FHWA Study Tour for Bridge Maintenance Coatings

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DEDICATION

This report is dedicated to the memory of John Peart, the leader of this scanning tour panel. It was through Mr. Peart's perseverence, dedication to his technical field, and personal sacrifice that this effort was possible.

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EXECUTIVE SUMMARY

Over the past 10 years, the complexity of steel bridge maintenance involving coating system removal and replacement has increased dramatically. Regulatory impact in environmental protection and worker safety, coupled with rapid changes in coating material technology, have fueled an evolution of changes in the domestic bridge maintenance coating market. The net result of these changes has been the creation of new, often complex engineering technologies and cost increases exceeding an order of magnitude for bridge maintenance coating work.

Because it is a leader both in procuring infrastructure construction and maintenance services and developing and implementing new highway maintenance technology, the Federal Highway Administration (FHWA) takes an active role in pursuing technical solutions through domestic and global outreach. In this spirit, the FWHA Office of International Programs commissioned a team to pursue technology transfer of steel bridge maintenance coating methods with the European highway community.

This team met with its counterparts in government and industry in Switzerland, Germany, the Netherlands, and the United Kingdom, between October 6 and October 22, 1995. The team consisted of U.S. experts in aspects of bridge-coating maintenance assembled from the FHWA and various State organizations. The following paragraphs highlight the comparative methods and materials discovered during the team's efforts in Europe.

Field Contracting Operations

The key words describing bridge maintenance painting contracting operations seen in Europe are: access and environmental protection. Unlike current U.S. industry trends toward small, lightweight, modular containment with designed-in ventilation, European containment structures for abrasive-blasting operations are designed as large, semipermanent structures. These structures contain the maximum possible area of the bridge substructure or superstructure. In addition, great care is taken to design containment structures that allow access for workers and equipment without affecting bridge traffic. The containment structures are suspended as work platforms from the substructure or superstructure of the bridge, allowing maximum access while not interrupting traffic. A good deal of thought is given to the design and materials used in constructing containment to contain a maximum amount of debris from abrasive-blasting operations. This is demonstrated by the use of double and triple liners of both flexible and rigid materials (e.g., rubber matting, plywood) for containment floors and the overlapping and mechanical fixing of seams in flexible containment materials.

In spite of the care and investment in their design and construction, the containment structure designs observed by the team do not always address ventilation, airflow, and worker protection issues. All the large containment structures observed required extremely long hoses to access the work on the end of the structure opposite from the support facilities for the job. In one instance, this distance was over 200 m. When the supply hose for blasting the surface is this long, productivity falls dramatically as the contractor reaches the far end of the structure. The compressor capacities did not appear to provide adequate pressure at the nozzle for all areas of the structure.

The field contractors in Europe do not concentrate capital investment on advanced equipment. Rather, investment is made in the design and construction of containment. Based on the limited number of sites visited, it appears European contractors rely on a large number of man-hours to complete the work.

Recycled steel abrasive equipment is not used as extensively in Europe as it is in the United States, and containments are not designed to assist in the collection and movement of spent abrasive. Abrasive is handled by shoveling or vacuuming at the end of each work day. Also, the lack of ventilation tends to leave a significant amount of dust and fines on the interior surfaces of the containment.

Permanent or semipermanent work platforms are commonly used for maintenance of substructures. Many of these platforms are part of the original bridge design, recognizing the importance of maintenance for long-term performance of a structure. This is in contrast to current practice in the United States, where bridge maintenance is seldom a design consideration.

All the European transportation officials, contractors, and paint suppliers emphasized the importance of quality assurance in surface preparation and paint application. Quality of the job is a primary focus. In general, the Europeans were willing to nominally increase spending for high-quality work, on the assumption that life-cycle maintenance would be reduced through improved performance of the corrosion control systems.

Materials and Methods

Abrasive-blast cleaning to near-white (Sa 2.5 or SSPC SP10) is the predominant surface preparation for maintenance coating of bridges in Europe. Alternative maintenance strategies, such as overcoating or zone-painting, are generally not used in the same sense as in the United States. The Europeans showed some interest in the U.S. experience with overcoating, and the Swiss and Germans mentioned working on standards for assessing the feasibility of overcoating for bridge maintenance. Currently, however, the philosophy is to apply a high-durability paint system onto a properly prepared surface early in the failure cycle of the existing bridge coating in order to avoid any significant metal loss. The U.S. delegation agreed to participate with the Europeans, where possible, in upcoming efforts to define acceptable criteria for overcoating.

Abrasives used in field operations are generally expendable copper slag or coal slag. The copper slag materials are sometimes recycled at off-site separation facilities. This is true particularly in the Netherlands, where off-site recycling is mandated as a method of controlling waste volumes generated by these jobs. Recyclable steel abrasives, which are used increasingly in the U.S. bridge painting industry, are not used extensively in Europe.

Coating materials used in Europe differ somewhat from those used on U.S. steel bridges. This stems from a different philosophy toward steel bridge corrosion protection in continental Europe, the United Kingdom, and the United States. The three continental countries visited specify the use of multicoat paint systems using primers (generally epoxy) containing zinc-phosphate as a corrosion-inhibiting pigment. The use of micaceous iron oxide as a barrier pigment is prevalent throughout Europe. This pigment is used in various vehicles, such as epoxies and moisture-cured polyurethanes. In the United Kingdom, new steel construction has been metalized for many years. Zinc flame spray was originally the standard, but because of problems with early topcoat failures, the system of choice is now arc-sprayed aluminum at 3 to 4 mils as a primer for three to four topcoats of epoxy, urethane, or silicone alkyd. These early topcoat failures may have been the result of salt contamination before topcoating. These practices differ from the prevalent U.S. use of sacrificial zinc-rich primers followed by barrier topcoats for new construction.

Worker Health and Safety

General worker health and safety issues in European bridge painting operations are of concern, as evidenced by the use of head, hearing, and full body protection, but the operations observed in Europe do not place the same emphasis on lead exposure hazards as current U.S. regulatory practices do. In all four countries, regulators, transportation officials, and contractors were aware of the general hazards to workers posed by lead paint removal and maintenance. However, no regulations or guidelines were discovered that are as far-reaching or detailed as the U.S. Occupational Safety and Health Administration (OSHA) regulation for worker health and safety during removal of lead-containing paint (29 CFR 1926.62). Loose-fitting, supplied-air hoods with head and face protection were used for blasters, but none of the sites had a formal program for care and maintenance of respirators. Also, the facilities observed for worker cleanup and hygiene (i.e., hand-washing and shower stations) would not meet current OSHA requirements.

The containment structures visited in the four countries were designed to maximize access and minimize traffic and environmental impact. These practices make adequate airflow and ventilation difficult to achieve. The differences between current U.S. practices and those observed in Europe for protecting workers from lead hazards result from the aggressive approach taken, in the last several years, by U.S. regulators, structure owners, trade and labor organizations, and contractors regarding the specific hazards associated with lead paint removal. This phenomenon has not occurred in Europe to date. As a rule, personal exposure monitoring of employees is not performed and blood-lead level checks are only performed annually or biannually in Europe. The new U.S. OSHA standard (1993) requires personal breathing zone air sampling and frequent blood-lead level checks.

Environmental Considerations

In contrast to the less rigorous attention paid to worker hygiene standards, the European bridge maintenance community appears to be quite attentive to the impact on the environment caused by bridge-coating maintenance. The Swiss and Germans have considered using measures resulting in 95 percent containment efficiency as a practically achievable mass balance for abrasive and paint material/debris relationships. This is consistent with many of the more forward-thinking design concepts currently seen in the United States. The Dutch, in particular, have given tremendous thought to the design of the tightness of their containments. All containment seams observed were mechanically sealed or sealed with foam. A combination of impervious rigid and flexible materials was used to eliminate emissions. Furthermore, multiple tarping is used to seal the flooring of containment structures in Germany and the Netherlands. Environmental air monitoring is not performed, except for observation of the requirement for no visible emissions. Soil monitoring is usually conducted before and after projects. Typically, no net increase in soil lead levels is allowed.

Agency-Contractor Relations

There is a more cooperative relationship in Europe among bridge agencies, painting contractors, and paint suppliers than in the United States. This was evident in the fact that many of the bids for work are distributed to a limited number of qualified vendors. Various countries have their own specific criteria for qualification of contractors; however, the general relationship between federal and local agencies and maintenance painting contractors appeared to be much more cooperative, and certainly far less litigious, than is the current situation in this industry in the United States.

The purpose of the limited bidder lists used for competition of contracts is to ensure both financial viability of potential contractors and quality. Quality is ensured by basing the qualified contractor list on past performance on similar jobs. Obtaining well-planned work, using a formal written approach, was of utmost importance to the European bridge owners. The philosophy of limited bidder lists may change, because the current transition toward an economically unified Europe requires countries to consider bids from companies of other member nations.

European bridge owners have a more progressive attitude toward painting bridges under warranty than do those in the United States. Specifics of warranties differ among the nations, but most were found to hold contractors and paint vendors liable for field performance for a 5-year period. With recent changes in FHWA funding policy, painting under warranty will now be considered an option for states on federal-aid jobs. The European experience can serve as a good guide for these future U.S. efforts.

In all countries visited, the cost for full paint removal and replacement with multicoat paint systems appeared to be competitive with current prices in the United States. After currency conversions, the costs for field removal and reapplication of painting systems is currently the equivalent of U.S. \$10.00 per ft^2 in Europe. This approximates the median in current costs in the United States. Although the Europeans do not have the magnitude of worker health and safety and environmental monitoring costs of U.S. industry, increased costs of European jobs associated with use of nonrecyclable abrasive and, perhaps, reduced productivity offset these savings.

Bridge Management Systems

The European countries have a more aggressive approach to planned bridge maintenance than the United States. The Europeans also have a better approach to bridge maintenance record-keeping than the United States. Each of the countries visited had a slightly different approach to maintenance planning; however, in each case, corrosion protection for bridges is rehabilitated on a scheduled basis. That is, repainting or maintenance painting of bridges is conducted every 6, 8, or 12 years, depending on the country, the paint system, and the severity of exposure. In some instances, spot-painting may be performed before planned maintenance. This corrosion control and preservation is not performed for bridge structures in the United States on a regular basis, except in some instances on structures owned and operated by toll authorities or by selected states with aggressive maintenance philosophies.

In some cases, the European approach to planned maintenance appears to be to expend maintenance dollars on bridges that are in fairly good condition (by common U.S. standards); however, the planned approach reflects the difference in attitude between the United States and Europe concerning the importance of early maintenance to avoid future costs. In some cases, a greater use of overcoating strategies may be useful to European bridge owners; these options are being investigated.

Metalizing

Metalizing for long-term protection of bridge steel has been the standard in the United Kingdom for many years. It is estimated that 80 to 90 percent of British shop-fabricated bridge steel is now metalized. The approach is to use a relatively thin coat of thermal-sprayed aluminum as a primer for various topcoats. Often these topcoats will contain a corrosion-inhibiting primer (e.g., zinc-phosphate epoxy) in a "belt-and-suspenders" approach. In the United States, the approach to metalizing is to use zinc, a zinc alloy, or aluminum in a heavier build (8 to 14 mils) and apply topcoats only for cosmetics or as a porosity sealer. Representatives from the British Metalizers Association concurred with the potential performance benefits of a thicker metalizing coating using a zinc or aluminum. The British originally used zinc, but found early depletion to be a problem, because of the likelihood of contamination in the period between shop metalizing and field topcoating.

In spite of differences in the specifics of the alloy and topcoat systems, the British experience of 30 years of field performance of metalized coatings does add credence to the durability claims of these materials. Interest in this system for specified U.S. bridge applications continues to grow.

1.0 INTRODUCTION

In recent years, many governments have been alerted to the hazardous materials content of industrial coatings and their potential for polluting the environment and damaging workers' health. The result has been regulations prohibiting the use of the hazardous elements in new coating systems and requiring mandatory protection of the environment and workers during maintenance, removal, and disposal of existing coatings. In the United States, it is estimated that 92,000 bridges are protected from corrosion by lead-containing paints. Because of increased regulations, the cost of maintenance repainting has risen dramatically, from \$1.00 or \$2.00 per ft^2 to \$10.00 to \$15.00 or more per ft^2. Much of the cost increase stems from containment for lead-containing paint removal and worker safety issues.

Communications with European community industry and transportation personnel indicate that they share U.S. concerns over the potential hazards of paints. These issues are complicated by the recent re-unification of Germany, where neglect of the infrastructure by the Eastern sector has resulted in increased demands on maintenance funds. In addition, many east-west roads need significant refurbishment to handle the major increase in truck traffic from the East.

The Montreal Protocol has raised worldwide awareness of the need for paints with lower levels of volatile organic compounds (VOCs). Many of the existing protocols that provide proven corrosion protection between 5 to 15 years will need to change. While Europe has led in developing many coating formulations, such as moisture-cured polyurethanes and coatings with micaceous iron oxide pigments, the proposed VOC reductions will present an unprecedented challenge to the European transportation community.

Through establishing lines of communication with scanning tours, such as this one, the European community can benefit from years of U.S. research in containment, coupled with regulatory issues related to worker health and safety. The United States can benefit from policies and procedures that are becoming more coherent within the European community.

The following report documents the findings of the study tour. This report is organized to present the findings of the panel in two ways. The first section of the report highlights the more interesting similarities and differences in bridge painting practices found in the four countries visited. This section is organized by country in the chronological order of the trip. The second section of the report documents the panel's findings with respect to several specific subject areas, including environmental and worker protection practices, painting practices and paint systems, metalizing, and contracting. These subjects reflect the general topics of greatest interest to the U.S. panel and are areas of current interest to the U.S. bridge painting community.

The findings reported here are the result of meetings with transportation officials, coating manufacturers, and contractors in each of the host countries. Before the tour, a list of technical questions was submitted to each of the host organizations. These questions were often used to direct dialogue between the U.S. panel and the various hosts. The goal of the questions was to orient the host organizations to the specific interests of the panel and to stimulate dialogue; therefore, specific answers are not reported as such in this report. However, the list of questions is provided as Appendix A to orient the reader to the topics of discussion during the trip.

In addition, the observations of the panel members during visits to six bridge rehabilitation projects make up a great deal of the results reported herein. These site visits were arranged by the various hosts to show the U.S. panel "typical" bridge painting operations to the extent possible. It must be noted that time and schedule constraints played a large part in determining the specific sites visited. Other bridge painting sites in the host countries would probably vary greatly in arrangement and procedures (just as is the case in the United States); however, the panel attempted to relate the qualitative findings at these sites as being "typical" of those for the host country.

2.0 SUMMARY OF U.S. PRACTICE

A major goal of the scanning tour was to exchange innovative ideas and methods for steel bridge preservation and painting and hazardous paint removal in Europe and the United States. This was accomplished through observation of European bridge painting operations and comparison with current U.S. practice, as understood by the panel. In this context, a brief description of U.S. bridge maintenance painting practice is appropriate.

Until the mid-1970s, bridge painting in the United States consisted primarily of application of lead-containing alkyd paints (e.g., red-lead, basic lead silico-chromate) over steel with millscale left intact. These types of coatings were used for new construction and maintenance painting. Over the past 20 years, bridge owners have turned to various other paint materials and have called for much more extensive levels of surface preparation for protective coatings on structural steel. These changes were motivated in part by a desire to reduce life-cycle maintenance burdens by using more durable coating and surface preparation systems and, more important, by efforts to comply with increasing environmental regulation.

Lead, chromium, and other heavy metals have come under increasingly tight regulation. This has increased the cost of maintaining structures coated with these materials and stimulated industry to develop coating formulations with significantly less "environmental impact." Regulations for solvent levels in paint formulations have also driven change. The majority of bridge owners in the United States now use some form of metallic zinc-rich primer paint system for new construction steel. Several states have also pioneered the use of waterborne formulations, and metalizing and galvanizing have been used selectively by several states.

Maintenance painting practices have been very dynamic in the United States over the past several years. Bridge owners vary in their approaches, from aggressive removal of hazardous coatings in an "abatement" strategy, to deferral of maintenance where hazardous coatings are involved. Maintenance painting is accomplished using lead-free alkyds, epoxymastics, moisture-cured urethanes, waterbornes, and zinc-rich systems, depending on the philosophy of the particular bridge owner and the specifics of the bridge structure being maintained. Overcoating over intact paint after washing and power-tool cleaning has become popular among U.S. bridge owners. This approach allows maintenance painting of a structure at a significantly reduced cost. However, overcoating does carry the risk of early failure associated with application of paint over deteriorated coatings or less-than-ideal steel surfaces.

Until the late 1980s, bridge maintenance abrasive blasting was accomplished with no containment of blast debris and dust. Concern over environmental and community impact of these practices was the impetus for developing increasingly tight containment structures to capture and collect hazardous blast debris and dust. These systems were generally constructed to enclose a large portion of the structure with flexible tarp materials and had interior scaffolding and rigging for access of workers and inspectors to the structure. These containments were found to be effective in preventing contamination of the environment surrounding a bridge and in facilitating collection of waste debris following blasting; however, they tended to concentrate high levels of airborne lead, which led to elevated blood lead levels and occupational illnesses among workers. Also, the early larger containment designs were used with expendable abrasives. This approach tends to create a voluminous waste stream for collection, treatment, and disposal. Control of larger volumes of waste is difficult throughout the duration of a job.

Recently, smaller cross-section containments, coupled with high-volume dust collectors and designed ventilation and air flow, have come into use. These containments are often used in conjunction with recycled steel abrasive equipment. This approach is intended to reduce the dust exposure to the workers inside the containment and manage the recyclable abrasive as a working material rather than a waste. Because the containment structure is smaller, it must be moved more often; which is a tradeoff for a reduced waste stream, lower worker dust exposures, and increased visibility afforded by the use of recycled grit.

3.0 SCANNING TOUR OVERVIEW

3.1 Switzerland

The Swiss Federal transportation authorities tend to favor concrete construction over steel for bridges; less than 5 percent of the highway system bridges in Switzerland are steel. However, many of the local areas (such as the City of Bern) have older steel and even iron bridge structures. Most of these are protected with paints that contain lead. Removal of these paints during maintenance has created problems and a corresponding cost burden on the authorities. The Swiss public is sensitive to issues surrounding the removal of hazardous paint because of its potential impact on the environment and livestock animals through introduction of the heavy metal into the food chain. (This particular perspective is unique to Switzerland and has not been encountered in the United States, to date.) Our discussions with the Swiss revealed an intense degree of concern for preserving the integrity of the natural environment. It is obvious that this stems from a long-standing tradition of environmental responsibility.

Additional concerns were expressed toward the PCBs contained in certain paint formulations, particularly older chlorinated rubber formulations that used PCBs as plasticizers in some coating formulations. These paints have not been used extensively on bridges in the United States in the past, but may have been used as striping materials for road delineation. To the best knowledge of the delegation, the issue of PCBs in industrial coatings has not been raised in the United States.

Swiss officials reported significant cost increases in repainting operations resulting from the increased degree of environmental protection required. These increases (after monetary conversion) are on the same order as those recently experienced in the United States (i.e., five- to tenfold cost increases). These increases in Swiss painting operation costs result from the increased labor and materials burden associated with containment of blasting operations and subsequent disposal of spent abrasive and paint waste. Officials mentioned that all hazardous paint waste is disposed of outside of Switzerland. Additionally, soil testing is required before and after each job to assess environmental impact. The Swiss have established limits for the increase in lead concentration in the soil over baseline of 50 parts per million (ppm). This limit would be considered quite stringent by U.S. standards.

The Swiss tend to choose full paint removal by expendable abrasive (copper slag) blasting followed by application of an epoxy or urethane paint system when maintaining steel bridges. The primers chosen generally contain either inorganic zinc pigments or zinc phosphate pigments for corrosion inhibition, with heavy use of micaceous iron oxide pigments in intermediate coats as moisture barrier protection.

The use of overcoating was discussed, but Swiss officials appeared to be rather skeptical of the quality of performance achievable through overcoating methods. The Swiss were quite interested in the U.S. experience with overcoating, because these techniques offer the potential for substantial cost savings.

The Swiss are quite sensitive about fugitive emissions from blasting containments. The panel only saw one job in progress, a locally administered job on a mountain tram structure near Zurich. The containment was quite large, with no visible evidence of high-volume ventilation and dust collection. (See Figure 2, following the text of this report.) Blasting operations had recently been completed at the time of the visit, but only one small blower was seen for ventilation purposes. The interior of the containment structure was heavily coated with fine dust, a further indication of little ventilation. The blast and paint application job appeared to be of a high quality in the completed areas. For example, in the walking areas at the top of the structure, grit had been added into the topcoat to provide traction for tramway personnel.

Although the one site visited was not administered by the highway agency, the contractor was said to be one of the major corrosion-control contractors in Switzerland. The worker health and safety practices seen fell somewhat short of the U.S. requirements in current OSHA Lead-in-Construction regulations (29 CFR 1926.62). The "cleanup" phase activities that the team witnessed involved several workers operating without High Efficiency Particulate Air (HEPA)-type respirators in an obviously lead-laden breathing environment. Also, cleanup and clothes-changing facilities that would be considered "proper" by U.S. standards were not available. These impressions were reinforced during conversations with a major bridge painting contractor in Bern. Judging from the expense and extent of their containment structures, the Swiss obviously have a general knowledge of the dangers of exposing the environment and the public to lead-containing dust. The Swiss use the German maximum airborne concentration (MAK) levels for airborne toxic substances. It is also apparent that the issue of specific hazards of lead dust to bridge workers has not yet become a serious concern in Switzerland. The opinion of the panel was that this was due to a reduced level of knowledge and experience with specific lead health effects, somewhat akin to the experiences in the United States approximately 5 to 7 years ago (i.e., before the issuance of the current OSHA regulation in 1993). The delegation hopes that its visit and discussions would have the positive effect of relating U.S. experiences in worker protection to aid the Europeans in short-cutting the path to safer working conditions under tight containment scenarios.

3.2 Germany

The German highway system is similar to the Swiss system in that most of the significant bridges are relatively new (i.e., less than 40 years old) and fabricated from concrete. However, even though only a small percentage of German highway bridges are steel, the extent of the system means that the Germans do have many steel bridges to maintain. Corrosion control and hazardous paint issues are major concerns for German bridge maintenance efforts. Many of the older steel structures are coated with lead-containing paint, and the highway system uses de-icing salts heavily because of the cold climate prevalent throughout Germany. Currently, the German transportation authorities are tackling serious maintenance and construction burdens in the East following the recent German re-unification. Much of the Eastern infrastructure must be upgraded to accommodate the increase in traffic caused by opening international borders.

Discussions with officials at the German Ministry of Transportation indicated the Germans tend toward full removal of old paint systems by abrasive blasting when maintenance is performed. Currently, zinc-phosphate pigmented primers and micaceous iron oxide intermediate and topcoats are specified for steel structure painting. Generally, overcoating technologies have been discussed, but not used extensively because of the inferior life cycle expected from overcoating applications.

German officials expressed serious concern for protecting the environment during field bridge painting operations. Great care is taken in specification and construction of containments. Foremost concerns are containment of blast debris approaching 100 percent, productivity, and traffic impact. Hence, German containments are generally designed to hang below the deck structure so as not to affect traffic flow and are designed to be as large as possible to access as much of the steel structure as possible without having to move containment and slow productive work. The delegation visited a large containment job at the *Hasseltallbrucke* outside of Frankfurt. The containment structure was the largest any of the team had ever seen, at approximately 125 m long and spanning the entire width of the four-lane highway bridge. This containment structure was set up for partitioning so that blasting, blow-down, and painting could be accomplished in various sections of the containment at the same time (Figure 3). Also, the floor of the structure was double and triple lined with plywood and tarps to effectively collect all paint chips and spent abrasive. Parallel rails were set up to allow for a mobile scaffolding to access the 4-m web of the facsia beam.

In spite of the innovative design and ease of access provided by the structure, this particular containment had a few drawbacks. First, the lack of ventilation was evident from the large amounts of dust fines throughout the structure. Cleanup crews were working in fairly heavy dust exposures during our visit. The ventilation used during blasting consisted of a single corrugated-duct dust collector, which was carried along by the blaster to wherever he was working. No ventilation was operating during the cleanup operations during our visit.

Worker hygiene practices at the *Haseltallbrucke* bridge site were marginal in terms of U.S. standards. (Note that many U.S. bridge sites have recently been cited by OSHA as being marginal or worse by the same standards.) Continuous flow, air-supplied blast helmets (type CE) were used by blasters but were not maintained or stored properly. Separate shower facilities were available, but access to and from worksites was not strictly controlled, as is currently required by OSHA. The Germans have established a personal exposure limit for lead. The personal exposure limit, also used by the Swiss, of 100 micrograms of lead per m^3 of air, is twice the U.S. exposure limit of 50 micrograms per m^3. However, personal air monitoring is not generally conducted. Blood lead levels for workers are required annually. The current maximum allowable blood-lead levels for workers are 70 micrograms per dL of blood for men and 25 micrograms per dL of blood for women. The maximum allowable level in the United States is 50 micrograms per dL for all workers.

3.3 The Netherlands

Roadway bridges in the Netherlands are under the control of the *Rijkswaterstaat*, which also controls the waterworks and the extensive dam and lock systems that protect the low-lying lands of Holland from the sea. The Dutch have an aggressive attitude toward steel-structure maintenance. They tend to blast and repaint structures relatively early in the corrosion process. The structures that the team observed undergoing maintenance painting had some degree of corrosion, but were not allowed to reach an advanced level of corrosion (metal loss) before maintenance. The Dutch have the advantage that most of their steel structures were originally constructed following a marine corrosion control philosophy and were abrasive blasted before application of the original coating. Subsequent maintenance is reduced.

Because most of the Netherlands is close to the ocean, and cold winter conditions require the use of de-icing salts, the exposure conditions on most steel structures would be considered relatively harsh. For this reason, the Dutch have taken a conservative approach to surface preparation and have not pursued overcoating or touchup painting to any great extent. As do the Germans, the Dutch use primers filled with zinc phosphate for corrosion inhibition in a multilayer coating system. The *Rijswaterstaat* is pursuing the use of more durable coating systems and has ongoing coating durability test programs to evaluate performance. The Dutch are interested in the use of waterborne (acrylic and alkyl-silicate zinc) coatings, but have not applied waterborne paints on a large scale at this time.

The Dutch authorities expressed a keen interest in obtaining quality coating application services from contractors. They appeared to work extremely closely with contractor personnel to achieve high-quality work, and lists of potential bidders for contracts are limited to firms with adequate financial standing and demonstrated experience in bridge repainting operations. Bridges are painted under an interesting warranty arrangement in Holland. After letting of a painting contract, the owner, contractor, and paint supplier meet on-site, and the contractor applies the specified surface preparation/coating system to selected areas of the bridge. Once all parties agree the specification was properly followed in the selected areas, these areas are designated for evaluation for warranty conformance. The entire bridge is painted following the specification. If failure occurs first on the structure, while the "warranty areas" remain intact, the contractor is considered liable for the failure. If failure occurs on the warranty areas, the coating manufacturer is held liable, because its representatives were present at application of these areas and signed off that the coating was properly applied. The warranty generally applies for a 5-year period. This warranty scenario appears to be a useful means of assigning liability for coating performance, which is often the source of unresolvable controversy in the United States.

The panel visited two bridge painting sites in Holland. Both of these sites were fully contained for abrasive blasting with excellent attention given to the design and construction of the containment structures. The containments were designed to contain a large amount of steel to minimize movement of the structure. Both flexible, impenetrable tarps and rigid plywood were used for exterior containment walls, with interior scaffolding for structural support and access to the steel within the containment. All joints and seams in the exterior walls were mechanically fastened and sealed with foam to prevent emissions (Figure 4). Entryways were constructed from rigid materials to allow for controlled access to the containment structure. Placards indicated the presence of lead in the work area (Figure 5). The areas around the containment structures appeared to be well-kept, and there was little evidence of significant debris outside the containment structure. In fact, a public access bicycle path was kept open adjacent to one of the containment structures.

The areas inside the containment showed signs of a lack of adequate ventilation. All surfaces showed significant settling of abrasive blast dust and fines, and industrial hygiene practices appeared to be marginal by current OSHA standards. One of the containments had a single dust collector (≈ 10,000 cubic feet per minute (CFM)) for a containment at least 200 ft (61 m) long by 50 ft (15.25 m) wide. This ventilation was probably intended for local ventilation to improve visibility for the blasters (Figure 6).

Respirators were used by blasters, but it was obvious there was no formal respirator maintenance plan, as respirators were found stored inside the work area. Worker hygiene facilities were also limited at the site.

3.4 United Kingdom

The United Kingdom has a significant number of steel bridges, and much of the current new construction involves the use of structural steel. For many years now, the United Kingdom has used metalizing as the coating of choice for new steel structures and has had good reported performance. Until approximately 10 years ago, various zinc alloys were used, and now the alloy of choice is pure aluminum. Thermal-sprayed aluminum is used as a primer coat at approximately 4 mils and sealed with three to four topcoats to form a complete system. This system is reported to provide more than 30 years of corrosion protection and is currently used on approximately 80 percent of shop-fabricated bridge steel.

The British Highways Agency dictates policy for maintenance painting of existing steel structures. Maintenance decisions are based on various factors, including exposure environment, budgets, and impact on traffic. These factors are used to determine the most appropriate surface preparation and coating systems for maintenance. Particular emphasis is placed on ease of access at a specific structure for maintenance. Minimizing impact to traffic is considered to be extremely important. Structures on high-density roadways (i.e., those that make access for maintenance difficult) are generally painted with the most durable system to avoid future maintenance impact on traffic to the greatest extent possible. British officials are sensitive to the economic impact of traffic, particularly around large cities. Discussions indicated that the assumption is that traffic impact costs to the economy far outweigh the actual cost of performing maintenance. This life-cycle cost argument has provided the impetus for using durable coating systems (e.g., metalizing) by the Highways Agency.

During discussions, British highway officials emphasized the importance of bridge maintenance management throughout the life cycle of the structure. The maintenance history of each bridge is kept in a book dedicated to that particular structure. Several, but not all, of the states in the United States also maintain similar records for structures. The British maintain that these records are invaluable in providing a maintenance history for each bridge.

The United Kingdom has also intentionally built permanent enclosures, fabricated from fiberglass, around the steel substructure of several bridges to create a more benign micro-environment around the steel. British highway officials reported this to be an extremely effective long-term corrosion-control method that provides a permanent platform around the steel structure for access for inspection and future maintenance.

4.0 ENVIRONMENTAL AND WORKER PROTECTION PRACTICES

All countries visited voiced similar philosophies of protecting the environment and human health. Based on conversations and limited documentation provided, the philosophies and regulations are similar to those found in the United States. Generally, the employer or contractor in each country is required to protect the environment and workers.

4.1 Environmental Protection

Environmental protection was found to be of great concern. The removal of lead-containing paint is conducted in containment systems. The observed containments were constructed around elevated support structures on bridges or suspended under the bridges. Abrasive and debris are not supposed to escape the containment and settle in the environment. A 95-percent capture rate for spent abrasive and debris has been proposed in at least two of the countries visited. All projects visited during the tour potentially released nonrecoverable abrasive and debris into the environment. The following paragraphs discuss specific aspects of environmental protection, including containment systems, air monitoring, soil monitoring, and waste disposal.

4.1.1 Containment Systems

Construction materials included scaffolding, plywood, dimension lumber, and reinforced impermeable or permeable tarps. Sizes of the containments varied but were generally large, with one massive suspended platform that was approximately 125 m long, 25 m wide, and 5 m high. Despite the extensive investment of time and materials used in construction, most of the containments visited had uncontrolled openings and access areas. Mechanical ventilation, such as dust collection systems, when used, was not adequate in providing airflow sufficient to significantly reduce airborne dust concentrations within these large containment systems (Figure 7). Spent abrasive and debris, sometimes several centimeters thick, was found on the floor of all containments. Typically, visible airborne dust was present, generated by prevailing winds and the movement of workers inside the containment, even in the absence of abrasive blasting.

Containment structures seen were designed to allow for maximum access to the structure and containment of debris. Automatic debris and waste recovery systems were not used in any of the containments seen during the tour. Debris collection was achieved through manual shoveling and vacuuming at the end of each shift.

Ground tarps were sometimes used as secondary containment systems. The effectiveness of ground tarps appeared highly variable, based on such factors as vertical distance to structure, wind direction and velocity, and effectiveness of the primary containment system.

4.1.2 Air Monitoring

No requirement or specification requiring environmental air monitoring for sources other than stationary sources was discovered during the tour. Bridges are not considered stationary sources. Environmental air monitoring requirements for abrasive blasting of lead-containing paint from bridges and other structures, as best as could be determined, are nonexistent.

Environmental air monitoring for total lead in dust and particulate size (PM10) is becoming more popular in the United States; however, the applicability and usefulness of this practice is often questioned for bridge-repainting sites. It is interesting to note that high-volume air monitoring is not conducted routinely in Europe in spite of the obvious high degree of concern for environmental protection. Current FHWA research may lead to more reasonable and applicable protocols for environmental monitoring during bridge-painting operations.

4.1.3 Soil Monitoring

Soil lead level monitoring before, during, and after the project is usually required. The Swiss have noted that as much as 70 micrograms of lead per m^2 per day may be deposited during movement and teardown of containment systems. Allowable levels of total lead in soils were found to be as low as 50 ppm.

These practices differ somewhat from U.S. practice. Currently, some states are requiring pre- and post-job soil monitoring for lead contamination, but it is not a universal requirement. Characterizing the contamination level of soils surrounding bridge job sites is difficult at best. Identifying the specific source of lead found in any one location further complicates the issue. A significant amount of field monitoring and research is currently underway to attempt to better define appropriate soil-sampling protocols.

4.1.4 Disposal

Recycling (off-site) or proper disposal of hazardous abrasive-blast media is required. Approved haulers transfer the contained waste to authorized treatment and/or disposal facilities (Figure 8). With the exception of Switzerland, such facilities are located in each country. Our inquiries did not discover widespread use of recyclable metallic (steel) abrasive, as is currently the trend in the United States. The European highway community prefers to use expendable coal or copper slag abrasive. In the Netherlands, abrasive waste must be recycled following each job. This recycling is accomplished at a centralized off-site location. This practice tends to significantly reduce the overall quantity of waste generated from bridge-repainting operations.

4.2 Worker Protection

The requirement to protect workers is generally the employers' responsibility. (An exception, however, exists in the newly enacted Construction Regulations of 1994 in Great Britain, which place the responsibility on the owner of the project and others.) Worker protection programs ranged from implemented to nonexistent. Safety issues seemed to be well addressed. For instance, scaffolding was found to be in good condition and properly erected. Toe boards, midrails, top rails, and crossbracing were common. Health issues, particularly protection of workers from lead-containing dust, were found to be less well addressed.

The impression of the panel was that these job sites were akin to the condition of similar sites in the United States in the late 1980s. It has only been since the implementation of the OSHA Lead-in-Construction standard in 1993 that worker protection from lead hazards has become a critical design issue for U.S. bridge rehabilitation painting jobs. This phenomenon apparently has not occurred in Europe to date.

Areas of discussion surrounding lead-specific health issues include worker training, engineering controls, respiratory protection, medical monitoring, and decontamination facilities and worker hygiene.

4.2.1 Worker Training

No specific requirements for training workers on the hazards of lead-containing paint removal were discovered during the tour. When asked about worker training, the hosts generally replied that workers are told that removal activities may cause health problems. Crews typically consisted of a small core of permanent, skilled journeymen. The remainder of the workforce was skilled or unskilled transient workers. There appeared to be a general knowledge of the hazards associated with lead; however, the work sites visited reflected the lack of a formal program designed to minimize risk associated with the lead hazard.

4.2.2 Engineering Controls

Containments, as previously indicated, were used to control environmental contamination. Dust collection systems, when used, were inadequate to suppress visible airborne dust levels inside containment, even in the absence of abrasive blasting. Dust collectors were seen on several sites; however, these dust collectors (~ 10,000 standard cubic feet per minute (SCFM); see Figure 9) did not appear capable of moving the quantity of air required to significantly reduce the hazard in the containment.

4.2.3 Respiratory Protection

The primary protection afforded individuals involved in bridge paint maintenance practices is the use of respirators. In the United States, the proper use of respirators for lead-paint operations is found in 29 CFR 1926.62, the OSHA Lead-in-Construction standard. OSHA also has a separate standard for the proper use, maintenance, storage, and fit-testing for various respirators (Figure 10). The panel found no evidence of similar guidance in the European nations visited. Abrasive blasting was not occurring at any of the sites during the time of the visits; however, it was obvious that respirators were used during abrasive-blasting operations. The following respirator types were observed: continuous-flow, abrasive blast hoods; half-mask air-purifying respirators, equipped with high-efficiency filters, organic vapor cartridges, or a combination of organic vapor/high-efficiency; and disposable dust/mist respirators. One contractor in Germany had designed its own version of a full-body respirator for abrasive blasting. This respirator was unique in that the blast helmet could be made integral with an impermeable suit. Air was supplied in the continuous-flow mode with exits at the wrists and ankles of the blaster (Figure 11).

United States health officials consider a formal respirator program, including proper fitting, training, care, maintenance, and use of respirators, to be of utmost importance to protecting workers from airborne hazards, such as lead paint dust. Based on experience in the United States over the past 10 years, the absence of such a program at the sites visited by the panel makes protection of worker health during lead-paint removal extremely difficult.

Individuals familiar with allowable worker exposure levels cited the Federal Republic of Germany Maximum Concentration Values in the Workplace (MAK - 0.1 mg/m^3 for lead). However, exposure monitoring to determine actual worker exposures during abrasive blasting, cleanup, containment moving, project inspection, and other operations had not been conducted.

4.2.4 Medical Monitoring

Pulmonary function tests were conducted by a major contractor in Germany. Otherwise, medical monitoring to determine the physical fitness of workers wearing air-purifying respirators was not discovered during the tour.

Blood lead levels were determined annually or biannually according to most people asked. In Germany, allowable blood lead levels were 70 micrograms of lead per dL of blood for males and 25 micrograms for females.

4.2.5 Decontamination Facilities and Worker Hygiene

Decontamination facilities, as now required in the United States, were seen at job sites in Germany and Holland. These facilities did not follow a linear "clean-to-dirty" area transition, as is the norm for U.S. bridge site facilities. The arrangement of hygiene facilities in proximity to working, living, and eating areas may limit their effectiveness in controlling the lead dust hazard.

Protecting workers and the environment when using the abrasive-blasting method on lead-containing paints is a difficult task at best. Containment systems that protect the environment can tend to increase worker exposure levels. The host countries have taken great strides toward environmental protection. In doing so, workers' health is potentially jeopardized.

Techniques and conditions seen at lead-containing paint removal projects in Europe in many ways mirror similar projects seen in the United States. The issues are certainly the same.

Communication with experts in other countries should continue and be expanded through programs such as the FHWA scanning tours. Sharing information on a multinational level may lead to more efficient and cost-effective solutions to the problems involved in protecting the environment, workers, and the steel bridge infrastructure during maintenance and removal of lead-containing paint.

5.0 PAINTING PRACTICES AND PAINT SYSTEMS

5.1 United Kingdom

The United Kingdom includes England, Scotland, Wales, and Northern Ireland. In England, 4.7 percent (~1,000) of the bridges under the control of the Highways Agency are steel and 90 percent of all bridges are less than 25 years old.

To protect steel structures from corrosion, basic paint systems are recommended based on environment, accessibility, and required durability of the system. Environment is determined based on location and degree of atmospheric pollution. Location may be either inland or marine, where inland is defined as locations that are not affected by sea salt spray. Atmospheric pollution is based on the amount of sulfur dioxide (SO_2) in the atmosphere and is estimated from Relative Value of Acid Deposition in the United Kingdom, 1986-1991, a map available from the Farm Research Team at Berkshire, England. Based on a review of the map, ratings of A for mild or B for harsh are assigned to a location. Furthermore, in all cases, the micro-environment of the location is evaluated to potentially modify an A classification into a B classification. Accessibility is classified as ready access or difficult access, based on the type of structure and restrictions on working time due to rail, river, or auto traffic.

Required durability is based on the expected service life of a structure. Typically, the requirements are, "no maintenance up to 8 years," "minor maintenance from 8 years," and "major maintenance after 15 years." Based on an assessment of these requirements, five basic and three alternative paint systems are recommended, as shown in Table 1.

In order for a specific manufacturer's paint to be used, the paint formulation must be registered with the Bridge Engineering Division of the Highways Agency. This includes testing and qualifying manufacturers' formulations and ensuring compliance with performance requirements. In addition to the formulation, a history of each type of paint, including first date of formulation and reason for any subsequent changes in information, is required.

This information is classified as "commercial-in-confidence" and is only shared with the Defence Research Agency (DRA) paint laboratory. The DRA is responsible for checking that paints conform to the declared formulations. Two samples of paint to be used on a structure are supplied to the DRA for analysis and are identified as "A" and "B" samples. "A" samples are required in all cases where more than 50 L of any one coat of paint are to be applied. These samples consist of paint from previously unopened 5 L tins. "B" samples are 500-mL samples taken from the painter's kettle or from the airless spray gun nozzles.

Environment		Access	System Type	Surface Prep.	Metal Spray	Coat 1	Coat 2	Coat 3	Coat 4	Coat 5	Coat 6	Min. Total DFT (μm)
Location	Type											
Inland	A	R or D	1	First Quality	Aluminum metal spray (100 μm)	Aluminum epoxy sealer						
Inland	A	R	2	First Quality		Red oxide, ZnCr blast primer	Zinc phosphate, epoxy ester	Zinc phosphate, epoxy ester	MIO, phenolic undercoat	MIO, phenolic finish		200
Inland	B	R	4	First Quality		Zinc phos, AR blast primer	Zinc phos, AR undercoat	Zinc phos, AR undercoat	MIO, AR undercoat	AR finish		250
Inland	A or B	R	4 Alter-native	**First Quality**		Zinc phos, HB epoxy blast primer (SHOP)	MIO, HB epoxy undercoat (SHOP)	Polyureth fnsh or MC poly-ureth fnsh				300
Marine	**A or B**	**R**	8	First Quality		Zinc phosphate AR blast primer	Zinc phosphate AR undercoat	Zinc phos, AR undrct	**MIO, AR undercoat**	**AR undrct**	**AR finish**	300
Marine	**A or B**	**R**	8 Alter-native	First Quality		Zinc phos, HB epoxy blast primer (SHOP)	MIO, HB epoxy undercoat (SHOP)	Polyureth finish or MC poly-ureth fnsh				300
Inland or Marine	**A or B**	D	10	First Quality	Aluminum metal spray	Aluminum epoxy sealer	Zinc phos, AR undrct	MIO, AR undercoat	**AR finish**			250
Marine	**A or B**	D	10 Alter-native	First Quality	Aluminum metal spray	Aluminum epoxy sealer	Zinc phos HB epoxy undrct (shop)	MIO, HB epoxy undrct (shop)	**Polyureth fnsh/MC Polyureth fnsh**			300

AR= Acrylated Rubber HB=High Build MC=Moisture Cure MIO=Micaceous Iron Oxide

Table 1. Summary of Department of Transport Painting Specifications for Highway Works (August 1993)

If an alternative paint is offered by a paint manufacturer, the following information must be supplied:

- Evidence of long-term performance (greater than 15 years) in a similar environment.
- A performance record for 5 to 15 years; the formulation is then registered after testing by an independent, professionally and technically competent testing authority.
- A proven performance record of less than 5 years; the formulation is then registered following successful testing by an independent, professionally and technically competent testing authority and after satisfactory completion of site trials over 5 years.

5.1.1 Maintenance Painting

Where the need for maintenance painting has been determined, protection systems are chosen based on the following categories of failure:

- *Category I.* Local failures only. Finishing coat otherwise sound, such that a repaint of the whole structure is not necessary.
- *Category II.* Normal weathering of finishing coat, e.g., chalking, surface affected by deposits, with some areas of local failure. Adhesion generally sound, such that, after cleaning down, the system can accept local buildup of undercoats and overall coating of the whole structure with an undercoat and finish.
- *Category III.* General failure of system, with disruption of undercoats and primer. Widespread corrosion varying from heavy rusting of the substrate to spot rusting on the surface of the paintwork. In some cases, considerable areas of white corrosion products may be visible on the surface, possibly due to extensive corrosion of a metal coating or a zinc-rich paint.

For Category I or II failures, the maintenance agent can perform a survey to establish the extent, intensity, and methods of surface preparation needed to ensure satisfactory performance of the maintenance paint system. For Category III failures, a specialist surveyor is appointed.

Before work is performed, feasibility trials for the proposed methods of surface preparation and painting systems are performed. At least two separate areas of the structure are chosen for trials. The proposed methods of surface preparation are carried out in each of the two areas. This is followed by application of a given paint system to each area.

From start to finish, the time between initial paint inspection and the start of maintenance painting can typically be 10 months or more, because feasibility trials are performed before contract documents are finalized (see Figure 1). The intervening 6 months between feasibility testing and paint testing allow a reasonable time to assess the viability of the proposed coating system, because at least one winter will have passed.

This is a similar approach to that being proposed for the many overcoating maintenance applications in the United States. The use of a "patch test" is generally recommended to ensure overcoat compatibility before full-scale application over the entire bridge structure.

5.1.2 Surface Preparation

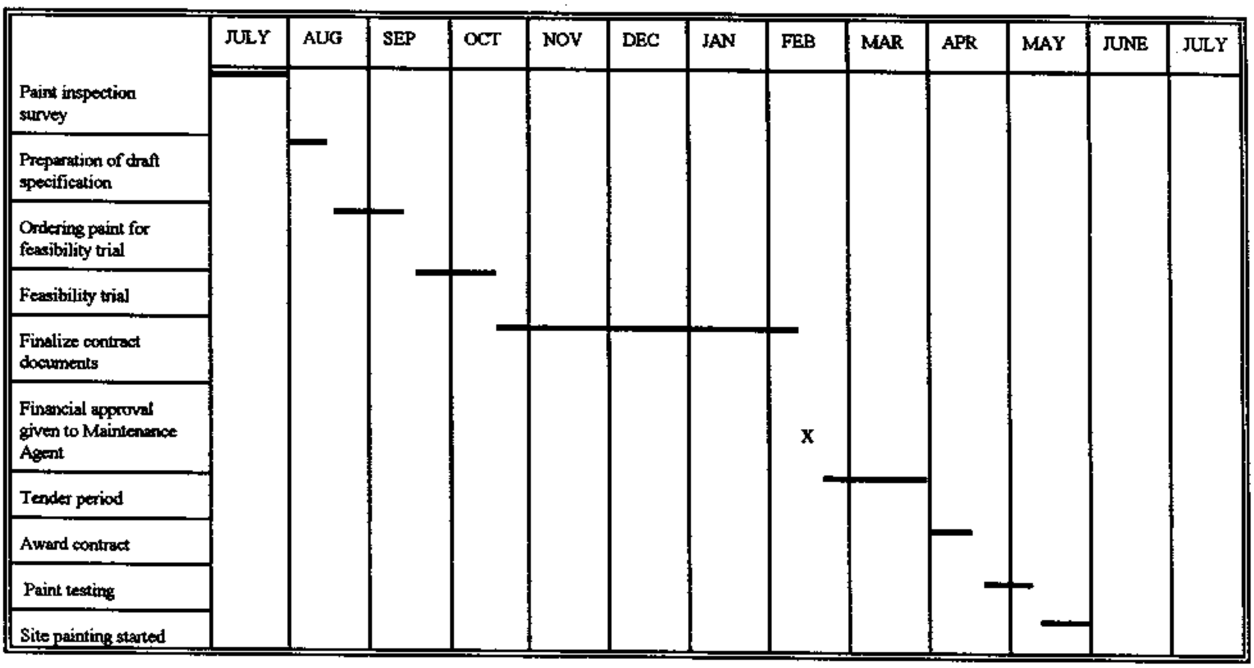
In general, areas contaminated by oil or grease are washed using a solution of water and emulsion cleaner, followed by rinsing with clean cold water before surface preparation.

The following methods of surface preparation are used:

- Scrubbing with a stiff bristle brush using water and a cleaning agent, followed with a cold water rinse
- Scrubbing with a dry, stiff-bristled brush
- Scraping, aided by hand or power brushing
- Abrading, using abrasive paper or power-driven flexible abrasive pads
- Grinding
- Blast cleaning, including:
    - Dry blast cleaning
    - Wet blast cleaning, using low-pressure air/water/abrasion system
    - Wet blasting using high-pressure air/water/abrasion system
    - Combined wet/dry blasting

At the beginning of any job, the contractor carries out surface preparation procedure trials on areas totaling 2 to 10 m^2, as designated by the engineer, using the labor and equipment to be used on the job. The contractor demonstrates the ability to carry out the specified methods of surface preparation to the required standard. The remaining surface preparation is not started until these trials and the first stage of the painting procedure trial have been passed as satisfactory by the engineer.

British highway officials noted a tendency toward the use of wet abrasive blasting for surface preparation in recent years. This technique is reported to provide a suitable profile on the surface, while minimizing dust generation during blasting.



Note: Guide based on the assumption that the paint inspection survey and feasibility trial are carried out in the same year and the maintenance painting contract started the following year.

Figure 1. Sample program for maintenance painting a steel highway structure

5.1.3 Painting Procedure Trials

Immediately following satisfactory completion of the surface preparation trials, the contractor carries out painting procedure trials on the prepared surfaces using the labor and equipment to be used in the work. Contractors must demonstrate the ability to apply the paints selected in accordance with the specification and supply sufficient paint for the trials, as agreed to by the engineer.

To avoid delay, the trials may be carried out in three stages:

1. Primer and first undercoat.
2. Undercoats and patch coats, where appropriate.
3. Last undercoat and finish.

5.1.4 Future Trends

The preceding paragraphs are a synopsis of today's practices. The Montreal Protocol and intergovernmental agreements on transboundary pollution have led to a target of "30 percent reduction of VOCs" by the end of the century, and the U.K. Environmental Protection Act (1990) addresses these issues. Major users of paint coatings must register if they use more than 5 tons of solvent per year. This equates to a paint consumption figure of approximately 13,000 L. Registration had to have taken place by September 1992 in England and Wales and by March 1993 in Scotland. Experience has shown that most eligible applicators have joined, and that local authorities are policing the Act and monitoring progress of the members.

The Environmental Protection Act was introduced in England after consultation with all concerned parties. Initially, it was conceived around the erroneous premise that all paint users had a "production line" facility and were able to collect VOCs readily and control the venting of these via an exhaust stack. A wider view has since been taken to encompass on-site application of coatings. Thus, the target figure for VOC emissions of 50 mg/m^3, measured as carbon, by 1998—basically achieved by incineration processes—was widened to take in the concept of "compliant coatings." The reasoning was that it was better to reduce the solvent content of coatings, rather than just incinerate emissions from existing low-solid coatings, which only produces "greenhouse effect" gases, such as CO_2.

The target for this alternative approach was for paints to meet a figure of 250 g/L by 1998, which equates to a volume of solids of about 70 to 75 percent for compliant coatings. Further consultation with the paint industry brought about a realization that this figure for topcoats and finishes was inadequate, because the high-solid products could not produce the desired standard of finish for some industries. The new target introduced at the end of 1994 was 420 g/L.

Like current and pending U.S. regulation, VOC rules in the United Kindgom have various specialty categories based on coating use. For example, for etchants, wash primers, and blast primers (or preconstruction primers), the target figure is 780 g/L because of their low solids content and because water-based equivalents are not yet generally available.

As in the United States, VOC target figures are constantly under review and may well be changed in England before 1998, if technology progresses.

5.2 Germany

Germany has approximately 34,000 road bridges, but less than 7 percent of them are steel. Most of these bridges are less than 40 years old. The majority of steel bridges, which total 1.9 million m^2 of steel, are over the Rhine and Danube Rivers. Because the German railway system has over 25,000 steel bridges, many of their painting and maintenance practices have been adopted for steel road bridges.

Unlike typical U.S. practices, each structure has a logbook from initial erection to structure dismantling. Included in this logbook are each inspection report, list of maintenance items performed, and the cost to perform maintenance. In addition, computer files of typical bridge details and their cost for maintenance are maintained. These data are used to estimate the potential cost of maintenance for similar details in future bids. For contracting purposes, contractors must provide a line item bid, which is used to update the computer-related files and to identify bids that are out of line with the norm. Bids for road bridges have to take into account the contract clause of ZTV-KOR, meaning they must include protection against corrosion of steel structures.

Bridges undergo a 1-year and a simple 3-year inspection, before the first major inspection after 6 years. This is possible since contractor warranties usually apply for 5 years with no defects allowed to that point (contractors typically repair minor defects during that period).

Also, unlike in the United States, bridge designers are required to design bridge structures to maximize corrosion protection and accessibility for maintenance activities. German standard DIN 55928, Part 2, describes the minimal requirements for designs to optimize corrosion protection. Included are the preference for welding over bolted or riveted connections; accessibility for inspection and maintenance, including guide rails for blast cleaning and spraying vehicles; treatment of gaps and edges; and measures to prevent retention of soil deposits and water.

As in other European countries, the location and environment of each structure determine the protective coating systems used. Table 2 lists the levels of corrosion load and corresponding environmental classifications.

If the corrosivity of the environment is in doubt, coils of wire of a given metal are exposed on-site for a year and the mass loss rates measured (DIN 50417, Part 1). This is similar to a standard maintained by the American Society of Testing and Materials (ASTM).

	1	2	3
Line	**Level of Corrosion Load and Description**	**Type of Atmosphere**	**Corrosivity Class**
1	Negligible Corrosion Load: Atmosphere of sulfur dioxide and other pollutants; relative humidity <60% (e.g., inside buildings in which operation conditions do not entail a corrosion load and to which the outside air has no direct access, as well as in hollow structures).	R (enclosure)	1
2	Low Corrosion Load: Atmosphere without significant quantities of sulfur dioxide and other pollutants (e.g., rural areas and small towns).	L (country)	1 and 2
3	Moderate Corrosion Load: Atmosphere with moderate quantities of sulfur dioxide and other pollutants (e.g., densely populated areas but without heavy industrialized zones).	S (town)	2 and 3
4	High Corrosion Load: Atmosphere with high quantities of sulfur dioxide and other pollutants (e.g., industrial conurbations and zones lying in the prevailing wind direction from such areas).	I (industry)	3 to 5
5	Very High Corrosion Load: Atmosphere polluted with particularly corrosive substances (e.g., chlorides) and/or with permanently high relative humidity (e.g., above the sea and in the immediate coastal region or in the vicinity of traffic areas exposed to salt spray load).	M (marine)	4 and 5

Note: Because the transition from one type of atmosphere to the next or from one corrosivity class to the next is fluid, intermediate states are possible.

Table 2. Types of Atmosphere and Corrosivity Classes Under Atmospheric Corrosion Conditions

The future trends in Germany are toward two-component epoxies (2 comp. EP), two-component polyurethanes, and moisture-cured polyurethanes (MCPO), all with low VOC content and no hazardous metal pigments. Furthermore, for minimally prepared surfaces during maintenance painting, an MCPO penetration primer is used. Table 3 compares corrosion control among such systems.

	Solvent-Based		Solvent-Free	
	MCPU	2 comp. EP	2 comp. PU	2 comp. EP
VOC	0	0	+	+
SSPC-SP10	+	+	+	+
St 2-3	++	0	?	?
Weather Window	++	–	–	–
Dew Point	++	–	–	–
2-Coat Buildup	+	+	++	++
Storage Stability	+	+	+	+
Downtime	+	0	++	++
Productivity	+	0	+	0

++ = good + = yes – = no 0 = partly

Table 3. Comparison Among Reactive Systems

5.3 Switzerland

Switzerland has a total of 3,200 bridges under federal control, of which approximately 2 percent are steel. The Swiss have the same requirements for life expectancy for both steel and concrete bridges—80 years. Average life expectancy will be about 120 years. Because of the relatively low number of bridges, a lack of expertise exists in many areas when major problems are encountered. Bridge engineers more familiar with concrete construction consider steel bridge coatings a marginal problem, and their knowledge of it varies widely.

EMPA, a quasi-public Swiss testing laboratory, has evaluated coatings applied between 1900 and 1990 to assess potential health risks and options for paint removal. The materials in existing paint systems on structures of potential concern and their primary quantities are listed below:

- 2,000 t lead as lead oxide
- 10 t chromium (VI)
- 10,000 t chlorinated rubber containing 200-400 t of PCB
- 3,500 t coal-tar coatings containing about 600 kg benz(a)pyrene
- 200,000 t Zn in zinc-coating, approximately 20 percent exposed to atmospheric corrosion.

In 1980, it was estimated that 90 percent of all steel bridges in Switzerland were coated with lead-containing paints; today, only 30 percent remain. In Europe, overcoating is known as spot-painting with complete topcoating, usually with paint systems of similar or identical chemistry. Table 4 lists existing systems and recommended overcoating systems. The trends in Switzerland for new coating systems for new construction and maintenance are listed below.

In response to the questionnaire in Appendix A, the following coating systems were presented as currently being used in Switzerland:

New Construction

Primers:	2-pack zinc phosphate or highly pigmented zinc based on epoxy resin primers, lead- and chromate-free
Intermediate coat:	2-pack coat high-build micaceous iron oxide epoxy or high-build (low solvent content) epoxy combination
Topcoat:	2-pack high-build micaceous iron oxide polyurethane topcoat or 2-pack glossy polyurethane topcoat
Advantages:	extremely resistant to chemical and mechanical wear and water for structures exposed to aggressive atmosphere, especially high film thickness per coat, therefore cost-saving.

Protection and Maintenance on Existing Structures (surface-tolerant coatings)

Primers:	2-component epoxy-combination of low solvent content as priming coat for steel (provides good penetration and wetting ability, permits high-build application, lead- and chromate-free, provides good corrosion protection even with lower standards of surface preparation) or pack synthetic resin primer, lead- and chromate-free, compatible with most coating systems
Topcoat:	Universal high-build coating, modified synthetic resin combination with active corrosion-protection pigments (high solid)
Advantages:	especially high film thickness per coat (cost saving), low solvent content, compatible with the most coating systems (one- and two-component types), excellent adhesion directly to steel and galvanized surfaces, particularly suited as maintenance coat on top of old coating systems.

Binder of Existing Deposition	Alkyd	Epoxy Ester	Urethane Alkyd	Polyacrylic	Polyvinyl	Polystyrene	2K-Epoxy	2K-Polyurethane	1K-Polyurethane	2K-CoalTAR/ Epoxy	1K-CoalTAR/ Polyurethane
Alkyd	■	⊠	⊠	⊠	□	□	□	□	□	□	□
Epoxy	■	⊠	⊠	⊠	□	□	□	□	□	□	□
Urethane Alkyd	⊠	⊠	⊠	□	□	□	□	□	□	□	□
Polyacrylic	□	□	□	⊠	⊠	□	□	□	□	□	□
Polyvinyl	□	□	□	⊠	⊠	□	□	□	□	□	□
Polystyrene	⊠	⊠	⊠	□	□	□	□	□	□	□	□
2K-Epoxy	⊠	□	⊠	⊠	⊠	□	■	■	⊠	■	⊠
2K-Polyurethane	⊠	⊠	⊠	⊠	⊠	□	□	■	⊠	⊠	⊠
1K-Polyurethane	⊠	⊠	⊠	⊠	⊠	□	⊠	⊠	■	⊠	■
2K-Coal TAR/ Epoxy	□	□	□	□	□	□	□	□	□	⊠	⊠
1K-Coal TAR/ Polyurethane	□	□	□	□	□	□	□	□	□	⊠	⊠
Silica	□	□	□	□	□	■	□	□	□	□	□
Coatings											
Flame Spray Zn Coating	□	□	□	■	⊠	□	■	■	□	□	□
Arc Spray Zn Coating	□	□	□	⊠	⊠	□	■	■	■	■	■

■ Custom Combination ⊠ Compatible □ Not Compatible

1. The long-term adhesion of alkyd resin on Zn dust coatings is problematic.
2. The closure of pares, as well as the top coating, must be compatible with the spray Zn coating.

Table 4. Overview of Compatibility

5.4 The Netherlands

The Netherlands has 1,500 steel bridges, 7 to 10 percent of which are rehabilitated yearly. The first major maintenance is after 25 years, the second occurs after 40 years, and a major overhaul is conducted after 55 years. Maintenance of the highway bridge system is controlled by the *Rijkswaterstaat*, which also controls the engineering and maintenance duties for the extensive system of dams, locks, and storm-surge barriers that protect the low-lying country from the sea. Many of these structures are fabricated from steel, so this agency has quite extensive experience with corrosion control by coatings for steel structures.

The Dutch take an aggressive approach toward corrosion control and coating maintenance. The bridges seen by the panel were in need of some maintenance painting, but the total removal and replacement of the paint system would certainly be considered "aggressive" maintenance by U.S. bridge painting standards (i.e., perhaps less than 10 percent of the structure had visible corrosion). This attitude is akin to the corrosion-control practices undertaken for steel in the marine industry; given the co-responsibilities of the *Rijkswaterstaat* for bridges and marine structures, this relationship is obvious.

According to officials at the *Rijkswaterstaat*, the Dutch tend to use coating systems similar to those used in Germany for atmospherically exposed steel structures (e.g., bridges). These systems include abrasive blasting to an Sa 2.5 (SSPC SP10) surface preparation with a multicoat system using zinc-phosphate primers. Micaceous iron oxide pigments are used in intermediate and topcoats, with polyurethane topcoats being the norm. The *Rijkswaterstaat* has also investigated the use of other types of coating systems. Recent testing on inorganic zinc-rich primers has produced promising results; however, the use of waterborne inorganic zinc in the laboratory has shown problems with early rusting due to improper curing. Similar problems have been seen in the United States.

An interesting study by the Dutch railways indicates that, for bridges with a span of 20 m, it is cheaper to build a new bridge after 30 years than to maintain an old one. This represents a savings of about 12 percent or U.S. $660,000 per bridge.

The Dutch authorities expressed a keen interest in achieving quality coating application services from contractors. They appeared to work extremely closely with contractor personnel to achieve high-quality work, and lists of potential bidders for contracts are limited to firms with adequate financial standing and demonstrated experience in bridge-repainting operations.

6.0 METALIZING

The term "thermal spraying" is commonly used to describe a family of coating technologies associated with the application of thick coatings onto components to reduce or eliminate the debilitating effects of wear and/or corrosion. Metalizing is the term for the processes commonly used for corrosion protection of steel. The most common techniques are the combustion-wire process and the two-wire arc process. In the combustion-wire process, a flame is generated by combusting a mixture of fuel gas and oxygen or air. A wire composed of the material to be applied is fed axially through the flame and melted (Figure 12). The molten particles are accelerated by the expanding gases and splat onto a component to form a coating. In the two-wire arc process, two wires are continuously fed into a device, such that the wires converge to a point in space. The wires are held at different electrical potentials, such that an electric arc is generated between them. These wires are, in essence, consumable electrodes and are continuously melted. A jet of gas, usually compressed air, is used to atomize the molten material and accelerate the resultant droplets onto the component surface.

6.1 Metalizing Materials

As with any coating process, the proper choice of coating material may determine whether or not the desired goals are achieved. Historically, thermal spray coatings of pure zinc and pure aluminum have been used for applications involving the protection of steel structures from corrosion.

6.1.1 Zinc

Zinc provides long-term corrosion protection to steel through galvanic action at the steel/zinc interface and through its ability to protect itself with its own corrosion byproducts. Zinc has a lower oxidation potential than iron and will preferentially corrode to prevent the steel from rusting. This property provides cathodic protection to any small discontinuities or damage done to the zinc coating that may expose the steel to the environment. When zinc is exposed to air, a very thin layer of zinc oxide forms. When exposed to moisture in the atmosphere, the zinc oxide reacts with the moisture to form zinc hydroxide. During the drying process, the zinc hydroxide reacts with carbon dioxide to form an insoluble zinc carbonate layer on the surface, providing excellent protection to the underlying zinc.

6.1.2 Aluminum

Aluminum provides a barrier to the corrosion of steel by forming an inert aluminum oxide layer on the surface of the coating. When damaged, this coating provides protection to exposed steel in the vicinity of the coating defect. Like zinc, aluminum has a lower oxidation potential than iron and, therefore, provides galvanic protection to the steel substrate.

Extensive use by the U.S. Navy indicates that aluminum has a slightly longer life than zinc in marine environments. Aluminum also offers enhanced abrasion resistance over zinc. Zinc and aluminum are often alloyed to obtain optimum properties, for example: 85% zinc/15% aluminum.

6.2 Metalizing Practices

In 1974, the American Welding Society (AWS) completed a 19-year study that indicated that aluminum coatings between 3 mils and 7 mils offered complete protection of bare metal (a rating of 10 by ASTM D610) in sea water, industrial, and severe environments. In addition, zinc coatings 12-mils thick provided similar protection in sea water, while 9 mils provided similar protection in industrial or severe environments.

The use of sealers reduced the necessary thickness of zinc to 6 mils or less. In 1993, the AWS issued a Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites, ANSI/AWS C2.18-93, which is now considered the definitive document for preparing specifications for bid documents in the United States. Philosophies differ with regard to the use of thermal-spray technology on bridges.

In Switzerland, the birthplace of thermal-spray technology in the 1890s, and in the Netherlands, thermal spray is infrequently, if ever, used. In Germany, which has thermal-spray specifications, the processes are infrequently practiced on the national level. In the United Kingdom, France, Belgium, and the Scandinavian countries, thermal spray is considered the preferred corrosion protection system. In England, metalized coatings, particularly aluminum, are used as a primer followed by up to five topcoats.

Subsequent topcoats are considered barrier coatings, not necessarily sealers. The benefit of this approach is that, when the topcoats fail, the thermal spray layer allows up to 5 years before remedial action must be taken. This allows planning and prioritization of maintenance activities. The disadvantage is that when the unsealed thermal-spray coating is exposed to the environment, it may not be amenable to maintenance topcoating and may have to be selectively removed, exposing bare steel.

In the United Kingdom, over 90 percent of all new steel bridge construction uses thermal spray technology. In 1994, between 3 and 3.5 million m^2 of steel were protected by thermal spray. Of this, 2.5 million was protected by zinc and the remainder by aluminum. In England, there are 20 contractors who use 10 t of material or more annually, 30 contractors who use between 5 and 10 t annually, and 25 contractors who use less than 5 t. Not all the material sprayed is for bridges, because offshore applications, buried pipelines, and lighting columns are similarly protected.

As part of the tour, the team visited Fairfield Mabey, where thermal spray coatings are applied in the shop. The team was impressed by both the thermal spray process and the degree of automation of the facility in terms of handling steel (Figure 13).

The metalizing application was still done by hand-held spray. Following is a short list of bridges protected by thermal spray coatings.

Bridges in the United Kingdom Protected by Thermally Sprayed Coatings

Humber Bridge (1982)	17,000 t structural (55,000 T) steelwork Main span = 1,410 m (1377 T) Total = 2,220 m 124 boxes, each comprising 8 deck plates 8 ft wide by 60 ft long plus footway = 60,000 m^2 @ .400-in thick = 72 t zinc Etch primer, brush primer, Zn phosphate epoxy ester (3 coats) After fab into boxes chlorinated rubber
Menai Straits Rail Bridge, Britannia (1971)	Aluminum-sprayed and 3 coats of paint
Severn Bridge (1966)	14,000 t in 88 hollow deck sections (each 60 ft long) and towers Towers and upper-deck surfaces - 75 micrometers Under-deck surfaces 65 Zn/35 Al - 75 micrometers
Forth (Road) Bridge (1963)	Built alongside the rail bridge (of constant painting fame, every 3 years)
Tamar Bridge, Plymouth (1961)	75 micrometers Zn, etch primer, white lead in an oil-modified phenolic medium 2 more coats on-site above.
New Conway Bridge (1960)	Reinforced concrete deck. Tivetted steel arch, 530 t steel, 175 tons concrete All of outside of arch and splash and immersion areas, Zn sprayed, 100 micrometers. Calcium plumbate, white lead undercoat and gloss

7.0 CONTRACTING

7.1 Field Contracting Operations

The key words describing field contracting operations seen in Europe are access and environmental protection. Unlike current U.S. industry trends toward small, lightweight, modular containment with designed-in ventilation, European containment structures for abrasive-blasting operations are designed as large, semipermanent structures. These structures contain the maximum possible area of the bridge substructure or superstructure. In addition, great care is taken to design containment structures that allow access for workers and equipment without affecting bridge traffic. The containment structures are suspended as work platforms from the substructure or superstructure of the bridge, allowing maximum access while not interrupting traffic. A good deal of thought is given to the design and materials used in constructing containment to contain a maximum amount of debris from abrasive-blasting operations. This is demonstrated by the use of double and triple liners of both flexible and rigid materials (e.g., rubber matting, plywood) for containment floors and the overlapping and mechanical fixing of seams in flexible containment materials.

In spite of the care and investment in their design and construction, the containment structure designs observed by the team do not always address ventilation, airflow, and worker-protection issues. All the large containment structures observed required extremely long hoses to access the work on the end of the structure opposite from the support facilities for the job. In one instance, this distance was over 200 m. When the supply hose for blasting the surface is this long, productivity falls dramatically as the contractor reaches the far end of the structure. The compressor capacities did not appear to provide adequate pressure at the nozzle for all areas of the structure.

The field contractors in Europe do not concentrate capital investment on advanced equipment. Rather, investment is made in the design and construction of containment. Based on the limited number of sites visited, it appears European contractors rely on a large number of man-hours to complete the work.

Recycled steel abrasive equipment is not used as extensively in Europe as it is in the United States, and containments are not designed to assist in the collection and movement of spent abrasive. Abrasive is handled by shoveling or vacuuming at the end of each work day. Also, the lack of ventilation tends to leave a significant amount of dust and fines on the interior surfaces of the containment.

Permanent or semipermanent work platforms are commonly used for maintenance of substructures. Many of these platforms are part of the original bridge design, recognizing the importance of maintenance for long-term performance of a structure. This is in contrast to current practice in the United States, where bridge maintenance is seldom a design consideration.

All the European transportation officials, contractors, and paint suppliers emphasized the importance of quality assurance in surface preparation and paint application. Quality of the job is a primary focus. In general, the Europeans were willing to increase spending nominally for high-quality work, on the assumption that life-cycle maintenance would be reduced through improved performance of the corrosion-control systems.

7.2 Agency-Contractor Relations

There is a more cooperative relationship in Europe among bridge agencies, painting contractors, and paint suppliers than in the United States. This was evident in the fact that many of the bids for work are distributed to a limited number of qualified vendors. Various countries have their own specific criteria for qualification of contractors; however, the general relationship between federal and local agencies and maintenance painting contractors appeared to be much more cooperative, and certainly far less litigious, than is the current situation in this industry in the United States.

The purpose of the limited bidder lists used for competition of contracts is to ensure financial viability of potential contractors and quality. Quality is ensured by basing the qualified contractor list on past performance on similar jobs. Obtaining well-planned work, using a formal written approach, was of utmost importance to the European bridge owners. The philosophy of limited bidder lists may change, because the current transition toward an economically unified Europe requires countries to consider bids from companies of member nations.

The European bridge owners have a more progressive attitude toward painting bridges under warranty than do those in the United States. Specifics of warranties differ among the nations, but most were found to hold contractors and paint vendors liable for field performance for a 5-year period. With recent changes in U.S. federal highway funding policy, painting under warranty will now be considered an option for states on federal-aid jobs. The European experience will serve as a good guide for these future U.S. efforts.

Bridges are painted under an interesting warranty arrangement in Holland. After letting of a painting contract, the owner, contractor, and paint supplier meet on-site, and the contractor applies the specified surface preparation/coating system to selected areas of the bridge. Once all parties agree the specification was properly followed in the selected areas, these areas are designated for evaluation for warranty conformance. The entire bridge is painted following the specification. If failure occurs first on the structure, while the "warranty areas" remain intact, the contractor is considered liable for the failure. If failure occurs on the warranty areas, the coating manufacturer is held liable, because its representatives were present at application of these areas and signed off that the coating was properly applied. The warranty generally applies for a 5-year period. This warranty scenario appears to be a useful means of assigning liability for coating performance, which is often the source of unresolvable controversy in the United States.

In all countries visited, the cost for full paint removal and replacement with multicoat paint systems appeared to be competitive with current prices in the United States. After currency conversions, the costs for field removal and reapplication of painting systems is the equivalent of U.S. $10.00 per ft^2 in Europe. This approximates the median in current costs in the United States. Although the Europeans do not have the magnitude of worker health and safety and environmental monitoring costs of U.S. industry, increased costs of European jobs associated with use of nonrecyclable abrasive and, perhaps, reduced productivity offset these savings.

8.0 CONCLUSIONS

The goal of the scanning review program is to exchange information on infrastructure issues, review existing technologies, and establish lines of communication. The limited time available on any scanning tour can only offer a "snapshot" of the overall technical issues and provide a basis for determining mutual interest and establishing points of contact. The bridge maintenance painting practices scanning team was impressed by both the depth of knowledge displayed by the individuals we met and by the quality of workmanship exhibited on the site visits. It was obvious that the process for establishing maintenance practices was well thought out and that contractors worked well with structure owners and had pride in their work. This report contains a small portion of the information obtained from our European colleagues; as more documents are translated and reviewed, we hope to gain more insight into European bridge maintenance painting practices.

A comparison of U.S. and European bridge maintenance painting practices has resulted in the following observations:

- The European countries are confronted with the same hazardous materials and cost issues as currently confront U.S. bridge owners, only on a smaller scale. The European nations visited do not have problems with lead-containing paint on the same scale as the United States, because Europe has a smaller number of older steel bridges, most of which were painted with an abrasive-blast surface preparation upon construction. The European steel bridges do not have the ongoing problem of maintenance of millscale-covered steel that exists in the United States.

- Protecting the environment during hazardous paint removal is of great concern to the European bridge community. For environmental protection, the Europeans tend to rely on design and construction of containments and planning of repainting operations, as opposed to monitoring and oversight, as is the trend in the United States.

- European bridge painting operations are not currently regulated to the extent of U.S. bridge painting operations in the area of worker health and safety. For this reason, various components of paint removal jobs now mandated in the United States (e.g., high-volume ventilation, formal respirator programs, worker air monitoring, controlled access for workers) were not seen at the sites visited.

- Warranties are very common in European bridge painting contracts. These warranties generally cover a period of 5 years and are sometimes structured to define liability between the contractor and the paint manufacturer in terms of specific performance criteria.

- The paint systems currently specified in the countries visited differ from those commonly used on bridges in the United States. Primers with zinc phosphate pigments, as used in Switzerland, Germany, and the Netherlands, have not been extensively used in the United States. Coatings with micaceous iron oxide pigments are used extensively in Europe, but on a limited basis in the United States. The pervasive use of a multicoat system with a thermal-sprayed aluminum primer in the United Kingdom is also unique.

- Based on dialogue with European highway officials, investment in job-site quality assurance is considered to be a priority.

- Bridges in Germany and the Netherlands are painted according to scheduled maintenance plans. Bridges are painted after a specified period based on their exposure location and other technical and historical factors. This practice allows for longer term bridge maintenance budgeting.

- European bridge painting contractors do not appear to invest heavily in capital equipment. Rather they tend to rely on a larger number of man-hours to complete these jobs. The trend in the United States has been toward the use of modular, reusable containment systems and abrasive recycling and dust collection equipment, requiring a significant upfront investment. The operations seen in Europe had custom containments fabricated on-site and expendable abrasives with manual recovery of spent abrasive.

- The vast majority of bridge maintenance painting in the countries visited employs a near-white metal abrasive blast (SSPC SP-10 or Sa 2.5) using expendable slag abrasives. Recyclable steel abrasives are not widely used. The European nations do not face the same problems as U.S. bridge owners with respect to existing millscale. Most existing steel bridges in Europe were abrasive blasted upon initial construction.

- Overcoating has not been embraced in the European countries visited because of skepticism over its performance.

- Waterborne industrial coatings have found increasing use in the United States in recent years. In spite of pending restrictions on VOC content of paints in Europe, waterborne formulations have not been widely specified.

9.0 RECOMMENDATIONS

The U.S. panel developed several short-term recommendations for modifying current U.S. bridge maintenance painting practice based on the European experience. Various panel members have begun to take action in the following areas:

- Use the European experience with warrantied bridge painting jobs to assist in demonstrating and implementating similar practices in the United States.

- Leverage current U.S. efforts to selectively test and implement metalizing with the extensive experience of the United Kingdom in this technology area.

- Revisit current U.S. practices for environmental air and soil monitoring during bridge maintenance painting operations.

- Evaluate the utility of European contracting and quality assurance practices in U.S. bridge painting operations. This effort may be most successful performed in concert with an organization such as American Association of State Highway and Transportation Officials (AASHTO).

- Evaluate the relative performance of coatings containing nontoxic inhibitive pigmentation, such as zinc phosphate. Evaluate the performance of coatings containing micaceous iron oxide as a barrier pigment.

- Based on the Swiss experience, investigate the past use of PCB-containing coatings on highway structures.

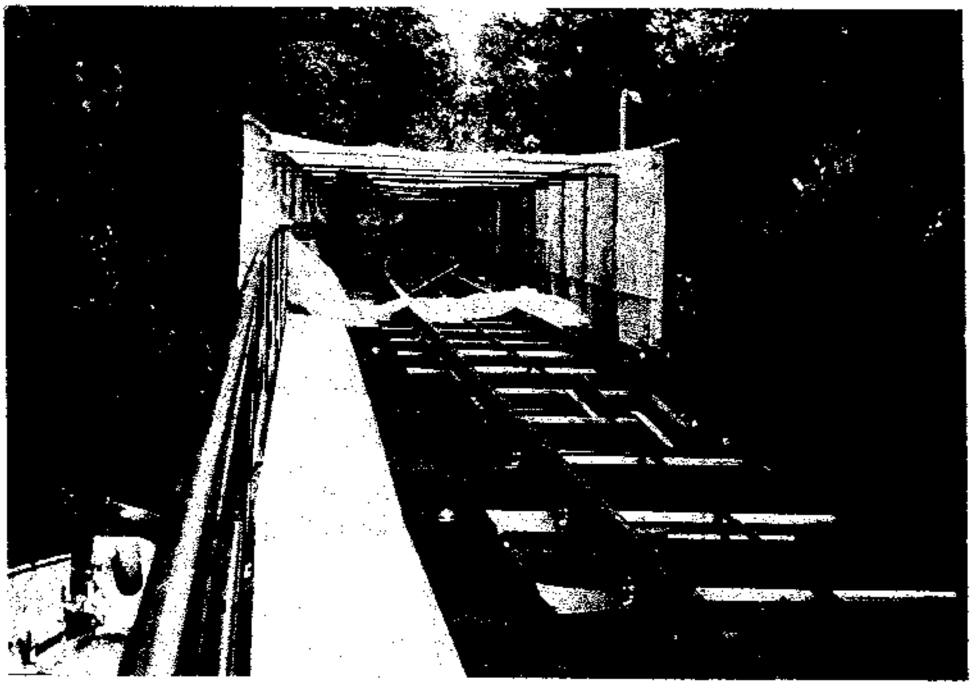


Figure 2. View of containment on steel tram structure, Zurich, Switzerland

Figure 3. View inside large containment structure, Haseltallbrucke, Germany. Note rails for mobile scaffolding, rigid flooring, and facia girder on left.

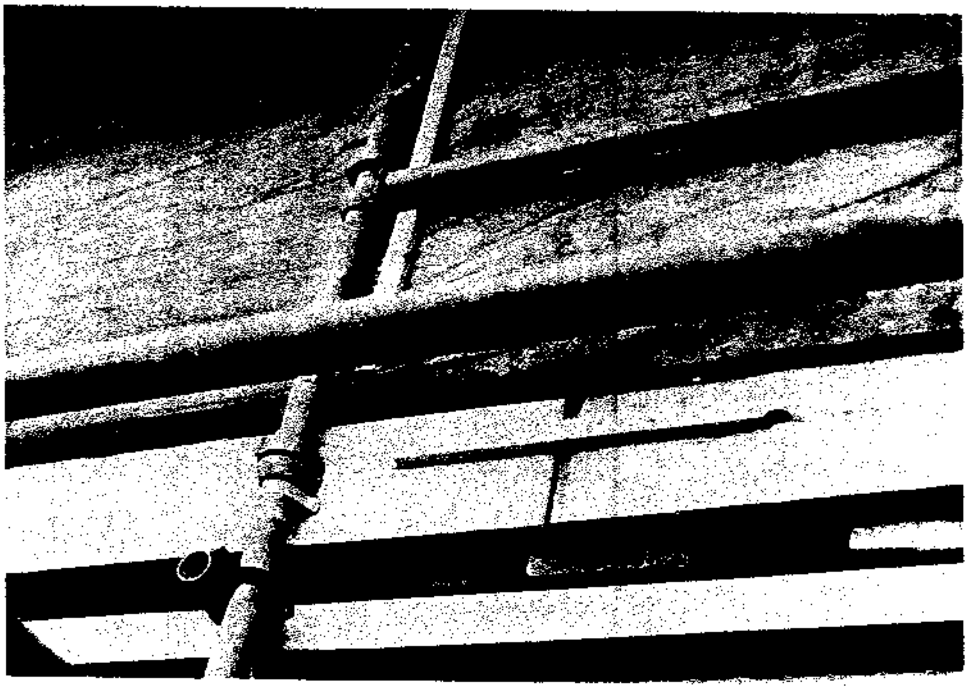


Figure 4. Mechanically fastened joints in containment tarps. All joints are nailed closed with wooden supports.

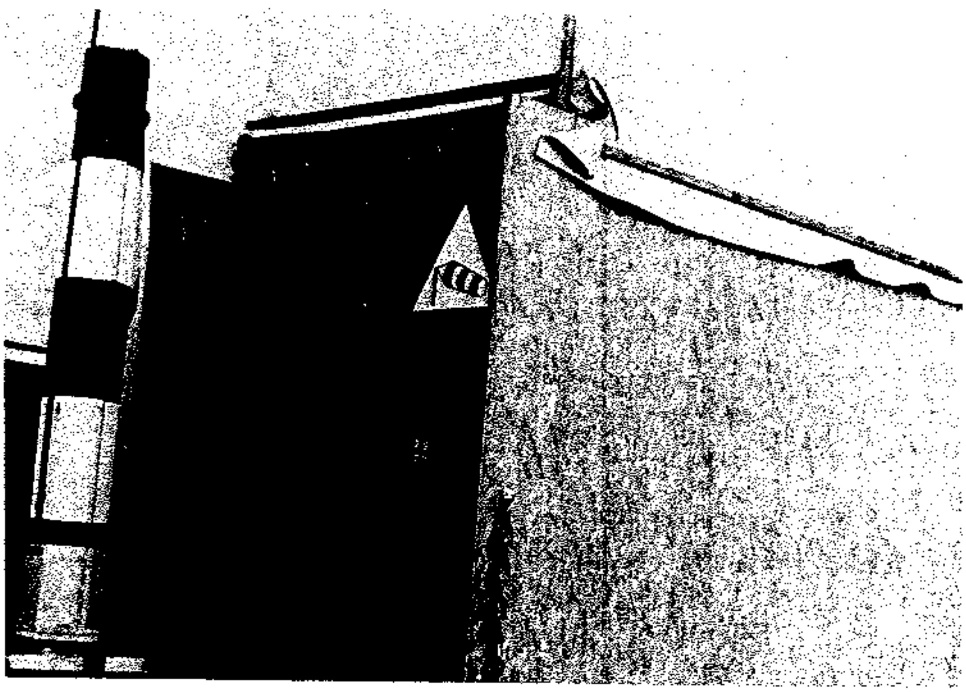


Figure 5. Rigid entry doorway to containment structure in the Netherlands. Note the foam sealing the seams and the "lead" pencil warning sign above the fixed hinged doorway.

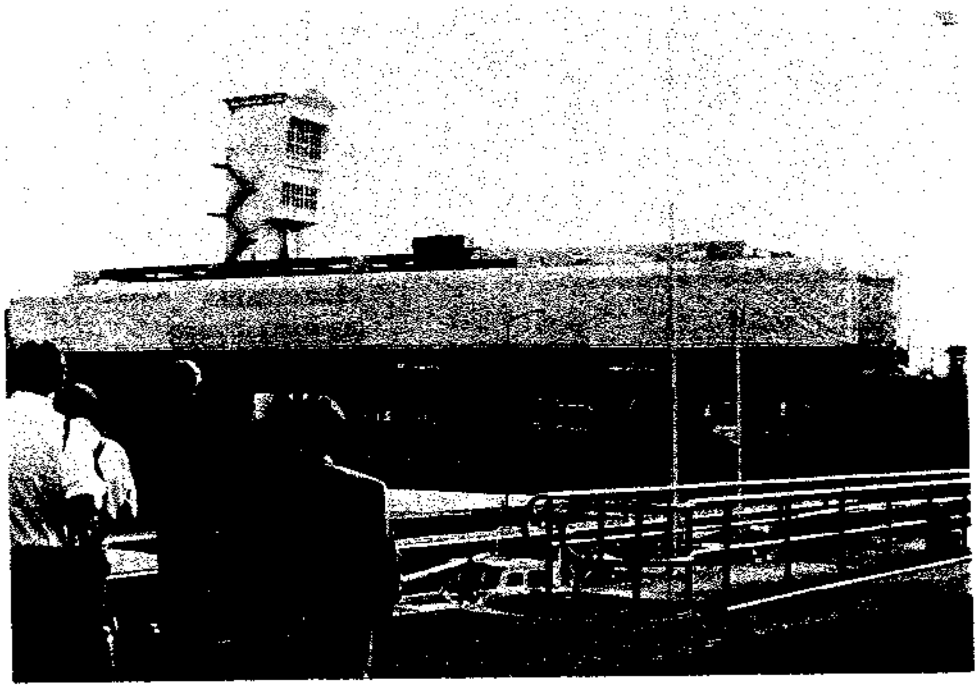


Figure 6. Containment structure on a bridge in the Netherlands. Construction is part rigid, part flexible. Note that traffic is allowed to pass between the twin containments on each side of the truss.

Figure 7. Large containment structure in the Netherlands. Note the ventilation.

Figure 8. Spent abrasive waste collected for hauling and disposal in Switzerland.

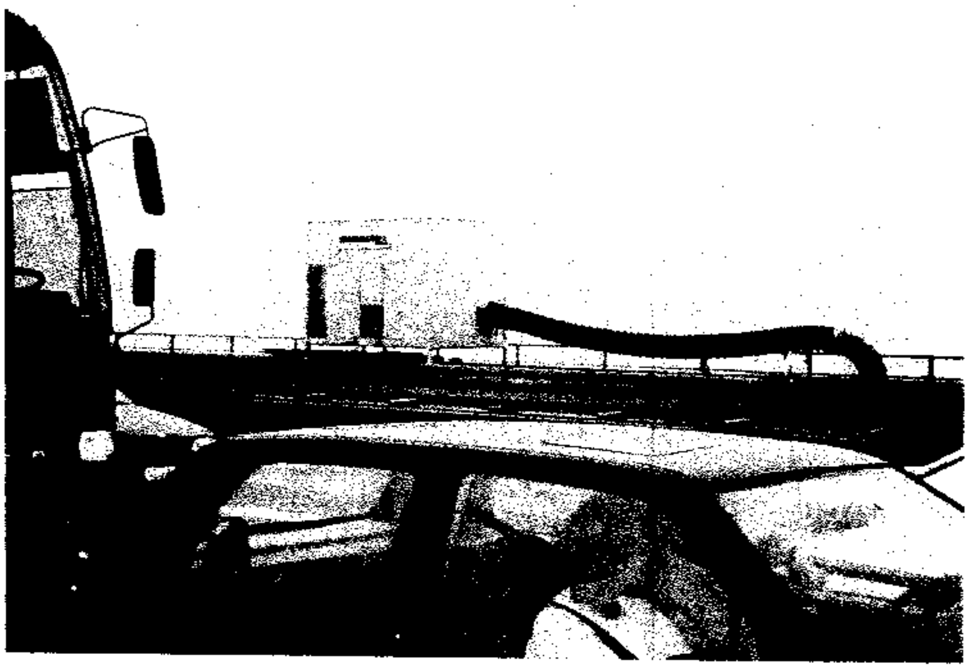


Figure 9. Ventilation for containment structure underneath bridge in Germany.

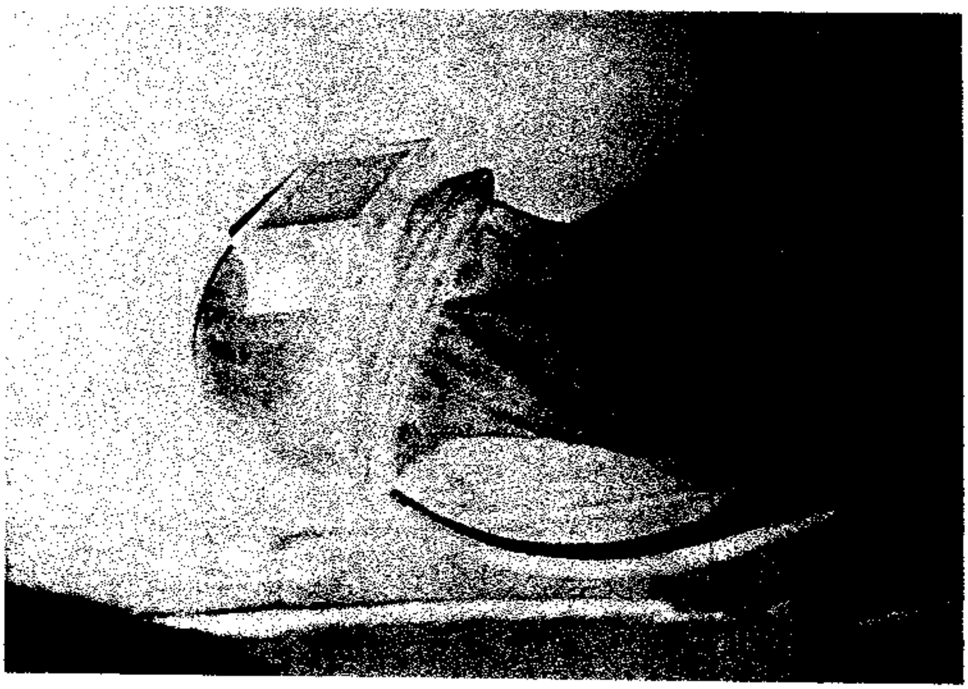


Figure 10. Typical continuous-flow, air-fed respirator with helmet. Stored inside containment.

Figure 11. Full-body, continuous-flow, air-fed respirator designed by a German contractor (Peiniger International).

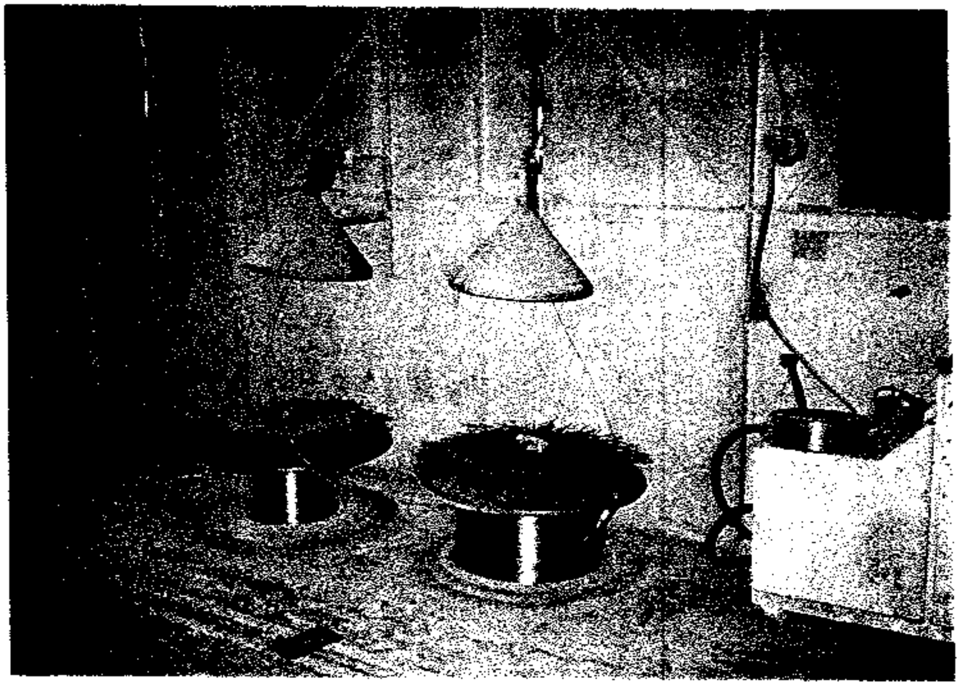


Figure 12. Coils of aluminum wire for metalizing at Fairfield-Mabey in Wales. Wire is fed directly to metalizing booth behind wall.

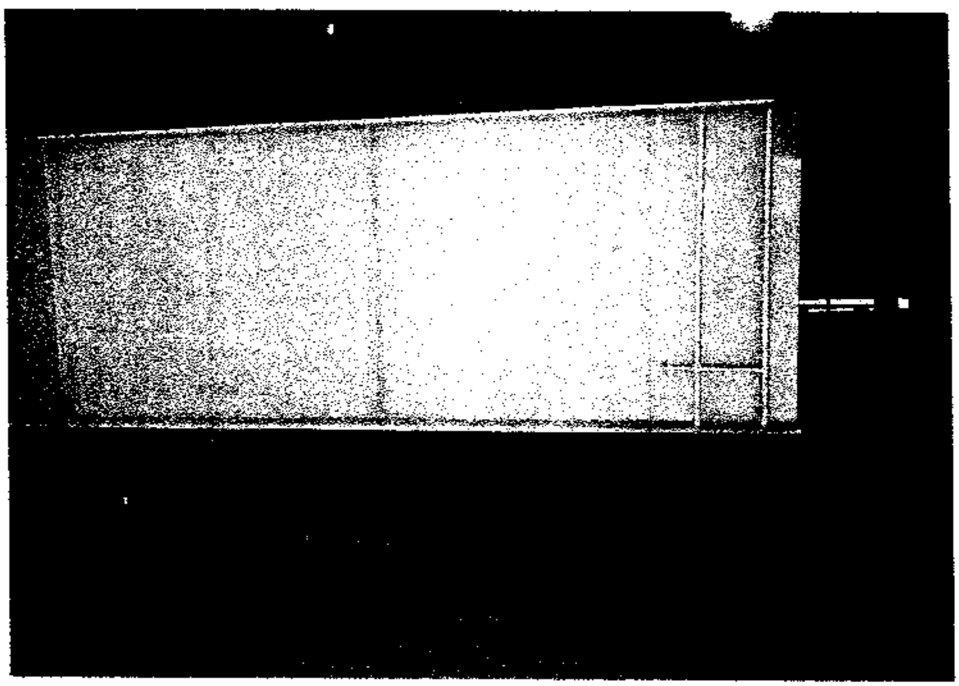


Figure 13. Finished metalized girder before sealing with topcoats.

APPENDIX A: BRIDGE MAINTENANCE COATINGS QUESTIONNAIRE

The survey that appears below was developed by the team to focus the scope of the study and facilitate information gathering. This questionnaire was sent to the hosting agencies abroad, before the team's visit.

1. Government Agencies

1.1 What effect have environmental and health and safety regulations had on bridge maintenance painting practices?

1.2 What is the magnitude of your steel bridge maintenance burden? How many steel bridges do you have? Are they painted with lead-based paint?

1.3 Do you have a Bridge Maintenance Management Plan? Does it specifically address corrosion control and painting issues? What are some of the key elements of this plan?

1.4 Do you use specific criteria to determine when repainting is necessary?

1.5 What are the corrosion control systems (paints) you are currently using on bridges? For new construction? For maintenance painting? Is there a formal procedure for qualification of paint products?

1.6 What type of contracting procedures do you use? Do you have performance-based specifications? Do you have a procedure for qualifying contractors?

1.7 What is the approximate cost per square meter of surface area for repainting?

1.8 Do you use third-party quality assurance inspectors on bridge repainting jobs?

1.9 Do you use de-icing salts on your bridges in winter?

2. Metal Spray Coatings

2.1 Are metal sprayed coatings being widely used currently for corrosion protection of steel bridges?

2.2 What type of application equipment is used for metal spray coating application? In the shop? In the field? What is the deposition rate?

2.3 What type of alloy is commonly used (i.e., zinc, aluminum, or Zn/Al alloy)?

2.4 What type of performance have you seen from these coatings systems?

2.5 Is it possible for us to inspect an aged structure coated with a metal sprayed coating?

2.6 Do you have a standard specification for application of metal sprayed coatings? At what thickness are these coatings applied? Are they seal coated?

3. Paint and Resin Manufacturers

3.1 What is the state of the present European bridge coating market in terms of materials?

3.2 What is the market for coatings intended for maintenance of coatings on existing structures? How about surface-tolerant coatings?

3.3 What are the new product trends?

4. Contractors

4.1 What type of contracting procedures do you use? Do you follow performance based specifications? Do you have a procedure for qualifying as a painting contractor? Are there special requirements for lead paint jobs?

4.2 What are the requirements for environmental and worker safety and health that impact your bridge repainting jobs?

4.3 Are you using recyclable abrasives?

4.4 Are you responsible for traffic control? Waste disposal?

4.5 Can we visit a typical bridge repainting job site?

4.6 What are the typical costs per square meter for bridge repainting?

4.7 What type of specialized equipment do you use? Do you fabricate or purchase this equipment?

5. Worker Health and Safety

5.1 What level of worker monitoring (air/blood) do you require for lead jobs?

5.2 What type of environmental monitoring do you perform?

5.3 What level of training do you require for workers and supervisors?

5.4 What involvement do industrial hygienists have in bridge repainting jobs?

5.5 What is the degree of enforcement of worker safety regulations? Are there substantial penalties for noncompliance with regulations?

6. Added Amplifying Questions

6.1 How much ASTM A588 weathering steel do you use? How has it performed? Do you have specific recommendations for its use?

6.2 What type of bolts do you use with new construction that is painted? Do you use black bolts, galvanized, etc.?

6.3 What is the cost differential between conventional coatings and metalizing systems for bridge protection?

6.4 Are there warranties given on bridge painting jobs?

6.5 Are regulations for worker safety written with "action levels" which initiate protection requirements?

6.6 Is any type of automated blasting equipment being used in the field?

6.7 What are the field practices for decontamination of workmen?

6.8 What is the treatment for faying surfaces in maintenance coatings?

6.9 What materials and equipment are used to construct and ventilate containments?