BROMINE

By Phyllis A. Lyday

Domestic survey data and tables were prepared by Maria Arguelles, statistical assistant, and the world production table was prepared by Glenn J. Wallace, international data coordinator.

The quantity of bromine sold or used in the United States was 230 million kilograms (Mkg) valued at $162 million (table 1). The value of bromine sold or used was $0.70 per kilogram (kg) (table 3). Primary uses of bromine compounds were in flame retardants (38%), drilling fluids (22%), sodium bromide solutions (10%), brominated pesticides (mostly methyl bromide) (8%), water-treatment chemicals (7%), and others, including photographic chemicals and rubber additives (15%) (Chemical Market Reporter, 1997). International distribution of bromine production in 1998 was as follows: the United States, 45%; Israel, 36%; China, 8%; the United Kingdom, 6%; and other countries, 5% (table 6). Because of depleting reserves, environmental constraints, and the emergence of Israel as the world's second largest producer with 35% of the world market, the United States' portion of world production has decreased steadily since 1973, when the United States produced 71% of the world supply, to 45% in 1998.

Legislation and Government Programs

Methyl bromide was listed as a Class I ozone-depleting substance in the 1990 Clean Air Act, and was scheduled to be phased out in the United States by January 1, 2001. The American Farm Bureau Federation supported coordinating the U.S. and international phaseouts of the chemical (Chemical Market Reporter, 1998d). As part of the omnibus spending package, the U.S. Congress extended the phaseout of methyl bromide until January 1, 2005, to coincide with the deadline for developed countries under the Montreal Protocol on Substances that Deplete the Ozone Layer. Under the change to the Clean Air Act Amendments of 1990 (CAA) (P.L. 101-549), U.S. production and importation must be reduced from 1991 levels as follows: 25% by 1999; 50% by 2001; 70% by 2003, and a full ban by 2005. Domestically, methyl bromide has proven to be a difficult pesticide to replace because of its low cost and usefulness against a large variety of agricultural pests. The amendment allows for the exemption of "critical uses" of methyl bromide that have not yet been defined. The dominant use was for preplanting soil treatments. It is also used for structural applications, such as termite treatments. About 4% of its use is as a chemical intermediate. Quarantine uses accounted for from 5% to 8% of the total worldwide consumption of methyl bromide. Three producers, Albemarle Corp., Great Lakes Chemical Corp., and Israel's Dead Sea Bromine Co. Ltd. (DSB) are the major manufacturers. Under the Montreal Protocol, developing countries have until 2015 to phase out methyl bromide production (Morse, 1998).

The U.S. Environmental Protection Agency (EPA) reported that 643 chemicals, including bromine, were included on the Toxic Release Inventory (TRI) list of hazardous chemicals. The TRI was passed by Congress in 1986 after a chemical catastrophe in India as Section 313 of the Emergency Planning and Community Right-to-Know Act (P.L. 99-549). It was intended to give communities the information they need to plan for chemical emergencies. The TRI, considered to be one of the Nation's most significant environmental laws, requires more than 26,000 industrial facilities to report to the U.S. Government. The Government's latest report showed a 51% decrease in toxic releases between 1995 and 1996. Starting in 1999, the EPA planned to present data for individual industry sectors and will make comparisons between similar facilities. In 1997, the reporting was extended to July 1999 to include the following sectors: metal mining, coal mining, electric utilities, commercial hazardous-waste-treatment facilities, chemical and allied product wholesalers, bulk petroleum terminals, and solvent recovery services. The chemical industry and other businesses objected to releasing chemical data use, arguing that doing so would give competitors access to proprietary production information (Hess, 1998a).

In December, the EPA announced a new office for information management, information policy, and technology stewardship, that will be headed by a national program manager. The new office will include the highly visible TRI program, which will be moved from its current location in the Office of Pollution Prevention and Toxics. The data collection and analysis functions that are now scattered throughout the agency will be consolidated to include one-stop reporting, singly-facility identification, environmental statistics, and watershed information. The office was expected to be operational by summer 1999 (Chemical and Engineering News, 1998c).

In June 1999, managers of 66,000 facilities that handle toxic or flammable chemicals must tell the public how they will respond to accidents, their accident record, and the worst-case scenario for a process out of control. To fall under the requirements of the risk-management plant provisions of the CAA, a facility must store on-site 1 or more of 140 toxic and flammable chemicals above threshold amounts of 4,536 kg (10,000 pounds) or volumes exceeding the equivalent of 9,464 liters (L) (2,500 gallons). The Chemical Manufacturers Association (CMA) objected to the Internet posting, warning that the accident information could be used by terrorists. Eventually, the Federal Bureau of Investigation and other Federal security agencies agreed and joined the CMA in lobbying Congress and the EPA, which dropped the Internet requirement. The EPA is now trying to comply with the 1990

CAA, which originally called for the plans to be made public. No State, Federal, or local government agency has the resources to sift through the details of the 66,000 facility plans, which are expected to run about 70 pages for a typical chemical plant. The law's framers believed that public exposure of a company's potential for bad accidents would change its behavior in the same way that annual publication of industrial chemical releases brought about big reductions in those releases (Johnson, 1998).

For the first time, EPA listed a bromine compound as a hazardous waste solely on the basis of structure-activity-relation studies. These studies involve the use of health-effects information for a compound with a chemical structure and properties very similar to those of the chemical of concern. About 34 metric tons per year (t/yr) of 2,4,5-tribromophenol and its wastes are produced by Great Lakes, the only manufacturer of the compound in the United States. Although the scope of the rule is small, the precedent it sets is big. The organobromine compound will now be subject to the Resource Conservation and Recovery Act's stringent land disposal ban (Chemical & Engineering News, 1998d).

Bromine is taxed under the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund), that has gone through two reauthorizations since its enactment in 1980. The 1986 Superfund Amendments and Reauthorization Act made considerable changes to the remedy selection component of the law. A second reauthorization in 1990 extended only the program and its taxing authority (Chemical Manufacturers Association, Superfund, accessed April 8, 1999, at URL http://www.cmahq.com/cmawebsite.nsf/pages/issueadvocacy). Superfund taxes on industry, which generated $1.6 billion per year, have not been collected since December 1995. Superfund's trust fund is projected to run out of money in 2000. Efforts to craft a bipartisan bill have differed over liability for companies, cleanup standards, public participation, and the roles of States and the Federal government in the toxic waste site cleanup program (Hess, 1998b). In 1998, the U.S. Public Interest Research Group released a report based on data from the EPA that purports to identify Superfund toxic waste sites with the most potential liability. The report claimed that these top polluters were pushing to pass bills and riders in Congress that would weaken cleanup standards at the nations's worst hazardous waste sites and reduce public participation in cleanup decisions (Chemical Market Reporter, 1998b).

The EPA, the Environmental Defense Fund, and the CMA announced that 62 of the Nation's largest chemical companies, including 2 that produce bromine, have volunteered to ensure that some 600 commonly used chemicals are screened for basic toxicity; the companies are CMA members. The agreement was a significant step to gather complete screening data for 2,800 high-production-volume chemicals that are used or imported in quantities exceeding 454 t/yr (1 million pounds per year). CMA's Internet tracking publicly displays the chemicals and timetables set for the companies. The Council of Chemical Associations, an international industry trade association, set a goal of testing 1,000 chemicals by 2004. The Synthetic Organic Chemical Manufacturers Association announced its support of the program as a result of commitments made by EPA (Johnson, 1999). The testing will be carried out under a cost-sharing program operated by the Organization of Economic Cooperation and Development (OECD), which comprises 29 countries, including the United States (Chemical Market Reporter, 1998c).

The EPA invited nominations of qualified candidates for peer review committees addressing reports on Class V Underground Injection Control (UIC) wells that included manufacturing facilities producing speciality chemicals, such as boron, bromine, magnesia, or their derivatives. A study of UIC Class V wells is being conducted to satisfy a consent decree with the Sierra Club Legal Defense Fund, Inc., and must be completed by September 1999. The EPA was drafting reports that summarize the available information on these wells (U.S. Environmental Protection Agency, 1999).

In 1996, Congress passed the Food Quality Protection Act (FQPA) to improve the safety of food and to protect the public from exposure to pesticides. As a result of the Act, the jurisdiction for food-contact antimicrobial shifted from the Food and Drug Administration to the EPA. The shift caused a backlog that is being cleared up. The Act also created an Antimicrobial Division within the EPA's Office of Pesticide Programs that would reduce the backlog of antimicrobial registrations (McCoy, 1998).

The bromide ion and residual bromine were 2 of the 408 pesticides in pesticide tolerance regulations. Pesticide tolerances regulations promulgated under Sections 408 and 409 of the Federal Food, Drug, and Cosmetic Act (FFDCA), 21 U.S.C. 346a and 448, appear in parts 180, 185, and 186 of Title 40 of the Code of Federal Regulations. Part 180 contains pesticide tolerance regulations for pesticide chemical residues in raw agricultural commodities. Such regulations were promulgated under FFDCA Section 408. Parts 185 and 186 contain food additive regulations for pesticide chemical residues in processed food. These regulations were promulgated under FFDCA Section 409. The FQPA was signed into law in August 1996. This recodification is consistent with the FQPA, which placed all pesticide tolerances under Section 408 of the FFDCA, thus eliminating the distinction between pesticide tolerance for raw and processed foods (U.S. Environmental Protection Agency, 1998a).

Ethylene dibromide was included in the list of 33 hazardous air pollutants that the EPA believes pose the greatest potential threat to public health in the largest number of urban areas. The EPA released a draft of its Urban Air Toxic Strategy in September 1998 and planned to finalize it by June 1999. Air toxic are those pollutants that are known to cause or suspected of causing cancer or other serious health effects in people. Members of the CMA are concerned about how the Strategy might affect sources that have to comply with a long list of provisions that deal with air toxic and the CAA because some of the chemicals are listed in several sections of the Act. The EPA acknowledges that its does not know very much about the actual health risks that may be posed by the compounds it identified. To understand fully the risk, the level of pollution to which people are exposed must be known; the monitoring data, however, are scarce and limited (Raber, 1998).

The EPA listed bromine in the Federal Register (U.S.

Environmental Protection Agency, 1998b). A meeting in March discussed the various aspects of the acute toxicity and the development of Acute Exposure Guideline Levels.

The EPA listed a final rule not to list as hazardous 10 waste streams from the production of bromochloromethane, ethyl bromide, tetrabromobisphenol A (TBBA), 2,4,6-tribromobisphenol wastewaters, octobromodiphenyl oxide, and decabromodiphenyl oxide (U.S. Environmental Protection Agency, 1998c).

The U.S. Department of Transportation (DOT) published a notice of proposed rulemaking amending the Hazardous Material Regulations (HMR) that included bromopropane to maintain alignment with international standards by proposing numerous changes. The DOT also published a notice of proposed rulemaking for the Research and Special Programs Administration amending certain requirements in the HMR that included bromotrifluoromethane to establish four new DOT cylinder specifications and to revise the requirements for maintenance, requalification, and repair of all DOT specification cylinders (U.S. Department of Transportation, 1998a, b).

The Consumer Product Safety Commission held public hearings to receive scientific and technical information relating to the toxicity, exposure, bioavailability, and environmental effects of flame retardant chemicals, including bromine compounds that may be suitable for use in residential upholstered furniture. The Commission will evaluate the information obtained from the hearings as part of its deliberations on whether to propose a standard to address the hazard associated with small open flame ignitions of upholstered furniture (Consumer Product Safety Commission, 1998).

Production

Domestic production data for bromine were developed by the U.S. Geological Survey from a voluntary survey of U.S. operations. Of the operations to which a survey request was sent, six responded, representing 98% of total elemental bromine sold or used (table 2).

Albemarle announced the construction of a 50,000-t/yr TBBA plant, a flame retardant marketed as SAYTEX RB-100, to be operational by August 1999 in Magnolia, AR. TBBA is used in epoxies, phenolic, acrylonitrile-butadiene-styrene, polystyrene, polycarbonate, and unsaturated polyesters. Bromine flame retardants are used in electronic equipment to increase the fire resistance of the plastic housings and the computer printed circuit boards. TBBA is also used in computer housings and electrical connectors and in carpet and office furniture (Chemical & Engineering News, 1998b; Chemical Market Reporter, 1998 a, g).

Albemarle announced plans to increase capacity for its bromides used in water treatment by 50% and its bromides used in cleaning products by 20%. The Surface Active Unit represents about one-sixth of the company with $150 million in annual sales. The Surface Active Unit was divided into the cleaning, water treatment, and fine chemicals groups is projected to achieve annual revenue and profit growth in the 15% to 20% range during the next 5 years. To achieve the growth, Albemarle formed an alliance with Bromitron Corp. to manufacture a line of chlorine-free products for use with a line of electrolytic bromine generators for the disinfection of pools, spas, and fountains. Bromine’s advantages over chlorine includes mildness to the eyes, greater bacteria kill rates, and reduced bleaching and odor. Bromine is environmentally friendlier than chlorine because it is less volatile in water and not lost into the atmosphere as readily (Scheraga, 1998a).

Great Lakes is the world’s leading fully integrated producer of bromine-based speciality chemicals. Four units were formed during a reorganization in 1998 that resulted in the elimination of 600 jobs during 18 months for a net reduction of 12%. Bromine products were included in each of the four units—flame retardants, Polymer Additives; bromine intermediates, Performance Chemicals; bromide sanitary products, Water Treatment; and oilfield brines, the Energy Services and Products and Services. Great Lakes continued to divest of noncore activities, including furfural and derivatives, Eastern European chemical trading business, and environmental services firms. Great Lakes purchased the assets of PPG Industries Inc. for an estimated $2 million and became the sole owner of the former Arkansas Chemicals Inc. plant, now called the Great Lakes Newel plant. The spinoff of its petroleum additives unit, creating Octel Corporation, was completed on May 15 (Chemical Market Reporter, 1998f). Octel was a global leader in the production and marketing of tetraethyl lead, an octane enhancer in gasoline.

TETRA Technologies, Inc. was one of the largest users of brominated products in the world. Calcium and zinc bromide were produced for oil and gas applications. The Speciality Chemicals Division, acquired the clear brine fluids business of The Dow Chemical Co. and entered into a contract to purchase crude bromine and produce purified bromine and bromine derivatives at its Michigan facility in 1996. In the first quarter 1998, the new bromine facility in Ludington that produced purified bromine and two derivatives began operations to produce calcium bromide for drilling and completion fluid. The production came into the market at a downturn of the oil and gas markets. Later in the year, production of sodium bromide began, a key ingredients in a line of brominated biocides for water treatment (TETRA Technologies, Inc., 1998). Tetra had brine leases in Arkansas, but had not made a decision to retrofit the plant purchased from Dow in 1988 or to begin virgin bromine production.

Ambar Inc. planned to have a 14-Mkg (30-million-pound) elemental bromine facility in Manistee, MI, to produce elemental bromine and brominated salts on-stream early in 1999. This will be the first new elemental bromine plant constructed since the mid-1970's when two separate plants began producing elemental bromine. The next decade brought the closure of four plants in California and Michigan as bromine use in gasoline was phased out. Ambar would be supplied by pipeline with bromine-containing brines after production of magnesium hydroxide from Martin Marietta Magnesia Specialties Inc. Ambar planned to manufacture and consume brominated well drilling fluids, but was considering selling excess elemental bromine.

Consumption

The EPA's Methyl Bromide Phaseout Program stated that by 2005, those applications still using methyl bromide will do so because they have no choice. A variety of chemicals were being tested as replacements for methyl bromide. One positive example of replacement was sulfuryl fluoride (F_2O_2S), used as a fumigant in residential and commercial structures. It is effective against several pests, including dry-wood and Formosan termites, beetles, and moths, and penetrates deeply into the wood. By 1996, sulfuryl fluoride had replaced methyl bromide in 85% of structural fumigations in the United States. Sulfuryl fluoride, however, cannot be used to treat food grain or plants. Methyl bromide was still the common method used to limit the spread of damaging insect populations around the world. The U.S. Department of Agriculture recommended the use of methyl bromide to treat wood packaging materials from China because of the lack of good alternatives. A voracious, nonnative insect pest has been found in material at 26 scattered warehouse and residential sites in 14 States. China may have to use as much as 12,565 metric tons (t) of methyl bromide to treat wood destined for the United States. This represents a 75% increase in use compared with 1996 levels for all applications, including soil treatment, in Asia. The EPA figures showed that only 4,069 t, about 6% of all methyl bromide used globally, was used to fumigate timber worldwide in 1996. Phosphine gas, PH_3, has replaced methyl bromide primarily for the pest fumigation of grain and food commodities. Treatment requires the use of pellets of metal phosphides, usually aluminum or magnesium, which react with atmospheric moisture to produce the gas. However, phosphine is very damaging to fresh commodities. The negative aspect of phosphine gas is that it is explosive at high concentrations and can cause corrosion of some common metals and alloys. Treatments leave a residue of metal oxides and hydroxides (Reisch, 1998).

A new phosphine-based fumigant is supplied as a mixture of 2% phosphine by weight in carbon dioxide. The mixture is not flammable and does not leave a residue. Other chemical replacements for methyl bromide have not entered the domestic market as easily. Pesticide tests in Australia show that carbonyl sulfide is effective for treating perishable and durable commodity products and particularly useful for grain treatment, but is not a U.S. registered pesticide. Another potential pesticide, methyl iodide, was recently granted a patent for its use as a fumigant (Reisch, 1998).

Pesticides, such as bromine compounds, were used to protect food from pests, such as insects, rodents, weeds, mold, and bacteria (U.S. Environmental Protection Agency, 1998c). Some pesticides can cause health problems at certain levels of exposure. The EPA sets standards on the amount of pesticides that may remain on food, if pesticides were applied. The FQPA set a tougher standard for pesticides use on food. By 2006, the EPA must review all old pesticides to make sure that their use on food meets the new, tougher safety standard. If a pesticide was authorized that does not meet the safety standard, then the EPA will work with grocery stores to inform consumers of such pesticides, foods that might contain them, and equally nutritious alternatives.

Bromine is a relatively low-cost, effective biocide. The most common bromine biocide source, liquid sodium bromide, must be oxidized to hypobromous acid to be effective. Solid bromine products were available but required special feeders and were prone to dusting. Sales of stabilized bromine technology solved a problem that the bromine industry pursued for 15 years. A proprietary inorganic compound that stabilizes hypobromous acid eliminates the need for chlorine-based cooxidant. Besides simplicity of use, stabilizing bromine provides other water treatment advantages. Benefits of the new products included reduced volatility of the acid, reactivity to scale and corrosion inhibitors, and toxicity and simplicity of use. Uses included brominated based antimicrobial to treat pulp mill water and oil-drilling muds (McCoy, 1998).

Bromine is used in the free radical polymerization of isoprene rubber. Light causes the bromine molecule to dissociate into two active bromine atoms called free radicals because they have an unpaired electron and is therefore not used for rubber exposed to sunlight. Isoprene was used as a inner liner for tubeless tires and in tubes for tires because of its very low air permeability compared with natural rubber and other synthetic rubbers. Goodyear Chemical, a division of Goodyear Tire & Rubber Co., planned a sixth plant in Texas to produce polyisoprene for production of tires. The location was chosen adjacent to Goodyear's Beaumont synthetic rubber plant (Scheraga, 1998c).

Calcium bromide, usually shipped as a 52% aqueous solution weighing 6.44 kg per 3.78 L (14.2 pounds per gallon), was used as clear brine fluids in oil and gas drilling industries. Drilling and completion are separate operations. Completion activities can follow drilling immediately, or the well can be capped, allowing completion to be scheduled at a later time. Clear brines are chloride- or bromide-based, high-density, solids-free solutions used in well completion and workover operations. Drilling fluids were formulated on-site to achieve predetermined densities, calculated on the basis of the temperature and pressure expected to be encountered in the particular well. Zinc bromide solutions have a specific gravity of 2.7. Clear brine fluids prevented contamination of the well pores with mud and therefore increase the productivity of the completed well (Mannsville Chemical Products Corp., 1998).

German scientists mapped tropospheric bromine oxide concentrations as a function of location and time by using the Global Ozone Monitoring Experiment spectrometer on the European Research Satellite. High bromine oxide concentrations in the troposphere always occurred near sea ice and lasted only 1 to 3 days. These results indicate that bromine is being released autocatalytically from sea salt and that this may be the source of the bromine oxide rather than the degradation of unstable, halogen-containing organics (Chemical & Engineering News, 1998a).

Lead content in a peat bog on a Swiss mountain contains a continuous 14,500-year record of atmospheric conditions, including recent deposition of lead from leaded gasoline. Ethylene dibromide is included in the octane booster in leaded gasoline to act as a "scavenger," thus preventing lead from depositing in the engine. Lead data from the 1920's should reflect the effects of tetraethyl lead using bromine as a scavenger in gasoline. A scientist planned to quantify the effect of human activity on emissions of metals to the environment. To pinpoint the origins of atmospheric lead, the team dated a core, analyzed it for lead, and measured the ratio of lead 206 to lead 207. Lead soil dust formed by weathering of rocks is associated with a baseline ratio of 1.20. About 3,000 years ago lead levels increased because of mining. A decline about 300 years ago coincided with the importation of lead ores and the decrease in local mining (Roubi, 1998).

In Hawaii, native plants were being used to take up ethylene dibromide by using an 11-year-old, peer-reviewed extramural program called the Superfund Basic Research Program (SBRP). SBRP was yielding partial solutions to some of the major problems that have plagued the Superfund hazardous waste site cleanup program (Hileman, 1999). Information on SBRP is available on the World Wide Web (National Institutes of Health, Superfund Basic Research Program, accessed July 2, 1999, at URL http://www.niehs.nih.gov/sbrp/home.htm).

Transportation

Dow, a producer and shipper of bromine, and Union Pacific Corp. settled a lawsuit over unsatisfactory rail service. Dow had filed a breach of contract suit because of disruptions in rail service that cost more than $25 million in lost revenue and extra shipping expenses (Prince William Journal, 1998).

World Review

Publication of the International Organization for Standardization (ISO) 9000 was planned for November 2000. Bromine operations were 3 of more than 200,000 ISO-9000-based quality-management systems being operated worldwide to ensure their efficiency and customer requirements. All of the more than 11,500 standards are reviewed at least every 5 years. The ISO 9000 series was published in 1987 and reviewed in 1994 (Chemistry International, 1999). The ISO technical body responsible for developing the revised standards has established a World Wide Web site to provide information (British Standards Institution, ISO Revisions, accessed July 2, 1999, at URL http://www.bsi.org.uk/bsi/services/isorevs.htm). Information may also be obtained from ISO's national members. (International Organization for Standardization, Welcome, accessed July 2, 1999, at URL at http://www.iso.ch/).

European Union.—The countries of the European Union are starting to phase in the Biocidal Products Directive (BPD), a rule intended to harmonize biocide laws in the countries that have them and implement them in those countries that do not have them. Registration is required of all commercial biocides including bromine compounds during the next 10 years. Of the 900 active ingredients used as biocides in Europe, only about 200 are expected to remain after BPD (McCoy, 1998).

France.—Elf Atochem continued the switch from bromide derivatives to fine chemicals at its Port-de-Bouc plant in southeast France. The plant had been threatened with closure because 70% of plant capacity was in bromides—dibromethane and methyl bromide that will be banned after 2005 (tables 5 and 6).

Israel.—The production of bromine and potash began in 1931 at Kalia. The soluble minerals exist mainly as chloride and bromine anions and magnesium, sodium, and potassium cations. Bromine has been produced as a byproduct from waste bitterns associated with potash production from the Dead Sea since 1957 by DSB. After potash was removed in solar ponds, the waste bitterns were processed with chlorine to recover bromine. The bromine-free bitterns were then processed to recover magnesium.

In 1985, the Israeli Government began efforts to sell a share of Israeli Chemical Co. Ltd. (ICL) to offset an investment program. ICL was a group of chemical and mineral industrial companies, with research institutes, technical facilities, and commercial and marketing services. Israel Corp., bought an additional 17% stake in March 1997, which brought its share of ICL to 41.9%. In 1997, the Israeli Government announced a decision to sell off its 31.5% stake of ICL valued at $441 million; the sale required the approval of the finance committee of the Israeli Parliament (Phosphorus & Potassium, 1998).

Israel's finance ministry proposed to accelerate infrastructure projects, which included bromine expansions, throughout the country to help with high unemployment. The national unemployment rate was 8.3% in May 1998, more that 1% higher than that of 1997 (Engineering News Record, 1998). DSB announced an expansion of production capacity for bromine and bromine compounds from 200,000 to 250,000 t/yr at its Sdom plant. Bromine Compounds Ltd., a wholly owned subsidiary of DSB, increased its production capacity to 80,000 t/yr of calcium bromide at its plant at Ramav Hovav. Calcium bromide was used as a clear fluid in oil and gas wells in the completion and workover stage. DSB was a major producer of bromine and bromine compounds. The company was 90% owned by ICL. DSB, in turn, owned a number of subsidiaries, including AmeriBrom, Inc., and Eurobrom, B.V., through which it markets its bromine products (Industrial Minerals, 1998b).

Jordan.—Albemarle signed a memorandum of understanding with Arab Potash Co.'s (APC) Jordan Dead Sea Industries Co. (Jodico) and the Kingdom of Jordan for the construction of a world-scale joint-venture bromides facility in Safi, Jordan; the plant was expected to be in production by 2001. Jodico was established by APC as a holding company to undertake the extraction of chemicals, other than potash, from the Dead Sea. The plant will produce bromine, calcium bromide oilfield completion fluid, and TBBA flame retardant, primarily for marketing in Europe and Asia. Some bromine will be available for the merchant market. Albemarle had plants and brine reserves in Arkansas and a plant in Thann, France (Scheraga, 1998b).

Ukraine.—JSC Brom, of Krasnoperekopsk, located at the Sivash Gulf, Sea of Azov, Crimea, was reported to have 52,000 t/yr of bromine capacity (Industrial Minerals, 1998a).

United Kingdom.—Albemarle UK Ltd., a subsidiary of Albemarle, announced the acquisition of the Teesport operation of Hodgson Specialty Chemical Division of BTP plc for approximately $14 million. Teesport was completed in 1991 and served as a custom manufacturing and oilfield chemicals plant. The addition of products that Teesport produced will complement Albemarle's clear completion fluids, amines, and quats to the oilfield services industry (McChesney, and Whitlow, 1998).

Current Research and Technology

Albemarle was working with Bromitron Corp. on a generator that electrolytically produces bromine on-site from sodium bromide. The generating equipment would be useful to the residential pool and spa market (McCoy, 1998).

A study of bisphenol-A, conducted by researchers at the University of Missouri, has found no evidence of biological effects from low-dose exposures; the new study, sponsored jointly by the Society of the Plastics Industry (SPI) and the Bisphenol A Sector Group of the European Chemical Industry Council (Cefic), was significantly larger and more comprehensive than the previous work. Both studies used negative control groups, but the SPI-Cefic study added a positive control group Bisphenol-A is a building block monomer used primarily to produce TBGA for use in polycarbonate and epoxy resins (Chemical Market Reporter, 1998h).

Chemists at the University of California, Irvine, used a quantitative expression to estimate the atmospheric residence time of methyl bromide. Historically, estimates of the residence time were based on highly uncertain estimates of its sources from natural and man-made sources and the process that removed it from the atmosphere. A new method uses the spacial variability of the amounts of bromine compounds in air samples collected over the Pacific Ocean during 1996 National Aeronautics and Space Administration aircraft missions. The known atmospheric residence time of the four compounds was plotted against the variability in the samples, showing that the compounds with the shortest residence times vary the most in their spatial distribution. By plotting the measured variability of methyl bromide on the curve, they were able to estimate its atmospheric residence time (Chemical & Engineering News, 1998e).

Two carbonyl groups of the same molecule reacted with two different reagents in the same one-pot reaction by using a dibromide complex as the catalyst. The achievement added to the one-pot tandem, cascade, or domino techniques that are aimed at doing the maximum number of chemical transformations in one reaction (Stinson, 1998c).

Bromine was included in the list of fine chemicals that were used in the production of chemicals in drugs and pesticides. Most fine chemical advances were in assembling asymmetric centers to make drugs and pesticides that are chiral—no internal plane of symmetry and the molecule and its mirror image are not superimposable. Modern chiral technology can make single isomers that are useful in drug selectivity information and for computer-aided drug design (Stinson, 1998b). By using two bromine compounds, chemists at the University of Tokyo increased the yield and stereoselectivity to generate two asymmetric-centered products (Stinson, 1998a).

Outlook

Petroleum.—Demand for bromine as a gasoline additive has declined each year since the EPA issued regulations in the 1970's to reduce and eliminate the lead in automotive gasoline. In 1979, the amount of bromine sold reached a peak of 225 Mkg. The rapid decline to 141 Mkg in 1986 was a direct result of the limits on lead in leaded automotive gasoline. The European Community continued discussions to reduce lead levels in gasoline. Bromine in petroleum additives was expected to continue to decline over the long term. Federal laws enacted to encourage alternative forms of power in automotive engines are likely to have a depressive effect on bromine demand. The CCA require mobile sources, such as cars and trucks, to use the most effective technology possible to control emission. Electric cars that do not require bromine gasoline additives were on the market in California. Newer prototypes of the fuel cell that burn gasoline can double the mileage and thereby decrease emissions by using unleaded gasoline.

Sanitary Preparations.—Bromine was used in indoor swimming pools, hot tubs, and whirlpools. The sanitary preparation field is an area where bromine was found to be safer than its substitutes because bromine has a higher biocidal activity level for the same amount of product. Growth areas are in the pulp and paper industry, cooling towers, and Government-regulated food-washing applications. Albemarle reported double-digit sales growth of brominated biocides as it replaced chlorine and other products in a variety of applications (McCoy, 1998). The use of bromine will continue to grow in sanitary preparation, closely following the gross national product in real growth.

Fire Retardants.—Bromine is a reactive flame retardant in that it enters into any chemical reaction with the components of the systems in which it is used. In addition, bromine acts as a synergist with many other fire-retardant materials, that is, it increases the effectiveness of the fire retardant. Business Communications Company estimated the U.S. flame retardant chemicals market to be 344,000 t (758 million pounds) during 1998. It expected the market to grow by 5% per year through 2003 and reach 444,000 t (969 million pounds). A lack of acceptable alternatives to bromine was expected to fuel 8.5% annual growth for bromine-based flame retardants through 2003 to 142,000 t (313 million pounds) despite environmental concerns (Chemical Market Reporter, 1998e). Brominated compounds were estimated to be 15% of Western European consumption of flame retardants (Keegan, 1998).

Other Uses.—Use of calcium, sodium, and zinc bromides in well-completion fluids decreased during the 1980's as the domestic petroleum industry suffered a severe recession. In 1997, however, the oil-services sector posted another strong performance with drilling rig counts up by 18% compared with those of 1996. Domestic demand for calcium bromide clear fluids peaked in 1997 at an estimated 507,000 t (230 million pounds), 31% of which was imported. About 95% of calcium bromide produced was used as an oil and gas completion fluid.

In 1998, demand began decreasing because of a reduction in well completion activity as a result of a reduction in demand for petroleum and petrochemicals caused by an economic crisis in Asia (Mannsville Chemical Products Corp., 1998). Oilfield chemicals used in drilling, completion and work over, and production operations remained significantly more profitable internationally than in the United States.

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[1]Prior to January 1996, published by the U.S. Bureau of Mines.

TABLE 1
SALIENT BROMINE AND BROMINE COMPOUNDS STATISTICS 1/

(Thousand kilograms and thousand dollars)

	HTSUS 2/ number	1994	1995	1996	1997	1998
United States:						
Bromine sold or used: 3/						
Quantity		195,000	218,000	227,000	247,000 r/	230,000
Value		$155,000	$186,000	$150,000	$198,000 r/	$162,000
Exports: 4/ 5/						
Elemental bromine:	2801.30.2000					
Quantity		6,470	3,220	2,920	2,330	1,490
Value		$7,270	$3,790	$3,970	$3,590	$3,440
Bromine compounds: 6/	(7/)					
Gross weight		13,700	13,300	13,100	10,700	10,200
Contained bromine		11,500	11,200	11,100	9,050 r/	8,550
Value		$21,100	$19,900	$22,100	$21,200	$18,000
Imports: 4/ 8/						
Elemental bromine:	2801.30.2000					
Quantity		319	2,220	415	1,650	1,200
Value		$194	$1,460	$305	$1,200	$1,060
Bromine compounds:						
Ammonium bromide:	2827.59.2500					
Gross weight		1,120	288 9/	11,700 10/	33,000 10/	471 9/
Contained bromine		917	235 9/	9,370 10/	2,690 10/	384
Value		$1,850	$832 e/ 9/	$9,580 10/	$22,000 10/	$1,280 e/
Calcium bromide:	2827.59.2500					
Gross weight		14,700	730 9/	--	803 9/	350 9/
Contained bromine		11,700	584 9/	--	642	280
Value		$5,380	$262 e/ 9/	--	$289	$213 e/
Potassium bromate:	2829.90.0500					
Gross weight		166	275	301 9/	378 9/	141
Contained bromine		79	132	144 9/	181	67
Value		$538	$933	$1,140 9/	$1,650 r/	$571
Potassium bromide:	2827.51.0000 11/					
Gross weight		1,280	171 9/	733 9/	705 9/	910 9/
Contained bromine		858	115 9/	493	474	611
Value		$2,270	$420 e/ 9/	$1,780 r/	$1,710 r/	$2,220 e/
Sodium bromate:	2829.90.2500					
Gross weight		276	944	1,200	1,220	1,100
Contained bromine		146	500	634	646	584
Value		$714	$2,360	$3,030	$3,170	$2,900
Sodium bromide:	2827.51.0000 11/					
Gross weight		1,400	1,400 9/	1,240 r/ 9/	2,730 r/ 9/	3,960 9/
Contained bromine		1,090	1,070 9/	965	2,120 r/	3,070
Value		$1,770	$2,550 9/	$1,910 r/	$4,210 r/	$6,090 e/
Other compounds:	2903.30.1550					
Gross weight		14,300	5,850 12/	6,520	8,910	8,990
Contained bromine		8,680	4,880 12/	5,090	6,900	6,770
Value		$42,600	NA	$14,900	$16,700	$18,900
World: Production e/		420,000 r/	437,000 r/	483,000 r/	517,000 r/	514,000

e/ Estimated. r/ Revised. NA Not available

1/ Data are rounded to three significant digits.

2/ Harmonized Tariff Schedule of the United States.

3/ Elemental bromine sold as such to nonproducers, including exports, or used by primary U.S. producers in preparing bromine compounds.

4/ Bureau of the Census.

5/ Export values are free alongside ship (f.a.s.).

6/ Bureau of the Census. Includes methyl bromine and ethylene dibromide.

7/ Data for these compounds are derived from HTSUS numbers 2903.30.0500 and 2903.30.1500 information.

8/ Import values are cost, insurance, and freight (c.i.f.).

9/ The Journal of Commerce Port Import/Export Reporting Service.

10/ The respective data for "bromides/bromines and oxides" of ammonium, calcium and zinc are combined and reported here; imports for 1996 included 568 thousand kilograms and imports for 1997 included 83 thousand kilograms of zinc bromide.

11/ "Bromides of sodium" or of "potassium" import data are usually reported by a mutual HTSUS number, 2827.51.0000.

12/ Certain compounds reported for 1995 are not included in the total.

TABLE 2

ELEMENTAL BROMINE-PRODUCING PLANTS IN THE UNITED STATES, 1998

State and company	County	Plant	Production source	Capacity 1/ (million kilograms)
Arkansas:				
Albemarle Corp.	Columbia	Magnolia (a)	Well brines	
Do.	do.	Magnolia (b)	do.	140 2/
Great Lakes Chemical Corp.	Union	Newell	do.	25
Do.	do.	Catesville	do.	
Do.	do.	El Dorado	do.	93 2/
Do.	do.	Marysville	do.	59
Michigan:				
The Dow Chemical Co.	Mason	Ludington 3/	do.	20
Total 4/				337

1/ Actual production capacity is limited by brine availability.

2/ This represents the cumulative capacity of the two identified plant sites.

3/ Bromine produced at this plant is reprocessed in Arkansas.

4/ Chemical Marketing Reporter, v. 251, no. 13, p. 37.

TABLE 3

YEAREND 1998 PRICES FOR ELEMENTAL BROMINE AND SELECTED COMPOUNDS 1/

Product	Value (cents) Per pound	Per kilogram
Ammonium bromide, National Formulary (N.F.), granular, drums, carlots, truckloads, f.o.b. works	--	--
Bromine:		
Drums, truckloads, works 2/	123	271
Bulk, tank cars, works 2/	56-68	123-150
Bromochloromethane, drums, bulk, f.o.b. Magnolia, AR	127	280
Ethyl bromide, technical, 98%, drums, truckloads	127	280
Ethylene dibromide, drums, carloads	95	209
Hydrobromic acid, 48%, drums, carloads, truckloads, f.o.b.	56	123
Hydrogen bromide, anhydrous, cylinders, 2,500 pounds, truckloads	475	1,047
Methyl bromide, tank cars	77	170
Potassium bromate, granular, powdered, 200-pound drums, carloads, f.o.b. works	179	395
Potassium bromide, N.F., granular, drums, carloads, f.o.b. works	110-112	242-247
Sodium bromide, technical, truckloads	70	154

1/ Source: Chemical Market Reporter. Current Prices of Chemicals and Related Materials, v. 254, no. 26, December 28, 1998, p. 22-28.

2/ Delivered prices for drums and bulk shipped west of the Rocky Mountains, 1 cent per pound higher. Bulk truck prices 1 to 2 cents higher per pound for 30,000-pound minimum.

TABLE 4

U.S. IMPORTS OF OTHER BROMINE COMPOUNDS 1/ 2/

Compounds	HTSUS 3/ number	1997 Gross weight (kilograms)	1997 Value 4/ (thousands)	1998 Gross weight (kilograms)	1998 Value 4/ (thousands)	Principal sources, 1998
Hydrobromic acid	2811.19.3000	188	$175	257	$263	Israel 100%.
Ethylene dibromide	2903.30.0500	2,050	1,350	170	418	China 100%.
Methyl bromide	2903.30.1520	3,370	6,360	3,740	6,820	Israel 100%.
Dibromoneopentyl glycol	2905.50.3000	1,550	4,970	1,110	3,620	Do.
Tetrabromobisphenol A	2908.10.2500	306	526	1,490	2,690	Do.
Decabromodiphenyl oxide and octabromodiphenyl oxide	2909.30.0700	1,450	3,310	2,220	5,100	Do.
Total		8,910	16,700	8,990	18,900	

1/ These data detail the information included in table 1, imports of "Other bromine compounds."

2/ Data are rounded to three significant digits.

3/ Harmonized Tariff Schedule of the United States.

4/ Declared cost, insurance, and freight valuation. (c.i.f.)

Source: Bureau of the Census.

TABLE 5

WORLD BROMINE ANNUAL PLANT CAPACITIES AND SOURCES, DECEMBER 31, 1998 1/

Country and company	Location	Capacity (thousand kilograms)	Source
Azerbaijan:			
Neftechala Bromine Plant	Baku	5,000	Underground brines.
China:			
Laizhou Bromine Works	Shandong	30,000	Do.
France:			
Atochem	Port-de-Bouc	13,600	Seawater.
Mines de Potasse d'Alsace S.A.	Mulhouse	2,300	Bitterns of mined potash.
India:			
Hindustan Salts Ltd.	Jaipur		Seawater bitterns from salt
Mettur Chemicals	Mettur Dam	1,500	production.
Tata Chemicals	Mithapur		
Israel:			
Dead Sea Bromine Co. Ltd.	Sdom	190,000	Bitterns of potash production from surface brines.
Italy:			
Societa Azionaria Industrial Bromo Italiana	Margherita di Savoia	900	Seawater bitterns from salt production.
Japan:			
Toyo Soda Manufacturing Co. Ltd.	Tokuyama	20,000	Seawater.
Spain:			
Derivados del Etilo S.A.	Villaricos	900	Do.
Turkmenistan:			
Nebitag Iodine Plant	Vyshka	3,200	Underground mines.
Cheicken Chemical Plant	Balkan	6,400	Do.
Ukraine:			
Perekopskry Bromine Plant	Krasnoperckopsk	3,000	Do.
United Kingdom:			
Associated Octel Co. Ltd.	Amlwch	30,000	Seawater.

1/ Excludes U.S. production capacity. See table 2.

TABLE 6

BROMINE: ESTIMATED WORLD REFINERY PRODUCTION, BY COUNTRY 1/ 2/

(Thousand kilograms)

Country 3/	1994	1995	1996	1997	1998
Azerbaijan	3,000	2,000	2,000	2,000	2,000
China	31,400	32,700 r/	41,400 r/	31,000	40,000
France	2,190	2,260	2,024 4/	2,000	2,000
India	1,400	1,500	1,500	1,500	1,500
Israel	135,000	135,000	160,000 r/	180,000 r/	185,000
Italy	300	300	300	300	300
Japan	15,000	15,000	15,000	20,000	20,000
Spain	200	200	100	100	100
Turkmenistan	100	100	102 4/	130 4/	150
Ukraine	3,000 r/	3,500	3,000	3,000	3,000
United Kingdom	33,800 4/	26,200 4/	30,600 r/ 4/	30,000 r/	30,000
United States 5/	195,000 4/	218,000 4/	227,000 4/	247,000 4/	230,000 4/
Total	420,000 r/	437,000 r/	483,000 r/	517,000 r/	514,000

r/ Revised.

1/ World totals, U.S. data, and estimated data are rounded to three significant digits; may not add to totals shown.

2/ Table includes data available through April 16, 1999.

3/ In addition to the countries listed, several other nations produce bromine, but output data are not reported; available general information is inadequate to formulate reliable estimates of output levels.

4/ Reported figure.

5/ Sold or used by producers.