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HAZARDS FROM USE OF RESINOUS BINDERS

By HERBERT J. WEBER
Director, Safety, Hygiene and Air Pollution Control, American Foundrymen's Society, Des Plaines, Ill.

The various resinous binders used in foundry processes can be used with complete safety if the necessary precautions are followed. Therefore it is well to consider here the nature and characteristics of these materials if a regimen of good safety and hygiene practices is to be adopted.

Shell process resins are two stage, whereas baked resin core binders are single stage. The two-stage resin is formed by reaction with formaldehyde and an excess of phenol in the presence of an acid catalyst. The product, novolak, is thermoplastic and needs an added catalyst, usually hexamethylenetetramine, to make it thermoset.

A single stage resin is formed by reaction with phenol and an excess of formaldehyde in the presence of an alkaline catalyst. The product is thermosetting without the need for an additional catalyst.

Shell Process Hot-Coating Resins

Shell process hot-coating resins are:

1. Lump novolak, consisting of: phenol-formaldehyde polymer, free phenol, formaldehyde (trace), hexamethylenetetramine,[1] and release agents.[1, 2]

2. Water-borne resins consisting of: phenol-formaldehyde polymer, free phenol, formaldehyde (trace), ethyl alcohol (four to nine per cent), water (five to 25 per cent), hexamethylenetetramine,[1] and release agents.[1, 2]

Shell Process Cold-Coating Resins

Shell process cold-coating resins are:

1. Dry powder containing: ground lump novolak, hexamethylenetetramine, metallic stearates,[1] denatured alcohol, and water.[1]

2. Varnish (alcoholic solution) containing: dissolved lump novolak, denatured alcohol (25-35 per cent), hexamethylenetetramine,[1] and release agents.[1, 2]

1. Material added during coating process.
2. Release agents include metallic stearates, high melting point waxes, or silicone polymer.

Dry-Blend Shell Process

The dry-blend process consists of mixing the sand grains with the dry powder previously described under cold-coating resins.

Baked Resin Core Binders. The materials used in baked resin core binders are:

1. Liquid phenolics (single stage): low molecular weight phenol formaldehyde polymer; free formaldehyde (three-five per cent); phenol (trace); water, and alkaline catalyst residue.

2. Powdered phenolics (single stage): higher molecular weight phenol formaldehyde polymer; free formaldehyde; phenol; alkaline catalyst residue.

3. Liquid urea: free formaldehyde; urea (trace); water; and catalyst residue (inert).

4. Powdered urea: higher molecular weight urea formaldehyde polymer; free formaldehyde; and free urea.

5. Furfurylated urea formaldehyde resins: furfurylated urea formaldehyde polymer; free furfuryl alcohol; free formaldehyde; urea (trace); water; and catalyst residue.

Hot Box Resins (Wet Resin Sand)

Hot box resins are:

1. Urea formaldehyde resins containing: furfurylated urea formaldehyde polymers; catalysts such as salts (range: neutral to very acid); inorganic acids; and organic acids.

2. Modified phenol formaldehyde resins: phenol-formaldehyde polymer; urea formaldehyde polymer; free phenol; free formaldehyde; free urea; and catalyst (salts).

Self Curing Resin-Binder Systems

Self curing resin-binder systems are:

1. Furan binder containing: furfuryl alcohol formaldehyde polymer; free furfuryl alcohol; free formaldehyde; catalysts residues (inert); and strong acid catalysts.

2. Modified furan binder containing: same as furan binder; urea formaldehyde furfuryl alcohol polymers.

Toxicity

Almost all of the materials and their decomposition products used in these processes are toxic, but organic impairment of the body is not likely to occur in the normal operation. The principal effect on man is dermatitis, and even dermatitis does not occur from completely polymerized resins but rather from the excess of free phenol, free formaldehyde, hexamethylenetetramine or alcohol.

Formaldehyde has an irritating effect on the eyes, mucous membranes, and skin. It has a pungent and suffocating odor so that a toxic atmosphere is intolerable to man. However, numerous cases of dermatitis have been reported among workers handling it. The maximal allowable concentration in air (MAC) is five parts per million. The MAC for formaldehyde is not a level which if exceeded would result in poisoning; rather, it is a level which if exceeded will result in a nuisance and unpleasant environment.

Phenol is a well known poison and is not only a skin irritant but is a local anesthetic as well, so that burns may not be felt until serious damage has been done. It can be absorbed through the unbroken skin and appear in the urine, to which it imparts a smoky color. Therefore, besides being capable of causing dermatitis, it can do organic damage to the body. The maximal allowable concentration in air is five parts per million.

Hexamethylenetetramine is not known to cause organic poisoning. It is, however, a primary skin irritant, which can cause dermatitis by direct action on the skin at the site of contact if permitted to act in sufficient concentration and for a long enough time.

Furfuryl Alcohol. There have been no reports from industry of health hazards associated with the use of furfuryl alcohol. Daily doses of one gram to dogs were without effect, and a dose of 150 milligrams administered orally to man caused no disturbance. However, as with other alcohols it will de-fat the skin and, therefore, contact with it should be avoided as much as possible. It reacts with mineral acids (even dilute) and some strong organic acids with explosive violence. Therefore, great care should be taken to avoid accidental mixing with such acids.

Ethyl Alcohol is practically non-toxic and relatively non-irritating to the skin. However, continuous daily contact with it will produce cracking of the skin. Its vapors are highly irritant to the eyes. The MAC is 1,000 parts per million.

Methyl Alcohol is sometimes used instead of ethyle alcohol. The former is poisonous. Systemic poisoning can occur from absorption through the unbroken skin or from prolonged inhalation. It has a particular effect on the optic nerve. The oxidation and removal of methyl alcohol from the body requires a greater period of time than for ethyl alcohol. Consequently, there is not only a prolonged effect following a single overexposure to methyl alcohol vapor, but also a tendency for it to accumulate in the body.

The systemic effects are due to the conversion of methyl alcohol to the more toxic products of oxidation, formaldehyde and formic acid. It should be noted that methyl alcohol can generate vapor concentrations in air greater than twice those of ethyl alcohol. Because of this difference in their rates of evaporation, any given vapor concentration of methyl alcohol will be generated more quickly than the same vapor concentration of ethyl alcohol.

Hence, because of its toxic nature and greater volatility, methyl alcohol is much more hazardous than ethyl alcohol and, therefore, much more effective, and extensive ventilation is required for methyl alcohol. It is also insidiously toxic, because of its virtual lack of warning properties as contrasted with those of ethyl alcohol. Therefore, in the case of methyl alcohol, ventilation sufficient to maintain vapor concentrations below 200 parts per million (the maximal allowable concentration) is required; whereas in the case of ethyl, ventilation sufficient to eliminate a fire hazard is all that is necessary. This will be described later. Obviously, any horseplay with poisonous materials should not be tolerated.

Urea decomposes to carbon dioxide and ammonia. Ammonia has adequate warning properties and is intolerable in toxic concentrations.

Silicones. The nonhydrolyzable types of silicones used as mold release agents are of a low order of toxicity. From a practical standpoint their hazards are minor. The hydrolyzable types, however, are highly corrosive and can cause severe burns, but they do not possess the physical properties required for shell operations and, therefore, are not likely to be used in the foundry.

Carbon Monoxide is given off during pouring operations. The MAC for an eight hour exposure is 50 parts per million. The atmospheric concentration of toxic dusts can be averaged for an eight hour day to arrive at the MAC. Thus, peak concentrations far in excess of the MAC can be cancelled out by those concentrations which are far below the MAC and no deleterious effects will result.

This is not true for carbon monoxide. For example, an exposure to carbon monoxide of 400 parts per million for one hour is the maximum tolerable without noticeable effects even if the exposure for the rest of the day is zero. Tubich, et al.* found peak breathing zone concentrations of 600-700 parts per million during pouring of shell molds. The lethal effects of even short exposure to high concentrations of carbon monoxide are well known.

Smoke is an atmospheric contaminant resulting from incomplete combustion, and consisting predominantly of small gas borne particles of carbonaceous material. It is given off during baking and pouring of shell molds. Smoke, per se, from shell molds or cores is innocuous, and only in heavy concentrations is it a nuisance.

Silica Dust from shell operations has the same effect on the lungs as that from any other foundry operation and is, therefore, capable of producing silicosis under certain conditions. However, in order to produce silicosis there must be sufficient exposure, in terms of time and concentration, to free crystalline silica dust of particle size below five microns. It usually requires two to 20 years (average 10), and then only when dust concentrations greatly exceed the maximal allowable, to produce a case of silicosis.

The maximal allowable concentrations of silica-bearing dust are determined by the following formula:

$$\frac{250}{\%\ S_iO_2 + 5} = MAC$$

It may be stated that the silicosis risk from the shell process is no different than the risk in conventional foundry operations.

*A.M.A. *Archives of Industrial Health*, vol. 21 p. 424 (May 1960).

Prevention and Precautions of Dermatitis

Predisposing Causes

These are the principal factors concerned with predisposition to dermatitis:

1. Nature of the skin. Persons with red hair or fair skin are more susceptible than those with dark complexions. Oily skins withstand solvents better than dry skins. Hairy skins are more apt to develop oil folliculitis than dry skins.
2. Age. Young workers are usually more susceptible than older workers.
3. Sex. There are less cases of dermatitis among women, probably because of cleaner habits and because they ask for treatment for the slightest skin irritation.
4. Season of the year. Dermatitis is more prevalent in warm weather than in cold.
5. Perspiration. One who perspires excessively is more susceptible to dermatitis than one who does not.
6. Skin diseases. Workers with open skin lesions are more likely to be affected.
7. Allergy. Despite all precautions, dermatitis will occur in those persons allergic to resin bonded sand.
8. Uncleanliness. This is probably the most important factor in predisposing to dermatitis.

Prevention

An unusually extensive dermatitis under conditions of proper cleanliness, subsiding on removal from exposure, and flaring up after return to use of resin, indicates that the person involved has become allergic. Further work with this material by this person is not recommended. The wearing of rubber or latex gloves over a pair of throw-away cotton gloves has been found to give effective protection.

Protective hand creams are of some benefit, especially when used as an adjunct to other personal protective equipment. Adequate facilities for washing, showering, and changing work clothing should be provided. A simple safety rule would be: "Avoid contact as much as possible by any feasible means and observe strict personal cleanliness."

Treatment

Treatment of dermatitis should be given by a physician, or a nurse acting under his orders. Treatment by nonmedical personnel should not be permitted.

Foundry Control

Carbon Monoxide. In general, local exhaust systems generally used in mechanized pouring lines will be adequate for controlling carbon monoxide during the pour off.

Silica Dust. Silica dust from shell operations usually occurs in significant quantities during shake out and dry mixing. However, because of the excellent casting peel from the shell and absence of burn-in, silica dust exposures in the cleaning room are far less than in other types of casting cleaning. Methods for control of foundry dusts are adequately described in the AFS *Engineering Manual for Control of In-Plant Environment in Foundries.*

Acids and Acid Salts. Acid and acid salts should be handled in such a way as to avoid spattering or contact with the body. Depending on the type of exposure for operations involving the use of these materials, consideration should be given to the need for corrosion resistant devices such as hoods, face shields, sleeves, boots, aprons, leggings, spats, and protective creams.

Alcohols. The alcohols are highly flammable, and should never be used near open flames or other sources of ignition. Containers should be periodically inspected for leaks. Clothing accidentally saturated with alcohol should be immediately removed and dried out. In one plant, a man was burned to death when he approached an open flame with alcohol saturated clothing.

Explosion Hazards. Blending the resins, sand and alcohol in a muller is dangerous unless the vapors rising from the muller are properly diluted with air. A safe dilution is three cfm/lb of sand capacity. This exhaust volume prevents escape of dust and vapor, and keeps the atmosphere inside the mixer below 25 per cent of the LEL (Lower Explosive Limit) for air-ethyl alcohol mixtures. These exhaust volumes are confirmed by using this standard dilution formula.

$$Q_{LEL} = \frac{388 \times 100 - (\%\ of\ LEL)}{Mol.\ Wt.\ of\ Liquid}$$

Where

Q_{LEL} = Dilution air required per lb. ethyl alcohol evaporated.

388 = cu. ft. vapor occupied by mol. wt. in lb. of any vapor.

LEL = 4.3% for ethyl alcohol (ethanol).

Mol. Wt. = 46 for ethanol.

Substituting:

$$\frac{388 \times 100 - (25\% \times 4.3)}{46} = 843\ cu.\ ft.$$

A 1,000 lb sand batch in which three pounds ethanol are added and evaporated in 10 min.:

Air required for safety:

$$3\ lb.\ ethanol \times \frac{843\ cu.\ ft.}{lb.} = 2523\ cu.\ ft.$$

Air actually supplied:

$$10\ min. \times 1{,}000\ lb.\ sand \times \frac{3\ cu.\ ft.}{lb.\ sand}\ or$$

$$30{,}000\ cu.\ ft./lb.$$

As far as explosion hazard is concerned, this is enough air even for an open type mixer. It is also enough from a toxicity standpoint, as shown by the formula, for the maximal allowable concentration (MAC) of ethanol is 1,000 parts per million:

$$Q_{MAC} = \frac{388 \times 1{,}000{,}000 \times K}{Mol.\ Wt.\ Liquid \times MAC}$$

Where

Q_{MAC} = cu. ft. dilution air required per lb. ethanol.

K = An experience factor varying from 3 to 10.

Substitution (using lowest K factor):

$$Q_{MAC} = \frac{388 \times 1{,}000{,}000 \times 3}{46 \times 1{,}000} = 25{,}300\ cu.\ ft./lb.$$

Assume, as before, three pounds ethanol are evaporated in 10 minutes.

Then:

$$\frac{3\ lb.\ ethanol}{10\ min.} \times \frac{25{,}300\ cu.\ ft.}{lb.} =$$

$$7{,}590\ cfm\ required$$

Air actually supplied:

$$\frac{3\ lb.\ ethanol}{10\ min.} \times \frac{30{,}000\ cu.\ ft.}{lb.} = 9{,}000\ cfm$$

Sometimes methyl alcohol (methanol) is used instead of ethanol. In such event, 9,000 cfm would be sufficient to prevent explosion, but approximately five times more would be required from a toxicity standpoint. In either case the amount of dilution air is large, so that the use of a closed top muller exhausted to 25 per cent of the lower explosive limit is indicated.

Resin dust is explosive also, as are other finely divided organic or metallic dusts such as hexa, magnesium, and the like. In one case, maintenance men working overhead disturbed a three-year accumulation of resin-sand dust on the rafters. The dust cloud was ignited by the gas flame in the shell curing ovens, causing an explosion. The practice of blowing down dust with compressed air may create explosive dust clouds. Settled dust should be removed by wet or vacuum methods.

General

The irritating atmospheric contaminants such as phenol, formaldehyde, ammonia and the like, arising from shell operations are a nuisance. The amount and type of exhaust ventilation required for good working conditions will depend on the local situation. Experience to date shows that hazards involved in making castings in shell are no more serious than those related to other foundry methods.

SAFE USE OF ISOTOPES IN FABRICATION AND ERECTION

By KARL A. KRASIN
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In practically every phase of life we accept risks in return for certain gains. It is often said that the risk in dealing with radiation is particularly serious because radiation cannot be seen, felt, or heard by any of our normal senses.

This is, perhaps, not a valid statement in comparison with other risks. It may be said that the risk inherent in driving a motorcar is controllable because the driver is at the wheel. But a head-on collison caused by someone driving on the wrong side of the road presents a completely uncontrollable risk situation on the part of innocent victims. Apparently, we willingly accept 50,000 traffic deaths per year plus 200,000 crippling accidents for the practical benefits derived from the use of motorcars. We do not abandon cars because of accidents or prohibit bathing because some people drown. The solution is to teach everyone to swim and promote good driving.

As far as radiation is concerned, on the one hand there is no doubt that exposure to certain amounts of it is detrimental to health. It can cause temporary or permanent damage to the human body and it can be lethal. On the other hand, once we know what its dangers are and how to protect ourselves and others against them, there is much less need to fear it than many other risks we constantly encounter.

You can learn to take the necessary precautions and understand what you are doing without going too far into the details of radiation physics and mathematics. However, some basic knowledge of the nature and behavior of radiation as well as the properties of protective materials, shielding, and operating procedures for radioisotope equipment is essential.

Broadly speaking, the term "radiation" means any emission of energy from a point of origin. Heat from the sun, light from a lamp, and radio waves from a transmitter are all forms of radiation in this general sense. It is only when the radiation is capable of penetrating matter and causing ionization along its path that it is called "ionizing radiation."

Normally, the number of negatively charged electrons in the outer structure of an atom of matter exactly balances the number of positively charged protons in its nucleus. In ionization, sufficient energy is imparted to an atom to upset this electrical equilibrium. The atom loses an electron from its outer "shell" and becomes a positive ion. The displaced electron often transfers to a neighboring atom, making it a negative ion. Thus each ionization event usually results in the formation of an opposite pair of ions.

Ionization leaves the affected atoms in an excited state. Chemical and/or physical

changes may then take place as equilibrium is regained. For example, there may be a regrouping of some of the atoms into altered molecular combinations. These changes that take place produce several different forms of ionizing radiation, such as x-rays, gamma rays, alpha and beta particles, and neutrons. For the purpose of this discussion we will concentrate mainly on gamma radiation, which is produced by Cobalt 60 and Iridium 192.

Cobalt 60 has the energy level of approximately a million volt x-ray machine, a half-life of 5¼ years, and one curie will produce 14.5 roentgens per hour at a distance of one foot.

Iridium 192 has the energy level of approximately a 400 kilovolt x-ray machine, a half-life of 75 days, and one curie will produce 5.9 roentgens per hour at a distance of one foot.

Half-life is defined as the length of time that it takes a radioactive material to lose one-half of its original intensity.

A roentgen is the term used for expressing radiation intensity. A milliroentgen has a value of 1/1000 roentgen. When used with cobalt and iridium it is also used to express the dosage received by the human body.

Ionizing radiation is a natural phenemenon as well as something that is produced artificially. Man has always lived in its presence. Our natural radiation background results from the following factors:

Cosmic radiation @ sea level	50 mrem/year
Cosmic radiation @ 7.5 miles	500 mrem/year
Radionuclides in earth's crust	50 mrem/year
Frame house	50 mrads/year
Granite house	300 mrads/year
Watches	8 mrem/year
Internal body burden	30 mrem/year
	188 mrem/year
Chest x-rays	.5 to 5rem/exposure
Dental x-rays	.3 to 3rem/exposure
Routine Gastro-Intestinal x-ray	1r/exposure
Average/year	28-300 mrem/year
Shoe fitting machines	7,000-14,000 mrem/20 sec exposure
TV	.5 mrem/hr @ 2 inches from receiver

There are other isotopes in use, such as Cesium 137 and Thulium 170, however the major portion of industrial work use cobalt and iridium.

The variables which influence the affect that radiation has on an individual are: the amount of the body exposed; the part of the body exposed; the time span over which the dose is administered; the age of the individual exposed; and the biological difference among individuals. For instance, the allowable dosage for the area of the body exposed varies as follows:

Whole body, lens of the eye, gonads, blood forming areas	1¼ Rem/Qtr
Hands & forearms, feet & ankle	18¾ Rem/Qrt
Skin of the whole body	7½ Rem/Qtr

The Atomic Energy Commission standard operating limit is based on whole body exposure of no more than 1¼ rems/qtr year. In addition, the AEC limits the total exposure received at work at no more than 5R times the number of years since the person was 18 years old (i.e., MPD=5 (n-18) where n is the age of the individual). No one under 18 years of age is to be employed in radiography work. Thus, for a 35 year old man the permissible accumulative exposure would be 5(35-18) or 85 Rem. For a 40 year old man the mpd would be 5(40-18) or 110R, etc. The maximum permissible dose can be used in excess of five rem/year up to 12 rem/year until the man has used up his accumulated permissible dose, then he must drop back to the limit of five rem/year.

The cells of the body that are most sensitive to radiation are: white blood cells; immature red blood cells; cells lining the gastro-intestinal canal; cells of the reproductive organs; skin cells; cells of the blood vessels; and cells of the tissue, bone, muscle and nerves.

Persons exposed to radiation cannot spread radiation damage to others. The only hazard can be caused by contamination; that is, by dust or loose particles, or breathing, swallowing, or breaks in the skin.

Overexposure to radiation can cause physical damage such as: injuries to superficial skin tissues in the form of burns and ulcerating non-healing wounds; malignant tumors; general effects on the body, particularly on the blood and blood-forming organs in the form of anemia and leukemia; other effects such as loss of hair, cataracts, impaired fertility, and reduction of life span. Overexposure can also cause genetic or hereditary effects on offspring which may

not show for several generations. Some damage will be temporary and some will be permanent, and as already mentioned, a large enough dose will be lethal.

The hazard is increased as more of the body is included in radiation exposure. It is greatest when a large part or the whole body is irradiated. If a finger or hand receives 400-500 r of x- or gamma radiation in one day, it will certainly result in local reaction but in very little systemic reaction. But if the whole body is exposed to such a dose, the results would be fatal. Since in many cases it is difficult to determine the width of the radiation beam or the amount of scatter generated, it should always be assumed that exposure to radiation is a "whole body" exposure.

The tables below show some of the effects that can be expected for various radiation doses.

Symptoms of Exposure to Whole-Body Penetrating Radiation

Exposure (REM)	*Probable Biological Effects*
0–25	No significant effect nor delayed reaction.
25–100	Exposed individual may have headache, dizziness, odd taste in mouth, or smell in nostrils. May have slight blood change. Usually able to return to work without any delayed effects.
100–200	Results in nausea, fatigue, vomiting. Delayed effects may shorten life expectancy as much as one per cent.
200–300	Results in nausea, vomiting in first 24 hours. Two weeks later, loss of hair, loss of appetite, general weakness and fever, sore throat. Recovery in about three months.
300–600	Nausea, vomiting and diarrhea within hours of exposure. (400 REM is fatal to 50 per cent.)
600 or more	Symptoms as above, followed by possible eventual death of all individuals exposed.

When you study medical and industrial regulations, you may well ask why more emphasis is placed on safety precautions in the handling of radioisotopes in industry than there appears to be for the use of x-ray equipment.

Industrial applications in general present somewhat greater hazards than medical applications for the following reasons:

1. Workloads can be very much higher; automatic installations often operate continuously.

2. Industrial workers are usually not familiar with the biological effects of radiation and they are, therefore, less likely to be safety conscious in this respect.

3. There are greater differences in technic, since the radiographic objects may vary from a small component to a huge tank or casting.

4. Medical radiography is largely confined to specially designed rooms with radiographers shielded from radiation by a control cubicle. In industry, on the other hand, the radiation source is often taken to the "vessel" in open areas without any fixed shielding to protect the operator or other personnel.

Secondly, there are additional hazards in radiography with radioisotopes: a radioisotope is radiating all the time, while an x-ray unit gives off radiation for a predetermined exposure time only. X-ray apparatus "fails safe"; radioisotope source containers generally do not.

On the other hand, the advantages of gamma ray projectors, such as portability, reliability, and ease of operation, and independence of power and water supply should always be considered. They outweigh by far the slight extra risks that may be involved by using properly trained personnel.

It's obvious that the primary beam of either an x-ray or an isotope unit will be of higher intensity and hence more dangerous than scatter or background radiation. However, since scatter radiation is far more difficult to measure, it can present a more difficult shielding or protection problem. By definition, scatter radiation is radiation of varying intensity which bounces off the weldment, walls, or other objects in a random manner. Scatter radiation can reach places where direct radiation does not—behind the thick wall, for example. The problem of scatter radiation is complex and can be calculated only with difficulty under the various conditions encountered in radiography. Even though scatter radiation may be

of much lower intensity than the primary beam, its effect can be just as hazardous over a long period of time and should be accurately measured with a calibrated survey meter in good working order.

Exposure to radiation can be limited in three ways: time; distance; and shielding. If you work near radiation, the simplest way to limit your exposure is to stay in the vicinity as short a time as possible. If there's a time limit on your job, observe it.

A second method is to maintain a safe distance between you and the source of radiation. What distance is safe? In general, the effect of radiation falls off sharply as you increase your distance from the source. Double the distance and your exposure is cut to one quarter. As an example of the inverse square law, take an x-ray beam directed against a steel tank. At a distance of four feet, the radiation intensity will be 1/16th what it is at the focus point of the beam on the tank. At eight feet, the intensity will be ¼ what it was at four feet, or 1/64 that at the focus point. If the radiation at the eight-foot distance is less than the maximum permissible exposure as established by local, state, or federal regulations, then any other point eight feet away from the source of the radiation should be a safe area.

The third method is shielding by placing some material between the source of radiation and area to be controlled. The amount of radiation that can get through any material depends upon the nature of the material and its atomic structure, and its thickness.

The absorption of radiation in or transmission by the ionizing radiation is exponential in character, and this value can conveniently be expressed by means of a term called "half-value" layer, or half-value thickness. The half-value layer is the thickness of material required to reduce the radiation intensity to one-half its original intensity. Thus, it can be shown that if you place .49 inches of lead into a radiation beam from a cobalt 60 source, only half the radiation will get through. The radiation from an iridium 192 beam will be reduced to half its intensity by .19 inches of lead. Similarly, the thickness of material which will reduce the intensity of the radiation to one-tenth is called the tenth value layer.

Every method of effectively combatting radiation depends on first being able to measure the level that must be protected against. This leads to a need for surveillance and constant monitoring of potentially hazardous environments. The following rules are suggested for individuals engaged in either radioisotopic or x-ray inspection of weldments:

1. Respect radiation as one would an electric fence—keep as far away as possible.
2. Exposure times should be known and carefully controlled.
3. All employees entering radiation areas should have a film badge, a pocket dosimeter, and a survey meter to assess radiation levels.
4. Establish safety measures—and rigidly enforce them.

How are radiation hazards legislated? Since 1954, the Atomic Energy Commission has been granting licenses to industry for the use of nuclear materials. Since those forms of nuclear energy which are under AEC license are only part of the radioactive sources which can be harmful, many states have passed legislation controlling radiation from x-rays, accelerators, radium, etc. Almost half of the states require the registration of radiation sources. Seven states have comprehensive radiation protection codes.

The Atomic Energy Commission recommends the creation of a "supervised" area for all radiography or NDT inspection projects involving x-ray or isotopic equipment. This supervised zone is an area within which the exposure that one can receive exceeds 0.5 rem per year, which is one-tenth the total permissible exposure for operators. The zone should be marked off by walls, shielding, or obstacles, or by signs placed three feet above floor level — DANGER — RADIATION — every 15 feet.

At the time of the first exposure, the zone should be calculated and then completely checked out. It can be done as follows: calculate the restricted 2mr/hr limit, and locate the ropes, signs, and flashing lights. Then during the exposure an assistant is posted at the radiation equipment to cut off the current or withdraw the isotopic source on signal, while a complete survey is made of the periphery of the radiation zone with an appropriate radiation survey meter.

Any point on the edge of the zone should not indicate a radiation exposure of more

than two mr in any one hour, or if the individual's continuous presence in the area could result in his receiving a dose in excess of 100mr in any consecutive days.

In the case of the intermittent use of the radiation-producing equipment, such as on-and-off radiography of welds, calculations should be made as to the percentage of time radiation is being produced. Thus, if the equipment is in use 50 per cent of the time, the exposure permissible could be doubled, etc. For maximum protection, it would be a good idea to check the limits of the radiation zone daily at the time of the first exposure.

Currently, federal licenses are required for the use of one to 250 microcuries of radioactive isotopes—the number of microcuries depending upon the specific isotope. Below these individuals level, no license is required.

There are 22 so-called "agreement" states which have licensing agreements with the AEC and which provide control over radiation-producing sources within their state: Alabama, Arizona, Arkansas, California, Colorado, Florida, Georgia, Idaho, Kansas, Kentucky, Louisiana, Mississippi, Nebraska, New Hampshire, New York, North Carolina, North Dakota, Oregon, South Carolina, Tennessee, Texas, and Washington.

A typical section of an agreement state's regulations for control of radiation includes a specific reference on radiation survey instruments: "The licensee or registrant shall maintain sufficient calibrated and operable radiation survey instruments to make physical radiation surveys as required. Each radiation survey instrument shall be calibrated at intervals not to exceed three (3) months and after each instrument servicing, and a record maintained of dates of calibrations. Instrumentation required by this section shall have a range such that two milliroentgens per hour through one roentgen per hour can be measured." Recalibration of the survey instruments is relatively simple and is most often performed by field service representatives of the instrument's manufacturer. Some instruments are sent to the National Bureau of Standards.

Although there are a variety of scanning and monitoring devices which can be easily used by the person who works with radiation, it's recommended that a trained health physicist be used if necessary to insure the use of suitable instruments in the proper way, to interpret the readings obtained, and to make necessary recommendations for reducing hazards.

The main reason it takes a somewhat skilled person to accurately measure radiation is that radiation hazards arise from a wide variety of sources and the monitoring methods must vary accordingly. This is particularly true in situations involving a mixture of two or more types of radiation.

Organizations or individuals who utilize radioisotopes must comply with AEC regulations Title 10 Part 34, which requires the use of a radiation survey meter capable of reading 2mr/hr. to 1 r/hr.; a pocket dosimeter or pocket chamber (0-200mr); a film badge; and a Geiger counter instrument capable of measuring 0.005 microcuries of removable contamination from the source container. All industries, whether in an agreement state or not, are controlled by these regulations. Other radiation sources are not controlled by individual state regulations. The above listed instrumentation is also appropriate as basic survey protection equipment for most other radiation-producing equipment, x-ray units, electron beam welders, etc.

Over the past 40 years, manufacturers of surveying and measuring equipment have introduced many devices designed to better protect the worker who must be near radiation. These devices include the pocket dosimeter, the "beeper" or "chipper" worn on belt or in the pocket, the Geiger counter (the Geiger-Mueller tube), the ion chamber, and scintillation counters. Usually it takes a combination of these instruments to effectively warn of the dangerous levels of radiation. Basically, this is true because radiation consists of different energies of rays or particles and many different intensity levels —not all measurable with one instrument.

The design theory behind all radiation exposure measuring devices is that the detector should respond to radiation in the same manner as human tissue would—where the main effects of radiation occur.

Modern radiographic source-manipulating devices or "projectors" are so designed that it is no longer necessary to handle unshielded radioactive sources directly. When not in use, the source is normally contained in an adequately shielded storage safe or storage

container and is moved out of its safe by means of remote control for radiographic exposures. In one design of a safe remote handling arrangement, the radioactive source itself is sealed in a stainless steel capsule securely fastened to the end of a steel cable. By means of a remote control, the cable propels the source from the safe to the end or snout of a source guide tube which has been positioned for radiography on a tripod stand or other holder. At the end of each exposure, the cable, cranked in the opposite direction, pulls the source back into the safe. Signal lights or an odometer indicate whether the source is in the safe, in the snout, or in between. In some models the indicating light system can be used to operate additional audible and visual warning systems or other safety devices such as door locks. The AEC regulations require that source holders be equipped with a lock to prevent operation or tampering by unauthorized personnel.

The guide tube can be connected to a beam-shaping device or collimator so that the radiation beam may be confined to the shape of a cone by means of a lead shield as opposed to an unshielded or free source which emits radiation in all directions. A collimator permits the use of the beam for radiography while reducing the protection required in other directions. The collimator may be mounted on a portable adjustable stand so that it can be positioned for radiography.

By means of interchanging lead shields in the collimator, a variety of beam angles and shapes can be obtained. Confining the radiation beam to the necessary minimum not only blocks the unwanted primary radiation but also greatly reduces scattered radiation from surrounding walls, floors, and possibly other objects. This reduces the radiation area or shielding material required and therefore helps to minimize work interruptions for plant employees not directly concerned with the radiographic procedure. Since collimated beams also reduce the amount of scattered radiation reaching the film, they will increase radiographic quality by increasing contrast and, therefore, increase visibility of detail.

In some cases, the source is shielded by the object to be radiographed such as a pressure vessel or tube radiographed from the inside out, but where this is not the case, collimators should be used as much as possible.

Control cable operated units also greatly facilitate the safe replacing of spent sources by means of connecting the source guide tube to a source changer. A source changer is a shielded storage container into which a spent source can be deposited and from which a new source can be extracted in very much the same way a radiographic exposure is made.

The radiographic set-up and positioning of the source should be completed before the source is moved from the storage container at the end of each exposure. Even though indicators and warning lights may show that the source is in the "safe" or "stored" position, the best way to make absolutely sure of this is to use a radiation survey meter. Since there is always some slight leakage from loaded storage containers, the source must be in the container when the highest radiation intensity is at the container.

In operating gamma radiation projectors, care must be used in directing the beam away from areas where other people are working. The area around the source should be surveyed with a radiation meter for primary, scattered and transmitted radiation and the area should be posted with radiation signs in accordance with current AEC or other applicable regulations.

Radiographic rooms or areas must be provided where radiography may be safely performed. For in-plant radiography, the most suitable facility is, of course, a special room which can be permanently protected and to which access can be controlled. Wall thickness and layout of the room should be such that the radiation outside the room is reduced to levels which comply with current AEC and other applicable regulations. A radiation warning sign should be posted at the entrance to the room.

In planning a radiographic room, advantage should be taken of the section of the plant that can best be used from the radiation safety point of view. While it would be desirable to have wall thicknesses such that the radiation beam can be pointed in any direction, this may not be possible nor is it necessary in many cases. Proper planning of the location of the radiographic setup within the room will help to keep radiation levels in occupied areas outside the

room to a minimum. The center of a room may not always be the best location for a setup; better protection can sometimes be obtained by placing it in a corner of the room or next to a wall bordering an unoccupied area.

Careful attention should be given to the possibility of secondary radiation from the roof or other objects over the room or site, which may reach individuals outside the radiographic area. Though the intensity of scattered radiation may not exceed a fraction of one per cent to a few per cent of that of the primary radiation, the exact amount is difficult to predetermine since it will depend upon several factors. The only reliable way to be certain that a potential hazard from scattered radiation does or does not exist is to make measurements with a radiation survey meter.

Where radiography must be performed in an open plant area, the area must be roped off and posted with warning signs or otherwise barricaded for the appropriate radiation levels in accordance with current AEC or other applicable regulations to prevent unauthorized personnel from entering the area. Sometimes a good solution is to perform radiography at night or other times when few or no other persons are around in that part of the plant. Similar measures must be taken in field applications such as the radiography of welds on pipelines, pressure tanks, refineries, and other construction projects. Considering the time required for radiation surveys, roping and posting the perimeters of radiation areas, it would seem that a permanent or even semi-permanent radiographic room is probably the more economical and most certainly the safest solution in spite of the initial expense.

Any radiographic room or site to which access is restricted should be under direct surveillance by the person in charge to make certain that unauthorized workers, bystanders, or curiosity-seekers do not enter. The radiographer in charge must be thoroughly trained in radiation safety and he is responsible for maintaining adequate precautionary measures to prevent unnecessary exposures to anyone. The site should also be equipped with a control device to cause the level of radiation to be reduced to a safe level, or sound an alarm (either visible or audible) so that the individual and the radiographer in charge are made aware of the entry.

To keep radiation levels outside the radiographic field in open areas to a minimum, good use can sometimes be made of temporary shielding material such as concrete or cement blocks or specially designed mobile shields.

A reliable and suitable radiation survey meter should always be available at each installation or site. Radiation surveys at the site for the purpose of establishing working times within the area should be a routine procedure. A survey also gives the radiographer a quick means of measuring dose rates around the site to determine where restrictive barriers should be placed.

Although the allowable radiation leakages from storage containers is low, it still is too high for anyone to be in close proximity to the container for an extended period of time. Storage containers, when not in use, must therefore be stored in locations inaccessible to unauthorized personnel. All such storage facilities, including moveable containers, must be posted with the appropriate warning signs and equipped with locks. Moreover, storage facilities must, of course, be such that no one outside the storage room could receive more than the allowable exposure.

Transportation of radioactive sources must be done in accordance with the regulations pertaining to the carrier and the method of transportation involved. Sources carried by rail or commercial motor vehicles are subject to the Interstate Commerce Commission (ICC) regulations. These regulations are enforced by the Bureau of Explosives and the Association of American Railroads. Shipment by air is controlled by Civil Air Regulations, whereas transportation by water comes under the jurisdiction of the United States Coast Guard. The United States Post Office Department has regulations covering shipment of radioactive materials by the postal services. The latest information concerning transportation of sources should be obtained from the appropriate agency for the carriers involved.

Over-exposures to radioactive materials do occur, and each such incident is investigated, when the personnel acknowledge the incident. Periodically some of the incidents are reported to holders of isotope licenses in order to alert and explain the necessity of using the proper care in following procedures when using these materials. These

reports show that in almost all cases of overexposures the radiographer did not use a survey meter, the meter was not in operable condition, or it was not used properly.

Even though the exposure device may be equipped with lights or warning devices, the only safe way to make sure the source is safely stored is to use the survey meter.

In order to determine whether your survey meter is working properly, many license holders mark a spot on the camera and check the meter at the same location each time the meter is to be used. This serves two purposes, (1) it checks the meter for accuracy and (2) proves the source is in the camera. However, in checking the accuracy of the meter the decay curve for the isotope must be taken into consideration. This operation does not substitute for having the meter calibrated every three months as required by the AEC or state license.

EXPLOSION POTENTIAL OF FINES GENERATED IN GRINDING, POLISHING, AND CUTTING OF ALUMINUM ALLOYS

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The explosion potential of aluminum powder is widely recognized, but the fact that aluminum fines produced during normal operating procedures may well have, to some degree, the same explosion possibilities is not well appreciated. Because most fabricators do not know of this problem and its inherent danger, we felt it necessary to make this presentation. We will describe for you a few of the more serious accidents that have occurred in this field over the last several decades. Following these accident descriptions, we will outline in some detail the type of dust collecting equipment that can be used in these processes and the safety precautions required in their use.

A very serious explosion of this kind occurred in the mid 1940's at Bridgeport, Connecticut. The explosion took place in the finishing room of an aluminum foundry where they were snag grinding castings. Six people were fatally injured. A small fire was observed in the grinding hood and, as an employee was going to apply G1 powder, it is believed that a spark from the fire was carried into the exhaust system, which set off a minor explosion when it reached an explosive mixture of dust and air. This first explosion triggered a second major blast that destroyed the equipment and caused the multiple deaths.

Another major explosion occurred in 1964 in the trim room of a sand foundry. It was somewhat similar to the first one described. In this instance, two men were working adjacent to each other on swing frame abrasive cut off saws. The saws were being used to trim off excess metal such as headers and risers from sand castings. There were floor level collecting hoods positioned to collect the aluminum fines from the saws and a swing frame abrasive grinder. These collector hoods were connected to a 20-inch duct which led to a cyclone-type collector bin on the roof of the building. This was a dry collection system.

The two swing frame saw operators were both experienced men. At the time of the explosion, one operator was cutting a section with a steel chill tube in it from a large crank case casting. In doing so, he cut into the steel chill tube and threw sparks into the collecting hood. These sparks set off a minor explosion which in turn, stirred up dust in the system which triggered a major explosion. This explosion blew back through the system and burned both operators so seriously that they later died. The explosion destroyed the collecting system, and blew out windows in the trim room.

The saw operators had been warned repeatedly not to cut into steel chill rods. Evidence proved that this operator had been doing so for over two minutes, when the explosion took place.

A third incident occurred just three years ago when a dust collecting unit exploded and burned two men so seriously that they had to be hospitalized. This unit was being used to collect dust from hoods enclosing four wire brush wheels used to remove oxidation from aluminum tape. This dust was composed of aluminum, aluminum oxide, and steel. The dust was conducted from the hoods into a collecting drum having a cover mounted filter and exhaust fan assembly. Air was drawn from the drum through the filter bag, into a two stage fan combination, and exhausted around the motors to the atmosphere. The drum was approximately ½ full of water with a layer of dust on top of it. This explosion was not a dust explosion. Rather, it resulted from an accumulation of hydrogen, generated by the reaction of aluminum fines and water. The motors and switches were not explosion proof.

A fourth and extremely serious explosion of aluminum fines occurred in Cleveland just a few years ago. At this comparatively small foundry, the castings were smoothed up in the finishing room, using belt grinders and wheels. Over the years, a considerable amount of aluminum fines had accumulated on the

building steel, window ledges, and on top of equipment. A serious fire broke out and all plant and office personnel were safely evacuated. Firemen moved into the building with hose equipment. The high pressure hose kicked a cloud of aluminum dust into the air and caused an explosion which in turn triggered several more explosions. These explosions destroyed the building and caused the death of five firemen. We would like to emphasize at this point that if the dust and fines can be carried to adjacent building structures by air currents, then you well may have the potential for an explosion.

Now, let us discuss how we can minimize the possibility of accidents such as we have just described. Much of the information that we will pass on is available in N.F.P.A. Code No. 65, "Dust Explosion Prevention Aluminum Processing 1970," and we should have a N.S.C. data sheet on this subject in the near future.

Machines which produce aluminum fines with explosive potential shall be provided with suitable hoods or enclosures connected to a collector with ducts that have sufficient suction to collect and transport all dust. The hoods and enclosures shall be maintained so that the fine particles will either fall or be projected into them in the direction of the air flow. Individual dust collection units shall be located as close as possible to the dust source so that the connecting duct will be short. If more than one machine is to be served by a single dust collector, the machines should be arranged close to the collector so that all connecting ducts shall be as short and straight as possible. Short, straight ducts reduce the explosion hazard and accumulations of tallow, wax, grease, or oil with metallic fines can be readily seen on inspection and removed. Ducts shall be of metal construction and fabricated with a smooth interior and with internal lap joints pointing in the direction of air travel and without unused capped side outlets or other dead end spaces in which dust could accumulate. The dust systems, collectors, and machines shall be grounded electrically in accordance with recommendations of the N.F.P.A. Code No. 77M, "Static Electricity." The system shall be installed in accordance with N.F.P.A. Code No. 91, "Blower and Exhaust Systems for Dust Stock and Vapor Removal."

Wet Type Dust Collectors. Wet type dust collectors convert dust into sludge. This sludge must be covered by a blanket of water since wet aluminum fines are highly combustible, particularly in the presence of hydrogen. Hydrogen has a very low explosive limit and requires a very low energy level to initiate an explosion. A minor hydrogen explosion could serve as a fuse or primer for a major sludge explosion.

The dust collector shall be arranged to prevent contact of dusts in the dry state with high speed moving parts. The exhaust fan for drawing the dust-laden air into the collector shall always be located on the clean air side of the collector.

Sludge shall be removed from the collector at least daily and more often if conditions warrant. Sludge shall not be allowed to accumulate to a depth of more than 2½ inches, and sludge must always be covered with water.

Wet collectors shall have positive ventilation of the sump at all times, and the scrubber exhaust fan control must be interlocked so that:

1. The exhaust fan will operate for at least three minutes to purge the system of hydrogen before the process can be started.

2. The process cannot operate unless the exhaust is operating.

3. The process cannot operate unless there is sufficient water in the scrubber.

4. The process cannot operate if there is a failure of water pressure servicing the scrubber.

5. The scrubber exhaust fan shall continue to operate for a minimum of two hours after the process is shut down.

Dry Type Dust Collectors. Air duct velocities shall not be less than 3,500 feet per minute and shall be monitored at regular intervals, to make certain they are not dropping below safe levels. Dry dust concentrations must be less than five ounces per thousand cubic feet of air. Where dry dust collection equipment is used, the collection point shall be located outside the building.

Special care shall be exercised to guarantee the internal cleanliness of dry systems at all times, to avoid accumulations of material at locations other than in the collectors themselves, and to prevent the creation of an explosive dust cloud under any circumstances. Dust shall be removed from dry collectors at least daily or more often, if conditions warrant.

Dry dust collectors and other equipment where dust explosion hazards exist should be provided with adequate explosion vents. The guide for explosion venting, N.F.P.A. Code No. 68, contains information on methods of providing adequate explosion vents.

Extreme care shall be taken to prevent the introduction of water either directly or by condensation into a dry collector system since hydrogen is generated when aluminum fines are in contact with water.

Sludge and Dust Removal and Disposal. Sludge shall be placed in non-combustible containers, preferably of not over 50 pounds capacity each, and removed from the building promptly. Dust shall be removed from the collectors at least daily, or more often if conditions warrant.

Sludge and dust disposal shall be by one of the following methods:

1. It can be mixed with a large volume of sand and discarded in a dump.

2. It can be dumped in an open pit. The pit shall be fenced or guarded from public access.

3. It can be spread over the ground in an isolated area where it will oxidize. An area of this sort shall be fenced or guarded from public access.

Equipment Selection. Electrical equipment within five feet of the dust producing source which in normal operation can be expected to produce an occasional spark shall be approved for Class II, Group E locations under Article 500 of the National Electrical N.F.P.A. Code No. 70. Examples of such equipment are pushbuttons and toggle switches. All other electrical equipment shall be enclosed in dust-resistant enclosures of NEMA 5 or NEMA 12 construction.

All motors and pulleys should be equipped with conductive drive belts and the belts should be tested at least once each six months for loss of conductivity.

Elimination of Ignition Sources. No open flames or lights, smoking, electric, or gas cutting or welding equipment shall be permitted in the section of the building where aluminum dust is produced or handled. If it becomes absolutely necessary to use cutting or welding equipment for making repairs, all machinery in the section where the work is to be done shall be shut down, the ducts cleaned, the collectors emptied and cleaned, and all accumulations of aluminum dust shall be thoroughly cleaned up and removed from the area. The area must also be free of solvents and solvent vapors. A well-administered permit system for welding and cutting is strongly recommended.

Grinding wheels should not be dressed where the hot material thrown off by the dressing tool, can ignite deposits of aluminum dust in the hood, ductwork, or around the framework of the equipment.

If it is not feasible to remove wheels to a safer location for dressing, hoods should be thoroughly cleaned or removed entirely before wheel dressing operations are started. All deposits of dust on and around the wheel should be removed before, during, and after dressing.

Housekeeping. Good housekeeping shall be practiced in the entire work area. The floors, exposed structural members, piping, conduit, and ducts shall be kept free of dust. Ductwork shall be inspected on the inside for accumulations of dust as frequently as exploratory experience dictates and cleaned thoroughly if necessary.

Cleaning shall be done with a soft brush or squeegee, non-sparking scoop, and containers. Do not use a brush with plastic bristles. Foreign objects, especially combustibles such as paper, cigarette butts, etc., shall never be introduced into a dry collector system.

Solvents shall not be stored near areas where aluminum dusts or fines may be generated. Tests by the Underwriters' Laboratories indicate that aluminum dust in contact with methyl chloride, carbon tetrachloride, or carbon tetrachloride-chloroform is capable of explosion, and the methyl chloride may form a spontaneously combustible aluminum methyl compound.

Fire Extinguishing Equipment. Only dry powder shall be used on fires in which there are aluminum fines or aluminum dust. The use of fine dry sand (preferably that screened through a 20-mesh sieve) or approved powder is an effective method of isolating incipient fires of aluminum fines. An ample supply of sand or powder should be kept in covered bins or covered receptacles. These receptacles should be placed in operating

areas where they can be easily reached at all times. A long-handled shovel shall be provided at each receptacle to afford a ready means of laying the sand or powder around the perimeter of the fire. The implements shall be made of aluminum or other nonferrous material.

Nearly all vaporizing liquid fire-fighting agents react violently with burning aluminum, and they shall not be used where aluminum dust fires may occur.

Water streams or liquid sprays of various kinds that vaporize quickly are highly dangerous; they cause dust to be thrown into the air, and the ignited particles instantly cause a violent explosion. For the same reason, any mechanical agitation or disturbance of the burning dust must be avoided. For these reasons, control of the activities of an outside fire-fighting department is important since this hazard in fighting aluminum dust fires may not be recognized.

Recommended Clothing. Outer clothing of a porous or loose weave shall not be worn since dust will easily accumulate on and even in this type of cloth. The material should be closely woven, trousers shall not have cuffs, and aprons or jackets shall not have pockets. Clothing with frayed edges should be avoided. Chemically treated clothing that will not support combustion is recommended. This type of clothing may require retreatment after a number of washings.

Further Precautions. Finally, if you believe that your manufacturing procedure is developing fines with explosion potential, you will want to make a positive determination of the degree of your hazard. We suggest that you contact the U. S. Bureau of Mines and, although they do not do this type of testing anymore, they have had a broad experience in the past. They can tell your laboratory personnel how to run such an analysis or refer you to a facility that can make the proper tests.

An important factor that must not be forgotten is that a change in the mechanics of your processes, such as speeds, fineness of the abrasive medium, lubricating material, or a change in the type of alloy being processed may well create a sufficient difference in the particle size of the fines to develop a hazard potential that did not previously exist. Any change of the type described or change that could result in fines of a smaller size being generated should precipitate immediate reanalysis of the fines.

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1972

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March 21, 2001

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Respectfully,

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