

# Safety and Handling of UV/EB Curing Materials



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Ultraviolet (UV) and electron beam (EB) curing has been recognized as a commercially successful low VOC coating and adhesives technology for more than 25 years. However, many misconceptions still exist concerning the safety of the materials and equipment used in UV/EB curing. Such misconceptions have overshadowed the fact that UV/EB materials are, in general, less hazardous and easier to control than most solvents. In some cases, a misunderstanding of safety issues has blocked adoption of this powerful compliance technology.

This paper discusses the physical hazards of UV/EB technology, provides data on raw material toxicity, and describes the engineering controls and industrial hygiene practices which have been developed to assure workplace safety. The practical evaluation of workplace hazards and safe handling practices will enable potential end-users of UV/EB technology to make a rational decision when choosing options for compliance.

## Historical Perspective

When UV/EB technology was first introduced as a commercial technology, there was still little understanding of the toxicology of acrylate monomers. In these early days, many hydroxy-functional molecules were acrylated in an effort to identify UV-curing materials with valuable performance features. Unfortunately, a few of these newly developed acrylates were severely irritating.

The commercial offering of these poorly understood substances combined with the poor industrial hygiene practices associated with handling of conventional coatings and inks, as well as

worker and end-user inexperience with UV/EB materials, inevitably led to incidents of severe worker reactions to some of the formulated UV/EB curing products.

Carcinogenicity concerns raised by toxicity testing of acrylates in the early 1980s<sup>1</sup> further raised questions about the safety of working with acrylates.

This prior history has led to negative generalizations and misconceptions about UV/EB safety, in spite of the later development of less irritating materials and publication of more favorable toxicity test results.

## Physical Hazards of UV/EB Technology

### Non-Ionizing (Ultraviolet) Radiation

Never look directly at the UV bulb or cure zone. Direct radiation from a UV lamp can cause skin reddening (sunburn) or eye injury, such as “snow blindness” or “welder’s eye,” which occurs when too much UV is absorbed by the outer surface of the cornea.

The biological effects of ultraviolet radiation result mostly from exposure to wavelengths below 325 nm.

- VUV (100-200 nanometers)—absorbed by air and poses no danger to humans.

- UVC (200-280 nanometers)—Also called “far UV” and includes the ‘germicidal’ wavelengths. Although solar UVC is absorbed by the earth’s ozone layer, UVC from UV lamps can be a serious hazard. Fortunately, most materials (plastics and glass) will filter out UVC.
- UVB (280-315 nanometers)—most responsible for reddening and burning of the skin and damage to the eyes. This is the range for which most safety threshold levels are stated.
- UVA (315-400 nanometers)—represents the largest portion of UV energy and is most responsible for human skin aging and

increased pigmentation. UVA is at the lower limit of sensitivity of the human eye. Also called “near UV.”

- UVV (400-450 nanometers)—UV wavelengths that extend into the visible range.

The National Institute for Occupational Safety and Health (NIOSH) document *Criteria for a Recommended Standard: Occupational Exposure to Ultraviolet Radiation* (PB214 268)<sup>2</sup> establishes guidelines for exposure limits and safe use of UV radiation in the workplace. These exposure guidelines are based on and are similar to the American Council of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values. *(ACGIH and NIOSH guidelines can be updated from time to time, so the most current published values should be confirmed.)*

The NIOSH document provides a complex formula to assign allowable exposures for different UV wavelengths. In general, allowable UV-radiation intensity increases in inverse proportion to shorter duration of exposure, and a lower threshold limit is required for longer exposures. For example:

- For UVA (315 - 400 nm), the guideline is 1 milliWatt/cm<sup>2</sup> for exposures greater than 16 minutes, but
- At 270 nm the limit is only 0.1 µWatt/cm<sup>2</sup> for 8-hours continuous exposure.

Adherence to these exposure limits normally prevents skin and eye effects in most workers. Sensitized individuals may exhibit effects even at low exposures, and they should not work in the vicinity of UV-curing equipment or be exposed to sunlight.

### **Ionizing (Electron Beam) Radiation**

The potential physical hazards of EB curing result from possible leakage of high velocity electrons and X-rays from the curing station. Physiological consequences would be similar to X-ray

burns and, therefore, strict measures are taken to eliminate this possibility.

Engineering controls include proper equipment design to assure that the electron beam is directed at the target area, and that stray electrons and X-rays are minimized. Shielding is provided to prevent any leakage of electrons or X-rays into the work environment. EB-curing equipment is installed under manufacturer supervision to assure that it is working as designed. The EB unit is provided with a radiation detector which automatically shuts down the power if a high level alarm is exceeded.

The federal government has set permissible exposure levels to X-rays, and employees working with the EB-curing equipment wear monitoring badges to detect and quantify any exposure to stray radiation. State and local governments have regulations controlling the use of radiation-producing equipment and all EB units must be licensed.

Extensive specialized training is required before any worker is permitted to operate EB-curing equipment. Again, good written operating procedures and documentation are important for safe use of the equipment.

### **Ozone**

Ozone is a pungent-smelling, irritating gas which is generated by reaction of atmospheric oxygen exposed to UV/EB radiation. The physiological symptoms of exposure include respiratory irritation, fatigue and headache. Proper ventilating equipment minimizes this hazard in the workplace.

As with all industrial processes, written procedures, worker training and documentation are critical requirements to assure productive and safe use of the processing equipment. This applies to all aspects of the use of industrial technology and will be a common theme throughout this paper.

## **UV/EB-Curing Materials**

Table 1 shows a listing of acrylate monomers commonly used in UV/EB-curing formulations and their acronyms.

**Table 1. Common UV/EB-Curing Acrylate Monomers**

| Acronym | Chemical Description                     |
|---------|--|
| 2-PEA   | 2-phenoxyethyl acrylate                  |
| BCEA    | beta-carboxyethyl acrylate               |
| EOEOEA  | ethoxyethoxyethyl acrylate               |
| GPTA    | glycerol propoxylate triacrylate         |
| HDODA   | hexane diol diacrylate                   |
| PETA    | pentaerythritol tri/tetra acrylate       |
| PNPGDA  | propoxylated neopentyl glycol diacrylate |
| TMPEOTA | trimethylolpropane ethoxy triacrylate    |
| TMPTA   | trimethylolpropane triacrylate           |
| TRPGDA  | tripropylene glycol diacrylate           |
| TTEGDA  | tetraethylene glycol diacrylate          |

UV/EB-curing acrylate oligomers are low-molecular weight polymers which have pendant acrylate groups. The polymer backbone (acrylic, amino, epoxy, polyester, silicone, urethane, etc.) contributes the basic properties of the cured article, while the acrylate groups serve to link up the lower molecular weight species in the curing reaction.

In addition to oligomers and monomers, typical UV/EB-curing formulations also can contain additives, such as photoinitiators, pigments, slip agents, adhesion promoters, etc.

## Chemical Toxicity of UV/EB-Curing Materials

Chemical toxicity is a safety concern in any industrial process that utilizes chemicals, and UV/EB curing is no exception. Most people can work safely with these products by using the proper protective clothing and handling procedures.

### Acrylate Acute Toxicity

In general, UV/EB-curing acrylates have low systemic toxicity, but they can cause skin and eye irritation or burns. Since they do not cause immediate irritation, exposure can go unnoticed. Some individuals may also become sensitized to these chemicals as a result of contact. Individuals who become sensitized should discontinue working in the areas where exposure can occur.

Most acrylate oligomers and monomers have a low vapor pressure, and inhalation of vapors is unlikely to occur at room temperatures. Some of these products may form stable aerosols which can be inhaled and may also cause skin and eye irritation.

Low molecular weight acrylate monomers represent the most physiologically active materials in this class, due to the low molecular weight and high level of acrylate functionality.

The substantially higher molecular weight and lower net acrylate functionality of acrylate oligomers result in a lower level of physiological activity than the acrylate monomers. Skin and eye

irritation due to oligomer exposure normally are minimal to mild, and the oligomers exhibit very low acute toxicity.

Table 2 summarizes the typical toxicological profile of the low molecular weight acrylate monomers.

Skin and eye irritation can be expressed through "Draize Scores"<sup>3</sup> or the "Primary Irritation Index" (PII)<sup>4</sup>, which is the sum of the 24- and 72-hour Draize scores, divided by two and rounded to the nearest tenth. However, caution should be exercised when interpreting these irritation scores. Although they appear to be precise numerical ratings, they are averages and should be viewed as rough estimates of irritation potential. It has been shown that repeating Draize and PII tests for the same material, either within or between laboratories, often yields significantly different results. This variation results from the subjective nature of the test itself, human error, animal variability and the numerous variations that exist in testing protocols. Unfortunately, often too much reliance is placed on the Draize score or PII as an absolute indicator of chemical skin and eye hazards, and this is not always the best basis for making decisions about workplace safety.

Table 3 show Draize test results for a number of commonly used commercial acrylate monomers, approximately in order of greater irritation potential.

**Table 2. Low Molecular Weight Acrylate Monomer Toxicity Overview**

|                   |   |
|-------------------|---|
| Ingestion         | High LD50 (EPA rating III to IV)  |
| Inhalation        | Low volatile emissions, vapor pressures mostly < 0.1 mm Hg @ 25°C, high LC50  |
| Skin Absorption   | Low absorption through skin, high LD50  |
| Dermal Irritation | Mild to moderate (EPA rating II to IV) Delayed action, exposure can go unnoticed Skin blisters can develop on prolonged contact   |
| Eye Irritation    | Mild to severe (EPA rating I to III)  |
| Chronic           | Skin sensitization can occur. Not an animal teratogen. Not on any list of carcinogens. Some animal skin painting studies have shown a weak carcinogenic effect. No other significant chronic effects known. |

*See the publication "Advantages of UV/EB for a Safe Work Environment" on the RadTech web site for a more detailed review of toxicology and exposure routes.*

**Table 3. Acrylate Monomer Skin and Eye Irritation<sup>5</sup>**

| Monomer | Skin Irritation Draize Score <sup>a</sup> | Eye Irritation Draize Score <sup>b</sup> |
|---------|---|--|
| GPTA    | 1.5                                       | moderate                                 |
| TPGDA   | 2.5                                       | 7.4                                      |
| TMPEOTA | 2.6                                       | 44                                       |
| TTEGDA  | 4.4                                       | 103                                      |
| PETA    | 4.6                                       | 109                                      |
| TMPTA   | 5.0                                       | 46                                       |
| HDODA   | 6.2                                       | 16                                       |

a) 0 = no irritation; 8.0 = severely irritating

b) 0 = no irritation; 110 = severely irritating

Acrylate monomers, in general, have low acute toxicity, as shown in Table 4.

**Table 4. Acrylate Monomer Acute Oral and Dermal Toxicity<sup>6</sup>**

| Monomer | Acute Oral LD50 (rat) | Acute Dermal LD50 (rabbit) |
|---------|-----------------------|----------------------------|
| PETA    | 1,350 mg/kg           | > 2,000 mg/kg              |
| EOEOEA  | 1,860 mg/kg           |                            |
| HDODA   | > 5,000 mg/kg         | > 3,600 mg/kg              |
| TMPTA   | > 5,000 mg/kg         |                            |
| 2-PEA   | > 5,000 mg/kg         |                            |
| TRPGDA  | 6,800 mg/kg           | > 2,000 mg/kg              |
| PNPGDA  | 15,000 mg/kg          | 5,000 mg/kg                |
| GPTA    |                       | > 13,000 mg/kg             |

**Acrylate Chronic Toxicity**

There has been a great deal of controversy and misinformation concerning whether or not acrylates are carcinogenic. Most acrylates consistently give negative (not mutagenic) results in bacterial reverse mutation test, most commonly known as the Ames Test, and other mammalian point mutation assays conducted on cells in an artificial environment outside a living organism (in vitro). However, these same substances consistently give positive responses when tested in the mouse lymphoma assay and/or other in vitro mammalian cell assays.

Studies of workplace exposure to TRPGDA by Nylander-French<sup>6</sup> claimed evidence of carcinogenicity, but the results are questionable, since the test animal has been rejected by other groups because it is overly sensitive to external stimulus.

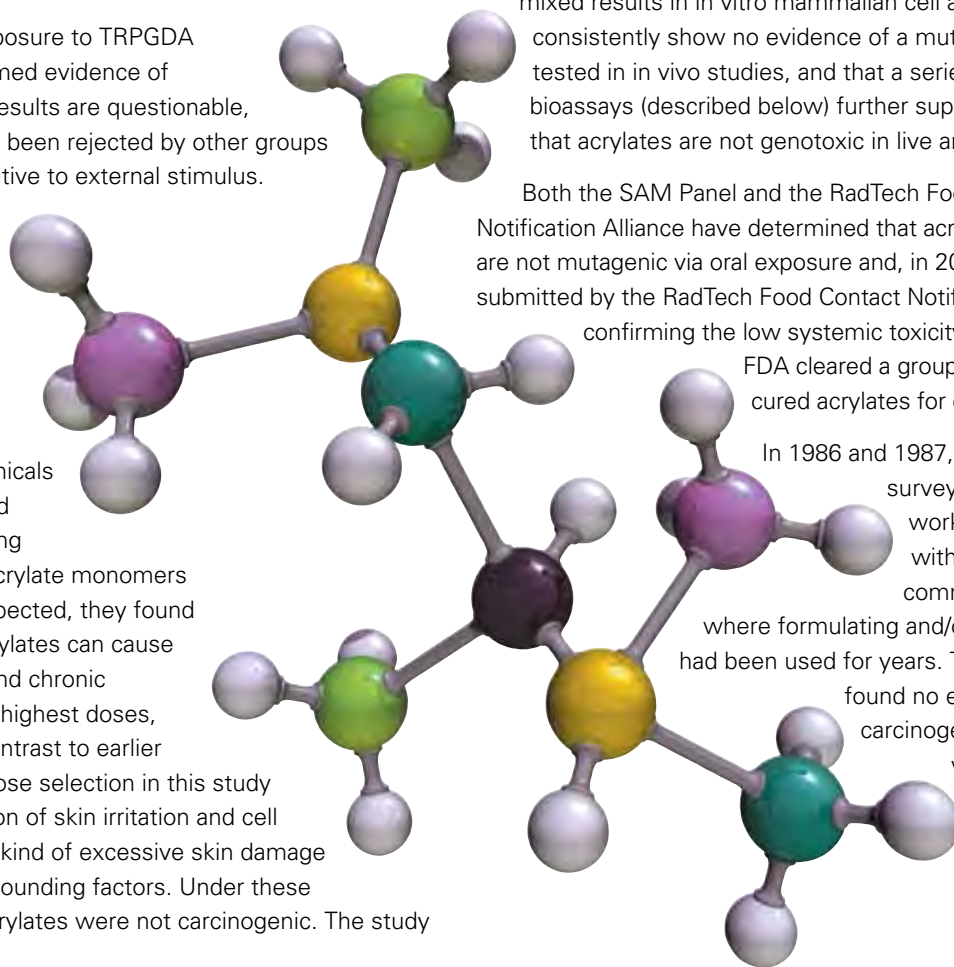
In the late 1990s, the American Chemistry Council Specialty Acrylates and Methacrylates (SAM) Panel in collaboration with the EPA High Production Volume Chemicals Program (HPV)<sup>7</sup> evaluated the effects of chronic (long term) skin exposure to acrylate monomers (Van Miller et al.).<sup>8</sup> As expected, they found that skin exposure to acrylates can cause cell proliferation, acute and chronic inflammation and, at the highest doses, localized cell death. In contrast to earlier studies with acrylates, dose selection in this study was based on examination of skin irritation and cell proliferation to avoid the kind of excessive skin damage that could introduce confounding factors. Under these conditions, the tested acrylates were not carcinogenic. The study

concluded that severe skin damage was most likely the cause of tumorigenesis in earlier acrylate studies, and should be controlled in carcinogenicity evaluations of this class of chemicals.

A comprehensive review of acrylate mutagenic and genotoxic potential, published in 2008<sup>9</sup>, considered the results of more than 200 short-term open literature in vitro and live animal (in vivo) mutagenicity studies of acrylate and methacrylate esters. This review confirmed that while acrylates as a class demonstrate mixed results in in vitro mammalian cell assays, they consistently show no evidence of a mutagenic effect when tested in in vivo studies, and that a series of chronic rodent bioassays (described below) further support the conclusion that acrylates are not genotoxic in live animals.

Both the SAM Panel and the RadTech Food Contact Notification Alliance have determined that acrylate monomers are not mutagenic via oral exposure and, in 2008, based on data submitted by the RadTech Food Contact Notification Alliance confirming the low systemic toxicity of acrylates, the FDA cleared a group of UV- and EB-cured acrylates for direct food contact.

In 1986 and 1987, several NIOSH surveys<sup>10</sup> described actual workplace experience with acrylates in commercial plants where formulating and/or UV/EB curing had been used for years. The NIOSH surveys found no evidence of acrylate carcinogenicity in workers who had long-term exposure to UV/EB curing materials.



### Cycloaliphatic Epoxy Toxicity

Cycloaliphatic epoxy compounds are preferred in certain specialty UV-curing applications. Table 5 shows an overview of the toxicity of these materials.

**Table 5. Cycloaliphatic Epoxy Toxicity Overview**

|                   |   |
|-------------------|---|
| Ingestion         | Low toxicity, high LD50   |
| Inhalation        | Low volatile emissions, vapor pressures mostly < 0.1 mm Hg @ 25°C |
| Skin Absorption   | Low absorption through skin, high LD50                            |
| Dermal Irritation | Mild (EPA rating IV)  |
| Eye Irritation    | Mild to moderate (EPA rating II to III)                           |
| Chronic           | Limited evidence of carcinogenicity                               |

### Photoinitiators And Additives

Photoinitiators, pigments and additives vary widely in their toxicity and handling characteristics. Individual material safety data sheets (MSDS) must be consulted to determine safe handling of these materials.

## Safe Handling of UV/EB-Curing Materials

The following sections cover safe handling of UV/EB-curing materials. This review is based on good industrial hygiene practice and handling principles, and does not imply that there are any extraordinary or severe hazards associated with these materials.

The great majority of commercial UV/EB-curing usage is based on acrylate chemistry. While the primary focus here is the safe handling of acrylates, the same principles of worker training and good industrial hygiene practices apply as well to the less common epoxy systems.

### Minimizing the Risk of Dermatitis

#### *Elimination of Severe Irritants and Development of New Less Irritating Monomers*

Early unfavorable experience quickly caused producers to drop highly irritating materials, such as neopentyl glycol diacrylate, from their commercial product line. Recognition of the irritation issues associated with acrylates also prompted development of lower irritation materials. Acrylated alkoxyated compounds, in general, exhibit less irritating effects, and a wide range of these materials is offered commercially.

#### *Prevent Skin and Eye Contact*

UV/EB-curing oligomers and monomers should not be permitted to enter the eyes, and direct skin contact should be avoided. Proper eye protection must be worn at all times when handling oligomers and monomers. Face shields and other equipment may be used to protect the face. Contact lenses should never be worn.

The type of protective clothing recommended depends on the type of potential exposure; in all cases, protective clothing must be clean and have long sleeves. For routine laboratory operations, an impervious apron of polyethylene or neoprene is preferred. Impervious gloves such as neoprene are also recommended. A combination of barrier cream and protective gloves is recommended. Barrier creams alone are not recommended,

because they provide a false sense of security. Barrier creams should be applied to clean hands and should not be applied after exposure. Good practice is to wash gloves frequently with soap and water.



When working with larger quantities of materials or where greater exposure hazards might be present (such as when loading or unloading tanks or reactors, treating spills, sampling products, bleeding, draining or flushing lines), additional precautions should be taken. Under these conditions it is essential that proper eye protection, rubber boots and gloves of impervious materials be used. In areas where an aerosol is likely, an impervious slicker suit should be worn.

Protective clothing contaminated with small amounts of UV/EB-curing materials can be laundered separately in an alkaline detergent and re-used. If protective clothing becomes heavily contaminated, it should be properly discarded by placing in a sealed plastic bag and incinerating. Discard all contaminated shoes, belts or other leather goods, which cannot be decontaminated adequately to allow safe use.

#### *Prevent or Control Aerosols*

The vapor pressures of most acrylate oligomers and monomers are so low that vapor inhalation usually is not a problem. Under normal conditions, no special respirator equipment is required, but ventilation for odor control is advisable.

However, these products may form aerosols when spraying acrylate formulations, at liquid transfer points or during application with high-speed rollers. Aerosols also can form under

the conditions of fire or uncontrolled polymerization. A fresh air mask or an organic vapor respirator should be worn whenever aerosols are present.

While most UV/EB-curing materials have very low vapor pressure, they may be used in conjunction with solvents, diluting monomers or other co-reactants of much greater volatility. Consequently, buildings used for processing or storage must be well ventilated to prevent local accumulation of solvent vapors. Point of operation or local exhaust is more effective where solvent vapors or aerosols are emitted from local sources.

### *Safe Cleanup Procedures*

It is important to remember that UV/EB-curing materials do not evaporate, so spills and incidental contamination will remain until cleaned up. Equipment touched with contaminated gloves can be the source of exposure if touched later by unprotected skin.

Wipe up spills and contact areas immediately. Work areas should be kept clean, and all equipment and tools soiled with UV/EB-curing materials should be thoroughly cleaned after use. Note that since UV/EB-curing materials do not dry out or cure under normal conditions they remain liquid and can be cleaned up easily with less aggressive solvents, such as soap and water or citrus and vegetable oil cleaners. Solvents can be used for cleaning equipment, but only if the appropriate protective clothing is worn and if a safe means of disposal is available.

### *Personal Hygiene*

Hands should be washed with soap and water immediately after handling any containers or equipment which have come in contact with the oligomers and monomers. Routine wash-ups should be carried out before breaks, at lunchtime and after work as part of the safety program. Solvents should not be used for cleaning the hands or skin, because they may increase the penetration of these products into the skin, and dermatitis may occur. Hand creams or lotions should be used at the end of the work period to reduce the drying of the skin caused by frequent washing.

As with any chemical, food and beverages should not be consumed in areas where UV/EB-curing materials are handled.



## Premature Polymerization

UV/EB curing materials are designed to be reactive under controlled conditions, and care must be taken to prevent premature polymerization. In most cases, uncontrolled polymerization simply results in solidification of the material in its original container or in localized gels, making it unusable.

A few products, particularly those with very high acrylate content (certain tri-, tetra-, and hexa-functional acrylates), have the potential to generate a great deal of heat during uncontrolled bulk polymerization, which can cause rapid pressure buildup in closed containers. With these highly reactive materials, pyrolysis may occur with the formation of volatile degradation products which are acrid and irritating.

Any unexplained change in temperature may indicate the onset of polymerization. Bulging drums or any unexplained change in bulk temperature may indicate the onset of premature polymerization.

The following basic principals and procedures normally assure stable handling and storage of UV/EB curing materials:

### *Polymerization Inhibitors*

All acrylated materials are supplied with a low-concentration, free-radical inhibitor to prevent uncontrolled polymerization when they are stored properly. Most of these inhibitors are effective only in the presence of dissolved oxygen. Consequently, these products should not be subjected to conditions that will displace oxygen, such as sparging with nitrogen.

Do not exceed the supplier's recommended shelf life, since inhibitor concentration can decline over time and acrylates can have widely varying shelf stability.

### *Thawing Acrylates*

Some acrylate oligomers and monomers may freeze or crystallize in cold weather or even under normal storage conditions. When these products crystallize, the inhibitor may become unevenly distributed, leaving some portions of the material inadequately inhibited.

Frozen containers of product can be conveniently melted by heating in a warm water bath or a warm room for 24 to 48 hours at a maximum temperature of 100° to 130°F, following the supplier's recommendations. Thawed material should be agitated to redistribute the inhibitor.

If acrylate monomers freeze in bulk storage tanks, they can be melted by circulating tempered water through tank coils or jackets. The monomers should be stirred or recirculated while heating the tank to redistribute the inhibitor.

### *Avoid Excessive Localized Heating*

Adhere to the supplier's recommended maximum storage and handling temperatures. Never use steam or electrical heating

systems such as tapes, coils, mantles or jackets to thaw frozen acrylates, since these can produce localized hot spots that might lead to uncontrolled polymerization or product deterioration. Take care not to position acrylate drums immediately next to steam lines, which can lead to local hot spots.

Piston, lobe or gear pumps should be avoided to prevent frictional heat related gel formation. Low-viscosity monomers can be transferred using centrifugal pumps, preferably with recessed impellers to keep the material flowing away from the seal surfaces.

Air-powered diaphragm pumps are recommended for pumping higher viscosity oligomers and oligomer/monomer blends. In many cases, these also are the best choice for handling monomers. These pumps can generally be run dry or deadheaded without damaging the pumps or causing the material in them to degrade or gel.

### ***Avoid Exposure to Light and Contact with Polymerization Initiators***

UV/EB-curing materials should be stored in amber glass or opaque containers to avoid exposure to light and UV sources. Containers must be kept closed and away from oxidizing agents, acids, alkalis, peroxides, polymerization initiators, free-radical initiators, X-ray or ultraviolet radiation, photosensitizers or azo compounds.

Acrylates can undergo vigorous addition reactions with some amines and thiols. Cationic cycloaliphatic-epoxy, UV-curing systems can react with strong acids, amines, thiols and anhydrides. Unintended contact with these materials should be avoided.

Reactive metals which can promote free-radical reactions (such as unlined carbon steel, copper alloys, brass and bronze) should not be used as materials of construction in direct contact with acrylates.

## **Storage and Transfer of Acrylates**

### ***Drums***

Drums should be stored with bungs side upward and maintained at the recommended temperature. The bungs should be loosened occasionally to relieve any buildup of internal pressure.

Care should be used when handling drums to prevent damage to the protective lining, which can cause discoloration or degradation of the product and possible leakage. Any leaking drums should be removed to an adequately ventilated area and the contents should be transferred to a clean, suitable container

Drum unloading areas should have adequate ventilation and a sump to contain spills. Drums should be emptied using equipment designed to minimize spillage and operator contact with the drum contents. Operators must be dressed in the proper protective clothing. Always attach a static grounding device, even if the drum contents are not combustible. Immediately after



completing the transfer process, equipment should be carefully cleaned, with care taken not to contaminate the area. Empty drums can be sent to a recycler for reconditioning and re-use.

### ***Bulk Storage***

UV/EB-curing materials normally can be safely stored in lined carbon steel (such as Heresite P413D or equivalent baked phenolic), 304 and 316 stainless steel. The few materials which contain free-acrylic acid must be handled and stored as corrosives. The storage tanks should be equipped with continuous temperature monitoring devices with remote readout for each to allow detection of heat increase resulting from premature polymerization. Tanks should be well insulated and should have internal coils capable of supplying heat as well as cooling. All valves, piping, and pumps must be constructed of 304 or 316 stainless steel to avoid iron contamination.

### ***Material Transfer***

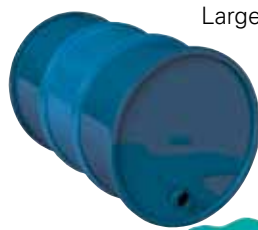
Equipment which minimizes any potential direct contact with the workers should be used where possible. Since most acrylate products have low volatility and high flash points, they pose very little threat from auto-ignition and can be safely conveyed and blown clear through lines by air pressure. Nitrogen or other inert gases should not be used for pressure, since these gases may remove dissolved oxygen, causing the inhibitor to become ineffective.

## **Spill Control and Waste Disposal**

All spills and leaks of UV/EB-curing materials should be cleaned up immediately. As general good practice, remove all sources of ignition.

Only personnel wearing the proper protective clothing and adequately trained in cleanup and disposal procedures should be permitted in the area. A fresh air mask or organic vapor respirator,

chemical safety goggles, impervious gloves, clothing and rubber boots are recommended. Leaking containers should be removed to well-ventilated areas where leakage can be safely contained. Towels and cloths used to clean up spills should never be reused, but disposed of immediately.



Large spills can be absorbed using a dry absorbent. Good ventilation should be provided until the area has been cleaned up. Transfer the contaminated absorbent into suitable containers for disposal.

Contaminated areas should be thoroughly washed with a strong alkaline detergent. Washings should be collected for appropriate disposal, and care should be

taken to prevent inadvertent contamination of underground water. The use of solvents for cleanup of large contaminated areas is not recommended, since the solvent would introduce significant new toxicity, fire and environmental hazards.

All cleanup and disposal must be carried out in compliance with federal, state, and local regulations regarding health, air and water pollution.

See the RadTech publication *Guidance On Cleanup And Disposal Of UV/EB-Curing Waste Materials* for a more detailed discussion of hazardous waste management.

## Regulatory Considerations

Most UV/EB curing materials are not regulated by DOT as flammable or corrosive. Exceptions are BCEA, which has a high content of corrosive and combustible acrylic acid, and styrene.

A few acrylates are listed by DOT as marine pollutants and may require corresponding labels for shipments. With these exceptions, and unless diluted with flammable solvents, UV/EB-curing materials generally are not “hazardous waste” (toxic, corrosive, flammable or reactive) as defined under RCRA regulations. However, as with all chemicals, contaminated materials and wastes should be disposed of in accordance with federal and local requirements. See the RadTech publication “Guidance on Cleanup and Disposal of UV/EB-Curing Waste Materials” for additional details.

Most UV/EB-curing materials contain little to no VOC and are not currently specified in any federal or state Community Right-To-Know list. However, a few monomers, such as TPGDA, GPTA, TMPEOTA and PEA, can be considered to be glycol ethers and may be classified as hazardous air pollutants (HAPS) under the Clean Air Act.

European regulations require extensive labeling of acrylates, and specific requirements should be determined for UV/EB curing products intended for distribution in this region.

## Worker Training

Clearly defined work procedures and effective worker training are essential for safe application of any industrial technology. UV/EB curing is no exception and many early problems were due to poorly understood safe handling principles and poor hygiene habits with solvent systems that do not produce an immediately noticeable physiological reaction.

## Comparison of Solvent and UV/EB Systems

The immediate dermatitis effect that can occur when UV/EB formulations containing acrylates are mishandled acts as a warning that handling procedures must be improved. Unfortunately, it also raises concerns about working with these

**Table 6. Comparison of Solvent and UV/EB Systems**

| Hazard                 | Solvents   | UV/EB Materials  |
|------------------------|--|--|
| Acute Toxicity         | Narcosis, kidney damage, blood damage, fetal toxicity, liver damage, dermatitis, death   | Dermatitis, blisters   |
| Chronic Toxicity       | Known carcinogens and suspect carcinogens, cirrhosis, permanent nerve damage, blood damage, kidney damage, reproductive damage | Not carcinogenic below maximum tolerated dose (skin damage irritation), not mutagenic in oral and dermal testing, possible sensitization |
| Exposure Routes        | inhalation, eyes, skin absorption, ingestion   | eyes, skin surface, ingestion  |
| Flammable, Combustible | mostly yes   | mostly no  |
| Explosive Vapors       | mostly yes   | mostly no  |
| VOC                    | yes  | mostly no  |
| Hazardous Waste        | yes  | mostly no  |
| Reactive               | no   | yes  |



materials, because the consequences of poor hygiene practices are so noticeable.

Solvent systems often do not have such immediate warning properties, even though the consequences of poor industrial hygiene practice can be severe. As a result, UV/EB-curing systems may incorrectly be perceived as more hazardous than conventional technology. The following table provides some perspective on the relative hazards of solvent and UV/EB systems.

## Conclusions

In general, UV/EB-curing materials are less hazardous than solvents in the work environment.

Early inexperience with handling acrylates and poor work habits resulted in cases of occupational dermatitis. These incidents and early toxicity testing reports generated concerns and some misconceptions about the safety of UV/EB-curing technology. Severely irritating products have been eliminated from commercial use and new, less irritating materials are available for formulating UV/EB-curing systems.

Subsequent testing has shown that earlier concerns about acrylate toxicity were overstated. UV/EB-curing materials have low systemic toxicity and acrylates as a class have been shown not to be carcinogenic via dermal and oral exposure.

Good industrial hygiene practices, knowledge of safe handling procedures and worker training are essential for safe handling of any chemical. When these principles are followed, experience has shown that UV/EB-curing technology can be handled safely in widely varying industrial applications.

RadTech<sup>11</sup> has available a number of publications covering safe use and disposal of UV- and EB-curing materials and equipment, including:

- Health And Safety Guide (English, French and Spanish versions)
- Advantages of UV/EB for a Safe Work Environment (includes a more detailed review of toxicology and exposure routes)
- UV and EB Equipment Safety Topics, RadTech Equipment Safety Task Force (includes more information on UV Workplace Exposure Meters, Personal Protective Equipment (PPE) and Safety Glasses, Light Shield (Enclosure) Design, Mercury, Spills and Cleanup, Bulb Disposal, RF (Microwave) Considerations, Nitrogen and Hazardous Environments, X-rays, Ozone Hazard and Ozone Exposure Regulations or Guidelines (ACGIH), Exhaust Ventilation Design, Heat, High Voltage, Electrical Equipment Labeling, Interlocks and Equipment Certification)
- Ultraviolet Curing Lamp Safety And Handling (includes more details on applicable regulations)
- Guidance On Cleanup and Disposal of UV/EB Curing Waste Materials (includes more information on applicable procedures and regulations)

- Regulatory Impact Reviews (includes information on the Clean Air Act, Food Packaging regulations, California South Coast Air Quality Management District developments and more)

RadTech Europe also has published guidelines for UV and EB safety and handling.<sup>12</sup>

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