CONTAMINANT ASSESSMENT AND TECHNOLOGY DEMONSTRATION TO DESTROY PCB-CONTAINING CAPACITORS IN THE RUSSIAN FEDERATION: APPLYING THE LLRW EXPERIENCE

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ABSTRACT

In 2000, in response to findings of the Arctic Monitoring and Assessment Program, the eight-member Arctic Council adopted the Arctic Council Action Plan to Eliminate Pollution of the Arctic (ACAP). Within ACAP, priority was given to the phase-out and management of persistent organic pollutants, particularly polychlorinated biphenyls (PCBs), in the Russian Federation. Following initial studies of PCB sources and treatment options, this project has entered a third phase that involves demonstrating, in Russia, technologies for destroying PCB-containing substances and equipment. Advanced Russian oxidation technologies capable of achieving high temperatures and residence times within the oxidation chamber are being used to destroy free PCB liquids from large transformers. To destroy PCBs in Russia's smaller capacitors, where separation of the PCBs from the container material is not feasible, an international team of experts selected plasma arc high-temperature thermal destruction from among the technologies evaluated. This technology has the potential to accept entire capacitors as feed, maintain the concentrations of contaminants in the off-gas within established limits, and recover the metal and other inorganic contaminants as slag. Another advantage is that the volumes of off-gases that need to be treated to reduce contaminant emissions are smaller. Also, European experience using plasma arc technology to treat low-level radioactive waste (LLRW) has provided unique technical expertise that can be applied to PCB waste in Russia. This paper describes the current status of this international cooperative PCB project using a plasma arc system originally constructed for destroying hazardous waste at a U.S. Naval Base. It highlights the role of contaminant assessment in overall project planning, including steps from system modification and testing to final waste management. It addresses contaminants associated with the materials awaiting treatment, emissions from the system during treatment, properties of the inorganic slag produced during treatment, and the project's relationship to experience with LLWR destruction activities. Current project activities in Russia include siting, developing infrastructure, establishing compliance with regulatory requirements, and investigating the feasibility of applying the technology to obsolete pesticides and other hazardous and toxic waste contaminants in Russia.

INTRODUCTION

Studies by the Arctic Monitoring and Assessment Program (AMAP) [1] and others have demonstrated an alarming increase of contaminants in the environment and in biological systems in Arctic regions, including areas that are a considerable distance from the industrial and agricultural regions where the contaminants were released. Of particular concern is a class of pollutants that persist in the environment for decades and accumulate in animals at different levels in the food chain by factors of up to 70,000. These pollutants, referred to as persistent organic pollutants (POPs), can circulate globally throughout the atmosphere and in the oceans of the world through a highly complex process. Certain POPs are considered more persistent and bioaccumulative than others. These include certain halogenated hydrocarbons, such as polychlorinated biphenyls (PCBs) and their combustion by-products, dioxins and furans, as well as several organochlorine pesticides, such as chlordane, DDT, dieldrin, and toxaphene.

POPs are nearly always detected in human biological samples from Arctic regions. For example, concentrations as high as 7.5 parts per million (ppm) have been measured in polar bear fat [1]. Some evidence suggests that high levels may be related to abnormalities, such as hermaphroditism, in these animals [2]. One key concern for humans is that POPs concentrate in breast milk, which leads to exposure in infants. For example, in breast milk fat collected in the Murmansk region of Russia in 2000, PCB levels were 0.35 ppm by weight [3].

The accumulated evidence strongly suggests that some POPs have the potential to cause adverse health effects in humans, with the nature and severity depending on the level of exposure. The potential effects associated with POP exposures include immune dysfunction, neurological deficits, reproductive anomalies, behavioral abnormalities, and cancer. A main concern has been potential effects on fetuses and children from exposure during critical periods of development.

Preventing further releases of these compounds as quickly as possible is a high priority for controlling and reducing environmental levels. To address this issue, the Stockholm Convention on Persistent Organic Pollutants was drafted and signed in May 2003. The various countries signing this treaty, which included both the United States and the Russian Federation, are making a commitment to take important steps to reduce the level of POPs in the environment. The steps include banning the production and use of selected obsolete pesticides, banning the production and new use of PCBs, putting national action plans against certain by-products of combustion (including dioxins) in place, requiring the use of best available technologies on new sources of POP by-products in key categories, and imposing controls on handling POP waste and on any trade in these chemicals. Although the Stockholm Convention initially covered 12 of the most critical POPs, a science-based process was also put in place to consider whether other chemicals should be added.

In response to the AMAP assessments of POPs in the Arctic regions, a high-level eight-nation intergovernmental Arctic Council was established in 1996 to address sustainable development and environmental protection issues in the Arctic regions. The Arctic Council members are Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden, and the United States. Consistent with the commitments being proposed under the Stockholm Convention on POPs, in 2000, senior ministers of the Arctic Council established an intensified Arctic Council Action Plan to Eliminate Pollution of the Arctic (ACAP).

Included under ACAP were projects such as eliminating or reducing dioxins and furans emissions in regions of Russia that impact the Arctic, reducing atmospheric mercury releases from Arctic states, managing stockpiles of obsolete pesticides in areas of Russia that impact the Arctic, and phasing out PCB use and managing PCB-contaminated waste in Russia. The highest priority was given to the latter project of eliminating/managing PCBs in Russia.

Management of PCB-Contaminated Wastes in the Russian Federation

The ACAP project for managing PCB-contaminated waste in Russia is aimed at developing and implementing pilot demonstrations that may serve as a model for the Russian federal program. The project has completed the identification of major PCB production, storage, use, and waste sites within the

Russian territories. Reports from this work have been published by AMAP [4, 5] and are available at the AMAP web site: http://www.amap.no.

The ACAP project activities associated with the destruction of PCB-contaminated wastes address the differences among three sources and their remediation technologies: soils and other environmental media contaminated with PCBs, large transformers with PCB liquids, and small capacitors with PCB liquids. Other activities include assessing regulations, collecting and storing PCBs, and replacing PCBs with alternative fluids.

An ACAP study of PCB-contaminated sites [4] recommended that the preferred method for rehabilitating one of the more heavily contaminated sites is to use thermal desorption and a cyclone kiln for destruction. The study concluded that this approach should reduce the PCB content in soil to the levels required by environmental protection guidelines. It also recommended that other PCB-polluted sites in Russia must be evaluated on a case-by-case basis.

In the ACAP effort to develop an inventory of PCBs in electrical equipment in Russia [5], it was estimated that there are about 20,000 tonnes of PCBs in 10,000 large transformers and more than 10,000 tonnes of PCBs in over 500,000 capacitors.

As a part of the ACAP effort to eliminate/manage PCBs in Russia, a project was begun with the objective of destroying about 250 tonnes of PCBs from the large transformers in the northwest region of Russia. The PCBs will be drained from the transformers and destroyed with a Russian "cyclone reactor" that combines a high-efficiency combustion technology with high-temperature neutralization of the hydrochloric acid that is a by-product of the incineration. The drained transformers are to be cleaned by a combination of thermal and solvent processes.

Russian PCB-Containing Capacitors and Selection of Destruction Technologies: Contaminant Assessment

The Russian industrial capacitors containing PCBs (Fig. 1a) are typically [0.38 × 0.12 × (0.35 -0.64)] meters with a composition in weight percent of about 40% PCBs, 15% steel, 30% paper or polypropylene film, 13% aluminum foil, and 2% other materials, such as solders. Destruction of PCBs in the capacitors requires an approach that is different from the one used for transformers because of the technical impracticality of efficiently separating the PCBs from the complex structure within the capacitors (Fig. 1b). No safe, reliable technology currently exists in Russia to address these materials.

A team of Russian and other international technical experts who evaluated alternatives for destroying the PCBs in capacitors concluded that plasma arc thermal destruction would be the preferred technology. The decision was based on the following system characteristics [6]:

- It has demonstrated effectiveness in destroying halogenated organics.
- It has low emissions of dioxins/furans and other contaminants.
- Metal-encased capacitors could be fed into a plasma arc system with minimal preprocessing and no need for disassembly or draining.
- Processing temperatures of more than 1,200^{o}C ensure complete destruction of PCBs.
- The volume of off-gas for treatment is considerably less than that from incineration technologies.
- Metallic components can be captured in slag.
- It can be applied to destroy other POPs, such as obsolete pesticides.

a) Typical exterior capacitor dimensions **b) Typical internal capacitor contents**

Fig. 1. Russian industrial capacitors.

The development of plans for eliminating/managing PCBs in Russia by using plasma arc technology benefited from the experience gained in using similar systems for low-level radioactive waste (LLRW) management in Europe, particularly at the Zwischenlager Würenlingen AG (ZWILAG) facility in Switzerland. Technical issues that were identified and successfully addressed in the LLRW experience that are relevant to PCB and other chemical waste applications include how to design and operate the slag-handling system to avoid clogging the outflow. The design and operation of the secondary combustion chamber is also of interest with regard to optimizing throughput while maintaining sufficient residence time. Chamber volume and use of a second plasma torch or alternative fossil-fuel heating source are among the design considerations for the secondary combustion chamber. The LLRW experience indicated that the designs of the input feeder and shredder equipment are also critical to the successful operation of the overall plasma arc system.

A Plasma Arc Centrifugal Treatment System with an 8-foot-diameter primary processing chamber (PACT-8) that was designed and built by Retech Systems, LLC (Fig. 2), for the U.S. Naval Research Laboratory (NRL) was made available to the Russia PCB project as a technical assistance contribution. (The system was originally built for the purpose of destroying hazardous waste at the Norfolk, Virginia, Naval Station, However, the Navy decided not to put the system into operation because the potential users reduced their generation of hazardous waste, which meant there would be insufficient feed material to justify installation.) The unit is disassembled and in storage at the Norfolk Naval Station facilities in Norfolk, Virginia. Modifications required to use the PACT system in Russia for the demonstration project are underway. These include rewiring the power supplies for operation on the Russian electrical grid and testing the shredder-feeder system with capacitors as input. The system is on target for shipment when modifications have been completed and the necessary import and siting arrangements have been established.

The projected PACT-8 system parameters for normal operation when destroying Russian PCB capacitors are processing rates of 350 and 500 kilograms/hour (for capacitors with polypropylene and paper content, respectively) and power consumption of 1,000 kilowatts. (Electrical power consumption will be higher during startup.) The system was designed for compliance with U.S. regulatory requirements (see Table I). For typical Russian capacitors, about 0.4 tonne of slag will be produced per tonne of capacitor processed.

The PACT-8 can achieve and maintain temperatures of 1200^{o}C in the primary processing chamber (PPC) (Fig. 3) which is sufficient to destroy most organic materials. For processing of capacitors, the gas

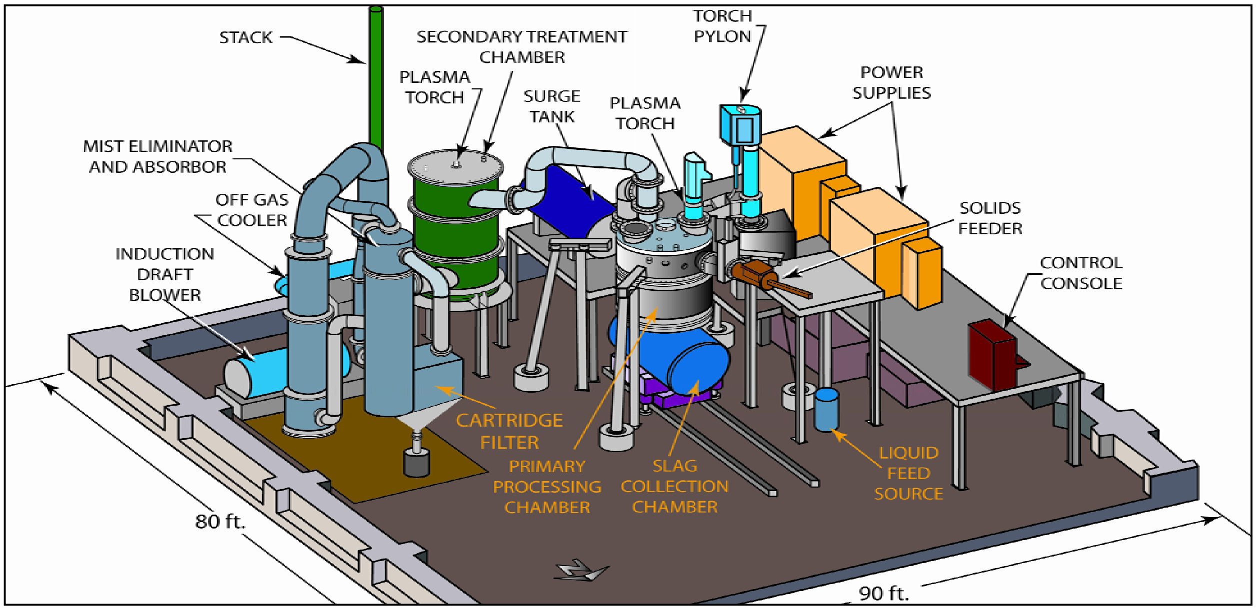

Fig. 2. Schematic diagram of plasma arc centrifugal treatment (PACT) system [7]. (Most of the decking is not shown in order to more clearly show components.)

Table I. Applicable U.S. Regulatory Requirements for Environmental Releases[a]

Dioxins and furans	0.20 nanogram TEQ/dscm
Particulate matter	34 milligrams/dscm
Mercury	45 micrograms/dscm
Semivolatile metals (Cd and Pb, combined)	24 micrograms/dscm
Low-volatile metals (As, Be, and Cr, combined)	97 micrograms/dscm
Hydrogen chloride and chlorine	21 ppmv
Carbon monoxide	100 ppmv
Hydrocarbons (expressed as propane)	10 ppmv
Minimum DRE for each POHC	99.99%

[a] Notes:
TEQ = toxicity equivalency of 2,3,7,8 tetra-chlorinated dibenzo-p-dioxin.
dscm = dry standard cubic meter.
ppmv = parts per million by volume.
DRE = destruction and removal efficiency.
POHC = principal organic hazardous constituent.
All values must be corrected to 7% oxygen.
Standards require meeting either CO limits or hydrocarbon limits, not both.

exiting the PPC is typically at 1000 to 1300°C and consists principally of CO, CO_2, H_2O, HCl and N_2 which is used as a purge gas . The gas enters the Secondary Treatment Chamber where it has a residence time of at least 2 seconds to ensure completion combustion of the CO.

Molten slag consisting of inorganic material flows out of the bottom center of the rotating primary chamber. Because of the high temperatures and the material agitation from the rotation, no volatile organics remain in the slag. By varying the feed input, the slag can be controlled to have glass characteristics with low leach rates. It is expected that Russian approval will have to be obtained to dispose of the slag as a nonhazardous by-product.

The estimated consumption of process gas per tonne of capacitors destroyed includes 310 to 720 cubic meters of oxygen and 510 to 720 cubic meters of nitrogen. The larger values are for capacitors with polypropolene construction material; the lower values are for paper.

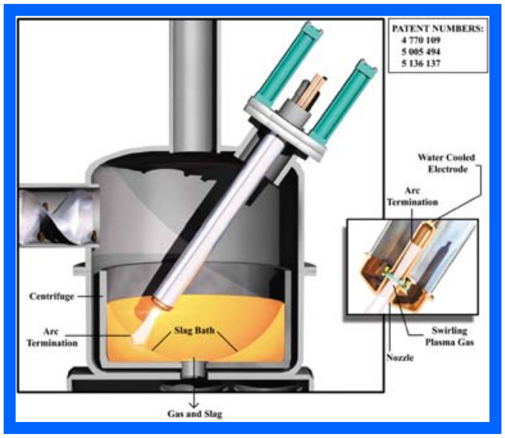

Fig. 3. PACT primary processing chamber. (Source: Retech Systems, LLC)

The PACT-8 acceptance test demonstrated that system emissions at the stack exit could be maintained as low as, or lower than, applicable U.S. regulatory requirements (shown in Table I). On the basis of these tests, the State of Virginia issued air emission permits to construct and operate the system. Additional modifications to control gaseous emissions, such as adding activated charcoal filters in the cartridge filterbaghouse, can be implemented as necessary.

During tests at Retech before the PACT-8 was delivered to the NRL, when a mixture of methanol and trichloroethane was fed, dioxins were found in concentrations higher than the regulatory limit [7]. Upon analysis, it was determined that the problem could be mitigated, if not entirely solved, by applying insulation to the off-gas cooler. The insulation will reduce the time that the off-gas remains at temperatures in the critical range for reforming dioxins (300-450°C). Test programs conducted on other PACT-8 systems located in Munster, Germany; Zwilag, Switzerland; and Butte, Montana and on Retech's in-house PACT-8 showed that using an insulated off-gas cooler essentially prevented the gas from spending any time in the critical temperature region and that this solution was uniformly successful in meeting off-gas dioxin regulatory requirements. As an added precaution, activated charcoal filters can be used in conjunction with the baghouse to effectively remove the minute amounts of dioxins that may be present in the off-gas stream. The contaminated filters can be destroyed by recycling them back into the system input stream.

When the NRL PACT-8 system was being built and tested, it was not anticipated that it would be used to destroy PCBs, and the acceptance test did not include PCB feeds. However, other tests of similar systems demonstrated that DREs of 99.9999% with trichloroethane and 99.99989% with hexachlorobenzene, a PCB test surrogate, were achievable (Table II).

From inorganic feed materials, the PACT-8 system produces a solid residue consisting of a glasslike, nonleachable substance (slag) that is easy and safe to handle, transport, and dispose of or recycle. The PACT-8 final slag waste form has been thoroughly tested by using methods approved by the U.S. Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE). Results are summarized in Table III. The overall performance assessment shows that PACT-8 slag easily meets the EPA and DOE constraints.

Table II. Destruction and Removal Efficiencies (DREs) Achieved in PACT Tests

Compound	Waste	DRE (%)	DRE (%) Regulatory Limit
Xylene	Medical ash: glass, metal	99.99986	99.99
Hexachlorobenzene (HCB)	Carbon, bone	99.999668	99.99
Hexachlorobenzene	Soil, semivolatiles	99.99988	99.99
Hexachlorobenzene	Pyrotechnic sludge	99.99989	99.99
Trichloroethane (TCA)	Liquid TCA/methanol mix	>99.9999	99.99
Tetrachloroethylene	Soil, diesel fuel, zinc, steel	99.9995	99.99
Bis (2-ethylhexyl) phthalate	Soil, diesel fuel	99.998	99.99
2-Methylnaphthalene	Soil, diesel fuel	99.9997	99.99
Xylene group	Soil, diesel fuel, zinc, steel	99.9934	99.99
Hexachloroethane	Soil, diesel fuel, zinc, steel	99.9997	99.99

Table III. PACT-8 Slag Tests Results [8]

Category	Slag Performance
Liquids	No free liquid
Pyrophoric materials	No pyrophoric material
Explosives and compressed gases	No explosives or compressed gases
Compressive strength	2.5 times higher strength than regulations
Leachability	10 to 100 times lower than regulations
Immersion	Maintains compressive strength
Biodegradation	Maintains compressive strength
Biological hazards	No biological or infectious materials
Radiation stability	Maintains compressive strength
Longevity	Minimal leaching over 10,000 years

Site Assessment

To guide the evaluation of candidate sites in Russia for the ACAP project demonstration, an international team of technical experts developed a detailed checklist. Principal criteria included (1) a recognized PCB problem in the vicinity of the location; (2) availability of a qualified Russian organization to install and operate the treatment facility; (3) local, regional, and national organizational support for the demonstration project; and (4) a site suitable for development and operation of a treatment facility and its required infrastructure. Eighteen potential partners in Russia were considered, and on-site evaluations were conducted at the nine locations that represented the most viable sites and organizations. Assistance in the coordination of site visits in Russia was provided by the Russian-Norwegian Cleaner Production Centre. On the basis of these evaluations, the Volga Chemical Company (Chimprom) in Volgograd , and the Autonomous Nonprofit Organization and Research and Production Association Ecolline in Yaroslavl were identified as leading candidates for installing and operating the demonstration technology at approved locations. The expert team found that (1) both the Volga and Yaroslavl regions contain PCBs and other hazardous wastes that need to be managed; (2) Chimprom and Ecolline have well-qualified implementing organizations; (3) local, regional, and federal organizations expressed support; and (4) the sites in Volgograd and Yaroslavl are well-situated for transporting PCB-containing capacitors to them, and they have appropriate infrastructure available. Thus, both were found to be well suited as a potential partner and associated demonstration site.

CONCLUSION AND NEXT STEPS

On the basis of the performance assessments for treating LLRW and other types of waste and evaluations by an international team of technical experts, plasma arc technology was determined to be a viable technology for destroying PCB-containing capacitors in Russia. The contaminant assessment indicated that gaseous, liquid, and solid effluents can be maintained within acceptable limits, although further testing and fine-tuning of operating factors throughout the demonstration project are essential. If the demonstration project is successful, it could form the basis for creating the first central facility for treating chemical hazardous wastes in Russia.

In preparation for its transport to and its installation and operation in Russia, modifications are being incorporated into PACT-8. These include changes to the electrical system to achieve compatibility with the Russian electrical grid and changes to the feeder system to effectively process capacitors without first draining the PCB liquids. Designs of site buildings and infrastructure to accommodate the PACT-8 are also being completed in Russia.

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