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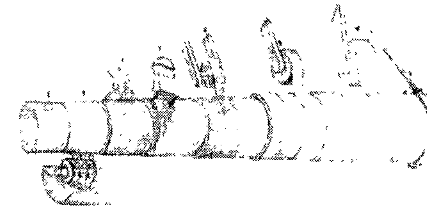

As Near Perfect as We are Likely to Get:" 20th Century Public Health Endorsements of Asbestos in Filters and Pipe

For ACI, Asbestos Claims & Litigation, Chicago, 27 June 2016

Abstract

Asbestos-cement pipe and asbestos filters were only two of many historical uses of the mineral that were originally adopted by public health authorities in the 20th century for their then-perceived public health benefits, including workplace safety. The quotation in the title, for example, is from industrial hygienists Philip Drinker and Theodore Hatch's 1954 *Industrial Dusts*, in which the authors recommended crocidolite asbestos filters for workplace air, including for dust masks. Asbestos-cement pipe was approved in 1934 by the U.S. Public Service and the American Water Works Association, and by OSHA in 1971. It remains an approved assembly in 35 states and nearly all large U.S. cities, although International Association of Plumbing and Mechanical Officials standards adopted in 1975 prohibit cutting or grinding a-c pipe with power tools.

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Why discuss asbestos filters and asbestos-cement pipe in the same presentation? Because they have related uses historically in public and occupational health types of service, and because the consensus engineering standards for some historically approved assemblies of each included crocidolite asbestos. Both were included in the decision of the U.S. War Department (later Defense) decision to designate chrysotile a critical material for wartime emergency purposes, and crocidolite a strategic material, the highest category for purposes of wartime priority controls and postwar defense stockpiling.[1]

What follows is the historical detail and documentation behind the PowerPoint, which includes only a brief historical overview of both types of asbestos-containing assembly. In this longer version, I go into more detail on how each came to be approved by public and occupational health authorities.

Asbestos Filters in the 19th Century

Asbestos, an expensive and rare material in the early 19th century, was prized by scientists in Europe, Britain and the United States as a filtration material because it is chemically and electrically inert, and forms a fine mesh of fibers for separation of particles or microorganisms from fluids and gases.

Spontaneous Generation and the Germ Theory

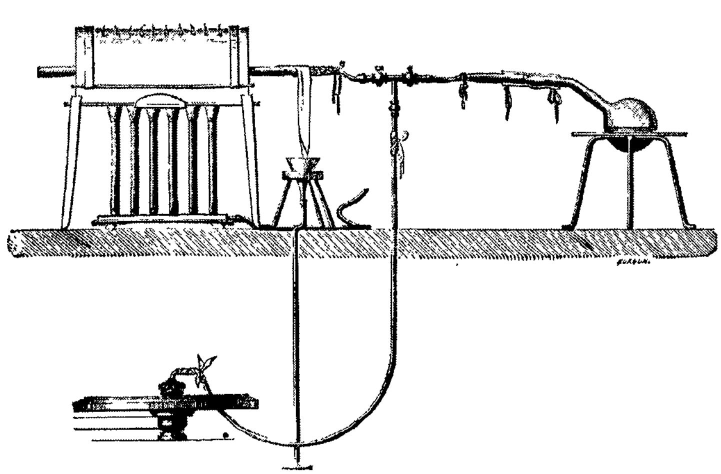
In the 19th century, cities all over the world suffered significant annual mortality from water-vectored diseases, especially cholera and typhoid.[2] Children and the elderly had the highest death rates from these ailments; the poor suffered disproportionately because they were the populations most likely to be living next to fecal-polluted bodies of water. There were two competing dominant theories of disease etiology between late 18th and late 19th century: miasmatism and contagion.

Miasmatists, including, for example, Florence Nightengale, believed that diseases were more prevalent in areas in which miasmas, vapors rising from the ground, were unhealthy.[3] Contagionists believed that persons could be infected by contact with diseased persons, contaminated goods, and fecal-polluted water.[4] John Snow's (1813–1858) experiments in 1854 with the Broad Street pump in London lent increased credibility to the contagionist theory, as did the experiences of cities like Cincinnati, where cholera sickened riverbank communities in droves, but mainly spared those on high ground like Mount Healthy, Ohio, which got its name during the cholera pandemic of 1849-50.[5] It was the end of the century, however, before the medical and public health community on both sides of the Atlantic arrived at consensus on the theory of contagion.[6]

Hippocrates (460 BC-370 BC), who wrote of "Airs, Waters and Places," suggested that some locations were healthier than others. Since this theory was compatible both with contagionism and miasmatism, physicians could not agree on how to interpret the epidemiological data from 18th and 19th century epidemics and pandemics. In part, however, the theory of miasmatism rested on another theory, that of spontaneous generation, which held that disease agents could be generated spontaneously in water and air. Many physicians and scientists, although they were aware that small "animacules" could be observed in water using a microscope (invented by Anton van Leeuwenhoek, 1632-1723), could not believe that such small entities could cause diseases that decimated urban populations.[7]

Louis Pasteur was able to show, in an 1859-62 series of what would now seem to be simple experiments, but which were groundbreaking in his day, that filtered water and air, if kept sealed, did not produce the "animacules" visible in unfiltered water. He argued persuasively that among these "animacules" were the harmful "germs" of disease. Filtering through asbestos removed the microorganisms and purified the water, eliminating the water-borne disease agents. Pasteur had chosen asbestos paper as the filter medium in his demonstrations to other scientists, as he had found through experimentation that the mineral in filter form removed more organic material from water than any other filtration medium. In 1852, the cholera vibrio was identified by the Italian Filippo Pacini (1812-83) as one of these "germs," although it was not until well after Pacini's death that his work was recognized, after publication of Robert Koch's (1843-1910) work on cholera in 1884.[8] The typhoid bacterium was identified in the same decade.

Figure 1: Pasteur's apparatus for disconfirming the theory of spontaneous generation, 1862.



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In the United States, two marker events brought about paradigmatic change in medical and sanitary engineering policy for prevention and control of waterborne disease.[9] The first was the employment of a contagionist strategy by the City of New York in the cholera epidemic of 1866 (known to epidemiologists as the Fifth Pandemic). The second was the disastrous typhoid epidemic of 1885 in Plymouth, Pennsylvania, in which more than 1100 persons of a population of about 8,000 became ill and 114 died.[10]

When the U.S. Public Health Service (US PHS) and the American Water Works Association (AWWA) joined forces to combat water-vectored disease in the United States in the early 20th century, asbestos filters, both in the laboratory and in the field, formed part of the arsenal of sanitation and disease prevention. Since Pasteur's discoveries in 1859, experiments in producing sanitary water filters had been under way in Germany and elsewhere.[11] By the 1920s, US PHS and AWWA were working with the U.S. Bureau of Standards (U.S. Department of Commerce) to develop standards for all aspects of water supply and sanitation, including filtration methods, pipe, plumbing, reservoirs, and sewage treatment and disposal. Many of these standards specified asbestos in one form or another.[12]

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The Gooch Crucible and Chemical Filtration

When Yale chemistry professor Frank Austin Gooch (1852–1929) invented the sintered crucible and test method that still bears his name, asbestos was already, as we have seen, a well-known material for chemical, biological and medical filtration. Dozens of test methods developed by the U.S. Bureau of Standards and other laboratories employed the Gooch crucible, which came to be routinely specified in methods of test.[13] In Professor's Gooch's memorial article in the National Academy of Sciences' *Biographical Memoirs*, his fellow chemist Ralph Van Name characterizes the invention of the Gooch crucible as follows:

> The great value of this device lay in the fact that the filtering medium was a mat of asbestos fiber, introduced in suspension in water and compacted by suction. Not only does this supply an efficient filtering surface unattacked by most acids and readily adaptable to the needs of precipitates of different degrees of fineness, but precipitates which could not be heated in contact with paper fiber without undergoing decomposition could be collected, ignited, and weighed, in the filtering crucible itself, thus greatly simplifying the procedure. Criticised at first by some who attempted to use it with asbestos of inferior quality, but vindicated by the overwhelming

> testimony of others, this device soon became, and still is, one of the indispensable tools of the analytical chemist.[14]

U.S. Public Health Service sanitary engineers Jacob Bloomfield (1897-1977) and Joseph Marius DallaValle (1906-1958), for example, co-authored a 1935 U.S. Public Health Service Bulletin now frequently cited in asbestos litigation, *The Determination and Control of Industrial Dusts.* The authors, however, report the use of the mineral themselves as a filtration agent in gravimetric analysis using a Gooch crucible, on p.43 of the Bulletin.[15]

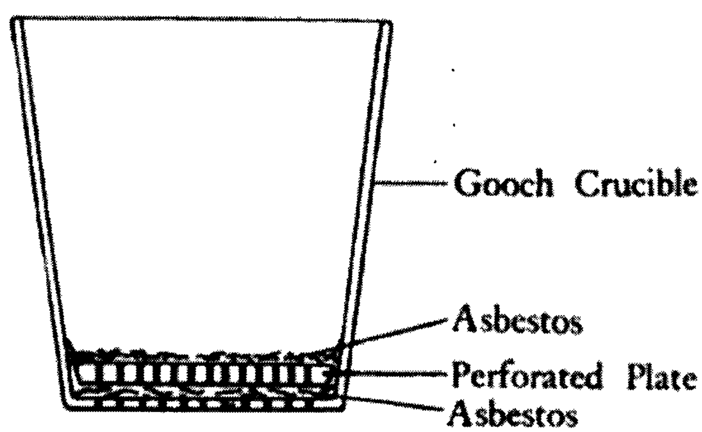
The international movement for standardization of tests and measurements had begun in the 19th century, and had by 1916 resulted in the U.S. in the formation of the American Standards Association, now the American National Standards Institute. ANSI's website describes the organization's history as follows:

> In 1916, the American Institute of Electrical Engineers (now IEEE) invited the American Society of Mechanical Engineers (ASME), the American Society of Civil Engineers (ASCE), the American Institute of Mining and Metallurgical Engineers (AIME) and the American Society for Testing Materials (now ASTM International) to join in establishing an impartial national body to coordinate standards development, approve national consensus standards, and halt user confusion on acceptability. These five organizations, who were themselves core members of the United Engineering Society

(UES), subsequently invited the U.S. Departments of War, Navy and Commerce to join them as founders.

As consensus standards are developed in industrial democracies, test methods must be developed for them to determine whether any given assembly or product complies with the standard. The ANSI (American National Standards Institute) Due Process standard, first promulgated in 1919 and continuously revised since, requires that every ANSI-accredited standard be testable by an approved standard test. Asbestos played a major role in many of these test methods, because it was chemically, electrically and thermally inert.[16] Some types, especially crocidolite, had unequalled properties for filtration.[17]

Figure 2: The Gooch Crucible of 1884, still in use in laboratories today



Asbestos Filters 1900-1945

Between the time of Frank Gooch and the end of World War II, many new uses for asbestos filters in chemistry, physics, medicine, food science, and industrial filtration of liquids and gases were discovered in the Americas and Europe.[18] Asbestos filters were used to remove impurities from textile dyestuffs, and from the linseed oil used in wood finishing, as well as crude petroleum being prepared for storage.[19] Blast furnaces gases were cleaned with asbestos filters, as were boiler water contaminated with oil, and the intermediate products of sugar refining.[20]

Most relevant to this discussion of the evolution of the Kent Micronite™ filter was the development of gas masks, with their requirement for highly sophisticated selective filtration of gases.[21] For example, the gas mask filters used in firefighting were required to allow oxygen (O^2) to enter the lungs, but prevent the passage of carbon monoxide (CO). That this was a scientific challenge may be judged by the fact that neither human lungs nor our red blood corpuscles can make this distinction between the two gases. [22]

After decades of military and civilian research and testing, crocidolite asbestos was chosen by the U.S. Army Chemical Warfare Service as the filter of choice for the American armed forces in World War II.[23] Among the scientists who contributed to the project was Nobel prizewinning chemist Irving Langmuir and Harvard sanitary engineer and industrial hygienist Melvin W. First.[24] As supplies of the mineral from South Africa were uncertain due to enemy action and to diversion of British shipping into military transport, much of the crocidolite used for this purpose in the U.S. was imported from Bolivia.[25] All asbestos was controlled during the war as a critical material, but certain types of crocidolite had the higher status of "Strategic" before 1945. Of this, U.S. Bureau of Mines geologist Oliver Bowles wrote in 1959:

> Long blue fibers are exceptionally well adapted for gas filters. Bolivian blue is preferred for this use. This is the only type of blue fiber that was regarded as strategic during World War II and the early postwar period.[26]

Later in the same report, Bowles notes that

> High-grade tremolite and anthophyllite varieties of amphibole asbestos are more resistant to chemical action than chrysotile. Suitable fibers of these varieties are washed, thoroughly fiberized, and acid-treated to remove soluable impurities. The prepared fibers are used in Gooch crucibles or for other filtering processes employing strong acids or alkalis.[27]

All asbestos was controlled during the war as a critical material; and stockpiled afterwards by the Department of Defense well into the 1980s.[28] Of U.S. efforts to find substitutes for asbestos during World War II, Ann and

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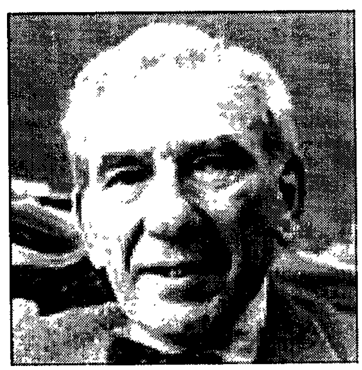
Myron Sutton wrote in *Science Digest* in 1958 that "The trouble is that nothing else is like asbestos, and it thus has specialized uses for which no substitutes are available. It is a tough mineral to duplicate."[29]

Figure 3: Harvard professor of public health, Melvin W. First (1915-2011), who served as an advisor to the U.S. Army Chemical Warfare Service and other U.S. military and nuclear agencies concerned with filtration and air quality.[30]



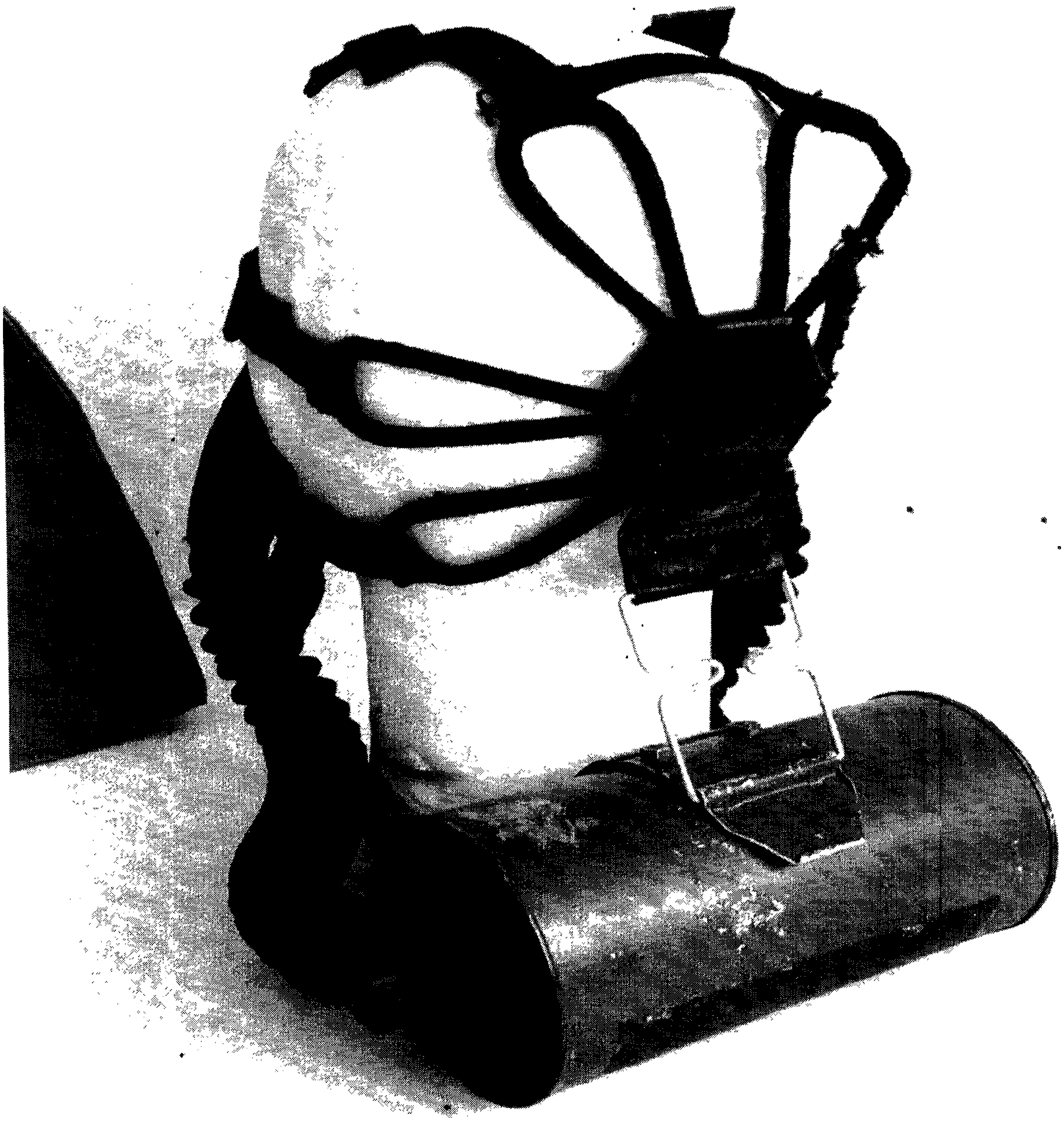
Dr. First, by then at the Harvard Air Cleaning Laboratory in the university's School of Public Health, reported to the 1968 Atomic Energy Commission Air Cleaning Conference that:

> It was found that greatest efficiency could be achieved with either African or Bolivian blue crocidolite which can be reduced to very fine fibers of exceptional length by mechanical beating. ...
>
> In the early days of World War II, the British sent to the

U.S. Army Chemical Corps Laboratories at Edgewood, Maryland, a piece of this paper that had been removed from a captured German gas mask canister. This was just what the Chemical Corps had been seeking for use as a gas mask smoke filter and they, together with the Naval Research Laboratory, proceeded to duplicate it and have it manufactured in large quantities on conventional paper-making machinery by the Hollingsworth and Vose Company. The first successful paper for the U.S. Navy, containing Bolivian crocidolite, was called H-60. The U.S. Army paper, containing African crocidolite, was designated H-64 and later was called Type 6 by the Army Chemical Corps.[31]

Figure 4: Nobel laureate chemist Irving Langmuir (1881-1957)

Figure 5: U.S. military gas mask c1943. The cylindrical component in the foreground contained the asbestos filter.



Asbestos Filters in the Postwar U.S.

In the decision environment of the early 1950s, crocidolite asbestos was highly regarded as a filtration material for fluids and gases by a broad array of scientists and safety professionals.[32] The Atomic Energy Commission, for example, in its 1952 *Handbook on Air Cleaning: Particulate Removal,* prepared by Sheldon K. Friedlander, Leslie Silverman, Philip Drinker and Melvin W. First under the auspices of the Harvard School of Public Health's Department of Industrial Hygiene, described its nuclear-facilities air filters for removal of "poisonous and radio-active dusts" (p.28) as follows:

> Cellulose-Asbestos Paper. At present, the AEC makes great use of CC-6 paper which was originally developed by the Chemical Corps [of the U.S. Army] for use in gas masks. It consists of fine asbestos fibers mixed with coarser cellulose fibers to give mechanical strength and act as a support for the asbestos. The asbestos mesh does most of the filtering. Efficiency is initially high and increases with use. ... Cellulose asbestos paper is expensive and not available in large quantities.[33]

This assembly was published as a military standard in 1954 and revised in 1955.[34] In a 1958 article in the *American Industrial Hygiene Association Journal,* Allan West of the U.S. Army Chemical Warfare Laboratories described the development of the Army's gas mask, including its asbestos filters (see illustration below).[35] The military specification for this type of asbestos filter was still in effect in 1969.[36]

Figure 6: The U.S. Army gas mask filter unit of 1958, with pleated asbestos paper filter manufactured by Hollingsworth & Vose

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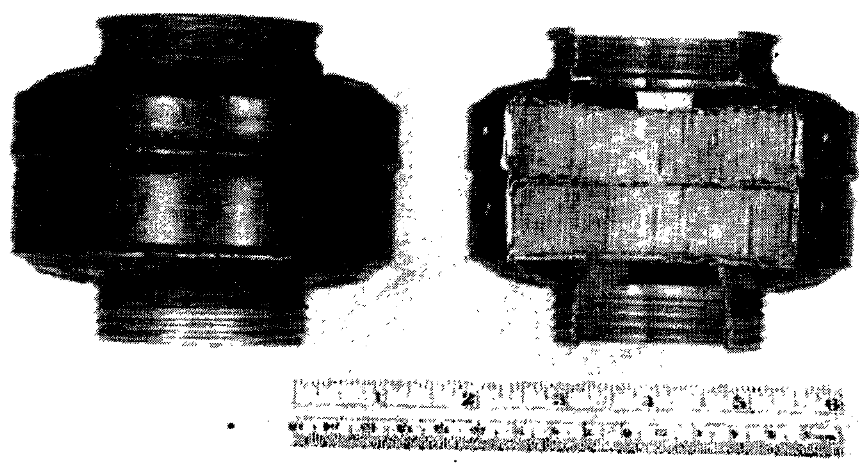

FIGURE 4. E4R5 gas mask aerosol filter

In 1955, British industrial hygienist G. H. Vokes identified the crocidolite/esparto grass filter then in use in gas masks and radioactive-particle protection as an "absolute filter," the most effective available at the time.[37] The following year H. E. Seifert and E. G. Callison described the use of this type of filter in bacteriological hoods, used in the production of vaccines, to protect workers from the pathogens from which both live- and killed-virus vaccines were (and are) made.[38] Henry F. Allen M.D., a bacteriologist at

Harvard Medical School, wrote in a 1959 issue of *JAMA* of the efficiency and effectiveness of pleated "glass-asbestos paper" in removing bacteria from hospital air.[39]

In a U.S. Public Health Service publication in 1962, Herbert M. Decker of the U.S. Army Chemical Corps described the development of crocidolite and esparto-grass filters during World War II for "gas masks and building filtration systems." He too characterized this filter assembly as an "absolute filter," defined as "those that have an efficiency greater than 99.99 per cent for removing bacterial particles having a diameter of one to five microns."[40]

The Chemical Laboratory of the American Medical Association tested the effectiveness of the filters of both the first Kents manufactured in 1952 and a later (1953) modification with a more loosely-packed asbestos filter that improved draw, finding in their July 1953 report that

> The filter of Brand B-1 [the Kent Micronite™] is the most effective in removing nicotine and tars from the mainstream smoke. However, the sample of later manufacture, brand B-2, is much less effective as the filter is more loosely packed, apparently in an effort to improve the smoking qualities.[41]

The Laboratory found that, while both Kent filters were considerably more effective than any of the competitor filter assemblies, B-1 removed 60 per cent of the nicotine and 55 per cent of the tar, but B-2 removed only 41 and 44 per cent respectively. Their tables of results are reproduced below.

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Table 1: Results of AMA Chemical Laboratory, "Study of Cigarettes, Cigarette Smoke, and Filters," published in *JAMA*, 4 July 1954.

TABLE 1.—*Moisture, Nicotine Content, and Physical Characteristics of Four Brands of Cigarettes*

Column	1	2	3	4	5	6	7	8	9
	Type of Filter	Date Sample Obtained	Average Weight of Cigarette, Gm.	Average Weight of Filter-Tip, Gm.	Total Length of Cigarette, Mm.	Average Length of Filter-Tip, Mm.	Average Circumference of Cigarette, Mm.	Moisture in Tobacco, %	Nicotine in Tobacco (Moisture-Free Basis), %
Brand A-1	Paper	May, 1952	1.065	0.165	70.0	11.0	26.0	8.66	1 93
Brand A-2	Fiber	December, 1952	1.123	0.183	69 5	11 3	26.3	9.75	1.92
Brand B-1	Asbestos laminated with paper	April, 1952	1.059	0.159	69.5	10.9	26.7	8.51	1.88
Brand B-2	Asbestos laminated with paper	October, 1952	1.011	0.159	69.5	10.9	26.7	9.84	1.94
Brand C-1	Cotton	May, 1952	1.047	0.168	69.0	16.0	25 3	9.27	2.54
Brand C-2	Cotton	August, 1952	1 033	0 173	69.0	16.0	25.3	10.77	2.44
Brand D	No filter	February, 1953	1.094	.....	70.0	. ..	26 5	10.71	2.02

TABLE 2.—*Analysis of Smoke from Four Brands of Cigarettes*

Column	1	2	3	4	5	6	7	8	9	10
	Weight of Tobacco Actually Smoked (Dry Weight), Gm.	Average Volume of Mainstream Smoke per Cigarette, Ml.	Weight of Nicotine Found in Mainstream Smoke per Cigarette, Mg.		Reduction of Nicotine in Mainstream Smoke, %	Nicotine in Tobacco Actually Smoked Which is Transferred to Mainstream Smoke, %		Weight of Tars Found in Mainstream Smoke per Cigarette, Mg.		Reduction of Tars in Mainstream Smoke, %
			With Filter-Tip Removed	With Filter-Tip		With Filter-Tip Removed	With Filter-Tip	With Filter-Tip Removed	With Filter-Tip	
Brand A-1	0.629	340	2 85	2 60	9	24	21	15.9	15.1	5
Brand A-2	0.660	351	2 82	2 43	14	22	19	16 8	13.9	17
Brand B-1	0 635	328	2.52	1.60	60	21	8	15.0	6.8	55
Brand B-2	0.591	350	2 49	1.47	41	22	13	16.7	9 4	44
Brand C-1	0.681	461	3.91	3.38	14	23	20	18 5	15.6	16
Brand C-2	0.655	415	4.00	2.93	27	25	18	19.6	15.1	23
Brand D	0.635	350	....	2.74 *	..	..	21 *	....	17.8 *	..

* Placed in this column for comparison with full-length cigarettes.

Asbestos-Cement Water, Sewer and Vent Pipe in U.S. Plumbing and Heating Codes

Asbestos-cement pipe for carriage of potable water and waterborne sewage was first considered for use in the United States in 1923, when the United States Public Health Service (US PHS) reported on the use of Eternit™ for water pipe in Italy.[42] The U.S. search for reliable pipe materials received fresh impetus in 1933 from a serious outbreak of amoebic dysentery in Chicago, with 98 deaths, caused by the corrosion and leakage of cast iron sewage pipe into the potable water distribution system in two downtown hotels (see **Figure 11**).[43] Unlike cast-iron and steel pipe, asbestos-cement resisted the "three demons of electrolysis. tuberculation and corrosion" (see figures below.)[44] That corrosion and leakage of cast iron and lead water pipes are still public health issues is evident from the current Flint, Michigan water crisis.

In Flint, the lead seals used historically in cast iron water mains have been steadily corroding since 2014, contributing to the very high lead levels leaching from corroding lead and copper distribution pipes.[45] The AWWA predicts that Flint MI, Jackson MS, and Ithaca NY are only early examples of what has been called an "epidemic of corrosion" of water infrastructure, which will require a national investment in pipe replacement of about $1.7 trillion by 2050.[46] The figures below depict major types of ferrous-metal, copper, and lead pipe corrosion.

All modern industrial democracies worldwide regulate water, sewer and fire suppression pipe assemblies, permitting the installation of only those that have been tested and approved by the authority having jurisdiction. In most of these nations, including the U.S., consensus engineering standards for construction were and are adopted and enforced by a variety of government agencies at all three levels of government: national, state, and local.[47] Lower jurisdictions, such as counties and municipalities, may impose more restrictive local standards than those of higher ones.[48] New York City, for example, has more restrictive construction and public health standards than less urbanized areas of New York State because it is densely populated, with millions of lives, many of them in high-rise structures, at risk from fire, carbon monoxide poisoning, and infectious disease.[49]

Asbestos was specified in a broad range of assemblies in the first three-quarters of the 20th century, approved in accordance with American National Standards Institute (ANSI) due process requirements for standards development, including but not limited to friction products, pipe, fiber reinforcement of plastics, protective clothing, electrical and thermal insulations, welding and cutting gear, filters, conduit, roofing, millboard, gaskets, packing and seals.[50] All were tested and approved by Federally-accredited standards-development organizations, including the U.S. Bureau of

Standards (now NIST), the National Fire Protection Association, the American Society for Testing and Materials, and the American Society of Mechanical Engineers. Assemblies in which asbestos was required by building laws before 1990 include cathodic wrap for underground steel gas pipe, hot-air register insulating paper, and electrical insulation for conductors in switchboards.[51] Compliance with these standards was also required for obtaining the insurance necessary for mortgage financing.[52]

Asbestos-cement pipe was in demand in industrial nations in the 20th century after 1934 because it was a tested and approved assembly, supported by approvals from a wide range of government agencies, independent engineering associations and non-governmental organizations worldwide, including those concerned with public health (see Figure 10, below). Other materials, including fiber glass, did not pass standard engineering tests for fiber-reinforced cement pipe until engineers and scientists had spent many decades seeking to overcome the chemical and regulatory barriers to developing asbestos-free pipe assemblies.[53] Mechanical engineers Reno King and Sabin Crocker, writing of asbestos-cement pipe in the 5th edition (1967) of the *Piping Handbook*, described its "Applications" as follows:

> Asbestos-cement pipe is essentially immune to corrosion in the ordinary sense. It is not subject to electrolysis or to attack in so-called "hot" soils. It does not tuberculate. This pipe will not cause

> discolored water. It is highly resistant to chemical attack, particularly that encountered in sulfate soils.[54]

The U.S. Environmental Protection Agency's Office of Water wrote of pipe standards and approved assemblies in 2000 that:

> Pipe manufacturers follow requirements set by the American Society of Testing Materials (ASTM) or American Water Works Association (AWWA) for specific pipe materials. Specification standards cover the manufacture of pipes and specify parameters such as internal diameter, loadings (classes), and wall thickness (schedule). The methods of pipe construction vary greatly with the pipe materials.[55]

When King and Crocker evaluated asbestos-cement pipe in 1967, it was considerably more expensive to purchase and install than cast iron in equivalent assemblies. The materials and installed-in-trench cost of A-C sewer pipe in 1964, for example, was about 15% higher than that of cast iron, and the price differential was about the same for water pipe.[56] Due to its resistance to corrosion, however, asbestos-cement pipe has proved much less subject to breakage over time in the ground, according to a study by Utah State University Buried Structures Laboratory (see

Figure 7, below).[57] The American Water Works Association reported in 2012 that replacement costs for all three types of iron pipe in use in the U.S. will be higher than for any other type of pipe assembly.[58]

Figure 7: Cost data for sewer construction, from United States. Public Health Service. Division of Water Supply and Pollution Control. *Sewer Construction Cost Index, Construction Cost Trends Municipal Sewers.* Washington, 1964.

Table IV.—Material Cost Data for Category 7 "Pipe in Trench" of a Hypothetical $1 Million Sewer Construction Project

Type of material	Feet of pipe	Unit price	Material price
Vitrified clay	21, 316. 98	$1. 709	$36, 431
Concrete	18, 332. 05	3. 688	67, 609
Cast iron	3, 085. 95	2. 215	6, 835
Asbestos cement	3, 187. 00	2. 5122	8, 006
Totals	45, 921. 98		118, 881

Figure 8: Water pipe main break rates by pipe material, from Folkman, Steven. *Water Main Break Rates in the USA and Canada: A*

Comprehensive Survey. **Logan UT: Utah State University Buried Structures Laboratory, 2012.**

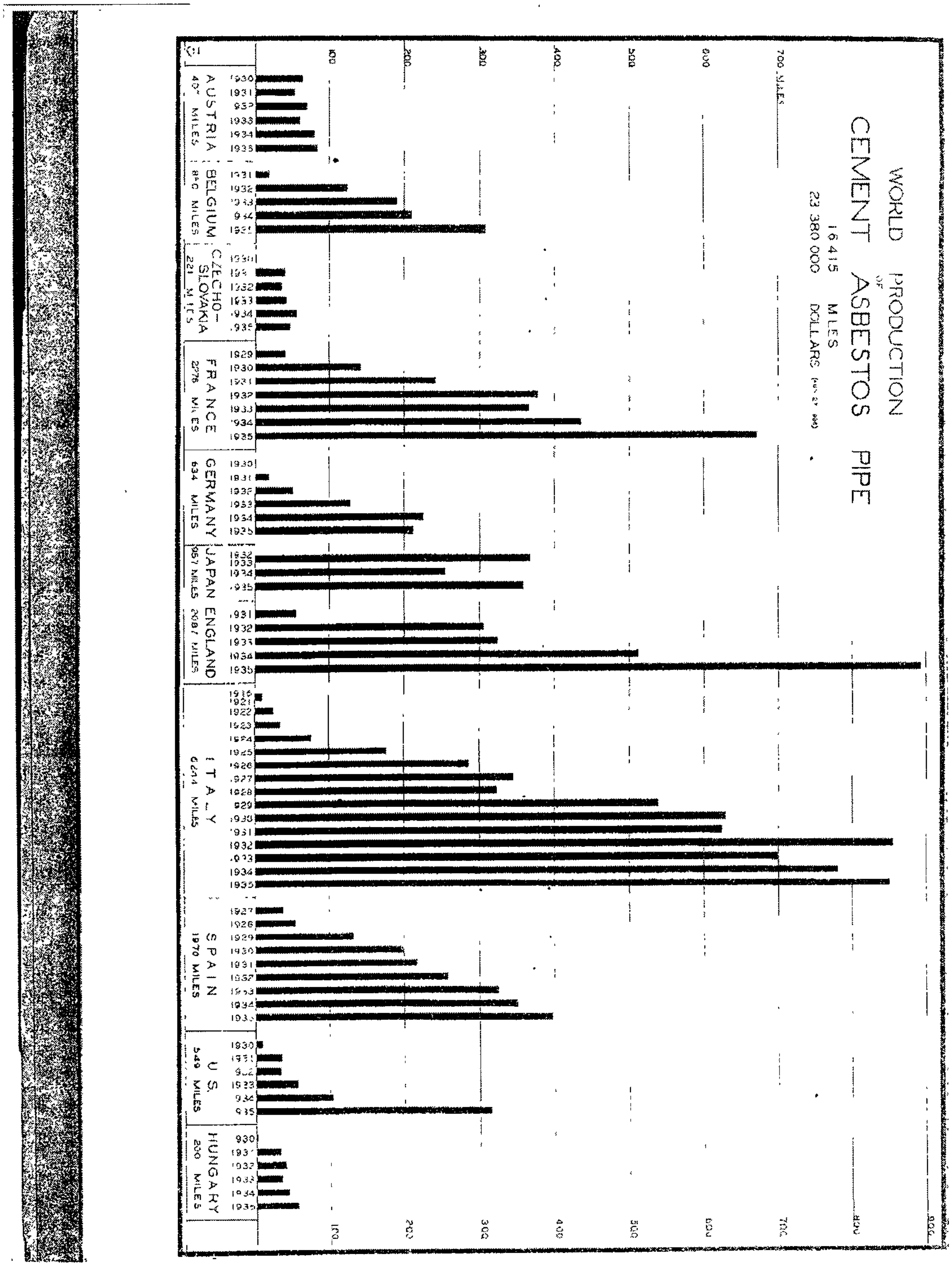
PIPE MATERIAL	LENGTH MILES	NUMBER OF FAILURES	FAILURE RATE #/(100mi)/(year)
CI	33611.0	8204	24.4
DI	33238 7	1620	4 9
PVC	26840 3	689	2 6
CPP	2355.3	128	5.4
Steel	4300.1	581	13 5
AC	13502.8	954	7.1
Other	3755.3	787	21.0
TOTAL	**117603.4**	**12963**	**11.0**

Figure 9: Aggregate Replacement Value of Water Pipes by Pipe Material and Utility Size (millions 2010 $s), from AWWA report *Buried No Longer*, 2012.

Region	CI	CICL	DI	AC	PV	Steel	PCCP	TOTAL
Northeast Large	48,958	8,995	5,050	2,308	1,875	335	0	67,522
Northeast Medium & Small	66,357	61,755	28,777	26,007	16.084	5,533	6,899	211,411
Northeast Very Small	14,491	15,992	10,661	7,281	7,937	329	462	57,152
Midwest Large	37,413	9,151	3,077	2,504	1,098	784	512	54,539
Midwest Medium & Small	74,654	92,106	51,577	37,248	30,506	8,682	11,152	305,925
Midwest Very Small	37,597	28,943	25,464	12,428	19,720	601	828	125,581
Southeast Large	30,425	28,980	29,569	21,229	14,936	9,337	7,227	141,703
South Medium & Small	54,772	98,608	140,079	103,659	102,804	21,394	17,160	538,475
South Very Small	43,183	24,998	49,791	34,529	47,823	1,461	1,244	203,028
West Large	15,448	16,055	28,949	14,774	14,723	7,443	6,215	103,607
West Medium & Small	15,775	50,145	70,355	50,541	48,885	12,276	9,806	257,782
West Very Small	16,344	11,199	17,910	13,166	17,245	545	453	76,862
Total	455,416	446,927	461,258	325,674	323,637	68,719	61,957	2,143,589

CI: cast iron; CICL: cast iron cement lined; DI. ductile iron; AC asbestos cement; PV. polyvinyl chloride, PCCP: prestressed concrete cylinder pipe

Figure 10: World production of asbestos-cement pipe through 1935



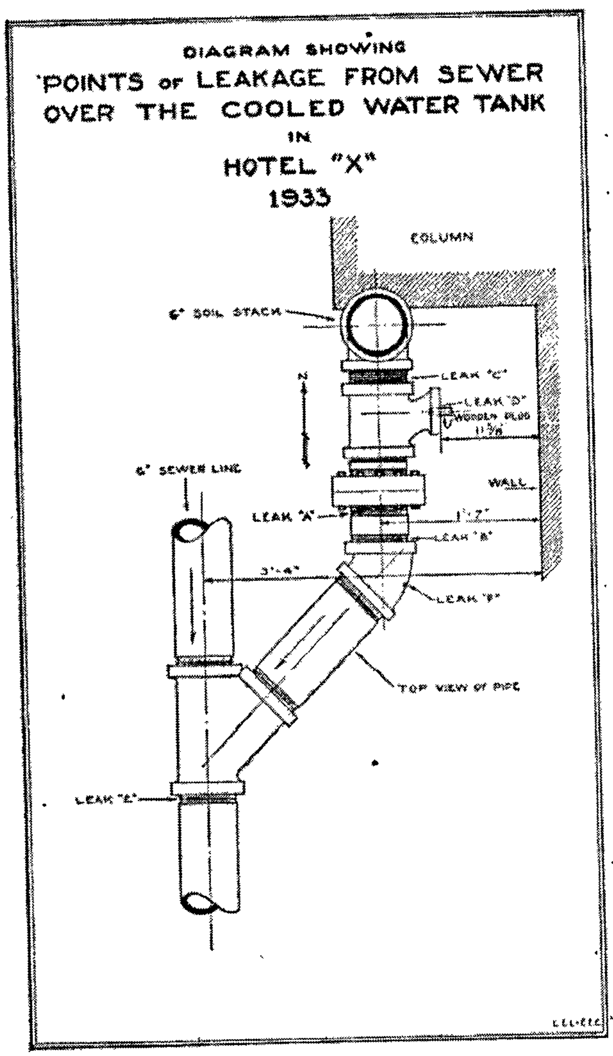
"As Near Perfect as We are Likely to Get"

Standards development organizations worldwide in the 20th century, including AFNOR in France, the British Standards Institute in the UK, and the member organizations of the American National Standards Institute in the U.S., formed technical committees, which included state authorities, academics, scientists from independent testing laboratories, public health professionals, insurers, and minority representation (limited to 30% of membership) from manufacturing industry, to consider and develop technical standards that were adopted into national, state or departmental, and local laws.[59]

Building and plumbing codes, and the engineering standards incorporated into them, were developed in Western industrial nations for the purpose of preventing harm to citizens from defects in, or failures of, the built environment.[60] Until the end of the 20th century, and in some cases beyond, asbestos was specified and approved and in code-compliant assemblies in the U.S., Europe and elsewhere that passed inspections by the authorities having jurisdiction (AHJs).[61] Asbestos-cement pipe, heating vent and electrical-conduit assemblies underwent this process, in essence a form of peer review for technology, in the mid-20th century, after asbestos-cement pipe was first introduced from Europe in 1931, where asbestos-cement was already approved for water, sewer and gas pipe, conduit, roof coverings, vents, and even garbage chutes (see Figures and captions below).

"As Near Perfect as We are Likely to Get"

Figure 11: Leakage of sewage from cast iron pipe caused an epidemic of amoebic dysentery in Chicago, Illinois, in 1933, in which 98 persons perished.



epidemic this leakage was an important factor.

The more important reasons are the large number of infections among guests at hotel X on June 28 and 29, and a relative lack of infections among guests at hotel Z; also the excessive rainfall on the evening of the latter date which contributed to flooding of the sewer system of hotel X, which probably caused heavy pollution of this special drinking-water system.

The points of leakage in the branch sewer over this water tank are shown in figure 22. They were around a wooden plug in a cleanout Y and holes in the pipe due to corrosion, particularly at threads. Because of the insulating pipe covering on this sewer, the leaks due to corrosion are not considered to have been as serious as the one around the wooden plug.

Apparently at some time the branch sewer over the

Figure 12: Electrolytic corrosion of underground steel pipe. In the 20th century, asbestos-cement pipe was often used in underground service because it was not subject to any of the three major types of corrosion. Note caption in original regarding rate of corrosion without cathodic protection. From Wright, John E. *Practical Corrosion Control Methods for Gas Utility Piping*. Kansas City, Mo.: Gas Service Co., 1981: 1.

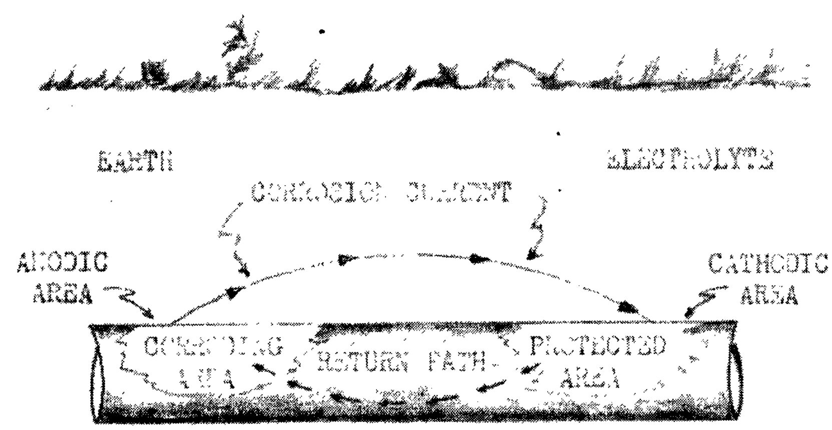


FIGURE 1 — One ampere of corrosion current flowing for one year will consume 20 lb of steel.

Figure 13: Corrosion of metal water pipes in Flint, Michigan, 2015, from Edwards, *Flint Water Study.* Asbestos-cement pipe is highly resistant to chemical corrosion.

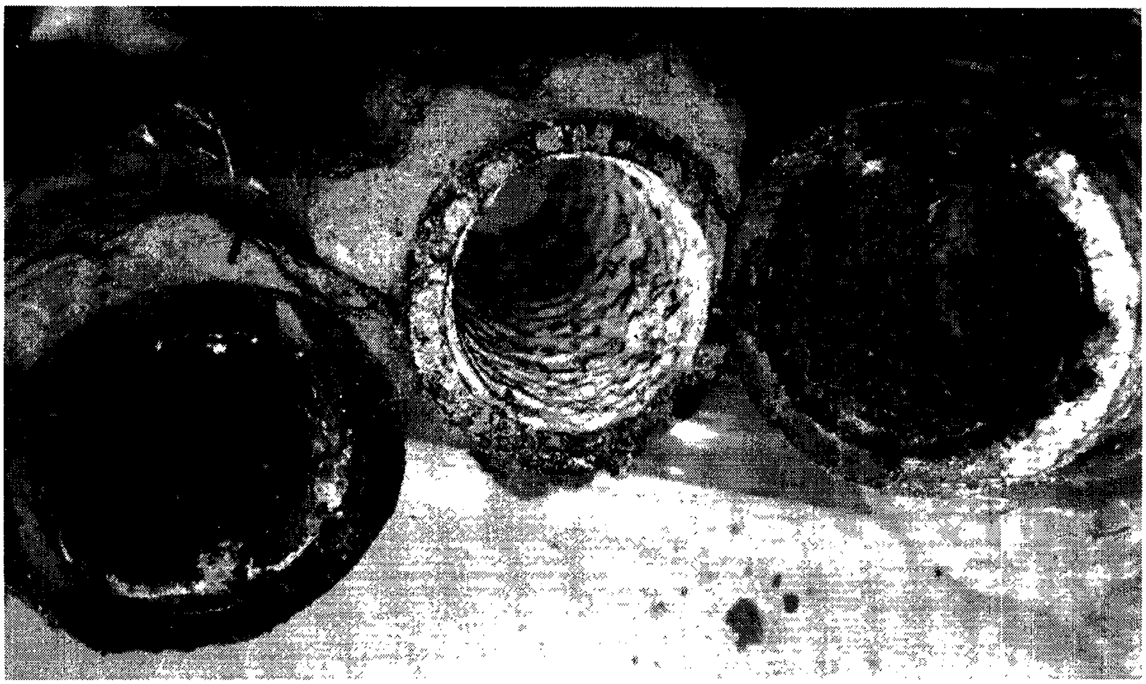


Figure 14: According to the Colorado Geological Survey, this cast iron water pipe required replacement after only 8 years in the ground, in an area of the state with chemically aggressive water and soil.

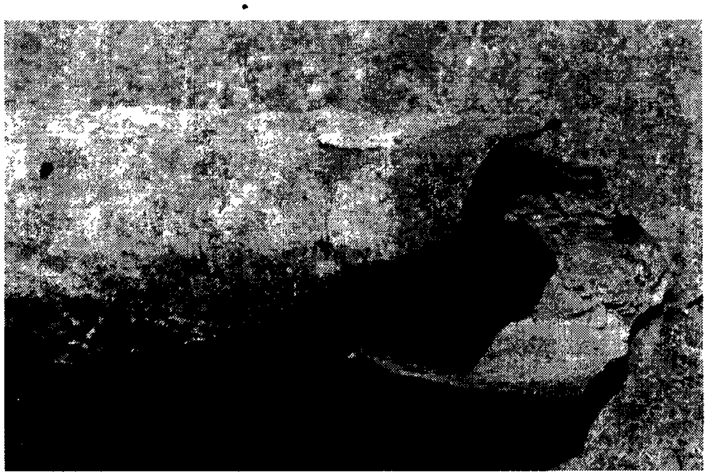


Figure 15: Tuberculation of the interior of ductile iron pipe. Asbestos-cement pipe is not subject to this type of corrosion, although certain types of "soft" waters will weaken it over time.

Figure 16: Corrosion of carbon steel water pipe after 20 years in service.

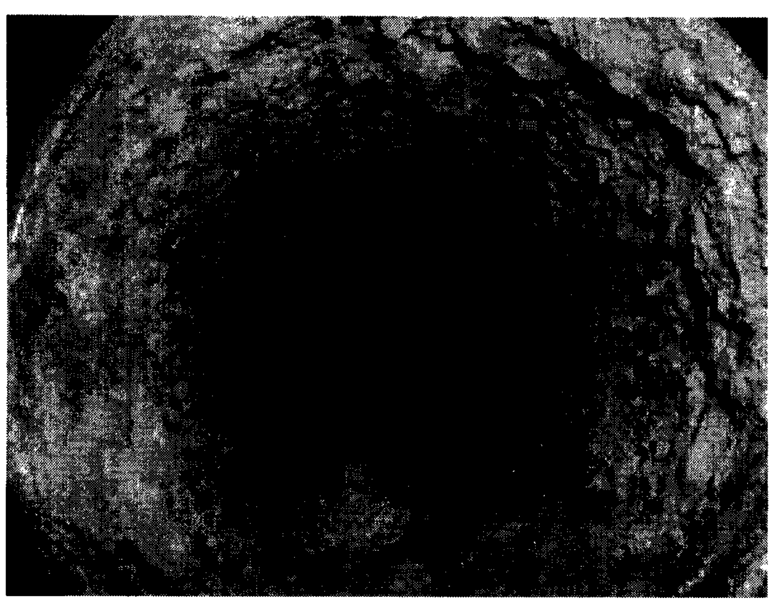


Figure 17: Corrosion of copper water pipe. Lead in joints in this assembly leaches into drinking water if measures are not taken to control chloride levels in the water.

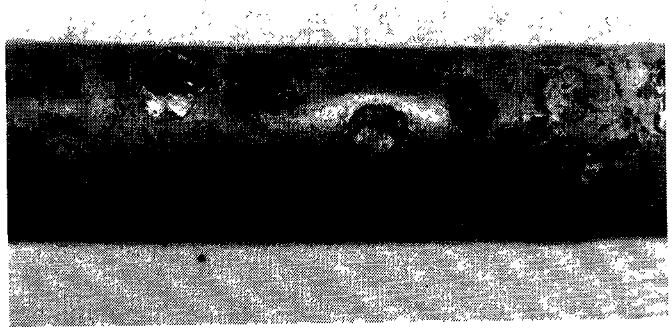


Figure 18: Tuberculation and corrosion to failure of lead pipe, from http://www.terz.ch/restaur/zinnpest_e.htm.

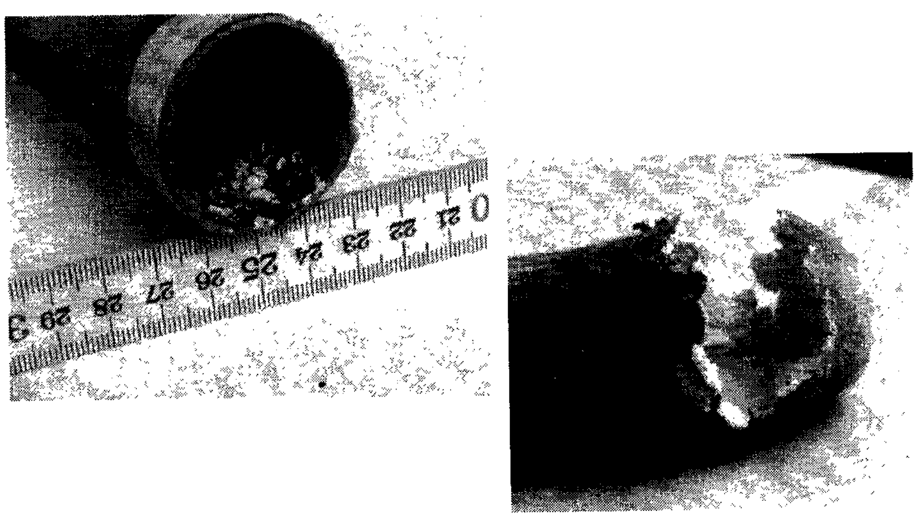


Figure 19: Vitrified clay pipe is approved only for wastewater (sewage, stormwater, and process waste systems), as its bursting strength is under 50 psi. It is rarely used in diameters under 6 inches. Advantages are very high resistance to chemicals, including acids, and long service life; disadvantages include weak mortar joints, brittle qualities in shear loading, seismic vulnerability, short lengths that increase installation cost, and high purchase price, especially in the larger diameters.[62] The beaded streams of water at bottom center are indications that this pipe is leaking at the joints. Image from Trelleborg.

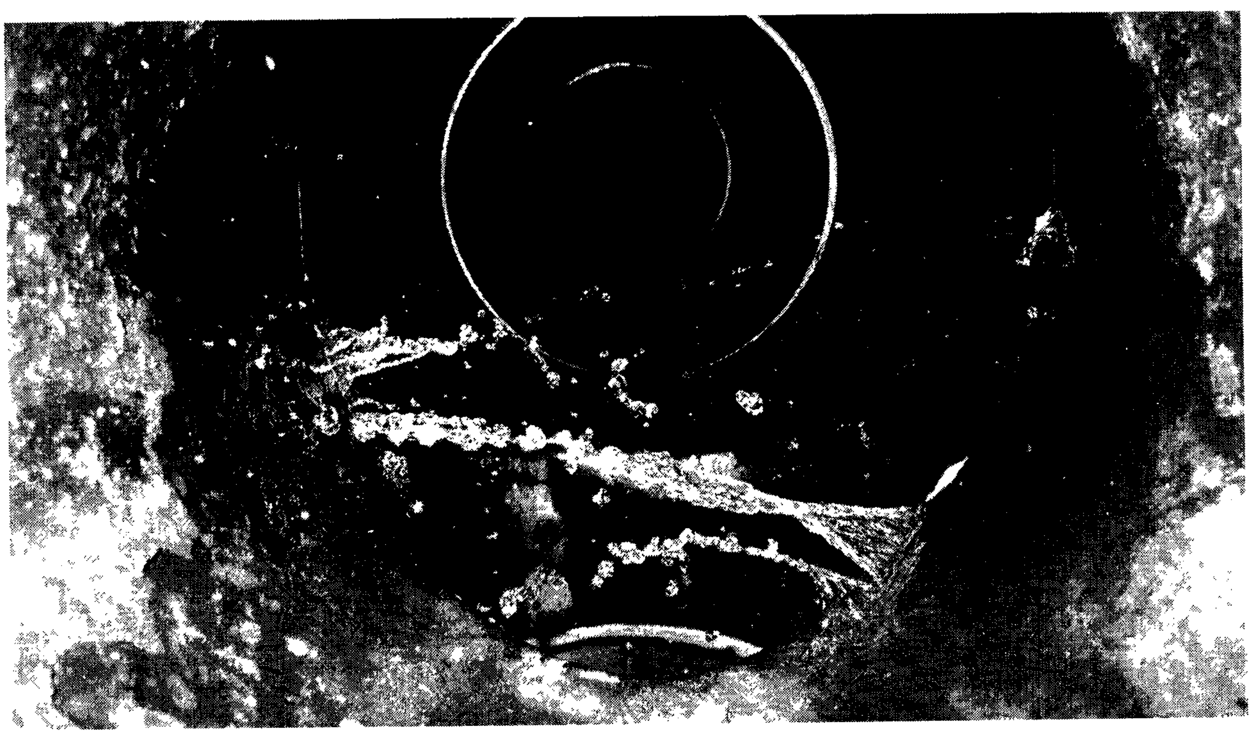
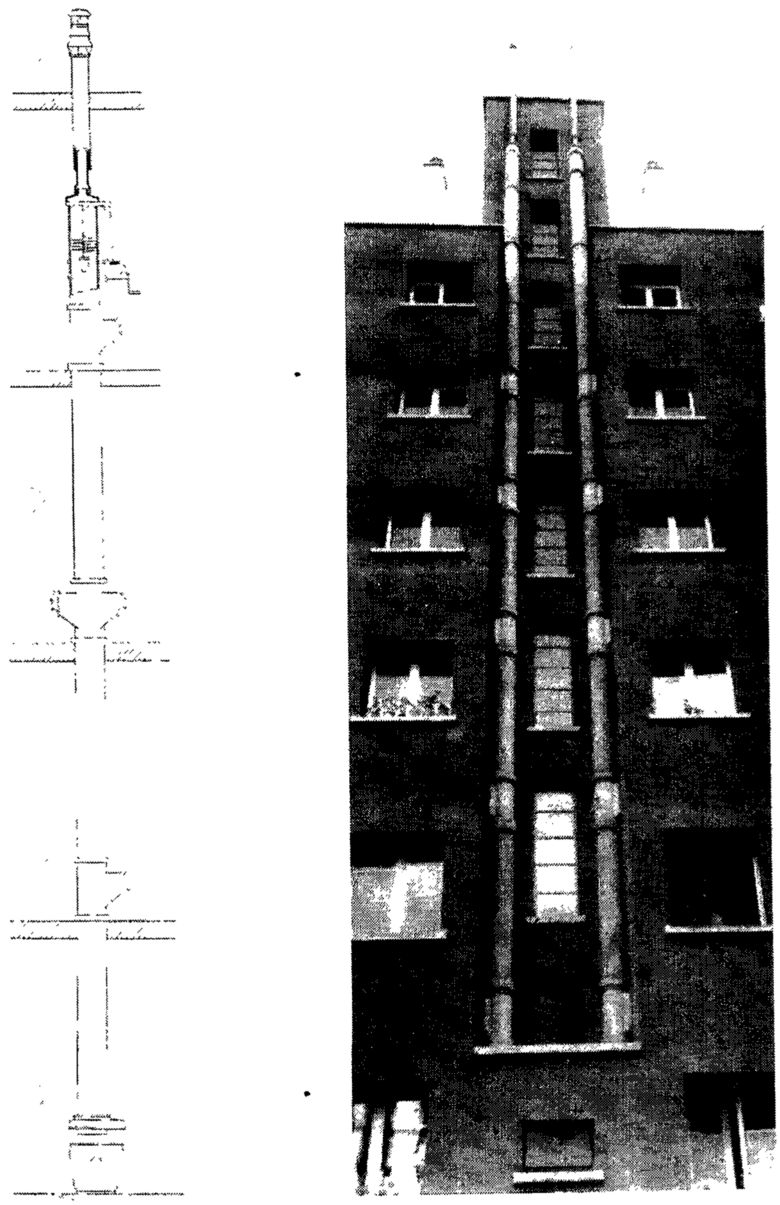


Figure 20: Officially-approved asbestos-cement refuse disposal chutes installed in apartment complex in Bondy (Seine), France, in 1964.



Standards and Approvals for Asbestos-Cement Water Pipe

The approvals process for asbestos-cement water pipe under the British Standards system in the UK was well under way by 1930, with British and American sanitary engineers sharing experiences, test results, and engineering configurations.[63] The American Water Works Association (AWWA) began the standards development process for asbestos-cement water pipe in 1934, although the first adopted standard was not published until close to the completion of a long-term testing program, described below.[64]

During World War II, cast-iron pipe was not available for expansion or repair of existing water and sewer systems, as both iron and steel were on the strategic materials list.[65] Asbestos-cement pipe was therefore in demand, but as in all other wartime manufacturing in combatant nations, the military had priority over civilian uses of pipe.[66]

Meanwhile, a number of real-life experiments by both civilian and military authorities suggested that asbestos-cement pipe and conduit had a variety of uses in peace and war.[67] Sixty-two thousand feet of asbestos-cement water pipe, for example, were installed in the late 1930s in the cinder-filled (and therefore highly alkaline) salt marsh known as Flushing Meadow for the 1939 "World of Tomorrow" World's Fair in New York City. Tests in 1942 by the

Borough of Queens engineer revealed that the pipe remained uncorroded despite the harsh underground conditions.[68]

Asbestos Magazine received reports during the war that "Asbestos-Cement pipe used in certain bombed zones has shown little, if any breakage from concussion."[69] To conserve strategic steel and iron in the war years, asbestos-cement sheet and pipe were used in temporary structures in Britain, Canada and the U.S., including in military training camp construction.[70]

The constraints of the Great Depression and World War II prevented the formation of a formal AWWA technical committee on A-C pipe until 1949, after which the consensus process of developing, approving and publishing a tentative standard for asbestos-cement water pipe moved rapidly to completion by May 1953, with the release of AWWA C400-53T.[71] Selection and installation standards for asbestos-cement water pipe, developed in cooperation with IAPMO, US PHS, FHA, the U.S. Navy, ASTM and ANSI, were approved as tentative standards in 1964 and as adopted standards in 1965.[72] Meanwhile, in the four decades between 1930 and 1970, testing, approval and installation of asbestos-cement pipe was progressing in France, Germany, Argentina, Holland, Brazil, Canada, Australia, New Zealand, Russia, Hungary, and Sweden as well as Italy and the UK.[73] An installation standard for asbestos-cement pipe was developed by AWWA and ASTM by 1964, which by 1978 had been expanded into an AWWA-sponsored manual of safe work practices for asbestos-cement, which, after 1975, included IAPMO Installation Standard 15 (see Figure 21 below).[74]

Testing of underground pipe under hundreds of different soil conditions had begun at the U.S. National Bureau of Standards in 1912.[75] A new series of tests, including tests of asbestos-cement pipe, was initiated in 1937 in conjunction with US PHS, the Federal Housing Administration, and the AWWA, which continued until 1957.[76] The US PHS specified and approved asbestos-cement pipe in the National Plumbing Codes of 1949 and 1962 as well as subsequent editions.[77]

The standards for asbestos-cement water, sewer and pressure pipe in force in the U.S. in the 1980s were as follows:

- ASTM C 296 Standard Specification for asbestos-cement pressure pipe.
- ASTM C 428 Standard Specifications for asbestos-cement nonpressure sewer pipe.
- ASTM C 500 Standard Methods of testing asbestos-cement pipe.
- ASTM C 508 Standard Specification for asbestos-cement perforated underdrain pipe.
- ASTM C 644 Standard Specification for asbestos-cement small- diameter nonpressure sewer pipe.
- AWWA C 401 Standard practice for the selection of asbestos-cement

distribution pipe, 4 in. through 16 in. (100 mm through 400 mm), for water and other liquids.

- AWWA C 402 Standard for asbestos-cement transmission pipe, 18 in. through 42 in. (450 mm through 1050 mm), for potable water and other liquids.
- ANSI/AWWA C603 Standard for installation of asbestos cement pressure pipe.
- IAPMO IS 15 Standard for installation of asbestos cement pipe, which prohibits the use of power tools in the field installation. Hand tools only were approved for cutting and beveling of asbestos-cement pipe. This standard was developed and adopted by the International Association of Plumbing and Mechanical Officials in the early 1970s, and was incorporated into the *Uniform Plumbing Code* in 1975. A page from the 1981 edition of IS 15 is included below as Figure 21.[78]

"Hand tools" have been defined in Federal labor law since 1938 as those without a source of power other than that of the human users.[79] It was necessary to make this rule early on in Federal occupational safety regulation because workers under 18 years of age were and are prohibited from using most kinds of power tools, including power saws, cement mixers, meat slicers and trash compactors.[80]

Figure 21: IAPMO Installation Standard for Asbestos cement pressure pipe for water service and yard piping, 1981.

ASBESTOS CEMENT PRESSURE PIPE FOR WATER SERVICE AND YARD PIPING 99

end of the pipe only, never to the rubber gasket or groove, unless specifically recommended otherwise by the manufacturer.

802.2.2 The end of the pipe and the coupling or fitting bell shall be assembled using a bar and wood block or a pipe puller. "Stabbing" or "popping" the pipe into the coupling (pipe is suspended and swung into the bell) is not recommended.

802.3 When a field cut is made, cut the pipe square, using hand pipe-cutters which use a cutting edge, or hand saws. To properly enter the rubber gasketed joint, the end of the pipe must be machined before insertion, using hand machining tools.

1004 Materials

1004.1 **Location.** AC piping shall be installed only outside the foundation of any building or structure or parts thereof. It shall be buried in the ground for its entire length with cover as provided in Sec. 317.1. It shall not be installed within or under any building or structure or mobile home or commercial coach or parts thereof. The term "Building or structure or parts thereof" shall include structures such as porches and steps, roofed porte-cocheres, roofed patios, carports, covered walks, covered driveways and similar structures or appurtenances.

1008 Installation, Testing and Identification

1008.1 Installation

1008.1.1 **Alignment and Deflection.** Pipe and fittings shall be aligned properly without strain. Pipe may be deflected in accordance with the manufacturer's recommendations provided that it shall not be permanently staked or blocked to maintain this deflection. If soft soil conditions exist, deflected joints may be permanently blocked or staked to maintain the deflection. The amount of deflection shall be: 5° for sizes 4" (101.6 mm) through 12" (304.8 mm); 4° for 14" (355.6 mm) and 16" (406.4 mm); 3½° for 18" (457.2 mm) through 24" (609.6 mm) for pipe belled on the job site. For factory-belled couplings, one half (½) the above deflections by size shall be allowed.

1008.1.2 **Working Pressure.** Maximum working pressure shall be as follows:

MATERIALS, SIZES AND MAXIMUM WORKING PRESSURES

PIPE	SIZES	MAXIMUM PRESSURE
Class 100	4"-24" incl. (101.6-609.6 mm incl.)	100 psi (689 kPa)
Class 150	4"-24" incl. (101.6-609.6 mm incl.)	150 psi (1378 kPa)
Class 200	4"-24" incl. (101.6-609.6 mm incl.)	(200 psi (1378 kPa)

1008.1.3 **Laterals and Saddles.** Installation of laterals, saddles or tapped couplings in AC piping shall be as required by their listings.

Standards and Approvals for Pressure, Process and Sewer Pipe

As the name implies, pressure pipe is intended for use with liquid contents that are moved by the action of one or more pumps, rather than that of gravity, which is the motive force of the contents of nonpressure pipe.[81] Process (industrial) and sewer pipe were (and, in some nations, still are) manufactured in both pressure and nonpressure assemblies. Both assemblies are made in Types I and II, in which the latter has chemical requirements that require a different cement/asbestos formulation from Type I.[82] Type I a/c pipe must pass only the four major test arrays enumerated in ASTM Standard C 500, *Standard Methods of Testing Asbestos-Cement Pipe,* for hydrostatic proof (resistance to leakage and weeping in service), flexure (resistance to transverse bending loads), straightness (deviation along the length of the pipe), and crushing strength (resistance to collapse under external loading).[83]

Type II a/c pipe must also pass a test for uncombined calcium hydroxide, which measures chemical resistance.[84] Over a period of several decades of testing in the 20th century, chrysotile alone in Portland cement did not pass this test; crocidolite, which is one of the most chemically-resistant materials known, was added to the Type II formula in order to comply with the standard of chemical test.[85] U.S. Bureau of Mines mineralogist Oliver Bowles (1877-1958), writing of this in a 1959 strategic defense survey of the mineral, asserted that "Crocidolite (blue asbestos), mined in Africa and Australia, is regarded as a necessary constituent of asbestos-cement pipe."[86] The chemical aspects of this use of crocidolite are explained in detail in Professor-Dr.-Ing. Kurt Hünerberg's magisterial study of asbestos-cement pipe, published in German in 1963, 1968 and 1977, in Russian in 1968, and in French in 1971.[87]

Type II asbestos-cement pipe was used for underground service in which corrosion by pipe contents (including sewage) and/or by aggressive waters, salinity, or "hot" (alkaline) soils are significant issues.[88] It was also used extensively for electrical and telephone line conduit and heating equipment vents (see next section).

Figure 22: Brennan and Nemerow's asbestos cement pipe testing apparatus, Syracuse University, 1963.

also cut from the pipes for use in small-scale sodium sulfate exposure tests and for acid-resistance tests.

The remaining eight pipes of each group were exposed to sodium sulfate solution for 28 days. Four pipes designated series A were submerged in a solution with an initial concentration of 0.15*M*. In this series the concentration increased because liquid lost through evaporation was replaced with 0.15*M* solution. Four members designated as series B were exposed to a 0.15*M* solution that was maintained at constant concentration by replacing the evaporation losses with water.

To ensure uniform initial environmental conditions, these pipe specimens were placed in an air-conditioned constant-temperature atmosphere for 3 days prior to submerging them in sodium sulfate solution. Stainless steel bolts inserted into drilled and tapped holes in the pipes were used as gage points. The hexagonal heads of these bolts projected above the pipe surface far enough to measure changes in length over a gage length of about 34 in. Measurements between the stainless steel inserts were made with a vernier caliper that was frequently standardized against an Invar steel bar maintained at constant temperature in an ice water bath.

These specimens were subjected to a daily cycle consisting of complete submersion in the solution for 16 hr (Fig. 1) and 8 hr of drying in a forced warm-air cabinet (Fig. 2). Lengths between gage points were measured at the beginning of the 28-day period and after soaking and after drying at 7, 14, and 28 days. Elongations due to exposure to sodium sulfate are shown in Table I. These values are measured after the drying portion of the cycle.

After exposure all specimens were tested in bending to evaluate the effects of 28 daily cycles on strength and stiffness. These data on exposed pipes were compared with the data on the unexposed controls. There was no

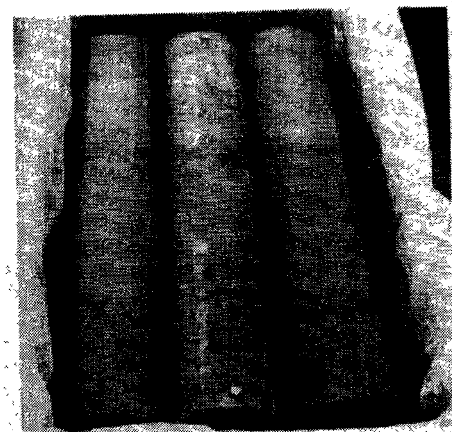


Fig. 1—Pipe specimens submerged in sodium sulfate solution.

TABLE I—LONGITUDINAL ELONGATION OF PIPE SPECIMENS, AVERAGE OF EACH GROUP.

Pipe Group Designation	Uncombined Calcium Hydroxide, per cent	Acetic Acid Solubility, g per 100 sq cm	Total Elongation, per cent: Series A, 7 days	Series A, 14 days	Series A, 28 days	Series B, 7 days	Series B, 14 days	Series B, 28 days
I	1.27	0.0251	0.133	0.112	0.115	0.131	0.113	[illegible]
II	2.94	0.07195	0.078	0.086	0.098	0.029	0.029	[illegible]
III	3.65	0.07732	0.080	0.091	0.102	0.026	0.022	[illegible]
IV	5.70	0.07598	0.048	0.051	0.043	0.018	0.018	[illegible]
V	5.76	0.08055	0.060	0.066	0.077	0.053	0.053	[illegible]
VI	11.75	0.09594	0.063	0.064	0.065	0.017	0.011	[illegible]

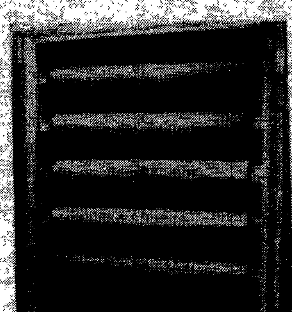


Fig. 2—Pipe specimens in drying cabinet.

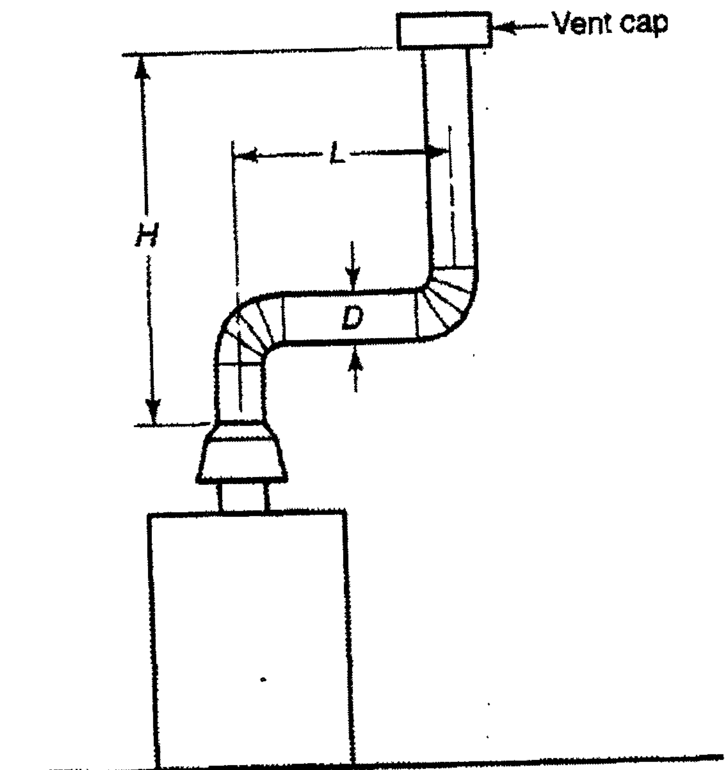
Fig. 3—Pipe specimen in loading frame in testing machine.

Standards and Approvals for Heating Vent Pipe

Asbestos-cement vent pipe for heat-producing equipment was and is approved by the *Uniform Plumbing Code*, and by European codes until the mid-to-late 1990s.[89] These assemblies are still code-compliant under the current (2012) *International Plumbing Code*, the successor to the *Uniform Plumbing Code.*

Historically, these assemblies were also compliant with heating codes such as those of the American Gas Association, that of the former National Board of Fire Underwriters (now the American Insurance Association), and that of ASHVE/ASHRAE.[90] The purpose of the asbestos in asbestos-cement heating equipment vents was to prevent thermal cracking of the cement, which would have allowed leakage of carbon monoxide, produced by incomplete combustion of fuels, through the fissures into living spaces.[91] Asbestos fabric or rope seals were used as vibration isolation connectors in heating duct systems for the same reason.[92]

Figure 23: Asbestos-cement water heater vent, from the 2009 *Uniform Plumbing Code*: 99.



Asbestos cement Type B or single-wall metal vent
serving a single draft-hood-equipped appliance.
(See Table 5-12)

FIGURE G.1(e) Asbestos Cement Type B or Single-Wall Metal Vent System Serving a Single Draft-Hood-Equipped Appliance.

Figure 24: French specification for the finial tee of an asbestos-cement smoke vent (*conduit de fumée*), from Charlent, Henri. *Traité Pratique de Plomberie et d'Installation Sanitaire: Comportant la Réglementation des Installations d'Eau et de Gaz dans les Immeubles d'Habitation.* 11e éd. mise à jour. ed. Paris: Garnier frères, Impr. Tardy-Quercy-Auvergne), 1972. Asbestos-cement was the only approved material for this assembly because of concerns about carbon monoxide leakage.

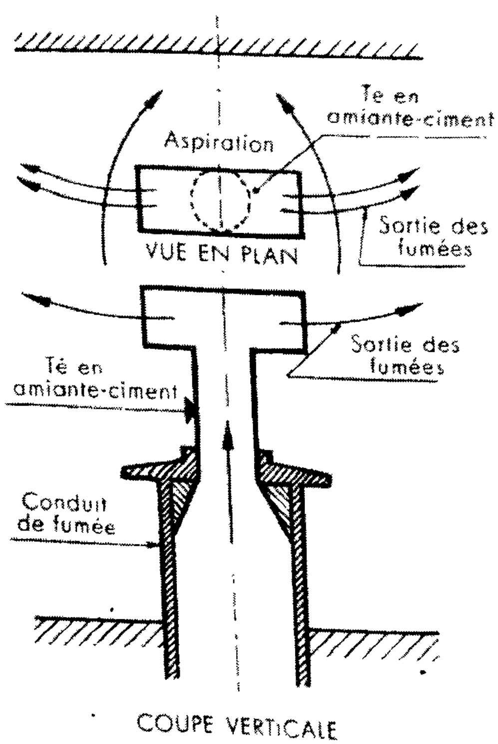


FIG. 960. — Té en amiante-ciment.

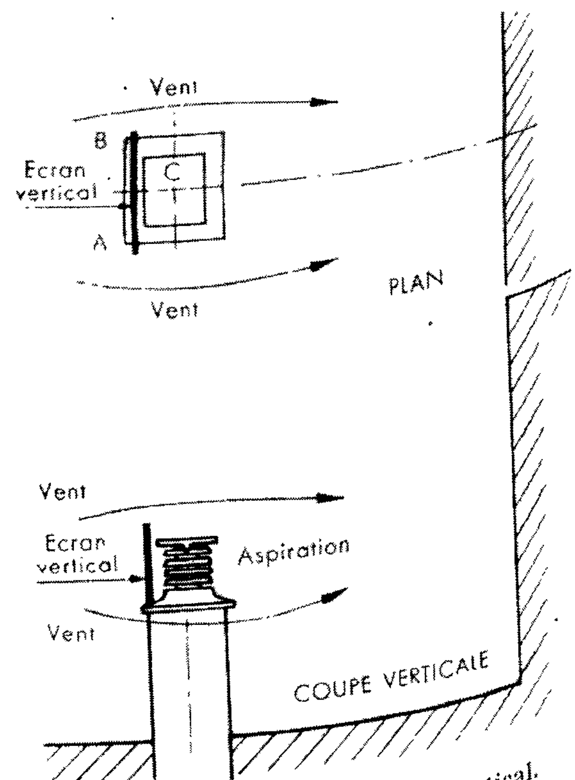


FIG. 961. — Écran vertical.

The PVC Controversy

Polyvinyl chloride (PVC) for pipe is first attested in American engineering literature in 1950, when *Gas Age* published an article about a recently-introduced anticorrosion PVC-film tape for underground pipe.[93] The American Society for Testing Materials (ASTM) was, in that year, testing various types of plastic pipe for possible use in industrial processes involving hydrofluoric acid; similar research was undertaken in Germany and reported in 1951.[94] Testing of PVC for water and sewer pipe was underway in the U.S., Europe and elsewhere by 1954, and continued through the 1960s.[95]

Britain approved PVC for cold water pipe in 1962, and revised the standard in 1968.[96] In-service and fire toxicity of PVC were explicitly addressed in some (but not all) of these testing programs.[97] The U.S. Bureau of Standards (Department of Commerce) published a standard for PVC "drain, waste and vent pipe" in 1965, and the American Water Works Association issued a standard for PVC pressure pipe ten years later.[98] Some jurisdictions had approved the use of PVC in a few types of process, water, and sewer service by the time of publication of the International Association of Plumbing and Mechanical Officials' (IAPMO) 1979 *Uniform Plumbing Code Illustrated Training Manual.*[99]

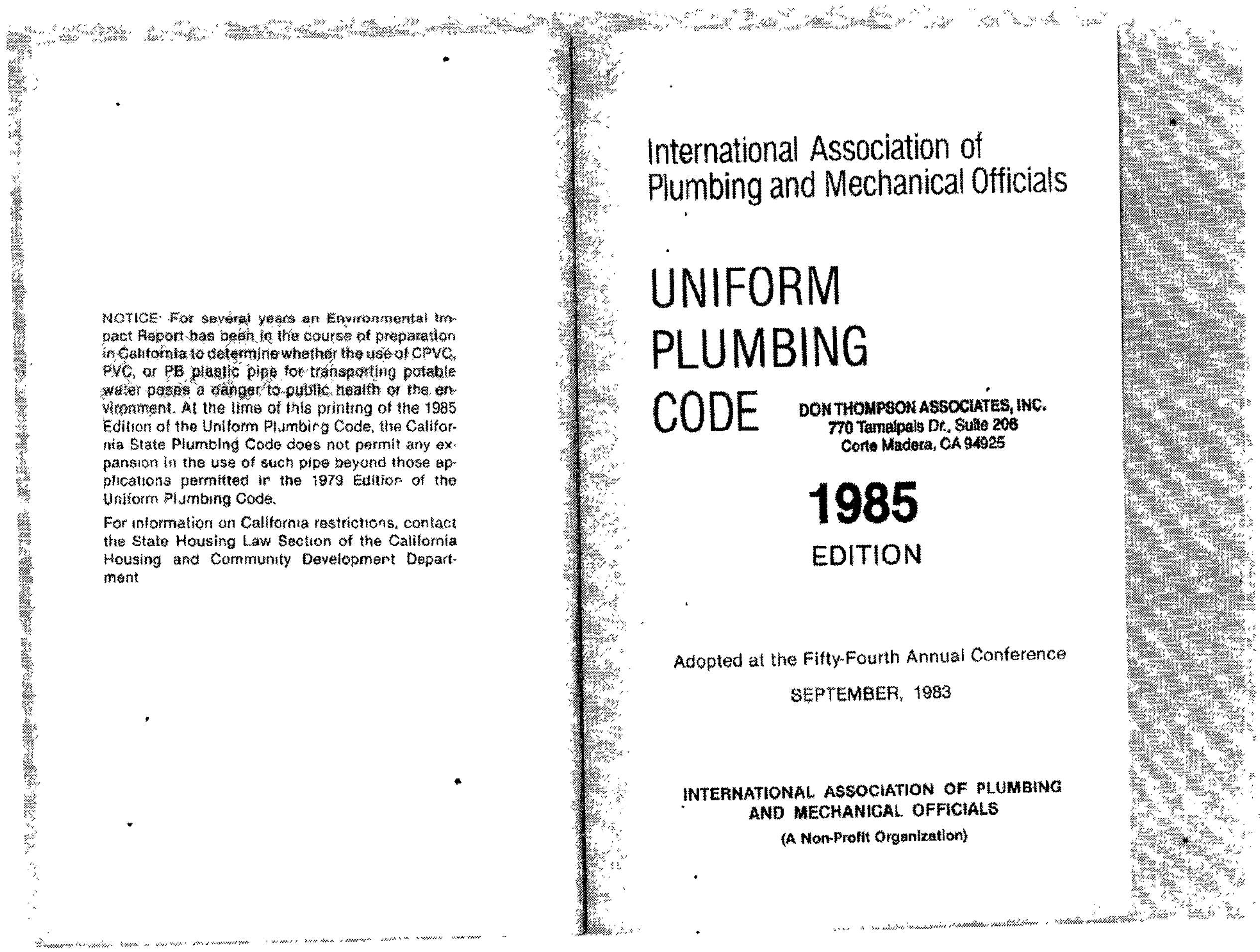
The adoption of PVC in the 1980s, however, was controversial. Donald

Goodman *et al.* reported in 1987 on the opposition to PVC in California that had resulted in the limitation of state approvals:

> In California, the plumbers union and others alleged that plastic potable water pipe (PVC, CPVC, and PB) poses health risks. They have blocked the expanded use of plastic pipe by forcing an environmental impact report (EIR) to be completed. The EIR is now in its seventh year, and the California Department of Housing and Community Development (CA DHCD) is acting as the lead agency. As part of the EIR, Stanford Research International (SRI) completed a literature survey in 1983 on the public health effects of plastic pipe on potable water. That report identified four issues which need to be addressed in the EIR process: leaching, permeation, worker health and safety (exposure to solvent cements), and fire safety.[100]

Because the issue remained unresolved at the time of publication of the 1985 *Uniform Plumbing Code*, the publisher, IAPMO, affixed a notice to the inside cover of the code, shown below.[101]

Figure 25: IAPMO's notice of the California Environmental Impact Report on PVC, in the 1985 edition of the *Uniform Plumbing Code.*



NOTICE: For several years an Environmental Impact Report has been in the course of preparation in California to determine whether the use of CPVC, PVC, or PB plastic pipe for transporting potable water poses a danger to public health or the environment. At the time of this printing of the 1985 Edition of the Uniform Plumbing Code, the California State Plumbing Code does not permit any expansion in the use of such pipe beyond those applications permitted in the 1979 Edition of the Uniform Plumbing Code.

For information on California restrictions, contact the State Housing Law Section of the California Housing and Community Development Department

International Association of Plumbing and Mechanical Officials

UNIFORM PLUMBING CODE

DON THOMPSON ASSOCIATES, INC.
770 Tamalpais Dr., Suite 206
Corte Madera, CA 94925

1985 EDITION

Adopted at the Fifty-Fourth Annual Conference
SEPTEMBER, 1983

INTERNATIONAL ASSOCIATION OF PLUMBING AND MECHANICAL OFFICIALS
(A Non-Profit Organization)

As of 1987, the United Association of Journeyman and Apprentices of the Plumbing and Pipefitting Industry and the International Brotherhood of Electrical Workers were still actively opposing plumbing and electrical code approvals of PVC pipe and conduit on both environmental and occupational health grounds.[102] Some jurisdictions, including Chicago, had imposed bans on PVC pipe in response to these campaigns by organized labor.[103]

"As Near Perfect as We are Likely to Get"

By the mid-1990s, however, PVC was widely accepted and adopted for water and sewer service by code authorities worldwide.[104] Writing of this transition from the 1950s in the *Journal of ASTM International* in 2011, engineer Bob Walker observed that

> As a substitute for the well-established pipe mainstays of that era—iron, steel reinforced concrete, asbestos cement, and vitrified clay; PVC pipe was initially viewed as having insufficient strength and stiffness to be a viable contender. All these early views had to be changed. ... the questions and doubts surrounding PVC pipe's performance capabilities were overcome. ... PVC pipes now account for the majority of all new water and sanitary sewer installations."

Walker goes on to assert that "By 2004, PVC accounted for 78 % of the combined U.S. and Canadian buried water pipe market for pipe diameter 4 in. and larger."[105]

The PVC pipe controversy, unsurprisingly, passed in 1985 into the hands of the National Sanitation Foundation (NSF), a nonprofit testing and standards development organization that has, since 1944, worked closely with Federal and state public health agencies to develop materials, equipment, and safe-practices standards for food, water, and sanitation. After three years of research and testing, the NSF published its revised Standard 61 *Drinking Water System Components* in 1988, which promulgated a list of maximum allowable contaminant leachate levels from PVC and CPVC water system pipe and its solvent cements, adhesives and sealants, and a battery of tests required for NSF certification, which was required for AHJ approval under the Uniform Plumbing Code.[106] More than 90 potential contaminants of drinking water are currently regulated under NSF standard 61 and U.S. Environmental Protection Agency regulations.[107]

Performance-in-service (as opposed to health) standards for plastic pipe were and are incorporated into revisions of NSF/ANSI Standard 14 *Plumbing System Components.*[108]

Notes

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