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GAMMA RADIATION DAMAGE AND DECONTAMINATION EVALUATION OF PROTECTIVE COATINGS AND OTHER MATERIALS FOR HOT LABORATORY AND FUEL PROCESSING FACILITIES

G. A. West
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FEBRUARY 1965

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FOREWORD

This report presents radiation and decontamination resistance data on various industrial materials tested on a laboratory scale to aid in the selection of materials for the construction and maintenance of radiochemical laboratories at Oak Ridge National Laboratory.

These materials were acquired (1) by accepting samples from some vendors who solicited Oak Ridge National Laboratory, and (2) by a non-exhaustive scanning of industrial publications and inquiring of those vendors whose products appeared to be of interest. The limited scope of the testing program did not justify ascertaining and contacting all possible sources of acceptable materials. Doubtless there are many useful materials which were not tested. Accordingly, this report does not present a comprehensive comparison of all materials in the general groups tested.

It is not the purpose or intent of this report to endorse or condemn any of the products so tested or to implicate in any way a manufacturer or distributor of such products, but rather to present data compiled during the course of laboratory operations which may be of interest to others working on similar problems.

Materials that apparently exhibited poor radiation and decontamination resistance properties in these tests need not be considered inferior products, because slight variations according to composition (such as the nature or content of plasticizers, binders, fillers, pigments, etc.) may affect decontamination and corrosion resistance properties quite drastically. Although a detailed study of varying composition was not made, it was fairly evident that in all probability a poorly rated product could easily be made to test higher by a slight change in raw materials or processing procedure.

The tests presented in this report are empirical tests which have been developed only for immediate comparison purposes. Standard methods have not been established for decontamination tests, and because of the variety and number of samples involved there is reason to believe that a few products may have received incorrect ratings.

The authors believe, however, that this report presents data adequate for empirical purposes and that it contributes heretofore unpublished data that may be of general interest to users of radioactive isotopes in the selection of materials for radiochemical facilities.

The tests presented herein fulfill Oak Ridge National Laboratory's immediate needs, and an extension of this test program is not planned.

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ABSTRACT

Protective coatings and other plastic materials were evaluated by irradiation in a gamma source and by decontamination tests as an extension of previous tests and for possible use in hot laboratories and fuel processing facilities and other process environs at Oak Ridge National Laboratory. Materials used may be subjected to gamma exposures of 10^4 to 10^5 r/hr and neutron exposures of 4.2×10^4 to 2.1×10^5 neutrons/cm^2/sec.

Epoxy, modified phenolic and inorganic zinc protective coatings were superior to the other generic types tested in radiation environments. Exposure to radiation in the presence of water decreases the serviceable life of organic coatings about 50%. For example, the best coating, epoxy, was found to be serviceable in water exposure up to about 5×10^9 r and in air, surprisingly, up to 1×10^{10} r. Vinyls and glossy epoxies were superior to the other coatings in decontaminability.

Among a group of miscellaneous material tested, a nonmetallic plastic heat transfer compound was unaffected at 1×10^{10} r exposure in air.

1. INTRODUCTION

Protective coatings are used extensively on the structural and working surfaces of radiochemical processing facilities to protect substrate materials and to aid in decontamination. New facilities where high radiation and rare radionuclides will be produced prompted another investigation in the search for acceptable protective coatings. The investigation, an extension of previous tests,[1,2] was made primarily to evaluate protective coatings

potentially useful in hot laboratory and fuel processing facilities at Oak Ridge National Laboratory in cubicles, transfer areas, laboratories, and general service areas. The most severe exposure will be incurred by coatings on the concrete surfaces of the cubicles, where they will be subjected to high radiation (alpha, beta, gamma, and neutrons) and periodic submergence in deionized water. The anticipated level of gamma radiation is from 10^4 to 10^5 r/hr and a neutron exposure of 4.2×10^4 to 2.1×10^5 neutrons/cm^2/sec. Some of the coatings must also withstand abrasion from heavy wheeled carts, etc. and the attack of cleaning reagents.

Other plastic materials (not coatings) were also tested for service in hot-cell areas where the experimental process development studies are conducted.

Protective coatings and the other materials were obtained for testing and evaluation by accepting test specimens (steel or concrete blocks, coated by the manufacturer, blocks or sheets of plastic, etc.) from various manufacturers who contact the Laboratory in the normal course of business. Many additional specimens were submitted by companies invited by letter to participate in the program. All participants were encouraged to submit not only their standard formulations but experimental ones as well, which would allow their own particular knowledge and experience to be brought to bear on the coating problem.

Fifty-seven coatings were submitted for radiation tests in deionized water and 62 for tests in air. The 12 protective coating manufacturers participating in the test submitted samples of their products, which they recommended for the proposed service conditions, applied on 16-gauge steel, 2 x 6 in., and on concrete panels, 2 x 2 x 6 in.

The coatings were evaluated as to their comparative resistance to gamma radiation. All coatings and some materials were tested for ease of decontamination. The radiation exposures were conducted in a cobalt-60, gamma source (1.33 Mev, maximum energy) at intensities from 0.9 to 2.08 x 10^6 r/hr. Temperatures ranged from 40 to 80°C. The coated specimens prepared by each manufacturer were placed in the cavity (about 1 ft^3) at the radiation source in both air and deionized water environment. The samples were not completely submerged in water, so any reaction or effect at the air-water interface could be determined. The coatings were inspected for radiation damage at various exposures, about 5 x 10^7, 1 x 10^8, 2.5 x 10^8, 5 x 10^8 r, and each additional 5 x 10^8 r exposure, thereafter.

Comparative decontamination factors (DF's) were obtained for the coatings after drying a solution of mixed fission products on their surface and measuring the amount of radioactivity that remained after the contaminant had been removed by a water flush and an acid scrub.

2. SUMMARY

Protective coatings and other materials that have a high resistance to radiation and ease of decontamination facilitate the operation and maintenance of hot laboratories and processing facilities. Also, protective decontaminable surfaces permit the quantitative recovery of valuable isotopes from structural surfaces should they escape from processing vessels.

Epoxy, modified phenolic, polyester, vinyl and inorganic coatings were evaluated to obtain comparative ratings following an exposure to ionizing radiation in air and in deionized water and contamination-decontamination tests.

The results indicate that the epoxy group of coatings are more resistant to gamma radiation than the other generic organic type tested (Table 1), and, in general, the vinyls are easier to decontaminate to a biologically safe working level (Table 2).

A summary of the top-rated coatings for resistance to radiation follows. The exposures presented refer to the radiation level at which the coatings were adjudged as having failed.

A. Irradiation in deionized water:

1. Tygoweld No. 54-60 (epoxy, U.S. Stoneware) at 4.81×10^9 r.
2. No. 74-66 system with Fiberglas (epoxy, Amercoat Corporation) at 4.78×10^9 r.
3. Plasite 7155 (modified phenolic, Wisconsin Protective Coating Company) at 4.5×10^9 r.

B. Coating systems with Fiberglas fabric embedded for structural strength, irradiated in deionized water:

1. No. 74 primer, No. 74 surfacer, No. 66 seal (epoxy, Amercoat Corporation) at 4.78×10^9 r.
2. No. 66 primer, No. 66 surfacer, No. 66 seal (epoxy, Amercoat Corporation) at 1.0 to 3.6×10^9 r.
3. Coroline 505.2 (epoxy, Ceilcote Company) at 1.34 to 3.0×10^9 r.
4. UC-9647 (epoxy, Pittsburgh Plate Glass Company) at 2.33×10^9 r.
5. UC-12168 (epoxy, Pittsburgh Plate Glass Company) at 1.83 to 2.33×10^9 r.

6. Phenoline 368, Phenoline 300 finish (modified phenolic, Carboline Company) at 1.02 to 1.14 x 10^9 r.

7. Phenoline 300 surfacer, Phenoline 302, Phenoline 300 finish (modified phenolic, Carboline Company) at 1.02 to 1.14 x 10^9 r.

C. Coatings still serviceable after 1 x 10^{10} r exposure in air:

1. No. 74-66 system with Fiberglas fabric (epoxy, Amercoat Corporation).

2. No. 66-66 system with Fiberglas fabric (epoxy, Amercoat Corporation).

3. Phenoline 368 system (modified phenolic, Carboline Company).

4. Colma Protective Coating (epoxy, Sika Chemical Company).

5. No. 1680 over Dimetcote No. 3 (inorganic, Amercoat Corporation).

D. The vinyl coatings tested were surprisingly resistant to gamma radiation in air: 2.2 to 6.6 x 10^9 r; their resistance in deionized water ranged from 1.0 to 8.79 x 10^8 r. The three best vinyl coatings tested in deionized water were:

1. Series A (David E. Long Corporation) at 8.79 x 10^8 r.

2. No. 86 primer, No. 99 seal or No. 99 seal semigloss (Amercoat Corporation) at 6.9 x 10^8 r.

3. No. 86 primer, No. 33 HB (Amercoat Corporation) at 6.6 x 10^8 r.

E. The four vinyls exhibiting the best resistance in air were:

1. No. 86 primer, No. 99 seal semigloss (Amercoat Corporation) at 6.6 x 10^9 r.

2. Rustbond Primer No. 6C, polyclad 933-1, polyclad 1200-20 seal (Carboline Company) at 4.9×10^9 r.

3. No. 38 primer, No. 88 seal (Amercoat Corporation) at 4.38×10^9 r.

4. Series A (David E. Long Corporation) at 4.28×10^9 r.

Decontaminability measurements of the four best decontaminable coatings show that three are vinyls and one an epoxy, as follows:

	Total DF	Coating System
1.	9.3×10^3	RO-221 primer, TP-216 seal with a silicone release agent (vinyl, U.S. Stoneware Company).
2.	6.3×10^3	No. 66 primer, No. 66 seal gloss (epoxy, Amercoat Corporation).
3.	4.5×10^3	Nukemite-40 (vinyl, Amercoat Corporation).
4.	3.6×10^3	Rustbond 6C primer, polyclad 933-1, polyclad 1200-20 (vinyl, Carboline Company).

The protective coatings were evaluated by visual observation, physical comparison, and measurement by instruments before and after the radiation-decontamination tests. Some general observations follow:

The polyamid cured epoxy coatings were more resistant to radiation than the other organic coatings when immersed in deionized water. However, this ultimate resistance depends on the type and amount of fillers, additives, antioxidants and the curing conditions.

In general, all coatings tested are less affected by radiation when exposed in air than when immersed in deionized water.

If a coating is reinforced with Fiberglas fabric, it is generally more resistant to radiation in water exposure and retains its resistance

to impact better than an unreinforced coating. However, Fiberglas fabric does not appear to extend the useful life of a coating irradiated in air. On the other hand, a dispersion of chopped Fiberglas filler did not seem to improve a coating's resistance to gamma radiation in either water or air exposure.

The coating's color does not affect its resistance to radiation. Light colors are useful for light reflection up to about 5×10^8 r gamma radiation.

Most of the vinyl coatings were more resistant to radiation in air than in previously reported tests.[2]

Decontamination is accomplished best on (1) a hard, smooth, nonporous, and acid resistant coating, or (2) hard, nonporous undercoats with a seal coat that is easily removed by reagents.

3. TEST CONDITIONS FOR THE PROTECTIVE COATINGS

The protective coatings applied on steel and concrete were irradiated by a Co^{60} gamma source, which produces a comparable energy and resultant effect as a neutron-producing source.[3]

The decontamination of the protective coatings and other materials was conducted by applying a contaminant consisting of mixed fission products to the surface and attempting removal by a water flush and an acid scrub.

3.1 Radiation Damage

The effect of gamma radiation on several protective coatings recommended by the manufacturer for potential use in hot laboratories and hot cells was determined. The radiation tests were conducted at the ORNL Isotope Division Cobalt-60 Storage Facility (Fig. 1). The cobalt-60, stored

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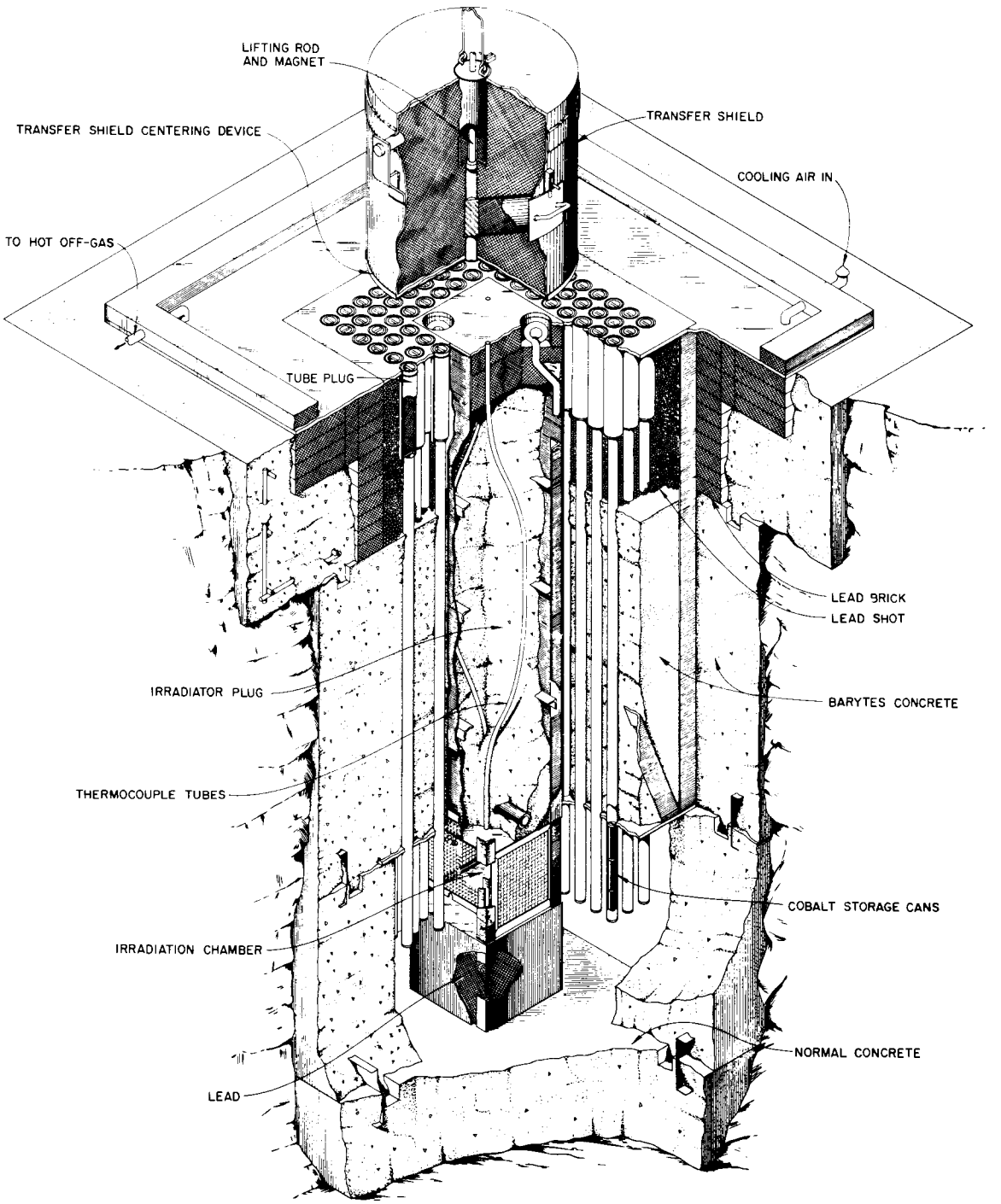

Fig. 1. Cobalt Storage Garden

in varying amounts, about 73,000 to 150,000 curies, resulted in varying intensities of gamma radiation: 0.9 to 2.08 x 10^6 r/hr. The temperatures ranged from 40 to 80°C. The average intensity was 1.1 x 10^6 r/hr, (gamma photons of 1.33 Mev, maximum energy).

The test specimens were supplied by the coating manufacturer, who applied the coatings on panels of carbon or stainless steel, 2 x 6 in., 16 gauge, and on concrete, about 2 x 2 x 6 in. One end of each concrete panel was uncoated so that any gas evolved could escape and would not damage the coating bond to the concrete.

3.2 Tests to Determine Ease of Decontamination

The decontamination test was designed to compare the various coatings as to the ease of removing radiochemical activity from the surface by first using a simple water flush and then by scrubbing with an acid solution. A recognized standard test to measure the decontaminability of a surface does not exist; therefore, the same measurement method applied in previous tests[1] was used.

The following stepwise decontamination measurement represents the decontamination to be expected for a material after an aqueous fission product spill has been dried on the material's surface, rinsed with cold water and then scrubbed with cold 3 M (17.2%) HNO_3.

1. The center portion of each specimen was contaminated with 0.100 ml of mixed fission product solution at 0.86 to 3.0 r/hr (Table 2), predominately Ce-Pr^{144}, Zr-Nb^{95}, and Ru^{106}, at a pH of about 5. The solution was allowed to evaporate to dryness.
2. The beta-gamma activity was then recorded from readings obtained by a cutie pie, a hand held type of radiation-monitoring instrument. The average contamination activity was 2.4 r/hr.

3. The specimens were then rinsed in a gentle stream of running cold tap water for 2 min with the stream impinging on the slanted surface about 1 in. above the contaminated spot.
4. The specimens were then allowed to dry, and their beta-gamma activity again measured as in step 2. The ratio of these activities were recorded as "Water DF".
5. The final decontamination was performed by submerging each specimen in a solution of 3 M (17.2%) HNO_3 at room temperature, and then scrubbing with 25 forward and 25 back strokes of a medium-hard brush, with moderate pressure. A 1-min rinse in cold water and drying in air, followed by a third beta-gamma activity measurement, completed the procedure. The ratio of the initial Cutie Pie reading to the third is recorded as "Total DF".

4. EVALUATION OF THE PROTECTIVE COATINGS AFTER EXPOSURE TO GAMMA RADIATION AND TO THE CONTAMINATION-DECONTAMINATION SEQUENCE

The protective coatings were evaluated after the irradiation and decontamination tests. The results of these evaluations made by visual observations, physical comparison, and measurement by instruments before and after the tests are presented.

4.1 Rankings According to Resistance to Gamma Radiation

The polyamid cured epoxy coatings followed by some formulations of modified phenolics tend to have the best radiation resistance in deionized water (Table 1). Zinc-base inorganic, for example, Dimetcote No. 3, have equal or better radiation resistance than the epoxies but are difficult to decontaminate and have limited resistance to chemical attack. Studies

showed that the radiation resistance of protective coatings is dependent upon the composition of the compounds, the curing agents, the antioxidants, fillers, additives, and curing conditions.[4] The coatings reinforced with Fiberglas fabric retained resistance to impact after radiation much better than unreinforced coatings. Experimental formulations where a dispersion of chopped Fiberglas filler was added did not appreciably improve the coating's resistance to gamma radiation. Some doubt as to the beneficial effects of Fiberglas reinforcement arises from the fact that two identical samples of an unreinforced coating may be observed to have failed in a radiation field at dissimilar levels of radiation. This variation is mainly attributed to (1) a difference in coating application (temperature and time) and (2) the curing age before irradiation. For example, the effect of curing age was noted where one coating, aged 24 months, was a factor of 1.7 more resistant to radiation in deionized water than the same type coating aged only two months.

The radiation exposure data reported (Table 1) is the total exposure (roentgens) at which there was a noticeable breakdown of the coating system. The recommended upper tolerance limit of exposure would be less than that reported. Most of the coating failures at the higher exposures (more than 10^9 r) resulted from (1) deterioration of film (embrittled and chalked), (2) loss of adhesion, and (3) a marked decrease in resistance to impact. The most severe attack on coatings in deionized water occurred at the air-water interface, where extreme chalking, erosion, and softness was evident on most of the coating systems. The failures of some coatings in deionized water were attributed to (1) the formulation's lack of resistance to the deionized water; and (2) the chemical attack from the decomposition of

water to hydrogen peroxide, a radiolytic effect of gamma radiation on water. The breakdown of coatings in both air and deionized water may also originate from the ionizing effect of radiation on the surface, from major chemical changes (cross linking) which occur in the material. Ozone, a powerful oxidizing agent, is formed by gamma radiation and may have contributed to the failure of some coatings.

The maximum temperature of 80°C within the Co^{60} source (intensity of 2.08×10^6 r/hr) should not have contributed to the failure of epoxies or modified phenolic coatings since they are recommended by their manufacturers to withstand temperatures of 93°C or greater in air. However, most of the vinyls are limited to a maximum service temperature in air of from 60 to 82°C and consequently may have been damaged at 80°C. Only four of the vinyls, Amercoat Corporation's 86-33HB, 86-99, and 38-88, and David E. Long's Series A coating received the higher temperature; the remaining 10 vinyls were tested at 40 to 50°C.

Initially, most protective coatings develop a discoloration of the surface as a result of gamma radiation. As radiation exposure increases the depth of discoloration also increases. The white-pigmented epoxies and modified phenolics start to turn yellow at 1 to 5×10^8 r and progressively darken to a brown-toast color at 1 to 2×10^9 r. The color changes may be caused by (1) nitrogen groups in the curing agents which cause a slight color change on oxidation of the material,[5] (2) radiation which produces accelerated aging by causing chemical changes, and (3) heat effect.

4.2 Rankings According to Ease of Decontamination

Decontamination measurements[a] made on small samples of the various

[a]Conducted by A. B. Meservey and D. H. Newman, Chemical Development Section A, Chemical Technology Division, ORNL.

protective coating systems, and floor and bench-top coverings, gave a comparison of the ease of decontamination of the different generic types and finish of each material (Table 2). A solution of mixed fission products of 0.86 to 3.0 r/hr was dried on the surface of each material tested and decontaminability measurements made by flushing the contaminated spot with cold water and scrubbing it with 3 M HNO_3 solution and counting the residual activity.

The radiation level of the contaminant (mixed fission products) used was a factor of 1 to 3.5×10^3 lower than that used in previous tests[1] (an average of 2.4 r/hr vs about 3,000 r/hr). Therefore, the decontamination factors achievable are lower, and the values obtained should not be compared directly with other results. The maximum DF obtainable was about 3×10^4. A 3.0 r/hr contaminant reduced to 0.001 r/hr indicates a DF of 3.3×10^4.

The decontamination factors varied on identical coating systems, probably reflecting the care with which the samples were prepared, such as in the cure and finish of the seal coat. Four test specimens with the Carboline Company's "No. 300 finish" coating had DF's of 1.7×10^3, 3.4×10^2, 2.8×10^2, and 2.7×10^2. Similar variations were observed on the other generic (epoxy and vinyl) types of coatings. The Wisconsin Protective Coating Company's modified phenolic coatings exhibited DF's from 1.18 to 6.75×10^2.

The protective coating systems, floor and bench-top materials, exhibiting the best decontamination factors in each respective generic classification were as follows:

A. Vinyl

1. RO-221 primer, TP-216 with a silicone release agent (U.S. Stoneware): DF = 9.33×10^3.

2. Nukemite-40 (Amercoat Corporation): DF = 4.5×10^3.

3. Rustbond 6C primer, polyclad 933-1, polyclad 1200-20 Carboline Company): DF = 3.6×10^3.

4. Rustbond 6C primer, polyclad 933-1 DG (Carboline Company): DF = 2.0×10^3.

5. RO-221 primer, SB-312 seal (U.S. Stoneware): DF = 1.33×10^3.

The average DF of the remaining 10 vinyl coatings tested was 3.4×10^2.

B. Epoxy

1. No. 66 primer, No. 66 seal gloss (Amercoat Corporation): DF = 6.3×10^3.

2. Plasite 9009 (Wisconsin Protective Coating Company): DF = 1.3×10^3.

3. UC-12168 system (Pittsburgh Plate Glass Company): DF = 1.3×10^3.

4. No. 74 primer, No. 74 surfacer, No. 74 seal (Amercoat Corporation): DF = 1.0×10^3.

The average DF of the remaining 17 epoxy coatings tested was 2.84×10^2.

C. Modified Phenolic

1. Phenoline 300 surfacer, 302, 300 finish (Carboline Company): DF = 1.7×10^3.

2. Plastie 7155 (Wisconsin Protective Coating Company): DF = 4.8 and 6.75×10^2.

3. Phenoline 368 system (Carboline Company): DF = 3.72×10^2.

4. Phenoline 368, 300 finish (Carboline Company): DF = 3.4×10^2.

The DF's of 16 samples of ten different modified phenolic coatings tested ranged from 0.52×10^2 to 1.7×10^3 for an average of 3.62×10^2.

D. Polyester

1. No. 1712 primer, Liquid Glass seal (Wilbur and Williams Company): DF = 2.6×10^3.

E. Inorganic

1. Dimetcote No. 3 (Amercoat Corporation): DF = 5.6×10^3, resulting from the decontamination reagent attack on the coating.
2. No. 1680 (Amercoat Corporation): DF = 0.63×10^2.

F. Floor and Bench-Top Material

1. ISO Shell Top No. MS-03439 (E. H. Sheldon Company): DF = 2.4×10^3.
2. Embossed tile, plain (Space White Industries): DF = 1.8×10^3.
3. No. SW-7042 tile, plain (Space White Industries): DF = 5.65×10^2.
4. Tessera vinyl Corlon tile No. 86549 (Armstrong Cork Company): DF = 0.95×10^2.

4.3 Remarks About the Effects of Gamma Radiation on Miscellaneous Materials

Several types of materials were irradiated in the Co^{60} gamma source to evaluate their use in radiochemical facilities. The materials (listed in alphabetical order), proposed use and test results are as follows:

	Material	Proposed Use	Remarks
1.	Amerplate and Knoblock (vinyl sheet by Amercoat)	Floors, bench-tops and tank lining	Embrittled at 5×10^8 r
2.	Colma Joint Sealer, types SL and NS (by Sika Chemical Co.)	Construction joints	Liquified at 1.6×10^8 r
3.	Colma Epoxy Joint Sealer (by Sika Chemical Co.)	Construction joints	52% expansion after 5×10^8 r

	Material	Proposed Use	Remarks
4.	Corite "HX" Resin (Corite Reynolds Corp.)	Process equipment and liners	(Physical property tests of 6×10^7, 5×10^8, and 2.8×10^9 r exposures, pending)
5.	Halon (fluorohalocarbon plastic by Allied Chemical)	Process equipment	Embrittled at 1×10^8 r
6.	Homalite No. 1100 plastic rod (epoxy, Homalite Corp.)	Process equipment	Embrittled at 9.8×10^8 r
7.	Koroseal (flexible PVC, B. F. Goodrich)	Gaskets	Loss of resilience at 7×10^8 r
8.	Kynar plastic sheet (polyvinylidene fluoride by Pennsalt Chem. Co.)	Process equipment	No noticeable deterioration at 5.6×10^8 r
9.	Methocel, 6% (water soluble sealant coating)	Sealant coating to aid in decontamination	Embrittled at 5×10^8 r
10.	Mica sheet, laminate, 5 mils thick	Process equipment	4, 13, 18, and 27% loss of light transmission[a] at 1×10^8, 5×10^8, 1.5×10^9 and 5×10^9 r, respectively
11.	Mylar sheet, 10 mils (polyester by duPont)	Process equipment	Embrittled at 1.9×10^8 r; 16% loss in light transmission
12.	Penton Nos. K-51 and 9215 (chloronated polyether by Hercules Powder Co.)	Process equipment	Embrittled at 5×10^7 r
13.	Plexiglas cast sheet (methyl methacrylate by Rohm and Haas Co.)	Process equipment	19% loss of light transmission at 5×10^7 r; embrittled from exposure to radiation (9.6×10^7 r) at 160°F
14.	Pliobond cement (Goodyear Tire and Rubber Co.)	Gasket weld	Embrittled at 6×10^8 r

	Material	Proposed Use	Remarks
15.	PVA (polyvinyl alcohol coating)	Protective coating to aid in decontamination	No apparent deterioration at 5×10^8 r
16.	Pyrex plate glass, 0.5 in. thick	Process equipment	Browning and 67 and 94% loss of light transmission at 1×10^5 and 1×10^6 r, respectively
17.	Quartz, 1/4 in. thick (from ORNL stores stock)	Process equipment	Light transmission loss from a purple discoloration of striation impurities: 4% at 5×10^7 r, 48% at 5×10^8 r, 66% at 2×10^9 r 73% at 5×10^9 r
18.	Silastic (1) RTV-501, (2) RTV-731 (by Dow Corning)	Equipment coating	Embrittled at 5×10^8 r
19.	Standard Thermon (plastic by Thermon Mfg. Co.)	Heat transfer compound	1×10^{10} r, no observable deterioration
20.	Unichrome molding plastic (type 218X, baked PVC by Metal and Thermit, Inc.)	Equipment lining	Embrittled at 1.5×10^9 r
21.	Dimetcote No. 3 (by Amercoat Corp.)	Coating for viewing window frames; exposed to radiation and No. 3268 mineral oil, Humble Oil Co.	No observable deterioration at 6.6×10^9 r
22.	No. 1101 primer, No. 12049 Black Epoxin (by Interchemical Corp.)	Coating for viewing window frames; exposed to radiation and No. 3268 mineral oil, Humble Oil Co.	Seal coat embrittled at 3.5×10^9 r

[a]A light source at 70 ft-candles power was used to measure light transmission.

Table 1. Radiation and Decontamination Rating of Several Protective Coatings

Radiation Source: Co^{60} at intensities from 0.9 to 2.08 x 10^6 r/hr, gamma, and 40 to 80°C temperature

Samples applied on (1) concrete, 2 x 2 x 6 in., and (2) carbon or stainless steel panels, 2 x 6 in., 16-gauge

(The listing shows decreasing order of the coating's resistance to radiation)

Coating System	Mfg.[1]	Generic Type[2]	Substrate Material	Coating Thickness (mils)	Radiation[3] Exposure (r)[4]	Radiation[3] Effect[5]	Radiation[3] Comparative Rating	Decontamination[6] Factor (DF)	Decontamination[6] Comparative Rating
Coatings Exposed in Deionized Water									
1. Tygoweld No. 54-60	8	Ep	Steel	18	4.81 x 10^9	A, B	Excellent	185	Fair
2. No. 74 primer - 74 surfacer - 66 seal[a]	1	Ep-pa	Concrete	54[b]	4.78 x 10^9	A	Excellent	280	Fair
3. No. 66 primer - 66 seal gloss	1	Ep-pa	Concrete	12	4.50 x 10^9	A	Excellent	6,333	Excellent
4. Plasite 7155	10	Mod. ph.	Concrete	24	3.80 x 10^9	A	Good (+)[c]	480	Good
			Steel	5	4.50 x 10^9	A	Excellent	675	Good
5. No. 66 primer - 66 surfacer - 66 seal[a]	1	Ep-pa	Concrete	57[b]	3.60 x 10^9	A, B	Good (+)	400	Good
			Concrete	75[b]	1.00 x 10^9	A, B	Fair	400	Good
6. No. 1680	1	Inor.	Concrete	2	3.71 x 10^9	A	Good (+)	63	Poor
7. Colma Protective Coating	7	Ep-pa	Concrete	13	3.46 x 10^9	A	Good (+)	325	Good
			St. steel	12	3.46 x 10^9	A	Good (+)	-	
8. No. 66 primer - 66 seal	1	Ep-pa	Steel	16	3.43 x 10^9	B, C	Good (+)	432	Good
9. Phenoline 368 system	2	Mod. ph.	Steel	15	3.15 x 10^9	C	Good (+)	372	Good
10. No. 74 primer - 74 surfacer - 66 seal[a]	1	Ep-pa	Concrete	54[b]	2.79 x 10^9	A	Good	280	Fair
			Steel	53[b]	2.14 x 10^9	A	Good	372	Good
11. Plasite 7122 system	10	Mod. ph.	Concrete	40	2.71 x 10^9	A, B	Good	83	Poor
			Steel	6	1.45 x 10^9	A, B	Fair	197	Fair
12. UC-9647 system[a]	5	Ep-pa	Concrete	46[b]	2.33 x 10^9	A, B	Good	144	Fair
			Steel	14[b]	2.33 x 10^9	A, B	Good	83	Poor
13. UC-12168 system[a]	5	Ep-am	Concrete	33[b]	2.33 x 10^9	A, B	Good	125	Fair
			Steel	14[b]	1.83 x 10^9	B	Fair	1,300	Excellent
14. Chem-Pon 2310 system	6	Ep-am	Concrete	30	2.25 x 10^9	A	Good	-	-
			Steel	25	1.58 x 10^9	A	Fair	17	Poor
15. Chem-Pon 2314 MP system	6	Ep-am	Concrete	24	2.25 x 10^9	A	Good	-	-
			Steel	15	1.58 x 10^9	A, C	Fair	13	Poor
16. R3-223-78N system	6	Ep	Concrete	15	2.25 x 10^9	A	Good	-	-
			Steel	15	1.58 x 10^9	A, C	Fair	16	Poor
17. Colma Surface Kote	7	Ep	Concrete	43	2.08 x 10^9	A, B, D	Good	450	Good
			St. steel	23	2.08 x 10^9	A, B, D	Good	433	Good
18. Phenoline 300 system	2	Mod. ph.	Concrete	18	2.08 x 10^9	A, E	Good	280	Fair
			Steel	20	2.08 x 10^9	A, E	Good	245	Fair

Table 1. (Continued)

	Coating System	Mfg.[1]	Generic Type[2]	Substrate Material	Coating Thickness (mils)	Radiation[3] Exposure (r)[4]	Radiation[3] Effect[5]	Radiation[3] Comparative Rating	Decontamination[6] Factor (DF)	Decontamination[6] Comparative Rating
19.	Phenoline 305 system	2	Mod. ph.	Concrete	24	2.08×10^9	A, B	Good	177	Fair
				Steel	18	2.08×10^9	A, B	Good	325	Good
20.	Colma Surface Kote[d]	7	Ep	Concrete	100	1.74×10^9	A, C	Fair	650	Good
21.	R3-233-80A system	6	Ep	Concrete	15	1.58×10^9	A, C, D	Fair	-	-
				Steel	15	1.58×10^9	A, C	Fair	286	Fair
22.	Colma Protective Coating[d]	7	Ep-pa	Concrete	45	1.48×10^9	A, C	Fair	372	Good
23.	Coroline 505.2 system[a]	3	Ep-am	Concrete	90[b]	1.34×10^9	A, C	Fair	139	Fair
				Concrete	80[b]	3.00×10^9	B	Good	-	
24.	Plasite 7100 system	10	Mod. ph.	Concrete	28	1.22×10^9	C	Fair	52	Poor
				Steel	9	1.45×10^9	D	Fair	118	Fair
25.	Phenoline 368, 18 filler, 300 finish	2	Mod. ph.	Concrete	33	1.39×10^9	A, B	Fair	340	Good
				Steel	27	1.02×10^9	A, B	Fair	-	-
26.	Phenoline 300 surfacer, 302, 300 finish[d]	2	Mod. ph.	Concrete	29	1.39×10^9	A, C	Fair	-	-
27.	Plasite 9009 system	10	Ep	Concrete	30	1.22×10^9	C	Fair	800	Good
				Steel	9	1.00×10^9	A	Fair	1,300	Excellent
28.	Phenoline 368, 300 finish[a]	2	Mod. ph.	Concrete	50[b]	1.14×10^9	A, B	Fair	340	Good
				Steel	42[b]	1.02×10^9	A, B	Fair	-	-
29.	Phenoline 368, 300 finish	2	Mod. ph.	Steel	17	1.14×10^9	A	Fair	270	Fair
30.	Phenoline 300 surfacer, 302, 300 finish[a]	2	Mod. ph.	Concrete	64[b]	1.02×10^9	A, B	Fair	1,700	Excellent
				Steel	54[b]	1.14×10^9	A, B	Fair	-	-
31.	Phenoline 300 orange or, 300 primer, 302, 300 finish	2	Mod. ph.	Concrete	44	1.07×10^9	A, B	Fair	-	-
				Steel	37	1.07×10^9	A, C	Fair	-	-
32.	No. 3340 surfacer - phenoline 305 finish	2	Mod. ph.	Concrete	20	1.02×10^9	A, B, E	Fair	177	Fair
33.	Tile Cote	9	Ep-pa	Concrete	22	9.90×10^8	C	Poor	186	Fair
34.	No. 74 primer, No. 74-B surfacer, 74 seal	1	Ep-am	Concrete	27	9.00×10^8	C	Poor	-	-
				Steel	15	9.00×10^8	C	Poor	-	-
35.	Series "A"	4	V	Steel	7	8.79×10^8	C	Poor	200	Fair
36.	No. 86 primer, 99 seal	1	V	Concrete	12	6.90×10^8	C	Poor	550	Good
37.	Phenoline 2351-53	2	Mod. ph.	Concrete	12	6.20×10^8	C	Poor	112	Fair
38.	No. 86 primer, 99 seal, semi-gloss	1	V	Concrete	10	1.00×10^8	B	Poor	565	Good
				Steel	10	6.57×10^8	A	Poor	900	Good
39.	No. 86 primer, 33HB	1	V	Concrete	12	1.00×10^8	B	Poor	21	Poor
				Steel	9	6.57×10^8	A	Poor	55	Poor
40.	No. 74 primer, 74-B surfacer	1	Ep-pa	Steel	13	3.84×10^8	C	Poor	335	Good
41.	No. 1732 system	1	Ep	Concrete	7	2.85×10^8	C	Poor	550	Good
				Steel	12	2.85×10^8	C	Poor	-	-
42.	No. 74 primer, 74 surfacer, 74 seal[a]	1	Ep-am	Concrete	54[b]	2.60×10^8	B	Poor	460	Good
				Steel	44[b]	2.60×10^8	B	Poor	1,000	Excellent

Table 1. (Continued)

Coating System	Mfg.[1]	Generic Type[2]	Substrate Material	Coating Thickness (mils)	Radiation[3] Exposure (r)[4]	Radiation[3] Effect[5]	Radiation[3] Comparative Rating	Decontamination[6] Factor (DF)	Decontamination[6] Comparative Rating
43. UC-9647, UL-8134[a]	5	(Ep)(V)	Concrete	40[b]	2.40×10^8	B	Poor	132	Fair
			Steel	15[b]	2.40×10^8	B	Poor	177	Fair
44. No. 1712 primer, Liquid Glass seal	9	Pe	Concrete	16	2.16×10^8	C	Poor	2,600	Excellent
45. RO-221 primer, AV-461	8	V	Steel	5	2.16×10^8	C	Poor	500	Good
46. RO-221 primer, TP-216 w/silicone release agent	8	V	Steel	6	1.20×10^8	C	Poor	9,333	Excellent
47. RO-221 primer, SB-312	8	V	Steel	3	1.20×10^8	C	Poor	1,333	Excellent
48. Tygorust primer, AV-461	8	V	Steel	7	1.20×10^8	C	Poor	372	Good
49. RO-221 primer, SB-312 w/mica	8	V	Steel	9	1.20×10^8	C	Poor	520	Good
50. Tygorust primer, SB-312	8	V	Steel	7	1.00×10^8	C	Poor	433	Good
51. E-88 primer, AV-461	8	V	Steel	6	1.00×10^8	C	Poor	325	Good
52. RO-221 primer, 567-170	8	V	Steel	5	1.00×10^8	C	Poor	265	Fair
53. Polyclad 933-3	2	V	Steel	3	1.00×10^8	C	Poor	156	Fair
				5	1.00×10^8	C	Poor	322	Good
54. No. 38 primer, 88 seal	1	V	Steel	8	1.00×10^8	A	Poor	33	Poor
Coatings Exposed in Air									
1. No. 74 primer, 74 surfacer, 66 seal[a]	1	Ep-pa	Concrete	54[b]	1.00×10^{10}	Still OK	Excellent	280	Fair
2. No. 66 primer, 66 surfacer, 66 seal[a]	1	Ep-pa	Concrete	57[b]	1.00×10^{10}	Still OK	Excellent	-	-
			Concrete	75[b]	1.00×10^{10}	Still OK	Excellent	400	Good
3. Phenoline 368 system	2	Mod. ph.	Steel	15	1.00×10^{10}	Still OK	Excellent	372	Good
4. No. 1680 over Dimetcote 3	1	Inor.	Steel	3	1.00×10^{10}	Still OK	Excellent	63	Poor
5. Colma Protective Coating[d]	7	Ep-pa	Concrete	45	1.00×10^{10}	Still OK	Excellent	372	Good
6. Colma Protective Coating	7	Ep-pa	Concrete	13	1.00×10^{10}	Still OK	Excellent	325	Good
			St. Steel	12	9.40×10^9	A, B	Excellent	-	-
7. UC-9647 system[a]	5	Ep-pa	Concrete	46[b]	5.40×10^9	B	Good	144	Fair
			Steel	14[b]	1.00×10^{10}	A, B	Excellent	82	Poor
8. No. 74 primer, 74 surfacer, 66 seal[a]	1	Ep-pa	Concrete	54	2.14×10^9	D	Fair	-	-
			Steel	53	1.00×10^{10}	Still OK	Excellent	372	Good
9. No. 74 primer, 74-B surfacer	1	Ep-pa	Steel	13	8.10×10^9	C	Excellent	335	Good
10. No. 66 primer, 66 seal gloss	1	Ep-pa	Concrete	12	8.10×10^9	B	Excellent	6,300	Excellent

Table 1. (Continued)

Coating System	Mfg.[1]	Generic Type[2]	Substrate Material	Coating Thickness (mils)	Radiation[3] Exposure (r)[4]	Radiation[3] Effect[5]	Radiation[3] Comparative Rating	Decontamination[6] Factor (DF)	Decontamination[6] Comparative Rating
11. R3-223-78N system	6	Ep	Concrete	15	>7.20 x 10^9	Still OK	Excellent	-	-
			Steel	15	>7.20 x 10^9	Still OK	Excellent	16	Poor
12. R3-223-80A system	6	Ep	Concrete	15	>7.20 x 10^9	Still OK	Excellent	-	-
			Steel	15	>7.20 x 10^9	Still OK	Excellent	286	Fair
13. Chem-Pon 2314 MP system	6	Ep-am	Concrete	24	>7.20 x 10^9	Still OK	Excellent	-	-
			Steel	15	>7.20 x 10^9	Still OK	Excellent	13	Poor
14. Tile Cote	9	Ep-pa	Concrete	22	7.00 x 10^9	C	Good	186	Fair
15. No. 74-B surfacer, 74 seal	1	Ep-pa	Concrete	27	6.30 x 10^9	B, C	Good	-	-
			Steel	15	6.30 x 10^9	B, C	Good	-	-
16. Tygoweld No. 54-60	8	Ep	Steel	18	6.03 x 10^9	B, D	Good	185	Fair
17. Plasite 7122	10	Mod. ph.	Concrete	40	5.30 x 10^9	A, C	Good	83	Poor
			Steel	6	6.03 x 10^9	B, D	Good	197	Fair
18. Plasite 7100	10	Mod. ph.	Concrete	28	5.88 x 10^9	B	Good	52	Poor
			Steel	9	6.03 x 10^9	B	Good	118	Fair
19. Plasite 7155	10	Mod. ph.	Concrete	24	6.02 x 10^9	B	Good	48	Poor
			Steel	5	6.02 x 10^9	B	Good	675	Good
20. Plasite 9009	10	Ep	Concrete	30	6.02 x 10^9	A	Good	800	Good
			Steel	9	6.02 x 10^9	A	Good	1,300	Excellent
21. No. 66 primer, 66 gray	1	Ep-pa	Steel	16	6.00 x 10^9	A	Good	432	Good
22. No. 86 primer, 99 semi-gloss	1	V	Concrete	10	2.64 x 10^9	D	Fair	565	Good
			Steel	10	6.60 x 10^9	A	Good	900	Good
23. UC-12168 system[a]	5	Ep	Concrete	33[b]	5.50 x 10^9	B	Good	125	Fair
			Steel	14[b]	5.50 x 10^9	B	Good	1,300	Excellent
24. No. 1712 primer, Liquid Glass seal	9	Pe	Concrete	16	5.50 x 10^9	D	Good	2,600	Excellent
25. No. 74 primer, 74 surfacer, 74 seal[a]	1	Ep-am	Concrete	54[b]	5.46 x 10^9	C	Good	460	Good
26. Phenoline 368, 300 finish	2	Mod. ph.	Steel	17	5.20 x 10^9	A, B	Good	270	Fair
27. No. 1732	1	Ep	Concrete	7	4.90 x 10^9	B	Fair	550	Good
			Steel	12	4.90 x 10^9	B	Fair	-	-
28. Rustbond 6-C primer, polyclad 933-1, polyclad 1200-20	2	V	Steel	8	4.90 x 10^9	A, B	Fair	3,600	Excellent
29. No. 1680	1	Inor.	Concrete	2	4.81 x 10^9	A	Fair	-	-
30. Phenoline 368, 18 filler, 300 finish	2	Mod. ph.	Concrete	33	4.74 x 10^9	A, B	Fair	-	-
			Steel	27	4.74 x 10^9	A, B	Fair	-	-
31. Phenoline 368, 300 finish[a]	2	Mod. ph.	Concrete	50[b]	4.70 x 10^9	B	Fair	340	Good
			Steel	40[b]	4.70 x 10^9	B	Fair	-	-
32. Phenoline 300 system	2	Mod. ph.	Concrete	18	4.68 x 10^9	A	Fair	280	Fair
			Steel	20	4.68 x 10^9	A	Fair	245	Fair
33. Colma Surface Kote	7	Ep	Concrete	43	3.46 x 10^9	A	Fair	450	Good
			Steel	23	4.68 x 10^9	A, C	Fair	433	Good

Table 1. (Continued)

	Coating System	Mfg.[1]	Generic Type[2]	Substrate Material	Coating Thickness (mils)	Radiation[3] Exposure (r)[4]	Radiation[3] Effect[5]	Radiation[3] Comparative Rating	Decontamination[6] Factor (DF)	Decontamination[6] Comparative Rating
34.	Phenoline 305 system	2	Mod. ph.	Concrete	24	4.53×10^9	A	Fair	177	Fair
				Steel	18	4.53×10^9	A	Fair	325	Good
35.	No. 86 primer, 99 seal	1	V	Concrete	12	4.42×10^9	C, D	Fair	550	Good
36.	No. 38 primer, 88 seal	1	V	Steel	8	4.38×10^9	A, B	Fair	33	Poor
37.	Phenoline 2351-53	2	Mod. ph.	Concrete	12	4.30×10^9	B, C	Fair	112	Fair
38.	Phenoline 300 primer or 300 orange, 302-300 finish	2	Mod. ph.	Concrete	44	4.29×10^9	A, B	Fair	-	-
				Steel	37	4.29×10^9	A, B	Fair	-	-
39.	Series A	4	V	Steel	7	4.28×10^9	B, D	Fair	200	Fair
40.	Phenoline 300 surfacer or 300 orange, 302, 300 finish[a]	2	Mod. ph.	Concrete	64[b]	2.10×10^9	B	Fair	1,700	Excellent
				Steel	54[b]	4.74×10^9	B	Fair	-	-
41.	Rustbond primer 6C, polyclad 933-3	2	V	Steel	3	3.45×10^9	A, B	Fair	156	Fair
				Steel	5	3.45×10^9	B, D	Fair	322	Good
42.	No. 86 primer, 33HB	1	V	Concrete	12	1.97×10^9	A	Fair	21	Poor
				Steel	9	3.42×10^9	A, B	Fair	55	Poor
43.	RO-221 primer, TP-216 w/silicone release agent	8	V	Steel	6	3.30×10^9	D	Fair	9,330	Excellent
44.	Coroline 505.2[a]	3	Ep-am	Concrete	90[b]	2.60×10^9	C	Fair	139	Fair
				Concrete	84[b]	3.00×10^9	B	Fair	-	-
45.	Colma Surface Kote[a,d]	7	Ep	Concrete	100[b]	2.60×10^9	A, C	Fair	650	Good
46.	Phenoline 300 surfacer or phenoline 300 orange, 302, 300 finish[d]	2	Mod. ph.	Concrete	29[b]	2.47×10^9	A, B	Fair	-	-
				Steel	31[b]	2.47×10^9	A, B	Fair	-	-
47.	UC-9647, UL-8134[a]	5	(Ep)(V)	Concrete	40[b]	1.83×10^9	A	Fair	132	Fair
				Steel	15[b]	4.93×10^9	A	Fair	177	Fair
48.	RO-221 primer, AV-461	8	V	Steel	5	2.30×10^9	C	Fair	500	Good
49.	Tygorust primer, SB-312	8	V	Steel	7	2.30×10^9	C, D	Fair	433	Good
50.	E-88 primer, AV-461	8	V	Steel	6	2.30×10^9	C, D	Fair	325	Good
51.	RO-221 primer, 567-170	8	V	Steel	5	2.30×10^9	C, D	Fair	265	Fair
52.	RO-221 primer, SB-312	8	V	Steel	3	2.20×10^9	C, D	Fair	1,330	Excellent
53.	Tygorust primer, AV-461	8	V	Steel	7	2.20×10^9	C, D	Fair	372	Good
54.	RO-221 primer, SB-312 w/mica	8	V	Steel	9	2.20×10^9	C, D	Fair	520	Good
55.	No. 3340 surfacer, 305 finish	2	Mod. ph.	Concrete	20	2.10×10^9	B	Fair	177	Fair
56.	Dimetcote-4	1	Inor.	Steel	3	5.00×10^8	D	Poor	-	-
57.	Chem-Pon 2310 system	6	Ep-am	Concrete	30	3.20×10^9	C, D	Fair	-	-
				Steel	25	3.20×10^9	C, D	Fair	17	Poor
58.	Nukemite 40	1	V	Steel	5	No test	-	-	4,500	Excellent
59.	Rustbond primer 6-C, polyclad 933-1 DG	2	V	Steel	7.5	No test	-	-	2,000	Excellent
			Exposure in No. 3268 Mineral Oil (Humble Oil Co.)							
1.	Dimetcote No. 3	1	Inor.	M. steel	3	$>6.60 \times 10^9$	Still OK	Excellent	5,600*	-
2.	No. 1101 primer, No. 12049 black epoxin (baked at 360 and 400°F, respectively, for 30 min)	11	Ep	M. steel	2	3.50×10^9	B	Good	No test	-

*Coating attacked by the 3 M HNO_3 decontamination solution.

Table 1. (Continued)

1. Manufacturers:

   1. Amercoat Corporation., 201 North Berry St., Brea, Calif.
   2. Carboline Co., 32 Hanley Industrial Court, St. Louis 17, Mo.
   3. Ceilcote Co., 4832 Ridge Road, Cleveland 9, Ohio
   4. David E. Long Corp., 133-20 91st Ave., Jamaica 18, Long Island, N. Y.
   5. Pittsburgh Plate Glass Co., Gateway Center, Pittsburgh 22, Pa.
   6. Plas-Chem Corp., 6177 Maple Ave., St. Louis 30, Mo.
   7. Sika Chemical Co., 35 Gregory Ave., Passaic, N. J.
   8. U. S. Stoneware Co., Akron 9, Ohio
   9. Wilbur and Williams Co., now owned by Stanley Chemical, Division of The Stanley Works, East Berlin, Conn.
   10. Wisconsin Protective Coating Co., 1136 West Mason St., Green Bay, Wisc.
   11. Interchemical Corp., Newark, N. J.

2. Generic Type:

   Ep-pa - Epoxy, polyamid cured
   Ep-am - Epoxy, amine cured
   Ep - Epoxy (cure unknown)
   Mod. ph. - Modified phenolic
   Pe - Polyester
   V - Vinyl
   Inor. - Inorganic

3. Radiation:

   Cobalt-60, gamma, at an average intensity of ~1.1×10^6 r/hr (0.9×10^6 r/hr, minimum; 2.08×10^6 r/hr, maximum) at temperatures from 40 to 80°C.

Table 1. (Continued)

4. Roentgen:
An exposure dose of x- or gamma radiation such that the associated corpuscular emission of 0.001293 g of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign. This quantity of ions is produced by the absorption of 87.7 ergs of radiation energy per gram of air (34 ev required per ion pair), for energetic x-ray and medium gamma radiation.

5. Radiation Effect:
A - chalked; B - embrittled; C - blistered; D - loss of adhesion; E - interfacial area attack.

6. Decontamination Factor:
The ratio of the original amount of contaminant (mixed fission products of $Ce\text{-}Pr^{144}$, $Zr\text{-}Nb^{95}$, Ru^{106}, at pH 5 and approximately 3.0 r/hr) to the amount removed by a 2-min water flush followed by 50 scrubbing strokes with a medium hard bristle brush in 3 M HNO_3.

[a]Coating reinforced with woven glass fabric laminate, such as Thalco 1522 w/Volan finish, 20 x 18 warp and fill, 9 mils thick, 6 oz. per sq yd.

[b]Woven glass fabric thickness included.

[c]The "plus" sign indicates a better than "good" rating.

[d]Fiberglass pigment in coating.

Table 2. Decontaminability Measurements of Several Protective Coatings

Contaminant: Mixed fission product solution ($Ce\text{-}Pr^{144}$, $Zr\text{-}Nb^{95}$, Ru^{106}) at pH about 5 and from 0.86 to 3.0 r/hr beta-gamma, radiation

Decontamination Method: Water rinse (2 min), 50 scrubbing strokes of a medium hard bristle brush in 3 M (17.2%) HNO_3

(Table listing is in decreasing order of decontaminability rating)

Coating System	Mfg.[1]	Generic Type[2]	Substrate Material	Contamination (r/hr)	Decontamination[3] Water Rinse (mr/hr)	Water Rinse (DF)	Acid Scrub (mr/hr)	Acid Scrub (DF)	Total (DF)
1. RO-221 primer, TP-216 w/silicone release agent	8	V	Steel	2.8	160	17.5	0.3	582	9,333
2. No. 66 primer, No. 66 seal gloss	1	Ep-pa	Concrete	1.9	230	8.3	0.3	766	6,333
3. Nukemite-40	1	V	Steel	2.7	190	14.2	0.6	316	4,500
4. Rustbond 6-C primer, polyclad 933-1, polyclad 1200-20	2	V	Steel	1.8	190	94.5	0.5	380	3,600
5. No. 1712 primer, Liquid Glass seal	9	Pe	Concrete	2.6	160	16.2	1	160	2,600
6. Rustbond 6-C primer, polyclad 933-1 DG	2	V	Steel	1.0	9	111	0.5	18	2,000
7. Phenoline 300 surfacer, 302, 300 finish (w/Fiberglas)	2	Mod. ph.	Concrete	1.7	83	20.5	1	83	1,700
8. RO-221 primer, SB-312	8	V	Steel	2.65	160	16.6	2	80	1,325
9. UC-12168 system (w/Fiberglas)	5	Ep	Steel	2.6	140	18.5	2	70	1,300
			Concrete	2.5	310	8.1	20	15.5	125
10. Plasite 9009	10	Ep	Steel	2.6	240	10.8	2	12	1,300
			Concrete	2.4	90	26.7	3	30	800
11. No. 74 primer, No. 74 surfacer, No. 74 seal (w/Fiberglas)	1	Ep-am	Steel	3.0	120	25	7.5	16	1,000
			Concrete	2.3	240	9.6	15.5	15.5	460
12. No. 86 primer, No. 99 semi-gloss	1	V	Steel	1.8	71	25	2	35.5	900
			Concrete	1.7	86	20	3	28.5	567
13. Plasite 7155	10	Mod. ph.	Steel	2.7	150	18	4	37.5	675
			Concrete	2.4	190	12.6	5	38	480
14. Colma Surface Kote (w/Fiberglas)	7	Ep	Concrete	2.6	400	6.5	4	100	650
15. No. 1732	1	Ep	Concrete	2.75	110	25	5	22	550
16. No. 86 primer, No. 99 seal	1	V	Concrete	2.75	250	11	5	50	550
17. RO-221 primer, SB-312 w/mica	8	V	Steel	2.6	72	36	5	14.4	520
18. RO-221 primer, AV-461	8	V	Steel	2.5	68	36.8	5	13.6	500
19. Colma Surface Kote	7	Ep	Concrete	2.7	200	13.5	6	33	450
			St. Steel	2.6	180	14.4	6	30	433

Table 2. (Continued)

	Coating System	Mfg.[1]	Generic Type[2]	Substrate Material	Contamination (r/hr)	Decontamination[3] Water Rinse (mr/hr)	Water Rinse (DF)	Acid Scrub (mr/hr)	Acid Scrub (DF)	Total (DF)
20.	Tygorust primer, SB-312	8	V	Steel	2.6	150	17.3	6	25	433
21.	No. 66 primer, No. 66 gray	1	Ep-pa	Steel	2.6	350	7.4	6	58.4	432
22.	No. 66 primer, No. 66 surfacer, No. 66 seal-gloss (w/Fiberglas)	1	Ep-pa	Concrete	1.6	91	17.6	4	4.4	400
23.	Phenoline 368 system	2	Mod. ph.	Steel	2.6	230	11.3	7	33	372
24.	Colma protective coating (w/glass pigment)	7	Ep-pa	Concrete	2.6	410	6.3	7	58.5	372
25.	Tygorust primer, AV-461	8	V	Steel	2.6	240	10.8	7	34.3	372
26.	No. 74 primer, No. 74 surfacer, No. 66 seal (w/Fiberglas)	1	Ep-pa	Steel	2.6	210	12.4	7	30	372
				Concrete	2.8	600	4.7	10	60	280
27.	Phenoline 368, phenoline 300 finish (w/Fiberglas)	2	Mod. ph.	Concrete	1.7	82	21	5	16.4	340
28.	No. 74 primer, No. 74-B surfacer	1	Ep-pa	Steel	2.0	560	3.6	6	90	333
29.	Colma protective coating	7	Ep-pa	Concrete	2.6	640	4.7	8	80	325
30.	E-88 primer, AV-461	8	V	Steel	2.6	160	16.2	8	20	325
31.	Phenoline 305	2	Mod. ph.	Steel	2.6	115	22.6	8	14.3	325
				Concrete	3.0	240	12.5	17	14	177
32.	Rustbond 6-C primer, polyclad 933-3	2	V	Steel	2.9	140	20.7	9	15.6	322
				Steel	2.8	120	23.3	18	6.7	156
33.	R3-233-80A system	6	Ep	Steel	0.860	20	43	3	6.6	286
34.	Phenoline 300 system	2	Mod. ph.	Concrete	2.8	240	11.7	10	24	280
				Steel	2.7	340	8	11	31	245
35.	Phenoline 368, 300 finish	2	Mod. ph.	Steel	1.9	190	10	7	27	270
36.	RO-221 primer, 567-170	8	V	Steel	2.65	130	20.3	10	13	265
37.	Series A	4	V	Steel	2.8	130	21.5	14	9.3	200
38.	Plasite 7122	10	Mod. ph.	Steel	2.75	180	15.3	14	13	197
				Concrete	2.5	390	6.4	30	13	83
39.	Tile Cote	9	Ep-pa	Concrete	2.6	245	10.6	14	17.5	186
40.	Tygoweld No. 54-60	8	Ep	Steel	2.4	230	10.4	13	18	185
41.	UC-9647, UL-8134 (w/Fiberglas)	5	Ep, V	Steel	2.65	140	19	15	9.3	177
				Concrete	2.65	290	9.1	20	14.5	132
42.	UC-9647 (w/Fiberglas)	5	Ep-pa	Concrete	2.6	220	11.8	18	12	144
				Steel	2.5	240	10.4	30	8	83
43.	Coroline 505.2 (w/Fiberglas)	3	Ep-am	Concrete	2.5	230	10.9	18	13	139

Table 2. (Continued)

Coating System	Mfg.[1]	Generic Type[2]	Substrate Material	Contamination (r/hr)	Decontamination[3] Water Rinse (mr/hr)	Water Rinse (DF)	Acid Scrub (mr/hr)	Acid Scrub (DF)	Total (DF)
44. Plasite 7100	10	Mod. ph.	Steel	2.6	150	16.6	22	6.8	118
			Concrete	2.6	480	5.4	50	9.6	52
45. Phenoline 2351-53	2	Mod. ph.	Concrete	2.7	510	5.3	24	21	112
46. No. 1680 over Dimetcote 3	1	Inor.	Steel	3.2	2900	1.1	51	57	63
47. No. 86 primer, No. 33-HB	1	V	Steel	1.8	180	10	33	5.5	55
			Concrete	1.8	320	5.6	88	3.6	21
48. No. 38 primer, No. 88	1	V	Steel	2.0	1500	1.3	60	25	33
49. Chem-Pon 2310	6	Ep-am	Steel	0.920	180	5.1	54	3.3	17
50. R3-223-78N	6	Ep	Steel	1.1	180	6.1	71	2.5	15
51. Chem-Pon 2314 MP	6	Ep-am	Steel	0.860	120	7.2	66	1.8	13
52. Dimetcote No. 3	1	Inor.	Steel	2.8	1800	1.5	0.5	3600*	5,600
		Floor and Bench Top Covering							
1. ISO Shell top No. MS-03439	13	-	-	2.4	140	17.2	1	140	2,400
2. Embossed tile (plain)	14	V	-	1.8	120	15	1	120	1,800
Embossed tile (welded joint)	14	V	-	1.7	110	15	12	9.3	142
3. No. SW-7042 tile (plain)	14	V	-	1.7	300	5.7	3	100	565
No. SW-7042 tile (welded joint)	14	V	-	1.7	170	10	9	19	189
4. Tufchem, with carbon (troweled)	12	-	Steel	2.4	520	4.6	5	104	480
5. Tufchem, regular	12	-	Steel	2.6	660	3.9	6	110	433
6. Tufchem, with carbon	12	-	Steel	2.5	780	3.2	12	65	208
7. Tufchem floor surface (troweled)	12	-	Steel	2.5	760	3.3	13	58	192
8. Tessera Corlon tile No. 86549	11	V	-	2.7	660	4.1	28	23.5	95
9. Amerplate sheet	1	V	-	2.6	560	4.6	330	1.7	8

*Coating attacked by the 3 M HNO_3 decontamination solution.

1. Manufacturer:
   1. Amercoat Corp., 201 North Berry St., Brea, Calif.
   2. Carboline Co., 32 Hanley Industrial Court, St. Louis, Mo.
   3. Ceilcote Co., 4832 Ridge Road, Cleveland 9, Ohio
   4. David E. Long Corp., 133-20 91st Ave., Jamaica 18, Long Island, N. Y.
   5. Pittsburgh Plate Glass Co., Gateway Center, Pittsburgh 22, Pa.
   6. Plas-Chem Corp., 6177 Maple Ave., St. Louis, Mo.
   7. Sika Chemical Co., 35 Gregory Ave., Passiac, N. J.
   8. U. S. Stoneware Co., Akron 9, Ohio

Table 2. (Continued)

1. Manufacturer: (Continued)
   9. Wilbur and Williams Co., now owned by Stanley Chemical, Division of The Stanley Works, East Berlin, Conn.
   10. Wisconsin Protective Coating Co., 1136 West Mason St., Green Bay, Wisc.
   11. Armstrong Cork Co., Lancaster, Pa.
   12. Pennsalt Chemical Corp., Natrona, Pa.
   13. E. H. Sheldon Co., Muskegon, Mich.
   14. Space White Industries, 1695 Elizabeth Ave., Rahway, N. J.

2. Generic Type:
   Ep-pa - Epoxy, polyamide cured
   Ep-am - Epoxy, amine cured
   Ep - Epoxy (cure unknown)
   Mod. ph. - Modified phenolic
   Pe - Polyester
   V - Vinyl
   Inor. - Inorganic

3. Decontamination:
   The ratio of the amount of contaminant (mixed fission products of $Ce\text{-}Pr^{144}$, $Zr\text{-}Nb^{95}$, Ru^{106}) to the amount removed by a 2-min water rinse followed by 50 scrubbing strokes with a soft bristle brush in 3 M HNO_3.

4. Roentgen:
   An exposure dose of x- or gamma radiation such that the associated corpuscular emission of 0.001293 grams of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign. This quantity of ions is produced by the absorption of 87.7 ergs of radiation energy per gram of air (34 ev required per ion pair), for energetic x-ray and medium gamma radiation.

   mr/hr (milliroentgen/hour) = a radioactivity measurement equal to one thousanth of a roentgen.

5. RECOMMENDATIONS

The protective coating evaluation tests, resistance to gamma radiation and ease of decontamination, revealed several coatings acceptable for hot laboratory and fuel processing facilities. There are probably other coatings with equally good properties but the test program did not permit a comprehensive testing of all materials. Some typical areas and the recommendations of protective coatings (listed in decreasing order of test performance) that would give adequate protection are as follows:

Area I

Concrete and steel surfaces located in areas such as hot process cells subjected to radiochemical solution spills, oxidizing acids, decontamination solutions, periodic submergence in deionized water and impact abrasion from equipment and remote handling tools. Fuel storage canals and fuel examination pits subjected to continuous immersion in deionized water plus impact and abrasion from heavy casks and fuel segmenting equipment.

Coatings: (1) Amercoat No. 66 epoxy system with Fiberglas fabric (Amercoat Corporation)

(2) UC-9647 epoxy system with Fiberglas fabric (Pittsburgh Plate Glass Company)

Area II

Concrete and steel surfaces of walls and ceilings in hot process cells, decontamination rooms, etc. and floors of hot areas not subject to heavy cask handling.

Coatings: (1) Amercoat No. 66 epoxy system (Amercoat Corporation)

(2) Amercoat No. 74 epoxy system (Amercoat Corporation)

(3) Phenoline 368 modified phenolic system (Carboline Company)

(4) Colma Protective Coating epoxy system (Sika Chemical Company)

(5) UC-9647 epoxy system (Pittsburgh Plate Glass Company)

(6) Tygoweld No. 54-60 epoxy system (U.S. Stoneware Company)

(7) Plasite No. 7155 modified phenolic system (Wisconsin Protective Coating Company)

Area III

Concrete and steel surfaces in low activity areas subjected to contamination, oxidizing acids and abrasion from light traffic.

Coatings: (1) Amercoat 86-99 vinyl system (Amercoat Corporation)

(2) Rustbond 6-C primer, polyclad 933-1, polyclad 1200-20 vinyl system (Carboline Company)

(3) Series "A" vinyl system (David E. Long Corporation)

(4) RO-221 primer, TP-216 vinyl system with a silicone release agent (U.S. Stoneware Company)

(5) Rustbond 6-C primer, polyclad 933-1 DG vinyl system (Carboline Company)

Area IV

Concrete block, steel, plaster and gypsum board surfaces located in non-radioactive areas, but are potentially subjected to contamination and resultant decontamination agents.

Coatings: (1) Amercoat 86-99 vinyl system (Amercoat Corporation)

(2) Amercoat 86-88 water base vinyl system (Amercoat Corporation)

(3) Rustbond 6-C primer, polyclad 933-1, polyclad 1200-20 vinyl system (Carboline Company)

(4) Series "A" vinyl system (David E. Long Corporation)

(5) RO-221 primer, TP-216 vinyl system with a silicone release agent (U.S. Stoneware Company)

(6) Nukemite 40 vinyl system (Amercoat Corporation)

(7) Amercoat 86-33HB vinyl system (Amercoat Corporation)

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7. APPENDIX

7.1 Radiation Intensity or Dose Rate

Specimens of materials were exposed to gamma radiation in the ORNL cobalt storage facility where there are varying amounts of Co^{60} because of the shipping and receiving of cobalt by the Isotope Sales Department. Measurements of the radiation intensity in this facility were made when the quantity of cobalt was changed so that accurate exposure calculations could be made.

The gamma-ray intensity or dose measurement of the cobalt was determined by exposing 15-ml aliquots of 0.032 M ceric sulfate solutions, 0.4 M in sulfuric acid, to the source. The samples in glass bottles were placed in the center of the radiation cavity and rotated during a 2 to 6 hr exposure to ensure a uniform exposure. Intensity or dose was computed from the equivalents of Ce^{4+} reduced, as determined by potentiometric titration with standardized $FeSO_4$ solutions or by spectrophotometric analysis of the Ce^{4+} ion. Yield values (molecules per 100 ev) were computed by the equation:[6]

$$G(Ce^{3+}) = 2.35 + 0.37(Ce^{4+})^{1/3} .$$

Dose values in water were computed by the following equation based on potentiometric titration (Fe^{2+}) data:[7]

$$\text{Dose (ev/g)} = \frac{NCe_o^{4+} - NCe_t^{4+} \times A}{G \times \rho} ,$$

where:

NCe_o^{4+} = normality of unirradiated Ce^{4+} solution,

NCe_t^{4+} = normality of irradiated Ce^{4+} solution for time (t),

A = Avogadro's number (6.023×10^{23} molecules per mole),

G = yield of Ce^{3+} in molecules per 100 ev absorbed,

ρ = density of 0.4 M H_2SO_4 (1.024 g/cc).

Note: 1 roentgen (exposure in water) = $\sim 5.81 \times 10^{13}$ ev/g.

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