Radiation technologies for waste treatment: A global perspective

Countries are studying irradiation systems for disinfection and decontamination of liquid and solid hazardous wastes

by
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Pollution of water, land, and air is a widespread and growing concern of global proportions. Media reports of diseases and contamination caused by the improper treatment and disposal of waste products occur on a regular basis. This heightened awareness of potential health hazards from insufficient or inappropriate waste handling methods has stimulated the search for effective waste treatment alternatives. In many countries, recycling initiatives are being seen at the individual, community, city, and state levels.

Of particular concern are wastes that present problems in two areas: those containing potentially infectious microorganisms (sewage sludge, biomedical wastes, wastewater) and those contaminated with toxic chemicals. Basic types of irradiation systems which are currently being used in waste treatment operations, or are being studied for this purpose, include gamma, electron-beam, ultraviolet, and X-ray.

Gamma irradiators, typically installed with an energy source of radioactive cobalt-60, have been widely used since the early 1960s in the sterilization of medical products and consumer goods. Their use in the disinfection of sewage sludge has been demonstrated on a full-scale basis at a plant near Munich, Germany; and at a biomedical waste sterilizer in Arkansas, USA, for the treatment of hospital wastes. Their use for degradation of toxics in soils currently is under investigation.

Similarly, electron-beam machines have seen decades of use in industrial processes. This technology has been proven effective in the disinfection of drinking water and wastewater. More recently, it has been used in pilot-scale studies to break down contaminants in soils and industrial waste slurries.

Ultraviolet irradiation systems have regained popularity at wastewater treatment plants as an alternative to chlorine. First used many years ago, these systems have undergone improvements that resulted in more robust equipment and more reliable operation.

Finally, the possible application of X-rays — whose use is well established for medical diagnosis and cancer therapy — for the treatment of wastes has been investigated. However, the technology has not yet been applied for this purpose.

A history of worldwide activities

For irradiation treatment in large-scale applications, several types of radiation sources are generally considered. A review of the state-of-the-art of the technology for irradiation treatment of water, wastewater, and sludge by four types of radiation was published by the American Society of Civil Engineers in 1992.* It summarizes the development status for the four types of radiation technologies investigated: ultraviolet, radioactive isotopes (primarily cobalt-60), linear accelerators or electron-beam machines, and X-ray machines.

Irradiation facilities for treatment of water have been constructed in many countries of the world. *(See table on page 12.)* The first large-scale plant was the Geiselbullach Gamma Sludge Irradiator, constructed in Germany in 1973. Another commercial application, also in

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**Radiation Treatment of Water, Wastewater and Sludge*, Task Committee on Radiation Energy Treatment, American Society of Civil Engineers, New York, (1992).

Irradiation facilities for treatment of water, wastewater, and sludge that have been or are operating

	Irradiator type	Waste type processed	Reason for treatment
Austria	Electron-beam	Drinking water	Reduction of chemical contaminants
	Cobalt-60	Wastewater	Reduction of phenols
Canada	Cobalt-60	Sludge	Disinfection prior to fertilizer use
Czech Republic	Cobalt-60	Drinking water	Disinfection
Germany	Cobalt-60	Sludge	Disinfection prior to land use
	Cobalt-60	Well water	To prevent biological fouling
India	Cobalt-60	Sludge	Disinfection
Japan	Cobalt-60	Sludge	Disinfection prior to composting
	Cobalt-60	Landfill leachate	Destruction of toxics
Norway	Cobalt-60	Sludge	Disinfection
	Electron-beam	Effluent	Disinfection
South Africa	Electron-beam	Sludge	Disinfection
United States	Electron-beam	Wastewater, sludge	Disinfection

Source: Adapted from Radiation Treatment of Water, Wastewater, and Sludge, a report by the American Society of Civil Engineers (1992). This listing includes pilot and full-scale facilities that have operated or are currently operating. More detailed descriptions and references are available in that report.

Germany, is the use of irradiation to reduce biological fouling of drinking water wells. Several electron-beam facilities are in operation to explore the commercial feasibility for water, wastewater, and sludge treatment.

Liquid sludge irradiator system in India

India's Sludge Hygienization Research Irradiator (SHRI) is the second such plant in the world. It was formally commissioned in the city of Baroda in early 1992. SHRI forms part of the programme of the Bhabha Atomic Research Centre, Bombay, in the application of radiation technology for public health and environmental protection. The irradiator was built in co-operation with the Government of the State of Gujarat, the Baroda Municipal Corporation, and the M.S. University of Baroda. The final objective is to treat the entire sludge output of about 110 cubic meters per day from the Gajerawadi Sewage Treatment Plant and use the hygienized sludge as a safe fertilizer.

SHRI has two separate identical irradiation circuits, each comprised of a silo, irradiation chamber, and recycling systems. Presently only one circuit is operated at a time. Each irradiation chamber has a maximum cobalt-60 loading capacity of about 500 kilocuries. At a dose of 4 kilogray (kGy), each irradiation circuit can handle up to about 100 to 120 cubic meters per day of sludge. *(See schematic on page 13.)*

The digested/undigested sludge is first passed into a silo and a measured volume of 3 cubic meters is fed by gravity into the irradiation vessel. The sludge is then circulated by a pump for a predetermined duration to prevent settling and to impart the desired dose. At the end of this operation, the sludge is drained into a storage tank from where it is pumped to drying beds. With the present cobalt-60 loading, a batch operation of two to three hours results in a nearly complete elimination of the microbial load, depending on the initial count. Three batches are disinfected each day.

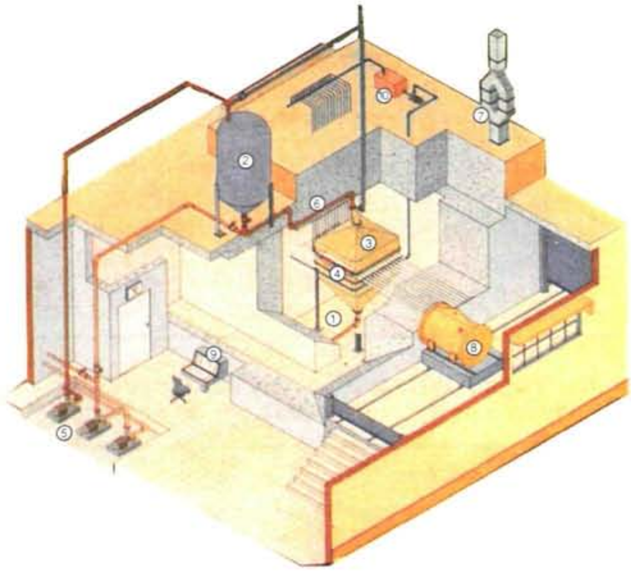
The disinfected and dried sludge has been used as a fertilizer in the SHRI facility's garden. Efforts are being made to supply the treated sludge to farmers in the region.

The facility, though originally designed for sludge hygienization, has been used to assess the technology's suitability for the treatment of effluent from sewage treatment plants. India's Ministry of Environment has expressed interest in radiation technology for large-scale treatment of municipal sewage effluent in cities along the Ganga river in northern India.

Destruction of toxic contaminants: Research in the United States

For the last 6 years, an interdisciplinary team of scientists and engineers has studied the effect of high-energy electron irradiation on the removal (ultimate destruction) of toxic organic chemicals in aqueous solutions and the factors that have been identified as important in efficiently destroying the chemicals. The results of these studies are applicable to waste treatment and the remediation of hazardous waste sites. The studies have been conducted at the Electron Beam Research Facility (EBRF) in Miami, Florida.

EBRF is located at the Miami-Dade Central District Wastewater Treatment Plant on Virginia Key, Miami, Florida. It features a horizontal 1.5 million electron volt (MeV) electron accelerator. The accelerator is an insulated-core transformer (ICT) type, capable of delivering up to 50 mA beam current. Varying the beam current changes the absorbed dose in a linear fashion, allowing for experimentation at doses from 0 to 8 kGy. The electron beam is scanned to 200 Hz to give a coverage of 1.2 meters wide and 5 centimeters high.



Above: India's sludge irradiation research facility in Baroda. As shown in the schematic, the facility includes the irradiation cell (1); storage silo (2); irradiation vessel (3); source assembly (4); pump house (5); recirculation lines (6); obnoxious gas exhaust (7); transport container (8); control console (9); and source coolant system (10).
Below: In Canada, lettuce is being grown in land fertilized with irradiated sludge at the Ontario Agricultural College as part of research activities. *(Credits: Bhabha ARC, India; Prof. Thomas Bates, Land Resource Science Dept., Univ. of Guelph, Canada.)*

Summary of the average dose to remove 99% of trichloroethylene from aqueous solution in the presence and absence of clay

No Clay		3% Clay	
Initial concentration range (micro-M)*	Average dose (kGy) required to remove 99%	Initial concentration range (micro-M)	Average dose (kGy) required to remove 99%
0.61 - 0 88	0.57	0 58 - 0.72	0.58
6 2 - 8.9	0.64	6.2 - 7 2	0 64
40 - 58	1.07	45 - 59	1.06

*1 micro-M = 0.131 mg per liter

Summary of the average dose needed to remove 99% of benzene from aqueous solution in the presence and absence of clay

No Clay		3% Clay	
Initial concentration range (micro-M)*	Average dose (kGy) required to remove 99%	Initial concentration range (micro-M)	Average dose (kGy) required to remove 99%
1.1 -2.1	0.56	1.1 - 1.3	0.49
17 - 24	0.72	16 - 19	0.96
23 - 87	2.00	25 - 76	1 81

*1micro-M = 0.078 mg per liter

At the design flow of 0.45 cubic meters per minute, influent streams at the EBRF are presented to the scanned beam in a falling stream approximately 4 millimeters thick. Since the maximum penetration in water is approximately 7 millimeters for 1.5 MeV electrons, some electrons pass through the stream. Thus not all of the beam energy is transferred to the water. By over-scanning the waste stream to ensure that the edges of the stream are irradiated, more energy is lost. The result is that the efficiency of energy transfer is approximately 60% to 85%. Thus, at 50 mA (75 kW), doses of between 6.5 and 8 kGy have been recorded. Total power consumption including pumps, chillers, and other auxiliary equipment is about 120 kW.

Removal of toxic and hazardous organic chemicals: Summary of results

Numerous studies have been conducted on organic chemicals that may be of interest in contaminated soils treatment, groundwater remediation, industrial waste treatment, and hazardous waste leachates. Results for two compounds are summarized below.

The data for the removal efficiency was obtained at several irradiation doses, at three initial solute concentrations, three different pHs, and in the presence and absence of 3% clay. The solutes were either prepared in concentrated stock solutions in the laboratory or injected into tank trucks as the trucks were being filled up with water. *(See tables.)*

Reaction byproducts for all of the compounds studied are highly oxidized in nature. For example, formaldehyde and formic acid, at micro-M concentrations, were the only reaction byproducts identified for trichloroethylene. The remainder of the parent compound was completely mineralized to $C0_2$ H_20 and HCI.

It has been shown, therefore, that high energy electron-beam irradiation is effective and efficient in destroying organic chemicals from aqueous streams. The examples shown here are typical of organic chemicals found in waste streams and at remediation sites for hazardous waste.

The Canadian sludge recycling facility: Marketing irradiated sludge

Municipal sewage sludge is the solid matter removed during wastewater treatment processes at sewage treatment plants. Sludge typically contains potentially harmful components such as infectious organisms (viruses, bacteria, parasites), heavy metals, and chemicals. It also contains nitrogen, phosphorus, and other nutrients beneficial to plant growth.

In several countries (Germany, India, Italy) the use of irradiation systems to disinfect liquid sludges prior to application on farm land has been successfully adopted. In Canada, a 4-year trial programme has led to a proposal to create a Sludge Recycling Facility, incorporating a cobalt-60-sourced sludge irradiator. If approved, the facility will convert sludge into a dry, soil-like product ready for bagging and marketing to horticultural firms.

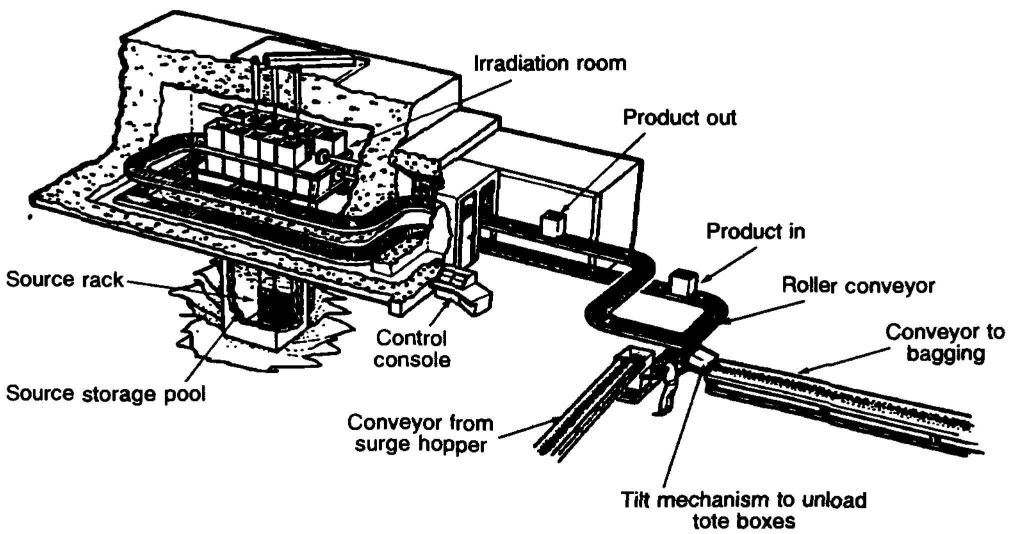
Sludge irradiation systems

Irradiation disinfection of sludge would typically be carried out in a gamma irradiator with a cobalt-60 source. There are more than 160 of these full-scale industrial irradiators operating around the world to sterilize syringes, sutures, surgeons' gowns, heart valves, ointments, talcs, and a multitude of medical and consumer products.

A sludge irradiation disinfection system consists of three main components :

- a concrete-walled disinfection room which houses the irradiator and cobalt-60;
- a product handling mechanism which moves the sludge into and out of the room; and
- a cobalt-60 energy source for disinfection.

Sludge disinfection system



Schematic of a municipal sludge irradiator

The cobalt-60 sources are an important part of the irradiator. Cobalt-60 is a deliberately produced radioactive isotope, the same as is used in the treatment of cancer patients in hospitals. Naturally occurring non-radioactive cobalt-59 is fashioned into pencil-like rods. These "pencils" are bombarded with neutrons in a nuclear reactor for one or more years, after which time about 10% of the cobalt-59 has been transformed into cobalt-60. The pencils are then removed from the reactor for further processing and preparation for shipment to users of industrial irradiation systems.

The cobalt-60 emits gamma rays as it decays to nickel. These gamma rays pass through sludge, killing microorganisms and parasites. They do not leave any residue in or on the sludge, and they do not make the sludge "radioactive". The irradiation process will not change moisture content, or the levels of nutrients and heavy metals — its sole function is to eliminate pathogenic organisms.

Irradiated sludge as a fertilizer product

Disinfected sludge can be safely recycled for use as a fertilizer, soil conditioner, or as an ingredient in a wide range of specialty fertilizer products. Sludge products compete well with soil amendment and animal manure products typically available in the marketplace.

Because it is organically based, sludge products offer long-term soil improvement, unlike chemical fertilizers which provide nutrients but have few soil-enhancement properties. The natural components of sludge-based products make it ideal for use around shrubs and flowers. It can also be integrated into new or existing lawns.

Future challenges and opportunities

This article has provided a very brief overview of the types of waste management problems for which various radiation technologies can provide solutions. In some cases, more research and testing is required before the technology can be used on a commercial basis; in other instances the technology is already being used, or is ready for use, on a full-scale basis.

Looking to the future, ongoing research in scientific centres points the way to new roles for the safe, reliable, and economic application of radiation technologies for waste treatment. Among these are electron-beam machines to rid flue gases of environmental pollutants such as nitrogen oxide and sulphur dioxide; machines using cobalt-60 to sterilize hospital and laboratory wastes for safe disposal; and the increasing use of ultraviolet in place of chlorine chemicals to disinfect wastewater.

As each year passes, citizens in all countries are confronted with a growing list of seemingly insurmountable environmental problems. To meet these challenges, high-technology solutions are being sought which will provide answers now, as well as in the future. Radiation technology provides a viable alternative in this ongoing search. ❐