PCBs, MINING, AND WATER POLLUTION

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ABSTRACT
The presence of PCB-containing electrical equipment in underground mines has been documented during US Environmental Protection Agency (EPA), Region 8, mine inspections conducted over the last 20 years. PCB-containing electrical equipment may be found in mines throughout the world because electrical systems in mines follow the same general patterns as any other industry. The abandonment of this equipment in underground mines is likely to cause worldwide ground water contamination in mining districts.

BACKGROUND
Polychlorinated biphenyls (PCBs) are a group of 209 man-made structurally related chemicals manufactured in the US from1929 until 1977 when manufacture was voluntarily discontinued. In 1978, manufacture was prohibited and use and disposal closely regulated by the PCB regulations written by EPA, as required under Section 6(e), of the Toxic Substances Control Act (TSCA). TSCA regulates the manufacture and use of industrial chemicals, including the disposal of PCBs. It was enacted in 1976 after the discovery that PCBs had become a ubiquitous environmental contaminant that had been detected in air, water, soils, and biosystems worldwide where they threatened human health and the environment. The discovery came in the mid 1960s when analytical equipment was sufficiently refined to detect the presence of PCBs. Unlike DDT, another ubiquitous environmental contaminant, which had been intentionally introduced into the environment on a large scale for insect control, PCBs had been confined to limited industrial uses. PCBs were now beginning to show up all over the world.

Despite the fact that manufacture has been prohibited in the US and many other countries, PCBs are still authorized by the PCB regulations for use in electrical equipment, primarily as dielectric fluids (or contaminants in dielectric fluids) in electrical equipment. The mining industry has been an extensive user of PCB-containing electrical equipment, and some of this equipment continues to be abandoned underground.

The major PCB use today is as a dielectric in electrical equipment servicing industries with large electrical power distribution and consumption where they continue to pose potential threats to the environment in the event of releases. This threat is particularly prevalent in the mining industry because mines generally penetrate the water table. When PCBs are spilled or PCB equipment is abandoned underground, the PCBs can be expected to be released into the ground water with no possibility of source retrieval. This can result in water pollution for which there may be no solution.

HEALTH AND ENVIRONMENTAL EFFECTS

PCBs are among the12 chemicals designated as persistent organic pollutants (POPs) that are targeted by the UN Stockholm Convention of May 2001, when 90 nations, the US, and the European Community agreed to reduce or eliminate PCB production, use, and/or release. The convention has been signed but not yet to ratified by the US. POPs are highly stable toxic organic compounds that persist in the environment, and accumulate in fat. PCBs are one of several truly global environmental pollutants. They have been found in low, but measurable levels, in nearly all marine plant and animal specimens, fish, mammals, birds, bird eggs, and humans. Human exposure to PCBs occurs primarily via low-level food contamination. All United States residents have measurable PCBs in their fatty tissues[1].

There is no longer any doubt that PCBs present a threat to human health and the environment even at extremely low levels. They can enter the body through the lungs, the gastrointestinal tract, and the skin. Once ingested, inhaled, or absorbed into the body, PCBs are circulated throughout the body in the blood and are stored in fatty tissue and several organs, including the liver, kidneys, lungs, adrenal glands, brain, heart, and skin. Once in the body, PCBs can wreak havoc[2]. Among the most stable organic chemicals known, they have found their way into air, water, soils, and animals worldwide. PCBs have become so widely distributed that the US Food and Drug Administration (FDA) found it necessary to issue tolerances for PCBs in cardboard, food packaging, soap, fish, meat, milk, and eggs. PCBs are highly concentrated in fatty tissue of organisms even when exposure levels are very low. Fish can bioconcentrate PCBs in their tissues by a factor as high as 740,000 times the PCB concentration of the water they inhabit[3]. This does not include PCBs from consumption of contaminated invertebrates. Rainbow trout that consume contaminated invertebrates have been shown to bioaccumulate PCBs by a factor of 10,000,000 in Lake Ontario[4]. This process of bio-accumulation has resulted in the closure of fisheries in the Great Lakes and the issuance of PCB sport-fisheries advisories for fish consumption in 100% of the Great Lakes and in 71% of the coastal waters along with 28 % of the lakes and 14% of the river miles of the lower 48 states.[5] Fish, birds, amphibians, and even polar bears have been shown to have birth defects and declines in fertility linked to PCB exposure. The oceans are the largest "sink" of PCBs, the consequences of which remain unknown. The median bioconcentration factors for PCBs from water into phytoplankton are between 10,000 and 1,000,000[6] but it is seldom noted that phytoplankton are the basis of the ocean food chain and are a major source of atmospheric oxygen[7].

In addition to being classified by the EPA as probable human carcinogens[8], PCBs have been demonstrated to impair memory and intellectual development in children[9] and adults[10] and to cause human liver disorders, chloracne, and reproductive problems. PCBs are endocrine disruptors[11], and are suspected to cause decreases in human sperm counts, increases in birth defects in reproductive organs, as well as increases in breast, prostate, and testicular cancers[12].

PCB PROPERTIES AND USES

PCBs were manufactured in the US under the trade name Aroclor until manufacture was discontinued in 1977. Aroclors are essentially different chlorine concentration fractions of PCBs that have different properties. Two of the most common are Aroclor 1254 and Aroclor 1260.

These Aroclors were mixed with solvents, for example trichlorobenzene, and sold under the trade names that appear on the manufacturer nameplates of PCB electrical equipment. Some of the more common PCB dielectric trade names are Pyranol, Inerteen, Elemex, and Chlorextol. There are many others. PCBs in the dielectrics of transformers, voltage regulators (variable voltage transformers), capacitors, and fluorescent light ballasts are the major industrial uses today.

The physical and chemical properties that make PCBs valuable commercially also make them environmentally detrimental. PCBs are very stable compounds, which resist breakdown from high temperatures and aging. Once in the environment PCBs persist for long periods of time: they can easily cycle between air, water, and soil[13]; they are orders of magnitude more fat soluble than water soluble and tend to concentrate in fatty tissues.

MINES AND PCBs

It should be emphasized that surface mines and the attendant crushing and milling facilities of both surface and underground mines may use PCB-containing electrical equipment. Depending on the cost effectiveness of removal and salvage, mines may be abandoned without removing any of the underground mining, haulage, hoisting, or electrical equipment. It is believed by experts in the mining industry that substantial quantities of PCB-containing electrical equipment were abandoned underground before the advent of the PCB regulations in 1978[14].

Underground mines are emphasized here because abandoned PCB-containing equipment is likely to cause water pollution that can affect the environment and the health of downstream fish, and wildlife, and human populations. PCBs are most likely to be in transformers, as shown in Figure 1, drums of used transformer oils, capacitors, as shown in Figure 2, and fluorescent light ballasts. Transformers may be grouped in permanent substations, located singly, or mounted on mine cars that can be transported throughout the working areas of the mine. Capacitors are generally found in locations similar to those of transformers. PCB-containing capacitors have been found in electric locomotives. In coal mines, capacitors are often in wheel or skid-mounted power centers as shown in Figure 3. The PCB regulations require these items be identified by PCB marks (or labels) if they contain 500 ppm (0.05%) or more PCBs and they are termed PCB transformers or capacitors.

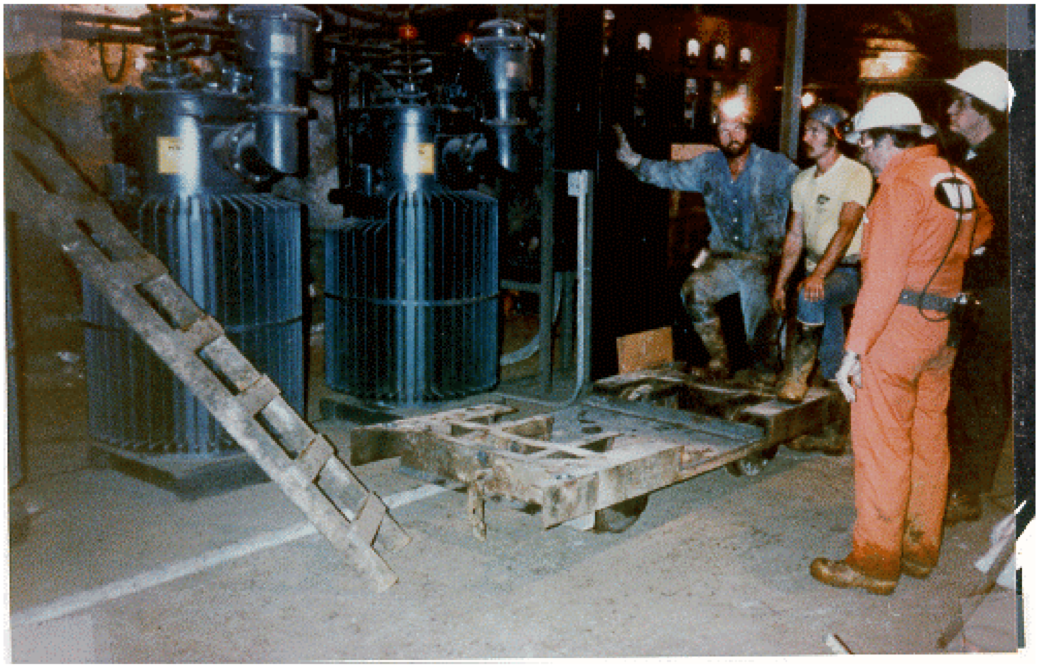

Figure 1.
76 Gallon PCB (Pyranol) Transformers (Cylindrical Objects with Cooling Fins and PCB Marks) on the 20 level of the Eagle Mine at Gilman, Colorado during an EPA removal due to abandonment and flooding.

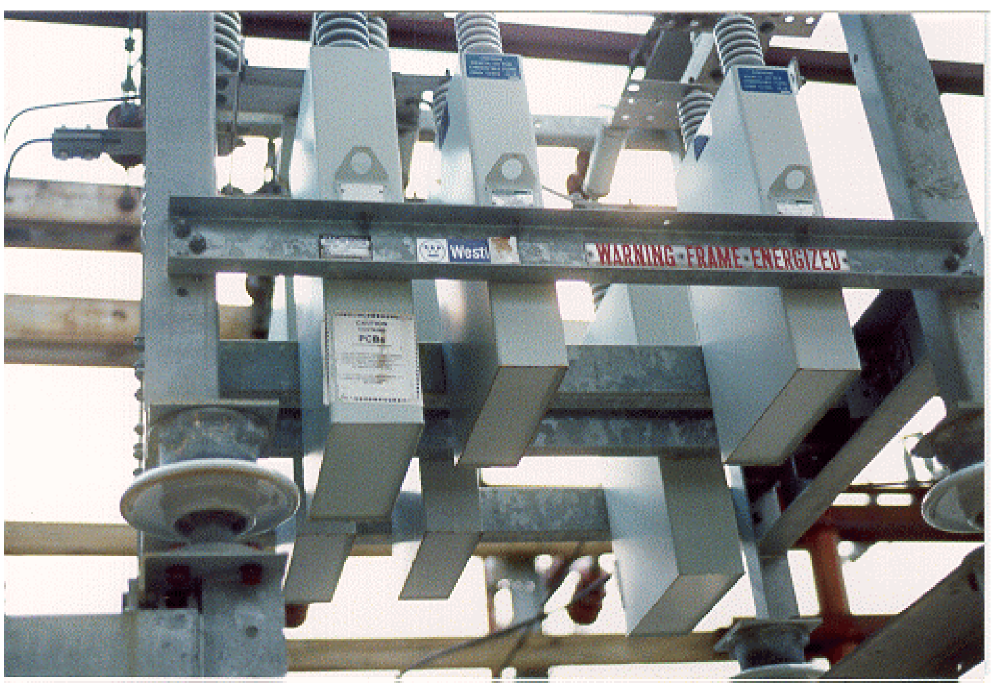

Figure 2.
Looking up at PCB Marked Capacitor on the left

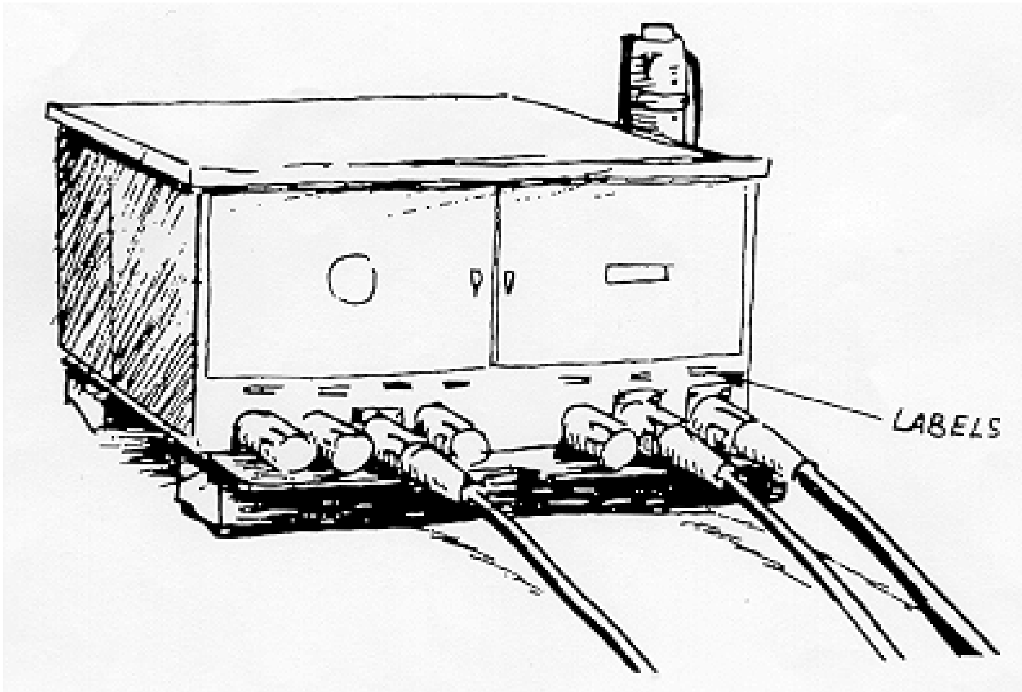

Figure 3.
Mine Power Center Commonly Containing Capacitors

A typical underground mine consists of entries from the surface to the working areas within the ore body. Entries can be vertical shafts, inclines, or horizontal adits. Shafts can be from a few tens of feet to a mile deep. Mines can be extensive in both vertical and horizontal dimensions. A few examples: the Homestake mine at Lead, South Dakota operated at a depth of over 8,000 feet below the surface. It was serviced by two approximately 5,000 foot shafts from the surface to the 5000 or main transfer level and two winzes i.e., underground shafts, below this level one of which descended to the 8000 level[15]. A trona mine near Green River, Wyoming, is operating on one level about 1,500 feet below the surface and encompasses an area of 50 square miles with 4500 miles of drifts[16]. Gold mines in South Africa are being worked at more than 11,000 feet below the surface with plans to go as deep as 16,000 feet in the near future[17]. Entries are often driven in "country rock", that is, rock of no economic value that is not part of the ore body. Country rock is usually more stable than the ore body and therefore more suitable for permanent installations. Mills, storage areas, and repair facilities for mining and electrical equipment may also be located underground in country rock. These areas are collectively referred to as "service areas" to distinguish them from the mining areas. Large mines can require hundreds of electrical substations and/or power centers that may harbor PCB-containing electrical equipment. However, one should not get the impression that only large mines have PCB-containing electrical equipment.

It is important to keep in mind that PCBs are not the only regulated man-made chemicals used underground. There are other chemicals, the release of which may pose environmental threats. Underground repair facilities, like any other repair facilities, may use solvents for cleaning and degreasing equipment. Two examples are trichloroethane and methylene chloride.

The disposal of these solvents is regulated under the Resource Conservation and Recovery Act (RCRA), which regulate the generation, handling, and disposal of hazardous wastes, but not PCBs. The release of these solvents can pose their own threats of ground water contamination. In addition, released solvents can mobilize PCBs, facilitating transport into ground and surface waters. Some mines maintain their own landfills and scrap yards, which have been shown to be repositories of improperly, disposed PCBs and RCRA solvents.

IS ABANDONED PCB-CONTAINING ELECTRICAL EQUIPMENT UNDERGROUND REALLY A PROBLEM?

Concerns have been expressed for the safety of inspectors underground. This issue will be further discussed in the section on Region 8 experiences with underground mine inspections. To illustrate this concern, the following statement defines a hypothetical series of events that has been used to explain why PCB-containing electrical equipment underground is not a problem, so that inspections will be unnecessary. Each of these events that could result in the release of PCBs is said to be unlikely when, in fact, all of them are likely to happen.

Some people argue that even if some electrical equipment abandoned in mines contain [sic] PCBs, the electrical carcass (spent container) will not rupture and the PCBs will not be released. And then, even if the PCBs were released in the mine, the liquid containing the PCBs would just sink to the bottom of the mineshaft. And then, even if the liquid did escape, the dilution ratio would be so great there would be basically no impact.

The following addresses three items from the above statement to show why the claims are incorrect.

(1) *The electrical carcass (spent container) will not rupture and the PCBs will not be released.*

It is common knowledge that most abandoned mines flood and cave in. Abandoned electrical equipment will be corroded by acid mine waters and/or crushed outright.

(2) *...even if the PCBs were released in the mine, the liquid containing the PCBs would just sink to the bottom of the shaft.*

Mines do not consist of shafts. Shafts serve as entries from the surface leading to other active transport or mining areas and constitute insignificant portions of mines in comparison to the mining areas. Mining typically results in extensive areas of highly fractured rock. Fracture produces additional avenues through which ground water from disrupted water tables can be expected to percolate throughout rock within and surrounding the entire mining area.

PCB trade name dielectric fluids are heavier than water and will sink, while mineral oil dielectrics contaminated with PCBs will float to the water surface. In either case, ground and surface waters will be contaminated.

Mines can be very extensive and complex. To illustrate this, Figure 4 is a map of the Idarado Mine

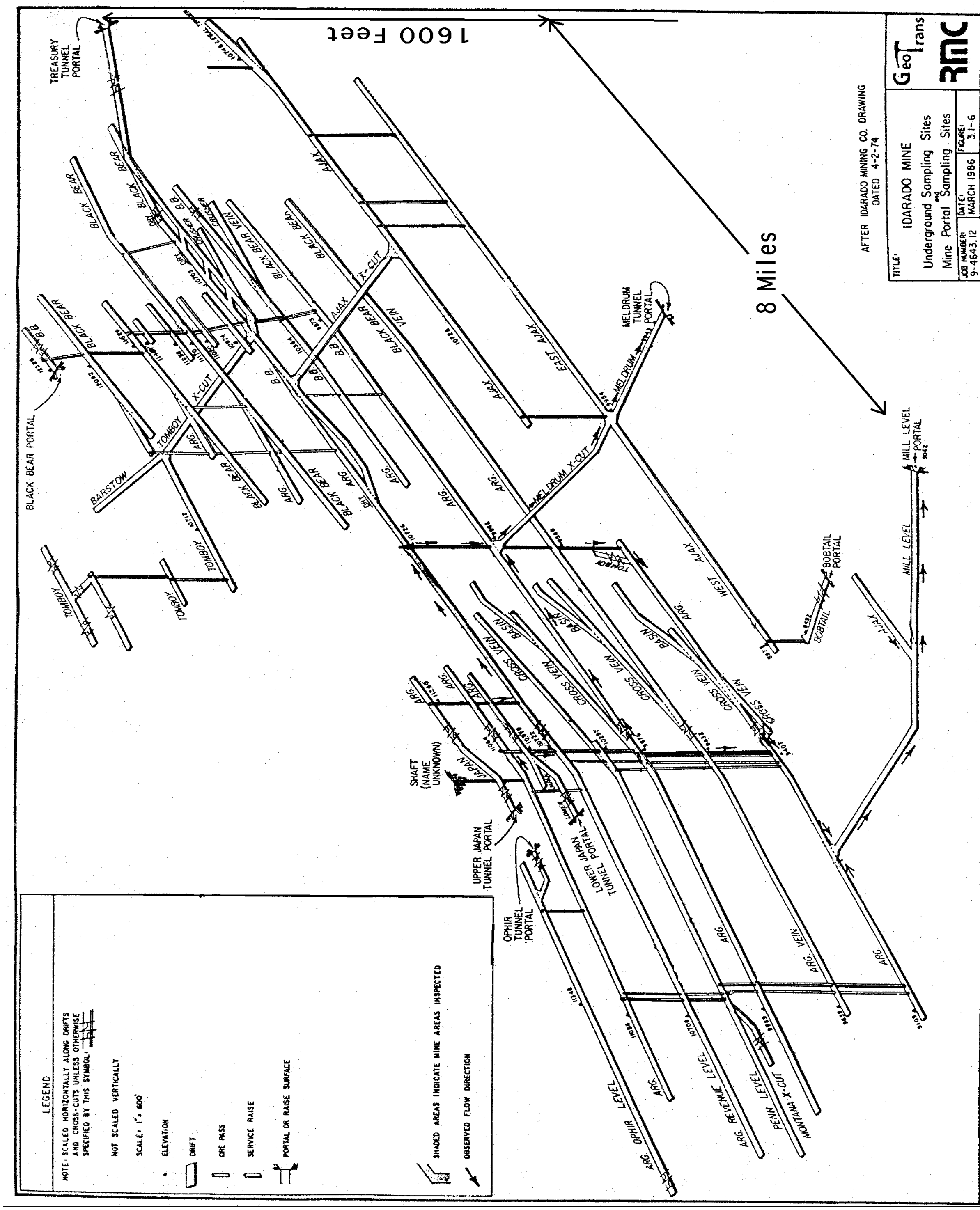

Figure 4.
Idarado Mine, Telluride, Colorado

[Note water drains from the upper levels to the Meldrum, Bobtail, and Mill Level Portals which contribute to the San Juan River. There are no shafts or winzes with bottoms for PCBs to sink to.] The distance "as the crow flies" between the Treasury Tunnel Portal, at the top of Red Mountain Pass on the Million Dollar Highway, in the upper right-hand corner, and the Mill Level Portal at Telluride, near the bottom center, is about eight miles. Only entries, major haulage drifts, and winzes appear on the map. The mining areas are not shown. This mine was confirmed to have PCB-containing electrical equipment underground during an EPA inspection in 1984.

(3) *...even if the liquid did escape, the dilution ratio would be so great there would be basically no impact.*

Hydrologists cannot predict ground water flow patterns or PCB dilution rates because of the fracture caused by mining operations and the unknown ground water pathways[18]. Regarding dilution impact, PCB water solubility is in the parts per billion (ppb) range. At the bioconcentration factor of 740,000 mentioned before, rainbow trout inhabiting water containing more than 18 parts per trillion (ppt) PCB can be expected to violate the FDA standard of 2 ppm for fish consumption[19]. This demonstrates that minute quantities of PCBs dissolved in water alone, and without taking into account the consumption of contaminated invertebrates, can get into the food chain in significant concentrations. Further, 0.064 ppt is the EPA recommended surface water human health criterion for waters inhabited by fish for human consumption. Consumption of contaminated fish is one of the major routes of human exposure[20].

EXPERIENCE WITH INSPECTIONS

EPA Region 8 encompasses six states: Colorado, Montana, North and South Dakota, Utah, and Wyoming. This area contains a substantial portion of the underground hard rock and coalmines in the country. Region 8 experiences should serve as an indicator for other agencies and other countries with mining industries. The Region 8 underground mine inspection program was begun with the promulgation of the PCB regulations in 1978. Within the Region, 75 mines have been inspected during the last 20 years, and 33 government-issued administrative complaints resulting in penalties for violations of the PCB regulations have been issued. This means that 44% of the mines inspected were in violation of the PCB regulations.

Inspections were focused on underground mines as a first priority because of the potential for abandonment of PCB-containing equipment and ground water contamination, so the majority of the inspections and administrative complaints involved underground mines. However, surface mines should not be overlooked. EPA issued an administrative complaint proposing a penalty of more than $1,000,000 for violations of the PCB regulations to an open-pit copper mine in 1994.

Whenever inspectors entered a district without a previous EPA enforcement presence they found a lack of awareness of the dangers and the PCB regulations. They found a similar lack of awareness by other government agencies that had authority over PCBs.

Inspections revealed PCB-containing electrical equipment in just about every conceivable activity: in draglines in open-pit coal mines, power shovels in open-pit metal mines, and 'bone yards' where transformers and capacitors were commonly destined for disposal. They were found in underground substations, pump stations, mine power centers and electric locomotives. PCB-containing electrical

equipment was also found in surface facilities including mills, smelters, metal refineries, breaker houses, and transfer facilities.

Most inspectors are not willing to do underground mine inspections due to mistakenly perceived personal hazard. Inspectors need only minimal training since they will be accompanied at all times by mine personnel. The training may be obtained from the Mine Safety and Health Administration (MSHA), which has jurisdiction over mine, safety, and an MSHA inspector if necessary may accompany inspectors. The MSHA conducts quarterly safety inspections of all working mines in the country. Region 8 is confident that if MSHA deems inspected mines safe for miners to work in, then they are safe for EPA inspectors to enter. Inspections historically have included only working mines and mines on standby to ensure safe entry. These inspections have been conducted with the intention of maintaining enforcement and to help prevent abandonment of PCB-containing equipment underground by persons unacquainted with the regulations.

Abandoned mines have not been part of the inspection program because of inaccessibility, flooding, cave-ins, and very real hazards that will not be dealt with here. However, it appears the major water contamination involving PCBs and mines in the future will come from PCB-containing equipment abandoned underground. An inspection program could help prevent future abandonment.

Some examples will illustrate the kinds of problems that are likely to be encountered. For instance, EPA has reason to believe that PCB-containing transformers were buried under waste rock in an underground coalmine directly above a burning coal seam. Because of 'bad air' in this location and hazardous conditions preventing the use of heavy equipment to remove the waste rock, retrieval of the transformers was not attempted.

An inspection in a previously uninspected mining district following an administrative complaint resulted in the burial of transformers by a different party at a nearby mine site. Upon exhumation by EPA, the transformers were found to contain no PCBs. The mine management, ignorant of the regulations and fearing an inspection and potential enforcement action, had tested the dielectrics for PCBs, but had been unable to understand the field test results and buried unregulated transformers!

In 1984, Region 8 conducted an Immediate Removal Action, under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA)[21] (or the "Superfund" law) in which the author participated in the Eagle Mine at the town of Gilman, a few miles from Vail, Colorado. CERCLA regulates cleanup of uncontrolled or abandoned hazardous-waste sites. The mine consisted of a 400 ft vertical shaft from the surface to the 16 level, the main haulage level. From the 16 level there are two inclines, the 1620 and the 1623, both servicing the 20 level. Levels were 100 ft vertically apart. Below the 20 level, the mine was flooded to the bottom at the 28 level. The mine consisted of about 100 miles of drifts[22], most of which were inaccessible due to flooding, bad air, and an active fire encompassing the 1623 incline. The entire mill with PCB-containing electrical equipment was underground, so that only concentrates destined for a smelter and tailings left the mine. The owner had been advised in writing by EPA to remove the PCB-containing electrical equipment from areas of the mine in danger of flooding before funds became insufficient to maintain the pump station at the 20 level. No action had been taken when the electrical service was discontinued. EPA assumed the electrical bills and removed three 76-gallon Pyranol (PCB) transformers and 27 large Pyranol capacitors during a three-day operation. Three previously drained 76-gallon Pyranol transformers were left at the 1623 incline substation because of the hazards and cost of removal from an active fire area. Whether or not PCB-containing electrical equipment

remains in the accessible portions of the mine and below the 20 level is unknown. This lack of information is typical of abandoned or flooded portions of mines. Although this operation may appear hazardous, the risks were known and controlled, and MSHA inspectors were present throughout the entire removal. If there had not been an EPA mine inspection program, the PCB transformers and capacitors would have been undetected, and today would be under more than 700 ft of water that drains into the Eagle River.

PCB MANAGEMENT AND DISPOSAL

The first task is to inventory the PCB-containing electrical equipment so that you can identify it and its location. Equipment should be marked so that it is easily recognizable, protected, and not inadvertently disposed. Written records are essential. Depending on finances, the second task is to replace the equipment and remove it to safe storage according to government regulations. The third task is disposal. It is of utmost importance to keep in mind the dangers and persistence of PCBs in the environment when deciding on storage locations and disposal. Open burning can convert PCBs to even more hazardous dioxins. Disposal of PCB-containing dielectric fluids in landfills can contaminate ground water. PCB-containing dielectric fluids require specialized disposal techniques that can destroy the PCB molecule. In some countries there are no adequate disposal facilities so that long-term storage will be necessary.

CONCLUSION

It is apparent from the extent of large underground mines that there are opportunities for illegal and improper disposal of hazardous wastes in workings that are so vast that it is unlikely the wastes could ever be located. Many mines, regardless of size, present these opportunities. These possibilities that can cause irremediable harm should be guarded against. The release of PCBs into the environment from end-use products not yet mentioned (such as electrical cable insulation, plastics, caulks, lubricants, paints, and printing inks), uncontrolled disposal, landfills, and underground mines where they were disposed of prior to the PCB regulations can be expected to add to the PCB environmental burden with unforeseeable consequences for the future. PCBs released underground from abandoned electrical equipment may cause water contamination in mining districts throughout the world, which can introduce PCBs into the worldwide environment and human food chain regardless of the location of their release. Routine underground mine inspections by a government authority having jurisdiction over PCBs would help prevent abandonment. There is no legitimate safety concern that should prevent such inspections. Both education and enforcement would have their places here. Whenever hazardous-waste cleanups and environmental restoration take place, the potential presence of PCBs should be considered.

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The EPA PCB regulations are at: www.epa.gov/pcb.

The views in this article express the opinions of the author and do not necessarily reflect EPA policies.

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