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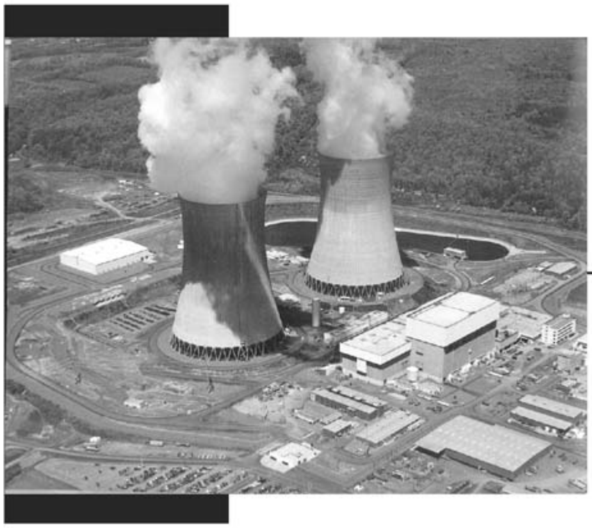
Plant Support Engineering: Aging and Degradation Survey for Nuclear Service Level I Coatings

Technical Report



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Plant Support Engineering: Aging and Degradation Survey for Nuclear Service Level I Coatings

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Final Report, December 2006

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PRODUCT DESCRIPTION

The nuclear industry has experienced some instances of degradation of the protective coating systems applied inside reactor containment (nuclear Service Level 1 coatings). These instances of degradation have become a concern to the industry, but the industry does not have a thoroughly documented history of the degradation or its causes. In response, EPRI has formed a project that is conducting research to gain an understanding of the coating degradation and evaluate the effects of aging on the qualified coatings used inside containment. This report is one product of that research.

Results and Findings

A survey of the U.S. nuclear industry was performed to gather data regarding qualified coating degradation and failure inside reactor containment. Conclusions that can be drawn from the data include the following:

- Analysis of the survey data shows that, in many cases, the generic systems with the highest percentage of area with signs of degradation involved modified phenolic epoxy (MPE) coatings. The reason is not immediately apparent, but a possible explanation is that MPE coatings may be more sensitive to application variables, including faulty application. (Application issues appear to play a major role in degradation, as noted next.) MPE is a widely used coating type, and much of the total area covered with MPE-based materials was in fact reported to be in good condition.
- Respondents were asked to name reasons for cases of degradation. Taken together, coating application issues (inadequate surface preparation, wrong thickness of the applied coating, or insufficiency of curing) were the most commonly reported causes.
- The most frequently reported visual evidence of coating degradation was delamination, followed by blistering, cracking, and flaking. These findings are consistent with the data regarding presumed causes of degradation, because symptoms such as delamination and blistering are often associated with coating application problems.
- Although the role of aging is an open question that is still the subject of ongoing research, the survey did collect statistical data on coating system installation dates (age of the systems). Analysis of these data does not appear to support the hypothesis that aging is a major degradation mechanism.

Challenges and Objectives

In a letter dated January 16, 2006, the U.S. Nuclear Regulatory Commission staff expressed concerns regarding the adequacy of the current industry method for assessment of qualified coatings within containment. In this letter, the staff presented potential resolution paths for the treatment of qualified coatings in relation to Generic Safety Issue 191, Assessment of Debris Accumulation on PWR Sump Pump Performance, the most severe being "Assume all coatings inside of containment (qualified and unqualified) fail under LOCA conditions and become available for transport to the sump." The objectives of this EPRI project were to obtain data concerning the magnitude and nature of degradation seen for qualified coatings within containment and to provide documentation to support a less-conservative assumption on the part of the regulator.

Applications, Value, and Use

This report will be of value to nuclear power plant engineering personnel with responsibility for the inspection and maintenance of the coatings inside the containment building of nuclear power plants. The report will also be of value to nuclear power plant engineering personnel with responsibility for the resolution of Generic Safety Issue 191.

EPRI Perspective

Only 6% of the more than 11 million square feet of nuclear Service Level I coatings inside containment (represented by the survey) have shown signs of degradation. Survey responses and analyses indicate that application-related issues are frequently the presumed reason for the degradation. The survey results do not point to aging as a cause. Currently, a study is underway to benchmark the performance of similar coatings in other (nonnuclear) industries. In addition, tests are being designed and will be performed to study the effects of aging on the coatings used in the typical PWR containment environment.

Approach

EPRI Plant Support Engineering (PSE) was approached by utility representatives of the Nuclear Utilities Coatings Council (NUCC) for assistance in documenting the magnitude and nature of degradation seen for qualified coatings within containment. A task group composed of utility coating engineers, consultants, contractors, and EPRI staff collaborated in developing the Evaluation of Coating Failures and the Potential Influence of Aging Project (also known as the Coating Aging Project).

The project was designed with the following phases:

- Task 1: Coatings Degradation Utility Survey
- Task 2: Coatings Degradation Research
- Task 3: Containment Coatings Adhesion Testing
- Task 4: Coatings Aging Research

This report documents Task 1, the Coatings Degradation Utility Survey.

Keywords

Coatings
Design basis accident (DBA)
Emergency core cooling system (ECCS)
Pressurized water reactor (PWR)

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INTRODUCTION AND BACKGROUND

The nuclear industry has experienced some instances of degradation of the protective coating systems applied inside reactor containment (nuclear Service Level I coatings). The degradation has become a matter of concern to the industry, but the industry does not have a thoroughly documented history of the degradation or its causes. In response, EPRI has formed the Evaluation of Coating Failures and the Potential Influence of Aging Project to gain an understanding of the degradation. This project, also known as the Coating Aging Project, includes the following activities:

- **Task 1, Coating Degradation Utility Survey**: Surveying the nuclear power utility industry to gather data regarding coating degradation and failure inside reactor containment.
- **Task 2, Coatings Degradation Research:** Compiling and analyzing similar data from all industries having usage history with the same coating materials and comparing this information with the nuclear utility experiences.
- **Task 3, Containment Coatings Adhesion Testing:** Collecting adhesion test data on actual aged documented, DBA-qualified containment coating systems and comparing the data to the original DBA-qualification requirement that containment coatings exhibit 200 psi (1.38 N/mm2) minimum adhesion.
- **Task 4, Coatings Aging Research:** Researching the radio oxidation of epoxy polymers under humid conditions.

The survey, known as Nuclear Utilities Coatings Council (NUCC) Survey 2005-07, *Nuclear Service Level I Coatings,* asked the following questions:

Questions 1, 2, 3:

> Describe a Service Level I (SL-I) qualified coating system inside your containment that you have NOT observed any signs of degradation with. Include (a) generic type of coating system and substrate, (b) product name(s), (c) date of installation, (d) estimated surface area with this coating system, and (e) general location where this coating system is used (for example, liner plate).
>
> *Note that questions 1, 2, and 3 refer to Service Level I qualified coatings that you have NOT had any signs of degradation with. Please use question 1 for the most significant SL-I coating system at the plant (greatest surface area). Please use question 2 for the second most significant SL-I coating system (second greatest surface area) and use question 3 for the third most significant SL-I coating system (third greatest surface area).*

Questions 4, 7, 10:

> Describe an SL-I qualified coating system inside your containment that you HAVE observed degradation with. Include (a) generic type of coating system and substrate, (b) product name(s), (c) date of installation / date of observed degradation, (d) estimated surface area (total and degraded) with this coating system, (e) location of degradation (for example, the containment dome), (f) description of degradation, and (g) whether the degradation was a failure, and if the area had been previously surveyed whether there were visual precursors prior to the failure (if so, describe).
>
> *Note that questions 4 through 12 refer to Service Level I qualified coatings that have had signs of degradation. Please use questions 4, 5, and 6 for the most significant SL-I coating system at your plant (greatest surface area) showing degradation. Please use questions 7, 8, and 9 for the second most significant SL-I coating system (second greatest surface area) showing degradation and use questions 10, 11, and 12 for the third most significant SL-I coating system (third greatest surface area) showing degradation.*

Questions 5, 8, 11:

> Describe what you think the cause of the degradation (in questions 4, 7, and 10) was (identify all that apply):
>
> - Excessive heat
> - High radiation
> - Poor application – poor surface preparation; insufficient curing; wrong dry film thickness (DFT)
> - Defective coating material
> - Improper coating selection
> - Chemical exposure
> - Don’t know
> - Other (describe)

Questions 6, 9, 12:

> Do you have documentation (apparent or root cause, failure analysis, corrective action program disposition) related to the degradation (in questions 4, 7, and 10) that you can send to EPRI (yes or no)?

Question 13:

> Enter text for any responses that require comments.

An important feature of NUCC Survey 2005-07, *Nuclear Service Level I Coatings*, was the level of effort taken to maximize the response rate and quality of the information obtained from the survey. This effort included systematic follow-up. NUCC-designated representatives were contacted for their responses until a representative sample from more than 85% of the U.S. nuclear fleet was obtained. Also, a contractor with significant experience in nuclear Service Level I coatings was hired to help solicit and analyze the responses.

This report presents the results of the survey. The main results of the data analysis are presented in Section 4 of the report, following this introduction, definition of terms (Section 2), and an overview of nuclear Service Level I coatings (Section 3). References are provided in Section 5, and Appendix A presents detailed information on specific brand-name coating products that was supplied by the three main manufacturers of coatings used by the nuclear facilities that responded to the survey.

2
DEFINITIONS AND ACRONYMS

BWR	Boiling water reactor
Coating	Polymeric materials, applied to a surface in a fluid phase, that cure to a continuous film. The term coating is sometimes used interchangeably with the term paint.
DBA	Design basis accident
DFT	Dry film thickness
ECCS	Emergency core cooling system, a safety system used to cool a nuclear reactor and containment in the case of an accident
Epoxy-Phenolic Coatings	Also known as phenolic-epoxy coatings. These coatings are based upon a resin resulting from a reaction between epoxy phenol novolac and phenolic resins. These coatings must be baked at elevated temperatures to accomplish curing.
Failure	As defined by the nonnuclear industry, a failure of a coating can range from minor issues (cases in which "any desirable attribute, such as color or gloss, has degraded so as to be visible") to more major issues such as flaking, peeling, blistering, and delamination. As defined by the PIRT panel for the nuclear industry, a failure of a coating exists when the coating has actually fallen off the substrate and is thus available for transport to the ECCS sump screens.
ILRT	Integrated leak rate test, an assessment involving pressurization of containment to determine whether any air leakage from the containment is occurring
IOZ	Inorganic zinc-rich. IOZ coatings are usually primers or single-coat systems. In other sources the acronym IZR is sometimes used instead.
MPE	Modified phenolic epoxy. This term refers to coatings that are based upon a resin resulting from the reaction between an epoxy phenol novolac resin and an aliphatic, cycloaliphatic, or aromatic amine curative. These coatings can be air dried and cured without baking. MPE coatings are widely used in nuclear plants, including within primary containment.
NRC	United States Nuclear Regulatory Commission
NUCC	Nuclear Utilities Coatings Council
OSHA	United States Occupational Safety and Health Administration
PIRT	Phenomena identification and ranking table, a table assessing parameters regarding the risk of a coating failure in nuclear containment
PWR	Pressurized water reactor

SD	Signs of degradation. In the NUCC survey of nuclear facilities, this term was used in the questionnaire asking facility owners to report on any coatings that showed signs of degradation, as well as on coating with no signs of degradation. Examples of signs of degradation include flaking, peeling, blistering, and discoloration.
SRV	Safety relief valve
SSPC	The Society for Protective Coatings, formerly known as the Steel Structures Painting Council
VOC	Volatile organic content

3

NUCLEAR SERVICE LEVEL I COATINGS: AN OVERVIEW

3.1 Introduction

Before providing an analysis of the results of the nuclear coatings aging and degradation survey, it is useful to first present some background information on protective coatings, covering their chemical structures, protective capabilities, and advantages within a nuclear containment setting. Although the information is general in nature, the discussion is limited in scope to coatings that are commonly used in nuclear containments.

Paints and other protective coatings are by far the most common means of protecting materials from deterioration. Besides offering protection, coatings also add color and visual attractiveness, provide light reflectivity, provide camouflage, reflect heat, absorb heat, and serve a variety of other functions.

In order to serve these functions, the protective coatings must remain intact and adherent on the surfaces to which they have been applied. There are many factors that can cause a coating to deteriorate and fail to meet its intended function. The most common are poor surface preparation of the substrate prior to application of the coating and insufficient or excessive thickness of the applied coating. Based on the collected data and the author's experience, these two factors likely account for over 75% of all coating signs of degradation. Another less common but somewhat prevalent cause is misspecification or misuse of the coating or coating system in an environment for which it was not intended or formulated. Finally, misformulation or batching errors do sometimes occur during the manufacturing of a coating, although these are rare despite being frequently alleged.

Coating deficiencies such as misspecification, poor surface preparation, improper application, insufficient or excessive film thickness, or other abnormalities detected and corrected during application are not included in this discussion. Such corrected deficiencies are considered "work in progress" and are a normal part of any coating application operation. Poor specification and improper installation of any material, component, item, or system will lead to poor performance or failure in the nuclear industry, as in any other industry.

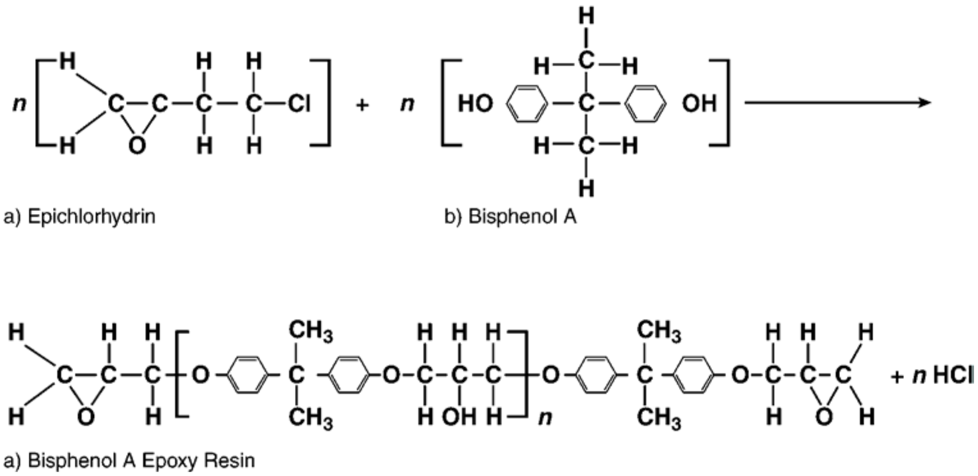
Although this section of the report is focused on nuclear Service Level I coatings, it is important to first understand, in general terms, what a coating is. Fundamentally, industrial coatings (sometimes called paints) in the dry film (that is, after application and cure) consist primarily of a **binder** and a **pigment**. The binder "binds" the pigment particles to each other and forms a bond to the underlying surface, which may be another layer of coating or a substrate. The binder (sometimes called a *resin*) may be an organic material that contains one or more carbon molecules or an inorganic material that does not contain a carbon molecule (most commonly it is a silicate or silicone). Catalyzed coatings have a cross-linking hardener, or coreactant, that cross-links and cures the coating. The film-forming organic or inorganic resin or binder that holds the pigment particles together and provides adhesion to the substrate contributes the greatest effect to the environmental resistance of a coating system. The pigment particles themselves provide opacity and color, add to coating film strength and impermeability, and in some cases provide galvanic or inhibitive corrosion protection.

Additives are sometimes used in coatings for various reasons. For example, low-cost fillers may be added to the pigment composition for film reinforcement. Solvents (whether organic compounds or water) enable dissolution or emulsion of the resin, provide liquidity, and allow for ease of application. For the most part, solvents (and water) volatilize after application. Other coating additives are used in small quantities to improve flowability, leveling, pigment dispersion, and emulsification (of water-based coatings), and for a host of other reasons beyond the scope of this report.

Deterioration of a properly applied protective coating begins at the molecular level as a degradation mechanism affects the molecules that constitute the resin or pigment in the coating. In time, as the coating is continuously exposed to the various effects of its environment, it can become stressed to the extent that it loses physical and mechanical properties, resulting in discoloration, cracking, peeling, loss of adhesion, and loss of function or suitability.

3.2 Chemical Structure of Coating Resins

In generic descriptions of most protective coatings, terms such as epoxy, epoxy phenolic, and silicate are used. These terms refer to the resin (binder) used to hold the pigment particles together and adhere the coating to the substrate. The chemical structure of any resin can be depicted by a structural formula diagram. For example, the structural formula for bisphenol A epoxy (the most common type) is shown in Figure 3-1. (Parts a and b of the figure depict the original components that are combined to form the epoxy resin, and part c depicts the resin after formation.)



a) Epichlorhydrin

b) Bisphenol A

a) Bisphenol A Epoxy Resin

Figure 3-1
Bisphenol A Epoxy Resin Structure [1]

The structural formula for bisphenol A depicts each atom (carbon [C] and hydrogen [H]) in the molecule. The lines between each of the atoms indicate the chemical bonds that hold the atoms together to form a molecule. The number of lines (or bonds) extending from each atom reflects the valence of that particular atom. Hydrogen, for example, always has only one line (or bond) extending to another atom, whereas carbon usually has four lines or bonds. (The valence of hydrogen is 1, and the valence of carbon is 4.) In some cases, carbon atoms form a ring structure in which a bond is shared loosely between one carbon and its carbon neighbors. Such an arrangement is represented in chemical structure diagrams (such as Figure 3-1) as the benzene (C_6H_6) ring (⬡) structure. Resins containing the benzene ring structure are said to be *aromatic* materials. *Aliphatic* materials are defined as those lacking the benzene ring structure.

3.3 Zinc-Rich Coatings

Zinc-rich coatings are widely used for corrosion control purposes due to their high metallic zinc loading and their ability to provide galvanic (anodic) protection to an underlying steel substrate, preventing corrosion and undercutting. The zinc metal in a zinc-rich coating acts as an anode in combination with steel (the cathode) and sacrifices galvanically to protect the steel. When the zinc within the coating is depleted, the coating system no longer provides galvanic protection, and the coating is usually replaced. It is far easier to remove and replace the coating than to replace the steel substrate. Only coatings containing sacrificial metals such as zinc or aluminum provide galvanic protection to carbon steel surfaces. Other types of coatings that do not contain sacrificial metals, such as epoxies, phenolics, and other organic coatings do not have this unique capability.

There are two basic types of zinc-rich coatings: organic and inorganic. Organic zinc-rich coatings provide galvanic protection, but they are not widely used within primary containment of nuclear facilities because of their lower temperature, abrasion, and radiation resistance as compared to their inorganic zinc-rich coating counterparts.

3.3.1 Inorganic Zinc-Rich Coatings: Basic Types

There are three basic types of inorganic zinc-rich coatings:

- Post-cured water-based alkali silicates
- Self-cured water-based alkali silicates
- Self-cured solvent-based alkyl silicates

Of these three types, the self-cured solvent-based alkyl silicates are the only type that has been used within the primary containment of nuclear facilities, due to their relative ease of use and their commercial availability at the time most nuclear facilities were being constructed. Post-cured inorganic zinc silicates are labor-intensive to apply, and the self-cured water-based alkali silicate technology developed later than that of the self-cured solvent-based technology and never saw significant application in nuclear containments. Therefore, only self-cured solvent-based alkyl silicates will be discussed here.

3.3.2 Self-Cured Solvent-Based Alkyl Silicate Coatings

These coatings consist of a silicon-oxygen (-Si-O-; silicate) matrix that holds the zinc dust pigment particles together and adheres them to an underlying steel substrate. Zinc dust loading at a minimum of 77% by weight is necessary for categorization of a zinc-rich coating by SSPC (SSPC Paint Specification No. 20). The silicate matrix originates as a prepolymer of a polymeric organic polysilic acid. There are a number of such prepolymers, but ethyl silicate $(C_2H_5)_4SiO_4$ is the prepolymer of choice. This material is prehydrolyzed by adding a precise small quantity of water to an alcoholic solution of ethyl silicate. If the pH is adjusted with hydrochloric acid or another suitable acid, the ethyl silicate is said to be *acid hydrolyzed*. During this reaction, some of the alkoxy (ethyl-oxygen) groups are removed by hydroxyl groups (OH) from the water. Alternatively, if hydroxyl groups are provided by amines in a form that is nonreactive with the organic polysilicate, the prepolymer is said to be *base hydrolyzed*. The amine reacts with water, producing hydroxyl groups that react with the alkoxy groups.

Regardless of how the prepolymer is hydrolyzed, the subsequent curing reactions are the same. The final properties of the silicate binders are also essentially the same, regardless of the method of prepolymerization.

Immediately before application, mixing the prehydrolyzed binder solution with the zinc dust pigment particles increases the solution's alkalinity, making the silanol groups (Si-OH) reactive. In the resulting condensation reactions, silanol groups can react either with each other or with an adjacent alkoxy group. If the silanol groups react with each other, the silicate matrix is formed along with water as a by-product. This water by-product can further react with the partially prehydrolyzed ethyl silicate, continuing the hydrolysis (curing) reaction. However, because so little water is liberated during the condensation reaction, the hydrolysis reaction is very slow. If the silanol reacts with an adjacent alkoxy group, the silicate matrix is formed along with the corresponding alcohol as a by-product (for example, when the prepolymer is ethyl silicate, the by-product is ethyl alcohol). This is also a very slow reaction.

In order to complete the curing reaction, the addition of water is necessary. The usual source of water is humidity from the atmosphere. Alternatively, if there is insufficient humidity, water may be sprayed or misted upon the curing zinc-rich film. Eccleston has shown that temperature and humidity during the initial film formation dictate the properties of solvent-based borne zinc silicates [2]. He concludes that at low humidity, water evaporates rapidly from the coating and is not available for the hydrolysis reaction. In addition, because the water is also a solvent, the film dries out much more quickly and the coating is reactive for a shorter period. In contrast, at a high humidity, the rate of evaporation is slower; water is retained in the film for a longer time, and hydrolysis and condensation reactions occur to a much greater extent. As the temperature increases at constant atmospheric moisture content, both the water and the organic solvent evaporation rates increase. The film, therefore, has less time to react with either atmospheric moisture or the water released from the condensation of silanol groups before the curing reaction ceases. Even immersion of an uncured coating in water after it has dried out does not measurably increase curing. After solvent evaporation, the physical and chemical condition of the coating appears to be irreversible. Therefore, curing under low-humidity conditions by the spray application of water will succeed only if carried out before the coating dries out. Hot conditions are detrimental only if accompanied by low humidity. If the curing reaction is too slow, the zinc particles may become oxidized on the surface, reducing the galvanic effectiveness of the zinc in the coating and the adhesion of the silicate matrix to the zinc pigment particles. This, in turn, reduces the cohesive strength of the zinc-rich coating.

The silicate curing mechanism is illustrated in Figure 3-2. (The *n* in the figure represents the number of molecules.) Zinc metal pigment particles are held in the interstitials of the matrix [3].

Solvent-based ethyl silicate coatings offer various advantages in nuclear primary containments. Among these are their ability to protect galvanically, their excellent abrasion and impact resistance, their high heat resistance, and their inorganic composition. As a result, silicate zinc-rich coatings have been widely used within the primary containments of many nuclear plants.

In many cases, during manufacture of a steel part (including manufacture of liner plate, structural steel, and support steel parts), the fabrication shop applies zinc-rich primers because they require minimal touch-up after shipping, handling, and erection. After erection, often the zinc-rich primer is topcoated with a suitable nuclear qualified topcoat, usually an epoxy. This approach is taken to provide additional corrosion resistance, enhance decontaminability, and change the color from a gray to a more light-reflective lighter color or to various colors for color coding. In other cases, the liner plates are first assembled and erected in the field, then abrasively blasted and epoxy coated. However, in some cases, the zinc-rich primer is left untopcoated, simply for economic reasons.

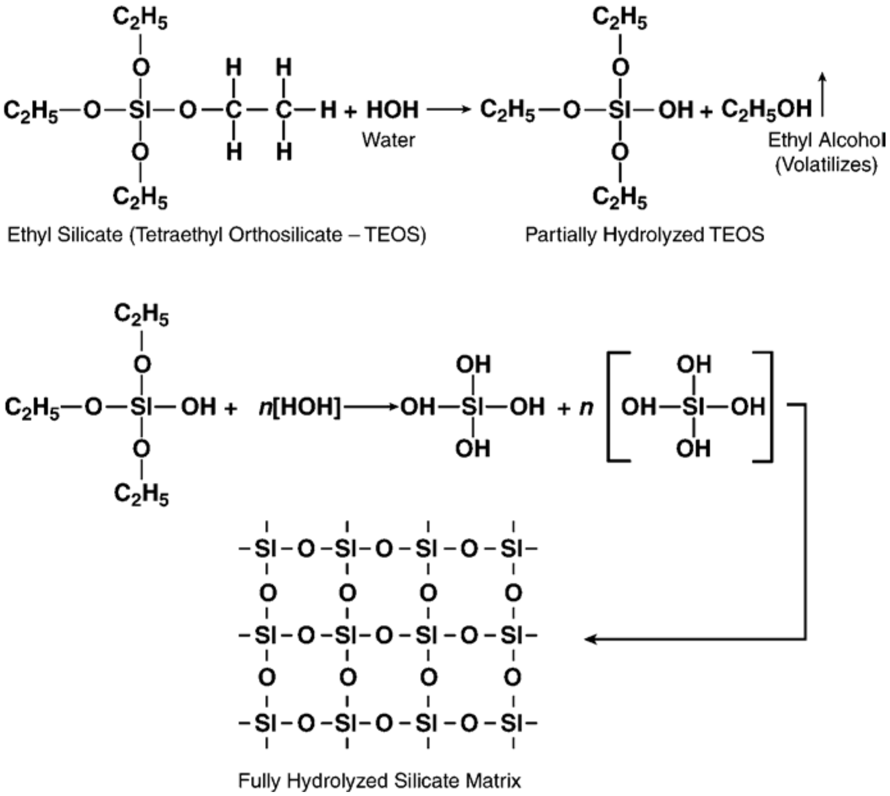


Figure 3-2
Matrix Formation of Ethyl Silicate

3.3.3 Inorganic Zinc-Rich Coatings: Sensitivity to Application Variables

Inorganic zinc-rich coatings are somewhat difficult to apply, because they require a clean surface (SSPC-SP 10 or better), good thickness control, and sufficient moisture during curing. The clean surface is necessary for good adhesion and because intimate zinc-to-steel electrical contact is necessary for galvanic protection. Careful thickness control is necessary to prevent excessive thickness, which can result in the defect known as *mud cracking*. This phenomenon, when it occurs, looks very much like the cracking that develops in a dried mud puddle (hence its name). Most inorganic zinc-rich primers are specified for application thicknesses from 2.5 to 5 mils (0.0635 to 0.127 mm). Above that range, mud cracking may develop, especially in dry, warm weather. Sufficient moisture is necessary to ensure proper curing, as discussed earlier. In dry environments, moisture may need to be spray-applied to the silicate binder to ensure proper curing.

Proper mixing of the coating prior to application is also important. First, the binder must be thoroughly mixed, and then the zinc dust pigment slowly sifted into the binder during constant mixing, to ensure complete wetting and to prevent pigment agglomeration. The mixed material must be continuously agitated in a spray pot to ensure that settling of the heavy zinc pigment does not occur.

During spray application, the spray gun must be held perpendicular to the substrate, and at the proper distance (6–8 inches [15–20 cm] for conventional spray, 6–12 inches [15–30 cm] for airless spray) to minimize *dry spray*, a phenomenon that tends to occur with inorganic zinc-rich coatings due to their high pigment-binder ratio (they have a relatively small amount of binder compared to organic coatings). Dry spray is the deposit of atomized coating material that has dried before contacting the substrate. It is more of a concern in warm, dry environments. Application of a topcoat over a zinc-rich primer that has excessive dry spray will lead to poor adhesion, because the topcoat will adhere to the dry spray, which itself has poor adhesion to the proper inorganic zinc film.

Excessive thickness of zinc-rich coating at overlaps, welds, and other areas where thickness is hard to control are problem areas in terms of proper curing. Additionally, because the silicate binder has little tensile strength (it is glasslike), stresses due to the curing of a subsequent topcoat (or induced mechanical, temperature, pressure, vibration, or other stresses) may readily cause disbondment to occur within the primer of a topcoated inorganic zinc-rich system, at areas of high thickness.

3.3.4 Inorganic Zinc-Rich Coatings: Failure Mechanisms

Disbondment – Failure of an organic-topcoated inorganic zinc-rich primer system, when it occurs, may be manifested by disbondment of either the topcoat or the primer. Because the weakest link in the coating system is the cohesive strength of the inorganic zinc-rich primer, the most common of these failures is a cohesive break (disbondment) within the primer. This results in chips of coating with zinc primer adhered to the epoxy topcoat underside, leaving a reduced thickness of zinc primer on the substrate. In cases where the inorganic zinc-rich coating is not topcoated, if disbondment were to occur, the zinc would disintegrate as a powder (either as unreacted zinc dust or as a reacted zinc carbonate, zinc hydroxide, or other zinc reaction product).

Insufficient moisture during curing – Perhaps the most common inorganic zinc-rich coating failure mechanism is that of insufficient moisture supply to the silicate binder during curing. This can occur in a low-humidity environment, or it can occur after topcoating. If the silicate binder is not suitably cured prior to application of the topcoat, the topcoat may prevent the necessary atmospheric moisture from reaching the primer. This type of failure is distinctive in appearance and is often accompanied by the presence of an alcohol odor.

Tiger striping – Another type of inorganic zinc-rich coating failure has been observed with in the torus and suppression pool of a BWR, where the primer remained untopcoated. This phenomenon occurs only in high-purity water, such as that found in a nuclear suppression pool. Corrosion rust lines are formed in a "tiger stripe" pattern over much of the zinc surface below the water line. In the vapor phase, the condensation streams are random, like rain on a window. At the water surface, the water droplets carry oxidized insoluble zinc, which forms a gel within the droplet. In immersion, this gel becomes anodic to the adjacent zinc coating due to oxygen concentration differences. The gel deposits form at the waterline, grow, slide, grow again, slide less, grow, and so on. The deposits stop sliding in the 4–5 o'clock zone. Pitting is deepest where the nodules stop sliding. Blowdown interrupts pitting and tiger striping growth, as does water circulation.

Chemical exposure – Another failure mechanism affecting inorganic zinc-rich primers is exposure to chemical solutions that are outside the range of approximately pH 4 to 10. Zinc will be aggressively attacked by either acid and or alkali chemical solutions, if they are outside of this pH range.

Anodic reversal – Exposure to warm water at a temperature in excess of approximately 140°F (60°C) may result in an anodic reversal, with zinc becoming the cathode and steel becoming the anode in a galvanic couple, resulting in an accelerated corrosion reaction. This may occur to a zinc-rich coating under insulation, or also in a nuclear facility under accident conditions.

Aging over time – The effects of coating aging and accumulated irradiation on untopcoated zinc-rich primers are unknown, but are believed to be minimal, due to the inorganic nature of the silicate matrix (the lack of carbon-carbon bonding) and the bonding strength of silicate bonds. With epoxy-topcoated inorganic zinc-rich primers, the consequences of long-term aging within a nuclear containment are also unknown. It is believed that the organic properties of the epoxy topcoat will prevail over the inorganic attributes of the inorganic zinc-rich primer. Preirradiated and design basis accident (DBA) testing of untopcoated inorganic zinc-rich coatings (Carbozinc 11 and others) has shown little effect, whereas similar testing of an inorganic ethyl silicate zinc-rich primer topcoated with a phenolic-epoxy topcoat (Carbozinc 11-Phenoline 305) has shown large blisters that cracked and showed signs of disbondment at film thickness in excess of the vendor's recommendations when subjected to a DBA. However, other epoxy-topcoated inorganic zinc silicate coatings have not been as affected in similar testing.

3.4 Epoxy Coating Systems [4]

Epoxy coating systems usually come in two packages. The first contains the epoxy resin, pigment, and some solvent, and the second contains the copolymer curing agent. The packages are mixed immediately before application, and upon curing a large macromolecular structure is formed. The property of an epoxy coating is derived from both the type and the molecular weight of the epoxy resin and the copolymer curing agent used for cross-linking.

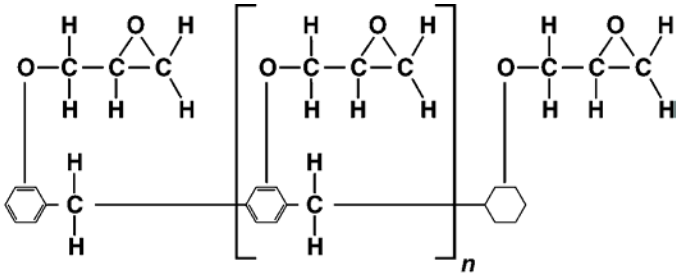
Epoxy coatings of various types are common in nuclear power plants because of their good chemical and water resistance, flexibility, and relative ease of application. Epoxy coating systems in nuclear containments may have an ethyl silicate inorganic zinc-rich primer or a conventional epoxy primer. Although epoxies will chalk upon exposure to sunlight, lighting systems within primary containment do not have the high-energy, low-wavelength component of sunlight that degrades epoxy coatings (285–400 nanometers).

During the construction period of most nuclear power plants (from the early 1960s to the early 1980s), bisphenol A epoxy resins were most commonly used. These epoxy resins were sometimes copolymerized with phenol to increase their cross-linking density in order to provide greater water and chemical resistance. Such more tightly cross-linked epoxy coatings were believed at the time to also be more decontaminable. Epoxy resins are sometimes combined with another type of resin, such as a phenolic resin. This modification results in a different material, with different properties than an unmodified epoxy, depending upon the type and amount of amount of the modifying resin added. Modified phenolic-epoxy resins are discussed later in this section.

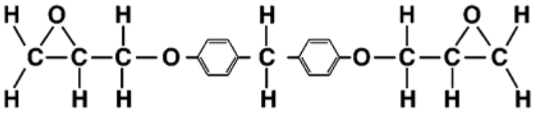
3.4.1 Epoxy Resins

Bisphenol A epoxy resins are made by reacting bisphenol A and epichlorhydrin. A dichlorohydrin of bisphenol A results, and when this is further reacted with sodium hydroxide, a diglycidyl ether of bisphenol A results. (The acronym DGEBA is thus another term commonly used to refer to bisphenol A epoxy resins.) Even within this family of resins there is much variability, as the molecular weight of a bisphenol A epoxy can vary from 350 to 4000. The bisphenol A epoxy resin reaction was illustrated earlier (in Figure 3-1). When the repeating unit n is 1 or less, the resin is a liquid with a honeylike consistency. These liquid epoxies are used for high-solids epoxies cured at ambient temperature. When the average molecular weight of the resin is increased by increasing n to approximately 2, the resin becomes a solid and must be dissolved with suitable solvents in order to be used as a coating material. Traditionally, an n of approximately 2 and a molecular weight of 800 to 1000 have been used in the formulation of the typical bisphenol A liquid epoxy that has been widely used in the nuclear power industry.

There are other epoxy resins, most notably bisphenol F resins and novolac resins. Bisphenol F epoxy resins have a lower molecular weight and greater chemical and moisture resistance than bisphenol A resins. When bisphenol F resins are reacted with aromatic amines and amine adducts, they can be formulated into high-solids epoxies and 100% solids epoxies (with little or no solvent). Epoxy novolacs are modifications of bisphenol F resins (bisphenol F being the simplest novolac resin). Epoxy phenol novolacs have a higher functionality than the bisphenol A and bisphenol F resins, and when cross-linked have greater resistance to heat, solvents, chemicals, and moisture than those resins. Due to their increased functionality and lower molecular weight, these resins are used in blends with bisphenol A resins to increase resistance and decrease VOC. These resins, however, are all of more recent development, due principally to VOC concerns and a desire for a highly cross-linked, relatively solvent-free environmentally compliant epoxy coating. Because of their more recent commercial use (widespread usage in coatings commenced in the mid-1980s), it is unlikely that bisphenol F or novolac epoxy resins were used to any great degree in any U.S. nuclear containments, except perhaps for repair and maintenance. The structural formulas for epoxy phenol novolac and bisphenol F are depicted in Figure 3-3.



a) Epoxy Phenol Novolac



b) Bisphenol F Epoxy Resin

Figure 3-3
a) Epoxy Phenol Novolac b) Bisphenol F Epoxy Resin [1]

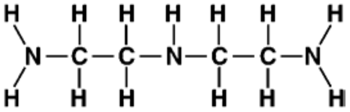
High bake epoxy phenolic coatings – High bake epoxy phenolic coatings (also know as epoxy phenolics) are extremely resistant to acids, alkalis, and solvents. High-molecular-weight epoxies with a high proportion of hydroxyl functional groups available for reaction are used. During manufacture, the epoxy is packaged with a phenolic resin (commonly a phenol formaldehyde resin), pigment, and an acid catalyst. Generally, an epoxy phenolic coating results from a reaction between an epoxy phenol novolac and a phenolic resin. After mixing, the coating is applied by spraying, and must be baked at temperatures from 300 to 400°F (150 to 205°C) in order for cross-linking to occur. Multiple-coat baked systems require brief intermediate baking between coats; longer baking times are commonly used after application of the final coat. The resulting coatings have the excellent acid and solvent resistance associated with the phenolics as well as the flexibility, adhesion, and toughness of epoxies. Epoxy phenolics have the good alkali resistance of the epoxy constituent, but straight phenolic linings have very poor alkali resistance.

Modified phenolic epoxy coatings – Some modified phenolic epoxy (MPE) coatings contain smaller amounts of phenolic resin and are much more akin to a conventional epoxy. These coatings are based on resins resulting from a reaction between an epoxy phenol novolac resin and an aliphatic, cycloaliphatic, or aromatic amine curative. These coatings can be air dried and cured without baking. MPE ambient cross-linked and cured coatings are widely used in nuclear plants, and within primary containment.

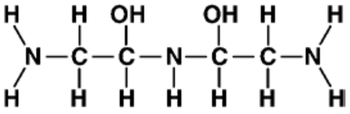
3.4.2 Epoxy Copolymer Curing Agents

Although epoxies are generally thought of as being catalyzed, the cross-linking reaction involved in their formation is in fact a copolymerization. The reaction occurs primarily through the epoxy ring end groups or the midchain hydroxyls of the epoxy resin. The curing agent is usually an amine or polyamide, with cross-linking derived through active hydrogens attached to the amino nitrogen. Although a variety of cross-linking agents can be used (including mercaptans, polybasic acids and anhydrides, phenols, and phenol-formaldehyde), the most common are the polyamines, the amine adducts, and the polyamides. Often, blends of different types of curing agents are used as the epoxy curative.

Polyamines – Polyamines (for example, diethylene triamine, hydroxyethyl diethylene triamine, and bishydroxydiethylene triamine) are relatively small linear aliphatic (lacking the benzene ring) molecules with a low molecular weight compared to the epoxy resin. (The chemical structures of two common polyamines are illustrated in Figure 3-4.) As a consequence, when reacted, they lead to tight cross-linking and high chemical and moisture resistance. However, during the cross-linking reaction, any unreacted amine may be squeezed out of the cross-linked film to the surface, resulting in what is known as an *amine blush* (this phenomenon is discussed further below, in the subsection on epoxy coating failure mechanisms). To minimize the formation of an amine blush, many formulators will specify a 15- to 30-minute induction period after mixing prior to application. This allows the reaction to begin and initial cross-linking to occur before the material is applied. Some of the small amine molecules will partially cross-link with epoxy resin molecules and become much larger in size, reducing the tendency of cross-linking shrinkage to squeeze them out of the reacting coating mixture.



a) Diethylene Triamine

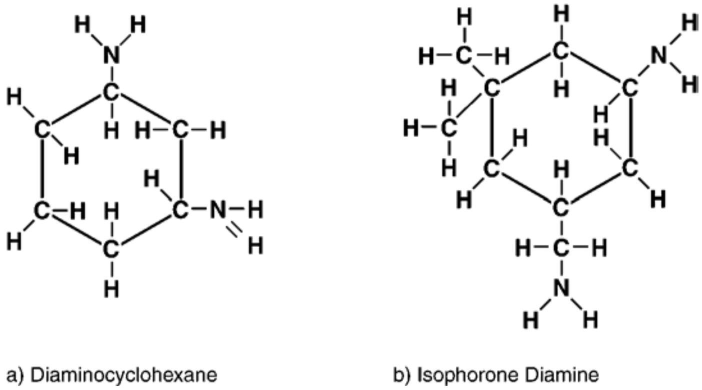


b) Hydroxyethyl Diethylene Triamine

Figure 3-4
Examples of Polyamines [5]

Amine adducts – Recognizing the problem of amine blush, many coating manufacturers supply the amine as a prereacted amine adduct. To make the adduct, epoxy pigments and solvents are packaged as before, in one container, but an excess of the amine is prereacted with some of the epoxy resin to increase its molecular size. This prereacted amine adduct resin is then packaged in a separate container, sometimes with additional pigment and solvent. Chemical cross-linking of the resultant applied film is not considered to be quite as tight as that provided by a non-prereacted amine, and the chemical resistance is said to be somewhat lower. However, application is much easier and not nearly as dependent on thorough mixing and induction time of the reactants.

Cycloaliphatic amines – These curing agents are characterized by an amino (-NH) group attached to a cycloaliphatic structure (a structure that is cyclic but that lacks the benzene ring). When the amino group is attached to a cycloaliphatic structure, the resultant resin has greater light stability and better heat resistance than the linear aliphatic polyamines discussed previously. All cycloaliphatic amines are slower reacting than linear amines, but they react faster than the polyamides. Chemical resistance of the linear aliphatic amines is superior to that of both the cycloaliphatic amines and polyamides, although the resulting molecule is more rigid and less flexible. The chemical structures of two commonly used cycloaliphatic amines are shown in Figure 3-5.


a) Diaminocyclohexane

b) Isophorone Diamine

Figure 3-5
Examples of Cycloaliphatic Amines [6]

Aromatic amines – This family of amines has an amino group attached to a structure containing the benzene ring. For years, 4,4-methylene dianaline (MDA; see Figure 3-6), an aromatic amine, was widely used to cure epoxy resins. It had a very long pot life, excellent acid and heat resistance, good moisture insensitivity, and good flexibility. This curing agent was used to cross-link some epoxy surfacers used on concrete substrates in nuclear power plants. However, in 1983 OSHA listed MDA as a carcinogen, and most coating manufacturers discontinued its use. It is believed that there are a number of nuclear plants with epoxy concrete surfacers that are cross-linked using MDA. It is important to recognize that MDA is only a carcinogen in the powdered form, when it can be inhaled during handling and application. When applied, it reacts by cross-linking with the epoxy resin, rendering it a much larger molecule that has different properties and cannot be inhaled. Accordingly, it is not a carcinogen after it reacts. Ameron's NuKlad 110 AA and 66 Series epoxy, in early formulations, contained methylene dianaline.

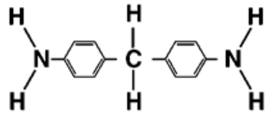
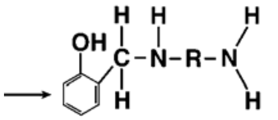

4,4′-Methylene Dianiline

Figure 3-6
MDA

Mannich bases – These are another type of aromatic amine, formed by the reaction of a methyol phenol and a multifunctional primary amine (see Figure 3-7). They are used principally for low-temperature curing epoxies and for coatings that cure under damp conditions, including underwater-cured epoxies.



R = a short-chain aliphatic molecular group

Figure 3-7
Mannich Base [7]

Mannich bases can be adducted with methylene diamine (see Figure 3-8) to produce a coreactant that cures at lower temperatures than any other amine-based curing agent. This adduct is also useful in formulation of high-solids, low-VOC maintenance coatings.

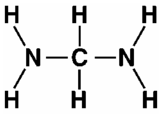
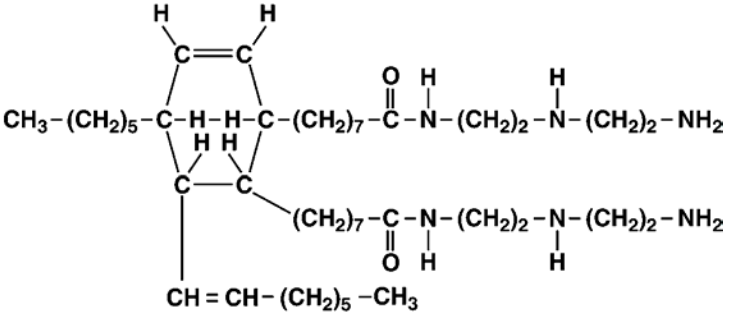


Figure 3-8
Methylene Diamine

Polyamides – These curing agents are the condensation products of a dimerized fatty acid with a polyamine (a *dimer* is a molecule composed of two similar subunits or monomers linked together). A terminal amine functionally allows cross-linking to occur as with a straight amine, although the polyamide molecule is much larger. The cross-linked film has improved flexibility, improved gloss and flow, excellent water resistance, and good chemical resistance. Polyamide-cured coatings, however, have somewhat less solvent and alkali resistance than amine-cured and amine-adduct-cured epoxies.

Specially formulated polyamide-cured epoxies have the ability to displace water from the substrate surface. Such materials can even be applied and cured underwater to form corrosion-resistant coatings. These underwater coatings have been used frequently in touch-up and repair of tori, suppression pools, and water-containing tanks, using divers to apply them.

The chemical structure of a polyamide is illustrated in Figure 3-9. A polyamide is the product of a fatty acid (commonly a tall oil) with a polyamine (NH or NH_2) functionality [6].

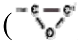


Polyamide Resin (Functionality of 8)

Figure 3-9
An Example of a Polyamide

Amido-amines – If a polyamine is reacted with a monofunctional fatty acid instead of a dimer fatty acid, the condensation product is an amido-amine instead of a polyamide. Although the properties of an amido-amine are similar in most respects to the properties of a polyamide, amido-amines have lower moisture and corrosion resistance than polyamides, and their flexibility and adhesion are slightly lower as well. However, they have a higher reactive functionality and a lower molecular weight than polyamide resins, which makes them useful in reactions with low-molecular-weight epoxies to make high-solids, low-VOC epoxy systems.

3.4.3 Epoxy Curing Mechanisms

The curing of an epoxy resin by a coreactant cross-linking agent occurs primarily through the oxyrane (epoxide ring) end groups (). Active hydrogens from an amine, amine adduct, polyamide, or other curing agent open the epoxide ring during the process of cross-linking. The cross-linking that occurs with the curing agent is between the hydroxyl groups (-OH) along the epoxy chain and the methyol ($-CH_2OH$) groups present in the phenolic resin. A possible secondary reaction is the reaction between the terminal epoxide groups of the epoxy resin and the hydroxyl groups of the phenolic resin.

The molecular weight of epoxy, the type and molecular weight of the cross-linking coreactant, and the functionality (number of reactive sites) of the coreactant all determine the nature of the cross-linked epoxy coating. If the coating is highly cross-linked, it will be more resistant to chemical and moisture permeation, but it will be less flexible and more brittle. Conversely, a lower cross-linking density will provide a tougher, more flexible material, but one with less chemical and moisture resistance. For nuclear immersion service, particularly in deionized water immersion, highly cross-linked epoxy-phenolics are used. Most of these systems were air dried and cured. However, in some instances involving suppression pools, the coating system was baked after application to drive out solvents and increase cross-linking density. An example of an amine (diethylene triamine) cross-linked epoxy is depicted in Figure 3-10.

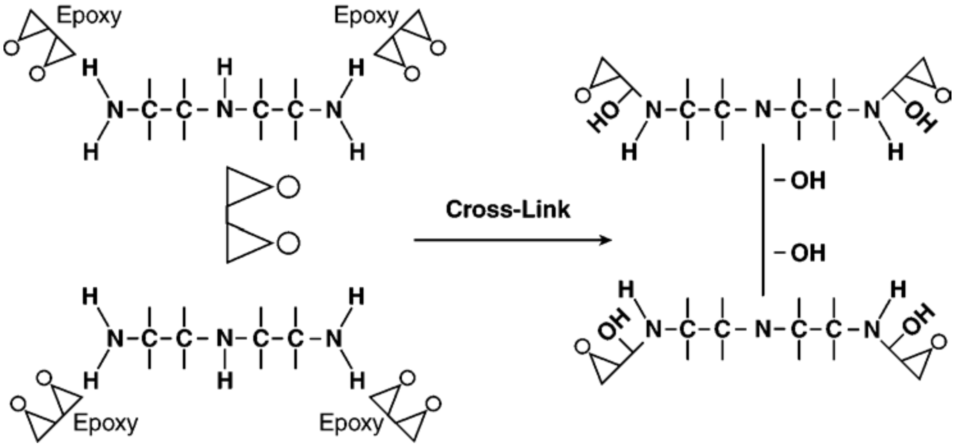


Figure 3-10
Epoxy Cross-Linking with an Amine [8]

3.4.4 Epoxy Coatings Within Primary Containment

Epoxy coatings of various types, cured using one or more of the curing agents described above, are widely used in every major nuclear power plant. This is due to their good moisture and chemical resistance, excellent adhesion, and ability to be formulated into a variety of coatings that can be cross-linked with a number of different curatives. Epoxy coatings can be applied over virtually any substrate and are a workhorse in the nuclear power industry, just as they are in the chemical processing industry, the marine industry, and most of the industrial painting world.

In nuclear power plants, epoxy coatings are used on steel substrates as topcoats over inorganic zinc-rich primers and also as complete coating systems (epoxy primer-epoxy topcoats). On concrete substrates, epoxy coatings are used as primers, surfacers, and topcoats. Often, the same coating system, or at least the topcoats of an epoxy coating system, can be overlapped from concrete onto steel (such as over embedment plates) to ensure a monolithic uniform surface. Epoxy coating systems are used on both primary containment steel and concrete in water immersion; to line tanks, suppression pools, sumps, and fuel pools; and in circulating water piping. Epoxy coatings are also used in primary containment atmospheric service on surfaces that include the containment vessel, liner plate, uninsulated piping, suppression pools, pipe supports, and many other steel and concrete surfaces. Virtually everything painted in primary containment with a qualified or acceptable coating system uses an epoxy coating. The only exception to this would be untopcoated inorganic zinc-rich coatings.

3.4.5 Epoxy Coatings: Sensitivity to Application Variables

The specific formulation of an epoxy coating, its copolymers, and its curing system dictates the sensitivity of the epoxy coating system to application variabilities. All cross-linked epoxies are multicomponent coatings and need to be thoroughly mixed prior to application. As a rule, however, most epoxy coatings are generally quite tolerant of application variables. They have good wetting and adhesion capabilities and reasonably good film-building properties. They may generally be applied over marginally cleaned substrates or damp surfaces (although neither practice is recommended).

However, most epoxies need a minimum temperature of approximately 50°F (10°C) to cure and to adequately release solvents. Highly cross-linked phenolic epoxy coatings must be applied in thin films (to aid in solvent volatilization) and must sometimes given a low-temperature baking before application of a final coat and a final high-temperature baking. Many amine-cured epoxy coatings need an induction time (15–30 minutes after complete mixing) to partially cross-link prior to application, in order to prevent amine blush. Application of a topcoat after the epoxy undercoat has fully cured may result in poor adhesion and ultimate disbonding of the topcoat. This is a major concern with low-temperature curing epoxy formulations, if ambient conditions warm up.

3.4.6 Epoxy Coatings: Failure Mechanisms

Application deficiencies – For the most part, epoxy coating failures are due primarily to either improper selection for a given service environment or to poor surface preparation and/or coating application. Care should always be taken to ensure that both parts A and B (and sometimes part C) are properly combined and thoroughly mixed. Compatible thinners should always be used, and the coatings should be mixed and applied according to the coating manufacturer’s recommendations. Many epoxy coatings are moisture sensitive and should not be applied when relative humidity is above 85–90%, due to amine blush concerns and curing problems.

Minimum temperature for cure – A concern when using epoxy coatings is that they are chemically cross-linked and must cure at temperatures generally above 50°F (10°C), unless specially formulated for low-temperature curing. Temperatures during the curing cycle generally should be consistently above 50°F, usually for a minimum of 72 hours or more for optimum cure for atmospheric service, and for at least a week for immersion service. If suitable temperatures are not maintained during curing, chemical cross-linking will not develop sufficiently to provide long-term protection in the intended service environment.

Recoat window – On the other hand, if an epoxy is to be recoated with an epoxy topcoat after the first coat has cured, adhesion of the second coat may be impaired because the solvents from the topcoat will not be able to penetrate, soften, and provide adhesion to the underlying cured epoxy coating. Most coating manufacturers provide information on an “overcoating window” in their product data sheets. If a subsequent topcoat is applied after this “window” has expired, adhesion may be diminished, ultimately resulting in cracking, peeling, and other disbonding of the topcoat from the underlying epoxy.

Amine blush – As explained in the subsection on epoxy curing agents, polyamines are relatively small molecules with a low molecular weight (compared to an epoxy resin). As a consequence, when reacted, polyamines lead to tight cross-linking of the epoxy resin, providing a high degree of chemical and moisture resistance. However, during the cross-linking reaction, any unreacted amine may be squeezed out of the cross-linked film to the surface, developing the so-called amine blush, a hazy white coloration on the coating surface. An amine blush is the reaction of an amine with carbon dioxide from the air to form an amine carbamate. Amine carbamates are water soluble and must be removed before any subsequent topcoat is applied. If they are not suitably removed by wiping with a wet cloth or by low-pressure water washing, residual amine on the surface may interfere with adhesion of subsequently applied coatings and/or cause blistering in immersion service. Blushing is particularly likely if the surface is cool and/or exposed to elevated humidity or if the environment is stagnant and poorly ventilated. It is manifested by a tactual stickiness or a yellow-brown colored surface stain. Testing using a universal litmus paper may detect the presence of an amine blush. If the litmus turns blue, indicating alkalinity, an amine blush on the surface may be present.

Solvent retention – If solvents are retained in an epoxy coating and that coating is placed in immersion service, solvent-induced blistering may occur due to the hydrogen bonding attraction of the solvent to polar water molecules. This phenomenon is not unique to epoxies; it will occur with any coating material placed in water immersion service. Such solvent-induced osmotic blistering will be more severe in high-purity (demineralized or deionized) water, as is found in suppression pools and in waters at elevated temperatures. Epoxies applied under high ambient temperature conditions may cure from the surface inward. This may result in solvent entrapment within the film cross-section, particularly if the substrate is cooler than the ambient temperatures.

Solvent retention has played a key role in the blistering that has been a historical problem with linings for suppression pools and coating systems in water immersion. The torus represents a unique environment in that the temperature within the torus is warm compared to the surrounding exterior torus room. The cooler exterior temperatures cool the torus steel, retarding solvent evaporation from a drying/curing epoxy interior coating film.

Embrittlement over time – Over time, exposure to heat and to low rates of ionizing radiation typical within an operating reactor containment may increase the cross-linking density of cross-linked epoxy coating systems so that they become increasingly hard, brittle, and less flexible. Cracking and/or disbondment may occur if the coating is overstressed. This is, of course, a potentially significant concern in the nuclear power industry; however, few data related to this phenomenon in relation to nuclear power plants exist at this time.

4

ANALYSIS OF THE SURVEY DATA

4.1 Introduction

This section presents an analysis of the data collected through NUCC Survey 2005-07, *Nuclear Service Level I Coatings*. This survey of U.S. nuclear plants was conducted to determine the condition of coatings within the primary containment of their facilities. The nuclear industry has experienced degradation (and, in some cases, failure) of protective coating systems applied inside reactor containment, and information was sought regarding the condition of coating systems described by respondents as being in good condition as well as systems showing signs of degradation.

A total of 55 survey responses was received, representing an 83% response rate (85 of the 103 operating nuclear units within the United States responded). The survey questions (reproduced in Section 1 of this report) asked respondents to describe qualified coating systems that have **not** exhibited any degradation—designated “Good”— and to describe qualified coating systems that **have** shown signs of degradation—designated “SD.” The survey requested data based on a series of questions, and the data requested was limited to the top three Good and the top three SD coating systems at each responding plant, with “top three” defined as the three largest systems at the plant in terms of surface area.

Although the determination of what was Good coating and what was SD coating was left to the responder, it became evident upon assessment of the responses that SD generally meant anything that was not Good. Survey respondents were further asked to describe any coating degradation and comment on whether it constituted a failure but not to supply data specifying total surface area involved in the failure. Thus, the data simply show either Good or SD surface areas. However, the descriptions of coating degradation (as later discussed) clearly indicate that most SD areas are the result of characteristics consistent with the onset of coating failure, such as, at a minimum, yellowing, blistering, cracking, peeling, and ultimately delamination from the substrate.

The surface area data for each generic coating type were categorized by substrate as well as broken down into Good or SD areas. Generic coating types are categorized by the generic coating system—for example, primer/intermediate/topcoat. A complete list of product names for each generic system, including the total square footage and number of plants at which the products were used, is presented at the end of this section (see Table 4-17).

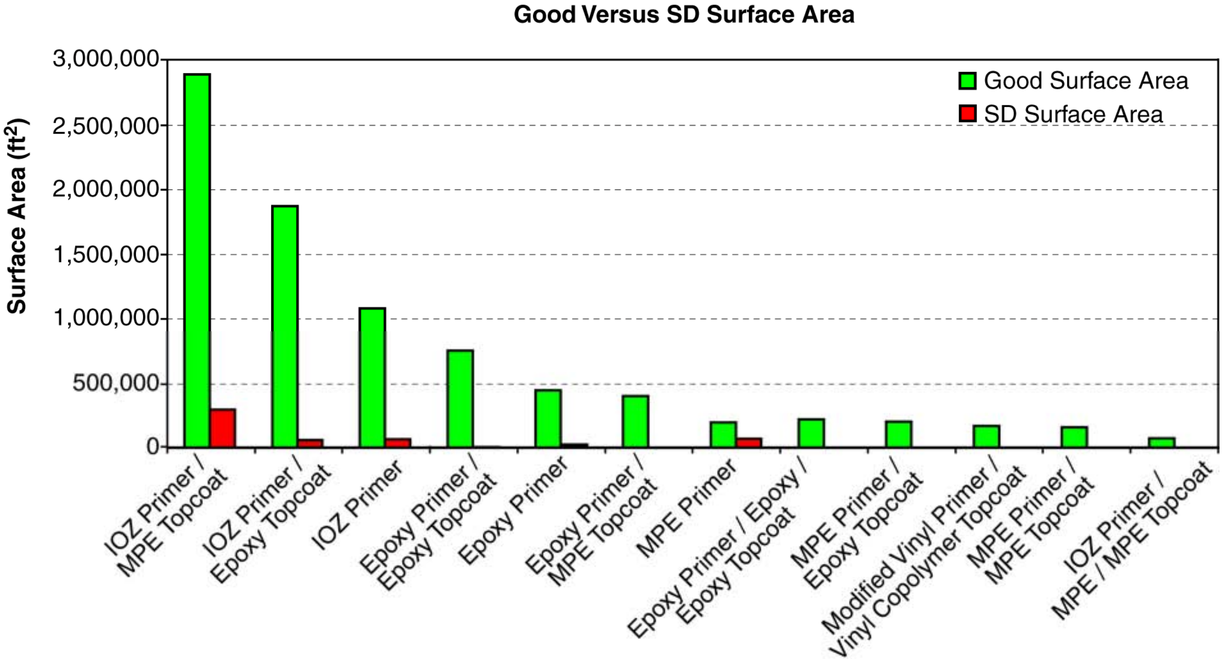
4.2 Generic Coating Systems for Steel

The data for all generic coating systems applied to steel are summarized in Table 4-1 and displayed graphically in Figure 4-1. The most widely used system consisted of an inorganic zinc (IOZ) primer and a modified phenolic epoxy (MPE) topcoat.

Table 4-1
Generic Coating Systems for Steel: Good Versus SD Surface Areas

Generic Type	Good Surface Area (ft^2)	SD Surface Area (ft^2)	Total Surface Area (ft^2)	SD Percent of Total Area
IOZ Primer / MPE Topcoat	2,888,959	294,185	3,183,144	9.2%
IOZ Primer / Epoxy Topcoat	1,866,155	57,251	1,923,406	3.0%
IOZ Primer	1,076,660	64,949	1,141,609	5.7%
Epoxy Primer / Epoxy Topcoat	750,250	2,160	752,410	0.3%
Epoxy Primer	443,500	11,750	455,250	2.6%
Epoxy Primer / MPE Topcoat	400,000	0	400,000	0.0%
MPE Primer	193,490	67,910	261,400	26.0%
Epoxy Primer / Epoxy / Epoxy Topcoat	220,000	0	220,000	0.0%
MPE Primer / Epoxy Topcoat	200,000	0	200,000	0.0%
Modified Vinyl Primer / Vinyl Copolymer Topcoat	167,500	1,500	169,000	0.9%
MPE Primer / MPE Topcoat	158,400	0	158,400	0.0%
IOZ Primer / MPE / MPE Topcoat	71,758	1,078	72,836	1.5%
Total Surface Area	8,436,672	500,783	8,937,455	5.6%

1 ft^2 = 0.093 m^2



1 $ft^2 = 0.093\ m^2$

Figure 4-1
Generic Coating Systems for Steel

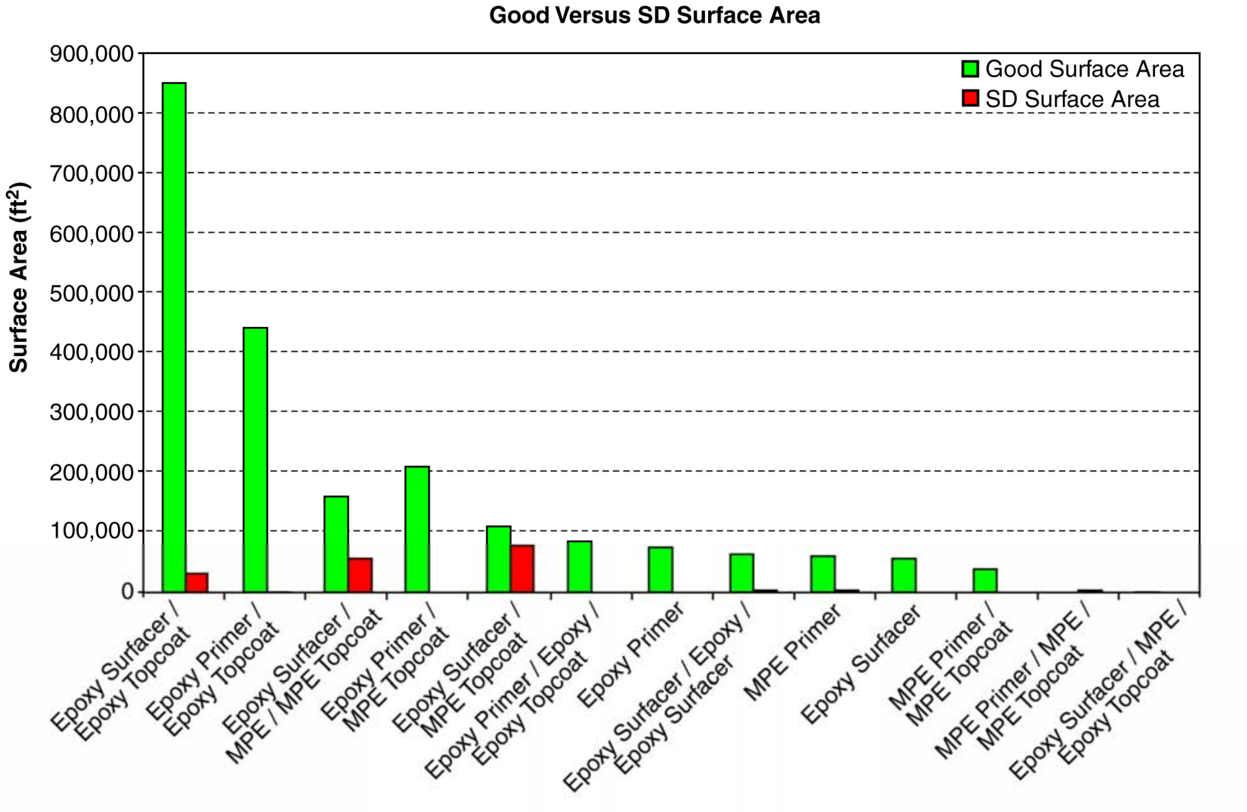
4.3 Generic Coating Systems for Concrete

The data for all generic coating systems applied to concrete are summarized in Table 4-2 and displayed graphically in Figure 4-2. The most widely used system consisted of an epoxy surfacer and an epoxy topcoat.

Table 4-2
Generic Coating Systems for Concrete: Good Versus SD Surface Areas

Generic Type	Good Surface Area (ft^2)	SD Surface Area (ft^2)	Total Surface Area (ft^2)	SD Percent of Total Area
Epoxy Surfacer / Epoxy Topcoat	849,900	31,500	881,400	3.6%
Epoxy Primer / Epoxy Topcoat	441,440	500	441,940	0.1%
Epoxy Surfacer / MPE / MPE Topcoat	159,300	56,500	215,800	26.2%
Epoxy Primer / MPE Topcoat	210,000	0	210,000	0.0%
Epoxy Surfacer / MPE Topcoat	109,200	78,120	187,320	41.7%
Epoxy Primer / Epoxy / Epoxy Topcoat	83,000	0	83,000	0.0%
Epoxy Primer	75,000	0	75,000	0.0%
Epoxy Surfacer / Epoxy / Epoxy Surfacer	64,000	1,200	65,200	1.8%
MPE Primer	61,400	1,600	63,000	2.5%
Epoxy Surfacer	58,000	0	58,000	0.0%
MPE Primer / MPE Topcoat	40,000	10	40,010	0.0%
MPE Primer / MPE / MPE Topcoat	0	3,000	3,000	100.0%
Epoxy Surfacer / MPE / Epoxy Topcoat	1,000	0	1,000	0.0%
Total Surface Area	2,152,240	172,430	2,324,670	7.4%

1 ft^2 = 0.093 m^2



1 ft^2 = 0.093 m^2

Figure 4-2
Generic Coating Systems for Concrete

4.4 Descriptions of Coating Degradation

The descriptions of coating degradation were quite varied. The responses were analyzed for key terms describing the modes of degradation or apparent visual precursors. By far the most commonly reported failure description was delamination of coatings, with numerous descriptions of intercoat delamination, where the topcoat delaminated from the primer or intermediate coating layer. The cases of intercoat delamination most frequently involved a modified phenolic or epoxy topcoat delaminating from an inorganic zinc-rich primer. Figure 4-3, a summary of the responses, shows that nearly half (47%) of the responses described delamination (or the associated terms *detachment*, *disbonding*, and *peeling*) as a cause of degradation. The next most common failure description was blistering (23%), followed by cracking (14%) and flaking (10%). There were few responses (2% or less) for other degradation descriptions.

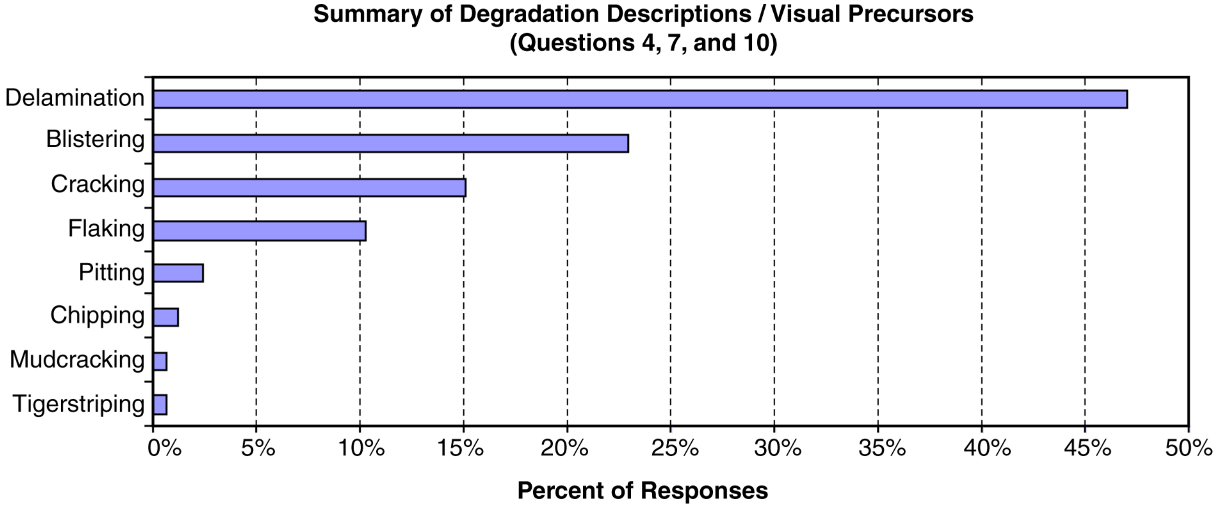


Figure 4-3
Coating Degradation Descriptions

Although the survey specifically asked about visual precursors to the degradation, delamination would be difficult to categorize as a precursor. By the time delamination is observed, degradation or failure is well underway. Blistering, cracking, and flaking of coatings would be better visual precursors because they are more likely to be apparent before widespread failure has occurred.

4.5 Reasons for Coating Degradation

The survey asked respondents to describe the cause of coating degradation. Table 4-3 summarizes these responses and indicates that the most common reason for degradation (totaling 36% of responses) was poor application due to poor surface preparation, the wrong applied dry film thickness, or insufficient curing.

Table 4-3
Reasons for Coating Degradation

Reason for Degradation	Number of Responses	Percent of All Responses
Poor application—poor surface preparation	32	17%
Excessive heat	24	12%
Poor application—wrong dry film thickness	21	11%
Poor application—insufficient curing	16	8%
Don’t know	14	7%
Improper coating selection	11	6%
Mechanical damage	7	4%
Chemical exposure	6	3%
Aging	4	2%
Ambient conditions / service environment	4	2%
High radiation	3	2%
Concrete expansion / settling	3	2%
Defective coating material	2	1%
Contact with borated water	1	1%
Steel expansion	1	1%
Concrete leachate	1	1%

The data from Table 4-3 are presented in graphical form in Figure 4-4.

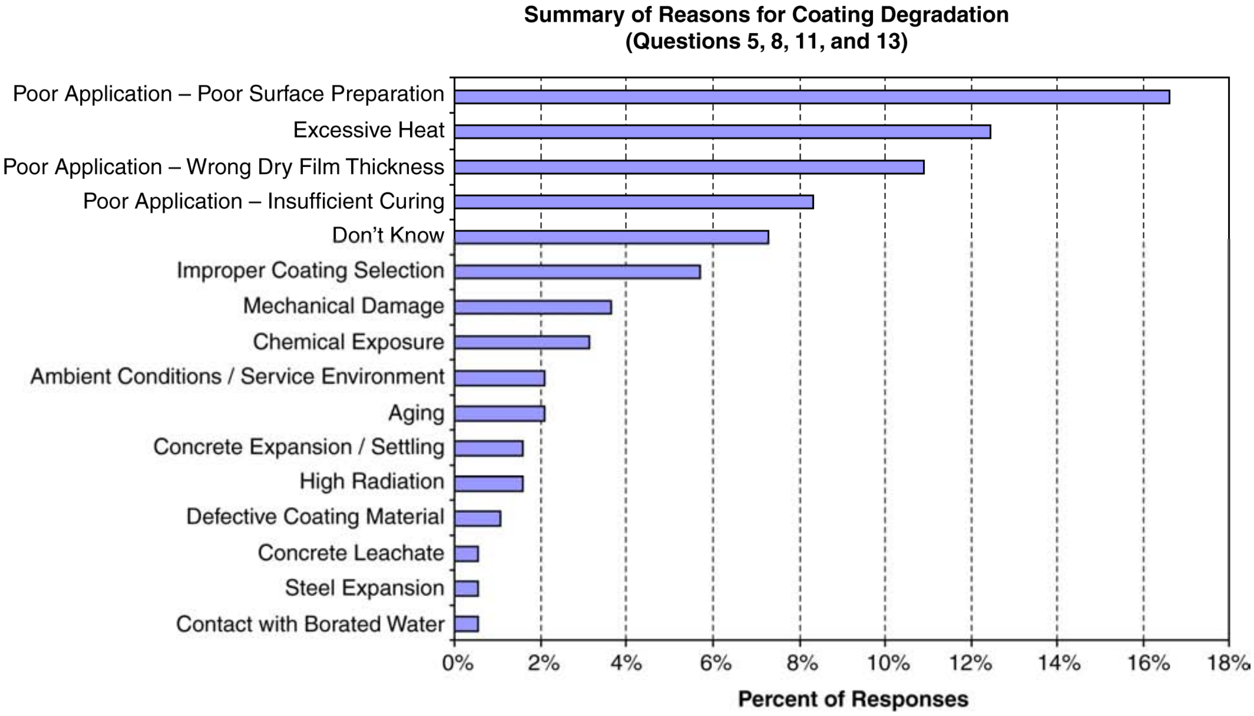


Figure 4-4
Summary of Reasons for Coating Degradation

When the reasons for coating degradation are aggregated (and "don't know" responses are eliminated), deficiencies occurring at the time of the coating system application (poor application—surface preparation, wrong dry film thickness, or insufficient curing; improper coating selection; defective coating material) aggregate to 60%. The operating environment (excessive heat, mechanical damage, chemical exposure, aging, ambient service environment, high radiation, concrete expansion/settling, borated water, steel expansion, concrete leachate) is the apparent cause for 40% of the degradation. If mechanical damage and concrete expansion/settling, neither of which are taken into consideration as part of a coating system's design parameters, are also eliminated from the results, 65% of degradation is attributed to application variables, and 35% to operating environment.

4.6 Documented Failure Analyses

The survey also asked whether a failure analysis had been documented for any reported coating degradation. Only five analyses were available. A summary of each follows:

- Use of nonqualified coatings due to an apparent lack of appropriate prime contractor oversight was reported. Approximately 15,000 square feet (1400 square meters) of nonqualified material was applied.
- Documentation was supplied, but it did not address reasons for coating failure. The documentation did report that flaking/damaged coating was identified between the inner and middle sump screens.

- Service Level 1 coating degradation was observed on piping downstream of the main steam system safety relief valve (SRV) tailpipes from prior outage inspections. Evaluation concluded that the degradation was likely due to “pipe temperatures reaching up to 325ºF (163ºC) during SRV testing performed during startup following each refueling outage and when SRV lifts occur during operations. These original construction coatings have become brittle by polymer cross-linking, which is common in these types of epoxy coatings as they age. Therefore, the coatings on SRV tailpipes are blistering/flaking due to age and thermal transients which caused the piping to expand and contract.” The affected coating was Keeler & Long 7107 epoxy, and the degraded area was conservatively estimated to be 158 square feet (14.7 square meters).
- Coating failure of a system consisting of Carboline CZ-11 / 305 was reported on containment fan cooler unit (CFCU) fan housings. An investigation described the following: “A large shard of paint was found delaminated. As a result, visual inspections were performed on the CFCU fan housings. As a result of the visual inspection, adhesion/cohesion testing was performed on all 5 CFCU fan housings. All of the paint on the CFCU fan housings was found to be defective. The failure mode appears to be excessive dry film thickness of the zinc primary coat. This constitutes approximately 1000 sq. ft. of defective coatings.”
- Two incidents of degraded coatings on service water pipes near sump screens were reported. When examined by applying a moderate amount of pressure with a dull putty knife, the coatings scratched and flaked easily in most areas. Possible explanations include aging and/or improper surface preparation or poor environmental conditions during original construction.

4.7 Environmental Stressors

The data concerning reasons for coating degradation, as previously discussed, provide the best basis for determining environmental stressors. The primary environmental stressor that was included in the responses was excessive heat, which was also identified in one of the failure analyses summarized above. Overall, excessive heat was given as the reason for coating degradation in 15% of the responses (based on data shown in Table 4-3). Other reasons that could be classified as environmental stressors were chemical exposure (4%), concrete or steel expansion (3%), and high radiation (2%). (The percentages given in parentheses represent the total combined responses for each reason.)

Excessive heat is clearly the environmental stressor that has caused the most issues with coating degradation. Most generic coatings, aside from inorganic zincs, are believed to be degraded over time by high temperatures, with the degree of degradation dependent on the maximum temperature of exposure and the duration of the exposure. Although qualified coating systems are undoubtedly chosen on the basis that they can withstand the expected service environment, excessive heat should be considered as a concern in the degradation of coatings.

Additional coating stressors within primary containment that were not explicitly mentioned by survey respondents include integrated leak rate testing (ILRT), and fluctuating temperatures and humidities during outages.

4.8 Analysis by Substrate and Generic Coating System Type

4.8.1 Steel Coating Systems

The data summary in Table 4-1 (Generic Coating Systems for Steel: Good Versus SD Surface Areas) showed an overall average of 5.6% SD, and identified that five of the generic coating systems used for steel have higher than a 2% SD surface area (the 2% cutoff point was chosen based on a simple review of all the SD percentages in Table 4-1). The data from these five generic systems received further analysis as follows:

- IOZ Primer / MPE Topcoat: 2,888,959 ft^2 total area, 9.2% SD; see Table 4-4
- IOZ Primer / Epoxy Topcoat: 1,923,406 ft^2 total area, 3.0% SD; see Table 4-5
- IOZ Primer (Untopcoated): 1,141,609 ft^2 total area, 5.7% SD; see Table 4-6
- Epoxy Primer (Untopcoated): 455,250 ft^2 total area, 2.6% SD; see Table 4-7
- MPE Primer (Untopcoated): 261,400 ft^2 total area, 26.0% SD; see Table 4-8

Table 4-4
IOZ Primer / MPE Topcoat System

IOZ Primer / MPE Topcoat	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
Ameron D-6 / 90	265,780	120	0.0%
Ameron D-6N / 90	118,760	0	0.0%
Carboline CZ-11 / 305	2,153,364	165,928	7.2%
Carboline CZ-11SG / 305	240,000	50,138	17.3%
Carboline CZ-11 / 368	58,000	18,000	23.7%
Carboline CZ-11 / 368 WG (or C890)	18,500	29,999	61.8%
Carboline CZ-11SG / Ameron 90	34,555	30,000	46.5%
Summation of above lines	2,888,959	294,185	9.2%

1 $ft^2 = 0.093\ m^2$

Table 4-4 shows that the most widely used system was the Carboline CZ-11 / 305 combination. The SD percent of total area for these Carboline coatings was higher than the average 6.0%. The other Carboline MPE topcoats, 368 or 368 WG, represented significantly less surface area, but also had higher SD areas. In comparison, the Ameron D-6 (or D-6N) / 90 system had virtually no reported SD surface area. The combination of Carboline CZ-11SG / Ameron 90, having a relatively small surface area, had a high SD rate.

Table 4-5
IOZ Primer / Epoxy Topcoat System

IOZ Primer / Epoxy Topcoat	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
Ameron D-6 / 66	260,200	2,750	1.0%
Carboline CZ-11 / 190HB / 191HB	90,000	0	0.0%
Carboline CZ-11 / 191HB	370,800	1	0.0%
Carboline CZ-11SG / 191HB	34,555	0	0.0%
Carboline CZ-11SG / 890	1,000	3,000	75.0%
Carboline CZ-11SG / Dupont Corlar 823	109,600	50,800	31.7%
Mobil/Valspar 13-F-12KR-00 MZ#7 / 76 Series-00 HB Epoxy	500,000	400	0.1%
Mobil/Valspar 13-F-12KR-00 MZ#7 / 89 Series-00 Enamel	500,000	300	0.1%
Summation of above lines	1,866,155	57,251	3.0%

1 ft^2 = 0.093 m^2

Mobil/Valspar 13-F-12KR-00 MZ#7 (referred to as *Mobil Zinc #7*) is an IOZ similar to CZ-11. Both are ethyl silicate acid-catalyzed types. The Mobil/Valspar IOZ was not used as a stand-alone IOZ primer and appears only in combination with the 76 and 89 series Valspar epoxy topcoats named in Table 4-5. This table shows that Ameron, Carboline, or Mobil/Valspar systems represent the vast majority of system use, with little reported SD surface area. The only product system with significant usage that stands out is the Carboline / Dupont Corlar combination, with a high percentage of SD surface area.

Table 4-6
IOZ Primer (Untopcoated) System

IOZ Primer (Untopcoated)	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
Ameron D-6 or D-6N	295,320	28,000	8.7%
Carboline CZ-11 or 11SG	781,340	36,949	4.5%
Summation of above lines	1,076,660	64,949	5.7%

1 ft^2 = 0.093 m^2

The data in Table 4-6 show a higher rate of degradation for Ameron primers than for Carboline primers, although both percentages are relatively low. The Carboline primers were used on substantially more surface area than the Ameron products. Based upon the coating manufacturers' responses presented in Appendix A, D-6 and D-6N are generically equivalent materials, with the N denoting nuclear. (N-grade coatings require more manufacturing documentation than their nonnuclear commercial equivalents.) D-6 is a base-catalyzed ethyl silicate IOZ. Similarly, CZ-11SG (specification grade) is the nuclear equivalent of CZ-11 commercial grade. CZ-11 is an acid-catalyzed ethyl silicate IOZ.

Table 4-7
Epoxy Primer (Untopcoated) System

Epoxy Primer	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
Carboline 801	0	1,000	100%
Carboline 890	1,500	0	0%
K&L 7475	32,750	0	0%
Mobil 78	409,250	10,750	2.6%
Summation of above lines	443,500	11,750	2.6%

1 ft^2 = 0.093 m^2

As shown in Table 4-7, the line item for the untopcoated epoxy primer system that drove the SD percentage to 2.6% was the Mobil 78. The survey respondent noted that the cause of the SD was “poor application; insufficient curing.” Regarding the Carboline 801, the survey respondent noted that the cause of the SD was “improper coating selection; insufficient curing; poor surface prep.”

Table 4-8
MPE Primer (Untopcoated) System

MPE Primer	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
Ameron 90	50,000	400	0.8%
Carboline 368 WG (or C890)	55,890	110	0.2%
Plasite 7155	0	67,000	100.0%
Plasite 7155H	87,600	400	0.5%
Summation of above lines	193,490	67,910	26.0%

1 ft^2 = 0.093 m^2

As shown in Table 4-8, for the single-coat MPE primer systems, Plasite 7155 stands out as having a high total for SD surface area. The survey respondent noted that the cause of the SD was “poor application; insufficient curing.” The other MPE coatings had little reported SD area.

4.8.2 Concrete Coating Systems

The data summary in Table 4-2 (Generic Coating Systems for Concrete: Good Versus SD Surface Areas) showed an overall average of 7.4% SD, and identified that five of the generic coating systems used for steel have higher than a 2% SD surface area (the 2% cutoff point was chosen based on a simple review of all the SD percentages in Table 4-2). The data from these five generic systems received further analysis as follows:

- Epoxy Surfacer / Epoxy Topcoat: 881,400 ft^2 total area, 3.6% SD; see Table 4-9
- Epoxy Surfacer / MPE / MPE Topcoat: 215,800 ft^2 total area, 26.2% SD; see Table 4-10
- Epoxy Surfacer / MPE Topcoat: 187,320 ft^2 total area, 41.7% SD; see Table 4-11
- MPE Primer: 63,000 ft^2 total area, 2.5% SD; see Table 4-12
- MPE Primer / MPE / MPE Topcoat: 3,000 ft^2 total area, 100.0% SD; see Table 4-13

Table 4-9
Epoxy Surfacer / Epoxy Topcoat System

Epoxy Surfacer / Epoxy Topcoat	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
Ameron Nu-Klad 110AA / 66	82,000	0	0.0%
Carboline 195 / 191HB	27,900	500	1.8%
Carboline 2011S / 890	160,000	0	0.0%
Mobil/Valspar 46-X-29KR-00 / 76 Series Topcoat	280,000	900	0.3%
Mobil/Valspar 46-X-29KR-00 / 89 Series Topcoat	170,000	100	0.1%
NuKlad 110AA / Ameron Amercoat 66	70,000	0	0.0%
Plasite 9028M1 / 9009	60,000	30,000	33.3%
Summation of above lines	849,900	31,500	3.6%

1 ft^2 = 0.093 m^2

Table 4-9 represents the generic coating system most widely used on concrete, consisting of an epoxy primer and epoxy topcoat. Little SD area was reported except for the Plasite 9028M1 / 9009 system, which represented a relatively small amount of the total surface are a for this generic system. The survey respondent noted that the cause of the SD was “laitance [milky deposit on the surface of new cement or concrete, usually caused by too much water] from concrete.”

Table 4-10
Epoxy Surfacer / MPE / MPE Topcoat System

Epoxy Surfacer / MPE / MPE Topcoat	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
Carboline 195 / 305 / 305	159,300	56,500	26.2%
Summation of above lines	159,300	56,500	26.2%

1 ft^2 = 0.093 m^2

The generic system represented in Table 4-10, Carboline 195 surfacer coated with Carboline 305 MPE, with an additional coat of the Carboline 305, consisted of just one product type, with a high percentage of SD area. The survey respondents noted that the causes of the SD were "poor surface prep; insufficient curing; wrong DFT; excessive heat" in one case and "excessive heat" in the other.

Table 4-11
Epoxy Surfacer / MPE Topcoat System

Epoxy Surfacer / MPE Topcoat	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
Carboline 195 / 305	109,200	78,120	41.7%
Summation of above lines	109,200	78,120	41.7%

1 ft^2 = 0.093 m^2

The generic system represented in Table 4-11 had only one product type, Carboline 195 surfacer and Carboline 305 MPE topcoat, with a high percentage of SD area. The survey respondent reporting a majority of the SD noted that the cause of the SD was "insufficient curing; wrong DFT."

Table 4-12
MPE Primer (Untopcoated) System

MPE Primer (Untopcoated)	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
Carboline 305	61,400	1,600	2.5%
Summation of above lines	61,400	1,600	2.5%

1 ft^2 = 0.093 m^2

Only one plant responded as having used the system represented in Table 4-12. The survey respondent noted that the cause of the SD was "poor surface prep; improper curing."

Table 4-13
MPE Primer / MPE / MPE Topcoat System

MPE Primer / MPE / MPE Topcoat	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
Carboline 305 / 305 / 195	0	3,000	100.0%
Summation of above lines	0	3,000	100.0%

1 ft^2 = 0.093 m^2

Only one plant responded as having used the system represented in Table 4-13. The survey respondent noted that the cause of the SD was “poor surface prep; wrong DFT.”

4.9 Installation Date

An analysis of the surface area data was performed with respect to the installation date or age of the coating systems. The installation date data were analyzed in a variety of ways, including by specific years, by a range of specific years, or by a general range (for example, 1970s). To allow for a meaningful review of this data, the initial year of date ranges was used as the basis for categorizing the data into 5-year intervals by substrate. The data are presented in Table 4-14.

Table 4-14
Surface Area Data Categorized by Installation Date and Substrate

Substrate	Installation Date Range	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
Concrete	1968–74	510,800	57,730	10%
	1975–79	755,500	38,000	5%
	1980–84	376,690	550	0.1%
	1985–89	110,600	900	0.8%
	1990–94	370,000	75,000	17%
	1995–99	33,000	0	0%
	2000–06	4,400	500	10%
Steel	1968–74	2,626,238	150,687	5%
	1975–79	1,965,390	27,900	1%
	1980–84	2,219,540	190,551	8%
	1985–89	199,600	62,098	24%
	1990–94	532,390	61,110	10%
	1995–99	192,850	6,000	3%
	2000–06	35,900	0	0%

1 ft^2 = 0.093 m^2

Somewhat surprisingly, the data do not show the highest percentages of SD to be associated with the oldest coatings. For both steel and concrete substrates, the highest percentage of SD area occurs more toward the middle of the year ranges, and for steel substrates, the three highest percentages fall into this intermediate area. The pattern can be seen even more clearly in Figure 4-5, where the data are represented graphically. This interesting data profile may be the result of when repairs were made to coatings and how the data were reported. For example, it is conceivable that the data for the oldest coatings (which would be expected to have a larger percentage of SD area based on aging concerns) may show a lower percentage of SD area than the data for intermediate-age coatings because some of the older coatings have been repaired and are currently in good condition as a result.

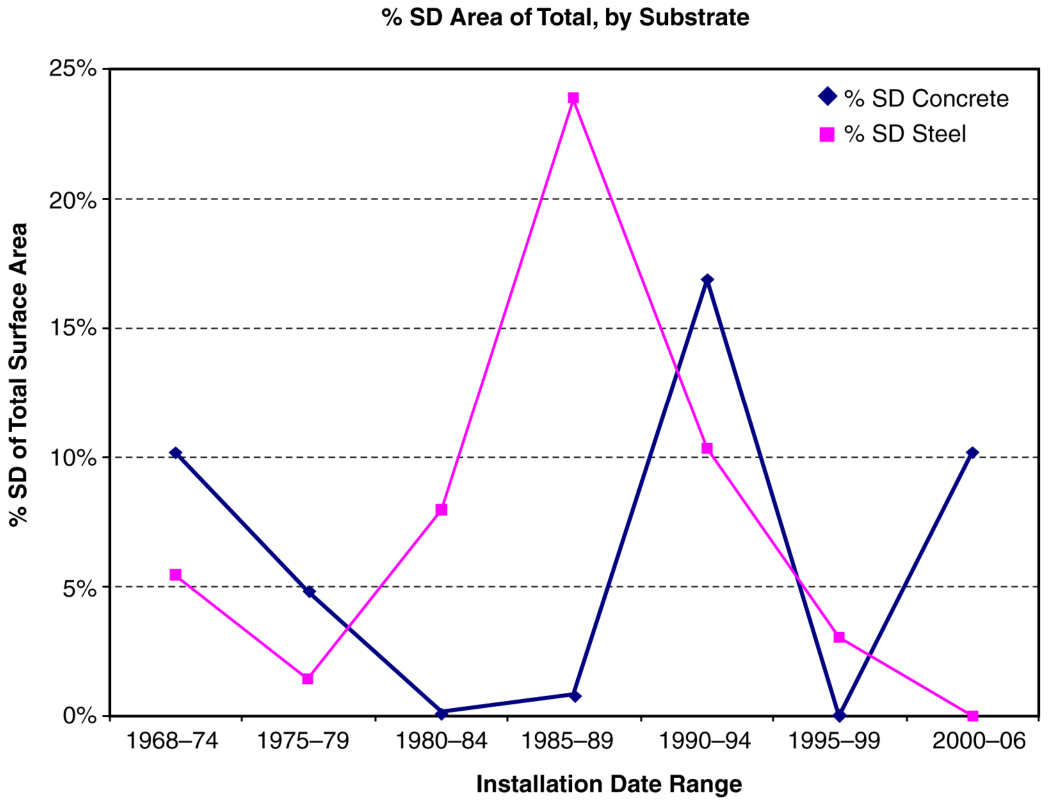


Figure 4-5
Comparison of Percent SD Area to Total Area by Installation Date and Substrate

Table 4-15 shows a further breakdown of the data based on installation date for several of the generic coating systems for which higher percentages of SD area were reported.

Table 4-15
Generic Coating System by Installation Date (Selected Systems with the Highest SD)

Generic Coating System	Installation Date Range	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
Epoxy Surfacer / Epoxy / Epoxy Surfacer	1980–84	19,800	500	2.5%
	1985–89	19,800	500	2.5%
	1995–99	20,000	0	0.0%
	2000–06	4,400	500	10.2%
Epoxy Surfacer / MPE / MPE Topcoat	1968–74	80,800	50,000	38.2%
	1975–79	78,500	6,500	7.6%
Epoxy Surfacer / MPE Topcoat	1968–74	61,200	3,120	4.9%
	1980–84	48,000	0	0.0%
	1990–94	0	75,000	100.0%
IOZ Primer	1968–74	375,550	950	0.3%
	1975–79	266,790	0	0.0%
	1980–84	418,920	34,000	7.5%
	1985–89	15,400	29,999	66.1%
IOZ Primer / Epoxy Topcoat	1968–74	260,200	1,650	0.6%
	1975–79	1,054,800	25,900	2.4%
	1980–84	550,155	25,201	4.4%
	1995–99	1,000	4,500	81.8%
IOZ Primer / MPE Topcoat	1968–74	1,384,480	145,949	9.5%
	1975–79	33,800	2,000	5.6%
	1980–84	578,815	53,600	8.5%
	1985–89	0	29,999	100.0%
	1990–94	210,000	60,000	22.2%

1 $ft^2 = 0.093\ m^2$

Table 4-15 does not show any clear trends for generic systems. For some of the systems, the highest percentages of SD areas occur in the early date ranges, whereas for others, the highest percentages of SD areas occur in the more recent ranges.

4.10 Plant Type and Reactor Type

Surface area data were also broken down by plant type and by the reactor subtype for each plant. The results are presented in Table 4-16.

Table 4-16
Surface Area Data by Reactor Type

Reactor Type	Reactor Subtype (See Note)	Good Surface Area (ft^2)	SD Surface Area (ft^2)	SD Percent of Total Area
BWR	GE-a Total	589,570	97,026	14.1%
BWR	GE-b Total	956,940	97,650	9.3%
BWR Total		1,546,510	194,676	11.2%
PWR	B&W Total	1,291,800	116,550	8.3%
PWR	CE-a Total	900,608	52,618	5.5%
PWR	CE-b Total	943,250	2,750	0.3%
PWR	W-a Total	388,400	6,120	1.6%
PWR	W-b Total	1,005,800	149,011	12.9%
PWR	W-c Total	458,500	6,500	1.4%
PWR	W-d Total	3,418,530	142,801	4.0%
PWR Total		8,406,888	476,350	5.4%

$1\ ft^2 = 0.093\ m^2$

Note:
Reactor subtypes were defined by NRC Plant Peer Groups. GE-a is General Electric plants, BWR-1, BWR-2, BWR-3, and older BWR-4; GE-b is General Electric plants, newer BWR-4, BWR-5, and BWR-6; B&W is Babcock & Wilcox plants; CE-a is Combustion Engineering plants without core protection calculators; CE-b is Combustion Engineering plants with core protection calculators; W-a is Westinghouse small plants; W-b is Westinghouse older three-loop plants; W-c is Westinghouse older four-loop plants; W-d is Westinghouse newer four-loop plants.

Table 4-16 shows that the percentage of SD area reported by BWR plants is approximately twice that reported by PWR plants. BWR plants represent 16% of the reported total surface area. The higher percentage of SD area may be the result of a more severe containment service environment for coatings in BWR plants. This is likely due to the smaller dry well containment of the BWR design, and perhaps the associated higher temperatures and radiation closer to the reactor vessel. Also, the suppression chamber, containing deionized water, has a more demanding service environment than the PWR nonimmersion containment.

4.11 Specific Product Systems

Table 14-17 presents a summary of each coating system, the number of nuclear plants with that system somewhere within primary containment (the top 3 Good or SD systems), and the total surface area in square feet of each specific product system.

Table 4-17
Product Names for Each Generic Coating System

Generic Coating System	Product Names	Plants	Total Surface Area (ft^2)	SD Percent of Total Area
Epoxy Mastic	Ameron Amerlock 400NT	3	18,000	0.6%
Epoxy Primer	Ameron 66N	2	16,000	0.0%
	Carboline 1340	2	10,000	0.0%
	Carboline 191HB	1	1,000	0.0%
	Carboline 801	1	1,000	100.0%
	Carboline 890	1	1,500	0.0%
	K&L 7475	1	32,750	0.0%
	Mobil 78	2	420,000	2.6%
	Mobil 84-V-2	1	48,000	0.0%
Epoxy Primer / Epoxy / Epoxy Topcoat	K&L 6548/7107 / D Series / D Series	2	20,000	0.0%
	K&L 6548/7107 / E Series / E Series	2	200,000	0.0%
	K&L 7107 / 7107 / 7475	1	25,000	0.0%
Epoxy Primer / Epoxy Topcoat	Ameron 66 / 66	1	100,000	0.0%
	Carboline 193LF / 191HB	1	1,000	0.0%
	Carboline 801 / 890	2	See Note	—
	Carboline 890 / 890	10	234,750	0.0%
	Carboline 890 / 890N	2	See Note	—
	Carboline Starglaze / 1201	1	75,000	0.0%
	Dupont Corlar 823 / 823	4	32,000	0.0%
	Imperial Starglaze 2011S / Nutec 1201	1	153,040	0.0%
	K&L 6129 / 4500	1	12,000	0.0%
	K&L 6548 / 7107	1	35,500	0.0%
	K&L 6548 / 9140	1	2,500	100.0%
	K&L 6548 / Epoxy Enamel	1	See Note	—
	K&L 6548/7017 / 7475	2	See Note	—
	K&L 6548/7101 / 7475	2	160	100.0%
	K&L 6548/7107 / 7475	2	58,000	0.0%
	K&L 6548/7107 / Carboline 801	1	See Note	—
	K&L 6548/7107 / E series	2	160,000	0.0%
	K&L 6548/7107 / E series or D series	1	100,000	0.0%

Table 4-17 (continued)
Product Names for Each Generic Coating System

Generic Coating System	Product Names	Plants	Total Surface Area (ft^2)	SD Percent of Total Area
	K&L 6548/7107 / E-1	1	5,000	0.0%
	K&L 6548/7107 / E-1-1860	1	400	0.0%
	K&L 7107 / 7475	2	See Note	—
	K&L 7107 / 7500	1	35,000	0.0%
	K&L 7107 / E series	4	40,000	0.0%
	Mobil 84 / Mobil 89	1	30,000	0.0%
	Nutec 6 / 1201	2	150,000	0.0%
	Starglaze 2011S / Nutec 1201	2	20,000	0.0%
	Stoneliner 5 / Tnemec 66	2	8,000	0.0%
Epoxy Primer / MPE Topcoat	Ameron 110a / 90	1	10,000	0.0%
	Ameron 114 / 90	1	200,000	0.0%
	Ameron 71 / 90	1	400,000	0.0%
Epoxy Surfacer	Ameron Nukem 108	1	58,000	0.0%
Epoxy Surfacer / Epoxy / Epoxy Surfacer	K&L 4000 / 4129 / D-1-1940	1	See Note	—
	K&L 4129 / 4000 / D-1 Series	1	40,600	2.5%
	K&L 4129 / 4000 / D-1-9140	1	4,900	10.2%
	K&L 5000	2	20,000	0.0%
Epoxy Surfacer / Epoxy Topcoat	Ameron Nu-Klad 110AA / 66	1	82,000	0.0%
	Carboline 195 / 191HB	2	28,400	1.8%
	Carboline 2011S / 890	4	160,000	0.0%
	Mobil/Valspar 46-X-29KR-00 / 76 Series Topcoat	4	280,900	0.3%
	Mobil/Valspar 46-X-29KR-00 / 89 Series Topcoat	2	170,100	0.1%
	NuKlad 110AA / Ameron Amercoat 66	1	70,000	0.0%
	NuKlad 114 / Ameron Amercoat 66	1	See Note	—
	Plasite 9028M1 / 9009	1	90,000	33.3%
Epoxy Surfacer / MPE / Epoxy Topcoat	Carboline 195 / 305 / 890	1	1,000	0.0%
Epoxy Surfacer / MPE / MPE Topcoat	Carboline 195 / 305 / 305	4	215,800	26.2%
Epoxy Surfacer / MPE Topcoat	Carboline 195 / 305	11	187,320	41.7%

Table 4-17 (continued)
Product Names for Each Generic Coating System

Generic Coating System	Product Names	Plants	Total Surface Area (ft^2)	SD Percent of Total Area
IOZ Primer	Ameron D-6	3	152,000	0.0%
	Ameron D-6N	3	171,320	16.3%
	Carboline CZ-11	8	226,340	15.0%
	Carboline CZ-11 / Inorganic White	1	80,850	1.1%
	Carboline CZ-11SG	9	511,099	0.4%
IOZ Primer / Epoxy Topcoat	Ameron D-6 / 66	6	262,950	1.0%
	Carboline CZ-11 / 190HB / 191HB	1	90,000	0.0%
	Carboline CZ-11 / 191HB	2	370,801	0.0%
	Carboline CZ-11 / 890	1	See Note	—
	Carboline CZ-11 / 890N	1	See Note	—
	Carboline CZ-11 / Ameron 66 or 90	1	See Note	—
	Carboline CZ-11SG / 191HB	1	34,555	0.0%
	Carboline CZ-11SG / 890	1	4,000	75.0%
	Carboline CZ-11SG / Dupont Corlar 823	4	160,400	31.7%
	Mobil/Valspar 13-F-12KR-00 MZ#7 / 76 Series-00 HB Epoxy	2	500,400	0.1%
	Mobil/Valspar 13-F-12KR-00 MZ#7 / 89 Series-00 Enamel	2	500,300	0.1%
IOZ Primer / MPE / MPE Topcoat	Carboline CZ-11 / 305 / 305	1	72,836	1.5%
IOZ Primer / MPE Topcoat	Ameron D-6 / 90	9	275,900	0.1%
	Ameron D-6N / 90	2	118,760	0.0%
	Carboline CZ-11 / 305	20	2,319,292	7.2%
	Carboline CZ-11 / 368	2	76,000	23.7%
	Carboline CZ-11 / 368 WG (or C890)	2	48,499	61.8%
	Carboline CZ-11SG / 305	5	290,138	17.3%
	Carboline CZ-11SG / Ameron 90	2	64,555	46.5%
MPE Primer	Ameron 90	6	50,400	0.8%
	Carboline 305	1	63,000	2.5%
	Carboline 368 WG (or C890)	1	56,000	0.2%
	Carboline Phenoline 368	1	See Note	—
	Plasite 7155	1	67,000	100.0%
	Plasite 7155H	2	88,000	0.5%

Table 4-17 (continued)
Product Names for Each Generic Coating System

Generic Coating System	Product Names	Plants	Total Surface Area (ft^2)	SD Percent of Total Area
MPE Primer / Epoxy Topcoat	Plasite 7155NP / 9009	2	200,000	0.0%
MPE Primer / MPE / MPE Topcoat	Carboline 305 / 305 / 195	1	3,000	100.0%
MPE Primer / MPE Topcoat	Ameron 90 / 90	5	158,400	0.0%
	Carboline Phenoline 300 / 300	1	40,010	0.0%
Modified Vinyl Primer / Vinyl Copolymer Topcoat	Carboline Rustbond Primer 6C / Polyclad 933-1	1	169,000	0.9%

1 ft^2 = 0.093 m^2

Note: In these cases, product was reported to be in use, but a square footage amount was not supplied by respondent.

4.12 Conclusions

A survey of U.S. nuclear plants was conducted to gather data on the condition of coatings within primary containment. A total of 55 responses was received, which represented 83% of the U.S. nuclear power plant fleet. The survey asked respondents to provide information on coating systems that had **not** exhibited degradation (categorized as “Good”) and on systems that showed signs of degradation (categorized as “SD”). Among the data collected were details on the specific composition of the coating systems, dates of installation of the coatings, location within containment, description of the degradation, estimated surface areas, and presumed causes of the degradation.

Some of the more salient conclusions that can be drawn from the data are the following:

- One particular type of coating was associated with signs of degradation more frequently and consistently than other types. This was modified phenolic epoxy coating, or MPE.
  - In analysis of generic systems used on steel substrates, an inorganic zinc-rich (IOZ) primer paired with an MPE topcoat showed approximately twice the amount of area with signs of degradation as other generic systems. Further analysis of specific product combinations used in these systems implicates the MPE topcoat, and not the primer, as being associated with the degradation.
  - In systems applied to concrete substrates, MPE coatings were a component of most systems where the percentages of area with signs of degradation were relatively high. Although systems involving MPE coatings were not among the most widely used for concrete (total usage was reported as 31%), they were involved in 81% of the total surface area reported as showing signs of degradation.

  - MPE coatings are widely used inside containment, and much of the total area covered with MPE-based materials was in fact reported to be in good condition. Nonetheless, the number of cases involving an association of MPE with signs of degradation naturally arouses interest. Although the reason is not immediately apparent, based on experience a possible explanation is that MPE coatings appear to be more sensitive to application variables, including faulty application, than are some other types of coating. Application issues do appear to play a major role in coating degradation, as noted next.
  - There are several brand-name products that fall within the generic product category referred to as MPE, and the data show a wide range in the percentages of area with signs of degradation associated with each. In other words, there are differences between the various products, and some appear to perform significantly better than others.
- Because failure analysis information was provided in only a handful of cases, it is difficult to draw broad-based conclusions regarding causes for reported degradation. However, an analysis of the data does provide a statistical profile of the most common reasons. Taken together, coating application issues (surface preparation, thickness of the applied coating, or sufficiency of curing) were the most commonly reported cause.
- The most frequently reported visual evidence of coating degradation was delamination, followed by blistering, cracking, and flaking. These findings are consistent with the data regarding presumed causes of degradation, because symptoms such as delamination and blistering are often associated with coating application problems.
- Although the role of aging is an open question that is still the subject of ongoing research, the survey did collect statistical data on installation dates (age of systems). Analysis of these data does **not** appear to support the hypothesis that aging is a major degradation mechanism.

5
REFERENCES

5.1 References Cited in the Report

1. Kenneth B. Tator, KTA-Tator, Inc., “Methods of Corrosion Protection,” *ASM Handbook, Volume 13A, Corrosion: Fundamentals, Testing, and Protection.* October 2003, p. 826.
2. Gerald Eccleston, “The Effect of Cure Temperature and Humidity on the Properties of Solvent-Borne Zinc Silicate Coatings,” *Journal of Protective Coatings*. January 1998, pp. 36–45.
3. Kenneth B. Tator, KTA-Tator, Inc., “Methods of Corrosion Protection,” *ASM Handbook, Volume 13A, Corrosion: Fundamentals, Testing, and Protection.* October 2003, p. 836.
4. Kenneth B. Tator, KTA-Tator, Inc., “Degradation of Protective Coatings,” *ASM Handbook, Volume 13B, Corrosion: Materials.* November 2005, pp. 589–599.
5. Kenneth B. Tator, KTA-Tator, Inc., “Organic Coatings and Linings,” *ASM Handbook, Volume 13A, Corrosion: Fundamentals, Testing, and Protection.* October 2003, p. 827.
6. Kenneth B. Tator, KTA-Tator, Inc., “Methods of Corrosion Protection,” *ASM Handbook, Volume 13A, Corrosion: Fundamentals, Testing, and Protection*. October 2003, p. 838.
7. Kenneth B. Tator, KTA-Tator, Inc., Organic Coatings and Linings,” *ASM Handbook, Volume 13A, Corrosion: Fundamentals, Testing, and Protection.* October 2003, p. 829.
8. Kenneth B. Tator, Kenneth Tator Associates, “How Coatings Protect and Why They Fail,” Corrosion/77: The International Corrosion Forum Devoted Exclusively to the Protection and Performance of Materials, San Francisco, CA, March 14–18, 1977.

5.2 Other References

Clive H. Hare, *Protective Coatings, Fundamentals of Chemistry and Composition*. Technology Publishing Company, Pittsburgh, PA. 1994.

G. P. A. Turner, *Introduction to Paint Chemistry, 2nd Ed.* Chapman and Hall, New York, 1980.

A

MANUFACTURERS' INPUT ON SERVICE LEVEL I COATINGS

The three main manufacturers of coatings used by the nuclear facilities in this survey are Ameron, Carboline, and PPG/Keeler & Long. A series of questions was submitted for their input, and the questions along with the manufacturers' responses are reproduced in this appendix. EPRI and KTA-Tator, Inc. appreciate the efforts of each of the coating manufacturers in submitting the comprehensive data regarding their coating products and systems. All responses are reproduced with the permission of the manufacturers.

The information presented this appendix is reproduced essentially as submitted by the coating manufacturers. Each manufacturer responded using a different format, and in some cases, minor formatting changes have been made in order to improve readability or to meet specifications for publication of the report. However, every attempt has been made to reproduce the manufacturers' responses with no alterations to the original text.

The responses of the coating manufacturers are presented in alphabetical order. Ameron answered questions about the Mobil Valspar systems. Carboline included information about Wisconsin Protective Coatings/Plasite and Southern Imperial Coatings nuclear coating materials. PPG/Keeler and Long responded regarding the Keeler & Long products that are now part of PPG. The Ameron protective coatings group (including all nuclear coatings) has also been purchased by PPG.

The questions asked of each coating manufacturer are as follows:

QUESTIONS

In the initial responses to the EPRI survey, the following <MANUFACTURER> coatings were used within primary containment of nuclear facilities:

<LIST OF COATING SYSTEMS>

A. I have the following questions regarding these materials/systems:
   1. Do you have product data sheets for these materials:
      a. old product data sheets (circa 1970-or earlier, when used)?
      b. recent product data sheets?

   2. Do you still manufacture/supply all of these materials:
      a. please list all that you presently supply for Service 1 containments

   b. please list all that you presently supply, even if not nuclear grade
   c. for those you still supply, has the product name changed? If so, please list the old and corresponding new names.
   d. for those you still supply, has the formulation changed? If so, please list and provide generic (non-proprietary) information for the reason of the formulation change, and the nature of the changes made.

3. Do you manufacture any new Service Level I nuclear coatings not listed above-if so, please list.

B. EPRI's Tim Eckert recently sent you an e-mail, from which the following is extracted:

"Task 3: For each and every identified generic coating type, the contractor will provide a discussion of:

- The chemistry of the coating, including key similarities and differences in the various types.
- Discuss why the coating type was selected for a given application.
- Known failure mechanisms.
- The sensitivities of the coating to application parameter variations.
- Example of generic coating types identified are:
  - Inorganic Zinc
  - Acid catalyzed
  - Base catalyzed
  - Epoxy
  - Phenolic
  - Amine
  - Amide
  - Modified Phenolic epoxy
  - Others

This email is a request for <MANUFACTURER> to provide some material (text, literature, etc.) to fulfill the above task, specifically for the Inorganic zinc. I would also like to broaden the scope to include some material for the Modified Phenolic Epoxy and other products that <MANUFACTURER> produces for the nuclear industry. Along with the material supplied, please include appropriate verbiage that will allow EPRI to reproduce the material in our report, with due reference and/or acknowledgement of course."

1. Will you <MANUFACTURER> submit information or material I can use to respond to these questions? I would very much appreciate any assistance you can provide, both in a general sense, and specifically regarding the products you manufacture.

C. The following is an excerpt from a letter Brian W. Sheron, Associate Director for Engineering and Safety Systems, Office of Nuclear Reactor Regulation wrote to Anthony R. Pietrangelo, NEI

> "NEI has stated that visual "precursors" were found to exist in all documented instances of degradation of reactor containment coatings. The NRC staff interprets observed visual degradation to mean that the coating systems in fact failed to meet their design requirements before visual indications existed, and had physical testing of the containment coatings been performed on a routine basis, the degradation would have been identified before visual indication appeared. Coatings that exhibit visual signs of degradation most likely have been in a degraded state for an extended period, representing a source of debris in a design-basis accident."

1. In light of the above, what inspection techniques would you recommend for the future inspection of <Manufacturer's> coating systems within primary containment to ensure the coating system meets it's design requirements?
    a. Visual inspection techniques
    b. Non-visual techniques
    c. non-destructive
    d. destructive
    e. other?
    f. Comments on coating inspection methods

2. Are your coating inspection recommendations suitable for all <MAUFACTURER>'s systems, or should there be different techniques for specific coating systems; substrates (steel/concrete); or for other reasons?

Ameron

Electric Power Research Institute (EPRI) - KTA-TATOR Information Request

NUCLEAR COATING MANUFACTURER'S SURVEY
AMERON

Submitted by Jim McCarthy

1a & b. We do keep historical product data sheets. Theoretically, every PDS revision is kept in our files, but in practicality, there are gaps in the revision history. I've pulled the oldest and newest PDS in each file to send to you.

- Dimetcote 6N dated February 1985
- Amercoat 66 Primer dated October 1968
- Amercoat 66 dated February 1986
- Amercoat 90 dated February 1981 and September 1984
- Nu-Klad 114 dated May 1986
  Nu-Klad 114 Technical Data Sheet dated October 1978
- Nulem All Purpose Resinous Cement, Technical Data Sheet dated November 1962
- Nu-Klad 110AA dated December 1982 and February 1985
- Amerlock 400 dated January 1983 and March 2005

2a. The following systems have been approved for Service Level I for many years:

- Dimetcote 6/Amercoat 90 (carbon steel)
- Dimetcote 6/Amercoat 90(repair)/Amercoat 90 (carbon steel)
- Amercoat 90/Amercoat 90 (carbon steel & concrete)
- Amerlock 400NT (carbon steel & concrete)

All of the above products are available on a make-to-order basis for Level I projects.

2b. Dimetcote 6 and Amercoat 90 are only available as made-to-order nuke-grade material. All the other products are available in non-nuke grade.

2c. We no longer supply Amercoat 66, NuKlad 114, NuKlad 110AA, and NuKlad 108. At present we are working on a suitable replacement for NuKlad 114. NuKlad 110AAN (formerly Amercoat 3366) replaces NuKlad 110AA and Amerlock Sealer replaces NuKlad 108.

2d. All Service Level I coatings formulas are frozen at the time of testing, so the formulas have not/will not change. The new products that replace the old NuKlad 110AA and NuKlad 108 were formulated to be more friendly from a EH&S perspective

3. The following systems have recently been tested and are also suitable for Service Level I:

- Amerlock Sealer/NuKlad 110AAN/Amercoat 90 (concrete)
- Amerlock Sealer/NuKlad 110AAN/Amercoat 90HS (concrete)

These products are also available on a make-to-order basis for Level I projects. (Non-nuke grades of Amerlock Sealer and Amercoat 90HS are also in our standard product line.)

Regarding the old Mobil products, we are not actively selling them. We made several batches of Mobil 78 for nuclear use by TVA/Browns Ferry. These were made nuclear grade according to our Quality System per the formulas that were given to us by Valspar and we certified that they "have essentially the same chemical and physical characteristics within the repeatability of raw materials that has previously been tested and accepted by TVA in accordance with ANSI N101.2, ANSI N101.4 and applicable provisions of ANSI N45.2."

Here is more input concerning the last couple of questions in your email:

- Dimetcote 6 is a base-catalyzed IOZ.
- Amercoat 66 was a polyamide-cured epoxy.
- Amercoat 90 and 90HS are amine-cured modified phenolic epoxies.
- Amerlock 400 and Amerlock Sealer are amine-cured epoxies.
- NuKlad 110AAN is an amine-cure epoxy.
- NuKlad 108, 114, and 110AA were aromatic amine-cured epoxies.

Regarding inspection techniques to help identify incipient coatings degradation, visual inspection techniques, if performed on a regular basis, should help predict coating degradation before degradation becomes widespread to the point where debris accumulation would become an issue in a design-basis accident. Specifically, for epoxy coatings, significant discoloration (yellowing) can be a sign of excessive or prolonged exposure to elevated temperatures. Elevated temps can promote post-curing and embrittlement of the coating film, with adhesion ultimately suffering. Visual observation of hairline cracking or other precursors to peeling and flaking would certainly indicate coating degradation beyond the incipient phase.

For Service Level I coating systems, where surviving a design-basis accident intact is of primary importance, I believe that adhesion is going to be the best indicator of system integrity. If the adhesion of the system is strong, then it likely retains most of the resistance properties it had when first applied. If the coating system has been stressed by age or the environment, then a significant degradation in adhesion is likely to occur. In my opinion, pull-off adhesion values are very useful for quantifying adhesion and observing the fracture plane. But I also believe concurrent knife adhesion spot testing is also very useful as a 'reality-check' since pull-off values can sometimes be misleading. This is more applicable to steel substrates than concrete, since the tensile strength of concrete is typically lower than that of the coatings applied to it, but I still believe there is value to this approach with concrete substrates.

Generic Coating Types	Chemistry of the Coating	Key Coating Similarities/Differences	Coating Selection/ Application	Known Failure Mechanisms	Sensitivities of Coating to Application Parameters
Inorganic Zinc -Acid Catalysed	Inorganic Zinc Silicate Coating	Excellent application properties even with airless spray, mild odor, good film-build tolerance, reduced overspray, good in-can stability, good cure rate at lower temps.	Excellent long-term corrosion resistance, resistance to DBA and radiation.	Splitting/mud cracking due to high DFT, topcoat bubbling and porosity.	Slower cure speed and slightly less abrasion resistance than base-catalyzed IOZ, pot life less affected by high humidity, not as sensitive to moisture contamination as base-catalyzed IOZ, in-can stability reduced at higher temperatures.
Inorganic Zinc-Base Catalysed	Inorganic Zinc Silicate Coating	Occasionally applied by airless but best applied by conventional spray, strong odor, faster cure rate and better film hardness and abrasion resistance than acid-catalyzed IOZ.	Excellent long-term corrosion resistance, resistance to DBA and radiation.	Splitting/mud cracking due to high DFT, topcoat bubbling and porosity.	Slightly less mudcracking resistance than acid-catalyzed IOZ, more prone to dryspray and in-can stability problems than acid-catalyzed IOZ, lower cure speed at low temps and relative humidity.
Epoxy-Phenolic	Reaction between epoxy phenol novolac and phenolic resin	Heat-cured, lower film build, excellent thermal and chemical resistance, withstands continuous water immersion at high temperatures, can be used under insulation up to 400°F.	Very good corrosion resistance, very good radiation resistance and DBA resistance, excellent chemical resistance and decontaminability.	Incomplete cure due to off-ratio or inadequate mixing or inadequate heat cure. Excessive embrittlement resulting in peeling, cracking, or flaking at higher film thicknesses.	Sensitive to substrate contamination particularly to salts resulting in blistering and premature failure, usually a low-build product requiring multiple application of thin coats.

Generic Coating Types	Chemistry of the Coating	Key Coating Similarities/Differences	Coating Selection/ Application	Known Failure Mechanisms	Sensitivities of Coating to Application Parameters
Epoxy-Amine	Reaction between epoxy resin and aliphatic, cycloaliphati or aromatic amine.	Ambient-cured, very good chemical and corrosion resistance, superior application by airless and conventional spray, high film build in one coat application for significantly reduced application cost.	Very good corrosion resistance, very good radiation resistance and DBA resistance, very good chemical resistance and decontaminability.	Sensative to substrate contamination particularly to salts resulting in blistering and premature failure. Incomplete cure due to off-ratio or inadequate mixing. Delamination due to amine blush formation at low temp/high humidity, incomplete curing at low temp.	Excellent application properties by airless spray. Cure rate and pot life are very temperature-sensitive. Low temps and/or high humidity can promote formation of amine blush.
Epoxy-Amide	Reaction between epoxy resin and polyamide formulated by reacting amines like TETA & TEPA with dimer acid	Ambient-cured, faster dry, certain products can cure below 40°F, increased surface tolerance, very good corrosion resistance, good chemical resistance, high film build.	Very good corrosion resistance, very good radiation resistance and DBA resistance, good chemical resistance and decontaminability.	Sensitive to substrate contamination, particularly to salts resulting in blistering and premature failure. Incomplete cure due to off-ratio or inadequate mixing, amine blush formation at low temp/high humidity, incomplete curing at low temp.	Excellent application properties by airless spray. Cure rate and pot life are very temperature-sensitive. Low temps and/or high humidity can promote formation of amine blush.
Modified Phenolic Epoxy	Reaction between epoxy phenol novolac\and aliphatic, cycloaliphatic, or aromatic amine	Excellent chemical resistance, high film build, withstands continuous water immersion to high temperatures, can be used under insulation up to 400°F.	Very good corrosion and chemical resistance, very good radiation resistance and DBA resistance, very good decontaminability.	Sensitive to substrate contamination, particularly to salts resulting in blistering and premature failure. Incomplete cure due to off-ratio or inadequate mixing, amine blush formation at low temp/high humidity, incomplete curing at low temp.	Excellent application properties by airless spray. Cure rate and pot life are very temperature-sensitive. Low temps and/or high humidity can promote formation of amine blush.

Carboline

Electric Power Research Institute (EPRI) - KTA-TATOR Information Request

NUCLEAR COATING MANUFACTURER'S SURVEY

Prepared by
Bruce Dullum
Carboline Technical Service
July 12, 2006

QUESTION A1

Do you have product data sheets for these materials?
a. Old product data sheets (circa 1970 or earlier, when used)?
b. Recent product data sheets

Yes, see listing below and product data sheets will be submitted for review.

Carbozinc 11* dated March 1971 and June 2005
Carbozinc 11 SG dated June 1997 and April 2003

Phenoline 305* Finish dated March 1984 and January 1993

Carboline 190 HB* November 1983 and October 1984

Carboline 191 HB* dated May 1979 and October 1981

Phenoline 368 Primer* dated August 1983 – Only 1 PDS found
Phenoline 368 Finish* dated January 1977 – Only 1 PDS found

Phenoline 368 WG dated July 1991 and April 2003

Carboguard 890* dated October 1990 and January 2004

Carboguard 890N June 2004 – only 1 PDS found

Carboline 195* dated August 1980 and November 1989

Carbomastic 801* dated July 1987 and August 1990

Carboline 1340* Clear dated September 1990 – only 1 PDS found

Carboguard 1340 dated September 1990 and August 2005

Rustbond 6C* September 1983 and November 1983

Polyclad 933-1* September 1977 and February 1982

Plasite 7155H* November 1988

Plasite 9009* February 1984

Plasite 7155HM1* No PDS found

***These items are obsolete and no longer available for Nuclear Level I**

QUESTION A2

Do you still manufacture/supply all of these materials?
Please list all that you presently supply for Service 1 containment.

Carboline currently produces the following Nuclear Level I materials:

9. Carbozinc 11 SG
10. Carboguard 890N
11. Carboguard 893N
12. Thinner #2
13. Thinner #21
14. Thinner #26
15. Thinner #33
16. Thinner #208
17. Carboline Zinc Filler
18. Carboline Special Zinc Filler
19. Phenoline 368WG
20. Phenoline Thinner
21. Carboguard 2011
22. Carboguard 2011S
23. Carboguard 1340
24. Alara 1146 Cavity Decon
25. Starglaze 2000

Please list all that you presently supply, even if not nuclear grade:

1. Carbozinc 11
2. Carboguard 890
3. Carboguard 893
4. Thinner #2
5. Thinner #21
6. Thinner #26
7. Thinner #33
8. Thinner #208
9. Carboline Zinc Filler
10. Carboline Special Zinc Filler
11. Phenoline 368WG
12. Carboguard 1340
13. Alara 1146

c. For those that you supply, has the product name changed? If so, please list the old and corresponding new names:

The Carboline product identification nomenclature history for Nuclear Level I coatings is as follows:

1. Carbo Zinc 11was changed to Carbo Zinc 11SG, which was subsequently changed to Carbozinc 11SG.
2. Carboline 890 was changed to Carboguard 890, which was subsequently changed to Carboguard 890N.
3. Carboline 893 was changed to Carboguard 893, which was subsequently changed to Carboguard 893N
4. Thinner #2 - no change
5. Thinner #21 - no change
6. Thinner #26 - no change
7. Thinner #33 - no change
8. Thinner 208 - no change
9. Carboline Zinc Filler - no change
10. Carboline Special Zinc Filler – no change
11. Phenoline 368WG – no change
12. Phenoline Thinner – no change

13. Starglaze 2011 was changed to Carboguard 2011
14. Starglaze 2011S was changed to Carboguard 2011S
15. Carboguard 1340 – no change
16. Alara 1146 Cavity Decon – no change
17. Starglaze 2000 – no change

d. For those you still supply, has the formulation changed? If so, please list and provide generic (non-proprietary) information for the reason of the formulation change and the nature of the changes made.

The formulations for the Carboline products including any changes, where applicable, are as follows:

1. Carbozinc 11SG
    a. Changes in thixatropes – The Carbozinc 11 (SG) underwent a thixatrope change prior to 1976
    b. Removal of heavy metal containing color pigments from the formula – The Carbozinc 11 (SG) Green 0300 was originally formulated using heavy metal based pigments. In 1984 these color pigments were removed and environmentally friendly iron oxide color pigments used in their place.
    c. Reformulation of Carbozinc 11 (SG) to improve product – The original Carbozinc 11 formula was changed in 1984. The changes were made for business reasons but Carboline was interested in retaining the nuclear business. As a result we elected to retain the old formula for nuclear only and to identify it as Carbozinc 11 SG (Specification Grade). The newly reformulated Carbozinc 11 is used for commercial non-nuclear applications to this day.
2. Carboguard 890N – During the life of the Carboguard 890 it has had two small modifications made to the formula to improve the shelf life stability of the product. The modifications are small and will not affect the performance of the Carboguard 890. However, to avoid any controversy, Carboline has kept the old unmodified formula and designated it as Carboguard 890N, which is, used for Nuclear Level I areas. The Carboguard 890 sold presently is the modified product and the Carboguard 890N is the unmodified product used for Nuclear Level I areas.
3. Carboguard 893N – No Change
4. Thinner #2 – No Change
5. Thinner #21 – No Change
6. Thinner #26 – No Change
7. Thinner #33 – No Change
8. Thinner #208 – No Change

9. Carboline Zinc Filler – No Change
10. Carboline Special Zinc Filler – No Change
11. Phenoline 368WG – No Change
12. Phenoline Thinner – No Change
13. Carboguard 2011 – No Change
14. Carboguard 2011S – No change
15. Carboguard 1340 – No Change
16. Alara 1146 Cavity Decon – No Change
17. Starglaze 2000 – No Change

QUESTION A3

Do you manufacture any new Service Level I nuclear coatings not listed above- if so, please list.

Carboline does not manufacture any new Nuclear Level I coatings other than what is shown above.

QUESTION B – Tim Eckert's previous e-mail:

"Task 3: For each and every identified generic coating type, the contractor will provide a discussion of:

- The chemistry of the coating, including key similarities and differences in the various types.
- Discuss why the coating type was selected for a given application.
- Known failure mechanisms.
- The sensitivities of the coating to application parameter variations.
- Examples of generic coating types identified are:
  - Inorganic zinc
  - Acid catalyzed
  - Base catalyzed
  - Epoxy
  - Phenolic
  - Amine
  - Amide
  - Modified Epoxy Phenolic
  - Other

This e-mail request for Carboline to provide some material (text, literature, etc.) to fulfill the above task - specifically for the inorganic zinc. I would also like to broaden the scope to include some material for the modified phenolic epoxy and other products that Carboline produces for the nuclear industry. Along with the material supplied, please include appropriate verbiage that will allow EPRI to reproduce the material in our report, with due reference and/or acknowledgement of course."

Carboline provides the following information based on the above request:

CARBOZINC 11 (SG)

History of Carbozinc 11 (SG)

Carbozinc 11 (Carbozinc 11SG) Inorganic Zinc Rich Primer is a two component primer used extensively in nuclear and commercial applications. It is used either by itself or topcoated with various coating materials. In the nuclear industry it has been used untopcoated and topcoated with epoxy and epoxy phenolic finish coats. The Carbozinc 11 (SG) was first developed by Carboline in the 1960s and Design Basis Accident (DBA) testing began in the late 1960s. Coating system commonly containing Carbozinc 11 (SG) are Carbozinc 11 (SG) by itself, Carbozinc 11 (SG) / Phenoline 305 and Carbozinc 11 (SG) / Carboguard 890 (N). The Carbozinc 11 (SG) has been and is presently still used extensively in nuclear power plants here in the USA and around the world.

Chemistry of Carbozinc 11 (SG)

The Carbozinc 11 (SG) is a two component, acid hydrolyzed, ethyl silicate, inorganic zinc rich primer that is cured by solvent evaporation and chemical cross-linking. There are also some inert fillers, iron oxide color pigments and hydrocarbon solvents contained in the Carbozinc 11 (SG). The presence of moisture and acceptable temperatures are required for the proper cure of the Carbozinc 11 (SG). The total zinc in the dry film is 85% by weight minimum.

Selection Criteria for the Carbozinc 11 (SG)

The Carbozinc 11 (SG) has been used extensively as a primer for the nuclear industry for several reasons. Among these reasons are:

1. The Carbozinc 11 (SG) is a good shop primer and is very resistant to mechanical damage during shipping and erection. The primer is compatible with many organic finish coats. During the era of new plant construction, this allowed the Contractor, Engineer and Owner to have the structural steel, steel embeds, liner plate, etc. primed in the shop and shipped to the site for storage and erection and finish coat if required.
2. The failure mode of the Carbozinc 11 (SG) in the event of disbondment is by fracturing within the film of the Carbozinc 11. The resultant material has a powdery consistency with a high specific gravity which was thought to eliminate the primer as potential debris in the event of a LOCA. Theoretically the primer would sink to the bottom before it would become floating debris and the size of the disbonded primer would be so small that it would not block the sumps.
3. The Carbozinc 11 (SG) could be used untopcoated or topcoated as required.

4. The Carbozinc 11 (SG) untopcoated has been successfully tested at a 340F DBA curve and is resistant to radiation exposure up to $4.5X10^9$ rads. The Carbozinc 11 (SG) topcoated with Carboguard 890 (N) has been successfully tested at a 320F DBA curve and has been tested at a radiation exposure of $1X10^9$ rads.
5. The Carbozinc 11 (SG) can be applied at substrate temperatures of from 0ºF to 200ºF (-18ºC to 93ºC) and at a relative humidity of from 40% to 95%. If the relative humidity is below 40% this can be compensated for by water misting the Carbozinc 11 (11SG).

Known Failure Mechanisms:

1. The Carbozinc 11 (SG) requires moisture for full cure. The Carbozinc 11 (SG) must be cured with adequate moisture from either the relative humidity above 40% or by adding moisture by misting the primer film. If the primer is not fully cured by the time it is topcoated it will likely be the source of future cohesive fractures and subsequent disbondment of the coating system.
2. The Carbozinc 11 (SG) is sensitive to excessive dry film thickness (DFT). DFTs above 6.0 mils may result in damage to the primer in the form of mudcracking.
3. The zinc in the Carbozinc 11 (SG) is amphoteric meaning that it is reactive to both bases and acids. Therefore the primer is not recommended for pH ranges below 5.5 and above 8.5.

Application Sensitivities:

1. The Carbozinc 11 (SG) should be applied by an experienced applicator so that the dry film thickness can be applied within the recommended limits. Due to the quick dry characteristics (not cure) it can be difficult to use a wet film thickness gauge. An experienced applicator can achieve excellent application results versus a novice.
2. The Carbozinc 11 (SG) is applied primarily by spray at a dry film thickness that ranges from 2.0 to 6.0 mils over abrasive blasted steel. The difference between the volume solids calculation and the actual dry film of the Carbozinc 11(SG) is complicated by the presence of voids in the freshly applied film. The voids are the result of the spherical zinc dust spaced interstitially within the ethyl silicate matrix. Therefore for estimating purposes Carboline provides a spreading rate of 333 square feet per gallon at three mils dry film thickness (DFT).

General Information:
The Carbozinc 11 (SG) formulation has been changed three times over the lifetime of the product. The changes made are as follows:

1. **Changes in thixatropes:**
   The Carbozinc 11 (SG) underwent a thixatrope change prior to 1976
2. **Removal of heavy metal containing color pigments from the formula:**
   The Carbozinc 11 (SG) Green 0300 was originally formulated using heavy metal based pigments. In 1984 these color pigments were removed and environmentally friendly iron oxide color pigments used in their place.
3. **Reformulation of Carbozinc 11 (SG) to improve product:**
   The original Carbozinc 11 formula was changed in 1984. The changes were made for

business reasons but Carboline was interested in retaining the nuclear business. As a result we elected to retain the old formula for nuclear only and to identify it as Carbozinc 11 SG (Specification Grade). The newly reformulated Carbozinc 11 is used for commercial non-nuclear applications to this day.

CARBOLINE 191HB EPOXY:

History of Carboline 191 HB Epoxy:

The history of the Carboline 191 HB is vague and there are no Carboline people around from the time frame when it was an active product. The original product data sheet is dated May 1979 and the last product data sheet found is dated October 1981.

The Carboline 191HB was an epoxy formulated for the nuclear industry and for commercial use. The Carboline 191 HB was used as a topcoat over Carbozinc 11 (SG), Carboline 191 Primer and Carboline 193 Primer. The Carboline 191 HB was designed primarily for new construction and not for maintenance of existing facilities. It is unknown why the Carboline 191 HB was discontinued.

Chemistry of Carboline 191 HB Epoxy:

The Carboline 191 HB was a two-component, polyamide cured epoxy topcoat that is cured by solvent evaporation and chemical cross-linking. There are inert fillers, color pigments, and hydrocarbon solvents in the Carboline 191 HB in addition to the resin and curing agents. Time and temperature are the primary factors in the cure of the Carboline 191 HB. The volume solid for the coating is 59% and the DFT is 4.0 to 6.0 mils.

Selection Criteria for the Carboline 191 HB:

The Chemists that formulated the Carboline 191 HB are no longer with Carboline and we do not have a historical documentation as to the selection criteria used for the Carboline 191 HB.

Known Failure Mechanisms:

Typical of epoxies.

Application Sensitivies:

The Carboline 191 HB was easily applied and would be considered comparable to two component epoxies in general.

PHENOLINE 305 EPOXY PHENOLIC

History of Phenoline 305

The Phenoline 305 was a two component, epoxy phenolic finish coat used in the nuclear industry. The Phenoline 305 was used primarily as a topcoat for Carbozinc 11 (SG) on steel substrates and a topcoat for Carboline 195 Surfacer on concrete substrates. Carboline developed the Phenoline 305 in the 1970s and DBA testing of the material began shortly thereafter. The Phenoline 305 was developed primarily for new construction and not for maintenance of nuclear power plants. The Phenoline 305 was discontinued in 1993 when the epoxy resin supplier discontinued the resin used and no acceptable performance equal could be found. The Phenoline 305 was formulated primarily for new construction and not for maintenance of existing plants.

Chemistry of the Phenoline 305:

The Phenoline 305 is a two component, amine cured modified phenolic finish coat that is cured by solvent evaporation and chemical cross-linking. There are inert fillers, color pigments and hydrocarbon solvents contained in the Phenoline 305. Time and temperature are primary factors in the cure of the Phenoline 305. The volume solid for the coating is 64% and the recommended DFT was 4.0 to 6.0 mils. The VOC content of the Phenoline 305 is 291 gms/ltr as supplied. The coating provides a hard, smooth, chemical resistant and radiation resistant coating material.

Selection Criteria for the Phenoline 305:

The Chemists that formulated the Phenoline 305 are no longer with Carboline and we do not have a historical documentation as to the selection criteria used for the Phenoline 305.

Known Failure Mechanisms:

The Phenoline 305 has been known to disbond when used in conjunction with Carbozinc 11 (SG) due to the cohesive splitting of the zinc primer.

Application Sensitivies:

The Phenoline 305 is easily applied and would be considered comparable to two component epoxies in general.

CARBOGUARD 890 (N) EPOXY:

The Carboguard 890 (N) is a two component surface tolerant epoxy used as a primer, intermediate and finish coat in the nuclear industry. The Carboguard 890 (N) is used for application over steel or concrete substrates in new construction, modifications and as a maintenance coating for Nuclear Level I areas. It is used in systems consisting of Carbozinc 11 (SG) / Carboguard 890 (N), Carboguard 893 / Carboguard 890 (N), Carboguard 2011S / Carboguard 890 (N). It is also used for maintenance repair of existing coating systems such as Carbozinc 11 (SG) / Phenoline 305 / Carboguard 890 (N), Carboline 195 Surfacer / Phenoline 305 / Carboguard 890 (N). The Carboguard 890 is still used extensively around the world for Nuclear Level I areas.

Chemistry of Carboguard 890 (N):

The Carboguard 890 (N) is a two component, cycloaliphatic amine, bisphenol A, surface tolerant epoxy coating. In addition to the epoxy resin and curing agents, the Carboguard 890 (N) contains inert pigments, color pigments, additives and hydrocarbon solvents. The volume solid is 75% and the VOC content is 214 gms/ltr as supplied. The recommended dry film thickness is 4.0 to 6.0 mils. The coating provides a hard, smooth, chemical resistant and radiation resistant coating material.

Selection Criteria for the Carboguard 890 (N):

The Carboguard 890 (N) was formulated to include surface tolerant properties for new construction and maintenance of Nuclear Level I areas. The Carboguard 890 (N) uses cycloaliphatic amine curing which allows for better chemical resistance, higher solids and lower VOCs.

Known Failure Mechanisms:

The Carboguard 890 (N) has been known to disbond when used in conjunction with Carbozinc 11 (SG) due to the cohesive splitting of the zinc primer.

Application Sensitivies:

The Carboguard 890 (N) is easily applied and would be considered comparable to two component epoxies in general.

General Information:

During the life of the Carboguard 890 it has had two small modifications made to the formula to improve the shelf stability of the product. The modifications are small and should not affect the performance of the Carboguard 890. However, to avoid any controversy, Carboline has kept the old unmodified formula and designated it as Carboguard 890N which is used for Nuclear Level I areas. The Carboguard 890 sold presently is the modified product and Carboguard 890N is the unmodified product used for nuclear.

CARBOGUARD 893 EPOXY PRIMER:

History of Carboguard 893:

The Carboguard 893 Primer is a two-component epoxy used for commercial applications and in conjunction with Carboguard 890N in the nuclear industry. The Carboguard 893 was developed in the 1990s as an organic primer for use with Carboguard 890N in Nuclear Level I areas and in commercial applications. The Carboguard 893 is used for application over steel substrates in new construction and modifications in Nuclear Level I areas. The Carboguard 893 is still used around the world for Nuclear Level I areas.

Chemistry of Carboguard 893:

The Carboguard 893 is a two component, cycloaliphatic amine, bisphenol A, epoxy coating. In addition to the epoxy resin and curing agents, the Carboguard 893 contains inert pigments, color pigments, additives and hydrocarbon solvents. The volume solid is 77% and the VOC content is 195 gms/ltr as supplied. The recommended dry film thickness is 3.0 to 5.0 mils.

Selection Criteria for the Carboguard 893:

The Carboguard 893 was formulated for new construction and modifications of Nuclear Level I areas. The Carboguard 893 utilizes cycloaliphatic amine curing which allows for better chemical resistance, higher solids and lower VOCs.

Known Failure Mechanisms:

Typical for epoxies.

Application Sensitivities:

The Carboguard 893 is easily applied and would be considered comparable to two component epoxies in general.

CARBOGUARD 2011S WATER-BORNE EPOXY SURFACER/FILLER:

History of Carboguard 2011S Water-Borne Epoxy Surfacer/Filler:

The Carboguard 2011S was brought over to Carboline as the result of the purchase of the Southern Imperial Coatings line in the 1980s. The Carboguard 2011S was previously known as Starglaze 2011S and was changed to its present name about 1999. The Carboguard 2011S is a three component, nuclear Level I grade, epoxy surfacer used to fill voids in concrete substrates prior to the application of other coatings. The product is used for new construction and for modifications. The Carboguard 2011S is often used with Carboguard 1340 Epoxy Primer/Sealer, Carboguard 890 (N) Epoxy and Phenoline 305 Epoxy Phenolic. The Carboguard 2011S is still in use today in the nuclear industry.

Chemistry of Carboguard 2011S:

The Carboguard 2011S is a three component, polyamide cured, water borne, bisphenol A, epoxy. In addition to the epoxy resin and curing agents, the Carboguard 2011S contains cement, sand, inert pigments, color pigments, water and water miscible solvents. The volume solid is 88% and the DFT recommendations are 15.0 to 60.0 mils. The VOC content of the Carboguard 2011S is 150 gms/ltr as supplied.

Selection Criteria for the Carboguard 2011S:

1. The Carboguard 2011S is a trowellable surfacer/filler that will fill bugholes and voids in concrete to provide a smooth easily decontaminable surface. The Carboguard 2011S can be topcoated with a variety of epoxy intermediate and finish coats.
2. Water-borne properties of the Carboguard 2011S reduce the solvents in containment that could adversely affect the charcoal filters.

Known Failure Mechanisms:

None known.

Application Sensitivities:

None

CARBOGUARD 1340 PENTRATING PRIMER SEALER

History of Carboguard 1340:

The Carboguard 1340 epoxy is used for coating and sealing concrete in commercial applications and in the nuclear industry. The Carboguard 1340 may also be used as a concrete curing agent. The Carboguard 1340 was developed in the 1990s as an organic primer / sealer for use with Carboguard 890N in Nuclear Level I areas and in commercial applications. The Carboguard 1340 is used for application over concrete substrates in new construction and modifications in Nuclear Level I areas. The Carboguard 1340 is still used around the world for Nuclear Level I areas.

Chemistry of Carboguard 1340:

The Carboguard 1340 is a two component, polyamido-amine, 100% solid epoxy penetrating sealer used for concrete substrates. The VOC content is 24 gms/ltr as supplied. The recommended dry film thickness is 1.0 to 2.0 mils.

Selection Criteria for the Carboguard 1340:
The Carboguard 1340 was formulated for new construction and modifications of Nuclear Level I areas and other commercial applications. The Carboguard 1340 is used in nuclear facilities to seal the concrete substrates to provide better decontamination and to minimize the amount of airborne radioactivity. It was also formulated as a primer for other Carboline products such as Carboguard 890N. The Carboguard 1340 has higher solids and lower VOCs.

Known Failure Mechanisms:
The Carboguard 1340 is primarily a penetrating sealer and forms only a minimal dry film on the surface of the concrete. There have not been any reported failures of the Carboguard 1340 to our knowledge.

Application Sensitivities:
Typical for epoxy penetrating sealers.

PHENOLINE 368 PRIMER

History of Phenoline 368 Primer:
The history of the Phenoline 368 Primer is vague and there are no Carboline people around from the time frame when it was an active product. The only product data sheet found is dated August 1983. The Phenoline 368 Primer was an epoxy formulated for the nuclear industry and for commercial use. The Phenoline 368 was used as a primer for Phenoline 368 Finish, Phenoline 373 Finish and Phenoline 368WG. The Phenoline 368 Primer was designed primarily for new construction and not for maintenance of existing facilities. It is unknown why the Phenoline 368 Primer was discontinued.

Chemistry of Phenoline 368 Primer:
The Phenoline 368 Primer was a two-component, aliphatic amine cured, modified phenolic that is cured by solvent evaporation and chemical cross-linking. There are inert fillers, color pigments, and hydrocarbon solvents in the Phenoline 368 Primer in addition to the resin and curing agents. Time and temperature are the primary factors in the cure of the Phenoline 368 Primer. The volume solid for the coating is 75% and the DFT is 4.0 to 6.0 mils.

Selection Criteria for the Phenoline 368 Primer:
The Chemists that formulated the Phenoline 368 Primer are no longer with Carboline and we do not have a historical documentation as to the selection criteria used for this material.

Known Failure Mechanisms:
Typical of epoxies

Application Sensitivities:
The Phenoline 368 Primer was easily applied and would be considered comparable to two component epoxies in general.

PHENOLINE 368 FINISH

History of Phenoline 368 Finish:

The history of the Phenoline 368 Finish is vague and there are no Carboline people around from the time frame when it was an active product. The only product data sheet found is dated January 1977. The Phenoline 368 Finish was an modified phenolic formulated for the nuclear industry and for commercial use. The Phenoline 368 was used as a finish for Phenoline 368 Primer. The Phenoline 368 Finish was designed primarily for new construction and not for maintenance of existing facilities. It is unknown why the Phenoline 368 Finish was discontinued.

Chemistry of Phenoline 368 Finish:

The Phenoline 368 Finish was a two-component, aliphatic amine cured, modified phenolic that is cured by solvent evaporation and chemical cross-linking. There are inert fillers, color pigments, and hydrocarbon solvents in the Phenoline 368 Finish in addition to the resin and curing agents. Time and temperature are the primary factors in the cure of the Phenoline 368 Finish. The volume solid for the coating is 75% and the DFT is 4.0 to 6.0 mils.

Selection Criteria for the Phenoline 368 Finish:

The Chemists that formulated the Phenoline 368 Primer are no longer with Carboline and we do not have a historical documentation as to the selection criteria used for this material.

Known Failure Mechanisms:

Typical of epoxies.

Application Sensitivities:

The Phenoline 368 Finish was easily applied and would be considered comparable to two component epoxies in general.

PHENOLINE 368WG:

History of Phenoline 368WG:

The history of the Phenoline 368 WG is vague and there are no Carboline people around from the time frame when it was originally developed. The earliest product data sheet found is dated July 1991 and the latest product data sheet is dated April 2003. The Phenoline 368 WG is an modified phenolic formulated for the nuclear industry and for commercial use. The Phenoline 368 WG has been used as a topcoat for Carbozinc 11 in the belly-band area of a Torus in a BWR. It has also been used as a tank lining for oil and oil/water solutions up to 200+ degrees. The Phenoline 368 WG was designed primarily for new construction but has also been used for maintenance of existing facilities. The Phenoline 368 WG is still in use today throughout the world.

Chemistry of Phenoline 368WG:

The Phenoline 368 WG is a two-component, aliphatic amine cured, modified phenolic that is cured by solvent evaporation and chemical cross-linking. There are inert fillers, color pigments, and hydrocarbon solvents in the Phenoline 368 WG in addition to the resin and curing agents. Time and temperature are the primary factors in the cure of the Phenoline 368 WG. The volume solid for the coating is 65% and the DFT is 4.0 to 6.0 mils.

Selection Criteria for the Phenoline 368WG:
The Chemists that formulated the Phenoline 368 Primer are no longer with Carboline and we do not have a historical documentation as to the selection criteria used for this material.

Known Failure Mechanisms:
Typical for epoxies.

Application Sensitivities:
The Phenoline 368 Finish was easily applied and would be considered comparable to two component epoxies in general.

CARBOLINE 195 EPOXY SURFACER

History of Carboline 195:
The history of the Carboline 195 is vague and there are no Carboline people around from the time frame when it was originally developed. The earliest product data sheet found is dated August 1980 and the latest product data sheet is dated November 1989. The Carboline 195 was formulated for the nuclear industry and for commercial use. The Carboline 195 was used as a concrete surfacer / filler and was topcoated with Carboline 191HB or Phenoline 305 for nuclear applications. The Carboline 195 was topcoated with Carboline 193, Phenoline 300 Finish and Phenoline 302 for commercial applications. The Carboline 195 was designed primarily for new construction but has also been used for maintenance of existing facilities. The Carboline 195 was replaced by the Carboguard 2011S.

Chemistry of Carboline 195:
The Carboline 195 was a two-component, polyamide cured, epoxy that is cured by solvent evaporation and chemical cross-linking. There are inert fillers, color pigments, and hydrocarbon solvents in the Carboline 195 in addition to the resin and curing agents. Time and temperature are the primary factors in the cure of the Carboline 195. The volume solid for the coating is 97% and the DFT is 10.0 to 60.0 mils.

Selection Criteria for the Carboline 195:
The Carboline 195 was formulated to provide a smooth, easily decontaminable base coat for concrete coating systems.

Known Failure Mechanisms:
Typical for epoxies.

Application Sensitivities:
The Carboline 195 was easily applied and would be considered comparable to two component epoxies in general.

CARBOMASTIC 801 EPOXY

History of Carbomastic 801:
The Carbomastic 801 was formulated as a surface tolerant coating available in a variety of colors for use in the new construction and maintenance of Nuclear Level I areas of nuclear power plants as well as for commercial applications. The Carbomastic 801 was designed to applied over steel

or concrete. The earliest product data sheet found is dated July 1987 and the latest product data sheet is dated August 1990. The Carbomastic 801 was used as a primer, intermediate or finish coat. The Carbomastic 801 could be topcoated with epoxies, polyurethane and other finish coats for commercial applications. The Carbomastic 801 was replaced by the Carboline 890.

Chemistry of Carbomastic 801:
The Carbomastic 801 was a two-component, cycloaliphatic amine cured epoxy that is cured by solvent evaporation and chemical cross-linking. There are inert fillers, color pigments, and hydrocarbon solvents in the Carbomastic 801 in addition to the resin and curing agents. Time and temperature are the primary factors in the cure of the Carbomastic 801. The volume solid for the coating is 76% and the DFT is 4.0 to 6.0 mils.

Selection Criteria for the Carbomastic 801:
The Carbomastic 801 was formulated as a surface tolerant epoxy for use in containment where minimum surface preparation is required.

Known Failure Mechanisms:
Typical for epoxies.

Application Sensitivities:
The Carbomastic 801 was easily applied and would be considered comparable to two component epoxies in general.

CARBOLINE 1340 CLEAR

History of Carboline 1340 Clear:
The Carboguard 1340 Clear was used for coating and sealing concrete in commercial applications and in the nuclear industry. The Carboguard 1340 Clear was also be used as a concrete curing agent. The Carboguard 1340 was developed in the 1980s as an organic primer / sealer for use with Carboline 195 and Phenoline 305 in Nuclear Level I areas and in commercial applications. The Carboline 1340 Clear was used for application over concrete substrates in new construction and modifications in Nuclear Level I areas as well as commercial projects. The Carboline 1340 Clear was replaced by Carboguard 1340.

Chemistry of Carboline 1340 Clear:
The Carboline 1340 Clear was a two component, polyamide epoxy penetrating sealer used for concrete substrates. The volume solid was 28%. The recommended dry film thickness is 1.0 to 2.0 mils.

Selection Criteria for the Carboline 1340 Clear:
The Carboline 1340 Clear was formulated for new construction and modifications of Nuclear Level I areas and other commercial applications. The Carboline 1340 Clear was used in nuclear facilities to seal the concrete substrates to provide better decontamination and to minimize the amount of airborne radioactivity. It was also formulated as a primer for other Carboline products such as Carboline 195 and Phenoline 305. The Carboline 1340 Clear was also used as a curing agent for concrete.

Known Failure Mechanisms:
None

Application Sensitivities:
Typical for epoxy penetrating sealers.

RUSTBOND PRIMER 6C VINYL
History of Rustbond 6C:
The history of the Rustbond Primer 6C is vague and there are no Carboline people around from the time frame when it was an active product. The earliest product data sheet found is dated September 1983 and the latest product data sheet is November 1983. The Rustbond Primer 6C was an modified vinyl formulated for application to steel substrates. The Rustbond Primer 6C was used as a primer for Polyclad 936, Carboline 1294 and Carboline 3630. The Rustbond Primer 6C was designed for new construction and for maintenance of existing facilities. The Rustbond Primer 6C was discontinued due to high VOCs.

Chemistry of Rustbond 6C:
The Rustbond Primer 6C was a single component modified vinyl primer. In addition to the vinyl resin, the Rustbond Primer 6C contains inert pigments, color pigments, additives and hydrocarbon solvents. The volume solid is 24%. The recommended dry film thickness is 2.0 mils.

Selection Criteria for the Rustbond 6C:
The Chemists that formulated the Rustbond Primer 6C are no longer with Carboline and we do not have a historical documentation as to the selection criteria used for the Rustbond Primer 6C

Known Failure Mechanisms:
None

Application Sensitivities:
None

POLYCLAD 933-1 VINYL
History of Polyclad 933-1:
The Polyclad 933-1 is a single component medium build vinyl coating. It was developed for application to steel, concrete or wood substrates. The Polyclad 933-1 was designed as an intermediate of topcoat applied over vinyl primers such as Rustbond Primer 6C.The earliest product data sheet that we have found is February 1977 and the latest product data sheet is June 1982.

Chemistry of Polyclad 933-1:
The Polyclad 933-1 was a single component modified vinyl intermediate/finish coat. In addition to the vinyl resin, the Polyclad 933-1 contained inert pigments, color pigments, additives and hydrocarbon solvents. The volume solid is 27%. The recommended dry film thickness is 2.0 mils.

Selection Criteria for the Polyclad 933-1:

The Chemists that formulated the Polyclad 933-1 are no longer with Carboline and we do not have a historical documentation as to the selection criteria used for the Polyclad 933-1.

Known Failure Mechanisms:

None

Application Sensitivities:

None

PLASITE 7155H

History of Plasite 7155H:

Dates back to the late 1950s. Primarily developed for various water services and high temperature water service such as high purity, tap and process water. Has many histories in the power and petroleum industry.

Chemistry of Plasite 7155H:

Three component cross-linked epoxy phenolic. Components consist of Part I-pigmented resin: Part II medium viscosity resin and Part III the curing agent. Solid content by volume 28%. Number of coats: 2 to 4-5 mil coats to total DFT of 8-10 mils.

Selection Criteria for the Plasite 7155H:

High purity water storage tanks, wet wells, borated water, rad waste water, piping and other equipment in the power industry: oil and water separators and other oil process equipment in the petroleum industry.

Known Failure Mechanisms:

None when applied as directed and used in a suitable environment with no upset conditions.

Application Sensitivities:

The formula contained a vinyl solution which could generate over-spray during application leading to a poorly applied lining when the product was not thinned properly and good application techniques were not followed.

PLASITE 7155HM1

NO DATA ON THIS PRODUCT (NOT SURE IT EXISTED)

However there was a Plasite 7155 H NP Primer

History of Plasite 7155HM1: Plasite 7155 H NP Primer

Dates back to about 1960.

Chemistry of Plasite 7155HM1: Plasite H NP Primer
Similar to 7155 but included inhibitive pigments. Three component cross-linked epoxy phenolic. Components consist of Part I pigmented resin; Part II medium viscosity resin and Part III curing agent. Solids by volume: 28%: Number of coats: 1 coat at 2-3 mils.

Selection Criteria for the Plasite 7155HM1: 7155H NP Primer
Used with a 7155 or 9009 system as an alternate to the 1st coat when the first coat was applied prior to fabrication.

Known Failure Mechanisms: (7155H NP Primer)
None when applied as directed and used in a suitable environment with no upset conditions.

Application Sensitivities: (7155H NP Primer)
The formula contained a vinyl solution which could generate over-spray during application leading to a poorly applied lining when the product was not thinned properly and good application techniques were not followed.

PLASITE 9009
History of Plasite 9009:
Estimated to date back to 1965.

Chemistry of Plasite 9009:
High solids amine cured epoxy with hard glossy finish resistant to radiation with good decontamination capability. Solid content by volume: 80%: 2 components – Part I resin/pigment blend, Part II curing agent; Number of coats: One or two to a 6-14 mil DFT range.

Selection Criteria for the Plasite 9009:
Primarily used in power industry and marine type exposures. Known for its resistance to radiation and decontamination capability. Concrete walls, floors, ductwork, structural steel and other equipment.

Known Failure Mechanisms:
None known.

Application Sensitivities:
Thinning as directed in product data sheet application instructions required to achieve proper coating flow-out an film building characteristics.

Additional requests from Ken Tator

1. "Additionally, however, I'd appreciate a concise discussion of acid and base hydrolyzed IZR's, and what Carboline sees as their advantages and disadvantages."

   Carboline's solvent based inorganic zinc primers are all acid catalyzed. The use of an acid catalyst gives a product with good curing characteristics, reasonable shelf stability and very good corrosion performance. Our only experience with base catalyzed solvent based inorganic zincs at Carboline was with single package more than 15 years ago. The base catalyzed products had issues with shelf stability and some sporadic corrosion issues.

QUESTION C

The following is an excerpt from a letter Brian W. Sheron, Associate Director for Engineering and Safety Systems, Office of Nuclear Reactor Regulation wrote to Anthony R. Pietrangelo, NEI:

"NEI has stated that visual "precursors" were found to exist in all documented instances of degradation of reactor containment coatings. The NRC staff interprets observed visual degradation to mean that the coating systems in fact failed to meet their design requirements before visual indications existed, and had physical testing of the containment coatings been performed on a routine basis, the degradation would have been identified before visual indication appeared. Coatings that exhibit visual signs of degradation most likely have been in a degraded state for an extended period, representing a source of debris in a design-basis accident."

1. In light of the above, what inspection techniques would you recommend for the future inspection of Carboline /Plasite coating system within primary containment to ensure the coating system meets its design requirements?
   a. Visual inspection techniques
   b. Non-visual techniques
      1. non-destructive
      2. destructive
      3. other?
   c. Comments on coating inspection methods

   Carboline recommends a visual coatings inspection/monitoring program.

2. Are your coating inspection recommendations suitable for all Carboline/Plasite/Imperial systems or should there be different techniques for specific coating systems; substrates (steel/concrete); or for other reasons?

   A visual coatings inspection program would be applicable to all coating systems supplied by Carboline.

PPG/Keeler & Long

Submitted By John DeBarba

Keeler&Long
PPG High Performance Coatings
856 Echo Lake Road P. O. Box 460 Watertown, CT 06795 Tel: 860-274-6701 Fax: 860-274-5857

STEEL SYSTEMS

Product System S-1:
Primer: KL65487107
Finish: KLE1-Series

Chemistry of the coating system, including key similarities and differences:

- Both primer and finish are polyamide epoxy coating material.

Discuss why the coating type was selected for a given application:

- Late 1960's and early 1970's DBA testing at Idaho Nuclear and Franklin Institute indicated epoxy coatings to be superior to other tested generic coatings. At that time, the owners of Keeler & Long made a decision to pursue testing only of epoxy type materials for use inside and outside containment of nuclear facilities.

Known failure mechanisms:

- Edge rusting where application resulted in low film thickness.
- Discoloration, flaking, cracking in areas subject to extended high temperature.
- Blistering from misapplication or moisture permeation

Sensitivities of the coating system to application parameter variations:

- Application of excessive wet mils can result in solvent entrapment (both primer and topcoat)
- Roller application of KLE-Series often produces bubbles, corrected with KL4093B Epoxy Bubble Breaker.

Product System S-10:
Primer: KL65487107
Finish: KLD1-Series

Chemistry of the coating system, including key similarities and differences:

- Both primer and finish are polyamide epoxy coating material.

Discuss why the coating type was selected for a given application:

- The KLD-Series was developed as a high solids finish coat that was more user friendly than typical polyamide epoxies (circa 1975)

Known failure mechanisms:

- Edge rusting where application resulted in low film thickness.
- Discoloration, flaking, cracking in areas subject to extended high temperature.
- Blistering from misapplication or moisture permeation

Sensitivities of the coating system to application parameter variations:

- Application of excessive wet mils can result in solvent entrapment (both primer and topcoat)

Product System S-11:
Primer/Finish: KL65487107

Chemistry of the coating system, including key similarities and differences:

- A polyamide epoxy coating material.

Discuss why the coating type was selected for a given application:

- Developed originally for use on steel surfaces in TORUS environment.
- This system was developed for use only on steel surfaces with an original qualification thickness of 8.0-18.0 mils DFT.
- Also is qualified as a repair system at 8.0-18.0 mils DFT.

Known failure mechanisms:

- Edge rusting where application resulted in low film thickness.
- Discoloration, flaking, cracking in areas subject to extended high temperature.
- Blistering from misapplication

Sensitivities of the coating system to application parameter variations:

- Application of excessive wet mils can result in solvent entrapment

Product System S-12:
Primer/Finish: KL4500

Chemistry of the coating system, including key similarities and differences:

- Epoxy-Polyamine

Discuss why the coating type was selected for a given application:

- Developed as a single coat application for steel surfaces used in conjunction with System KL-12 on concrete. The application method is to seal the concrete surface with KL4129, allow cure, then apply the KL4500 as supplied to concrete surfaces using a trowel, broad knife or other tool filling in voids, bugholes and other imperfections, then immediately spray apply a coat of KL4500 over all surfaces including steel. This eliminates the need to mask off steel surfaces and also eliminates the cure time between intermediate and finish coat.

Known failure mechanisms:

- Edge rusting where application resulted in low film thickness.
- Discoloration, flaking, cracking in areas subject to extended high temperature.
- Blistering from misapplication or moisture permeation
- Cracking due to shrinkage of coating that has been over-thinned, excessive DFT, or both.

Sensitivities of the coating system to application parameter variations:

- Application of excessive wet mils can result in solvent entrapment.
- Application of over-thinned material applied at excessive thickness will shrink and crack.

Product System S-14 (Floors Only):
Finish: KL5000

Chemistry of the coating system, including key similarities and differences:

- Epoxy-Amine

Discuss why the coating type was selected for a given application:

- This is a self-leveling floor coating designed for concrete surfaces but can also be used on steel. Qualified over steel to eliminate need for masking steel embeds allowing smooth transition and aid in any decontamination procedures.
- This floor coating system is desirable for use inside containment due to low VOC emissions. The KL5000 is 0.0 lbs/gal mixed and air dried.

Known failure mechanisms:

- None reported to date.

Sensitivities of the coating system to application parameter variations:

- None reported to date

Product System S-15:
Primer: KL65487107
Finish: KL9600N

Chemistry of the coating system, including key similarities and differences:

- The primer is Epoxy-Polyamide and the finish is Epoxy Polyamidoamine.

Discuss why the coating type was selected for a given application:

- KL9600N was developed in late 1980's and qualified for use in Level I areas 1993. The KL9600N is a market driven product developed using high solids resins and technology of polyamidoamine. VOC content of the KL9600N is 0.9 lbs/gal. (108 g/l). The KL9600N is qualified over the KL65487107 and also as a repair coating. Further Level I testing has qualified use over power tool cleaned surfaces without primer.

Known failure mechanisms:

- Edge rusting where application resulted in low film thickness.
- Discoloration, flaking, cracking in areas subject to extended high temperature.

Sensitivities of the coating system to application parameter variations:

- Application of excessive wet mils can result in solvent entrapment (both primer and topcoat)

CONCRETE SYSTEMS

Product System KL-2:
Curing Compound/Sealer: KL4129
Surfacer: KL6548S
Finish: KLE1-Series

Chemistry of the coating system, including key similarities and differences:

- Both primer and finish are Polyamide Epoxy coating material, surfacer is Polyamine Epoxy.

Discuss why the coating type was selected for a given application:

- For use only on concrete surfaces formulated to produce a chemical resistant coating system on poured concrete surfaces.

Known failure mechanisms:

- Cracking due to excessive film thickness

Sensitivities of the coating system to application parameter variations:

- Application of excessive wet mils in KLE-Series can result in solvent entrapment
- Roller application of KLE-Series often produces bubbles, corrected with KL4093B Epoxy Bubble Breaker.

Product System KL-8:
Curing Compound/Sealer: KL4129
Surfacer: KL6548S
Finish: KLD1-Series

Chemistry of the coating system, including key similarities and differences:

- Both primer and finish are Polyamide Epoxy coating material, surfacer is Polyamine Epoxy.

Discuss why the coating type was selected for a given application:

- For use only on concrete surfaces formulated to produce a chemical resistant coating system on poured concrete surfaces.
- The KLD-Series was developed as a high solids finish coat that was more user friendly than typical polyamide epoxies (circa 1975)

Known failure mechanisms:

- Cracking due to excessive film thickness

Sensitivities of the coating system to application parameter variations:

- Application of excessive wet mils in KLD-Series can result in solvent entrapment.

Product System KL-9:
Curing Compound/Sealer: KL4129
Surfacer: KL65487107
Finish: KLD1-Series

Chemistry of the coating system, including key similarities and differences:

- All coating materials are Epoxy Polyamide.

Discuss why the coating type was selected for a given application:

- For use only on concrete surfaces formulated to produce a chemical resistant coating system primarily used on floor surfaces.

Known failure mechanisms:

- Remote possibility of moisture permeation causing blistering.

Sensitivities of the coating system to application parameter variations:

- Application of excessive wet mils in KL65487107 and KLD-Series can result in solvent entrapment.

Product System KL-10:
Curing Compound/Sealer: KL4129
Surfacer: KL4000
Finish: KLD1-Series

Chemistry of the coating system, including key similarities and differences:

- Both primer and finish are Polyamide Epoxy coating material, surfacer is Polyamine Epoxy.

Discuss why the coating type was selected for a given application:

- For use only on concrete surfaces formulated to produce a chemical resistant coating system on poured concrete surfaces.
- The KLD-Series was developed as a high solids finish coat that was more user friendly than typical polyamide epoxies (circa 1975)
- The KL4000 was developed as a very viscous (paste) material that filled large voids in concrete surfaces.

Known failure mechanisms:

- Cracking due to excessive film thickness

Sensitivities of the coating system to application parameter variations:

- Application of excessive wet mils in KLD-Series can result in solvent entrapment.

Product System KL-12:
Curing Compound/Sealer: KL4129
Surfacer/Finish: KL4500

Chemistry of the coating system, including key similarities and differences:

- Primer is Polyamide Epoxy coating material, Surfacer/Finish is Epoxy-Polyamine

Discuss why the coating type was selected for a given application:

- Developed as a single coat application for steel surfaces used in conjunction with System KL-12 on concrete. The application method is to seal the concrete surface with KL4129, allow cure, then apply the KL4500 as supplied to concrete surfaces using a trowel, broad knife or other tool filling in voids, bugholes and other imperfections, then immediately spray apply a coat of KL4500 over all surfaces including steel. This eliminates the need to mask off steel surfaces and also eliminates the cure time between intermediate and finish coat.

Known failure mechanisms:

- Discoloration, flaking, cracking in areas subject to extended high temperature.
- Blistering from misapplication or moisture permeation
- Cracking due to shrinkage of coating that has been over-thinned, excessive DFT, or both.

Sensitivities of the coating system to application parameter variations:

- Application of excessive wet mils can result in solvent entrapment.
- Application of over-thinned material applied at excessive thickness will shrink and crack.

Product System KL-14 (Floors Only):
Primer Sealer: KL6129
Finish: KL5000

Chemistry of the coating system, including key similarities and differences:

- Epoxy-Amine

Discuss why the coating type was selected for a given application:

- This is a self-leveling floor coating designed for concrete surfaces but can also be used on steel. Qualified over steel to eliminate need for masking steel embeds allowing smooth transition and aid in any decontamination procedures.
- This floor coating system is desirable for use inside containment due to low VOC emissions. The KL6129 is 0.43 lbs/gal and the KL5000 is 0.0 lbs/gal mixed and air dried.

Known failure mechanisms:

- None reported to date.

Sensitivities of the coating system to application parameter variations:

- None reported to date

Electric Power Research Institute (EPRI) – KTA-TATOR, Inc.
Information Request

NUCLEAR COATING MANUFACTURER'S SURVEY
KEELER & LONG/PPG

Normal type – questions in survey
Italicized type – response to questions
Bold type – questions posed by EPRI (Tim Eckert)

First, I have some questions regarding your product designations:

a. E-Series-does that consist of an intermediate and a topcoat?

Normal application consists of one coat primer and one coat finish. The total qualified range is 3.0-14.0 for the KL65487107 primer and 2.5-6.0 for the KLE-Series. Application of two coats primer or two coats finish is acceptable as long as the product DFT is in range.

b. D-Series-same question

Normal application consists of one coat primer and one coat finish. The total qualified range is 5.0-12.0 for the KL65487107 primer and 3.0-6.0 for the KLD-Series. Application of two coats primer or two coats finish is acceptable as long as the product DFT is in range.

c. Epoxy Enamel-Millstone U2 indicated they used this material. Is this a product name, or if not, do you know what they used? If not, I can ask them.

The KLE-Series is known as Epoxy Enamel. The construction timeframe indicates this is correct product.

d. Do all these systems/ products seem correct?

Yes, we do have other products that have been used. KL9600N and KLHN-Series (Very MINOR Use).

A. I have the following questions regarding these materials/systems:

1. Do you have product data sheets for these materials:

   a. old product data sheets (circa 1970-or earlier, when used)? *Will send*

   b. recent product data sheets? *Will send*

2. Do you still manufacture/supply all of these materials:

   a. please list all that you presently supply for Service 1 containments

SEE ATTACHED SSU-1 *PROTECTIVE COATING SYSTEMS FOR NUCLEAR POWER PLANTS* *the back page lists all of the coating systems we supply.*

b. please list all that you presently supply, even if not nuclear grade *See SSU-2*

c. for those you still supply, has the product name changed? If so, please list the old and corresponding new names.

- *No. 4000 = KL4000*
- *No. 4129 = KL4129*
- *No. 4500 = KL4500*
- *No. 5000 = KL5000*
- *No. 6129 = KL6129*
- *No. 6548 = KL65487107*
- *No. 6548S = KL6548S*
- *No. 7107 = Changed to No. 6548 (mid 1970's) Changed to No. 65487107 (mid to late 1970's) see No. 6548 above*
- *No. 7475 = KLE1-Series, KLE2-Series*
- *No. 7500 = Discontinued*
- *No. 9600N = KL9600N*
- *E-Series = KLE1-Series, KLE2-Series*
- *D-Series = KLD1-Series*

d. for those you still supply, has the formulation changed? If so, please list and provide generic (non- proprietary) information for the reason of the formulation change, and the nature of the changes made.

I have attached QA-618A and R&D 119 to explain how a change would take place. I cannot recall any major changes in recent history. If there is any question we run an inhouse screening DBA. A major change was made to the old No. 7107 Epoxy Primer back in 1975. We removed the white lead from the product and replaced it with "friendlier" rust inhibitor. Once the No. 7107 was tested with reformulation the new code went to No. 6548 (you may see reference to this code in specification but was not used very long). This caused some confusion with customers so we made the code No. 65487107 Epoxy Primer. When PPG purchased K&L the system in place had to recognize the manufacturing location. A new code was set up as KL65487107.

3. Do you manufacture any new Service Level I nuclear coatings not listed above-if so, please list.

KL9600N and KLHN-Series (Very MINOR Use on KLHN).

B. EPRI's Tim Eckert recently sent you an e-mail, from which the following is extracted:

"Task 3: For each and every identified generic coating type, the contractor will provide a discussion of:

- **The chemistry of the coating, including key similarities and differences in the various types.**
- **Discuss why the coating type was selected for a given application.**
- **Known failure mechanisms.**
- **The sensitivities of the coating to application parameter variations.**
- **Example of generic coating types identified are:**
  - **Inorganic Zinc**
  - **Acid catalyzed**
  - **Base catalyzed**
  - **Epoxy**
  - **Phenolic**
  - **Amine**
  - **Amide**
  - **Modified Phenolic epoxy**
  - **Others**

This email is a request for K&L to provide some material (text, literature, etc.) to fulfill the above task, specifically for the Inorganic zinc. I would also like to broaden the scope to include some material for the Modified Phenolic Epoxy and other products that K&L produces for the nuclear industry. Along with the material supplied, please include appropriate verbiage that will allow EPRI to reproduce the material in our report, with due reference and/or acknowledgement of course."

I have attached responses for PPG Keeler & Long products only at this time. Not sure of any Modified Phenolic Epoxy K&L ever produced in the past.

1. Will you (K&L) submit information or material I can use to respond to these questions? I would very much appreciate any assistance you can provide, both in a general sense, and specifically regarding the products you manufacture. Please include a concise technical discussion and what K&L sees as their advantages and disadvantages?
2. Also, using the categories itemized in blue above, please classify your nuclear products, listed above.

C. The following is an excerpt from a letter Brian W. Sheron, Associate Director for Engineering and Safety Systems, Office of Nuclear Reactor Regulation wrote to Anthony R. Pietrangelo, NEI "NEI has stated that visual "precursors" were found to exist in all documented instances of degradation of reactor containment coatings. The NRC staff interprets observed visual degradation to mean that the coating systems in fact failed to meet their design requirements before visual indications existed, and had physical testing of the containment coatings been performed on a routine basis, the degradation would have been identified before visual indication appeared. Coatings that exhibit visual signs of degradation most likely have been in a degraded state for an extended period, representing a source of debris in a design-basis accident."

1. In light of the above, what inspection techniques would you recommend for the future inspection of K&L coating systems within primary containment to ensure the coating system meets it's design requirements?

    a. Visual inspection techniques

    b. Non-visual techniques

        1. non-destructive

        2. destructive

        3. other?

    c. Comments on coating inspection methods

I would primarily recommend visual inspection techniques performed by a qualified inspector.

For steel coating systems I would recommend visual inspection focusing on color changes primarily located in high heat areas. The epoxy coatings supplied by PPG Keeler & Long will yellow or in extreme cases turn brown. High radiation area can also turn an epoxy coating yellow or brown but this may not indicate a failure. If the area is known to have high temperatures a visual assessment is necessary to check for adhesion. This can be accomplished by "sounding" the surface, (if controversy occurs adhesion testing may be in order). If a hollow sound is detected the coating needs removal and replacement. Also, visually inspect for any cracking. This may be an indication of excessive mil thickness resulting in shrinkage. Also, inspect steel for any edge rusting.

For a concrete coating system I would suggest using same visual inspection as for steel plus close examination for blistering. This may be an indication of moisture under the surface and can be considered a form of failure. Removal and replacement may be necessary.

Visual Inspection should check for:

- *Rusting ASTM D 610*
- *Checking ASTM D 660*
- *Cracking ASTM D 661*
- *Erosion ASTM D 662*
- *Blistering ASTM D 714*
- *Flaking ASTM D 722*
- *Chalking ASTM D 4214*

2. Are your coating inspection recommendations suitable for all K&L systems, or should there be different techniques for specific coating systems; substrates (steel/concrete); or for other reasons?

   Yes, they would be good for all PPG Keeler & Long coating systems. See above differences for steel and concrete.

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