Northeast

Nuclear Energy

Memo

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Nuclear, Water Chemistry

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Subject: Performance History of Arcor Epoxy in Power Plant Cooling Water Systems

This memo constitutes a detailed report summarizing an history of power plant installations of the Arcor S-16 and S-30 epoxy systems. The applications cited represent Arcor systems much the same as have been used within the MP Unit 3 Service Water System. The information is presented in essentially chronological sequence and a tabulation is includedpresented that summarizes each of the projects discussed. To as great an extent as is possible, the performance assessments furnished are based on my first hand observations. The documentation furnished in the attachments is sufficient to confirm my presence during various installations and subsequent inspections. In some cases I've supplemented my observations with more recent input from others. In twoone cases (Chalk Point Units 1&2 and Millstone Unit 1) though, I was present only for the initial application and have not had the opportunity to subsequently inspect the work. The information related with respect to Chalk Point and Millstone Unit 1 is based solely on the testimony of plant personnel or other inspectors. The case histories presented deal primarily with nuclear and fossil plant main steam condenser waterbox (W/B) and tubesheet (T/S) lining applications in the northeastern U.S. The plants discussed represent various combinations of metals and cooling water types.

Summary

The preponderance of the Arcor S-16 and S-30 installed square footage of which I have firsthand knowledge regarding it's performance has proven to be a suitable lining for raw water service.

This report documents a few instances where systems comprised of multiple coats of S-16 have permeated. Those instances appear to have occurred as a result of :

1. Contamination of the coated surfaces with a soluble ionic contaminant (salt) which led to premature degradation of the Arcor. This was manifested by what is perceived to have been osmotic transport of water vapor through the epoxy and resulting impairment of it's bond.

2. CircumstancesInstances where the water contained by an S-16 lined metal substrate is somewhat (30(F() warmer than the surrounding environment.

The former (salt contamination) is an aspect of application QC, while the latter (permeation in general and "cold wall" permeation in particular) is as inherent property of the epoxy. It is reasonable to conjecture that the S-16 system will perform satisfactorily when applied in accordance with good QC practices, as long as the water within a system is typically at or cooler than room temperature (or the temperature of the backfill in which the lined pipe is buried). The corollary is that S-16 is more prone to permeation blistering when the water being conducted within the epoxy

lined surface is warmer than the environs for more than a day or two. The presence of Arcor's TS-RB paste grade rebuilding compound appears to nullify the permeation propensity of S-16. This is probably a reflection of the fact that the thicker film thickness inherent to the use of the paste grade material exponentially diminishes water permeation. TS-RB utilizes the same epoxy resin as the S-16, but is generally applied several times thicker.

The S-16 history implies that it should be expected to perform adequately on pipe spools and components located within a building, especially if the water is generally cool, as would be the case in, say, the Northeast. Such a scenario describes the MP3 SWS, which is largely within buildings (Aux., ESF & Intake) or buried. The fact that S-16 hasn't done particularly well at Millstone seems attributable to questionable installation practices and insufficient QC.

It would appear that S-16 is more likely to degrade on surfaces downstream from service water HXs where the water temperature would be elevated. It is likely that inspection of downstream Arcor S-16 would show ample manifestations of permeation, since permeated S-16 is prevalent in the colder upstream (safety -related) portions.

No instances of intercoat delamination or detachment from the substrate where S-16 systems were applied to waterboxes (W/Bs) or piping have been discovered.

S-30 Systems

The investigation associated with this report shows that the three referenced Arcor S-30 applications are all performing satisfactorily. The oldest of these is the PEPCO Morgantown Unit 2 project where a three coat, minimum 40 mil system consisting of Arcor S-30 White (the "primer" of choice prior to the development around late "1992 of the zinc phosphate inhibited "Prime"/ "Prime One1" products) /S-30 Fuchsia/S-30 Blue was spray applied using plural component equipment in April, 1992. Of the three S-30 systems reviewed, the Morgantown application was the more comparable to the MP3 SWS lining. Crystal River Unit 3 (CR#3), discussed below, included a thick intermediate layer of Arcor's TS-RB, rendering the net thickness more than four times that specified for the MP3 SWS. Also, the substrate for the CR#3 project was stainless steel, which is less prone to manifest corrosion than carbon steel or cast iron. (On the other hand, the warm gulf seawater is known to be far and away the most aggressive raw cooling water in the U..S.). While Tthe MP1 W/B application, discussed below, contained areas of TS-RB, though a large proportion does represent the same S-30 Prime/S-30 system used in the MP3 SWS. Also, the fact that the water is identical makes the MP1 W/B history quite extremely valuable as a basis for extrapolating expectations for Unit 3 SWS performance. The fact that the Unit 1 substrate is cast iron, while the MP3 SWS is 90-10 Cu Ni means that performance projections based on the MP1 W/Bs would be conservative. It is noteworthy that intercoat delamination of S-30 was only a minor problem for the referenced projects. A few square feet of S-30 topcoat did disbond in one or two of the Morgantown W/Bs. It seems likely that these disbondments, which were generally in the lower portions of those W/Bs, were a result of the warm epoxy (it was heated to facilitate the plural spray application that was used) shrinking from a cool surface or resulted from elated to loss of environmental conditions or recoat window in the region where the disbondment occurred. Combinations of these detrimental factors may have occurred It should be noted that the proportion of the Morgantown work where intercoat delamination of S-30 occurred is only a fraction of that which has occurred to date within the MP3 SWS.

Arcor's Ken Fowler has advised that an Arcor T/S cladding utilizing their TS-RB is difficult to apply compared with newer "Vicor" alternative formulations. This fact notwithstanding, the cladding applied at CR#3 has performed well in a harsh environment despite some flaws discovered during the RFO following its installation. Once the flaws were repaired, subsequent performance, despite a record run at 102% of rated power, has been totally satisfactory.

In those few incidents cited in this report where the Arcor S-30 was exposed due to topcoat delamination, the S-30 Prime (Prime One at CR3) remained intact and no corrosion occurred.

Case Histories

Background

Arcor was founded in Rockland, MA around 1983 by Sam Maggio, who had previously worked for Martek in nearby South Weymouth. (Martek was the original licensee for Plastocor in the U.S.). Mr. Maggio had dabbled in formulating Martek's epoxies though he was not a chemist. Arcor manufactured their epoxies in-house. Two key products in the Arcor line were "S-16" and "S-30," both solventless epoxies. S-16 was originally recommended for water service, while the more expensive S-30, designed for abrasion resistance, was targeted more for chemical environments. S-30 presumably builds better than S-16 but has a shorter pot life and less flexibility.

[***Refer to enclosed Table for summary of the case histories that follow***]

Seabrook Station

The Seabrook condenser consists of six, two pass bundles utilizing a total of twelve aluminum bronze (A/B) tubesheets (T/Ss). The Inlet/Outlet pairs of waterboxes are on the east side of the condenser and the Return W/Bs are on the west side. The Seabrook condenser tubes are pitched west to east (i.e., from the return end to the in/out end) to promote drainage. Arcor's first major project and their first nuclear project was the twelve Seabrook aluminum bronze tubesheets. Seabrook's condenser was tubed with titanium. This tube material maximized the potential for galvanic attack of the tubesheet, which was one of the design considerations driving the decision to coat the T/Ss. A "thin" system consisting of three coats of S-16 was applied by Cannon in January of 1986. The original intention was to use Plastocor cladding. The plant's water chemistry engineer encouraged application of epoxy cladding on the premise that its cost would be justified by the insurance epoxy cladding provides against joint leaks. Push-out tests were performed to quantify the joint integrity obtained with various products. Arcor S-16 was included as the only "thin" system represented in the test and did quite well (1150#) compared with far thicker(1/4") claddings (2500#(300#). The responsible Yankee Atomic (YNSD) engineer, Paul Brown, ultimately determined Arcor S-16 would be used (Attachment SB-1).

I served as YNSD's consulting engineer for the T/S coating project. As such, I was responsible for writing the specifications, reviewing Cannon's installation procedures, and for oversight of the work.

The Unit's circulating water system had seen service prior to the coating project. However, no effort was made to clean the tubes and clusters of salt crystals were apparent within the tubes

Seabrook was the first nuclear tubesheet project for the contractor, Cannon, and for Arcor and Cannon had no prior experience with Arcor (Attachment SB-2, p.2-1)., Plastic blast plugs comparable to those developed for the Plastocor process were specified to protect the tubes during abrasive blasting but coating plugs were not required or used with the thinner Arcor system. Cannon, for the first time in their experience, was required to design and procure plastic blast plugs (Attachment SB-2, p.2), and considerable R&D was done at the eleventh hour to come up with workable plugs. The first plugs often did not fit and therefore a mix of plastic plugs supplemented by rubber stoppers was ultimately used. The rubber stoppers used as blast plugs for the original installation were only used on the east T/Ss, i.e., on the low ends of the tubes.

As the abrasive blast progressed, a dulling of the blast was noted around the rubber stoppers. It was determined that the rubber "breathed" salt air from within the tubes, causing the fresh A/B to "turn." The resulting corrective action solution reached was to reblast and then immediately apply the Arcor S-16 before the metal could turn.

Chalk Point

Based on the apparent success of the Seabrook installation, a similar Arcor system, S-16 White/S-16 /S-30 Blue was specified for Potomac Electric's Chalk Point Station Units 1 and 2 Inlet W/Bs (Attachment CP-1, Table 4.6-2). The condensers are two train, twin bundle units. Cooling water enters at the center via common inlet W/Bs and flows in opposite directions through the two bundles and exits via cast iron outlet W/Bs. The work scope included all the W/Bs and T/Ss for both Units as well as the inlet flow splitters. These Units are once-through (brackish) tidewater drawn from the

Patuxent River. The system specified to restore the graphitized cast iron outlet W/Bs was S-16/TS-RB or S-16/S-30 (Attachment CP-1, Table 4.6-3). TS-RB is a paste grade rebuilding compound utilizing the S-16 resin system but highly filled with inert fillers to impart a putty like consistency. Typically, the TS-RB is used sparingly, with the objective of recontouring the substrate to fair-out pitting and depressions. The specification allowed an intermediate coat of S-16 for portions of the Outlet W/Bs that were relatively smooth. While the specification indicated that Arcor S-20 would be substituted for the S-30 when coating the T/S's (Attachment CP-1, Table 4.6-1), it cannot be determined from the records whether this product was actually used. S-20 is closer in properties to S-30 than S-16 but has superior caustic resistance. I cannot recollect why I would have specified S-20 for the T/S's; it was probably a recommendation of Arcor's S. Maggio. While the specification indicated that Arcor S-20 would be substituted for the S-30 when coating the T/Ss (Attachment CP-1, Table 4.6-1), it has been determined from the records that S-30 was actually used (see Attachment CP-2).

The Chalk Point Units 1 and 2 condenser T/S and W/B project was performed by Cannon on successive years (Unit 1, November, 1987/Unit 2, November, 1986). Attachment CP-2 confirms who did the Unit 2 work, when, and offers some insight as to the Arcor epoxy that was used.. Attachment CP-3 confirms that Unit 1 was the second project of the two, the work being done in "87.

On August 25, 1997 I had a telephone conversation with Harry Dworshak, the PEPCO-Chalk Point Supervisor of Planning Construction and Maintenance (301/843-4310). Mr. Dworshak was at Chalk Point when the Arcor applications were performed. His job description includes participation in outage work planning. His foreman enter the W/Bs regularly to "pick" the T/Ss (i.e., remove flotsam embedded in the inlet tube ends) and to perform tube cleaning. His duties, therefor, require that he be advised of any coating problems requiring maintenance and repair. He indicatedadvised that, to the best of his knowledge, the three coat Arcor S-16 system has performed satisfactorily.

Susquehanna Steam Electric Station(SSES)-Units 1&2

[*An Arcor epoxy system consisting of S-16, overcoated with either S-16 or, quite possibly, S-30, was applied to the SSES Unit 1 Inlet Tubesheets in 1987 or 1988. However, this application is not discussed in this report due lack of documentary evidence.*]

In August of 1989 and again in March of 1991, I served as Pennsylvania Power & Light's resident engineer for an Arcor application at Unit 2 of Susquehanna SSES (Attachment SS-1). Each of the three condenser bundles is served by four W/Bs. The 78" diam. cross-around (XØ) pipes connects the outlet W/Bs of one stage to the inlets of the next. The SSES 1 & 2 turbines and the condensers are three stage units (HP/IP/LP). All surfaces that requireding lining, including the T/Ss, awere carbon steel

Arcor was, by this time, recommending an S-16/S-30 topcoat combination (Attachment SS-2). However, it was decided that two coats of S-16 for a minimum of 24 mils would be applied to the cross-around pipe at SSES (Attachment SS-2, p.2 and SS-4) because there were not sufficient case histories with the S-16/S-30 combination. The scope of the SSES Unit 2 coating work performed in 1989 consisted of all twelve Iinlet tubesheets *(three coats of S-16 White/Fuchsia/Blue, to a nominal DFT of 30 mils - see Attachment SS-3, p.21, ¶ 17.0 and p. 27, ¶ 21.2. The color sequence used are validated in my handwritten log notes for the balance of the work done in "91(- see Attachment SS-6-) tThe coating type and sequence of colors was identical in "89 and "91),* sixteen waterboxes (same system and DFT as T/S's) and the four west side cross-around pipes. (two coats to a minimum of 24 mils-see Attachment SS-4).)... Though the W/Bs were deeply pitted (Attachment SS-5), little TS-RB was used to spackle the W/Bs. The pipe coating was spray applied by a crude method (refered to by Cannon as the "bazooka") aimed simply at getting the epoxy onto the surface. It was subsequently rolled. As a result, the epoxy in the pipe presented a washboard, thick circumferential bands (30 mils) followed by thinner (15-20 mil) bands (Attachment SS-4).

The respective work scopes for "89 (West Side) and the completion of the Unit 2 W/Bs and X/Ø pipe (East side-"91) are evident from the log notes for 03/18/"91 (Attachment SS-6). All in all, upwards of 17,000 square feet were lined with Arcor S-16.

In March of 1991, I returned to SSES to oversee the coating project that completed the Unit 2 lining work. Once again, Cannon was the contractor and Arcor S-16 epoxy the lining system. The work scope was somewhat less than the 1989 project, consisting of the four East Side XØs and the HP

Outlet W/Bs. My personal job log shows that some difficulty was encountered in preparing and priming HP W/B "C" due to water leaking from the tubes.

During the course of the 1991 project, I inspected much of the 1989 work which, at the time, had been in service for 18 months (refer to Attachment SS-6, 03/18/"91). No defects were found; an area of less than 1 sq. ft. appeared to be blistered, but upon probing, no sub-film corrosion "footprints" were seen.

During the Unit 2 second phase coating project in March of "91 I had occasion to see an MG Set HX cover on the Turbine Deck which, based on the color and according to plant personnel, had been Arcor S-16 lined during the prior RFO (contact PP&L's Coatings Engineer, Ray Tombaugh: 610/774-7758). The half of the cover corresponding to the second pass of this two pass HX was completely involved with blisters. The same permeation/ blistering had occurred on other HXs at SSES on pass partitions and covers. The design outlet water temperature is 105°F. This cover was insulated, which suggests (T was not the primary driving force behind the blistering. It would appear S-16 is particularly susceptible to permeation under the influence of warm, impinging water.

I next inspected these surfaces in July of "94 at which time the Arcor applied in "89 would have been in service for over 4 1/2 years. I judged the X/Ø pipes to be in very good condition. The W/Bs too were in good condition; a few small spots of corrosion were seen in one HP-Outlet. With the exception of the LP-Inlet T/Ss, the tubesheets were performing up to expectations for a thin film system. The LP Inlets were degraded, apparently as a result of debris (cooling tower fill) impingement. These T/Ss, one- third of the Arcor coated Inlets T/S's, are in need of replacement. Findings pursuant to the "94 inspection are contained in Attachment SS-7.

Again I inspected the SSES W/Bs and XØ pipe in late September, 1995 and once again the Arcor S-16 lining was seen to be performing very well in the piping. The back walls of one or twothe Outlet waterboxes showed a scattering of pinpoint rust spots. The water exiting the condenser tubes impinges on these surfaces. S-16 seems more likely to permeate, all else being equal, where it is impinged upon. Overall the condition of the Arcor on the waterboxes was satisfactory. These observations are documented in Attachment SS-8,stating near bottom of 2nd page.

November, 1996 was the last time I inspected these surfaces. While I was unable to find documentation of that examination, I recollect that the condition observed was much the same as that referenced in Attachment SS-8. The Arcor applied to the west side of the condenser would have been in service almost seven years at that point.

On Monday, August 25, 1997, in a telephone conversation with R.S. Tombaugh of PP&L, he stated that the performance of the Arcor at SSES, including the Inlet T/Ss for Unit 1, which received the Arcor three coat S-16 system (not discussed in this memo) has been satisfactory. Mr. Tombaugh (610/774-7758) is the Materials and Chemistry engineer who has had responsibility for SSES coatings since before the Arcor application described above.

Problems With the Seabrook Tubesheets

Around the first of January, 1990, I was advised by Seabrook/Yankee that the Arcor epoxy on the "B" inlet/outlet pair of Seabrook's T/Ss was failing and was asked to inspect the T/S's in question. I found the Inlet and Outlet "B" sheets to be severely deteriorated after only a couple years in service! Usually coatings on T/Ss "unravel" at the "terminator" where the epoxy meets the tube ID. That was not the case at Seabrook. Rather, a blister formed in the centroid of the T/S ligaments bounded by a triangle of tubes. This was a clear indication that the S-16 was being permeated by water vapor. The degradation on the "B/O" outlet T/S's was worse than that seen on the inlet "B/I, most likely due to the water being hotter. The deterioration of the three coat S-16 correlated to those T/S's on the low, east side of the condenser where the rubber stoppers had been installed.

Both T/Ss were recoated with Arcor under Cannon's warranty.

Again, in August of "91, and this time at the behest of Arcor, I once again was called in to inspect the "C/I" and "C/O" T/Ss as a result of reports of similar deterioration to that reported the previous year. In both instances I concluded that the premature failures were not caused by some general inferiority in the S-16. The "dulling" noticed during the original installation of the tubesheet blast

had been most noticeable around the rubber stoppers that were used as blast plug on the east side. I concluded that chloride contamination stemming from salt deposits within the tube ends was the primary contributing factor with respect to the Arcor deterioration. The "90 and "91 inspections and conclusions are found in Attachment SB-3.

As a result of ongoing problems, the C/I-C/O Arcor, which was by that time beyond the five year warranty that Cannon had been required to provide, was replaced with thick Plastocor cladding in the Fall of "92. The Seabrook plant started commercial operation in 1990. It is likely that the circulating water system was placed in operation sometime in "88. The two Arcor sheets replaced in the Fall of " 92 would probably have been in service for an aggregate operating interval of about four-plus years.

Subsequent Arcor replacements of the Arcor at Seabrook took place in June of "94 (3 East side T/Ss) and December of "95 (one Inlet and one Outlet). At that point, all six East side T/S's originally Arcor coated had been replaced. Most recently, another two Arcor T/S's were replaced with Arcor in the Spring of "97. These would presumably have been in service for about nine years. Only three of the original twelve Arcor coated tubesheets remain in service at present.

Morgantown Unit 2

A total of eight large carbon steel waterboxes were lined with a three coats of Arcor S-30 in April of 1992. The application was performed by Cannon/Sline (C/S: the former O.B. Cannon & Son, by this time merged with Sline). This was the first project where Cannon had used the Arcor system without S-16 as a part of the system. The condensers are once through, drawing from the Potomac River, across the river from Fredricksburg, Virginia. The Potomac is tidewater at this location.

Cannon and Arcor, collectively, had become apprehensive about the performance of S-16. The waterboxes received a three coat system consisting of S-30 White /S-30 Fuchsia/ S-30 Blue. The minimum thickness required was 40 mils. Application was by plural component spray, a process not used previously on power plant circulating water systems. TS-RB rebuilding paste was applied as a continuous layer in lieu of the S-30 Fuchsia intermediate coat on the floors, approximately 32 ft. up the sidewalls, and around manhole penetrations for extra wear resistance.

The coating system applied, the Contractor, the method of application and the DFT requirements are documented in Attachment MT-1 (see, in particular, Sections 8.0, 8.1, 13.0 and 17.0). The timeframe for the project and the fact of my participation is validated by virtue of my job progress log notes (handwritten), Attachment MT-2. The fact that Arcor initiated a change away from S-16 to what was at the time an unprecedented use of an all S-30 system is established in Attachment MT-3. Attachment MT-4, "Report on Epoxy Relining of Waterboxes, Morgantown Station -Unit 2" presents a definitive summary of this project and includes information on the unique plural spray equipment the was used.

In March of "94 I was at Morgantown to oversee the installation of Plastocor cladding on the Unit 2 T/Ss and this provided me with an opportunity to examine the Arcor S-30 system that had been applied two years previous. In part, my duties called for me to identify any repairs needed in the Arcor so that they could be performed in conjunction with the T/S work. I found the W/B lining to be in very good condition; there were a few dings resulting from mechanical damage such as dropped tools, Patent Scaffold impacts, etc. These findings appear in my handwritten log notes for 3/19/"94, Attachment MT-5. I did see two or three areas of 1 or 2 square feet each where the blue S-30 topcoat had cleanly disbonded as though there was absolutely no intercoat adhesion. This was the first time I had seen Arcor epoxy act in this manner. These disbondments were and was a precursor to thosee disbondment I was later to observe on a much larger scale at Millstone in 1997. The extent of the disbonding at Morgantown was very small. Upon concluding the Morgantown "94 project I wrote a Summary report that mentioned the Arcor S-30 disbondment seen in the Morgantown Unit 2 W/Bs (Attachment MT-6). That notation ascribed the disbondment to the possibility of missed recoat window. In retrospect, though, that seems too simplistic. The detachments were low in the W/Bs and might well relate to localized loss of environmental conditions.

The utility arranged for me to inspect all eight W/Bs again in April of "95 at which time the Arcor S-30 lining had seen three years of service. Attachment MT-7, a (handwritten) memo summarizing the findings of my inspection, and documents my assertion here that the Arcor S-30 system, as assessed

in "95, was performing very well. Typical of the hemi-head manhole covers found on the Morgantown W/Bs, it is virtually impossible to maintain any epoxy coating on the Tube-Turn type penetration ends that mate with the covers. These "O" ring compression zones present a chronic coating maintenance problem at Unit 2 and many other plants with epoxy lined W/Bs and this type of manhole covers.

On August 26,1997 I phoned Mr. Jerry Lamote of Potomac Electric Company (301/843-4522) asking for an update on the performance of the Arcor system. He was not comfortable making a statement until he had the opportunity to speak with those of the foremen reporting to him that have occasion to regularly enter the waterboxes for purposes of performing T/S "picking", to maintain the impressed current cathodic protection system, etc.. Mr. Lamote phoned back the following day and reported that it was the consensus of persons in the know with respect to the Arcor lining that it was performing very well. There have been no need for repairs except for the manhole penetration compression ends. The Arcor S-30 at this station has been in service for a five full years without need for anything more than routine touch-up.

[Arcor-Related Events: 1992/1993]

Numerous Arcor power generation customers reported problems with Arcor S-16 systems in the early "90's (Attachment AR-1). Several concerned users, including NU and Pennsylvania Power & Light (PP&L) banded together to fund testing at Lehigh University that was aimed at trying to ascertain the relative susceptibility of an array of Arcor and competitive epoxies to permeation under "cold wall" conditions. Arcor hired Mark Wanthal to perform R&D to shore up the technical capabilities of their product line. Mr. Wanthal was the first professional formulator to work on the Arcor formulations.

Independent of Lehigh and simultaneous with that testing (the Lehigh testing took place over most of the year 19932), Arcor instituted their own cold-wall testing program. Interestingly, Arcor's testing included mixes that were purposely "off-ratio", i.e., variations in the stoichiometry were included as a test variable. Arcor concluded as follows after nine months of testing (i.e., in November of "92,) "... S-16 can resist a cold wall temperature differential of up to 85°F without any compromise..." (Attachment AR-2, p.6). Arcor's testing also investigated S-30 systems in the cathodic disbondment phase of the testing. I had heard that Mr. Wanthal was considering a modified version of S-30 that would serve as a "primer' and it was rumored that the modified product might contain an inhibitor pigment. I was concerned that adding an inhibitor might compromise the cathodic disbondment characteristics of the system. Attachment AR-2 acknowledges that the modification, referred to at that time as "Alpha Technology", reflected an "anti-corrosive loading" i.e., an inhibitive pigment (see pp. 5 & 7 of Attachment AR-2). Also of interest in Attachment AR-2 is the fact that Arcor considered the <u>standard</u> colors for an S-16 system to be White/Fuchsia/<u>Blue</u>! (This contrary to the expectation at Millstone that Blue Arcor is indicative of S-30).

The parameters used in the Lehigh testing included thinner and thicker thicknesses (20 and 40 mils) and both water-to- air and water-to-water (T's of 35° F and 70°F. Approximately a year after the Arcor testing, the Lehigh test report ranked the Arcor S-30 and S-16 systems the best and worst respectively!

It is noteworthy that the Lehigh test:

1. Yielded results that differed markedly from those of Arcor's in-house testing with respect to the cold-wall resistance of S-16.

2. Contravene historical observations (particularly those based on Susquehanna's experience) that S-16 systems can provide years of satisfactory service in raw water immersion.

In January of "93, Sam Maggio was forced out of Arcor. Ken Fowler took over as principal of the company.(Ben Collins, who had been a silent partner with Mr. Maggio, supported Mr. Fowler's takeover and remains involved as a part-owner.) Shortly thereafter, Arcor terminated manufacture of their epoxies, electing to have them "toll blended" by Fox Industries in Baltimore. Mr. Wanthal left Arcor's employ in "94 and moved to the west coast. According to Ken Fowler, Mr. Wanthal can be contacted via Arcor..

Crystal River Unit 3

In the Spring of "93, I was present at Crystal River (CR) for the application of a thick Arcor cladding system to the Unit 3 (Nuclear) "Train B" Inlet and Outlet pair of W/Bs and the associated two T/Ss. The CR#3 components are stainless steel., tThe "B" train was being titanium retubed in conjunction with the coating project. The condenser is a once- through unit drawing water from the Gulf of Mexico. The specifications, which I had prepared, called for W/Bs to be clad as follows:

S-30 Prime One (10-15 mils)
TS-RB (110 mils) for W/Bs
S-30 (10-15 mils)

Attachment CR-1 contains excerpts from the governing Specification and the two Cannon/Sline procedures for cladding the T/Ss and the W/Bs- see W/B ¶'s 17.3.2, and 17.8 re W/B DFT. The purpose of the Attachment CR-2 Timesheet is simply to document that I was onsite during the application.

The net minimum thickness for the Arcor W/B system was 125 mils. The same system was applied to the T/Ss but the required T/S thickness was 220 mils). This was to be the first known use on a large project of the new "Alpha Technology" inhibitively pigmented Arcor S-30 primer, designated at that time as " S-30 Prime One"

When in came time to retube (and coat) the CR3 "C" and "D" trains, both to be done in May of "94, Florida Power Corp. decided for commercial reasons to use Plastocor on those four T/Ss and W/Bs. Once again I was present. My duties included an inspection of the "B" train Arcor. A buckshot scattering of fifty or more voids in the cladding were noted on the Inlet T/S Arcor (see my handwritten log notes; Attachment CR-3: 5/12/94. The TS-RB did not flow as well as necessary to complete encapsulate all of the plastic coating plugs used with the epoxy T/S cladding process. Presumably, air pockets formed within the TS-RB that were not apparent when the work was performed. The force of the Inlet end water impinging on the cladding during the one year since it had been applied was apparently sufficient to push-through the topcoat and expose the pockets. My examination showed that, in all cases, the S-30 Prime One alone, without benefit of the TS-RB overlay, had resisted the effects of the warm Gulf circulating water and was not breached at any of those points. Cannon performed repairs under my direction. No problems were seen on the Arcor cladding on the "B" train Inlet W/B (Attachment CR-3: 5/12/94). The T/S repairs were performed by Cannon/ Sline under their Warranty and were completed by 5/18/94 (Attachment CR-2).

On August 25, 1997, I phoned Jeff Peet (352/795-0504 X 6047 or 352/795-3571), the FPC engineer who coordinated the CR3 retube/epoxy cladding projects. He was able to get into the "B" train earlier this month and reports that the repaired T/S and the W/B Arcor are in fine condition. There was no sign of further honeycombing to that which had been seen on the Inlet T/S after its first year in operation. (Unit 3 had averaged 102% of rated power over the last few years, establishing a new worlds record!). Mr. Peet has not seen any evidence of intercoat delamination. He did notice that in some tube ends where water had accumulated in the invert, a brownish stain was emanating from the tube.[NO ¶] The train had sat idle for perhaps as many as four months without the customary pressure washing. Mr. Peet is of the opinion the stain is some sort of biological reaction due to the protracted lay up. Humidity in the sealed Train B would have been near 100%. He examined the ring of cladding at it's terminus in the tube mouths; he saw no evidence that the cladding or the joint beneath the cladding was the source of the streaking.

Millstone Unit 1 W/Bs

The eight cast iron waterboxes were detached from the condenser during the Winter "94 main steam surface condenser retubing. The extensively graphitized W/Bs were taken to the Quonset Hut near the switchyard for application of an Arcor epoxy lining. Specification SP-ME-905 defined the requirements (Attachment MP1-1). Cannon/Sline was selected as the applicator. One of the two Arcor systems specified was:

S-30 Prime One
TS-RB
S-30

This was the identical system to the Crystal River Unit 3 systems. Cannon had had problems with the S-30 Prime One at Crystal River not "wetting" the surface as well as the White S-16 Cannon had generally used as a primer prior to the Crystal River project. In anyt case, Cannon's bid reflected "S-30 Prime" because Arcor had superseded S-30 Prime One with S-30 Prime at the time of Cannon's bid. Attachment MP1-2 confirms that S-30 Prime was the first coat material. It is unclear why the product name was changed.

> **NOTE:** *Confusion surrounds the issue of just which Arcor S-30 first coat was used in that Arcor system that tested most favorably at Lehigh. Crystal River #3 used S-30 Prime One in March/April of '93 and Millstone Unit 1 used S-30 Prime in January/February of '94. Panels for the Lehigh test were coated by Cannon, probably in the Winter of '93. Carol Baxter, Cannon's QA Manager, was unable to find their test panel preparation records.get the Lehigh's Project Manager, John Dupont (610/758-3952) to indicated whether the University has no records that would indicate which product was used. Cannon cannot produce records of the panel preparation process. It would seem by the timing of the Lehigh project that either S-30 Prime One or S-30 Prime was used, though hearsay from knowledgeable sources suggests that S-30 White, the non-"Alpha Technology " original product may have been used. Interestingly, S-30 was the fall back product that Cannon and Arcor proposed be used instead of S-30 Prime when the plural application spray problems discussed below were encountered. Both organizations may have been comfortable reverting to S-30 White in view of the fact that Cannon successfully plural sprayed it at Morgantown.*

The role of the TS-RB was to rebuild/recontour areas that were pocked and scalloped once the graphite had been removed. It was considered not feasible for S-30 alone to build to a proper film thickness on excessively uneven substrate. The nominal DFT required by the specification was 40 mils. A thicker thickness was required on floors and 24" up the walls. Unlike the Crystal River Unit 3 - Train B Arcor application, the Millstonr unit 1 TS-RB did not get applied as a uniform "plaster" coat overall; but above the 24" lower wall band it was used sparingly on an as needed basis.

I was the resident coating consultant for the project reporting to Tom Doyle (MP XTN. 5605). At the onset to the MP1 project, Cannon attempted to use plural spray equipment, but were never successful. The S-30 Prime mottled or produced ribbon bands of improperly mixed base/ hardener component. The viscosity of the S-30 Prime, according to the Arcor Tech. Service representative assigned to the project, Tom Gardner, seemed to be somewhat thicker than it should have been. Though there was considerably discussion at the time of using a different Arcor product for the first coat, it was ultimately decided to stay with the S-30 Prime. The primer was applied to the surface with a crude spray device known by Cannon as a "bazooka" and was subsequently spread over the surface manually using brush and roller. Attachment MP1-3, Mmy handwritten log notes for the project, document the difficulties encountered with plural spraying of the S-30 Prime.

After a year and a half in service, the MP Unit 1 Waterboxes were inspected by Tom McDonald, Cannon's QC Representative for the project. Mr. McDonald had been present during the original application. HisThat November "95 inspection concluded that the Arcor W/B lining was in good condition and essentially free of substrate corrosion despite considerable mechanical damage (i.e., abuse as a result of maintenance evolutions that had occurred within the W/Bs). These findings are documented in Attachment MP1-4, which represents Mr. McDonald's inspection report. According to the report, the thickness of the lining on the W/B walls was approximately 50% more than the minimum 40 mils specified. Cannon subsequently performed repairs on the dozens of "dings" and nicks in each W/B that were marked by Mr. McDonald during his inspection. A two coat touch-up consisting of S-30 Prime/S-30 Blue was used.

Three outlet W/Bs were inspected in May "97 by Tech. Support's John Calderone. His report, Attachment MP1-5, indicated a single epoxy spall some 1" x 6", doubtless a result of mechanical impact of some sort. Otherwise, there was no indications of Arcor damage or deterioration.

[*It is regrettable that my inspection of the Unit 1 W/Bs could not be accommodated. Of the six case histories presented in this report, all of which represent projects in which I participated originally, only Chalk Point and Millstone do not include observations based on at least one subsequent follow-up inspection by me. Considering that I've been at Millstone full-time for over a year, and the Unit*

has been down all that time, it's ironic that inspection by a consultant recognized as the U. S. authority on the subject of power plant raw water linings couldn't be arranged.]

Conclusion

This investigation of Arcor's performance concludes as follows:

1. There is reliable evidence that S-16 systems, if properly applied, perform satisfactorily on piping and waterboxes for many years when the water is near or cooler than room temperature or under conditions when the substrate is not substantially cooler than the water. S-16 systems are prone to permeation blistering:

   A. On impingement surfaces at the hot ends of HXs, e.g., on covers.

   B. On substrates that are significantly cooler than the water. This "cold wall affect" is most pronounced on surfaces such as the warm side of HX pass partitions where the inlet water is cool relative to the outlet temperature. For the same (T, a water-to- water thermal gradient is more prone to cause S-16 to permeate than the same water-to-air temperature gradient! This finding was addressed in the Lehigh research.

   C. When used as a lining on outdoor pipe conducting warm water.

The S-16 system seems essentially immune to disbondment. There are no known cases where S-16 has disbonded from itself or from the substrate or where S-30 has disbonded from S-16.

Thin (2 or 3 coat) S-16 T/S coatings do not perform well on tubesheets.

1. There is reliable evidence that S-30 systems founded on both S-16 and S-30 (or S-30 Prime (or S-30 Prime One, which is considered essentially the same as S-30 Prime), if properly applied, will provide many years of satisfactory service. Operating performance and laboratory testing indicate that S-30 systems arend, in particular, those founded on S-30 Prime or S-30 Prime One, is extremely resistant to "cold wall" permeation.

An incident of intercoat delamination of S-30 did occur in one of the case histories cited in this report. In that case, the surface area affected was 0.1 - 0.2%.

Cladding type T/S applications consisting of S-30 Prime, TS-RB and S-30 topcoat, are difficult to apply and prone to air pocket formation that is revealed after a short time in service. Repairs are generally needed after initial operation run. Once the Arcor T/S cladding is repaired, it can be expected to provide satisfactory service for many years.

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