

INNOVATIVE TECHNOLOGY

Summary Report DOE/EM-0428

Reactor Surface Contamination Stabilization

Deactivation and Decommissioning
Focus Area



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Reactor Surface Contamination Stabilization

OST Reference #1839

Deactivation and Decommissioning
Focus Area



Demonstrated at
Hanford Site
Richland, Washington

INNOVATIVE TECHNOLOGY

Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at <http://ost.em.doe.gov> under "Publications."

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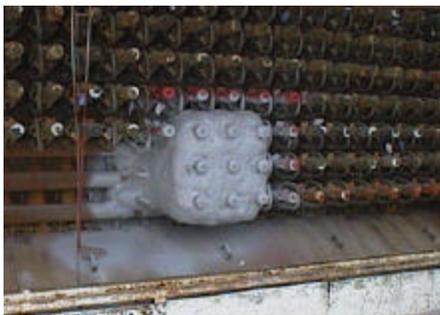
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SECTION 1

SUMMARY

Contaminated surfaces, such as the face of a nuclear reactor, need to be stabilized (fixed) to avoid airborne contamination during decontamination and decommissioning activities, and to prepare for interim safe storage. The traditional (baseline) method of fixing the contamination has been to spray a coating on the surfaces, but ensuring complete coverage over complex shapes, such as nozzles and hoses, is difficult. The Hanford Site C Reactor Technology Demonstration Group demonstrated innovative technologies to assess stabilization properties of various coatings and to achieve complete coverage of complex surfaces on the reactor face. This demonstration was conducted in two phases: the first phase consisted of a series of laboratory assessments of various stabilization coatings on metal coupons. For the second phase, coatings that passed the laboratory tests were applied to the front face of the C Reactor and evaluated. The baseline coating (Rust-Oleum No. 769) and one of the innovative technologies did not completely cover nozzle assemblies on the reactor face, the most critical of the second-phase evaluation criteria. However, one of the innovative coating systems, consisting of a base layer of foam covered by an outer layer of a polymeric film, was successful. The baseline technology would cost approximately 33% as much as the innovative technology cost of \$64,000 to stabilize an entire reactor face (196 m² or 2116 ft²) with 2,004 nozzle assemblies, but the baseline system failed to provide complete surface coverage.



Red Hawk coating at reactor face.



Master-Lee system.

• Technology Summary

Innovative technologies for stabilizing contamination on the reactor face were demonstrated by two companies: RedHawk Environmental, Inc., of Richland, Washington, and Master-Lee of Kennewick, Washington. The technology concept is to apply a coating system over a contaminated surface to fix the contamination and avoid airborne contamination during decontamination and decommissioning (D&D) activities and to prepare the reactor for up to 75 years of interim safe storage (ISS). The coating demonstrated by Master-Lee is a one-coating polymeric film 2.8 mm (90 mils) thick that did not provide complete coverage of the complex shapes on the C Reactor front face. The two-layer coating, foam plus a polymeric film 1.8 mm (70 mils) thick, demonstrated by RedHawk did completely cover the surfaces and, thus, is the main focus of this report. However, because the Master-Lee one-layer coating system may be useful in locations with easier access or on flatter surfaces, some information on it is also provided here. The traditional (baseline) coating is a film of Rust-Oleum No. 769 that is 0.05 mm (2 mils) thick that did not provide complete coverage. Both the polymeric coatings and the baseline passed 75-year accelerated oxidation and radiation exposures and other key laboratory assessments. Performance comparisons of the innovative (two-layer) technology field demonstration versus the baseline demonstration are as follows:

- Ⓒ Innovative contamination fixation, with fast curing (hardens in seconds) at ambient temperatures
- Ⓒ Complete surface coverage obtained by applying the polymeric film over a foam base
- Ⓒ More time consuming and labor intensive to apply, with more training required



C Improved as low as reasonably achievable (ALARA) practice because of the better fixation, but toxicity while spraying requires additional personal protective equipment (PPE).

Problem Addressed

The U.S. Department of Energy (DOE) is conducting D&D work at many of its nuclear facilities. Typically, the facilities undergoing D&D are contaminated, either chemically, radiologically, or both. In its D&D work, the DOE requires a coating system that can fix radioactive contamination to surfaces that cannot be cost-effectively decontaminated. The ideal coating should have a low toxicity, low air and moisture permeability, excellent adhesive properties, be able to completely cover complex shapes, work over wide temperature ranges, and provide high resistance to radiation and oxidation over long time periods.

Features and Configuration

The coatings offered by RedHawk and Master-Lee passed the initial laboratory assessments conducted first, and were subsequently demonstrated. Another foam coating, submitted by Eurotech of La Jolla, California, also passed critical laboratory assessments, but the vendor was unable to schedule a demonstration. The features of the innovative coating systems evaluated at the C Reactor are:

Two-Layer System: The RedHawk coating system consists of two layers: a polyurethane foam base layer covered by a polyurea film. The same equipment is used for spraying both the foam and the film.

One-Layer System: The Master-Lee coating is a single layer of polyurea film sprayed on the surface.

Potential Markets/Applicability

This technology is potentially valuable for any D&D project where physical removal of radioactive contamination is too costly or impractical. The DOE, the U.S. Nuclear Regulatory Commission, and the U.S. Environmental Protection Agency all have potential for wide use of this technology at their nuclear facilities. Private-sector remediation and demolition contractors may find either innovative system suitable, depending on the surfaces to be treated, for stabilizing contamination.

Advantages of the Innovative Technology

The following table summarizes the advantages and disadvantages of the innovative technology against the baseline (traditional) coating in key areas. It should be noted that although the baseline coating costs less, is not toxic, and is faster to apply, it failed to provide complete coverage.

Category	Comment
Cost	The successful two-layer innovative technology would cost \$64,000 to cover an entire reactor face; the baseline would cost \$20,900.
Performance	The two innovative coatings and the baseline coating passed key laboratory evaluations of aging resistance, but only the two-layer system completely covered complex shapes because a foam base expands to fill areas that are hard to reach.
Secondary Waste	All coating systems generate residual organic liquid wastes and contaminated PPE.
ALARA/Safety	The RedHawk coating system provided complete coverage and had the highest long-term ALARA rating. Exposure is longer during application, and the toxicity of the components is higher than with the baseline. Supplied-air respirators are used when applying the innovative coatings.
Ease of Use	The baseline coating (Rust-Oleum) was applied in half the time required for the best innovative coating system, so it can be considered favorable for readily accessible, simple shapes. The skill level required to apply the baseline is less.



Operator Concerns

- c For the innovative coatings, mobilization and application take longer than for the baseline coating.
- c The innovative coating formulations include diisocyanates that are toxic until the components begin to mix at the spray gun and polymerize.

Skills/Training

Workers must be able to operate paint spray guns and pneumatic equipment. The innovative coatings also require that operators have special training and experience with two-component proportioning equipment.

• Demonstration Summary

The technology demonstration was performed in two phases. For the first phase (August 1997 through March 1998), the coatings were applied by the vendors to small metal coupons and assessed by Wyle Laboratories of Huntsville, Alabama. For the second phase of the technology demonstration (March 19 and 24, 1998), the baseline and innovative coatings were applied to sections of the C Reactor face nozzle array.

Demonstration Site Description

At its former weapons production sites, the DOE is evaluating innovative technologies that might prove valuable for facility D&D. DOE's Office of Science & Technology/Deactivation and Decommissioning Focus Area, in collaboration with the Environmental Restoration Program, is undertaking a major effort of demonstrating innovative technologies at its sites nationwide. At the Hanford Site, 20 technologies have been demonstrated and assessed against baseline technologies currently in use. The Hanford Site Large-Scale Demonstration and Deployment Project (LSDDP) includes the C Reactor ISS as an important part of the overall effort. If successfully demonstrated at the Hanford Site, these innovative technologies could be implemented at other DOE sites and similar government or commercial facilities.

The innovative technologies described in this report are designed to stabilize radioactive contamination on the complex shapes of the C Reactor face. Each face of the C Reactor block, front and rear, is 14 m x 14 m (46 ft x 46 ft) and contains a number of nozzle assemblies 0.3 m (1 ft) apart. Each coating system demonstrated was applied to sections of the reactor front face.

Regulator Issues

No special regulatory permits are required for the operation and use of the innovative technologies. These coatings can be applied under the requirements of 10 CFR, Parts 20, 835, and proposed 834 for protection of workers and the environment from radiological contaminants; and 29 CFR, OSHA worker requirements.

Technology Availability

The innovative coating components for polyurea film are readily available throughout the United States from selected firms licensed by Huntsman Chemical Corporation of Austin, Texas. RedHawk has modified the formulation and makes it available as "SS-100." Master-Lee uses a modified formulation available from InstaCote (Erie, Michigan). The polyurethane components are not proprietary and are generally available.



Technology Limitations/Needs for Future Development

The two-layer foam and film coating system met critical performance objectives. Film coatings, especially thick, durable polymers such as the two innovative formulations demonstrated, either need a base layer over complex shapes or an innovative method of application. Film-only systems would need multi-directional spray tips to cover the backside of complex shapes. Alternative methods of achieving coverage by one-layer systems might include attaching a mesh or screen or a rigid cover over the reactor face nozzle assemblies end caps. Then a film could be sprayed over the entire mesh or over the rigid cover joints.

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Others

All published Innovative Technology Summary Reports are available at <http://em-50.em.doe.gov>. The Technology Management System, also available through the EM50 Web site, provides information about OST programs, technologies, and problems. The OST Reference Number for Reactor Surface Contaminant Long-Term Stabilization is 1839.



SECTION 2

TECHNOLOGY DESCRIPTION

• Overall Process/Technology Definition

Coatings offered by RedHawk and Master-Lee were among those that passed laboratory assessments, and these two firms were able to schedule field demonstrations. Both vendors use two-component formulations, whether for film or foam, that require an electrically heated proportioning and pumping system. RedHawk, however, uses a two-layer (foam and film) system, while Master-Lee has a one-layer (film only) coating system. The specifications are described below.

Material Specifications

Production of polyurea formulations is done by various firms under license from Huntsman Chemical Corporation (Austin, Texas).

The Master-Lee coating material is polyurea film, composed of a pre-polymerized resin and a “hardener” of diisocyanate that promotes the formation of InstaCote™ (Erie, Michigan). The polymer formulation is similar to polyurethane, but has added amino groups. The setting time to harden is 5 to 30 seconds. The coating will cure in 24 to 48 hours. The temperature of the area to be coated should be a minimum of 12.8°C (55°F). In order to ensure good adhesion without aggressive surface preparation, before spraying the polymer formulation a primer coat of a modified acrylic latex is applied with a hand-powered sprayer. (Master-Lee can apply InstaCote over a layer of foam, if desired.)

The RedHawk film material is similar to that used by Master-Lee, except that the material is called PolyShield™, formulated by Specialty Products (Tacoma, Washington). The base layer of polyurethane is allowed to set for 5 minutes before the final layer is applied. The final layer, a polyurea film, is sprayed beyond the edges of the foam for direct adherence to the reactor face. The polyurea is based on amine-terminated polyester resins, amine chain extenders and diisocyanate. It has a service temperature of -51°C to 177°C (-60°F to 350°F) and is hydrophobic. A primer coat of a polyether glycol is required only where the film extends beyond the foam.

Equipment and Power Requirements

The proportioning and application equipment are shown in Figure 1 and include two Gusmer Model H-2000/3500 2:1 air-driven supply pumps, which need air service of 6.2 to 7.6 bars (90 to 110 psi) and draw material from two 208-L (55-gal) drums. The proportioner electrically heats the components, and the materials are pumped at approximately 138 bars (2000 psi) pressure via two hoses to the spray gun. The hoses are heat-traced and insulated to maintain the materials at the proper temperature. The heating and pumping systems require 220 VAC single-phase electric power at 100 amps. The heated materials are mixed together at a Gusmer model GX-7 spray gun (Figure 2) and applied to the surface.

Equipment Details

The RedHawk coating applicator consists of a Gusmer Model H-3500 high-pressure proportioned that controls the mixture of two compounds and a Gusmer Model No. GX-7 spray gun. The same units are used for mixing and spraying the polyurethane foam and polyurea film. As the unit is operated, the pressure of the components is elevated to about 138 bars (2,000 lb) and 71°C (160°F). The hoses deliver two components in separate heated streams until they reach the mixing chamber in the spray gun. Here they are brought together in a 1:1 ratio to form the finished product. When the components mix, a slight exothermic reaction occurs, elevating the temperature to about 88°C (190°F). The GX-7 spray gun allows the applicator to spray in a range of output volumes, from 1.6 kg/min to 18.1 kg/min (3.5 lb/min to 40 lb/min), and features a self-cleaning valve/rod assembly that purges all mixed material from the gun at the end of each shot.



• System Operation

The materials begin reacting as they mix in the gun and travel through the spray tip. The diisocyanates react very fast, so there are no toxic diisocyanate fumes that become airborne long enough to be a hazard if the components are proportioned correctly. The coatings are hard within 30 seconds of spraying.

The Master-Lee crew consists of a spray-gun operator using full PPE with a supplied-air respirator and a proportioned operator outside the building. The RedHawk crew is similar, except that a third operator, in full PPE with a respirator, tends the hoses and at times can relieve the spray gun operator.

Setup

- C Stage equipment and material at the demonstration area
- C Connect all hoses to the proportioners
- C Connect electric power and air supply for the equipment
- C Start machine and recirculate material to test the equipment
- C Lay out hoses and connect spray gun
- C Test equipment before entering contaminated zone.

Note: Hoses, coating materials, and equipment must be maintained at a minimum temperature of 18.3°C (65°F).

Operation

Surface Preparation

- C Preload a hand-powered “garden” sprayer with mixture of adhesion promoter and water for the prime coat.
- C Spray mixture by hand onto surface to be treated. If a base layer of foam is to be used, this prime coat is needed only at the edges of the foam layer where the final film layer overlaps the foam onto the ends of nozzles and onto the reactor face.
- C Allow primer to dry for at least 1 hour.

Surface Coating

The spray gun operator applies the coatings by spraying back and forth to ensure uniform coverage. Thin layers are preferable to one thick layer to allow the heat to release. The surface temperature should be less than 38°C (100°F) before additional layers are applied. A technician monitors the proportioning equipment while it is operating to ensure the proper pressures are maintained.

A check of the thickness of the coating is made by cutting out four film coupons and measuring with a micrometer to ensure a minimum of 2.8 mm (90 mils) for the Master-Lee coating and 1.8 mm (70 mils) for the RedHawk two-layer coating. After the correct thickness is verified, all equipment is demobilized and surveyed and released from the area.



SECTION 3

PERFORMANCE

• Demonstration Plan

Site Description

As part of the D&D mission at DOE sites nationwide, DOE and its contractors must frequently fix contaminated equipment and surfaces that are not decontaminated, to prevent airborne contamination during D&D activities. For ISS of reactors, highly contaminated surfaces should be fixed. Coatings designed to immobilize contaminated surfaces were demonstrated as part of DOE's Hanford Site C Reactor ISS Project on March 19 and 24, 1998, on portions of a reactor face that has 2,004 nozzle assemblies with complex shapes. Figure 3 shows a typical nozzle assembly. Figures 4 and 5 show some of the nozzle assemblies on a reactor face.

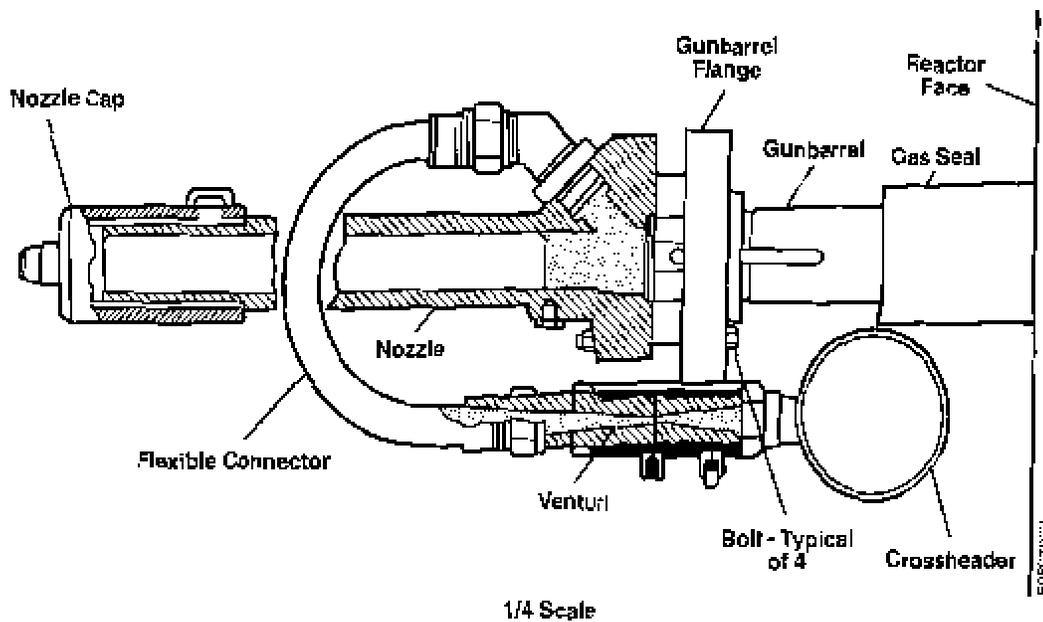


Figure 3. Typical nozzle assembly.



Figure 4. Group of 21 nozzles.

The purpose of this demonstration was to compare the capabilities of innovative technologies with those of the baseline technology, Rust-Oleum No. 769 primer.

The field demonstration began after laboratory assessments were completed on four innovative coating systems and the baseline coating system. One of the innovative coatings, a single-layer phenolic film, failed the initial laboratory adhesion assessment and was not considered further. The other three innovative coating systems passed enough laboratory assessments to be eligible for the field demonstration, but one of the vendors was not able to schedule the field work. Thus, two innovative coating systems and the baseline coating were demonstrated at the C Reactor.

Performance Objectives

A coating system is desired that meets the following criteria:

- C Provide complete coverage of complex shapes
- C Set up in a short enough time so that the coating does not run, drip, or fail to maintain thickness
- C Adhere without aggressive surface preparation (i.e., no preparation that might cause surface contamination to become airborne)
- C Withstand thermal aging in the presence of oxygen (air), radiological aging, and thermal cycling for 75 years
- C Maintain integrity when subjected to chilling, humidity, and biodegradation
- C Be non-toxic.

Demonstration Chronology and Specific Technology Demonstration Instructions

This evaluation was conducted in two phases. Phase one (August 1997 through March 1998) consisted of a series of laboratory assessments performed by Wyle Laboratories of Huntsville, Alabama, on four innovative coating systems and one conventional (baseline) stabilization coating. In addition to the laboratory assessments performed by Wyle, independent laboratories chosen by the coating vendors measured the permeability of the coatings. For phase two (March 19 and 24, 1998), two of the innovative coating systems that passed Wyle Laboratories' assessment were applied at the front face of the C Reactor, as was the baseline coating.

The Wyle assessments were performed on specimens of each coating that the vendors applied in their own shops to metal coupons (7.6 cm x 7.6 cm x 1.5 mm thick [3 in. x 3 in. x 3/16 in. thick]) supplied by Wyle. Two types of metal coupons were used to simulate the main surface types at the reactor faces: (a) rusted mild steel; and (b) stainless steel. The assessments included the following:

- A. Visual inspection of coated coupons returned from the vendors (and from Bechtel Hanford, Inc., for the baseline specimens), and photographs taken of any apparent damage.
- B. Initial adhesion evaluations per ASTM D 3359-95a. This adhesion procedure uses sticky pressure-sensitive tape to pull a portion of the coating, which has been scribed with an X-pattern using a knife, away from the metal coupon. The adhesion of the coating is rated by the analyst on a scale of 0 to 5, with 0 indicating removal of the coating beyond the area of the scribing to 5 indicating no removal. A rating of 4 or 5 was considered a passing score. This procedure was not applicable to some of the thick film or foam coatings; for these coatings, adhesion was judged subjectively while probing the coupon-coating interface with a knife.



- C. Thermal aging in an oxygen (air) atmosphere in a laboratory oven. The temperature and hours of aging were predetermined for each coating formulation based on the Arrhenius activation energy to simulate 75 years of aging. Visual inspection followed.
- D. Radiation aging in a chamber by exposure to gamma rays from a cobalt-60 source. The thermally aged specimens were exposed to 1560 rads, which simulates 75 years of exposure at the C Reactor face, where the field strength is approximately 2 mrem/hr. Another set of specimens, which had not been thermally aged, were exposed to 10 million rads to simulate locations where the field strength is much stronger than at C Reactor. After visual inspections, another set of adhesion evaluations were performed as indicated in paragraph B above.
- E. Thermal cycling in a circulating-air chamber. The thermally aged and radiation aged specimens were subjected to 820 cycles of heating and cooling to represent extreme diurnal temperature changes historically experienced at the Hanford Site. The temperature spread was automatically set at 27.8°C differential (50°F differential). The selected number of cycles represents the number of times over 75 years that the temperature spread is expected to be within 6.7°C (12°F) of the highest spread ever recorded, which was almost 27.8°C differential. After visual inspections, a final set of adhesion evaluations were performed as indicated in paragraph B above.
- F. Chilling for 24 hours at extreme temperatures. A separate set of coated coupons were kept for more than 24 hours in a chamber at -34°C (-29°F), representing the coldest temperatures on record at the Hanford Site. This was also followed by visual inspection.
- G. Humidity exposure per ASTM D 2247-94. The specimens chilled in step F were maintained for a week in a chamber with 100% relative humidity. The effect of humidity was evaluated by measuring the spread of rust that formed at the interface of a coating and a mild steel coupon surface. After visual inspections, a final set of adhesion evaluations were performed as indicated in paragraph B above.
- H. Biodegradation assessments per a modified version of ASTM G 22-76. Separate specimens were incubated with bacteria that had been cultured from a sample of soil obtained near the Hanford Site C Reactor. The incubation was in a high humidity atmosphere at 25°C (77°F) for 21 days. Modifications to the standard ASTM procedure were made so that the elevated temperatures would not prevent bacterial growth.
- I. Density measurements per ASTM D 792-91. The densities of the various coatings were measured using unaged materials only so that the added weight could be estimated if the front and rear reactor faces were coated.
- J. Permeability measurements on aged samples. The permeability measurements apply only to film samples that were not on metal coupons. Wyle aged the samples thermally and radiologically and sent them along with unaged samples to independent laboratories designated by the various coating vendors. The aged and unaged samples were each measured for water vapor transmission per ASTM D 1653-93, and for air permeability per ASTM D 1434.

Once the laboratory assessments were completed, the vendors of those coatings that passed the assessments were invited to demonstrate their technologies at the C Reactor. Three of the four coatings passed the assessments; of those three only two (RedHawk Environmental, Inc., and Master-Lee Engineering) were able to schedule demonstrations. Their technologies were applied to the reactor face along with the baseline technology.

Each promising coating system and the baseline coating were applied at different locations on the C Reactor front face to cover an array of complex-shaped, congested nozzle assemblies on a portion of face area. After the application, the coating thickness and completeness of coverage were evaluated. In addition, the equipment setup time, application time, cure time, and demobilization time were recorded.



• **Technology Demonstration Results**

Key Demonstration Results

Results of laboratory assessments are given qualitatively in Table 1 for two innovative coating systems and the baseline coating. A third innovative coating system, supplied by Eurotech (LaJolla, California), performed in the laboratory much the same as did the RedHawk coating system, except that permeability was not measured and thermal aging and film adhesion were not thoroughly assessed. Details of Wyle Laboratories procedures and quantitative results are given in Report No. 46506R98 by Wyle Laboratories, "Results Report of the Assessment of Stabilization Materials," dated June 29, 1998.

Table 1. Laboratory assessments

Type of Assessment	Innovative		Baseline
	Master-Lee Film	RedHawk Foam + Film	Rust-Oleum No. 769
Wyle Laboratories Assessments			
Check adhesion	P	Foam F/Film P	F*
Thermal & rad. aging	P	P	P
Check adhesion	P	Foam F/Film P	P
Chill; humidity; biodegradation	P	P	P
Thermal cycling	P	P	P
Check adhesion	P	Foam F/Film P	P
Effect of Thermal and Rad Aging on Permeability (Measurements by Independent Laboratories)			
Air Permeability	Increased by 10%	Decreased**	NA***
Moisture Permeability	Increased by 10%	Increased by 20%	NA***

Notes: P = Pass, F = Fail, NA - Not assessed

*The baseline coating did not cure until heated in lab thermal aging oven.

**Permeability decreased by aging.

***Permeability samples must be films without a metal coupon backing, and the baseline film samples prepared without metal backing disintegrated upon being thermally aged, so no permeability measurements were done for the baseline.

Quantitative results of Wyle assessments and of permeability measurements are given in Tables 2 and 3, respectively. In Table 2 the coupon numbers used for each assessment are given above the result. Thus, the reader can determine which coupons were used repeatedly in a series of various assessments. The coupon numbers are given in the following order: oxidized cold-rolled steel/stainless steel (Ox-CRS/SS). Where no stainless steel coupon was used, the coupon number is given without a slash-mark and represents a mild steel (cold-rolled steel) coupon. In Table 3 the water vapor permeability measurement is the most important of the two types of permeability measurements, because if water condenses at the base of a coating it may destroy the bond to the substrate. The water vapor permeability values noted in Table 3 are similar to those of 0.2-mm (8-mil) epoxy films that are generally considered as resistant to permeation. The changes in permeability are well within acceptable ranges.



Table 2. Reactor surface components stabilization material laboratory assessments results

Assessment Conducted	Coating Material Evaluated			
	RedHawk	Master-Lee	Eurotech EKOR	Rust-Oleum (baseline)
	Coupon # Ox-CRS / SS	Coupon # Ox-CRS / SS	Coupon # Ox-CRS / SS	Coupon # Ox-CRS / SS
1. Initial Adhesion ¹	16,17,18/41,42 5A (No Peeling)	11,12,13/36,37 5A (No Peeling)	1,2,3/26,27 Procedure Anomaly ²	21,22,23/46,47 Coating Not Cured ³
2. Thermal Aging a. 50 years ⁴ b. 75 years ⁵	16/41 Passed	11/36 Passed	1/26 Procedure Anomaly ⁶	21/46 Passed
	17/42 Passed	12/37 Passed	2/27 Procedure Anomaly ⁶	22/47 Passed
3. Radiation Exposure a. 1.0E7 Rads b. 1,560 Rads	19 (darkened) No Degradation	14 (darkened) No Degradation	4 No Degradation	24 No Degradation
	16,17/41,42 No Degradation	11,12/36,37 No Degradation	1,2/26,27 (51,52) ⁷ No Degradation	21,22/46,47 (56,60) ⁷ No Degradation
4. Intermediate Adhesion ¹	16 5A (No Peeling)	11 5A (No Peeling)	1 Foam Failed ²	21 4A (Trace Peeling)
5. Thermal Cycling	16,17,19/41,42 (50,61) ⁷ No Degradation	11,12,14/36,37 No Degradation	1,2,4/26,27 No Degradation	21,22,24/46,47 No Degradation
6. Low Temperature Exposure	18 No Degradation	13 No Degradation	3 No Degradation	23 No Degradation
7. Humidity ⁸	18 mean value = 9	13 mean value = 9	3 mean value = 9	23 mean value = 8
8. Final Adhesion ¹	16,17,18/41,42 5A (No Peeling)	11,12,13/36,37 5A (No Peeling)	1,2,3/26,27 Foam Failed ²	21,22,23/46,47 5A (No Peeling)
9. Biodegradation	43 No Biodegradation	39 No Biodegradation	28 No Biodegradation	48 No Biodegradation (surface stains)
10. Density	44 0.9463 gr/cm ³	39 0.897 gr/cm ³	29A (film) 1.642 gr/cm ³ 29B(foam) 0.263 gr/cm ³	64 1.883 gr/cm ³

1. Adhesion Rating: 5A-No peeling/removal

- 4A-Trace peeling or removal
- 3A-Jagged removal up to 1.5 mm (1/16 in.)
- 2A-Jagged removal up to 3 mm (1/8 in.)
- 1A-Removal of area of X incision (see item B on page 9)
- 0A-Removal beyond X incision

- 2. Eurotech submitted coupons completely covered on one side with foam + film and none with film only, so the prescribed ASTM method for adhesion could not be used. Probing the foam/coupon interface with a knife indicated that the foam did not adhere well. Where the film overlay contacted the edge of the coupon directly, probing indicated that there was adherence of the film
- 3. Rust-Oleum specimens failed initial adhesion due to the lack of complete curing of the coating
- 4. 50-yr thermal aging (oxidation) done at 90°C (194°F)
- 5. 75-yr thermal aging (oxidation) done at 113°C (235°F)
- 6. Eurotech=s initial measurements of activation energy was 1.4 eV versus a later value of 0.90 eV resulting in an aging equivalent of 1.3 yrs instead of 50 yrs and 1.9 yrs instead of 75 yrs
- 7. RedHawk and Eurotech each submitted a non-oxidized CRS coupon and an SS coupon each coated with film only
- 8. Rust Rating: 7= rust from 0.8 to 1.6 mm (1/32 to 1/16 in.) spread at scribe; 8 = rust from 0.4 to 0.8 mm (1/64 to 1/32 in.)
9 = rust up to 0.4 mm (1/64 in.); 10 = no rust



Table 3. Permeability measurements

	Air Permeability		Moisture Vapor Permeability	
	AGED	FRESH	AGED	FRESH
Red Hawk (Akron Polymer Laboratory)	cm³ mm/m² day atm		g/day/ft²	
	269 1.16 mm thick 2 atm pressure	316 1.19 mm thick 2 atm pressure	3.4 0.716 mm thick	2.8 0.804 mm thick
Master-Lee (K Chem Laboratory)	cm³/m²/day		g/day/ft²	
	260 2.39 mm thick 1 atm pressure	235 2.985 mm thick 1 atm pressure	3.265 2.39 mm thick	3.005 2.985 mm thick

Table 4 compares the innovative and baseline performance in the field demonstration for each group of nine nozzle assemblies (a 3 x 3 array). This size array is practical for the spray gun operator to coat between moves by the operator across a reactor face. It should be noted that the innovative coating formulations include diisocyanates that require use of a supplied-air respirator, whereas an air-purifying respirator is adequate when spraying the baseline coating.

Table 4. Performance per group of 9 nozzle assemblies

Type of Assessment	Innovative		Baseline
	Master-Lee Film	RedHawk Foam + Film	Rust-Oleum No. 769
Setup	40 min	64 min	30 min
Priming	*	1 min	1 min
Spray foam	None	20 min	None
Spray film	11 min	7 min	4 min
Demobilization	45 min	60 min	30 min
Crew	2	3	2
Coverage	Incomplete	Complete	Incomplete
Approx. film thickness	90 mil	70 mil	2 mil
Inspection time	Extensive	Short	Extensive
Secondary waste	Residual organics and PPE	same	same
ALARA	Coverage incomplete	Provides excellent fixation	Coverage incomplete
Safety	Formulation includes toxic diisocyanates	Formulation includes toxic diisocyanates	No highly toxic compounds
Ease of use/training	Special training and experience needed to operate proportioner	Special training and experience needed to operate proportioner	Only need general spray-painting experience

* The Master-Lee hand-powered sprayer intended for applying primer plugged. It took 25 minutes to apply the primer with a rag instead of spraying it.



Successes

- C The innovative polyurea film sets up almost immediately and adheres.
- C When the foam is used as an undercoat, it expands upon application and completely covers enough of the complex shapes so that the film overcoat can easily be applied with 100% coverage.
- C The film forms a low-permeability layer over the foam, and the film can adhere the coating system to the reactor face and to nozzle ends that protrude out from the foam.
- C Inspection of the foam + film system for quality control is simple.
- C The foam + film system provides coverage of complex shapes and acceptable adherence.
- C The innovative coating systems have the ability to adhere and to harden in a short time; withstand aging and thermal cycling up to 75 years; and maintain integrity when subjected to chilling, humidity, and potential biodegradation.
- C The innovative coating systems are simple to deploy, but require some special worker experience with the proportioning equipment.
- C The foam + film system provides long-term ALARA better than the baseline by achieving fixation with complete coverage.

Shortfalls

- C Both film-only coating systems, the innovative Master-Lee polymer and the baseline Rust-Oleum No. 769 primer, failed to cover the nozzle assemblies completely. The backsides of flanges and parts of curved, braided stainless steel hoses could not be reached by the spray gun.
- C Overall time (equipment setup, application, and demobilization) for the innovative coatings technology was two-and-one-half times longer than the baseline technology.

The baseline coating cured too slowly to perform initial laboratory assessments such as adhesion, and remained uncured until thermal aging started.

Meeting Performance Objectives

The Red Hawk coating system met the performance objectives, except for toxicity risks while spraying. The single-layer systems did not completely cover complex shapes, based on the application method.

• Comparison of Innovative Technology with Baseline

The baseline demonstration consisted of Rust-Oleum No. 769 damproof red primer applied with a conventional airless paint-spray pump and gun. The film thickness should be approximately 0.05 mm (2 mils) thick. The primer was mixed at the pump and delivered to the spray gun via hoses. During the application of this coating, only one member of the two-person crew was in full PPE with an air-purifying respirator (APR). The baseline coating failed the initial adhesion laboratory assessment because the coating had not cured. When unsupported film samples were thermally aged by Wyle Laboratories in preparation for permeability measurements, the samples disintegrated, so permeability measurements were not made for the baseline coating. In the demonstration at the front face of the C Reactor block, the baseline coating was applied without a foam underlayer and failed to cover all of the complex shapes of the nozzle assemblies, just as occurred with the innovative Master-Lee film-only application.



Also, the foam is somewhat held in place by the complex shapes (nozzle assemblies) that are permanently attached to the reactor face, because the foam is placed around and in between the complex shapes.

Foam samples were submitted by RedHawk and Eurotech for assessments by Wyle Laboratories. None of the foams adhered to the metal coupons. However, adherence of foam is not considered necessary if it is covered by a suitable film layer that overlaps edges of the foam onto nozzle ends and onto the reactor face and provides overall adherence of the two-layer coating system. The foam samples and three of the four innovative film samples passed enough laboratory assessments to be eligible for the field demonstration. However, Eurotech was not able to schedule a field demonstration, so its coating system was not evaluated at the reactor.

After thermal aging, the baseline coating passed the laboratory assessments and was also eligible for the field demonstration.

The innovative film coatings are polymeric formulations that are applied in thicknesses that are 35 to 45 times the thickness of the baseline coating. Such thick polymeric films harden very quickly into durable, elastic coatings, in contrast to the baseline coating, which cannot cure properly or maintain even thickness when applied heavily.

Skills/Training

Workers must be able to operate paint spray guns and air compressors. The innovative coatings require that operators have special training and experience and supervised experience with multi-component proportioning equipment.

Operational Concerns

- C The film-only coatings would be very difficult and tedious to inspect for quality control where there are congested piping arrangements as at the reactor front face, whereas a foam + film system would need relatively simple inspection, mainly where the film overlaps beyond the foam.
- C Respiratory protection must be worn when applying the coatings.
- C In radiologically contaminated areas, standard radiological work practices and engineering controls must be used to prevent the operating personnel or any part of the work area from becoming contaminated.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

• Technology Applicability

- C The polyurethane foam and polyurea film are ideally suited for any D&D activities that require fixation of contaminated equipment, walls, floors, and ceilings, especially where thick, durable coatings are desired that are resistant to oxidation and radioactive aging. Prior small-scale demonstrations indicated that polyurea film is resistant to abrasion, hydrophobic, and useful for radioactive debris transport vehicle liners, building roof components, and valve pits. This is also a very effective encapsulant for lead, lead-based paint, and asbestos. It can be used as a pond liner or spill barrier and secondary containment for aggressive chemical groups, including acids, alkalis, salts, oils, solvents, refined petrochemical products, and polychlorinated biphenyls (PCBs).
- C This technology is potentially valuable for any D&D project, and it is of particular value at sites where equipment may be either internally or externally contaminated. The applications of foams and films is a useful alternative in environments where airborne contamination caused by D&D operations is not acceptable.
- C The DOE, the U.S. Nuclear Regulatory Commission, and the U.S. Environmental Protection Agency all have potentially wide use of this technology at nuclear facilities under their jurisdiction. Private-sector remediation and demolition contractors will also be interested.

• Competing Technologies

- C A number of commercially available polymeric coatings with good resistance to aging can compete with polyurea films. Where complex shapes are to be coated and a base layer of foam is needed, comparable spray-on foams may work as well as polyurethane. If the foam is completely covered by a film, as in this demonstration, the foam does not need to be resistant to aging provided that the film is thick (at least 1.8 mm or 70 mils), tough, and elastic, as were both polyurea films demonstrated.
- C The silicon-based foam and film submitted by Eurotech were developed for use at Chernobyl and performed well during the laboratory phase of this demonstration. Eurotech was not able to schedule the second-phase application at the C Reactor face, but it is likely that the Eurotech foam and film system would have succeeded in the field demonstration and the system does not involve highly toxic substances such as diisocyanates that comprise part of polyurea and polyurethane formulations.

• Patents/Commercialization/Sponsors

The application equipment is commercially available. The polyurea formulation is licensed by Huntsman Chemical Corporation. Polyurethane foam is commercially available.



SECTION 5

COST

• Introduction/Methodology

This section provides a cost analysis for the successful innovative (RedHawk) technology and the baseline (Rust-Oleum) technology that use fixative coatings to stabilize radiologically contaminated surfaces, such as would be left behind during interim safe storage at the Hanford Site C Reactor. This analysis determined that the baseline is approximately 30% of the cost of the innovative technology. However, the innovative polymeric films are the more applicable method to use for reactor surface contaminant stabilization, because the polymeric films are thick and durable. By applying such films over foam, complete coverage is attained for long-term stabilization. The baseline technology does not completely cover complex surfaces unless the application method is modified.

The baseline and innovative technology costs are from direct observations of coating an array of reactor nozzles on part of the reactor face. The observed production rates from the demonstration form the basis of a cost analysis for 2,004 reactor nozzles covering the entire face of the reactor, an area of 196.6 m² (2,116 ft²). The baseline technology uses a paint spray pump (where the coating is mixed) connected via a hose to a spray gun. The innovative technology assumes a vendor-provided service using a Gusmer Model H-3500 high-pressure proportioner that controls the mixture of the coating compounds and delivers it via two hoses to a Gusmer Model No. GX-7 spray gun. Prior to the demonstration application, the baseline and innovative coatings were applied to 7.6-cm x 7.6-cm (3-in. x 3-in.) metal coupons and shipped to Wyle Laboratories for a series of assessments. Such laboratory assessments are not included in this cost analysis.

Cost Data

The baseline technology uses commercially available equipment (airless paint spray pump and gun), but the innovative technology uses equipment (Gusmer Model H-3500 high-pressure proportioner) that is rented from RedHawk Environmental at a rate of \$500 per day, and includes the spray gun, hose, air compressor, and trailer. This rate was converted to an hourly rate for the estimates. The raw materials for priming, foam, and film coating for the innovative technology and primer plus film coating for the baseline technology were based on vendor quotes. The material costs for the Rust-Oleum No. 769 used in the baseline technology is \$9.36 per liter (\$35.41 per gallon). In the innovative technology, the polyurethane foam is \$3 per kilogram (\$1.74 per pound) and the polyurea film is \$140 per kilogram (\$63.50 per pound).

Observed unit costs and production rates for principal components of the demonstrations for both the innovative and baseline technologies are presented in Table 5. Using data from the field demonstration, unit costs are derived for coating each nozzle assembly on a reactor face, and are shown in the table as \$/nozzle. This unit cost includes coating the flat face area behind each nozzle assembly.

Table 5. Summary of production rates and unit costs

Cost Element	Innovative		Baseline	
	Production Rate	Unit Cost	Production Rate	Unit Cost
Priming	298 nozzles/hr	\$0.72/nozzle	298 nozzles/hr	\$0.64/nozzle
Spraying Foam	25 nozzles/hr	\$9.00/nozzle	N/A	N/A
Spraying Film	62 nozzles/hr	\$11.27/nozzle	111 nozzles/hr	\$2.12/nozzle
Inspection Pre	not applicable	not applicable	91 nozzles/hr	\$1.14/nozzle
Post	153 nozzles/hr	\$0.53/nozzle	91 nozzles/hr	\$1.37/nozzle



The unit costs and production rates shown in Table 5 do not include mobilization or other losses associated with non-productive portions of work (such as suit-up, breaks, inspection, or touch-up work). The intention of this table is to show unit costs at their elemental level, free of site-specific factors such as work culture or work environment influences on productivity loss factors. Consequently, the unit costs shown in Table 5 are the same unit costs for the corresponding line item in Tables B-1 and B-2 of Appendix B.

Some features of the demonstration are unique to the Hanford Site and this demonstration and affect the costs. Consequently, the conditions at other sites will result in different costs. The following site-specific conditions for this demonstration are judged to be the principal factors that could affect cost:

- Ⓒ The work area is a radiological contamination area.
- Ⓒ The disposal cost for waste is \$60/ton (not a major factor in this cost analysis).
- Ⓒ One worker is stationed outside the contaminated area for the duration of the work.

• Cost Analysis

The mobilization, decontamination, demobilization, and waste disposal costs (for PPE and plastic hose sleeves only) are analyzed for the innovative and baseline technologies. The disposal cost of coating wastes and containers is assumed to be about the same for both technologies. The costs for coating an entire reactor face with the innovative and with the baseline technologies are summarized in Figure 6. Refer to Appendix B for detailed costs of the innovative and baseline technologies.

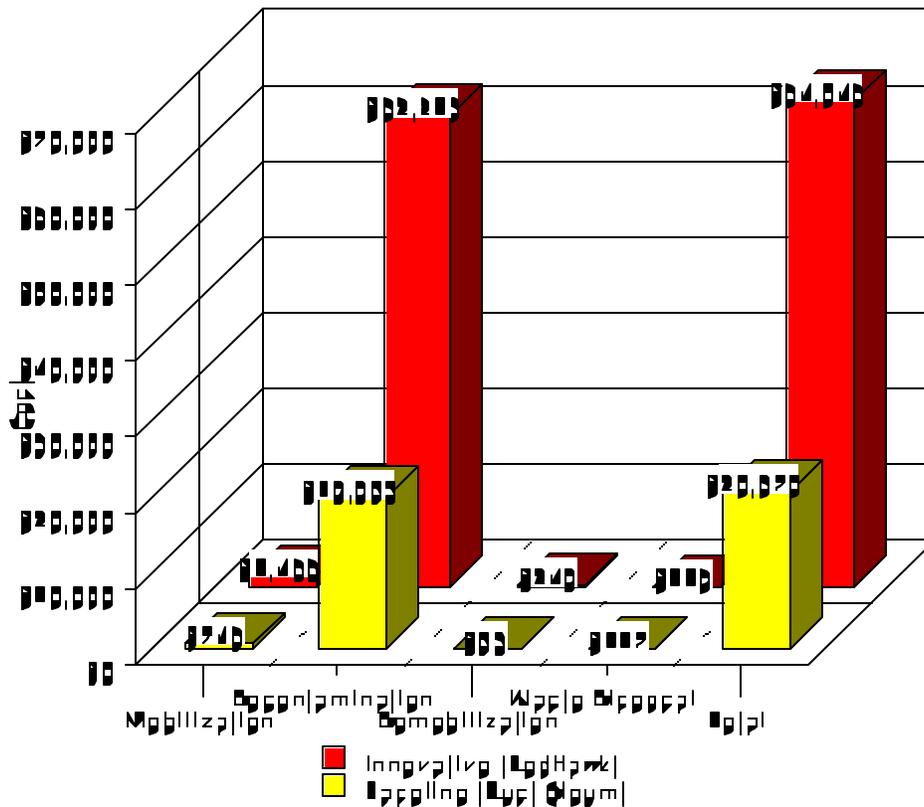


Figure 6. Cost summary.

• Cost Conclusions

The major cost drivers for the innovative technology are:

- C Material costs for the polyurea film
- C Spraying the foam
- C Spraying the film
- C Lost time
- C Donning and doffing PPE
- C Material costs of the PPE.

The baseline has the same cost drivers except for the polyurea film material costs, plus inspecting the coating and touch-up. (Inspection and touch-up needs are much less with the innovative foam and film coating system. The foam layer results in smooth surface with reduced area that is easy to see and reach.) The baseline avoids the cost of the foam application, and it also has a production rate for spraying the film that is almost twice the rate of the innovative technology. The labor rates, equipment rates, and the material costs for the innovative technology are another reason for the higher costs of the innovative technology. The labor and equipment costs for the innovative technology are more than twice the cost of the baseline. The material costs for the innovative technology are seven times the cost of the baseline. This may be offset if local craft workers can be used and as experience with the work is gained. The production rate increases and the quantity of foam used is decreased as workers become experienced in bridging the foam over large voids. The vendor believes that the observed production rates may be innovative by as much as 40% with experience, which would be gained rapidly after several groups of nozzles are coated during a project that encompasses stabilization of an entire reactor face.

The chemicals used by the innovative technology affect PPE requirements. The baseline technology uses an APR, while the innovative technology uses a supplied-air respirator, which includes additional cost for a breathing-air compressor attended by an industrial hygienist (IH). These additional costs are included under the IH hourly rate of \$54.77 per hour shown in Table B-1 of Appendix B.

The readers can estimate their costs by inserting their site-specific quantities into the tables in Appendix C. The tables are based on the quantities required per nozzle assembly. For complex shapes and distances between assemblies that are different than at the C Reactor face, the paragraph in Appendix C headed "Spray Foam" gives the foam quantity used per group of nine nozzle assemblies. This quantity can be adjusted based on 0.74 m² (0.8 ft²) of face area per group foamed to a depth of about 50 cm (20 in.). However, the reader is cautioned that foam does not have to fill all voids and that cavities may be left within the foam, with commensurate cost savings. The volume of cavities would be higher for complex shapes that are closer than the approximate 30 cm (12 in.) between nozzle assemblies. The volume of cavities would be less for wider spacing.



SECTION 6

REGULATORY/POLICY ISSUES

• **Regulatory Considerations**

- C No special regulatory permits are required for applying coatings to stabilize contamination.
- C The technology can be used in daily operation under the requirements of 10 CFR, Parts 20, 835, and proposed 834 for protection of workers and the environment from radiological contaminants; and 29 CFR, OSHA worker requirements.
- C Although the demonstration took place at a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site, no CERCLA requirements apply to the stabilization of above-ground reactor block components.

• **Safety, Risk, Benefits, and Community Reaction**

Worker Safety

- C Radiation protection worker safety instructions already in use at the facility apply.
- C The user of the technology must use contamination control practices when applying coatings.
- C Normal worker safety precautions and practices prescribed by OSHA for equipment operation (especially compressors) must be followed. Use of proper respiratory protection is needed when spraying formulations that contain diisocyanates.

Community Safety

- C It is not anticipated that implementation of the innovative technology would present any adverse impacts to community safety.

• **Environmental Impact**

- C It is not anticipated that implementation of the innovative technology would present any adverse impacts to the environment.

• **Socioeconomic Impacts and Community Perception**

- C No socioeconomic impacts are expected with the use of this technology.



SECTION 7

LESSONS LEARNED

• **Implementation**

- C Coatings reduce the risk of creating airborne contamination while D&D work, such as cutting, dismantling and disassembly, is performed, or the coatings enhance interim safe storage.

• **Technology Limitations/Needs for Future Development**

- C Currently, there is no need to modify the two-layer innovative technology demonstrated at the Hanford Site C Reactor.
- C Film-only systems would need multi-directional spray tips to cover the backside of complex shapes. Alternative methods of achieving coverage by one-layer systems might include attaching a mesh or screen or a rigid cover over the reactor face nozzle assemblies end caps. Then a film could be sprayed over the entire mesh or over the rigid cover joints.
- C The demonstration was carried out in a low-radiation field (<2 mrem/hr). In a high-radiation situation, the application of foam should be done with a remotely controlled spray gun instead of with the hand-held spray gun demonstrated.
- C The maximum distance between the proportioner and the spray tip (maximum length of hose runs) is 91.5 m (300 ft). This is a design limitation based on the rating of the electrical transformer that energizes the hose heating system.

• **Technology Selection Considerations**

- C The technology is suitable for DOE nuclear facilities or any other sites where radioactive or chemical contamination must be stabilized.
- C The polyurea film alone is suitable where direct spraying on the surface to be stabilized is possible, such as flat surfaces or places with open access. For complex or congested equipment shapes, the use of a foam base layer should be considered.
- C Where a non-toxic foam + film application is required, the Eurotech (La Jolla, California) coating system could be considered (but was not field-demonstrated).



APPENDIX A

REFERENCES

10 CFR Part 835, "Occupational Radiation Protection," as amended.

Proposed 10 CFR Part 834, "Environmental Radiation Protection," as proposed.

10 CFR Part 20, "Occupational Radiation Protection," as amended.

29 CFR Part 1910, "General Industry Occupational Safety and Health Standards," as amended.

29 CFR Part 1926, "Construction Occupational Safety and Health Standards," as amended.

Means Construction Equipment Cost Data, R. S. Means Co., Kingston, Massachusetts, 1997.

USACE, 1996, *Hazardous, Toxic, Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary*, U.S. Army Corps of Engineers, Washington, D.C.

Wyle Laboratories, "Results Report of the Assessment of Stabilization Materials for Use at the U.S. Department of Energy Hanford Site," Report No. 46506R98, Job 46506, June 29, 1998, Huntsville, Alabama.



APPENDIX B

COST COMPARISON

• Introduction

The cost effectiveness analysis computes the cost for fixative coatings applied for reactor surface contamination stabilization using hourly rates for equipment and labor observed in the course of demonstrating the innovative two-layer technology and the baseline technology for nine nozzle assemblies each. The observed production rates and durations were extrapolated to the entire reactor face, which consists of a 46-ft x 46-ft area with 2,004 nozzles. The extrapolation includes additional time for repositioning a manlift, because a manlift (or scaffolding) is required for working on the reactor face above the first several rows of nozzles. The analysis assumes that the innovative technology work is performed as a vendor-provided service (vendor-owned equipment and personnel).

The selected basic activities being analyzed come from the Hazardous, Toxic, Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary (HTRW RA WBS), USACE, 1996. The HTRW RA WBS, developed by an interagency group, is used in this analysis to provide consistency with established national standards.

Some costs are omitted from this analysis to make it easier to understand and to facilitate comparison with costs for the individual site. The overhead and general and administrative (G&A) markup costs for the site contractor managing the demonstration are omitted from this analysis. Overhead and G&A rates for each DOE site vary in magnitude and in the way they are applied. Decision makers seeking site-specific costs can apply their site's rates to this analysis without having to first back-out the rates used at the Hanford Site.

The following assumptions were used as the basis of the cost analysis for the innovative technology:

- C Oversight engineering, quality assurance, and administrative costs for the demonstration are not included. These are normally covered by another cost element, generally as an undistributed cost.
- C The procurement cost of 7.5% was applied to all purchased equipment so that the costs of administering the purchase are accounted for (this cost is included in the hourly rate).
- C The equipment hourly rates for the site-owned equipment that may be used in support of the innovative equipment (e.g., the site-owned truck that transports the rented innovative equipment from the warehouse receiving to the C Reactor) uses standard equipment rates established at the Hanford Site.
- C The equipment hourly rates for the Gusmer Model H-3500 high-pressure proportioner are based on a rental rate and operation cost from vendor quotes (no standard site rates for the proportioner were available).
- C The standard labor rates established by the Hanford Site for estimating D&D work are used in this analysis for the portions of the work performed by local crafts.
- C The analysis uses a 10-hour work day.
- C Material costs for the primer, foam, and film for the innovative technology and primer plus film for the baseline technology are based on vendor quotes.

MOBILIZATION (WBS 331.01)

Move Tools to Work Area: The observed time required, based on previous deployments, for retrieving the spray pump, spray gun, and other tools and equipment for the baseline technology from storage and moving them to the work area was used for both the innovative and baseline technologies and also considered the observed time required for the vendor to mobilize onsite for the innovative technology.



Sleeve Hose/Set-up Equipment: This activity applies only to the innovative technology and is based on observed duration. Hoses are sleeved with plastic film.

Setup/Warmup Equipment: This activity includes preparing the paint spray pump and gun for the baseline technology, and includes connecting the hoses to the spray gun for both technologies. Warm-up applies only to the proportioning procedure used with the innovative technology.

Pre-Test Equipment: This activity applies only to the innovative technology and is based on observed duration.

STABILIZATION (WBS 331.17)

Safety Meeting: The baseline work required a safety meeting for each morning following the first day of work. The costs for the innovative technology were assumed to be similar to the observed duration for the baseline.

Don and Doff PPE: This cost item includes time for each worker to fully suit-up in, and remove, PPE as well as material costs for the PPE. The time spent donning and doffing each day is based on observed times for previous deployments (long-term and large-scale jobs). Material costs for daily PPE for one D&D worker at the Hanford Site using an APR are shown in the table below:

Equipment	Cost Each Time		
	Used (\$)	No. Used Per Day	Cost Per Day (\$)
APR	71.06	1 ea	71.06
Face Shield	1.28	1 ea	1.28
Booties	0.62	2 pr	1.24
Coverall	5.00	2 ea	10.00
Double Coverall (5% of the time)			0.56
Hood	2.00	2 ea	4.00
Gloves (inner)	0.14	2 pr	.28
Gloves (outer)	1.30	2 pr	2.60
Gloves (liner)	0.29	2 pr	.58
Rubber Overshoe	1.38	2 pr	2.76
Total			94.36

The costs are based on a face shield price of \$64 each and assuming 50 uses, and on an APR price of \$603, assuming 50 uses, requiring four cartridges per day at a cost of \$14 each, and maintenance and inspection costs of \$150 over the life of the APR. One worker is assumed to remain outside the contaminated area and does not suit up. The supplied-air respirator used in the innovative technology is assumed to be the same cost as the baseline APR cost. An industrial hygienist (IH) is needed with supplied-air respirators. The IH hourly rate charge includes a pick-up truck, carbon dioxide monitor, air regulators, air compressor, and air hoses.

Apply Primer: The primer is applied with a garden-type hand-pump sprayer on to the nozzle cap surfaces, which protrude beyond the foam in the case of the innovative technology and on to all surfaces in the case of the baseline technology. The production rate is based on the observed duration of 1 minute of priming for nine nozzles, which includes priming around the periphery of the foam area for the innovative technology. One minute of manlift moving is assumed, based on previous demonstrations, for each group of nozzles. The time required is 1 minute per group of 9 nozzles for 58 perimeter groups + 0.5 minutes each for 165 groups of interior nozzles + 1 minute for 223 groups to move the manlift = 6.06 hours for all 2,004 nozzles.

An additional 40 minutes of drying time is assumed, which results in 6.73 hours total time, or 0.0034 hours/nozzle. The quantity of primer required for the innovative technology is for a 2-in.-diameter cylinder that protrudes 0.5 ft beyond the foam, plus a 2-in.-diameter cap, equaling 0.28 ft² per nozzle. An assumed over-spray doubles the amount for a total quantity of 0.56 ft² per nozzle. The total amount of area primed required for the



innovative technology is 0.56 ft² per nozzle, which is 1,122 ft² for 2,004 nozzles, plus primer for the border area, which adds approximately 184 ft² for an area of 1,306 ft² per 2,004 nozzles, or 0.652 ft² per nozzle. The material cost is \$63.50/gal, and at a 1-mil thickness the material will cover 560 ft² for a cost of \$0.113/ft². The cost per nozzle is 0.652 ft² at \$0.113 ft², or \$0.07/nozzle for the innovative technology.

The time required to apply the primer for the baseline technology is assumed to be the same as for the innovative technology. The material costs for the baseline's primer is \$35.41/gal and is assumed to cover 560 ft² (this is assumed to be the same as for the innovative technology) for a cost of \$0.063/ft². The surface area primed for the baseline technology is the face of the reactor (46 ft x 46 ft) plus the gas seal, gunbarrel, flange, venturi, crossheader, and nozzle, which is a total of 4.19 ft²/nozzle. The total area for the baseline technology is 46 ft x 46 ft + (4.19 ft² x 2004 nozzles), or 10,513 ft² for all nozzles or 5.25 ft²/nozzle. The primer per nozzle for the baseline is \$0.063 ft² x 5.25 ft²/nozzle = \$0.33/nozzle.

Spray Foam: The Gusmer Model H-3500 high-pressure proportioner controls the mixture of the polyurethane foam compounds and delivers the mixture to the Gusmer Model No. GX-7 spray gun for application. The observed duration for nine nozzles was 20 minutes or 2.22 min/nozzle. An additional time is assumed for repositioning the manlift (1 minute for each group of nozzles, or 223 groups of 9 nozzles x 1 minute equals 3.7 hours). The total time required is 3.7 hours + 2.22 min/nozzle x 2,004 nozzles equals 77.9 hours or 0.038 hours/nozzle. A total of 2.7 gallon of foam ingredients was used in the demonstration for nine nozzles (3 pounds of foam ingredients per each gallon,) and price per gallon is \$5.25. The material cost per nozzle is \$5.25/gal x 2.7 gal/9 nozzles, or \$1.58/nozzle. This activity applies to the innovative technology only.

Spray Film: The innovative technology uses a 70-mil thick polyurea film cover (finish coat). The observed time from the demonstration is 7 minutes for 8 ft² of reactor face with nine nozzle assemblies or 0.875 min/ft². Additional time is required for repositioning the manlift (assume 1 minute per each group of nine nozzles). The total time required is 46 ft² x 46 ft² x 0.875 min/ft² plus 223 groups x 1 min/group = 34.6 hours or 0.016 hours/nozzle. The material costs for the film are \$61.75/gal, with a demonstration-observed coverage of 1.2 gal for 9 nozzles or 0.13 gal/nozzle. The cost per nozzle is \$61.75/gal x 0.13 gal/nozzle, which equals \$8.23/nozzle.

The baseline coating was applied using a Grayco Ultraplus 1500 airless unit. The estimate for the baseline assumes 5.25 ft²/nozzle, the same area as for the application of the primer, at a rate of nine nozzles in 4 minutes (observed from the demonstration). Additional time is required for repositioning the manlift and is assumed to be 1 minute per group of 9 nozzles (based on past demonstrations). The total time required is (4 minutes + 1 minute) x 223 groups of nine, or 18.58 hours or 0.0093 hours/nozzle. The quantity used is assumed to be twice the normal quantity used in conventional painting for building construction (R.S. Means, 1 gal covers 290 ft²) or 145 ft²/gal. At a cost of \$5.41/gal, each nozzle has a material cost of 5.25 ft²/nozzle x \$5.41/gal /145 ft²/gal, or \$1.28/nozzle.

Inspections: The inspection requirements and duration are assumed based on the experience of a coating inspector. The inspection for the innovative technology includes spot checking the adhesion and film thickness as well as general checking for complete coverage for the film layer. It is assumed that the time required for inspection of the nozzles coated with the innovative technology is 2 minutes for nine nozzles plus 1 minute per nine nozzles for positioning the manlift. The inspection of the edge would extend the inspection for those nozzles located adjacent to the edge by 2 minutes per edge group. There are 14 to 15 groups for each of the four sides (total of 58 groups of 9) that border on the edge and will add 116 minutes to the inspection for a total inspection time of 785 minutes or 0.0065 hours/nozzle. The corresponding production rate is 153 nozzles/hour for inspecting the innovative technology. The inspection is assumed to be performed by an engineer trained in coatings inspection. During the inspection, the vendor's personnel work on other jobs for a period of two days (do not charge the project) but the equipment is left onsite and the additional rental for two days is applied to the cost of inspection.

The baseline is assumed to require a pre-inspection for identifying and removing any loose scale, dirt, and oil by vacuuming and wiping. Additionally, a final inspection is required for the baseline to ensure that all surfaces are adequately covered. The duration of the baseline's pre-inspection is assumed to require 5 minutes for nine nozzles plus 1 minute per nine nozzles for positioning the manlift, or 0.011 hours/nozzle. The corresponding



production rate is 91 nozzles/hour for pre-inspecting the baseline technology, and post-inspection time requirements are assumed to be similar.

Touch-up Face: Based on the results from the inspection, the coatings are re-applied to certain areas to ensure complete coverage. It is assumed that 30% of the innovative surface and 60% of the baseline surface require touching up.

Lost Time: The non-productive time used in this cost analysis for both the innovative and the baseline technologies is assumed to be 20% for such things as worker fatigue and work coordination issues.

DEMOBILIZATION (WBS 331.21)

Disassemble and Decontaminate Equipment: The durations observed for each of the innovative and the baseline demonstrations are used in their respective cost estimates.

WASTE DISPOSAL (WBS 331.18)

Disposal of PPE and Plastic Sleeving: A minimum disposal charge is assumed.

The details of the cost analysis for the innovative technology and for the baseline technology are shown in Tables B-1 and B-2, respectively.



Table B-1. Cost summary - innovative Reactor Stabilization technology

Work Breakdown Structure (WBS)	Unit	Unit Cost \$	Quantity	Total Cost \$	Computation of Unit Cost				Other Costs / and Comments		
					Prod. Rate	Duration (hr)	Labor & Equipment Rates				
							Labor Items	\$/hr		Equipment Items	\$/hr
MOBILIZATION (WBS 331.01) Subtotal					\$ 1,467.81						
Move Tools to Work Area	LS	\$ 1,082.32	1	\$ 1,082.32		8.33	2DD	\$ 63.94	PR+SG+TK+TR+ML	\$ 65.99	Proportioner transported with subcontractor
Sleeve Hose/Set-up Equip	LS	\$ 310.88	1	\$ 310.88		1.25	2DD+0.5IH+RH	\$184.93	PR+SG+ML+GN	\$ 63.78	
Pre-Test Equipment	LS	\$ 74.61	1	\$ 74.61		0.30	2DD+0.5IH+RH	\$184.93	same	\$ 63.78	Includes moving equipment to front face
STABILIZATION (WBS 331.17) Subtotal					\$62,212.57						
Safety Meeting	day	\$ 39.35	19	\$ 747.56		0.25	RH	\$ 93.60	same	\$ 63.78	
Don and Doff Personal Protective Equipment (PPE)	day	\$ 467.28	19	\$ 8,878.37		1.77	same	\$ 93.60	same	\$ 63.78	PPE of \$100.36/ person/day added to unit cost
Apply Primer	ea	\$ 0.69	2004	\$ 1,390.22		0.004	RH + .25IH+.25RCT	\$119.67	same	\$ 63.78	Add primer material cost \$0.07/nozzle to unit cost.
Spray Foam	ea	\$ 8.73	2004	\$17,503.84		0.039	same	\$119.67	same	\$ 63.78	0.039 hr./nozzle plus foam material cost \$1.58/nozzle
Spray Film	ea	\$ 11.17	2004	\$22,374.98		0.016	same	\$119.67	same	\$ 63.78	0.016 hr./sf plus film material cost of \$8.23/nozzle to unit cost
Inspect Coating	ea	\$ 1.19	2004	\$ 2,385.90		0.007	FE+DD	\$ 97.15	ML	\$ 10.63	
Touch-up Face	ea	\$ 2.94	668	\$ 1,960.69		0.016	RH+.25IH+.25RCT	\$119.67	PR+SG+ML+GN	\$ 63.78	Assume 30% of face and minimal material cost
Lost Time	LS	\$ 6,971.01	1	\$ 6,971.01		38	same	\$119.67	same	\$ 63.78	Assumes 20%
DEMOBILIZATION (WBS 331.21) Subtotal					\$ 248.71						
Disassemble & Decontaminate Equipment	LS	\$ 248.71	1	\$ 248.71		1	2DD+0.5IH+RH	\$184.93	same	\$ 63.78	
WASTE DISPOSAL (WBS 331.18) Subtotal					\$ 119.36						
Disposal of PPE & Sleeving	LS	\$ 119.36	1	\$ 119.36		0.5	2DD+H	\$118.71		\$ 0.00	Disposal fee of \$60 included
TOTAL					\$94,048.43						
Crew Item	Rate \$/hr	Abbreviation	Crew Item	Rate \$/hr	Abbreviation	Crew Item	Rate \$/hr	Abbreviation	Crew Item	Rate \$/hr	Abbreviation
Red Hawk Subcontractor	93.60	RH	Industrial Hygien	54.77	IH	Garden Sprayer	0.08	SG	Truck (flat bed)	4.74	TK
D&D Worker	31.97	DD	Rad Contr Tech	49.50	RCT	Proportioner, gun,	50	PR	Trailer (flat bed)	0.54	TR
Field Engineer	65.18	FE	Lead Sampling Technician	54.77	LT	Manlift	10.63	ML	Hydraulic Pump	1.46	HP



Table B-2. Cost summary - baseline Reactor Stabilization technology

Work Breakdown Structure (WBS)	Unit	Unit Cost \$	Quantity	Total Cost \$	Computation of Unit Cost					Other Costs / and Comments	
					Production Rate	Labor & Equipment Rates		Equipment Items	\$/hr		
						Labor Items	\$/hr				
MOBILIZATION (WBS 331.01)					\$ 747.94						
Subtotal											
Move Tools to Work Area	LS	\$ 694.97	1	\$ 694.97		8.33	2DD	\$ 63.94	SP+SG+TK+TR+ML	\$ 19.49	
Set-up/Warm-up Equipment	LS	\$ 52.97	1	\$ 52.97		0.5	2DD+0.5RCT	\$ 88.67	SP+SG+ML+GN	\$ 17.28	Includes moving equipment to the front face
STABILIZATION (WBS 331.17)					\$ 19,952.71						
Subtotal											
Safety Meeting	day	\$ 20.31	16	\$ 324.88		0.25	2DD	\$ 63.94	same	\$ 17.28	
Don and Doff Personal Protective Equipment (PPE)	day	\$ 332.48	16	\$ 5,319.67		1.77	2DD	\$ 63.94	same	\$ 17.28	PPE of \$94.36/person/day added to unit cost
Pre-Inspection	ea	\$ 1.03	2004	\$ 2,062.93		0.011	2DD+0.25 RCT	\$ 76.30	same	\$ 17.28	
Apply Primer	ea	\$ 0.65	2004	\$ 1,298.95		0.0034	same	\$ 76.30	same	\$ 17.28	Add primer material cost \$0.33/nozzle to unit cost
Spray Film	sf	\$ 2.15	2004	\$ 4,303.61		0.009	same	\$ 76.30	same	\$ 17.28	Add paint material cost \$1.28/nozzle to unit cost
Post-Inspection	ea	\$ 1.26	2004	\$ 2,522.49		0.011	FE+DD	\$ 97.15	same	\$ 17.28	
Touch-up	ea	\$ 0.84	1336	\$ 1,125.24		0.009	2DD+0.25 RCT	\$ 76.30	same	\$ 17.28	60% repainted and minimal material cost
Lost Time	ls	\$2,994.64	1	\$ 2,994.64		32	same	\$ 76.30	same	\$ 17.28	Assumed to be 20%
DEMOBILIZATION (WBS 331.21)					\$ 52.97						
Subtotal											
Disassemble & Decontaminate Equipment	LS	\$ 52.97	1	\$ 52.97		0.5	2DD+0.5RCT	\$ 88.67	same	\$ 17.28	
WASTE DISPOSAL (WBS 331.18)					\$ 116.70						
Subtotal											
Disposal of PPE and Plastic Sleaving	LS	\$ 116.70	1	\$ 116.70		0.5	2DD+1RCT	\$ 113.39		\$ 0.00	Disposal fee of \$60 included
TOTAL					\$ 20,870.32						
Crew Item	Rate \$/hr	Abbreviation	Crew Item	Rate \$/hr	Abbreviation	Crew Item	Rate \$/hr	Abbreviation	Crew Item	Rate \$/hr	Abbreviation
Industrial Hygienist	54.77	IH	Red Hawk Subcontractor	93.60	RH	Proportioner, Gun, Hose	50	PR	Air Compressor	6.74	AC
Field Supervisor	59.60	SU	Rigger	43.57	RG	Truck Tractor	11.71	TT	Truck (flat bed)	4.74	TK
D&D Worker	31.97	DD	Field Engineer	65.18	FE	Generator	3.07	GN	Trailer (flat bed)	0.54	TR
Teamster	36.35	TM	Lead Sampling Technician	54.77	LT	Spray Pump	3.50	SP	Manlift	10.63	ML



APPENDIX C

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Description
ALARA	as low as reasonably achievable
APR	air-purifying respirator
ASTM	American Society for Testing and Materials
BHI	Bechtel Hanford, Inc.
CERCLA	<i>Comprehensive Environmental Response, Compensation, and Liability Act of 1980</i>
CRS	cold-rolled steel
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
G&A	general and administrative (costs)
H&S	health and safety
HTRW	hazardous, toxic, radioactive waste
IH	industrial hygienist
ISS	interim safe storage
LLW	low-level waste
LS	lump sum
LSDDP	Large Scale Demonstration and Deployment Project
N/A	not applicable
Ox	oxidized (steel coupon)
PPE	personal protective equipment
RCT	radiological control technician
SAR	supplied-air respirator
SS	stainless steel
USACE	United States Army Corps of Engineers
WBS	work breakdown structure

