that the supplier has changed formulation of the oil. Remember, it is possible for a wide variety of and quantity of additives to be used to meet the same spec. Also, .remember that the level of additives detected is not necessarily an indication of the useful life of such additives.

3. CONTAMINANT METALS
Silicon. Sodium, Boron
These metals can have predetermined limits, once the new lube has been tested for initial base line data. An increase ill Silicon alone usually means the entrance of abrasives ("dirt"). The effect, if any, is easily noted by observing the change in wear metals. An increase in all three contaminant metals, or just sodium or Boron, may indicate coolant leakage (as these are elements from chemicals typically placed in coolants). Once again we must note the starting concentration of each metal in the new lube. If glycol antifreeze is in use, we can confirm its presence with a test.

4. OTHER PHYSICAL CONTAMINATION
These products, when found in excess of their norms, usually indicate a need for corrective action as well as a lube drain. The exception is when solids build up over an extended time interval, in which case they just show a need to drain the lube and/or change filters. Here again, age of the unit, makeup lube rate, application, lube type, and BMEP play a major role.

Water Contamination
PAL recommends that samples be taken when a unit is at operating temperature, or has been Shut down for only a short while (no longer than 30 minutes). As well as providing the most representative sample, it minimizes chances of obtaining samples with condensate water (unless there is a problem with systems using water traps). Water, therefore, should not normally be found in most system al levels above O.05% (500 ppm) provided samples are taken correctly. This is normally the lowest limit to which PAL inspects samples for water.

Oftentimes PAL detects metallic coolant additives rather than water because water is continually evaporated by a unit's heat. When water is detected, these same metals aid in qualifying the source (coolant, condensate, etc, salt or fresh water in marine situations).

EXEMPLARY METALS COMBINATIONS METALS DETECTED:	POSSIBLE EVALUATION
Sodium, Boron, Phosphorous Sodium	Washing Compound
Sodium	Saltwater or Coolant
Sodium Magnesium	Saltwater
Chromium, Sodium	Chromate' Coolant
Sodium, Boron	Coolant/Glycol
Silicon, Sodium, Boron	Coolant/Glycol

5. LUBE CONDITION INDICATORS
Viscosity, Neutralization Number (TAN/TBN)

Like wear metals, these values have tolerances and it is very important to have new lubes base data on these parameters before attempting to diagnose changes and trends. PAL has wealth of data in its files but such data can become obsolete over extended time periods, as oil companies find improved ways to meet particular specs and, thus, change their formulation for a product whose trade name remains the same.

For this reason one should periodically have PAL test incoming new lube batches. Certainly not every time, but perhaps every six months. Change for the better is good - not knowing about it could be confusing!

VISCOSITY
Viscosity of a lubricant is its flow rate with repect to temperature. Two things are therefore necessary in reporting viscosity:
Temperature at which the viscosity is measured.
The amount of time units for a given amount of the lube to flow through a given passage.

The two most common temperatures for oil viscosity are 40 degrees Centigrade and l00 degrees Centigrade. The units reported are Cel1tistokes, abbreviated "cSt". Viscosity was previously reported 100 degrees and 210 degrees F in units of SUS (Saybolt Universal Seconds). The change in viscosity temperatures and units is the result of an effort to standardize to a common world system; essentially it is metrication of the Viscosity reporting system.

Viscosity index is the change in flow rate of a lubricant with respect to temperature. As a lube is heated it will get "thinner"; its viscosity will decrease. The amount of thinning which takes place over a given temperature span can be expressed as Viscosity Index (VI), a term expressed as a number without units. The less tendency a lube has to thin with temperature increase, the greater its VI. Determination of VI requires two viscosities at different temperatures (usually 40 degrees Centigrade and 100 degrees Centigrade).

SIGNIFICANCE OF VISCOSITY: There are numerous references which cite that the viscosity of a lube is its most important single property, and perhaps this is true, at least. When the lube is new. By itself however, a viscosity does, not nearly qualify a lube. It basically defines the film thickness the lube will have for a given application.

New lubes placed in engines, or other machinery should be inspected for correct initial viscosity. Assuming no errors are made with the initial fill, the following factors can influence viscosity.

DECREASED VISCOSITY:	INCREASED VISCOSITY:
Liquid fuel contamination	Solids contamination
Non-emulsified water contamination	Certain emulsions. with water
Shearing of VI-improving polymers	Lube Oxidation/Degradation
Wrong make-up lube addition	Wrong make-up lube addition

Most modern lubes, particularly engine lubes, are "oxidation stable" under standard drain intervals so that, unless extended drains are contemplated, it is better to observe the 'contamination which influences viscosity rather than the viscosity itself. On the other hand, increased viscosity, in the absence of solids or other contamination, will usually indicate lube.

Oxidation/degradation and the viscosity is the most convenient means to measure this with reasonable effectiveness. Viscosity, along with Neutralization Number, should always be required by customers wishing to safely evaluate extended drain intervals for engines.

Neutralization Number
There are a variety of neutralization numbers utilized in the petroleum industry. This discussion is confined to the two Most commonly used versions.

Total Acid Number (TAN)
Simply stated, TAN is the amount of acid and acid-acting constituents found in the lube.
The term "acid" does not necessarily connote metal corroding materials themselves. Many chemicals, including necessary lube additives can have an acid number.

SIGNIFICANCE: Increases in TAN of used rubes from the starting point of the new lube (which may not necessarily be zero) usually indicate lube oxidation or corrosive acid contamination.

"Oxidation" is a general term used to describe the degradation of the basic lube product as a result of operating temperatures and/or churning with the air. Generally, oil thickening is associated with oxidation. Organic acids are prior to and during thickening, which can be detected by TAN increase. Oxidation of lube is not only significant from the standpoint of thickening, but the lubricating quality (lubricity) of the lube itself can also be reduced.
"Corrosive Acid" is formed primarily from sulfur blow-by products in the combustion process. Any amount of water contributes toward activating this acid to the point of parts corrosion. The formation of corrosive acids in engines is unavoidable, but alkaline (basic) materials are added to motor lubes to counteract the acid upon entry into the crankcase. corrosive acid in non-engine systems is usually an environmental problem. One exception is the formation of corrosive hydrochloric acid in refrigeration systems, where Freon deterioration may occur in the presence of moisture.

Total Base Number (TBN)
TBN is the amount of alkaline material (generally as corrosive acid neutralizer) in the lube, commonly referred to as "Alkaline Reserve".

SIGNIFICANCE: TBN is of primary concern in motor lubes, .as additives are placed in the lube when it is blended to neutralize corrosive sulfur acids formed in the crankcase in the normal process of combustion. Measurement of TBN allows one to know if the starting additive package is still capable of counteracting combustion acids; therefore, TBN is an essential element to the safe extension of lube drains.

Generally, a new lube starts with the highest TBN it will exhibit. From that point, TBN will tend to decrease as acids consume its alkaline properties. The addition of fresh makeup lube, however, helps forestall the decline in TBN, oftentimes allowing extension of lube drains in properly maintained engines. This will natural1y vary from unit to unit dependent upon individual conditions.

Typical motor lubes have TBNs of 5-7; "Highly compounded" oils may have TBNs of l2-15. Marine oils for engines using high sulfur fuel may have TBNs of 35-40, while upper cylinder lubricants in those same engines may exceed 70 TBN.

NOTE: TBN alone is not a relative indicator of lube quality, only its ability to neutralize corrosive acids. A higher TBN clearly demonstrates better capability to counteract acids, but does not mean the higher TBN oil is better than, or even equal to, a lower TBN lube with respect to other important properties.

It should also be noted that most motor lubes can have both a TAN and TBN in the new and used state. If one regards these terms as two distinctly different properties, there is no difficulty in explaining their simultaneous presence. Ideally one would perform analyses for both terms in the inspection of motor lubes, but TBN is by far the most important property of the two for motor lubes. TAN is usually acceptable when TBN is sufficient

TAN is almost exclusively used for non-engine systems because there is no combustion process taking place, and because many non alkaline lubes are in use in such systems, making the analysis for TBN pointless

TAN also applies for large stationary 2-cycle gas engines using "mineral oil" type lube.

A WORD ABOUT pH: pH and TAN are oftentimes confused. The concepts are quite involved but succinctly, pH is relative acid strength while TAN is total amount with no regard for strength. Weak acids, such as lube-oxidation products, do not significantly affect pH.

ADDITIVES
A lube consists of two major parts: Base Stock and Additive. The Base Stock is the primary lubricant and can be petroleum or synthetic. The Additive is usually a laboratory or synthesized product, or combination of products, which enhances the Base Stock's performance. Together the Base Stock and Additive make up the "finished lubricant". Usually the additive comprises less than 20% of the total lubricant volume, but there are no absolutes

Limitations. A lube is qualified primarily by its performance, not its additive quantities. Furthermore, the base stock is equally important to a lubes performance. Its chemical structure, resistance-to oxidation, wax content, etc., are all critical factors, as well as its compatibility with the proposed additive package.

Additive Metals:
Our plasma emission spectrometer routinely measures five potential additive metals: Magnesium (Mg), Calcium (Ca), Barium (Ba), Phosphorous (P), and Zinc (Zn), Boron (B) and Sodium (Na) may also be additives, as well as Molybdenum (Mo), though less frequently.

We detect these metals to aid in verifying the correct product is being used, but detection of metals alone cannot verify their continued effectiveness as an additive. The reason is very simple: when a spectrometer measures Ca (for example) it is measuring Ca in any form (additive or contaminant). When the Ca containing additive is placed in the lubricant it has a particular chemical structure, and one can not monitor that structure or its effectiveness with metals detection alone. In analyzing a new lube, However, we can be fairly well assured, and we can use this information to help predict the lubes performance capabilities.

Detergents
As the name implies, these compounds help maintain engine cleanliness by preventing deposits on critical areas such as ring lands, or by removing such deposits. They also help maintain deposits such as fuel, soot in suspension to be filtered out or drained with the lube. Metallic carriers are generally used (except where "ash-less" lubes are required) to bring the non-metallic portion, which is the "detergent" part of the compound, to the lube. The metal, however, is also beneficial in itself for it is alkaline, acting as a neutralizer for corrosive acids, thus helping to give the lube its Total Base Number.

Detergent Carriers
Ca, Mg, and Ba, in order of current use frequency, are the most common metals used as carriers. Typically only one of these three metals is found in a specific brand and type of motor lube, dependent on how the supplier chooses to meet the desired specification. It is possible, however, to find new lubes using a combination of metals to achieve the same purpose. There is no rule.

These metals impart alkaline properties to the lubricant, enabling it to neutralize corrosive acid. Mg has the highest alkalinity given weigh amount while Ba has the least For this reason Mg and Ca are nearly exclusively found in high performance motor lubes with sulfated ash limitations (such as lubes for Detroit Diesel engines).

Dispersants
Dispersants have overlapping properties with detergents, in that they, too, maintain particles in suspension. Many technical people distinguish the two terms by calling metallic particle suspenders detergents and totally nonmetallic (ash less particle suspenders) dispersants. They reduce the tendency of small particles to combine into larger particles, taking some of the burden off the filters, and prevent deposit of these particles on valve covers and moving parts, particularly at low temperatures. PALs solids test aids in monitoring the effectiveness of the lubes dispersants.

Defoamants
This material acts in a very complex chemical and physical manner to minimize foaming tendencies of lubes. It has limited solubility in lubricants of a non silicon nature, and this limited solubility helps effectiveness in accelerating the formation of large bubbles from small ones which dissipate from lube much more readily. The larger bubbles rise to the surface quickly and then break.

The most common defoamant in use is a silicon polymer. It is usually added at the low ppm level, thus it is not unusual see up to 12 ppm Silicon in new lubes, although 3-7 ppm is a typica1range. Testing the new lube is important, for additional Silicon from the starting level will usually indicate abrasives (dirt).

Anti-Wear and Anti-Oxidants
Zinc dithiophosphate, containing P and Zn in roughly equal proportions, is the most common anti-wear/anti-oxidant compound found in motor lubes and many gear lubes, thus we routinely investigate for its presence. There are several types of zinc dithiophosphates, with each having its own favorable properties for particular applications.

Zinc dithiophosphate is an additive that provides multifunction capability. In the anti-oxidant role it can break the oxidation chain of a lubricant; in the anti-wear role it chemically "plates" out on such components as cams and lifters, or gears and serves as a lubricant in the event that metal too metal contact takes place.

In as much as some ZN and P plate out, a decrease in these elements might be expected, but make-up lube, as with all additives, tends to restore the level, and maintain equilibrium. It is possible to find lubes that have P without Zn, used as an anti-wear agent.

Anti-Wear Properties
These materials are similar in scope to EP agents. Some plate or coat whi1e some combine chemically with metal surfaces, particularly ferrous (iron or steel), to form a protective coating, necessary in the event that the lube film is interrupted.

Anti-Oxidants
There are anti-oxidants for fuels and lubricants, and most of them are non-metallic. Oxidation is a general term used to describe the combining process with oxygen that a lubricant tends to do. This, in turn, forms undesirable compounds that are far less suitab1e as lubricants. A number of metals, most notably Copper, tend to aid (catalyze) oxidation. Some types of antioxidants, therefore, react chemically with the offending metal to nullify its catalytic effect. Another way to inhibit oxidation is to break the chemical chain by 4sacrificing the anti-oxidant. This type of compound has a great affinity for oxygen when it appears in oxidation products, and combine with it to form harmless compounds while simultaneously
stopping the oxidation chain.

Extreme Pressure (EP) Agents
EP agents increase the load carrying ability or film strength of lubes. This in turn prevents or at least minimizes direct metal-to-metal contact. Many gear systems need lubes fortified with EP agents to function properly. Some EP agents include sulfurized sperm oils and molybdenum disulfide.

Anti-Corrosives
These materials prevent chemical corrosion from occurring. They can accomplish this by forming a chemical, protective coating on metal surfaces, or they can directly attack and neutralize materials that usualiy cause erros.

Viscosity index (VI) Improvers
VI improvers consist of polymers whose properties change significantly with temperature such that a lubricant resists "thinning out" as its temperature increases. Polyisobutylenes were among the early compounds used. The latest technology uses copolymer chemistry, which seems to be far more stable, .particularly for use in diesel engines. A VI improvers function is to enable much improved cold starting capabilities while retaining necessary film thickness at operating temperatures

Pour Point Depressants
The pour point of a lube is simply the temperature at which it no longer pours. The amount of wax in a lube influences its pour point. Pour point depressants minimize the size of wax crystals formed in the lube. By so doing they allow the lubricant to achieve its lowest possible pour point, based on Its true viscosity characteristics and not on its wax content. Polymethacrylates are the general class of organic compounds used as pour point depressants, also providing some VI improvement

Other Metals
There are a number of other metals that are used as additives Molybdenum (Mo) as molybdenum disulfide is a solid lubricant used as a friction reducer or TP agent in certain specialty lubes. Levels of nearly 1 % (l0,000 ppm) are not unusual. Boron tends to be found co-existing with Mg additives at up to 4% of the Mg value. Similarly, Sodium may be found in the presence of Ca or Ba.

Unlike most additives, molybdenum is not dissolved in the base lube, but suspended as minute particles less than one micron in size. It should be noted that when Mo is used as an additive, detection of Mo to evaluate Mo-coated rings is not possible, again due to the lack of distinction between one form of a metal and another by emission spectrometric analysis. Similarly, if Zn is an additive, Zn from brass or bronze is masked. If leaded gasoline is an engines fuel, lead can not be used to evaluate potential bearing wear. We emphasize that new lubes should be tested for baseline data to avoid misinterpretation as to the source of the metal.

Typical Levels
A typical motor lube will have Mg, Ca, and or Ba from 500-3500 ppm, dependent on the specifications. (Automatic transmission fluids may have similar levels.) Lubes with high alkaline properties may have anywhere from 5000-8000 ppm Mg+Ca+Ba. Many industrial fluids have no metallic additives

P and Zn are generally found from 600-1500 ppm. Automotive gasoline and several diesel engines usually require a minimum of 1000 ppm valve train protection, as this is the area of highest "unit" loading in such systems.

Comments
Note: ADDITIVES, with the exception of solid lubricants, are soluble in base stocks and would normally not be susceptible to filtration depletion from typical automotive filters. It is possible, however, that in the course of being consumed, an additive could form an insoluble product capable of being filtered.

The above are only a portion of the various additives developed for petroleum products, but they represent most of the important ones. It should also be noted that several of the above properties can, at times, be fulfilled adequately by a single additive compound.