

Protective Coatings for the Ontario Power Generation Inc. Dry Storage Container

R. Lewak, Kinectrics Inc, Toronto, Ontario, B. Ellsworth, Ontario Power
Generation Inc, Tiverton, Ontario, richard.lewak@kinectrics.com,
brad.ellsworth@opg.com

Abstract

Ontario Power Generation (OPG), formerly Ontario Hydro, has been storing used CANDU fuel in the irradiated fuel bays (IFBs) at its nuclear generating stations since they began operation. As the IFBs began reaching capacity, the dry storage of previously cooled used fuel became an economically viable alternative to the construction of additional wet fuel bays and the OPG Dry Storage Container (DSC) was developed. The OPG DSC is a free standing reinforced concrete container, with an inner and outer carbon steel shell, for the storage and transportation of used CANDU fuel. The outer steel shell of the DSC is protected by an applied coating system to facilitate decontamination of the outer shell and to provide protective corrosion resistance. In 1990 a study was performed to determine the optimal commercial coating system to be considered as a protective coating on the DSC outer shell. An experimental program was undertaken to identify the optimal commercial coating system which had the best decontamination characteristics as well as maximum resistance to abrasion, weathering and durability. A total of nine coating systems were selected for study, five epoxy coatings, three epoxy/polyurethane coatings, and one polyurethane coating. Sand blasted carbon steel coupons, similar to the DSC outer shell, were coated by the manufacturers and submitted for testing of the decontamination characteristics such as activity uptake, decontamination of the coating, and the activity 'sweating' phenomenon. Tests identified four commercially available pure epoxy and epoxy/polyurethane protective coating systems as being the most promising for the exterior of the DSC surface. Of these four, the coating system chosen for use on the DSC was an epoxy/polyurethane system. After a decade of use, however, several safety and environmental concerns centering on the isocyanate content present in the polyurethane and the Volatile Organic Component (VOC) content of the coating system have arisen. These concerns prompted a second study to select an alternative DSC coating system which has a low VOC content and is isocyanate free. The selection procedure followed a similar pattern as previously, and consisted of a survey of coating system manufacturers followed by decontamination characteristics tests of the more promising coating systems. More than 40 coating systems were considered for use but the four most promising systems were selected for testing. The four systems tested consisted of a polysiloxane coating, two high-solids epoxy coatings, and a modification to the present coating system with the polyurethane topcoat replaced by a high solids epoxy. All the coating systems were isocyanate free and had VOC levels near or below 300 g/l. Activity uptake,

decontamination, and sweating tests similar to those performed previously were performed on coated carbon steel coupons with the above coatings as well as coupons with the present coating system. The alternative coating system with the best performance in decontamination tests was the polysiloxane coating which was recommended as an alternative coating system. Based on further discussion with the coating manufacturers it was recommended that the polysiloxane coating be used in combination with a high solid epoxy primer. This combination would give a superior coating for abrasion resistance and weathering.

1. Background

Ontario Hydro, now Ontario Power Generation (OPG), has been storing used CANDU fuel in the irradiated fuel bays (IFBs) at its nuclear generating stations since they began operation. As the IFBs began reaching capacity, the dry storage of previously cooled used fuel became an economically viable alternative to the construction of additional wet fuel bays. The Ontario Power Generation (OPG) Dry Storage Container (DSC) is a free standing reinforced concrete container used for the storage and transportation of used CANDU fuel. A cross sectional view of the DSC is shown in Figure 1.

The DSC consists of two sub-assemblies, a lid and a base. The inner and outer liners of the DSC are made from carbon steel. The inter space between the liners is backfilled with reinforced high-density concrete. The DSC has the capacity to store 384 used CANDU fuel bundles in four modules, each containing 96 bundles. Each fuel bundle has spent a minimum of 10 years in the station bays prior to being loaded into a DSC. The design life of a DSC is 50 years. The outer steel shell is protected by an applied coating system. The DSC requires a protective coating for the following reasons:

- 1) To facilitate in the decontamination of the outer shell.
- 2) To provide protection corrosion resistance of the outer shell.

During the used fuel loading operations the DSC is completely immersed in the IFB. The used fuel is transferred to the DSC over a maximum of a few days. The DSC is then removed from the fuel bay and the outer liner is decontaminated using a demineralized water spray header and manual decontamination techniques. The DSC is then transferred to the processing facility where it undergoes seal welding, helium backfill, NDE inspection, and is placed in final storage. Figure 2 shows a number of the containers in the storage facility.

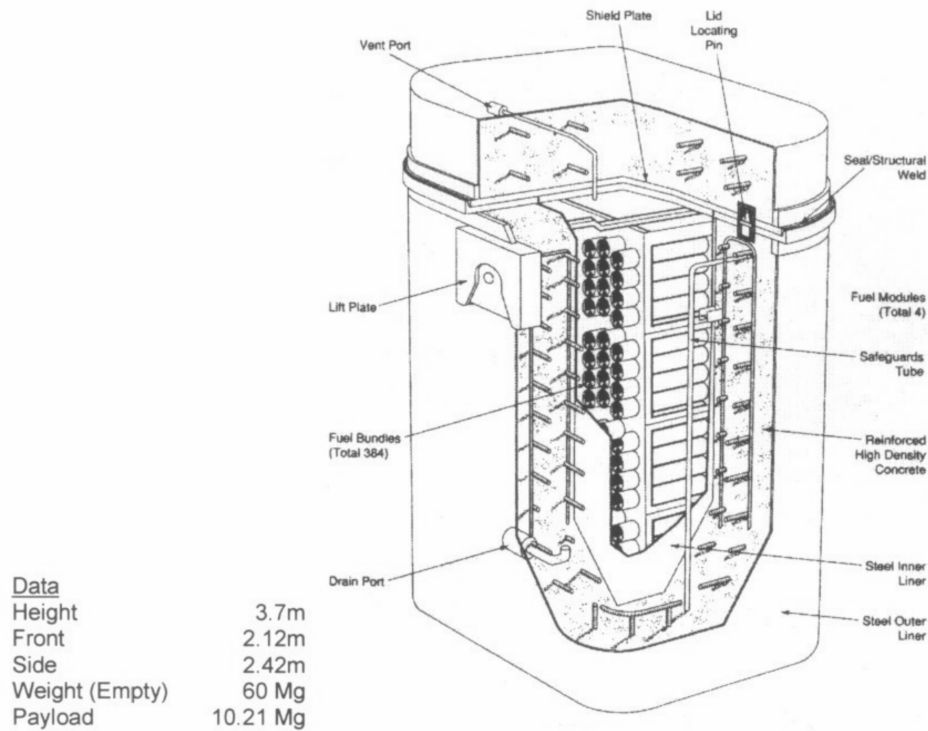


Figure 1. Cross section of Dry Storage Container



Figure 2. DSC's in Storage Facility

2. Selection of Original Coating System

In 1990 studies were performed at Ontario Hydro Research Division, now Kinectrics Inc., on the selection of a suitable coating system for the Ontario Hydro DSC outer carbon steel liner. The major criteria for the selection of a suitable coating system were:

1. The coating system should provide minimum pick up of contamination
2. The coating system should have maximum ease of decontamination

Requests for coating systems which could meet these criteria were sent to suppliers in Canada and the USA with a brief description of objectives, criteria and service conditions. From the suppliers replies a total of ten coating systems were selected for testing. These coating systems included five epoxies (EPX1, EPX2, EPX3, EPX6, EPX7), four epoxy/polyurethane systems (EPX+PU4 and 5 and 8 and 9), and one polyurethane (PU10). Five unprepared 6 inch x 2.5 inch x 1/8 inch thick cold rolled carbon steel coupons were sent to the suppliers for each coating system. The coupons were returned along with information on surface preparation method, coating thickness, primer used, number of layers, method of application and product identification. Visual observations were made and are shown in Table 1. The appearance and initial decontamination results on coupons coated with (EPX+PU)9 indicated that it was unsuitable and so this coating system was not included in subsequent experiments.

2.1 Experimental Tests

Activity Uptake Measurements

The radioactive isotope contaminant used was an aqueous solution of Cesium¹³⁷ Chloride in demineralized water at an activity level of 11 μ -Curies/Liter. This level of activity compared well with the Pickering NGS Auxiliary Bay total gamma activity level of 12.2 μ -Ci/l measured during October 1991. The coated coupons (one per each coating system) were exposed to the contaminant by immersing a 2 x 2-1/2 inch area in a beaker of solution. Activity pickup was then measured periodically on the same side of the coupon using a pancake detector with the distance between the surface of interest and the detector constant. A reference standard prepared on a blank stainless steel coupon was used to monitor any variation in the detector calibration. Although the duration of immersion of a DSC in the fuel bay is expected to be not more than two days the activity uptake was monitored every 24 hours over a 14 day period. The results are shown in Figure 3. All the coating systems show a rapid initial uptake followed by a slowdown and a reaching of equilibrium around 7 to 9 days.

TABLE 1. COATING SYSTEMS

System ID number	Surface Preparation	Primer	First Coat	Second Coat	DFT (mils)	General Appearance
EPX1	SP10	None	EPX1	EPX1	14	Smooth white coating with slight rusting on bottom edge
EPX2	SP5	None	EPX2	EPX2	8-10	Smooth white coating
EPX3	SP10	None	EPX3-a	EPX3-b	10-12	Smooth glossy white coating
(EPX+PU)4	SP10	EPX3-a	EPX3-a	PU4	11-12	Smooth glossy white coating
(EPX+PU)5	SP5	EPX5-a	EPX5-b	PU5	7.5	Many imperfections of coating
EPX6	SP5	None	EPX5-a	EPX5-b	6	Some imperfections of coating
EPX7	SP6	None	EPX7	EPX7	6	Smooth off white coating
(EPX+PU)8	SP6	None	EPX8	PU8	5-6	Smooth white coating
(EPX+PU)9	Degrease only	Yes	EPX8	PU9	3	Green rough with rusted edges
PU10	Degrease only	Yes	PU10	PU10	4	Smooth glossy white finish

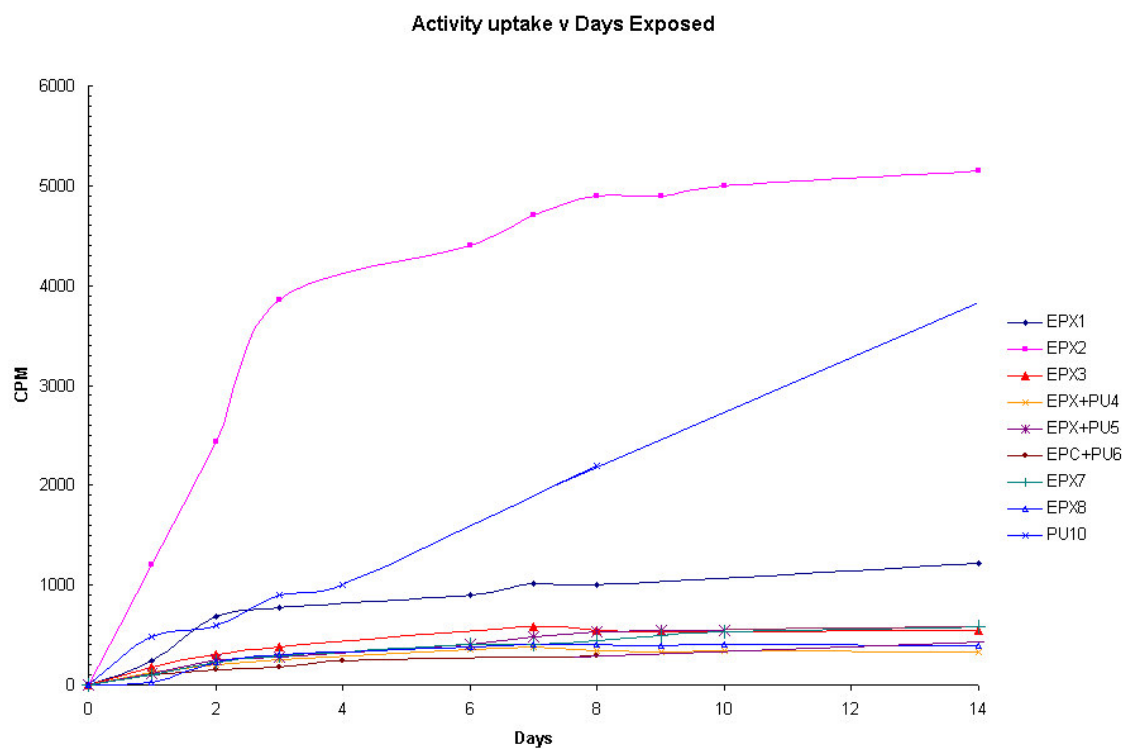
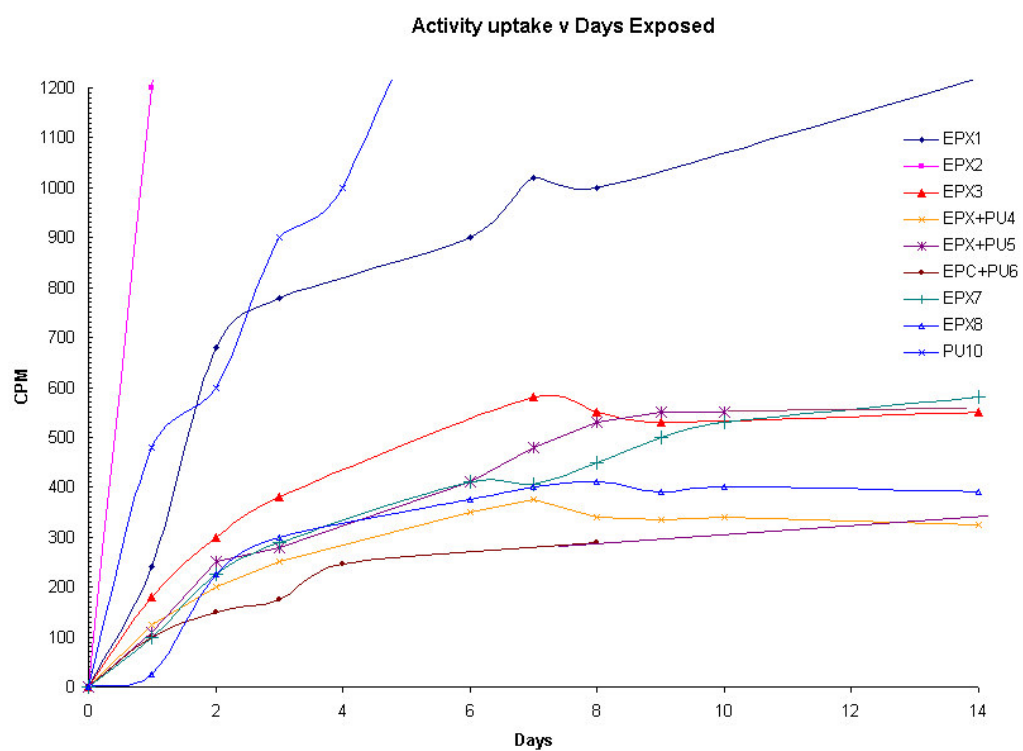


Figure 3. Activity Uptake v Days Exposed

Decontamination Tests

Two different procedures were used to decontaminate the contaminated coated test coupons:

Procedure A (ASTM Standard D 4256-89)

The contaminated coupon was suspended in a stirred beaker of enough demineralized water to immerse 2 inches of the coupon for 10 minutes. The coupon was then removed, air dried, and activity measured on the surface of interest. The coupon was then transferred into another stirred beaker containing fresh demineralized water for 10 more minutes and the activity measured as before. Results from this test, which was performed on one coupon of each coating system, are shown in Table 2. The decontamination factor is the ratio of the original contamination to the residual contamination.

Procedure B

Procedure B is believed to closely resemble the water jetting decontamination procedure performed on the DSC. In Procedure B the contaminated coupon was immersed in a beaker containing demineralized water and the entire assembly then immersed in an ultrasonic bath for 30 minutes. The coupon was removed, rinsed with demineralized water, air dried, and the activity was measured as before. Results from this test, the average result from four coupons of each coating system, are shown in Table 3.

Table 2. Decontamination using Procedure ‘A’

Coating System	Activity Uptake after (Days), CPM	Activity after Decontamination CPM	Decontamination Factor	Activity Removed (%)
EPX1	1220(14)	600	2.0	51
EPX2	5120(14)	5000	1.0	2
EPX3	520(14)	300	1.7	42
EPX6	370(14)	300	1.2	19
EPX7	545(14)	300	1.8	45
(EPX+PU)4	320(8)	150	2.1	53
(EPX+PU)5	570(14)	400	1.4	30
(EPX+PU)8	280(8)	50	5.6	82
PU10	2120(8)	900	2.4	58

Table 3. Decontamination using Procedure B

Coating System	Activity Uptake (9 days), CPM	Activity after Decontamination CPM	Decontamination Factor	Activity Removed (%)
EPX1	239	75	3.9	69
EPX2	3712	3012	1.24	19
EPX3	346	127	2.8	63
EPX6	537	137	4.1	74
EPX7	452	182	2.6	60
(EPX+PU)4	186	11	17.4	94
(EPX+PU)5	750	417	1.8	44
(EPX+PU)8	300	75	4.9	75
PU10	950	442	2.8	53

The test results indicate that the coating system having the lowest activation uptake and the highest decontamination factor using Procedure B is (EPX+PU)4.

Sweating Tests

To test the ‘sweat-out’ phenomenon of the paint systems the ultrasonic decontaminated coupons were swiped with smear paper and the activity measured on the paper and on the coupons. The first test was done at 4 days following the ultrasonic decontamination. The second test at 8 days after decontamination and the third test at 46 days. Dry swipes were done on the first two tests and a wet swipe on the third. The results are shown in Table 4.

It is difficult to conclude whether the ‘sweating’ phenomenon exists or not due to the uncertainty about the distribution of loose versus fixed contamination before swiping. It was assumed that ultrasonic decontamination removed all loose activity so that the three smears which brought the residual activity levels on EPX3, (EPX+PU)4 and (E+PU)8 to the background level, and a percentage decrease on EPX1, EPX6, EPX7, and PU10 is an indication of ‘sweating’. For the coating systems EPX2 and (EPX+PU)5 there is no significant change in activity after the three swipes which may indicate that their activity is fixed and that ‘sweating’ did not occur within 46 days.

Table 4. Results of ‘Sweating’ Tests

Coating system	Before Smear, CPM	After 1 st Smear, CPM		After 2 nd Smear, CPM		After 3 rd Smear, CPM	
		Smear paper	Coupons	Smear Paper	Coupons	Smear Paper	Coupons
EPX1	75	30	52	16	47	27	30
EPX2	3012	100	2850	57	2900	120	2700
EPX3	127	32	55	31	47	72	0
EPX6	137	17	82	16	74	45	42
EPX7	182	52	152	12	135	60	82
(EPX+PU)4	11	9	6	25	7	12	0
(EPX+PU)5	417	27	315	N/A	420	12	350
(EPX+PU)8	75	52	45	22	26	60	0
PU10	442	15	462	19	442	140	255

2.2 Selection of Original Coating System – Conclusions

The experimental tests indicated that in terms of activity uptake, decontamination using Procedure B, and ‘sweating’, the coating system having the best characteristics would be (EPX+PU)4. This coating system has been in use on the DSCs since 1995.

3. Selection of Alternative Coating System

Since the selection and application of the epoxy/polyurethane acrylic coating system in 1991, several safety and environmental concerns have arisen regarding the application of this type of coating system. In particular, these safety concerns have centered on the isocyanate content of the coating system which is present in the polyurethane and the Volatile Organic Component (VOC) of the coating system which is greater than 300 grams per liter. Therefore, a project to select an alternative coating system which is both isocyanate free and has a low VOC was undertaken. The selection procedure followed a similar pattern to the 1991 selection. A coating system specification was written which specified activity uptake as 320 CPM after 14 days exposure to 11 μ -Ci/l aqueous solution of Cesium¹³⁷ chloride, decontamination at least 90% using Procedure B. In addition the VOC level should be 300 g/l or less and the system must be isocyanate free. A total of 19 coating suppliers were surveyed and more than 40 products were suggested which could meet these specifications. Four coating systems were selected for further experimentation based on recommendations from the DSC manufacturer and production constraints. The coating systems consisted of a polysiloxane coating (PS1), two epoxy coatings (Epoxy 1 and Epoxy 2) and the original epoxy coating with an epoxy

polyamiduomine topcoat (EPX4 +EPXP). The original coating system (EPX+PU)4 selection was also included in order for comparison with 1991 test results. The coating systems are listed in Tables 5 and 6.

3.1 Experimental Tests

Sandblasted mild steel coupons, 6 x 2.5 x 0.5 inches in dimension were made by the DSC manufacturer, Niagara Energy Products (NEP). Five steel coupons were coated by the respective coating suppliers except for the (EPX+PU)4 coupons which were coated by Niagara Energy Products. All coupons were completely coated and had a white finish.

Activity Uptake

Three coupons of each coating system were immersed by 2 inches in an aqueous solution of Cesium¹³⁷ chloride in demineralized water at an activity level of 13 μ -Ci/l. Activity uptake was measured on one coupon of each coating system using a pancake detector at every 48 to 72 hours for 17 days of immersion. Results of the activity uptake are shown in Figure 4.

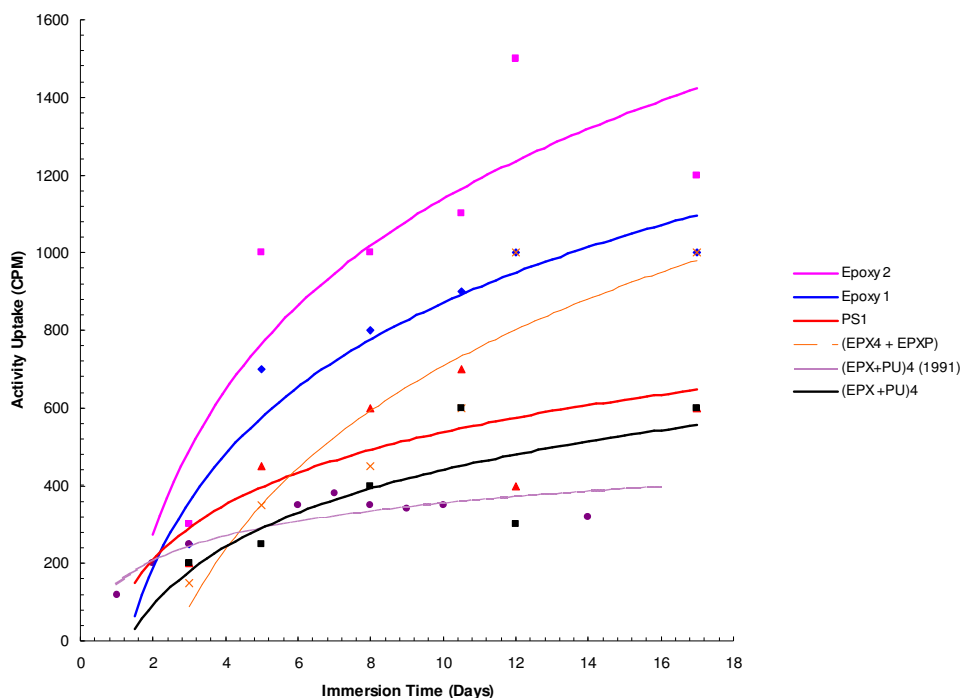


Figure 4. Activity Uptake of Alternative Coating Systems

Table 5. Alternative Coatings selected for Experiment

System ID number	Coating system Type	VOC (g/l)	Primer	First Coat	Second Coat	DFT (mils)
PS1	2 component polysiloxane	120	None	PS1	PS1	9.4
Epoxy 1	2 component high solids epoxy	180	None	Epoxy 1	Epoxy 1	12.2
Epoxy 2	2 component epoxy	192	None	Epoxy 2	Epoxy 2	14.2
EPX4 + EPXP	Epoxy plus Epoxy polyamidoamine	302 and 107 for topcoat	EPX4	EPX4	EPXP	10.7
(EPX+PU)4	Epoxy plus polyurethane acrylic	302 and 441 for topcoat	EPX4	EPX4	PU4	8.6

Table 6. Alternative Coatings selected for Experiment

System ID number	Coating system Type	Pot Life (hr)	Dry time at 20 to 25 C (hr)	Recoat time at 20 -25 C (hr)
PS1	2 component polysiloxane	4	4.5	3
Epoxy 1	2 component high solids epoxy	2.5 (1 with accelerator)	20 (9 with accelerator)	16 (4 with accelerator)
Epoxy 2	2 component epoxy	6	8	8
EPX4 + EPXP	Epoxy plus Epoxy polyamidoamine	10/4	6/12	24/24
(EPX+PU)4	Epoxy plus polyurethane acrylic	10/6	6/12	24/24

The coating systems behaved similarly to those in 1991 in that there was a large initial activity uptake which then tapered off with time.

Decontamination

Both Procedure A and Procedure B decontamination techniques were performed on one coupon of each alternative coating. The results were as shown in Table 7:

Table 7. Decontamination Test Results

Procedure A				
Coating	Initial Activity (cpm)	Activity after decontamination (cpm)	Decontamination factor	Activity Removed %
(EPX4+EPXP)	380	60	6.33	84
(EPX +PU)4	130	30	4.33	77
Epoxy 1	1080	60	18	94
Epoxy 2	1380	80	17.25	94
PS1	80	30	2.7	63

Procedure B				
Coating	Initial activity (cpm)	Activity after decontamination (cpm)	Decontamination factor	Activity Removed %
(EPX4+EPXP)	2350	50	47	98
(EPX +PU)4	170	50	3.4	71
Epoxy 1	1850	Undetectable above background	infinite	100
Epoxy 2	750	70	10.71	91
PS1	50	Undetectable above background	infinite	100

Using Procedure A, Epoxy 1 and Epoxy 2 have approximately the same decontamination parameters which are superior to the other coatings including the in-use coating. Using Procedure B the PSI and the Epoxy 1 coatings have equivalent decontamination characteristics which are superior to those of the other alternative coating systems and the in-use coating system.

'Sweating' Experiments

The 1991 'sweating' experiments were repeated on the alternative coatings on single coupons of each coating system. There were a few changes to the 1991 procedure. This included the second swiping occurring 7 days following ultrasonic decontamination and a third swiping 46 days following ultrasonic decontamination. Measurements were taken only on the coupon before swiping and on the swipe paper after swiping. The measured results in cpm are as follows:

Coating	Cpm after decontamination	4 days		7 days		46 days	
		Coupon	Swipe	Coupon	Swipe	Coupon	Swipe
(EPX4+EPXP)	50	20	0	80	20	20	0
(EPX+PU)4	50	40	10	80	10	40	20
Epoxy 1	0	20	10	40	0	20	20
Epoxy 2	70	30	10	100	20	60	0
PS1	0	20	0	40	0	0	0

It should be noted that the background radiation (~100 to 180 cpm depending on time of measurement) and the low values of contamination made any firm conclusions from the sweating tests are unlikely to be made. However, from these results it would appear that PS1 would have the best characteristics with regard to sweating. Epoxy 1 would have the second best sweating characteristics closely followed by (EPX4+EPXP).

3.2 Selection of Alternative Coating System – Conclusion

Based on the overall performance in activity uptake and decontamination, the following Ameron International coating system was chosen for handling and pre-heater testing:

Primer: Epoxy 1
Top Coat: PS1

Based on further discussion with the coating manufacturers it was recommended that PS1 be used in combination with Epoxy 1. This combination would give a superior coating for abrasion resistance and weathering hazards.

The handling and pre-heater testing involved running a trial DSC coated with the new coating system through the DSC processes that will most likely cause mechanical damage to the coating and to determine if the new coating is as abrasion resistant as the existing coating system. The DSC was handled using the Transporter, the overhead crane and attached weld pre-heaters. Comparing damage caused by each of the tasks to the trial DSC with loaded DSCs in the field showed that the new alternative coating system was as abrasion resistant as the current coating system used.

Based on the results of both the radiological and mechanical tests, the new coating system consisting of Epoxy 1/PS1 was recommended and implemented at the DSC manufacturers in December 2004. The first DSC will be delivered to the OPG sites in mid-January 2005 for loading, final commissioning and project close-out.