EPRI

Asbestos Disposal and Treatment Options

RP3006-02

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INTRODUCTION

Background

The Electric Power Research Institute (EPRI) has initiated research in controlling, removing, disposing of, and replacing asbestos. This report is part of the EPRI commitment to inform member utilities of the safest, most cost-effective ways to identify, manage, and eventually replace asbestos.

Utilities have used asbestos primarily for thermal and electrical insulation. It has been used for thermal insulation of pipes containing water, steam, coal, oil, and other fuel, as well as insulation of turbines, feedwater heaters, steam drums, and boilers. In addition, many gasket materials historically contained asbestos, which was well suited to the high temperatures and pressures required by industry. Asbestos also found use in electrical insulation around power cables, and asbestos-cement sheets have been used as cooling tower fill.

In addition, utilities also use asbestos-containing materials common to any company that owns buildings and vehicles, such as building siding, sprayed-on building insulation, floor and ceiling tiles, heating and ventilation gaskets, and insulation board. Table 1-1 summarizes the asbestos products and uses typically found in utility applications.

Plants built since the early 1970s typically have switched to asbestos-free materials for insulation and other products when suitable replacements are available. Calcium silicate, fiberglass, mineral wool, and refractory ceramic fibers have been used as asbestos substitutes. Utilities have had difficulty finding a suitable replacement for asbestos gasket material, however, and in many cases have had to use some asbestos-containing materials.

To address the needs of the utility industry, EPRI commissioned a report on available and emerging asbestos treatment options as part of their Noncombustion Waste Management Project (RP3006).

This report describes options for handling, treating, and disposing of asbestos and asbestos-containing material (ACM). Section 2 provides a background on hazards associated with asbestos. Section 3 addresses pertinent regulations covering asbestos and its treatment, and Section 4 discusses the widespread practice of the "managing ACM in place" and the technologies associated with this practice. Section 5 is a survey of current and emerging treatment technologies for asbestos waste, including costs and recommen-

Table 1-1
Summary Information on Asbestos Waste

Sources	Composition	Asbestos Hazards	Regulation	Waste Management	Disposal Options
Boiler Insulation	Chrysotile Amosite Crocidolite	Friable - hazardous when disturbed	NESHAP regulations concerning asbestos emissions are described in 40 CFR Part 61 Subpart M. OSHA regulations concerning occupational exposure are found in 29 CFR Part 1910.	Encasement or encapsulation and inspection until the material can be removed and replaced.	- Bagging of wet asbestos in specially labeled bags followed by disposal in an approved landfill - Solidification in concrete and disposal in an approved landfill - Vitrification - Chemical treatment
Pipe Insulation	Chrysotile Amosite Crocidolite	Friable - hazardous when disturbed			
Gasket Material	Chrysotile Amosite Crocidolite Anthophyllite	Typically coated, hazardous when cut or when binding has deteriorated			
Friction Products (brakes)	Chrysotile	Non-friable			
Sprayed-on or Troweled-on Insulation	Chrysotile Amosite Crocidolite	Friable - hazardous when disturbed			
Electrical Cable Insulation Floor Tiles	Chrysotile Crocidolite Chrysotile	Friable - hazardous when disturbed Non-friable except when drilling or cutting			
Asbestos Cement Board	Chrysotile	Non-friable except when drilling or cutting or if matrix has deteriorated			

dations for their use in utility applications, whereas Section 6 briefly discusses asbestos insulating replacement materials.

Utility Perspective

Radian Corporation contacted several utilities about their asbestos management practices. All the utilities had performed system-wide surveys and established in-place management programs for monitoring the condition of asbestos identified in their facilities. Some of the utilities had set a goal to make their facilities "asbestos-free" by a specified date.

The utilities surveyed handle small asbestos removal projects (e.g., valve replacement on an asbestos-insulated line) with in-house personnel. Larger jobs are contracted out to qualified abatement contractors.

Asbestos waste is disposed of in approved landfills. Some utilities specify which landfills the contractor can use. In these cases, before allowing asbestos waste to be shipped to the landfill, the utilities check the landfill's records and occasionally make on-site inspections to ensure reputability. The utilities believe that having this level of control reduces the possibility of future liability. Some have found that landfills in adjacent states offered lower disposal rates even when the cost of shipping was factored in.

Most utilities were not aware of asbestos treatment options such as vitrification or chemical treatment that might reduce long-term liability for the asbestos waste. One purpose of this report is to increase the general awareness of treatment options among utilities.

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ASBESTOS CHARACTERISTICS

Asbestos is a mineral consisting mainly of silica and magnesium. Asbestos minerals are divided into two groups: serpentine and amphiboles. Chrysotile, or white asbestos, is the only species of serpentine asbestos. The amphiboles include crocidolite, amosite, anthophyllite, tremolite, and actinolite; of which only crocidolite and amosite are commercially important. Chrysotile asbestos accounts for 95% of the asbestos used in commercial products.

The unique chemical and physical properties of asbestos that made it so widely used are its fire resistance, thermal insulation, high tensile strength, resistance to chemical corrosion, durability, and noise absorption. Asbestos has been used in some 3,000 different commercial products. Today most asbestos (66%) is found in asbestos-cement pipe in which asbestos fibers are used to increase structural strength of the pipe (2). Another common use is in friction products such as brakes and clutch plates for vehicles.

Asbestos has been mined in the U.S. since the early 1900s. In the early 1970s, U.S. consumption of asbestos peaked at 800,000 tons per year, but this level has since dropped by more than 70% as the health effects associated with the inhalation of asbestos fibers have become better understood (1).

The health hazard associated with asbestos comes from the inhalation of airborne asbestos fibers. Asbestos has been incorporated into both friable and nonfriable materials. A friable asbestos material as defined in the *Federal Register* is any material containing more that 1% asbestos by weight that hand pressure can crumble, pulverize, or reduce to powder when dry (3). Friable materials pose the greatest health risk because of their tendency to release respirable fibers into the air. Sprayed or troweled asbestos building insulation or pipe insulation are both examples of friable ACM, whereas floor tiles and transite board are examples of nonfriable materials.

Many asbestos-cement products such as pipe or cooling tower fill pose little or no hazard unless the matrix is destroyed by drilling, cutting, or by long-term destruction of the cement matrix. Airborne asbestos fibers can remain suspended in the air for many hours or travel great distances on a slight breeze.

Although the primary health hazard is associated with asbestos inhalation, at least one researcher has suggested that ingested asbestos fibers also may be linked to gastrointestinal cancers as well (4). The threat posed by asbestos fibers to the respiratory system is partially attributed to the system's ability to infiltrate the body's defense system. The body has several filtering mechanisms in the nose and mouth to remove large particles.

However, small particles such as asbestos fibers may elude these defenses and pass through the airways into the lung. Particles with diameters less than 3.0 to 3.5 micrometers are considered respirable.

Once particles have entered the mucous-lined airways to the lung, a second line of defense consisting of tiny hair-like structures called cilia sweep particles caught in the mucous lining back into the mouth where they are swallowed. Cigarette smoke temporarily paralyzes the cilia, allowing a greater number of inhaled fibers to pass into the lung. This may be one reason why cigarette smokers are 50 times more likely to develop lung cancer when exposed to asbestos than are non-smokers (1). Particles that reach the alveoli of the lung are attacked by macrophages, which attempt to digest them. However, macrophages cannot effectively digest mineral fibers such as asbestos; instead, they are killed by the asbestos fiber and form scar tissue on the lung.

Diseases associated with inhalation of asbestos fibers are:

- Asbestosis - This disease is the result of prolonged and relatively heavy exposure to asbestos, typical of the professional asbestos worker. It is characterized by a pulmonary fibrosis that causes progressive stiffening of the lung and impaired gas exchange. Symptoms include shortness of breath and a dry crackling sound in the lungs during inhalation. This disease resulted in the disability and death of many asbestos workers before the enforcement of occupational standards. The first case of this disease was diagnosed in 1906. About half of those that develop asbestosis also develop lung cancer.

- Carcinoma - Lung cancers caused by asbestos exposure have been known to occur 20 or more years after the exposure and are 50 times more likely to occur in a smoker than in a non-smoker exposed to the same levels.

- Mesothelioma - This is a rare cancer of the membrane lining the chest and abdomen. These cancers were first identified during the 1950s and most are associated with asbestos workers. Some incidents of the disease have also been observed in family members of asbestos workers or those living close to an asbestos mine. Some data suggest that amphiboles (amosite and crocidolite) are the major cause of mesotheliomas in asbestos workers. The latency period is typically greater than 30 years.

In industries where the asbestos is firmly bound in the product, such as in asbestos cement or in friction products, the incidence of disease has been very low. The highest disease rates have traditionally been found among asbestos textile workers and people who apply asbestos insulation, although the incidence of disease has declined since the application of strict standards for airborne asbestos.

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REGULATIONS AFFECTING ASBESTOS TREATMENT

The regulations covering asbestos waste treatment and disposal have been changing rapidly during the past few years. This section summarizes the status of applicable federal regulations, with particular emphasis on issues that affect asbestos treatment. In addition, actions taken by select states to regulate asbestos more stringently than the federal government are identified. In all cases the reader should refer to the primary sources such as the Federal Register or the Code of Federal Regulations for the most up-to-date regulations.

Federal Regulations

There are many health-related federal regulations associated with asbestos and ACM. Federal Occupational Safety and Health Administration (OSHA) regulations currently set worker exposure limits at a maximum of 0.2 fibers/cubic centimeter (cc) as an 8-hour time-weighted average (29 CFR Section 1910.1001). At the time of this report, OSHA was considering lowering this limit to 0.1 fibers/cc along with more stringent notification, training, and supervision requirements (5). In 1986, the U.S. Congress enacted the Asbestos Hazard Emergency Response Act (AHERA) which required schools to identify locations of asbestos and implement a management plan (6).

Department of Transportation regulations concerning asbestos can be found in 49 CFR Part 173 Subpart 1090. These regulations require that asbestos and asbestos-containing materials be shipped in rigid, leaktight metal or fiber drums, or in bags or other non-rigid packing that in turn are contained in fiberboard or wooden boxes. This regulation exempts asbestos that is fixed or immersed in a natural or artificial binder. Therefore, asbestos cement piping and brake shoes are not covered by this regulation.

In addition, EPA has adopted regulations under various statutory authorities that restrict the manufacturing, use, removal, treatment, and disposal of asbestos. The primary set of regulations consists of:

- The National Emission Standard for Hazardous Air Pollutants (NESHAP), 40 CFR Part 61, Subpart M--Asbestos (as amended November 20, 1990) (7) pursuant to the federal Clean Air Act; and

- The asbestos manufacturing and use ban (40 CFR Sections 763.160 - 763.179) (8) adopted in 1989 pursuant to the federal Toxic Substances Control Act (TSCA). (Note: On October 18, 1991, the U.S. Court of Appeals for the Fifth Circuit vacated this subpart and remanded it to EPA for further consideration. The EPA revised the ruling in April 1992 as a proposed rule.)

The regulations that have the greatest effect on how utilities remove, treat, and dispose of ACM are briefly reviewed below.

Asbestos NESHAP

Section 61.150 of the asbestos NESHAP (standard for waste disposal for manufacturing, fabrication, demolition, renovation, and spraying operations) requires that asbestos wastes be treated by one of the following methods:

- Treat the asbestos waste with water and seal it in leak-tight containers and label appropriately prior to disposal at waste disposal sites operated in accordance with the provisions in Section 61.154. (This method of bagging and disposing in landfills is currently the most common method of asbestos treatment and disposal by utilities);

- Process the asbestos waste into nonfriable forms and dispose of in accordance with Section 61.154; or

- Use an alternative disposal method that has received prior EPA approval.

The alternate disposal methods are not specified in the regulation, but could include treatment technologies that physically or chemically change the form of the asbestos waste. If the treatment process physically or chemically destroys the asbestos fibers, the resultant product or waste is not subject to the NESHAP regulatory requirements for disposal of asbestos as specified in Section 61.154. However, under the provisions of the regulation, any alternate treatment technologies require EPA approval as treatment facilities under Sections 61.05 through 61.15. The specific data requirements of the approval process are negotiated on a case-by-case basis between the applicant and the appropriate EPA regional office.

TSCA Manufacturing and Use Ban

On July 12, 1989, under the authority of the federal Toxic Substances Control Act (TSCA), EPA adopted, rules that prohibited the continued manufacture, importation, processing, and distribution in commerce of asbestos in most commercial products (8). These rules are found at 40 CFR Sections 763.160 - 763.179. Section 763.173 of the rules provides for an exemption process to the prohibitions in limited circumstances.

The rule, also referred to as the "Asbestos Ban and Phase Out" rule, identified by name certain types of products (e.g., roof coatings, drum brake lining, etc.) and placed these products on a manufacturing, import, processing, and distribution in commerce phase-out schedule, beginning in August 1990 and ending in August 1997. The rule also provided that any new application for asbestos not covered by the product categories specified in the rule, was prohibited, effective August 27, 1990 (for manufacturing, import, processing of the product) and August 25, 1992 (for distribution in commerce) unless EPA granted an application to exempt the product from the ban.

Exemption from the Manufacturing and Use Ban. The agency adopted detailed procedures for applying for and receiving an exemption to this ban. Basically, there were two different procedures: one applied to existing asbestos-containing products or existing uses of asbestos in products and the other covered new uses of asbestos in products or new asbestos products.

Processes that destroy asbestos fibers and produce a nonasbestos product fall under the new asbestos products category. Under this rule any process that destroys asbestos and produces a usable product would need to apply separately for an exemption to the rule. One of the main criteria of the exemption is demonstrating that the product "will not present an unreasonable risk of injury to human health (8)."

An important point to note regarding TSCA is that the need to secure an exemption does not apply to asbestos-processing technologies that render asbestos-containing materials into nonasbestos forms for disposal purposes. In other words, TSCA does not require approval of the technology or prohibit its use; that is covered only by the asbestos NESHAP. TSCA applies only if the converted asbestos material will be used to make new products.

Manufacturing and Use Ban. In 1991 the rule was challenged in court by an affected party, Corrosion Proof Fittings, in the 5th Circuit Court of Appeals. The result of the case was that the court remanded most of the rule back to the EPA, reasoning that it had overstepped its authority under the TSCA (9). However, court did allow the EPA to maintain its ban on products that were not in production as of July 12, 1989.

On April 2, 1992 the EPA published a proposed rule that lists a number of products that the EPA still feels fall under the unremanded section of the rule (10). Many insulation products were included in this proposed rule, whereas other products, notably asbestos-containing friction products, were omitted. Clarification of the rule was issued on November 5, 1993.

Since many of the products generated during asbestos abatement fall into the banned category, treatment of these wastes, even to make them into a non-asbestos product, constitutes a new use of the asbestos. Therefore, ACM treatment facilities, such as vitrification furnaces, still needed to apply for an exemption to the rule. Of the processes for destroying asbestos fibers, vitrification, was the furthest along commercially and therefore had the most to gain by obtaining an exemption to the rule.

One of the companies, Omega Phase Technologies, successfully applied for exemption to the rule. In June 1992, EPA published a proposed rule that would, if finalized, allow

Omega Phase Technologies to operate a vitrification furnace, destroy asbestos, and produce a glass-like material that could be reused.

In light of the exemption granted to Omega Phase Technologies EPA is considering a blanket exemption of all processes designed to vitrify asbestos. The blanket exemption of may appear in November 1993. This change would only affect asbestos vitrification processes. Chemical treatment and chemical/thermal treatments to destroy asbestos would still be considered a new use of asbestos and, these processes would either need to file for an exemption under the rule or convince the EPA that this treatment should be included in the general asbestos vitrification exemption.

State Regulations

A few states (including California) have classified asbestos-containing waste as a hazardous waste and require additional and often more stringent handling, manifesting, and disposal procedures than those required under the federal regulations.

In California, asbestos-containing waste is defined as a hazardous waste and must be disposed of at an approved hazardous waste disposal facility as mandated by the State Hazardous Waste Control Act. Under this act, treatment standards, which must be met before land disposal of asbestos takes place, were adopted on the basis of demonstrated available technology (BDAT). Although the Department of Health Services performed a study to establish BDAT for asbestos waste, they eventually adopted the federal NESHAP requirements for containment and wetting of the ACM to minimize release of fibers during land disposal.

Most state NESHAP and OSHA standards do not vary significantly from federal standards except in the areas of notification and disposal where some states are more stringent than the federal NESHAP requirements.

4

ASBESTOS MANAGEMENT

Managing asbestos in utilities requires an understanding of the handling and treatment of asbestos. This section discusses several approaches that have been successfully used to manage existing asbestos materials in the work place to minimize health risks. The first approach covers in-place management of asbestos. The approach consists of asbestos disposal or disposal alternatives used when utilities repair, replace or demolish equipment or buildings. The second approach is removal of the asbestos with subsequent disposal or treatment (see Section 5 for discussion of asbestos treatment and disposal). Most utilities will take a combined approach, managing the asbestos in place until its removal is either convenient or required.

EPA Guidelines

In July 1990, EPA released "A Building Owner's Guide to Operations and Maintenance Programs for Asbestos-Containing Materials" (12). The document encourages owners of buildings that contain asbestos to prepare and implement an operations and maintenance program for managing rather than removing asbestos. EPA based this recommendation on five facts:

- Fact One: Although asbestos is hazardous, the risk of asbestos-related disease depends on exposure to airborne asbestos fibers.
- Fact Two: Based on available data, the average airborne asbestos levels in buildings seem to be very low. Accordingly, the health risk to most building occupants also appears to be very low.
- Fact Three: Removal is often *not* a building owner's best course of action to reduce asbestos exposure. In fact, an improper removal can create a dangerous situation where none previously existed.
- Fact Four: EPA *only* requires asbestos removal to prevent significant public exposure to airborne asbestos fibers during building renovation or demolition
- Fact Five: EPA *does* recommend in-place management whenever ACM is discovered.

Establishing a comprehensive operations and management (O&M) program requires, among other things, a complete inventory of all asbestos-containing materials. It also requires the development of control strategies to minimize release of asbestos fibers. These include:

- Replacing damaged ACM;
- Using enclosure, encasement, and encapsulation techniques to minimize the accidental release of fibers;
- Notifying workers;
- Ensuring proper training and protection of those whose job requires handling ACM;
- Periodically surveying ACM for signs of deterioration; and
- Keeping proper records (12).

A site-specific O&M and initial training program can be established by utility employees or handled by an outside firm. Typically, an in-house individual is designated, trained, and becomes responsible for the day-to-day management of the program after it is established.

In-Place Management of Asbestos

Options for minimizing the release of asbestos fibers are enclosure, encasement, and encapsulation. Table 4-1 summarizes these options. The choice of which method to use is based on a number of criteria, including condition of the ACM, potential for accidental release of fibers, insulation substrate, and thickness of insulation. A detailed description of each method follows the table.

Asbestos in poor physical condition should be removed as soon as possible. The following management strategies apply only to ACMs that are in good condition or have only minor damage.

Enclosure

Enclosure involves isolating the ACM within a solid structure by building an airtight structure. This enclosure may be a sheetrock wall built around structural beams, new permanent ceilings to cover asbestos ceiling tiles (standard suspended ceilings are not considered airtight structures), or metal jackets around pipes. It is critical that an enclosure be airtight and permanent. (Rigid enclosures such as walls and metal jackets give the maximum protection.) Occasionally some ACM must be removed before an installation is enclosed.

Enclosure may be one of the best ways to manage asbestos piping insulation. Aluminum jackets are readily available, simple to install, and protect against minor abrasions and denting. Metal jackets, however, cannot tolerate damage from people standing or jumping on them, fastening chain slings around them, or laying scaffolding directly on top

Table 4-1
Comparison of Asbestos Management Techniques[a]

Method	Advantages	Disadvantages	Appropriate Applications	Inappropriate Applications	General Comments	Cost Estimates[b]
Removal	Eliminates asbestos source	Replacement with substitute material may be necessary	Can be used in all situations		Containment barriers needed	Surface material is $5-25/ft. Thermal Insulation is $5-20/per sq.ft.
	Eliminates need for special operations & maintenance program	Porous surfaces also may require encapsulation			Worker protection required	
		Improper removal may raise fiber levels			Wet removal required for all types of asbestos, (amosite will not absorb water or water with traditional wetting agents)	
Enclosure	Reduces exposure in area outside enclosure	Asbestos source remains and must be removed eventually	ACM is located in a small area (e.g., a column)	Damaged or deteriorating materials, causing rapid fiber release	Containment barriers needed	Varies
	Initial costs may be lower than for removal unless utilities need relocating or major changes are required.	Fiber release continues behind enclosure	Disturbance or entry into enclosure are unlikely	Water damage evident	Use of tools with HEPA-filtered vacuum attachments advisable	

Table 4-1
(Continued)

Method	Advantages	Disadvantages	Appropriate Applications	Inappropriate Applications	General Comments	Cost Estimates[b]
Enclosure (Continued)	Usually does not require replacement of material	Special operations program required to control access to enclosure for maintenance & renovation		Damage or entry into enclosure likely	Worker protection needed	
		Periodic reinspection required to check for damage		Ceiling to be enclosed is low		
		Repair of damaged enclosure necessary				
		Fibers released in dry form during construction of enclosure				
		Long-term costs could be higher than for removal				
Encapsulation	Reduces asbestos fiber release from material	Asbestos source remains and must be removed later	Material still retains bonding integrity	Material does not adhere well to substrate	Containment barriers needed	$3-10 per sq.ft.
	Initial costs may be lower than for removal	If material not in good condition, sealant may cause material to delaminate	Material not highly accessible	Water damage is evident	Airless prayers recommended	
	Does not require replacement of material	Periodic reinspection required to check for damage or deterioration	Material granular, cementitious	Material is fibrous, fluffy	Previously encapsulated materials may have to be re-encapsulated	

Table 4-1
(Continued)

Method	Advantages	Disadvantages	Appropriate Applications	Inappropriate Applications	General Comments	Cost Estimates[b]
Encapsulation (Continued)		Repair of damaged or deteriorating encapsulated surface required	After removal of ACM, if the substrate is porous	Material thicker than 1" (penetrating types)		
		Encapsulated surface difficult to remove and may require dry techniques for eventual removal	Temporary measure until removal can be scheduled	ACM that has been painted (penetrating)		
		Long-term costs may be higher than for removal	ACM that has been painted (bridging) Asbestos-cement products (bridging)	Asbestos-cement products (penetrating)		
Encasement	Reduces fiber release	Asbestos source remains and must be removed later	All forms and thicknesses of ACM	Water damage is evident or likely	Containment barriers needed	$5-10 per sq. ft.
	Initial cost may be lower than for removal	Requires periodic inspection			Worker protection needed	

[a]Guidance for Controlling Asbestos-Containing Materials in Buildings, EPA 560/5-85-024, June 1985
[b]Equipment Update, Asbestos Issues, May 1989, pp 95-104

of them. Training, employee awareness, and labeling of ACM-containing enclosures will still be required to prevent accidental release of fibers.

Enclosures also have been used effectively to isolate sprayed asbestos insulation on structural beams or in ceilings. Gypsum sheetrock with taped edges, tongue-and-groove boards, and boards with spline joints are all acceptable materials.

The disadvantages of enclosures are:

- Expense of installation;
- Possible difficulty of access to the area for repairs; and
- Possible contamination of the enclosure with asbestos fibers.

Enclosures such as sheetrock walls are impractical for covering areas that contain piping or electrical lines unless access is planned in the structure for required maintenance. Even if access is planned, the potential for disturbing the asbestos fibers is great. In the long term, enclosures may add to the overall cost of an abatement project, especially if they become contaminated with loose ACM, which would then require that the enclosure be disposed of along with the asbestos. Any damaged ACM should be removed before enclosing the remaining ACM. Enclosure can be combined with encasement or encapsulation to limit possible contamination of the enclosure with asbestos.

Encasement

Asbestos encasement consists of spraying or painting coatings onto ACM to trap asbestos fibers and limit their ability to become airborne. Encasement systems are hard, impervious coatings sprayed either directly on the asbestos or over a layer of sprayed-on non-asbestos insulation. At least one of the encasement systems currently on the market has the same resistance to fire as gypsum wallboard, so the fire rating is not compromised by encasement. Encasement systems offer protection against impact and abrasion, depending on the thickness of the coating. Suggested applications for encasement include elevator air shafts, electrical rooms, and computer rooms.

Encapsulation

As with encasement, encapsulation also consists of applying coatings that trap asbestos fibers. Encapsulants, however, tend to be less rigid and thinner than encasements. The many asbestos encapsulants on the market are used not only to encapsulate asbestos in place but also to encapsulate removed asbestos by reducing the fiber count in the work area. They can be used to "lock down" any fibers that remain on the substrate after the asbestos is removed.

Some products are intended for sprayed-on building insulation, while others are made specifically for high-temperature steam lines. Encapsulants are often use in the temporary repair of ACM insulation on piping. In some cases, the strength and resiliency of the encapsulant is reinforced by glass mesh wrapped around the pipe between the tack coat and full coat of the encapsulant. Small tears in the insulation can be completely repaired in this way. If a section of asbestos piping insulation is removed with a glove bag, for instance, the ends of the asbestos insulation that remain can be effectively treated with an encapsulant to seal them.

Two types of encapsulation products exist: bridging and penetrating. Bridging encapsulants form a nonpenetrating barrier against the release of asbestos fibers. These encapsulants provide some abrasion resistance; however, if through accident or impact the encapsulation is broken, the result may be release of underlying asbestos into the air.

Penetrating encapsulants are designed to penetrate through ACM insulation to the substrate (e.g., the pipe) to which the ACM was originally applied. The penetration of the encapsulant is limited by the product used and the density of the material. The penetrating encapsulant must reach the substrate beneath the insulation to provide additional support for the ACM and to prevent delamination. Before applying any encapsulant, a small area should be tested for penetration and for the ability of the insulation to support the weight of the wet encapsulant.

Many penetrating encapsulants are sprayed on the insulation in multiple coats with each coat being applied in such a way that the asbestos appears wet and unable to hold more encapsulant. After allowing enough time for the insulation to soak up the encapsulant, the process is repeated. Sometimes as many as five or six coats are applied. Once the encapsulant has dried and cured, no more can be applied. Dyes are typically added to penetrating encapsulant to facilitate an even application. The application of a penetrating encapsulant is best done by an experienced contractor.

Encapsulants provide a good "quick-fix" for repair of small areas of damaged insulation until removal can be scheduled. Sometimes manufacturers recommend applying a penetrating encapsulant followed by a bridging encapsulant.

Evaluation of Encapsulants. To develop a method for evaluating the suitability of various encapsulant formulations for asbestos removal, EPA commissioned a study by Battelle Laboratories (13). Battelle tested various encapsulant formulations, both bridging and penetrating types, against a standard set of criteria. These tests evaluated encapsulants for the following properties:

- Seals or locks in the asbestos fibers by either bridging over the surface or penetrating the matrix;

- Does not add toxic substances to the insulation or break down under direct flame impingement, releasing toxic gases or an undue amount of smoke;

- Maintains the fire retardant properties of the insulation;
- Can be applied with a minimum of effort and technical skill;
- Has sufficient resistance to impact, is flexible, and sufficiently resistant to penetration caused by reasonable physical contact;
- Is insoluble in water when cured;
- Is nontoxic and lacks noxious fumes during application; and
- Has sufficient aging characteristics to withstand normal atmospheric changes for a minimum of six years and retain sufficient surface integrity to allow recoating.

Of the 158 materials tested, only 33 met EPA's conditions for satisfactory encapsulation. Although the final report was issued in 1987, most of the testing was performed in 1979-80 (13).

While some products tested in the study are still on the market, a number of new products that have been introduced since then have not undergone similar testing. The EPA report suggests that ASTM propose a standard based on a similar test. To date no such standard exists, which makes it difficult to evaluate new encapsulants by an independent test procedure.

One disadvantage to using either bridging or penetrating encapsulants occurs during asbestos removal. The asbestos insulation typically is sprayed with water to limit the quantity of airborne asbestos released during removal. Because encapsulants make asbestos water-resistant, the material must be removed dry although the binding properties of encapsulants somewhat temper the release of fiber. Removal also may be more difficult since the material is attached to the substrate.

Another disadvantage to using sprayed asbestos treatment is the amount of airborne asbestos that might be generated during application of the treatment. Most manufacturers of these treatments recommend that an enclosed space with negative air pressure be established around the area to be treated. In a utility, where there is a great deal of open area (e.g., around a boiler or steam piping) or building an enclosed space with a negative air pressure would be a substantial portion of the removal effort. One utility we spoke with gave this as the reason for not using encasement or encapsulants for large areas. They decided that if they were already going to the trouble and expense of setting up the work area, they might as well remove the asbestos altogether.

Both bridging and penetrating encapsulant can facilitate delamination of asbestos from the substrate unless additional fasteners are installed that tie the encapsulant to the substrate. Because an encapsulant does not provide much resistance to abrasion or impact, its application should be limited to low-traffic areas.

Asbestos Removal

Because of remodeling, demolition, or material deterioration, asbestos eventually has to be removed from a facility. A standard abatement procedure for removing asbestos is described below.

As the owner of the asbestos, the utility retains responsibility and liability if asbestos is removed or disposed of improperly; therefore, it is important to retain some control over the entire abatement project. One of the highest priorities is choosing a reputable contractor. Appendix A of this report provides a copy of a checklist published by EPA for determining the qualifications of an asbestos abatement contractor.

If the amount of ACM removed is more than 260 linear ft. on pipes or 160 sq. ft. on other components, a "Notice of Intention to Demolish or Renovate" must be sent to EPA or the state within 10 days of the start of asbestos removal (if the state has been delegated NESHAP authority). Although a contractor may provide this service, the law (at the time of this report) states that it remains the owner's responsibility to get this document filed.

In addition to an abatement contractor, the utility will also need to hire an air sampling contractor during the abatement procedure to ensure that OSHA air quality standards are maintained. To maintain objectivity, this sampling and analysis work should be done independently of the work of the abatement contractor and the utility.

Asbestos removal must be carried out in an enclosed area; typically, polyethylene sheets are taped together to make an enclosure. Air handling units equipped with HEPA filters maintain a lower air pressure inside than outside the work area. In this way, air is pulled into the room, preventing asbestos fibers from escaping into the area around the abatement work.

The asbestos fibers are first sprayed with water containing a small amount of surfactant to prevent the release of a large number of fibers during removal. The asbestos insulation must be thoroughly wet before being loaded into bags.

Respirators and protective clothing protect workers from exposure during removal. Decontamination and shower facilities are added onto the enclosed area as safeguards against contamination of the environment with asbestos fibers. Air monitoring is performed during removal to detect any contamination of outside air with asbestos fibers.

The wet asbestos waste materials are double bagged in 6-ml. polyethylene bags labeled with a warning. Regulations also require that each bag contain the owner's identification.

After removal, the substrate is "locked down" with a sprayed-on encapsulant to prevent any fibers left in crevices from becoming airborne. The enclosure cannot be removed until air inside the work area has been tested for asbestos fibers and found to be within acceptable limits.

5

ASBESTOS TREATMENT

This section explores the status of several commercial and emerging ACM treatment technologies. For each treatment technology, the process and its advantages and disadvantages are described. Table 5-1 summarizes these options.

General Considerations and Criteria

An effective asbestos treatment program should do the following:

- Meet or exceed federal and state guidelines for safe disposal of asbestos;
- Minimize equipment and plant downtime;
- Reduce or eliminate the long-term utility liability associated with ACM; and
- Be cost effective.

Federal and State Guidelines

Federal and state guidelines are designed to prevent release of asbestos fibers to the air or water. Because the most common form of disposal is in an approved landfill, most regulations address the asbestos waste should be placed in a landfill and the amount and type of cover over the landfill. These regulations are explained in more detail in Section 2 of this report.

Continuing Liability

Current regulations stipulate that asbestos waste remains the property of the owner even if it has been correctly disposed of in an approved landfill. Some utilities attempt to minimize this continuing liability by being selective about the landfills where they send their waste, even if additional expense is involved. As landfill space becomes limited in populous states, more asbestos waste is being shipped out of the state of origin into states where disposal is less costly. The owner of the asbestos waste also is liable during the transportation process.

The advantage of many of the alternate processes discussed in this section is that they completely destroy asbestos fiber, often at the site of removal, thereby eliminating transportation and disposal liabilities.

Table 5-1
Asbestos Treatment Options

Method	Advantages	Disadvantages	Comments
Vitrification	Total destruction of asbestos; end of liability.	Material must still be bagged and transported to remote incinerator.	Furnace design dictates if metals must be removed before treatment.
	Different furnaces have been designed to operate on different fuels.	Estimated costs of $150-$400/ton for vitrification. No commercial vitrification sites currently operating in the United States.	
Solidification	Reduced hazard of accidental release during transportation or while in landfill.	Limited number of contractors to perform service (we found one).	
	Asbestos solidified on site, no bagging required.	Retain liability for asbestos waste since the fiber is not destroyed.	
	Compacted asbestos waste reduces volume from that of bagged waste.	Poor mixing with cement may yield a block less durable than standard cement block.	
		Depending on the amount of cement used, may cost significantly more than standard disposal practices.	
Chemical Treatment	Fiber destroyed on site; end of liability.	Only one commercial process currently on the market.	
		Workers must receive special technical and safety training before applying products.	

Landfill Disposal

Currently the most common approach for ACM disposal is in a landfill approved for asbestos. Requirements for asbestos handling and disposal are covered under the federal asbestos NESHAP rule discussed in Section 3. General provisions for disposal require waste to be properly bagged and labeled before it is transported to the landfill. Once at the landfill, the material must be covered within 24 hrs with at least 6 in. of cover, typically soil. The final cover must be 30 in. of non-asbestos fill. Certain landfills have specific container requirements in addition to the NESHAP rules, such as that all bagged wastes be placed in metal or fiberboard drums.

The cost of landfill disposal is a function of waste volume and of landfill space and varies significantly depending on the location of the landfill. The utility or waste generator is liable for any problems in transporting waste to the site and also for the waste at the landfill. This liability is never relinquished.

Vitrification

Vitrificating of materials contaminated with a toxic or hazardous component to reduce or eliminate their toxicity has been in use for many years. Asbestos waste is particularly well suited to this remediation technique since it is not the chemical components of the asbestos that make it hazardous but its fibrous form.

Vitrification changes these fibers by heating them to temperatures in excess of 1100°C until they are molten. Once cooled, the molten mass forms a glass-like material. Since the fibrous nature of the asbestos is destroyed, the associated hazard also is destroyed. All of the standard vitrification processes that we reviewed heat the asbestos to temperatures well in excess of 1100°C.

There are many different types of vitrification furnaces. Some are similar to furnaces used to make glass and use electrodes to heat the asbestos. Furnaces can also be directly fired by coal, oil, or natural gas.

Several of these vitrification technologies are described below. Although vitrification is well proven, at this time no commercial vitrification processes are operating for the purpose of handling ACM. This is a function of the higher cost of vitrification over landfilling. A summary of the information we collected on vitrification technologies can be found in Table 5-2.

The Vitrifix Process

In the early 1980s, Dr. David Roberts developed the Vitrifix process (14, 15). This process was demonstrated at a hazardous waste site in Gareloch, Scotland, where a 0.5 ton/day furnace was set up to treat asbestos. The results of the cleanup effort were reported

Table 5-2
Vitrification

Company	Contact	Process Description	Furnace Type	Energy Requirements	Permit Status	Commercial Status
Vitrifix Represented by Diversified Investors (212)888-2500	Dr. David Roberts	Uses electrodes to heat glass cullet and asbestos to make glass-like product	Electric	900-1100 KWH per ton ACM	EPA observed pilot test of system. No permit	No current commercial operation planned in US
Penberthey 631 S. 96th St. Seattle, WA 98108 (206)762-4244	Larry Penberthey	Uses electrodes to melt glass, which melts asbestos	Electric	150-175 KWH per ton ACM	No permit	No current commercial operating or planned
Omega Phase Technology 100 No. Essex Ave. P.O. Box 960 Narbeth, PA 19072 (215)664-6554	Dr. James Frederick	Two furnaces in series	Coal, Oil, Natural Gas	2900 KWH per ton ACM	Permit given preliminary approval	Furnace system operating in Australia;
GeoTech Development 1150 1st Ave Suite 630 King of Prussia, PA Fax(215)768-5244	Thomas West Sr.	Uses electrodes to melt asbestos; spins melt to produce insulation fibers	Electric	600-640 KWH per ton ACM	No permit	Demonstration furnace in New York
Vortec Corporation 3770 Ridge Pike Collegeville, PA 19424 (215) 489-2255	Dr. James Hnat	Cyclone furnace	Fossil Fuels	10 KWH/ton	No permit	Currently processing other waste streams

at the 1987 Conference of Industrial Water and Environmental Management (16). In 1987, the Vitrifix process was patented in the United States (17).

In the Vitrifix process, any iron must be separated out magnetically and the ACM must be chopped up before it can be vitrified. Glass cullet, the chopped ACM, and other chemicals are mixed in a screw feeder or on their way into the furnace. The furnace is maintained at 1200-1400° C via molybdenum electrodes and the asbestos has a residence time of 10 hours. The ratio of ACM to glass cullet can be as high as 4:1.

EPA Demonstration. In June 1987, Vitrifix demonstrated this technology to EPA at the Dalzell Corp. Glassworks in New Martinsville, WV. Different types of ACM contâining various forms of asbestos in concentrations as high as 50% were included in the test. EPA certified that the glass product contained no asbestos. They also identified several criteria they consider critical to the successful operation of the process:

- Cullet-to-waste ratio of 15%, minimum;
- Glass temperature of 2000° F (1100° C); and
- Furnace residence time of more than 6 hrs, and a residence time in the throat of the furnace of more than 5 minutes (18).

Commercial Development. No commercial development of this process is planned at this time.

Costs. For a 5 ton/day unit the electrical requirement is 1,110 KWH/ton of material. This requirement is 900 KWH/ton for the more efficient 50 ton/day plant. The planned commercial vitrification facility may charge $500/ton for processing ACM.

The Penberthey Process

This process also melts asbestos in an electric furnace. Containing a 24-inch bed of molten glass heated by molybdenum electrodes. The furnace temperature is typically 1200-1300° C. The glass-like product is shattered in water and can be disposed of in a landfill.

Mr. Penberthey estimated the electrical requirement per ton of ACM processed to be 150-175 KWH.

Commercial Development. No commercial development of this process is planned at this time; however, the company does have a furnace capable of processing 5 tons of asbestos per day that they are interested in demonstrating to potential clients.

The Omega Phase Transformation Process

The furnace used by Omega Phase Transformation is designed to accept solid waste, including metals and organic materials. Organic materials are consumed in the system and metals are melted and formed into ingots. This approach eliminates the requirement for separating the metal that is removed with the insulation from the ACM before processing the asbestos. Typically, no chemicals or glass are added (as in other processes) since the temperatures are high enough to vitrify the material without additives.

The basic unit consists of two furnaces. In the first, temperatures reach 1400-1500° C. At this temperature, the organic materials are completely combusted and the metal and asbestos receive preliminary heating. Gases are heated further to destroy all organic matter before being sent through the air pollution control unit. The second, bottom-fired furnace is located beneath the first and operates at about 1700° C. At this temperature, the conversion of the asbestos to glass and the metal to molten metal is completed. Since it is denser than the glass, the molten metal pools at the bottom of the furnace. Changes in conductivity between probes in the furnace indicate the metal level. When the metal level is sufficient, it can be discharged and formed into ingots. The liquid glass-like material collects above the molten metal and flows via a submerged throat out of the unit where it can be formed into a marketable product. The furnace will accept any material smaller than a cubic meter.

Commercial Development. Omega Phase Transformation sold a 25 ton/day furnace to a firm in Australia that vitrifies medical waste, but no asbestos. All plans for vitrification facilities in the U.S. have been placed on hold.

Costs. These furnaces are fired directly and can be fueled by oil, natural gas, or coal. Each furnace would require 10 million BTU to process one ton of asbestos. The designers estimate that once a commercial facility is completed, it will cost $300-400 a ton to process ACM.

GeoTech Development Corporation

This vitrification process melts the asbestos-containing material and transforms it into a glass-like material that can either be pelletized, formed, or spun into glass fiber. GeoTech Development Corporation has a 2 ton/day furnace in New York for demonstration purposes. The furnace is round with three central electrodes. When the ACM is vitrified, it flows through a hole in the center of the furnace out to where it can be processed. This is the only vitrification application that uses ACM to produce another fiber insulation material.

Costs. Energy costs for the furnace are 600-640 KWH/ton of waste. Capital costs for a 25 ton/day unit are estimated to be $2.5 million. Using commercial electrical rates, GeoTech estimates that a company would need to charge at least $175 per ton to stay in business.

Vortec Cyclone Melting System

Vortec Corporation has developed a high temperature furnace for vitrifying soils, ash, and fiberglass waste. The process destroys hazardous organic compounds and vitrifies silica-based materials so that heavy metals are encapsulated. Although the process was not specifically designed for asbestos, it could also be used for this material. All materials entering the furnace must be pulverized.

The furnace combines a fossil fuel and the material to be vitrified in a combustion and melting system (CMS). The CMS consists of a counter-rotating vortex preheater unit attached to a cyclone melter. Operating temperatures range from 1100-1600° C in the cyclone melter.

Commercial Development. The process is currently being developed to handle different types of hazardous and problematic wastes, such as fiberglass wastes and hazardous soils and sludges. No asbestos vitrification is planned.

Costs. Dr. James Hnat, the president of Vortec Corporation estimates that the efficiency of the furnace allows it to process asbestos at $ 50-60 per ton.

Plasma Asbestos Pyrolysis System

In August 1991, Dr. Lou Circeo vitrified 29 pounds of pure asbestos using a 300 KW plasma torch. The vitrification was complete in less than one hour. This demonstration was Phase I of Dr. Circeo's project at the Georgia Institute of Technology Construction Research Center, sponsored by the U.S. Army Construction Engineering Research Laboratory.

The plasma torch generates temperatures from 3000-7000° C, well in excess of the 1100° C required to vitrify asbestos. The technology is well established, having been developed by NASA in the 1960s to simulate the temperatures that a space craft would encounter during reentry. Plasma technology has been used in many industrial applications and is currently in use in the metallurgical industry. Besides asbestos vitrification, plasma heating is being considered for vitrification of hazardous wastes.

The process is currently being investigated to treat asbestos contaminated with radioactive materials.

Commercial Development. No commercial units are currently planned or under development. However, a unit using this technology is operating in France. This unit is described in more detail below.

Costs. Dr. Circeo has prepared a detailed economic analysis that includes labor, power, and original equipment costs. He estimates a cost per ton of $163, of which about 20% is power (assuming power costs of $50/MW).

Plasma Vitrification in France

Since 1986, the electric utility of France has been researching the use of high temperature plasma torches for the destruction of wastes (19). They were particularly interested in using this technology to vitrify asbestos wastes from the demolition of power plants.

In France vitrification is attractive for several reasons. The cost of disposing of asbestos waste in special landfills is 1,000 francs/ton($170/ton). Furthermore, landfill space is currently limited and in the future will become unavailable. Vitrification produces a significantly reduced volume of a nonhazardous usable product.

The furnace used to demonstrate this technology was cylindrical, approximately 8 ft. tall and 5 ft. wide. The plasma torch was rated at 800 kW/h. A HEPA filter on the exhaust prevented asbestos fibers from escaping. Exhaust gases were also scrubbed with a caustic solution to trap chlorides and heavy metals. Metal or fiberboard drums containing asbestos waste were tipped into the furnace where the containers were destroyed and the asbestos was vitrified. The frequency with which the drums were added was determined by monitoring the exhaust gases for carbon dioxide. When the carbon dioxide in the exhaust gases dropped to a minimal level, the container was considered destroyed and the furnace ready for another.

Several asbestos-containing materials from a power plant demolition were vitrified in the demonstration furnace. The materials ranged from insulation that was 90% amosite to a mixture of soil, ash, and concrete debris that contained 2-4% asbestos. Many types of insulation were vitrified with the metal mesh intact. The amount of time required for vitrification varied from 7-40 minutes depending on the material.

Although the plasma torch was not aimed at the bottom of the furnace, the temperature consistently exceeded 1400 °C.

Testing around the unit during operation and of the vitrified material revealed the following:

- No asbestos particles escaped in the exhaust gases;
- The vitrified material does not contain asbestos and does not leach heavy metals; and
- Vitrification required 1.9 -3.5 KWh/kg of material and was dependent on the material being vitrified.

Commercial Development

A commercial unit near Bordeaux, France, is due to be operational in 1993 (20). The unit is larger in capacity than the demonstration unit, handling more than 1000 lbs/hr of waste asbestos-containing materials. The torch, rated at 1 MW, is also larger. The estimated cost for building the installation is $5 million.

Microwave Vitrification of Asbestos

Vitrification of fly ash using microwave energy has been described in the literature as a method for converting fly ash to a ceramic tile-like material (21). The process requires that the fly ash be combined with a transition-metal microwave coupler such as magnetite contained in iron ore. When the fly ash was mixed with the iron ore and irradiated with microwave energy temperatures in the mixture reached in excess of 1100°C in less than 4 minutes.

Experimental Procedure. Since the fly ash vitrification temperatures were in the same range as those required for vitrification of asbestos, Radian conducted bench-scale tests to assess vitrification of asbestos using similar procedures to those required for fly ash. A sample of block insulation containing approximately 25% amosite asbestos was ground with a mortar and pestle and mixed with reagent grade magnetite. The mixture was placed in an aluminum oxide crucible and the crucible placed in a laboratory microwave. Although no direct temperature readings could be made, the crucible quickly began to glow red. A thin layer of the material found on the top and sides of the crucible appeared oxidized but vitrified; the material in the center was a solid mass. Analysis of this mass showed that the asbestos had indeed vitrified and had become part of the molten iron matrix.

Although the concept has been proven, more research is needed to determine if this concept could be developed into a commercial process.

Solidification

In the solidification process, asbestos waste is mixed with a pozzolanic material such as portland cement to form a solid concrete block. The waste is compact and nonfriable, and can be disposed of in approved landfills as asbestos-containing material. Solidification of all asbestos-containing wastes is the law in Germany. Although the process seems to be known in this country, we could not find an abatement contractor that solidifies asbestos for clients on a regular basis.

Regulatory Considerations

Solidifying the asbestos waste in concrete minimizes the risk of an asbestos release during transportation to the landfill and while it is being deposited. It does not, however, destroy the asbestos, and therefore cannot eliminate long-term liability as do the vitrification or chemical treatment processes.

Commercial Development

Typically, a cement mixer is set up inside an enclosure and the asbestos is fed into the mixer with portland cement. When the mixing is complete, the asbestos/cement mixture is poured into one-cubic-foot blocks and allowed to set for approximately 7 days. The blocks are identified with the generator's name and then transported to an approved landfill. Since the mixture still contains asbestos, it must be disposed of as an asbestos waste, even though the asbestos is no longer friable.

Proponents of solidification claim that, besides greatly lowering the risk of an accidental asbestos release during transportation and placement in a landfill, the cement-asbestos mixture is more compact and easier to handle. In addition, they claim that mixing asbestos with cement is less time consuming and labor intensive than bagging the material.

Solidification Parameter Testing

In discussions with abatement contractors that solidify asbestos, we were unable to find a prescribed asbestos/cement ratio for the mixture or any standards that the finished material must meet (i.e., compressive strength). This lack of standards appears to be the case in Germany as well, where all asbestos is solidified before to disposal (22).

Although asbestos fibers have been used for many years to strengthen cement mixtures, the amounts and types of filler material used in a particular type of insulation may significantly affect the final properties of the mixture. Proponents of solidification tout the stability and longevity of the cement/asbestos mixture as a significant advantage over standard practice.

Radian tested two types of asbestos insulation blocks to determine the effect of different amounts of cement in the mixture on four properties of the resultant concrete; unconfined compressive strength, abrasion resistance, leaching, and stability in freeze/thaw cycles. The following section describes the results of laboratory tests conducted to determine the strength and stability of various asbestos cement mixtures.

Solidification Test Results

To determine the properties of solidified ACM, we used two types of block asbestos insulation material. One contained 20% amosite fibers whereas the other was 35% chrysotile. Six ACM/cement mixtures and one ACM/fly ash mixture were made. A pure cement block also was prepared as a control.

The amosite ACM/cement mixtures contained by weight: 10% amosite ACM/90% cement, 25% amosite ACM/75% cement, 50% amosite ACM/50% cement, and 75% amosite ACM/25% cement. Three mixtures were prepared using the chrysotile ACM. Two contained (by weight) 25% chrysotile ACM/75% cement and 50% chrysotile ACM/

50% cement. The third mixture contained 25% chrysotile ACM/75% Class C fly ash by weight.

If 100 g of cement were required to make enough mix to fill the molds, 50 g of asbestos was added to the cement to make a 50% mixture. Enough water was added to make the mixture workable. The mixture was then carefully poured into five molds and dried. The test results for each of these mixtures can be found in Table 5-3.

Each solidified mixture was tested for unconfined compressive strength, leachability, abrasion resistance, and resistance to freeze/thaw cycles. The intention of these tests was to simulate, in a short time period, years of mismanagement and mishandling at a landfill. It was important to know not only if the material would eventually break down, but also if this breakdown would result in a fiber release. A detailed description of the test procedures is found in Appendix A.

Table 5-3
Solidification of ACM With Portland Cement

	Amosite					Chrysotile		Fly Ash/ Chrysotile
Percent ACM by Weight	**0**	**10**	**25**	**50**	**75**	**25**	**50**	**25**
Strength, psi	>2,500	1130	556	85	26	901	209	19
Leachability	+	sl	–	–	–	sl	–	–
Abrasion Resistance	sl	–	–	–	–	–	–	–
Freeze/Thaw	+	+	sl	–	–	+	sl	–

Strength readings are the average of three cubes:
+ = no significant deterioration
sl = slight deterioration
– = significant deterioration

Solidification becomes economically feasible only if there is more than 25% ACM in the mixture. However, our tests indicate that significant long-term stability is obtained only if the percentage of ACM is less than 20%. A more detailed explanation of the cost analysis can be found in Appendix B.

Recommendations

Our demonstration showed that stable blocks of ACM and cement mixtures can be obtained if the weight percent of ACM remains below 20%. Asbestos insulation mixtures with a high asbestos content exhibit greater physical strength than low asbestos content mixtures. The higher the content of the binding material, the weaker the asbestos block will be. Our economic analysis, however, indicates that solidifying asbestos in these mixtures is more expensive than placing the material in a landfill, assuming their potential liability costs are equal.

Chemical Treatment

A number of chemicals have been used to destroy the asbestos fiber. Generally they focus on attacking either the magnesium or silica in the asbestos. This changes the fibrous nature of the material so that the resulting product cannot be identified as asbestos. Depending on the chemical used there may be additional treatment steps required to make the byproducts nonhazardous.

All chemicals destroy the asbestos fiber and therefore the liability associated with asbestos. This can be an important consideration to a utility company concerned about landfill disposal.

Table 5-4 summarizes chemical treatment processes. In the following sections each process is discussed in detail. The ABCOV chemical treatment process is the only chemical treatment process currently in commercial use. A field demonstration of this process took place at an EPRI member utility. A description of the field test and its results are included in the chemical treatment section. The chemical/thermal treatments are discussed in a separate section directly following the chemical treatment section.

The ABCOV Process

In the ABCOV Process, a proprietary chemical is sprayed on the in-place ACM and the wet ACM is removed. Then, in a batch tank, the ACM is mixed with additional proprietary chemicals. The addition of these chemicals results in destruction of the asbestos fiber. Residual silicates can then be filtered and disposed of, and the solution discarded. The ABCOV process has been demonstrated in abatement efforts in New York. The vendor requires that anyone using their process take a special course on the safe handling of the chemicals.

Field Demonstration of the ABCOV Process

EPRI participated in a field demonstration of the ABCOV process that took place at Public Service Electric and Gas Company's (PSE&G) Kearny Generating Station in Kearny, New Jersey. Asbestos was to be removed from steam piping directly before the throttle valve of one of the turbines. A containment area was set up for removal. A separate area was established for the chemical treatment, allowing better access to power and a larger area for treatment.

The material was removed and bagged in the containment area around the valve. During the removal process, the insulation was sprayed with an ABCOV chemical instead of the standard amended water mixture to reduce the potential for airborne

Table 5-4
Chemical Treatments

Company	Contact/Information Source	Process Description	Commercial Status
DSI 153 Waverly Place New York, NY 10014 (212) 675-2270	Tony Nocito	Chemical destruction of the asbestos fibers	Commercial
Sulfuric Acid Treatment	Patent	Asbestos is destroyed with sulfuric acid. Residual sulfuric acid is neutralized and pozzolanic material is added to make cement.	Patent
Waste Acids	Paper 1985	Various commercially produced waste acids were tried; a mixture of chromic and nitric worked best	In development

fibers. Approximately 150 lbs. of asbestos insulation were removed. The bags were then transferred to the chemical treatment containment area.

The chemical treatment area was set up with two mixers so that one batch could be mixed while a previously treated batch container was being filtered. In the chemical treatment area, blocks of the removed insulation were added to an actively mixing ABCOV solution. After 30 minutes of mixing, the solution was tested by polarized light microscopy (PLM). Once asbestos destruction had been confirmed, the solution was filtered through a coarse drum filter. The filtered solution was then returned to the treatment vessel for rejuvenation with dry chemical and reuse.

Each mixer lid had a hose that collected fumes from the air space over the chemicals and pulled them through an activated carbon filter. This controlled any gases generated by the reaction in the drums. The exhaust from the scrubber was released back into the work area. Air circulation of about six changes per hour was maintained in the room by two HEPA-filtered air fans.

Because of the size of the treatment vessels the insulation was treated in three batches of approximately 50 lbs. each. The first batch treated only the asbestos insulation while the second included some painted canvas material that was covering the asbestos. This material was cut into pieces approximately the size of a sheet of paper and slowly added to one of the mixing solutions.

The third batch was treated with the solution used to treat the first batch. The concentration of the active ingredient was not tested, but approximately 20 lbs. of additional dry chemical was added to boost the chemical concentration in the mixture. Again, about 50 lbs. of asbestos were added and tested after 30 minutes. The microscopist indicated that all the asbestos was destroyed in this treatment as well.

PSE&G assigned two workers to remove the asbestos and two to assist in the chemical treatment. Because of concerns expressed by PSE&G about the possible exposure of their personnel to chemical fumes, the individuals involved in chemical treatment used an external air supply. PSE&G's Industrial Hygiene Group monitored the air in the chemical treatment area using passive and active monitoring devices for vapors from the raw chemical and for possible reaction products that might become airborne. Since the workers were handling asbestos, the industrial hygienists also monitored for asbestos fibers.

Demonstration Results

During removal of the asbestos insulation from the piping, workers noted that the ABCOV chemical that they sprayed on the asbestos penetrated the insulation faster than the standard amended water.

A slurry sample of the treatment mixture was taken 30 minutes after the treatment began and all samples were analyzed by polarized light microscopy. Each of these samples showed that the asbestos had been destroyed. Samples of the residual solid material filtered from the treatment solutions also showed no asbestos. The results were later confirmed by an independent laboratory using transmission electron microscopy (TEM) for all samples. In the batch where pieces of canvas insulation covering were added to the treatment mixture, only cellulose fibers from the material could be identified. A copy of this report is contained in Appendix B.

Samples of the treated slurry were also analyzed for toxic metals and for fluoride. These analyses revealed elevated levels of arsenic in the final product. Since no corresponding concentrations of arsenic had been found in testing performed in the laboratory, it was suspected that the contamination could have been associated with some of the equipment used to treat the process. However, after discussions with the vendor, it appears that other potential sources for the arsenic are possible, including the treatment chemical. The vendor has made adjustments to the process to control the contamination.

There were also slightly elevated levels of nickel and chromium that could be attributed to corrosion of the mixer blades during the treatment process. In addition, the sample contained a significant fluoride residue. Although fluoride concentrations will not make the waste characteristically hazardous, they will affect a utility's ability to dispose of any liquid waste to their local publicly owned treatment works (POTW).

The industrial hygiene testing revealed no airborne chemicals in concentrations high enough to be of concern to personnel working in the chemical treatment area. This indicates that individuals working in the chemical treatment area should use standard respiratory equipment for working with asbestos.

Disposal of Testing Byproducts

After the testing was completed, most of the used treatment chemical was filtered and returned for later reuse by the vendor since the chemical was still viable. In a large-scale operation, the ABCOV vendor (26) claims that the liquid can be filtered, boosted with dry chemical, and reused many times. Eventually the liquid would need to be disposed of. At that point it could be treated to precipitate out the active agents and the solids tested and disposed of in an approved landfill. However, for the purposes of this test, the byproducts were disposed of as a hazardous waste.

Conclusions

This field demonstration proved that the ABCOV process would destroy asbestos from a utility site. All the asbestos was destroyed within 30 minutes of the start of treatment. The vendor's substitute wetting agent used to minimize fiber generation met with worker approval.

During this brief test we were not able to accurately assess the cost of the treatment. Additional information on cost may be obtained as larger tests are performed with the process.

Developing Processes

During our patent search, we located a number of chemical processes for destroying asbestos that have not been developed commercially. Some may have particular advantages for treating utility industry asbestos. Some use chemicals that the utility industry is familiar with and can handle whereas while others are transportable from one plant demolition project to the other. One even uses fly ash to create a useful product. Before any of these processes could be used commercially, they would need to receive an exemption from the TSCA Ban and Phase Out Rule if they create any usable product.

Sulfuric Acid Treatment

A U.S. patent (27) describes a process for destroying asbestos with concentrated sulfuric acid. The sulfuric acid acts in two ways. First, it separates the filler material from the asbestos by dissolving the filler. Then, the continued action of the acid removes the magnesium from the asbestos fiber, structurally changing the asbestos and destroying its fibrous nature. After the asbestos has been destroyed, the excess acid is neutralized with lime or hydrated lime to a pH near 7.

The result of this decomposition and neutralization is a cementitious mixture of calcium and magnesium sulfates with silica from the asbestos. A pozzolanic material is added to this mixture to create a concrete-like product.

Waste Acids

Asbestos may also be treated with industrial waste acids. G. Baldwin and Leslie Heasman, of the Waste Research Unit at Hartwell Laboratory in England, attempted this in 1985 (28). They found that treatment with waste nitric/chromic acid from an electroplating industry destroyed the asbestos in 1-2 hrs. Dilute sulfuric acid and a mixture of a number of acids dissolved asbestos within 15 days and 40 hours, respectively. This method may have some potential for utilities that could use acidic wastes to treat small quantities of asbestos. We could find no commercial application of the technology.

Chemically Enhanced Thermal Treatments

Recently new methods chemically enhanced thermal treatment for destroying asbestos have been developed in the research laboratory. Information about these methods was found in a literature and patent search; none is currently available as a commercial process. In the current regulatory environment before any of these processes could be commercialized, it would need to receive an exemption from the Asbestos Ban and Phase Out Rule.

These techniques do not create a molten bath of silicates as the standard vitrification processes do. Instead, a chemical reacts with one or more elements in the asbestos fiber, destroying the fiber's shape and thereby eliminating the hazard.

With chemical/thermal treatments, aqueous chemical solutions are applied to the ACM after it has been fed through a chopper. When the treated ACM is heated, the chemicals attack the structure of the asbestos fiber, causing the mineral form to change.

This is different from the vitrification processes described earlier since the asbestos never actually becomes molten, although the fiber structure is changed enough that it is no longer identifiable as asbestos. These processes operate between 260-800° C, whereas the standard vitrification processes exceed 1100° C.

The chemical to be added and the temperature of the furnace are factors in determining the retention time needed in the furnace to achieve conversion. Several chemically enhanced thermal treatment processes are compared in Table 5-5.

Table 5-5
Chemically Enhanced Thermal Treatments

Chemical	Process Temperature	Residence Time	Reference	Comments
Ammonium Bifluoride	550° C	12 minutes	German Patent (29)	
Sodium Carbonate	800° C	30 minutes	US Patent (30)	
Ammonium Sulfate	260° C		Danish Patent (31)	Reaction occurs at 5 atm pressure
Sodium Borate Decahydrate	1100° C	60 minutes	US Patent (32)	

These processes destroy the asbestos fiber and therefore the liability associated with asbestos. This can be an important consideration to a utility company concerned with landfill disposal.

6

ASBESTOS-INSULATING REPLACEMENT MATERIALS

This section presents a brief overview of asbestos-insulating replacement materials. A complete discussion of asbestos replacements for gasket materials and insulation will be the subject of a final report from EPRI research project RP1030-46, to be published in 1992.

As utilities select replacements for asbestos insulation, it is important that these replacements are not only suited to their application but are free of the adverse health effects associated with asbestos. To this end, research into the health effects of asbestos replacements is currently underway. However, consensus on the health effects of these replacement materials has yet been reached.

Four materials are commonly used as asbestos replacements: fibrous glass, mineral wool, refractory ceramic fibers (RCF), and calcium silicate. Of these, only calcium silicate is nonfibrous in nature. Table 6-1 summarizes the characteristics and typical applications of these materials.

Fibrous Glass

This insulating material includes glass wool, continuous filament, and special purpose fibers. Silica sand, limestone, fluorspar, boron oxide, and glass cullet are used to make fibrous glass insulation. The material is mixed with an organic binder such as urea-formaldehyde and phenol-formaldehyde. The recommended service temperature limit is 540° C (1000° F); however, the organic binder will decompose at 180° C (350° F), giving off an acrid-smelling smoke. This is true of all fibers that use organic binders. Fibrous glass is typically used for pre-molded pipe and blanket insulation. The installation cost of fibrous glass insulation on a 2-inch pipe with an aluminum jacket is approximately $7.53 per ft.

Mineral Wool

There are two types of mineral wool: rock wool, made from magma rock, and slag wool, made from metallurgical slag. Organic binders are also used in the manufacture of mineral wools. The maximum recommended temperature for most mineral wool products is 700° C (1300° F), although some special formulations can tolerate temperatures as high as 1000° C (1900° F). Mineral wool is used in pre-molded pipe insulation, boards, and blankets. Installation costs for mineral wool insulation on a 2-inch pipe with an aluminum jacket is $5.61 per ft.

Table 6-1
Asbestos Replacements -- IARC Findings on the Carcinogenicity of Man-Made Fibers

Type	Temperature Range	Evidence in Humans	Evidence in Animals	Overall IARC Evaluation	IARC Carcinogenicity Grouping	Cost per foot[a]
Fibrous glass - pre-molded pipe insulation & blankets	450° C (1000° F) binding decomposes at 180° C (350° F)	Inadequate	Sufficient	Possibly carcinogenic to humans	2B	7.53
Mineral Wool - premolded pipe insulation, boards, and blankets	450° C (1000° F) binding decomposes at 180° C (350° F)	Limited	Limited	Possibly carcinogenic to humans	2B	5.61
Refractory Ceramic Fibers						
Alumina-silica	990-1450° C (1800-2600° F)	No Data	Sufficient	Possibly carcinogenic to humans	2B	
Alumina	1100-1650° C (2000-3000° F)	No Data	Sufficient	Possibly carcinogenic to humans	2B	
Calcium Silicate	650° C (1200° F)			Generally considered safe	Not rated	6.20

[a]The installation costs listed are for a 100-ft. straight run of 2" piping that is accessible by ladder; installation performed outdoors during the summer assuming a labor cost of $20 per hour (1).

Refractory Ceramic Fibers

Common RCFs are amorphous or partially crystalline materials formed from kaolin clay and aluminum and silicon oxide. This group also includes fibers of silicon carbide, silicon nitride, and boron nitride. Alumina-RCF can tolerate temperatures as high as 1650° C (3000° F), while alumina-silica RCF withstands temperatures up to 1400° C (2600° F). RCF is mainly used in making boards, blankets, and firebricks.

Calcium Silicate

Calcium silicate is a non-fibrous material, although some fibrous glass may be used as a reinforcing material. It is used in applications where temperatures do not exceed 650° C (1200° F). The most common use of calcium silicate is as pre-formed pipe insulation. The installation costs for calcium silicate insulation on a 2-inch pipe with aluminum jacket is $6.20 per foot.

Health Effects of Asbestos Alternatives

Since their introduction, fibrous materials have been known to cause irritation of the skin, eyes, and throat; however, no causal link has been established between synthetic non-asbestos fibers and the diseases associated with asbestos. The average fiber diameter is 2-9 μm for rock wools, 6-15 μm for fibrous glass (continuous filament), and 1.2-3 μm for RCFs. Fibers must have a diameter of less than 3 μm and an aspect ratio of greater than 3:1 (length-width) to be considered respirable. Most of the fibers released when working with the rock wools and fibrous glass are not in the respirable range (33).

There have been three major epidemiological studies completed to date on workers exposed to these alternate insulation materials. These studies have indicated a slight increase in mortality among rock wool and slag wool workers, but not among glass wool workers (54). No epidemiological data are available on workers exposed to refractory fibers.

Animal studies have shown no increase in tumors from the inhalation of fibrous glass or mineral wools. For RCFs, three studies led to conflicting conclusions: one indicated a significant increase in tumors, whereas the other two studies indicated no increase. Interim results from an ongoing study indicate that RCFs may indeed increase the number of tumors (35). The direct implantation of fibers into the pleural cavity of rats did result in an increase in tumors for mineral wools and RCFs (36).

Since calcium silicate is nonfibrous, it has not been subjected to the same scrutiny as the fibrous replacements. Calcium silicate is "generally recognized as safe" by the US FDA and classified as a nuisance dust by the American Industrial Hygiene Association.

7

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APPENDIX A: CHECKLIST FOR DETERMINING CONTRACTOR QUALIFICATIONS

a. Contractors shall demonstrate reliability in performance of general contracting activities through the submission of a list of references of persons who can attest to the quality of work performed by the contractor.

b. Contractors must demonstrate ability to perform asbestos abatement activities by submitting evidence of the successful completion of training courses covering asbestos abatement. At a minimum, the contractor shall furnish proof that employees have had instruction on the dangers of asbestos exposure, on respirator use, decontamination, and OSHA regulations.

c. Contractors must be able to demonstrate prior experience in performing previous abatement projects through the submission of a list of prior contracts, including: the names, addresses, and telephone numbers of building owners for whom the projects were performed. In rare circumstances inexperienced contractors may be qualified if they can demonstrate exceptional qualifications in the other contractor standards.

d. Additional evidence of successful completion of prior abatement project should be demonstrated by contractors through the submission of air monitoring data, if any, taken during and after completion of previous projects in accordance with 29 CFR 1910.1001(e).

e. Contractors must possess written standard operating procedures and employee protection plans which include specific reference to OSHA medical monitoring and respirator training programs. In addition, the contractor must be prepared to make available for viewing at the job site a copy of OSHA regulations at 29 CFR 1910.1001 governing asbestos controls, and Environmental Protection Agency regulations at 40 CFR Part 61, Subpart M, (NESHAPS) governing asbestos stripping work practices, and disposal of asbestos waste.

f. In those states which have contractor certification programs, contractors must possess state certifications for the performance of asbestos abatement project.

g. Contractors must be able to provide a description of any asbestos abatement projects which have been prematurely terminated, including the circumstances surrounding the termination.

h. Contractors must provide a list of any contractual penalties which the contractor has paid for breach or noncompliance with contract specifications, such as overruns of completion time or liquidated damages.

i. Any citations levied against the contractor by any federal, state, or local government agencies for violations related to asbestos abatement, shall be identified by contractors, including the name or location of the project, the date(s), and how the allegations were resolved.

j. Contractors must submit a description detailing all legal proceedings, lawsuits or claims which have been filed or levied against the contractor or any of his past or present employees for asbestos-related activities.

k. Contractors must supply a list of equipment that they have available for asbestos work. This should include negative air machines, type "C" supplied air systems, scaffolding, decontamination facilities, disposable clothing, etc.

Source: "Guidance for Controlling Asbestos-Containing Materials in Buildings." EPA 560/5-85-024, June 1985.

APPENDIX B: TESTING PROCEDURES FOR THE SOLIDIFICATION OF ASBESTOS CONTAINING MATERIALS

Unconfined Compressive Strength. The purpose of the unconfined compressive strength test was to evaluate the short-term shear strength and cohesion of the solidified asbestos insulation. This test was conducted 7 and 28 days after preparation of the samples according to ASTM C109-90, "Standard Test Method for Compressive Strength of Hydraulic Cement Mixtures" (23).

The compressive strength of the blocks dropped very rapidly as the weight percent of the asbestos increased. The blocks containing the chrysotile material were stronger than those containing the amosite. Chrysotile fibers are typically longer, and there was a higher percentage of asbestos in the chrysotile than in the amosite. Examination of the broken pieces indicated that the magnesium carbonate binding material from the insulation may have been responsible for some of the weakness exhibited by the blocks.

Abrasion. In this test, we assessed the durability of the solidified asbestos with emphasis on the potential for asbestos fibers to be abraded and released from the surface of a block. After 28 days of curing, three 2-inch cubes were placed in a sealed 1-L plastic container. The cubes were tumbled in this container, abrading each other for 18 hours. A sample of the abraded material was analyzed to determine if free asbestos fibers could be found in the sample.

All the materials showed some damage as a result of the abrasion test. The higher percentage asbestos insulation mixtures showed a higher degree of degradation than did the higher strength blocks. When the loose abraded material was tested by scanning electron microscopy (SEM), loose asbestos fibers were found, indicating that abrasion causes loose fibers that may become airborne, creating a health hazard.

Leaching. The leachability of the asbestos blocks was evaluated after 28 days of curing using ASTM D 3987, "Standard Test Method for Shake Extraction of Solid Waste with Water" (24). After the samples were weighed, they were agitated for 18 hours, filtered, and the filter was analyzed for asbestos fiber release by transmission electron microscopy (TEM).

All samples except the 10% amosite and the 25% chrysotile were significantly eroded by the water and tumbling action. The eroded material was filtered and tested by TEM.

Analysis of the filtered samples showed that the asbestos fibers were not held by the concrete and were free to become airborne once the material dried.

Freeze/Thaw. A freeze/thaw test was used to examine the potential for release of asbestos fibers after cycles of freezing and thawing. This test began 28 days after preparation of the sample mixes, which is a modification of the test age specified in "Test Methods for Solidified Waste Characterization" (25). The specimens were 2-inch cubes; two specimens of each mix were tested, one as a control and the other as the test.

After each specimen was weighed, it first was placed in the freezer in a sealed plastic bag at -20° C for 24 hours. The control was placed in the moisture chamber in a sealed plastic bag at 22° C for the same period. Both samples were removed from the plastic bags and 230 mL of distilled water was added to each specimen. The distilled water temperature was 4° C for the frozen test specimen and room temperature for the control specimen.

Both specimens were placed in the moisture chamber at 22° C for 24 hours and then transferred to new bags. The procedure was repeated 11 more times or until the specimens lost physical integrity. The water was collected and reused for the 12 cycles. At the end of the test, the water was filtered and the filter sent for analysis by TEM.

The 10% and 25% amosite and the 25% and 50% chrysotile suffered only slight deterioration during the freeze/thaw test. The higher percentage amosite and the fly ash/chrysotile mixtures lost their physical integrity during the freeze/thaw cycling and the test was terminated for these samples.

Costs for Solidification

Since asbestos insulation is a bulky material, many abatement contractors currently shred and compact it to save disposal space. The material also is compacted in the solidification process. Since asbestos disposal costs are determined by volume, this compaction can offset some of the additional costs of the cement. The reduced volume and non-friability of the final product are two advantages of solidification. The other advantage of solidification is that non-friability may reduce future liability.

On the basis of our work with small asbestos blocks, some of the cost savings associated with solidification can be estimated. Since the potential for future liability was not quantifiable, it was not included in this evaluation.

For the purpose of this analysis, we assumed that the labor to mix the asbestos with cement and pour it into blocks was not significantly different from the cost to double-bag the material and haul it to a dumpster. We did not include transportation costs to the landfill in either case. In each case, the calculated cost was based on solidification of one ton of dry ACM. For calculation purposes, we assumed a cost of $3.70 for a 94 lb.

bag of portland cement and $16/cu. yd/ for a disposal fee. This, we believe, is a moderate disposal fee in many parts of the country.

Table B-1 details the costs for each mixture.

Table B-1
Solidification Costs

		Amosite (wt %)				Chrysotile (wt %)	
	Bagging	**10%**	**25%**	**50%**	**75%**	**25%**	**50%**
Disposal Amount/ cu. yd.	13	12	7.4	6.5	6.3	6	5.5
Disposal Cost/ cu. yd.	$16	$16	$16	$16	$16	$16	$16
Total Disposal Cost	$208	$192	$118	$104	$101	$96	$88
Bag or Cement Cost	$64	$700	$235	$79	$26	$240	$79
Total Cost	$272	$892	$353	$183	$127	$336	$167

Assumptions:

- All figures based on one ton of dry ACM removed
- 13 cu.yd./ton for bagged asbestos waste
- Labor to bag or solidify essentially equal
- Portland cement is $3.70/94 lb. bag