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A GUIDE TO SELECTION OF ORGANIC MATERIAL SUITABLE FOR RADIOCHEMICAL WORK

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A GUIDE TO SELECTION OF ORGANIC MATERIALS  
SUITABLE FOR RADIOCHEMICAL WORK

James F. Bennett

July 12, 1954

Berkeley, California

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July 12, 1954

ABSTRACT

Organic materials were tested at the Radiation Laboratory to determine their suitability for radiochemical operations. The effects, if any, of irradiation, corrosive atmospheres, and temperature variables are listed. With these factors in mind, investigators may profitably use this information when deciding upon the best possible material for a given job.

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SUITABLE FOR RADIOCHEMICAL WORK

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July 12, 1954

INTRODUCTION

The organic materials used in our equipment were tested to determine their resistance to high levels of radiation, corrosive conditions, and variations in temperature. The following data answer some of the most important questions encountered in searching for the most desirable material for a given job. Information was obtained from actual tests at the University of California Radiation Laboratory and portions of it were abstracted from literature.

Ionizing radiation produces changes in organic materials by breaking the chemical bonds between atoms. If the broken bond is in the main polymer chain, chain cleavage results. Plastics that contain the most impurity -- e. g., filler, plasticizer, halides, sulfur compounds, etc. -- demonstrate the least resistance to radiation damage. In general, the harder the plastic the more resistant it is to radiation damage. The plastics tend to become more brittle and retain their tensile strength. The rubbers become harder and lose their elasticity and tensile strength. Irradiation increases the specific gravity of the elastomers that are hardened, and decreases the specific gravity of the elastomers that are softened. Plastics are generally more easily decontaminated than other materials.

There is no correlation between radiation damage suffered by organic materials and their resistance to chemical reagents and (or) their optimum temperature range.

The information that follows was partially gathered by workers at the University of California Radiation Laboratory using a multicurie  $\text{Co}^{60}$  source for radiation-damage testing. The work done generally confirms data abstracted from literature, with particular reference to work done by O. Sisman and C. D. Bopp at Oak Ridge National Laboratory. This material is intended to be a composite of data gathered from workers at ARCO, Oak Ridge National Laboratory, and University of California Radiation Laboratory.

When safety equipment is designed for work with radioactivity at University of California Radiation Laboratory there are four major aspects to be considered; they are radioactivity level, acid or base concentration, temperature, and decontaminability. In view of the high acid and (or) basic concentrations used in our chemistry operations, plastic materials seem to be more practical than metals or wood in most cases. However, a few of the rubber compounds and plastic paints are also discussed. The extent to which a material may be decontaminated is also an important aspect to consider when materials are selected for a radiochemical operation.

Polyethylene plastic is one of the most easily decontaminated. Polished stainless steel is only fair. For a complete report on this subject consult ORNL-52-10-230 or A. E. Salo at University of California Radiation Laboratory.

The first part of this report consists of the effects of radiation on a number of the more widely used plastics and rubbers. The second portion of the report deals with the effect of various chemical reagents. Part III is a section on optimum temperature.

## PART I. RADIATION DAMAGE

### A. Plastics

Plastic materials suffer radiation damage principally by ionization and chain cleavage. That is to say, if the broken bonds are between carbon atoms of the main chain and attached side atoms or groups that are not connected directly in the main chain, either unsaturation or cross linking between adjacent polymer chains may result. Those plastics which have a low initial specific resistance, i. e.,  $10^{10}$  to  $10^{12}$  ohm-cm, exhibit little relative change on irradiation. Plastics with a high initial resistivity (greater than  $10^{14}$  ohm-cm) may exhibit an appreciable change on irradiation. For example, lucite and polystyrene without plasticizer retain their high resistance. Although Saran, which does contain plasticizer, exhibits considerable change in resistivity.

With most materials, irradiations conducted in oxygen and in helium gas gave similar changes. An exception is stretched rubber, which shows more damage in oxygen because of ozone attack.<sup>1</sup>



In polyethylene plastic that has the structure of the unsubstituted paraffin chain,  $(\text{CH}_2)_n$ , cross linking rather than chain cleavage is the predominant process. This is evidenced by increases in hardness, tensile strength, and density.

With regard to resistance to irradiation, it has been found that organic materials fall into selected groups whose general characteristics are similar. The following groups of materials are listed in the order of their resistance to irradiations.

Group 1: Contains mineral-filled phenolics and mineral-filled furan plastics (Duralon, Havgel 41, asbestos-fiber bakelite, asbestos-fabric bakelite, and Karbate). Very little damage, except for darkening, occurs up to  $10^9$  r.<sup>1</sup>

Group 2: The styrene polymers (Styron 411C, Amphenol) have the best radiation resistance of the unfilled plastics. No change was detected after  $10^9$  r, except severe darkening.

Group 3: Modified styrene polymers (Stygon 475) have been classed separately because the impact strength does decrease. At  $10^9$  r, however, it is still as strong as in the unmodified material.

Group 4: Aniline formaldehyde (Cibanite) and polyvinyl carbazole (Polelectron) show a little decrease in tensile strength at  $10^9$  r.

Group 5: Polyethylene (polythene) and nylon are perhaps the best of the soft materials. Both show definite signs of breakdown at  $10^9$  r. Impact strength has decreased but tensile strength has increased. At  $4 \times 10^6$  r polyethylene is only slightly darker, and no other physical change is detected.

Group 6: Mineral-filled polyester (Plaskon-Alkyol) has lost about 50% of its tensile and impact strength at  $10^9$  r.

Group 7: Unfilled polyesters (Selectron 5038, resin CR-39) show a marked decrease in strength at  $5 \times 10^9$  r, and begin to develop cracks.

Group 8: Phenolics with organic filler (paper-base bakelite, linen fabric bakelite, Micarta) begin to fail at  $3 \times 10^4$  r. They swell and become brittle.

Group 9: Melamine and urea resins (Melmac, Beetle, Plaskon urea, Plaskon melamine) lose about 50% of their strength at  $2 \times 10^9$  r.

Group 10: Unfilled phenolics (Catalin, Textolite) have lost about 50% of their strength by  $10^9$  r. Textolite was slightly darker and more brittle at  $4 \times 10^6$  r.

Group 11: Vinylidene chloride (Saran) and vinyl chloride acetate (Vinylite V) very quickly shows signs of deterioration, but they are still serviceable at  $0.5 \times 10^9$  r. A series of modified halide polymers containing vinyl linkages, which are a group of thermoplastic synthetic materials (Tygon, Ace-Flex), are found here. At  $2.68 \times 10^5$  r, however, this material turned amber-brown but was still serviceable. At  $4 \times 10^6$  r-unplasticized polyvinyl chloride was noted to soften and become rubbery. A marked decrease in tensile strength was noted. These materials become very soft, blacken, and evolve HCl.

Group 12: This group included all the materials that are not considered serviceable beyond  $10^8$  r. They are: casein (Ameroid), methyl methacrylate (Lucite), the halogenated polyethylenes (Teflon and Fluorothene), and all the cellulose (cellulose nitrate, cellulose acetate, cellulose acetate butyrate, cellulose propionate, and ethyl cellulose). These materials become brittle and fill with small cracks. Teflon and Fluorothene were noted to become soft and tended to crumble more readily; a general loss of strength was seen at  $1.95 \times 10^3$  r. Lucite turned slightly yellow and was noted to be somewhat more brittle at  $4 \times 10^6$  r. Pressure-sensitive tapes were only very slightly affected. They appeared to be somewhat tacky, but no change in tensile strength was noted. The imbedding plastic Crystalite became more brittle, and very slight discoloration was noted.

## B. Rubber

In general, when rubber compounds are subjected to irradiation they become harder and lose their elasticity and tensile strength. However, an initial difference is noted in Hycar OR and Silastic. The tensile strength is initially increased in these compounds, but after long exposure the strength is decreased.

Natural rubber (latex), Neoprene N, GR-S, Koroseal 117, Hycar PH, Hycar OR, and Silastic 7-170 all hardened at  $10^6$  to  $10^9$  r. The threshold for latex was found to be approximately  $10^5$  r. In converse, butyl rubber and Thiokol soften with irradiation. Both butyl and Thiokol eventually become fluid; however, about 20 times as much exposure is required to produce softening in Thiokol as is required for softening butyl rubber to the same extent. A marked loss of weight occurs only for Thiokol and Hycar PA.

The materials that are hardened regain their tensile strength after long exposure, but only after severe embrittlement has reduced the elongation to less than one percent of the initial value. Vulcollan, which is a relatively new elastomer, has radiation stability similar to that of Hycar PA.

Irradiation increases the specific gravity of elastomers that are hardened, and decreases the specific gravity of the elastomers that are softened.

## C. Plastic and Rubber Paints

Plastic and rubber paints were tested at Oak Ridge National Laboratory and ARCO on steel, aluminum, and concrete surfaces, with results as follows.

Vinyl-base paints were tested on aluminum and on steel panels. Samples of Corrosite, Nukemite, and Amercoat 23, 33, and 55 were placed on aluminum panels and were irradiated with a  $3.5 \times 10^8$  r gamma  $\text{Co}^{60}$  source. All samples exhibited surface blisters and thus showed failure of the film. Large quantities of halide were present. Blistering of the panels is thus explained by the hydrogen halide attacking the aluminum.

When Amercoat 23 and 55 were used on steel panels and exposed to  $5 \times 10^8$  r gamma they showed similar failure. Therefore, these paints are not useful for exposure dosage greater than  $10^8$  r gamma.

Samples of Corrosite, Nukemite, G. E. Cocoon, Amercoat 23, 33, and 55, Zerok 110, Alkaloy 550, Amphesive 801, Prufcoat, Duralon 36, and Ampreg on ARCO concrete were irradiated to  $10^9$  r ( $\text{Co}^{60}$  gamma). These samples show no

evidence of failure at a dose of  $10^8$  r. The Amercoats, G. E. Cocoon, Corrosite, and Nukemite were examined microscopically at  $7.4 \times 10^8$  r, and it appeared that all samples, with the possible exception of Amercoat 23, began to deteriorate. Evidence of deterioration was based on formation of small white, blue, black, or green spots on the paint surface. The following materials also failed at  $10^8$  r: Black Amerplate, white polyethylene Amerplate, flame sprayed polyethylene; Kel F failed at  $10^7$  r. The following strip coats (sheet) failed at  $10^9$  r: Black Brevon, Blue Tygofilm, Black A89A, G. E. Cocoon, Amercoat strip.

Rubbers (sheet) Hycar 520 and Hycar 1004, with the exception of the natural rubber (latex), have butadiene and acrylonite polymers. All the others have vinyl polymers.

## PART II. CHEMICAL DAMAGE

The second, and perhaps the most important, aspect to be considered when selecting materials to be used in a radiochemical operation is the possibility of damage to these materials caused by chemical reagents. Owing to limited space, the chemicals come in close contact with the materials when used in Berkeley box operations. In some cases, the box atmosphere is literally saturated with fumes and condensate from these reagents. Hence use of the best possible materials available, i. e., those with the highest resistant properties, is essential.

The following list of plastic and rubber materials is intended to be a ready-reference chart from which the most desirable material-reagent relationship may be best satisfied.

RESISTANCE OF PLASTICS AND RUBBERS TO VARIOUS REAGENTS

MATERIAL*	Acids, weak	Acids, strong	Alkalis, weak	Alkalis, strong	Alcohols	Ketones	Esters	Hydro- carbons, aromatic	Hydro- carbons, aliphatic
Acrylate and Metha- crylate resin	E	E-except oxidizing	F	E	Sw or Di	D	D	Di	G
Casein	G	De	So	De	G	G	G	G	G
Cellulose acetate	F	De	F	De	Sx	Sx	Sx	G	G
Cellulose acetate butyrate	F	De	F	De	P	Sx	Sx	G	G
Cellulose nitrate	F-G	P in oxid.acids	F-G	De	Sx	Sx	Sx	G	G
Ethyl cellulose	F-G	P	G	G	F	F	P	P	G
Halide polymers polyvinyl linkages	G; ng in glac. acetic	G-D; ng in fumt HNO <sub>3</sub> or Aq. Reg.	G	P	D	Sx	Sx	Sx	Sx
Melamine formalde- hyde	E	G-De	G-E	G-E	E	E	E	E	E
Phenol formaldehyde	G	D	G-P-D	De	G	E	E	E	E
Phenol furfural (filled)	F	De	G	De	G	E	E	E	E
Polyamide resin	P	P	G	G	G	E	E	G	G
Polyester resin	E	P-G	P-G	P	P	P	P	P	P
Polyethylene	E	E	E	E	G	P	P	P	P
Polystyrene	E	G	E	E	E	E	Sw	Sx	F-G
Polyvinyl acetals (unfilled)	P	P	E	G	F-Sx	Sw	Sw	Sw	D
Polyvinyl acetate	G	P	G	P	Sx	Sx	Sx	Sx	E
Polyvinyl chloride	E	G-E	E	G-E	D	Sx	Sx	P-Sw	D
Rubber derivatives	E	E	E	E	E	P	P	P	G
Rubber-pure gum	G	G	G	D	G	G	F	D	D
Rubbers-synthetic	F	P-G	G	F-P	G-P	P	D-F	D-F	D-F
Tetrafluoroethylene	E	E	E	E	E	E	E	E	E
Urea formaldehyde	G	De	D	DE	G-E	G-E	G-E	E	E
Vinyl chloride-acetate copolymer	E	E	E	E	E	D-Di	P-Di	P-Sw	E

RESISTANCE OF PLASTICS AND RUBBERS TO VARIOUS REAGENTS (Sheet 2)

MATERIAL *	Acids, weak	Acids, strong	Alkalis, weak	Alkalis, strong	Alcohols	Ketones	Esters	Hydro- carbons, aromatic	Hydro- carbons, aliphatic
Vinylidene chloride	E	G-E	G; ng in NH <sub>3</sub>	G; ng in NH <sub>3</sub>	E	G	G	G	E

\*See appendix for list of trade names and their composition.

D - depends  
De - decomposes  
Di - dissolves  
E - excellent

F - fair  
G - good  
P - poor  
So - softens

Sw - swells  
Sx - soluble  
Ng - no good

### PART III. OPTIMUM TEMPERATURE RANGES

The optimum temperature ranges of the more widely used plastics and rubbers are also worthy of consideration. Although a given material may be desirable with regard to resistance to damage caused by irradiation and damage caused by chemical reagents, if it is not in the optimum temperature range of a particular operation that one factor may, and in some cases does, disqualify the material from being used.

The following list of characteristics is presented to show what material may be used to the greatest advantage at a given temperature.

OPTIMUM TEMPERATURE RANGES FOR VARIOUS PLASTICS AND RUBBERS

MATERIAL	Softening Point	Thermal Expansion (per °C)	Thermal Conductivity (cal/sec cm °C)	Heat Distortion	Brittle Point
Acrylate and methacrylate resin	66°-123°C	$9 \times 10^{-5}$	$(1-10) \times 10^{-4}$	50-85°C	...
Casein	94°C	$(4.1-6.8) \times 10^{-5}$	...	149°C	...
Cellulose acetate	60°-120°C	$(5-16) \times 10^{-5}$	$(4.5-8.7) \times 10^{-4}$	50-100°C	...
Cellulose acetate butyrate	60°-127°C	$(11-17) \times 10^{-5}$	$(4-8) \times 10^{-4}$	47-102°C	...
Cellulose nitrate	60°-90°C	$(6.5-16) \times 10^{-5}$	$(3.1-5.5) \times 10^{-4}$	43-66°C	...
Ethyl cellulose	93°-135°C	$(10-14) \times 10^{-5}$	$(3.8-6.3) \times 10^{-4}$	45-93°C	...
Halide polymers $\bar{c}$ polyvinyl linkages	210°F	...	...	...	-40-15°F
Melamine formaldehyde	...	$(1.5-4.0) \times 10^{-5}$	$(8-20) \times 10^{-4}$	115-160°C	...
Phenol formaldehyde	...	$(1.5-4.0) \times 10^{-5}$	$(5-20) \times 10^{-4}$	115-160°C	...
Phenol furfural (filled)	Chars 204°-290°C	$(2-4.5) \times 10^{-5}$	$(3.5-20) \times 10^{-4}$	132-146°C	...
Polyamide resin	~400°F	$5.5 \times 10^{-5} / ^\circ\text{F}$	$1.7 \times 10^{-4}$	115-150°F	...
Polyester resin	...	$(8.0-10.0) \times 10^{-5}$	$4 \times 10^{-4}$	140-400°F	...
Polyethylene	224°F	$9 \times 10^{-5} / ^\circ\text{F}$	$(2.3) \times 10^{-4}$	107°F	-50°F
Polystyrene	88°-121°C	$(6-8) \times 10^{-5}$	$(1.9-3.2) \times 10^{-4}$	73-88°C	...



OPTIMUM TEMPERATURE RANGES FOR VARIOUS PLASTICS AND RUBBERS (Sheet 2)

MATERIAL	Softening Point	Thermal Expansion (per °C)	Thermal Conductivity (cal/sec cm °C)	Heat Distortion	Brittle Point
Polyvinyl acetals (unfilled)	47°-200°C	(7.8-22.3) x 10 <sup>-5</sup>	(3.4-4.4) x 10 <sup>-4</sup>	47-100°C	...
Polyvinyl acetate	65°-175°C	8.6 x 10 <sup>-5</sup>	3.8 x 10 <sup>-4</sup>	40-50°C	...
Polyvinyl chloride	...	(7-25) x 10 <sup>-5</sup>	(3.9-4.0) x 10 <sup>-4</sup>	77-121°C	...
Rubber derivatives	75°-110°C	(7-13) x 10 <sup>-5</sup>	(2.6-3.0) x 10 <sup>-4</sup>	60°-105°C	...
Rubber-pure gum	...	...	0.00039	...	-54°C
Rubbers-synthetic	...	...	0.00046-49	...	-40-60°C
Tetrafluoroethylene	~400°F	5.5 x 10 <sup>-5</sup> /°F	1.7 x 10 <sup>-4</sup>	140°F	-90°F
Urea formaldehyde	...	(2.5-3.0) x 10 <sup>-5</sup>	7.1 x 10 <sup>-4</sup>	127-130°C	...
Vinyl chloride-acetate copolymer	60°-65°C	6.9 x 10 <sup>-5</sup>	(3.5-4.1) x 10 <sup>-4</sup>	60-69°C	...
Vinylidene chloride	116°-138°C	15.8-10 <sup>-5</sup>	2.2 x 10 <sup>-4</sup>	66-82°C	...

APPENDIX

List of Composition and Trade Names - Selected Plastics and Rubbers:

I. Acrylate and methacrylate resin:

Crystalite  
Lucite  
Plexiglas

II. Casein:

Ameroid

III. Cellulose acetate:

Bakelite (cellulose acetate)  
Fibestos  
Hercules (cellulose acetate)  
Lumarith  
Nixonite  
Plastacele  
Protectoid  
Tenite

IV. Cellulose acetate butyrate:

Tenite II

V. Cellulose nitrate:

Celluloid  
Nitron  
Nixonoid  
Pyralin

VI. Ethylcellulose:

Ditzler  
Ethocel  
Ethofoil  
Lumarith  
Nixon, Hercules

VII. Halide polymers with polyvinyl linkage:

Ace-Flex  
Tygon

VIII. Melamine formaldehyde:

Catalin  
Melmac  
Plaskon

## IX. Phenol formaldehyde:

Bakelite (phenol formaldehyde)  
Catalin  
Durez  
Durite  
Formica (P-F lamination)  
Gemstone (P-F cast)  
Haveg (P-F lamination)  
Indur  
Makalot  
Marblette  
Micarta (P-F lamination)  
Opalon (cast)  
Prystal (cast)  
Resinox  
Textolite

## X. Phenolic furfural filled:

Durite  
Duralon

## XI. Polyamide resin:

Nylon  
Polyester resin

## XI. Polyethylene:

Polythene

## XII. Polystyrene:

Amphenol  
Bakelite (polystyrene)  
Loalin  
Lustrin  
Stygon

## XIII. Polyvinyl acetals, unfilled:

Alvar  
Butacite (plasticized polyvinyl butyral)  
Formvar  
Saflex  
Vinylite X

## XIV. Polyvinyl acetate:

Gelva  
Vinylite A

## XV. Polyvinyl chloride and copolymer plasticized:

Koroseal (P-C modified)  
Vinylite Q

## XVI. Rubber derivatives:

Parlon (chlorinated)  
Plioform (modified isomerized rubber)  
Pliolite (modified isomerized rubber)  
Tornesit (chlorinated)

## XVII. Rubber - pure gum:

Latex

## XVIII. Rubbers - synthetic:

Buna N— (Hycar) (butadiene acrylonitrile copolymers)  
Neoprene (latices)  
Silastic (silicone rubber)  
Thiokol (organic polysulfide polymers)

## XIX. Tetrafluoroethylene:

Teflon

## XX. Urea formaldehyde:

Bakelite (Urea formaldehyde)  
Beetle  
Plaskon

## XXI. Vinyl-base paints:

Alkaloy  
Amercoat  
Brevon  
Cocoon  
Corrosite  
Nukemite  
Prufcoat  
Zerok

## XXII. Vinyl chloride - acetate copolymer:

Vinylite V

## XXIII. Vinylidene chloride:

Saran  
Velon

For a complete list of trade names see Modern Plastics Encyclopedia and Engineers Handbook, Plastics Catalogue Corporation, 1953, or Handbook of Material Trade Names, Industrial Research Service, 1953.

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6. For decontamination reference consult ORNL 52-10-230 or Albert E. Salo at University of California Radiation Laboratory.

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