On behalf of ENERFAB, I'd like to thank you for the opportunity to participate in your technical session. As fabricators we use many types of material to produce our products. The material of choice in the Citrus Industry is stainless steel.

With that in mind, I would like to talk to you today about corrosion in stainless steel.

The use of stainless steel in steel plate fabrication has evolved from a new wide spread use in the 1950's to highly technical uses in today's environment. The introduction of stainless steel as a revolutionary material that was a solution to all problems, has evolved into a current sixty-two alloy family class for specific applications and uses.

This evolution has also required significant changes in methods of fabrication, metallurgy, engineering, welding, design, and last but not least, fabrication. The most important step of any steel plate fabrication is the selection of the correct material. The selection criteria for materials would include heat, pressure, economic evaluation, environmental considerations, just to name a few. This election of particular types of stainless steel, for a given corrosive environment, often follows study of comparative data and sometimes even pilot or service testing. There are seven major benefits of using stainless steel vs. other material:

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1) Stainless steel is capable of withstanding a severe environment that is highly corrosive and subjected to high temperatures.

2) Stainless steel maintains purity of materials, which the Citrus Industry requires to maintain absolute freedom from contamination. As an example, the trueness of color might be jeopardized by even the slightest impurities.

3) Is for cleanliness. The hard, dense surface of stainless does not trap residue and bacteria.

4) Use of stainless lowers maintenance cost; again the hard, dense surface developed naturally on stainless steel products tends to minimize sticking and adhering of airborne dirt of materials brought in contact with it. Stainless steel does not require surface treatment, painting, or other protection.

5) Stainless steel provides strength at low weight in atmospheric, as well as elevated temperatures. In Citrus process equipment, stainless maintains its strength and resistance in both continuous heat and short term exposure to elevated temperatures.

6) Stainless steel maintains its toughness, even at low temperatures. Most materials become brittle as temperature decreases.

7) Stainless steel provides for salability of products. Beyond the economic and engineering reasons, stainless steel is used for its high appearance, quality, prestige, dependability, and durability.

The history of stainless steel and its use in the fabrication of process vessels began approximately 40 years ago. (Figure #1) At that time, steel mills looked like this. (Figure #2) ENERFAB looked like this. (Figure #3) Storage tanks looked like this.

Quite a bit has changed since the 1950’s. The manufacturing of stainless steel has evolved today into a 62 alloy class family. (Figure #4)

Today, our plant looks like this (Figure #5), and as you can see, the use of stainless steel in large tank farms also has changed.

What we'd like to do today is to discuss:
- What is stainless steel?
- The different grades and attributes of the product.
- What is the criteria for the selection of stainless steel?
- And, the possible problems if the selection design and fabrication procedures are not performed properly.

Let’s start with the manufacturing of stainless steel. Consider the elements contained in various grades of stainless steel — the principle element is iron, followed by chromium and nickel. Various grades also contain other elements such as magnesium, silicone, molybdenum, aluminum, titanium, columbian, vanadium, boron, copper and cobalt. However, the bulk of this mixture, as you can see, is none other than carbon steel — or iron.

Stainless steel making begins with the melting of 50 to 80% of recycled stainless scrap and specific amounts of raw material. (Figure #6) This “melt” as it's called, is heated to approximately 3000°F Fahrenheit. The material is then transferred to an A.O.D. Furnace (Argon Oxygen Decarbonization) where a combination of inert gasses and oxygen are introduced in the bottom of the furnace to remove impurities, and refine the actual chemistry of the batch or melt. Carbon is also removed during these steps and various elements are added, in the form of ferro alloys, to produce various grades of stainless steel.

Once these adjustments are made — and if within specific tolerances poured through a cooled
copper mold. (Figure #7) This process is called “Continuous Slab Casting.” Molten metals enter at one end, and the solid slab exits at the other. (Figure #8)

The term “Continuous” means the “heat” or “melt” becomes one continuous slab. The hot slab runs at a speed of about one yard per minute onto a long, run-out cut table. The table is equipped with torch cutters that cut the “heat” into convenient sized slabs for further processing. (Figure #9)

In the re-heating cycle, a scale or oxide is formed on the slab. The loose scale is removed by streams of water, which rapidly cool the slab — cracking the slag and scale which is blown off, leaving a smooth surface.

The first reductions come in a reversing mill. As many as 15 passes are taken on a slab before passing into a six stand mill for final reduction. The slab is now reduced to somewhere between 1/8 and 5/16 inch thick. (Figure #10) The slab is put into coil form by hot rolling.

The material is softened by heat treatment (annealing) — (Figure #11) the surface is cleaned (de-scaled), and the material is then ready to be reduced in thickness in cold forming. (Figure #12)

Cold rolling is done mainly on a one stand rolling mill. The coil runs across the mill with a typical 10% reduction.

Basically, there are two types of low strength grade stainless steel — ferritic stainless and austenitic stainless steel. These two alloys have different molecular structures, austenitic (being non-magnetic) and ferritic (which is magnetic). The stainlessness of these steels is due to the formation of a tight, adherent oxide skin on the surface, which tends to isolate the steel from chemical environments. The stainlessness is thus, not an intrinsic value of the material, but rather a product of the reaction to certain environments, primarily oxygen. The thickness of the protective oxide film is measured in Angstroms. (An A = 1/10 billionth of a meter.)

The stainless steel currently used in the citrus industry: 304, 304L, 316, 316L, are austenitic grades of stainless steel, or the 300 Series. This group is most commonly used for vessel fabrication in the citrus industry today. The 300 Series are considered by metallurgists and steel plate fabricators as the most formable, the most weldable, the most cost effective, and the most readily available of all the stainless steel alloys.

The “L” Grade simply delineates higher concentrations of chrome and lower concentrations of carbon ultimately making it more corrosion resistant than its other family members. (Figure #13)

What are finishes? There are many finishes available that can be applied to stainless steel. As you can see in this slide, there is a hot rolled finish, a cold reduced finish, and a polished finish. The determination of finishes can be measured in degrees of roughness or irregularities. (Figure #14) The RMS calculation is an average value used extensively in the United States, and is known as the “Root Mean Square”. It represents a very short section of a surface greatly magnified, which represents the distance in micro inches (one millionth of an inch) above and below a mean reference line; the corresponding division points on an irregular contour of the surface. The square root of the average of the sum of the squares of these distances equals the RMS “Root Mean Square”. The different lines divide irregularities, so the total area of peaks above the line equals the total area of the valleys below the line. (Figure #15)

In laymen’s terms, the smaller the RMS number, the smoother the finish. Incidentally, this is measured at our facility by means of an instrument called a Profilometer (which actually measures the profile).
Today, many process vessels and storage tanks are made of stainless steel.

There are many environments that stainless steel is subjected to in the Citrus Industry. All in themselves, completely different — requiring special handling, forming, and welding techniques. But in each case, proper material selection must take place in the specification stage, or problems could develop.

What are the magnitude of these problems? The annual cost of corrosion and protection against corrosion in the United States is estimated, believe it or not, at eight billion dollars. This tremendous cost is less surprising when we consider that corrosion occurs in varying degrees of severity, wherever metals or other materials are used. The answer to solving corrosion problems is not a simple task. The keynote speaker at the National Association of Corrosion Engineers Convention indicated that the single most serious problem effecting corrosion Engineers to date is identifying the source, or mechanism, that causes stress corrosion cracking, or SCC.

In today’s presentation, we’ll try to further define how to recognize corrosion in stainless steel, and some practical guidelines on protection of our assets.

**Corrosion Types**

There are many types of corrosion that are studied today by metallurgists. These would include:

1. **Galvanic Corrosion or Electrolytic Corrosion** — They are dissimilar metals that establish an anode and cathode relationship resulting in an electron flow which leads to pitting corrosion.
2. **Uniform Attatch Corrosion** — This would be similar to sulfuric acid storage in a carbon steel tank when corrosion is in an even reaction over time.
3. **Crevice Corrosion** — Results in a machine surface where rubber gasket traps corrosive median in the crevices.
4. **Pitting** — A result of localized attack (there are many items of this type).
5. **Intergranular Corrosion** — Where chromium is depleted from the heat effective zone which prevents the formation of an oxide film and this not allow the material to be passive.
6. **Selective Leaching** — The removal of certain elements to the median that is storage in the tank.
7. **Erosion Corrosion** — Where the abrasiveness of the material stored reacts with the vessel. This takes place in a slow gentle time period.
8. **Finally, but not least important, Stress Corrosion** — A combination of stress, chemical reaction and an active base material.

The three types of corrosion most commonly found in processing vessels are galvanic corrosion, intergranular corrosion, and stress corrosion (cracking). The affects of corrosion are easily explained by loss of assets, danger to employees, and loss of product. The first type of corrosion we’d like to speak about today is galvanic corrosion.

Galvanic corrosion is a form of pitting, or concentrated corrosion, resulting from electrolytic action between dissimilar metals. (Figure #18) This slide shows a carbon steel lined vessel equipped with a stainless steel top, coil and bronze fittings experiencing (Figure #19) galvanic attack in the carbon steel lined surface. Due to where these dissimilar metals fall upon the noble scale (Figure #20) an anode/cathode relationship develops, which sets up an electron flow which caused the pitting. This type of corrosion can also develop in “active” stainless steel (i.e., stainless steel that has been scratched or before passivating). (Figure #21) As you can see from this slide, pitting or concen-
terased corrosion is also a definite area for trapping bacteria, as well as jeopardizing the integrity of the vessel.

Intergranular corrosion or material sensitization is a corrosion that occurs due to fabrication negligence and abuse. Intergranular corrosion is often initiated when forming stainless steel material or welding. When improper welding techniques are utilized and the weld area is subjected to high heat the Heat affected zone becomes susceptible to corrosion. The high heat causes the chromium in the weld area to precipitate or leave the (HAZ) and the stainlessness is reduced.

There are several other welding fabrication techniques that must be recognized to avoid intergranular corrosion.

1) Slag Coated Electrodes
2) Heat Tint
3) Arc Strikes
4) Weld Starts and Stops
5) Weld Spatter

Slag Coated Electrodes - Small slag particles often become entrapped in the weld where a slight undercut or other irregularity exists.

Heat Tint - Actually, there is considerable controversy regarding the removal of Heat Tint. The cost of removal in some cases can be substantial. Advocates agree that in aggressive environments, where stainless steel grade approach their useful limits to resist corrosion, heat tints should be removed. There are several techniques to perform this operation dependent on the size of the work piece.

Arc Strike - Arc Strikes from welding operations damage stainless steels' protective film and create crevice like imperfections near the heat affected zone. This is compounded because they are usually located in the Heat affected zone where the protective film has been somewhat weakened by the heat of welding.

Weld Starts and Stops - These defects can be avoided by using run out tabs (extensions at the beginning and end of welds) and by beginning just ahead of the stop point and welding over each intermediate stop point.

Weld Spatter - Weld spatter creates a tiny weld where the molten piece of metal touches and adheres to the surface. The protective film is penetrated and tiny crevices are created where the film is weakened the most. These problems can be eliminated by applying an Anti-Spatter compound on either side of the joint to be welded. This compound is easily removed after completion of welding.

Fabrication Techniques - The forming and handling of stainless steel can also be a culprit in the initiation of intergranular corrosion. Improper grinding techniques can heat the surface and damage the protective film. The use of carbon steel wire brushes or lower grade stainless brushes (i.e., 300 Series brush on a 316L vessel) will leave deposits and become the initiation sites for corrosion.

And last but not least the rule of good housekeeping. Special care must be taken in shop fabricated vessels or field erected vessels to avoid iron entrapment in the surface during fabrication and dirt on the surface which will scratch the oxide film.

Enerfab's standard practice when handling stainless steel calls for a protective film on the interior surface of stainless to prevent possible scratching or damaging of the material. In an effort to prevent these types of corrosion, proper design, fabrication and welding techniques must be employed. This could include specific operations such as joint preparation, fit-up, peening and, of course, proper welding procedures and weld rod selection.
Perhaps the most prevalent type of corrosion we have seen as fabricators is stress corrosion. During a recent visit to a stainless steel mill, we had the opportunity to discuss the current state or evolution of material research. The Director of Research stated that he argues or debates the actual mechanism that causes stress corrosion with his staff, almost on a weekly basis.

**Stress Corrosion Cracking** – There are several theories explaining the mechanism of stress corrosion cracking. Currently, the most prevalent theory is the electrochemical theory. Galvanic cells are set up between regions in the grain boundaries of the material, and anodic paths are set up. When the alloy is stressed in tension and exposed to the corrosive environment, a localized electro-chemical dissolution of the metal, along with plastic deformation, opens the crack.

I'd like to draw a hypothetical example of discovering stress corrosion, and the failure of your equipment. Jim, your Maintenance Chief, walks into your office in the morning and informs you that the #1 Hot Water Tank has sprung a leak. The tank was immediately drained and a repair was attempted. He goes on to describe that he tried to weld the crack, (Figure #22) but it became larger. But he assured you that due to his careful superhuman effort, that the maintenance crew managed to stop the leak. You breathe a sigh of relief and go back to your morning coffee. The next day, or one week later, or even a month later, Jim comes back to your office – only this time, the tank cannot be repaired.

At this time, you decide to seek additional assistance. A local materials testing laboratory is called. A material sample taken, and cross sectional analysis prepared. (Figure #23) As you can see in this slide, the reason your Maintenance Foreman could not weld up this serious crack is that underneath the surface, intergranular cracks were spread throughout the material, and he never had a chance. At this time, you have thoroughly discovered that you have two problems: one, you have a tank that can't be repaired and therefore can't supply the plant with hot water, and two, you have to explain to your boss why you have a non-budgeted item for replacement. (Figure #24) In an effort to prevent a disaster like this from happening in the future, or perhaps to avoid it altogether, tanks under these operating conditions should be constructed from a proper alloy. One of the shortcomings of austenitic grades of stainless steel is their susceptibility to stress corrosion and cracking. Many papers have been presented outlining the benefits of cold working surface treatment as a preventative control measure for both of these modes of corrosion. By imposing a compressive stress on the surface that is exposed to the environment you eliminate one of the primary forces known to initiate corrosion. The effectiveness of shop peening was initially tested on conventional U Bend test specimens in 1000 hour tests in the boiling 42% magnesium chloride stress corrosion test. Another material that recently has become commercially available is 2205 duplex alloy. This nitrogen containing duplex alloy has done quite a job in all industries in the recent past in the United States. The alloy has been very popular in Europe for some 25 years. The main advantages are its yield strengths which is twice that of 316 stainless and its improved fatigue life and its outstanding corrosion resistance. This material features high resistance to chloride media attack, chloride stress corrosion cracking and intergranular corrosion as well as resistance to erosion and abrasion. Alloy 2205 is a 50/50 mix of austenite and ferrite. It is this characteristic mix of austenite and ferrite that gives the alloy its outstanding corrosion resistance. Caution must be taken during welding to prevent the alloy from becoming totally ferritic. If it converts to a ferrite, a loss in corrosion resistance is likely. If you cool the weld too rapidly, you don't give the ferrite enough time to partially transform to austenite. Duplex stainlesses are deliberately alloyed with nitrogen to improve a number of properties including corrosion resistance.

At this time, I would like to say that I am not a metallurgist, but I have been exposed to many premature failures in vessels. This learning process has taught me to scratch my head, and ask a lot of questions. Just when we thought we knew everything, suddenly a new problem came up. I had a call from one of our salesmen, who went to Florida to investigate what he thought was an agitator problem. He started to explain to me that there are these bugs down here, that are eating stainless steel. At this time, I questioned if he had finally lost his marbles. But as it turned out, it was a major problem.
The installation involved eight new 304 Stainless Steel Tanks, fabricated with an internal 2B Finish, with the weld seams ground smooth and flush. After erection the vessels were hydrotested for leaks. Following this procedure, the tanks were passivated to remove any residual iron oxide film on the surface of the stainless. (Figure \#26) Within three months, it was discovered that there was concentrated pitting, at random, throughout the floors and sidewalls of this installation. The cause of the corrosion turned out to be the result of microbiologically induced corrosion, or MIC as we call it.

These spots you see are actually colonies of bacteria from the well water which were deposited on the interior surface of the tanks. This bacteria caused localized oxygen starvation of the oxide film prior to sterilization. These areas were then susceptible to the initiation of localized pitting.

But as we found from research, this was not a new problem. People have been studying aspects of bio-corrosion since at least 1934, when a landmark paper was published by a Dutch research team. It has also been reported more recently in Hot Condensate Receiver Tanks, which operate at 212°F Fahrenheit or more, chlorinated H2O filtration systems and other well water sources. Ironically the magnitude of this microbially influenced corrosion is barely recognized outside the research community but, according to Ray Kemmer, Deputy Director of the National Board of Standards (NBS) a good portion of all corrosion is biologically induced.

Microbiological organisms or microbes may be classified in 4 general groups: 1) Bacteria 2) Fungi 3) Algae and 4) Yeast. Certain species from all groups are known to cause corrosion of metals.

In 1976 Greg Cobrin of E I Dupont reported that literature contains several notable examples of catastrophic corrosion attributed to microbes. In the 1950's and 1960's microbial deposits in Aluminum Alloy fuel tanks on jet aircraft plugged fuel lines and pitted and perforated the tanks and structural members. Investigation showed bacteria, fungi and yeasts which had contaminated the water phase of kerosene type fuels to be responsible.

With this in mind it became apparent, one again, that microbial corrosion is a serious and expensive concern to industry. The role of microbes in corrosion processes is not always clear. The mechanisms are not completely understood, and even today, much controversy and conflicting data exist. Frequently, the possibility of microbial influence in metallic corrosion is either completely overlooked or goes unrecognized. However, at least this much is known about microbes. They can:

1) Produce acids-inorganic, such as sulfuric, as well as organic, such as formic and acetic.
2) Destroy protective coatings.
3) Create corrosion cells-differential aeration (oxygen) and ion concentration cells are notable examples.
4) Produce hydrogen sulfide.
5) Concentrate anions and cations.
6) Oxidize metal ions.
7) Depolarize cathodic sites by consumption of hydrogen.
8) Foul equipment-cooling towers, water lines, heat exchangers, etc.

Corrosive microbes are classified in 6 general groups:

1) **Acid Producers.** Some microbes can oxidize sulfur compounds to sulfuric acid; a pH as low as 2 has been recorded where sulfur oxidizing microbes are active. Others can produce organic acids from organic compounds.

2) **Mold Growers.** The are primarily fungi.
3) **Slime Formers.** Certain algae, yeasts, bacteria, and fungi in this class. The deposits they form create concentration cells and foul equipment.

4) **Sulfate Reducers.** Perhaps the most publicized class of corrosive microbes, they reduce sulfates to sulfides and depolarize cathodic sites on metal surfaces by consuming hydrogen.

5) **Hydrocarbon Feeders.** Virtually all microbes feed on hydrocarbons, but those of specific concern to corrosion engineers disbond or destroy organic coatings or linings.

6) **Metal Ion Concentrators/Oxidizers.** Iron and manganese bacteria are important examples of this class. They generally form this, bulky deposits which create concentration cells or harbor other corrosive microbes.

Aerobic microbes thrive in air and actually need air to survive. Anaerobic microbes, however, can exist and multiply in the absence of air. There is considerable overlap within these classes of microbes. For example, certain mold growers also produce acids and form slimes. Microbes are present in virtually all natural soils and fresh and salt waters. Some may also be air borne from one location to another.

Dr. Richard Lutey has continued research of micro organisms involving the corrosion process. He stated that the most cited micro organisms involved in corrosion can be categorized into one of the following groups: Sulfate Reducing Bacteria (Desulfitobrio) or Iron Oxidizing Bacteria (Gallenella). In general, many different kinds of bacteria, and to some extent fungi, have been implicated as being capable of inducing or accelerating corrosion. Without underestimating the importance of slime forming microflora, our primary concern should be with the iron oxidizing bacteria and the sulfate reducing bacteria. However, most microbiologists readily agree that in addition to these groups many unrecognized micro organisms probably are involved in the corrosion process. And reported that the mechanisms are not completely understood and much controversy and conflicting data exists. Today the phenomenon of microbiological corrosion is generally accepted ad one of a number of mechanisms whereby corrosion of metallic materials can occur.

New techniques have been developed for testing and rapid diagnostic field kits are available for a rough cut gauge of corrosion. The hope is that field engineers can one day identify problems in their initial stages before the metals have been degraded beyond repair.

(Figure #27)

We'd like to reiterate some of the remedies known to combat these problems. As you can see in this slide, stress corrosion cracking can be prevented. Stress corrosion cracking occurs in temperature ranges of over 140° Fahrenheit with chloride concentration measured in parts per million, and residual tensile stress induced by the fabrication process.

Possible solutions to stress corrosion cracking would be either to eliminate the tensile stress put on the material by means of shot peening, which would then put the product surface in a state of compression; or another possible solution is to utilize the material that is immune, or seems to be immune, from the attack of chlorides. This material is known as 2205. Other materials exist, but material engineering has shown that 2205 is an economical, viable alternative that could be chosen.

In galvanic corrosion, a potential or voltage difference usually exists between the two dissimilar metals. This difference causes current to flow, and the less noble or more anodic material suffers an increased corrosion rate.

Intergranular corrosion can be eliminated by development of weld procedures to reduce or eliminate excessive high heat during the welding process, such as multiple passes or selection of low carbon material and weld rod. This, coupled with good general fabrication rules in the design stage, can minimize the potential of intergranular or material sensitization.
Microbiologically induced corrosion can be prevented by thorough testing of the water, and procedures for elimination of iron oxidizing and sulfate reducing bacteria prior to its exposure with stainless steel.

So as we can see, corrosion and the mechanisms that cause corrosion in the use of stainless steel are very nebulous subjects, which should be thoroughly analyzed in each individual application.

I hope I haven’t unduly alarmed you regarding the use of stainless steel – this was not my intention at all. Stainless steel is a wonderful product that we all use and depend on, but, like many things in life it has its limitations. When these limitations are recognized and proper material engineering is practiced, it can live up to all its expectations.
FIGURE #3 - STORAGE TANKS - 1950

FIGURE #4 - ENERFAB, INC. - 1992
FIGURE #5 - STORAGE TANKS - 1992

FIGURE #6 - STAINLESS STEEL MELT
FIGURE #7 - CONTINUOUS SLAB CASTING

FIGURE #8 - SLABS
FIGURE #9 - REMOVING SCALE

FIGURE #10 - HOT ROLLING COIL
FIGURE #11 - ANNEALING STAINLESS STEEL

FIGURE #12 - COLD ROLLING STAINLESS STEEL
**Figure #13 - Material Type**

<table>
<thead>
<tr>
<th>Material Type</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot rolled annealed &amp; pickled (HRAP)</td>
<td>125-128</td>
</tr>
<tr>
<td>Cold reduced (CRAP)</td>
<td>45-50</td>
</tr>
<tr>
<td>No. 7 polish finish (Polished)</td>
<td>5-9</td>
</tr>
</tbody>
</table>

**Figure #14 - RMS Graph**

\[
RMS = \sqrt{\frac{A^2 + B^2 + C^2 + D^2}{N}}
\]
FIGURE #15 - MICRO PHOTO OF COLD ROLLED & HOT ROLLED STAINLESS STEEL

FIGURE #16 - STAINLESS STEEL DISHEDED HEAD
FIGURE #17 - STAINLESS STEEL DISHED HEAD

FIGURE #18 - STAINLESS STEEL LINED VESSEL
FIGURE #19 - GALVANIC ATTACK ON CARBON STEEL

FIGURE #20 - NOBLE METAL SCALE
FIGURE #20 - GALVANIC CORROSION

FIGURE #21 - STRESS CORROSION
(3) Conditions present:

Chlorides present in water material-tensile stress hot temperatures (above 170° F)

Solution:

316L stainless/shot peen

or

2205 duplex stainless
FIGURE #25 - STAINLESS STEEL TANK FARM

FIGURE #26 - STAINLESS STEEL TANK FARM
<table>
<thead>
<tr>
<th>Corrosion types</th>
<th>Possible solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCC</td>
<td>Material selection</td>
</tr>
<tr>
<td></td>
<td>Chloride</td>
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<tr>
<td></td>
<td>Temperature</td>
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<tr>
<td></td>
<td>Tensile/compressive Stress</td>
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<tr>
<td>Galvanic</td>
<td>Knowledge of anodic/</td>
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<tr>
<td></td>
<td>cathodic relationships</td>
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<tr>
<td>Intergranular corrosion</td>
<td>Utilities proper</td>
</tr>
<tr>
<td></td>
<td>fabrication techniques and weld procedures</td>
</tr>
<tr>
<td>MIC</td>
<td>Perform H₂O acceptance techniques</td>
</tr>
</tbody>
</table>

FIGURE #27 - CORROSION TYPES & SOLUTIONS