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# SLUDGE MANAGEMENT BY HIGH-ENERGY ELECTRON IRRADIATION PRIOR TO LAND APPLICATION STATE OF THE ART*

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Sludge management by means of the application of digested sludge to the land for agricultural purposes and land reclamation is a high-priority conservation matter that is gaining acceptance in many parts of the world. As will be discussed in this paper, the disinfection of sludge by means of irradiation with high-energy electrons may become an important unit operation in preparing sludge for land application in the future.

As a consequence of Congressional actions within the past decade, the U.S. Environmental Protection Agency (EPA) has been enforcing stricter regulations on municipalities and industries and calling for higher degrees of wastewater treatment. These regulations include the removal of excessive concentrations of heavy metals at the industrial plants. Throughout this paper it is assumed that heavy metals will be within tolerable concentrations [1] in the residual solids (sludge) of municipal treatment plants. With more solids being removed by improved primary treatment and more secondary and tertiary treatment plants being installed, the quantities of sludge being produced are escalating rapidly, as shown in Table 1.

TABLE 1
ESTIMATED INCREASE IN PRODUCTION OF MUNICIPAL WASTEWATER SLUDGE, 1972 to 1985 [2]

| Sludge type | 1972 Equivalent population, millions | 1972 Dry tons per year[a] | 1985 Equivalent population, millions | 1985 Dry tons per year |
|---|---|---|---|---|
| Primary (0.12 lb/capita/day[b]) | 145 | 3,170,000 | 170 | 3,720,000 |
| Secondary (0.08 lb/capita/day) | 101 | 1,480,000 | 170 | 2,480,000 |
| Chemical (0.05 lb/capita/day) | 10 | 91,000 | 50 | 455,000 |
| Total | 256 | 4,741,000 | 390 | 6,655,000 |

a. ton x 0.908 = metric ton
b. lb x 0.454 = kg

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At the same time that the quantities of sludge are increasing, the methods of disposal are changing. In the future, ocean disposal will no longer be allowed, so greater quantities will have to be disposed of on land by sanitary landfilling, incineration, and land application, as shown in Table 2.

TABLE 2
CHANGES IN DISPOSAL METHODS FOR MUNICIPAL WASTEWATER SLUDGE, 1972 to 1985 [2]

| Disposal methods | 1972 Percent | 1985 Percent |
|---|---|---|
| Landfill | 40 | 40 |
| Land application | 20 | 25 |
| Incineration | 25 | 35 |
| Ocean (dumping and outfalls) | 15 | 0 |

*APPLICATION OF SLUDGE ON LAND*

If the predictions given in Tables 1 and 2 are correct, by 1985 the amount of sludge to be disposed of on land for agricultural and other purposes may approximate 1.7 million tons (dry weight) per year (1.5 million metric tons). How these quantities of sludge should be processed and where they should be disposed of are matters of great concern to environmental engineers today.

Depending on the moisture content and consistency of the sludge, the method of application to the land could be by sprinkler irrigation, subsurface injection, ridge and furrow trenching, or by other means of spreading and plowing. Reclamation of land and conservation of the humus and nitrogen values of the sludge can be as important as the solution to the problem of ultimate disposal.

The Prairie Plan of the Metropolitan Sanitary District of Greater Chicago for the reclamation of strip-mined land in central Illinois is probably the largest and best known sludge utilization plan in this country. Halderson and co-workers [3] have described the operations involved in disposing of 425 tons* per day of digested sludge to reclaim land that would be considered worthless from the agricultural standpoint. The agricultural cropping program for the growth of corn has proved to be highly profitable for tract farmers. Trace concentrations of heavy metals were found to be tolerable to the corn crop [4]. Of course, sludge must be stored during winter months near the land to be reclaimed and in a manner that protects the water and land environment. The Prairie Plan has been such a success [5] that it won the ASCE Award for the Outstanding Civil Engineering Achievement of 1974.

*U.S. tons (2,000 lb) are used hereafter in this text.

### *PUBLIC HEALTH CONSIDERATIONS*

In the Prairie Plan, disinfection of sludge is not deemed necessary for the farming of corn. However, test wells have been located all over the area, and procedures are carefully controlled. Samples are analyzed for any possible groundwater contamination.

A Draft Technical Bulletin published by the EPA in 1974 provides guidelines for "Acceptable Methods for the Utilization or Disposal of Sludges" [6]. Section 2 of the bulletin indicates that land application of stabilized sludges for agriculture, enhancement of parks and forests, and reclamation of poor or damaged terrain is an acceptable method for the utilization of sludge. A key point is that the sludge must be stabilized prior to land application

> . . . to reduce public health hazards (through substantial reduction of numbers of pathogens) and to prevent nuisance odor conditions. [6]

Further discussion of this subject is provided in a comprehensive report to the National Commission on Water Quality [7].

According to Miller:

> Recycling of sewage, primary and secondary effluents or liquid sewage sludges on land may present a potential health hazard because of the human and animal pathogens which these wastes contain. Among the common pathogens found in these waste materials are the bacterial pathogens *Salmonella, Shigella, Mycobacterium,* and *Vibro comma;* the hepatitis viruses, enteroviruses and adenoviruses; and the protozoan, *Endomoeba histolytica*. . . . Anaerobic digestion of sludge results in a significant reduction in numbers of pathogenic microorganisms, but does not result in complete elimination of pathogens.[8]

Farrell has pointed out:

> In Germany and Switzerland, there has been a substantial use of sludge on agricultural land and a concomitant concern about its potential infection hazard. This has led to regulations that sludge applied to pasture or agricultural land be reduced in pathogens beyond the level attained by digestion.[9]

In the United States, however, the states appear to be relying on federal policies yet to be developed by the EPA. Farrell concludes:

> During the next few years, regulatory agencies at the several levels of government will become concerned with pathogens in sludge applied to land. Codes of practice will require either pretreatment of sludges applied to cropland and pasture to reduce pathogens or special application procedures or practices, such as subsurface application or application only after harvest. To give desired flexibility of operation, some of the communities affected will doubtlessly choose irradiation as a safe and sure method for eliminating pathogens.[9]

### *IRRADIATION OF SLUDGE*

Much research has been done on the effects of irradiation on biological organisms, from microbes to man. The internationally accepted unit of dose for all forms of high-energy particles and radiation is the *rad.* This dosage occurs when 100 ergs of energy are absorbed per gram of matter. For the inactivation of microorganisms in sludge from municipal wastewater treatment plants, experiments have shown that a dosage of over 300,000 rads is required [10]. This can be done with gamma rays from radioisotopes like cobalt-60 or cesium-137 whose radiation energies are low enough (below 5 million electron-volts) to prevent induced radiation in sludge and side effects that might be injurious to the end use of the sludge.

However, it takes a tremendous amount of radioactive cobalt-60 to be of practical use; 70,000 curies of it would be used to produce 1 kilowatt of the ionizing power needed to destroy microorganisms [10]. Cesium-137 is a plentiful radioisotope, but it is even less efficient because 250,000 curies of it would be needed just to match 1 kilowatt of the output of a high-energy electron accelerator. And one must think about 50 kilowatts of power to irradiate 100,000 gallons of sludge per day!

Radioactive isotopes cannot be shut off, they would be an ever-present hazard in a wastewater treatment plant. When electric power is shut off from an electron accelerator machine, there is no residual radiation. Thus, it is reasonable to believe that only machine sources of high-energy electrons have the inherent safety, economics, flexibility, and power output to process sludge from municipal wastewater treatment plants.

In 1975 the International Atomic Energy Agency sponsored a "Symposium on the Use of High-Level Radiation in Waste Treatment" at Munich, Germany. The prospects for the future of sludge irradiation were described at this symposium by Trump and his colleagues [11]. In a summary of the discussions, Farrell [9] concluded that the effects of radiation applicable to sludge treatment included the following phenomena:

- Destruction of microorganisms and parasites
- Radiation-induced oxidation
- Modification of molecular structure (to decrease toxicity or enhance biodegradability)
- Changes in colloid systems (to improve settling or sludge dewatering)

## *ELECTRON BEAM IRRADIATION*

Electrons are the basic negative particles of nature, an essential component in the structure of all matter. In specially designed machines, electrons can be released from a solid metal, such as tungsten, by heating it to a sufficiently high temperature. The electrons are then accelerated in a vacuum by the application of an electrical field of several million volts; hence the machine is called an electron accelerator. These electrons represent a very special form of electrical energy. They can be forced into a beam of directed particles moving at nearly the velocity of light.

In Figure 1, taken from the paper by Eliassen and Trump [10], an idealized conception is presented depicting two opposing electron accelerators

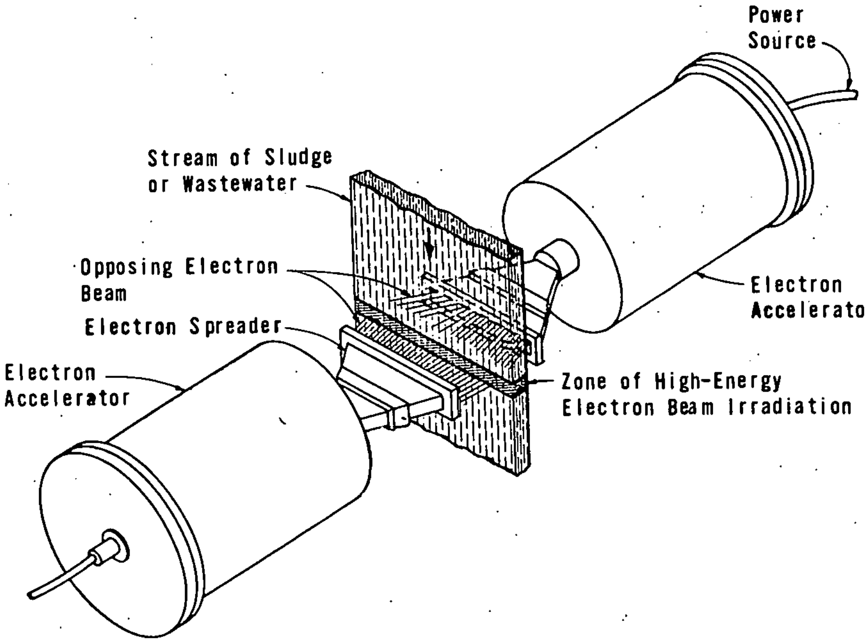



Figure 1: Idealized conception showing high-energy electron beam irradiation of a continuous flow of liquid undergoing disinfection.

and their beams of electrons impinging on a moving layer of wastewater sludge. The energy of the electrons is dissipated in the excitation and ionization of the millions of atoms and molecules which become targets of the electron beams. In practice, only one accelerator would be used.

With sludge, the maximum penetration of such electrons is about 1 centimetre for each 2 million electron-volts (MeV). By irradiating a thin, wide band of rapidly moving liquid with electron beams from opposite sides, as indicated in Figure 1, it is possible to deliver a nearly uniform dosage throughout the liquid stream with little wasted energy.

The electron energy, redistributed among the atoms and molecules, results in the chemical reactions already discussed: oxidation, reduction, dissociation, and degradation of complex molecules. By recombination of hydroxyl radicals, some chemically active molecules, such as hydrogen peroxide and ozone, are formed.

In many laboratories in various parts of the world, it has been proved that this ionization has a direct lethal effect on microorganisms (bacteria, viruses, spores, and molds) and on larger organisms (algae, protozoa, and parasites). These reactions can be initiated in a small fraction of a second as the material flows through the zone of intense ionization produced by the electron beams.

The outstanding safety inherent in the electron beam approach to sludge processing arises from (1) the high output power of the electron accelerators, (2) the localized region in which the ionization is applied, (3) the efficiency with which this power is produced from conventional 60-cycle AC power, and (4) the ease which it can be controlled over the range from fully *on* to fully *off*, at which point radiation ceases. These characteristics contribute to the realization of safe, compact, easily shielded installations that can be made as applicable to small community plants as to large city and regional plants.

Many researchers have produced conclusive evidence on the beneficial effects of ionizing radiation on the processing of foods, medical supplies, and plastics, as well as wastewater and sludges. Nevertheless, engineers, scientists, and regulatory agencies must have these phenomena demonstrated on a large enough scale to determine the applicability of electron beam irradiation to practical problems. This is standard procedure for most unit operations and processes used by environmental engineers: from laboratory, to pilot plant, to demonstration plant, to large-scale installations. Many checks and balances must come into play between conception and application to protect the public health and to assure accomplishment of scientific, engineering, and economic objectives.

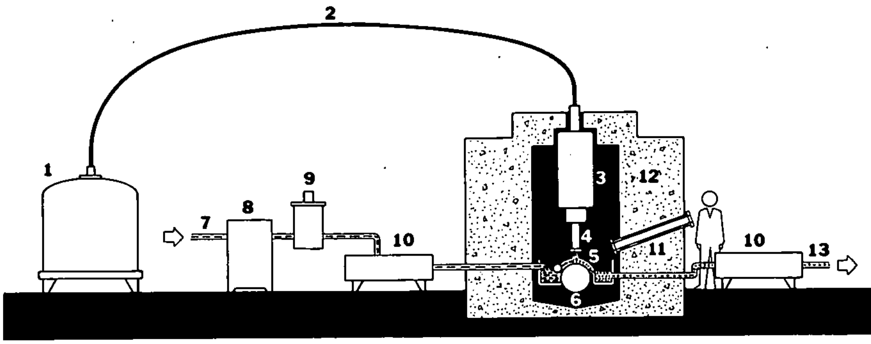
## *MDC DEER ISLAND DEMONSTRATION FACILITY*

Fortunately, such a procedure has been made feasible by the National Science Foundation (NSF) and its RANN program (Research Applied to National Needs). Through its Division of Advanced Environmental Research and Technology within the Applied Research Directorate, the NSF has sponsored many research and demonstration projects of interest to sanitary and environmental engineers. The objectives of these projects were discussed by Dr. E.H. Bryan, the environmental engineer in charge of this phase of NSF activities, in a paper entitled "Management of Municipal Wastewater Treatment Residuals" [12]. One of the outstanding NSF-sponsored projects mentioned by Dr. Bryan is the Deer Island Sludge Treatment Demonstration Plant, which includes a full-scale modular electron research facility installed at the Boston Metropolitan District Commission (MDC) Wastewater Treatment Plant at Deer Island. This project is under the direction of Dr. John G. Trump, with the cooperation of his MIT colleagues from several scientific and engineering disciplines. The NSF has awarded a companion grant to Dr. T.G. Metcalf of the University of New Hampshire to perform virology studies.

This project was made possible by the cooperation of the MDC, the Division of Water Pollution Control of the Water Resources Commission of the Commonwealth of Massachusetts, and the High Voltage Engineering Corporation of Burlington, Massachusetts. Martin Cosgrove is the project coordinator for the MDC.

Figure 2: Aerial view of MDC Deer Island plant with electron research facility location outlined. (High Voltage Engineering Corporation photo.)

The Deer Island plant is a primary wastewater treatment that serves a part of Boston and over 20 surrounding communities. In 1976, it processed an average flow of 330 million gallons per day. A photograph of the plant, with Logan International Airport across the channel and the City of Boston in the background, is shown in Figure 2. The arrow points to the location of the radiation facility building. It is adjacent to, and may draw sludge from,




1. Electron Beam Power Supply
2. High-Voltage Cable
3. Electron Accelerator
4. Electron Beam Scanner
5. High-Energy Electrons
6. Sludge Spreader
7. Input Line
8. Sludge screener
9. Grinder
10. Pump
11. Window
12. Concrete
13. Output Line

Figure 3: Schematic diagram of continuous-flow sludge irradiation system using high-energy electrons.

primary sedimentation basins, sludge thickeners, and sludge digesters. A schematic diagram of the high-energy electron facility is shown in Figure 3. This continuous-flow treatment system was designed to deliver a disinfecting dosage of 400,000 rads to 100,000 gallons of municipal sludge per day (one-third of the Deer Island plant's daily sludge throughput). This electron research facility was brought into operation in April 1976 and dedicated on May 19, 1976. A number of us in this audience were present at that dedication. I served as a representative of the High Voltage Engineering Corporation, of which I am a director, along with Dr. Denis Robinson, chairman of the corporation.

The source of ioning energy is a standard 750,000-volt 50-kilowatt electron accelerator with a 48-inch scanner system. The accelerator was rented to the MIT project by the High Voltage Engineering Corporation. This accelerator system transforms the input 480-volt 3-phase AC power into output electron beam power with a conversion efficiency of 80 percent. The AC power is generated at Deer Island from the methane produced by anaerobic digestion. The DC power is brought by high-voltage cable to the acceleration tube mounted in the upper region of the shielded vault, as shown in Figure 4.

To protect plant workers when the power is on, sludge irradiation is confined to the inside of a concrete-shielded vault. This vault was assembled of 100 large concrete blocks with walls 6 feet thick. The interior vault space is 8 feet wide by 12 feet high and contains all the radiation-producing and radiation-receiving apparatus. The amount of radiation in the environment beyond the concrete shielding is monitored and has proved to be far below radiation standards for humans.

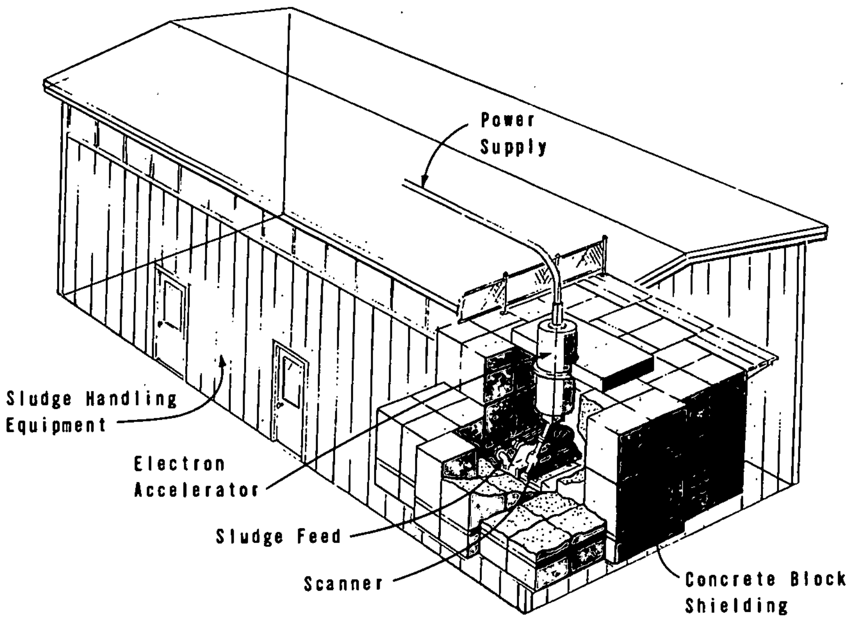



Figure 4: Cutaway diagram showing concrete radiation shield for electron accelerator and scanner at the MDC Deer Island wastewater treatment plant.

Sludge disinfection requires the delivery of an adequate ionization dose to *all* of the material. With energized electrons as the source of ionizing energy, this can be accomplished by spreading the sludge into a thin, wide layer which moves at a steady velocity through the rapidly transversing and scanning electron beam. The electrons must penetrate through the sludge thickness. Therefore, the sludge is carried over the top of a rotating stainless steel drum, as shown in Figure 5. There the sludge is ionized throughout its volume by the downward-directed high-energy electron beam, which sweeps 400 times per second across the full width of the drum. At the irradiation region, the sludge layer is 1.2 metres wide and 2 millimetres thick, and it is moving at the drum surface speed of 2 metres per second. The sludge receives its disinfection dose in this single pass with an exposure time of a few hundredths of a second. During this brief exposure, for a disinfection dose of 400,000 rads, over 10 trillion ($10^{13}$) energized electrons impinge on each square centimetre of the sludge surface. As they lose energy in collisions with atoms and molecules, the electrons produce ionization which accounts for the powerful effects of disinfection and degradation of chemical compounds. An absorbed energy of 400,000 rads will raise the temperature of water only 1 °C.

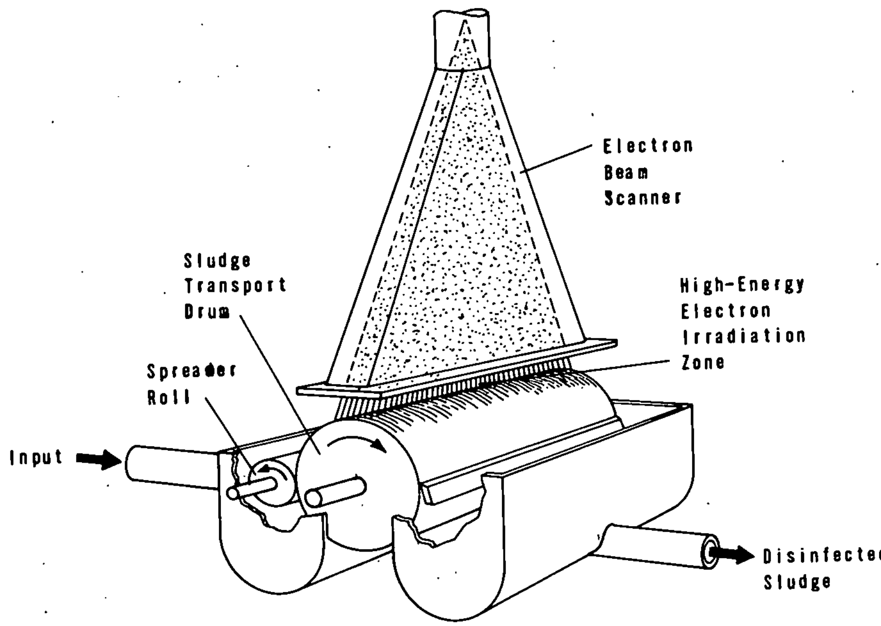



Figure 5: Cutaway diagram illustrating the method of irradiation of a thin, wide layer of moving sludge by a high-energy electron beam.

Primary sludge, liquid digested sludge, and thickened sludge can be irradiated. For thick sludges containing over 10 percent solids, however, the spreader and conveyor system would have to be altered. Secondary liquid sludges, which were not available at Deer Island, could be brought by tank truck and connected to the input line. Wastewater effluents from primary and secondary treatment plants could also be irradiated. But the efficiency would be less because for these low-solids effluents, the lower the solids content, the lesser the number of targets for the electrons and the lesser the ionization effects on the organic materials, including microorganisms.

Although the Deer Island Electron Research Facility has been designed as an experimental unit, it is the most powerful radiation module in existence at any wastewater treatment plant for the irradiation of wastewater and sludge. The rapid flow-through electron irradiation procedure and the small volume of target material exposed at any instant to the intense impinging beam contribute to the compactness and economy of the installation. In addition, the absence of induced radioactivity and the ability to terminate accelerator operation quickly by manual or safety-actuated switching are basic safety advantages over radioactive sources of ionizing energy.

*CURRENT STATE OF THE ART*

Dr. Trump and his colleagues have reported to the NSF that, during the first year of operation, biological measurements on digested primary sludge irradiated at the Deer Island facility have confirmed the effectiveness of electron disinfection at high flow rates. These measurements were made at the MIT microbiological laboratory and at the virology laboratory of the University of New Hampshire in its coordinated NSF program. They indicate that the destruction of bacteria and viruses at Deer Island closely parallels the disinfection achieved in small controlled quantities irradiated at MIT with its 3 MeV Van de Graaff electron accelerator.

Evidence of a preliminary nature showed destruction by electron irradiation of certain toxic chemicals in water (PCB and monuron, a pesticide). Improvement in the dewatering characteristics of irradiated sludge was also achieved.

Important engineering information has been obtained on many aspects of the operation of the system, especially on the dynamics of presenting a swiftly moving stream of liquid waste to the scanning electron beam for effective penetration and disinfection. Other factors of environmental, operational, and economic importance have been evaluated, including radiation safety, ozone emission, control of the sludge flow rate, averaged long-time bio-sampling, radiation dosimetry, electric power use, accelerator performance, capital and operating costs, disinfection costs per dry ton, and modes of utilization.

It is important to emphasize that the disinfection accomplished is a function of the total quantity of energy absorbed. Recall that this quantity is measured in rads, the absorption of 100 ergs of energy per gram of the absorbing material (in this case, sludge and the microorganisms contained in the sludge matrix). Thus, the dosage in rads depends on the number of electrons per second multiplied by the time of exposure. As stated previously, the Deer Island facility has been designed to provide a retention time of a few hundredths of a second. The total number of energized electrons per square centimetre of sludge is over 10 trillion ($10^{13}$) in that brief time, giving a dosage of 400,000 rads.

This dosage of high-energy electrons has been adopted after many years of experimentation [9,13], particularly at MIT and at Deer Island. Experiments were conducted on primary, digested, and waste activated sludge. The initial counts of microorganisms in the sludges to be subjected to irradiation are presented in Table 3. The average results to be expected, from thousands of tests, are shown in Table 4. It is obvious from these results that a dosage in the range of 300,000 to 400,000 rads is needed to produce or approach total kills of specific microorganisms.

A particularly interesting experiment was one in which the effects of sludge solids content on irradiation effectiveness were observed. On the basis of total counts, there was no significant difference in the effectiveness of irradiation of sludges with solids contents ranging from 1.4 to 22 percent

(1.4, 8.6, 15, and 22 percent). Initial counts ranged from $10^6$ to $10^7$ bacteria per gram of sludge.

Virus studies at Deer Island by Dr. Metcalf have begun. Methods of recovering viruses from large volumes of sludge must be improved. However, preliminary studies have indicated that electron irradiation does have a marked effect on Polio II virus and Bacteriophage P-22. The latter showed a survival of only $4 \times 10^{-4}$ percent at a dosage of 300,000 rads.

## TABLE 3

## INITIAL COUNTS OF MICROORGANISMS IN VARIOUS SLUDGES [9, 13]

| Class of microorganisms | Primary | Digested | Waste activated |
|---|---|---|---|
| Total coliforms | $6.1 \times 10^7$ | $7.8 \times 10^5$ | $3.7 \times 10^6$ |
| Gram V-E bacteria | $1.3 \times 10^8$ | $1.4 \times 10^6$ | $6.6 \times 10^6$ |
| Salmonella | $1.3 \times 10^4$ | — | — |
| Shigella | $10^4$ | — | — |
| Fecal streptococci | — | $1.9 \times 10^3$ | — |
| Total count | $2.1 \times 10^8$ | $6.4 \times 10^6$ | $1.4 \times 10^8$ |

## TABLE 4

## PERCENT SURVIVAL OF MICROORGANISMS AT SPECIFIC DOSAGES OF HIGH-ENERGY ELECTRONS [9,13]

| Microorganisms in various sludges | Percent survival | | | |
|---|---|---|---|---|
| | 100,000 rads | 200,000 rads | 300,000 rads | 400,000 rads |
| Total coliforms | | | | |
| Primary sludge | $10^{-3}$[a] | $10^{-6}$ | 0 | 0 |
| Digested sludge | $10^{-4}$ | $10^{-8}$ | 0 | 0 |
| Activated sludge | $10^{-1}$ | $3 \times 10^{-4}$ | $10^{-4}$ | 0 |
| Gram V-E bacteria | | | | |
| Primary | $10^{-2}$ | $3 \times 10^{-4}$ | $10^{-4}$ | $3 \times 10^{-5}$ |
| Digested | $10^{-4}$ | $10^{-8}$ | 0 | 0 |
| Activated | $10^{-1}$ | $5 \times 10^{-3}$ | $10^{-3}$ | 0 |
| Salmonella Typhimurium | | | | |
| Primary | $10^{-2}$ | 0 | 0 | 0 |
| Shigella | | | | |
| Primary | $10^{-2}$ | 0 | 0 | 0 |
| Fecal streptococci | | | | |
| Digested | 1 | 10p5,9$^{-1}$ | 0 | 0 |
| Total count | | | | |
| Primary | $10^{-1}$ | $10^{-2}$ | $5 \times 10^{-3}$ | $10^{-3}$ |
| Digested | $10^{-1}$ | $10^{-2}$ | $5 \times 10^{-3}$ | $10^{-3}$ |
| Activated | $10^{-1}$ | $10^{-2}$ | $2 \times 10^{-3}$ | $2 \times 10^{-4}$ |

a. $10^{-3}$ denotes survival of 0.001 percent.

Preliminary economic studies indicate that the pital cost for a 100,000 gallon per day module for sludge disinfection would be about $450,000 ($300,000 for the 50-kilowatt electron accelerator and $150,000 for the ancillary facilities and building). Operating costs, as currently estimated, would be $130,000 per year (electric power, $21,000; operation and maintenance, $65,000; amortization and interest, $45,000).

Total costs for the disinfection of 153,000 wet tons of sludge per year as currently estimated, assuming normal operation on a relatively continuous basis, would be 85 cents per wet ton. The cost per dry ton would depend on the solids content of the sludge: $17 per dry ton for sludge with 5 percent solids; $9 per dry ton for sludge with 10 percent solids; and about $3 per dry ton for filter or centrifuge cake with 30 percent solids. As stated previously, these are preliminary estimates which will be firmed up by the continuing work at the Deer Island facility.

Only a brief outline of the present state of the art has been presented. Much more remains to be done at Deer Island and in the laboratories of MIT hysical, chemical, and biological studies) and the University of New Hampshire (virology). But the basic facts of high degrees of disinfection have been demonstrated on a treatment-plant scale.

The present installation at Deer Island can be considered a module designed for a sludge flow rate of 70 gallons per minute. A full-scale plant would consist of a number of these modules in parallel. After the persent unit has been perfected, with all of the phases of sludge handling and radiation of optimum design proved in the demonstration plant, consulting engineers and water pollution control authorities can begin to consider the applicability of high-energy electron irradiation to specific problems.

Further work will provide additional data on the economics of sludge disinfection by high-energy electrons. Engineers can then make valid comparisons of the economic and disinfection efficiency of this method with that of other methods of sludge disinfection, including pasteurization, wet sterilization at high pressures, composting, and flash drying, among others.

### *SLUDGE MANAGEMENT— USING A VALUABLE RESOURCE*

Irradiation of sludge is expted to have the greatest impact on that phase of sludge management that deals with the application of sludge on land. In Table 2 it was shown that in 1985, 25 percent of the sludge from municipal wastewater treatment plants would be applied on land, 1.7 million tons (dry weight) per year. But where can it be applied?

As mentioned previously, the Prairie Plan of the Metropolitan Sanitary District of Greater Chicago uses an average of 425 tons per day for reclamation of strip-mined land. The U.S. Energy Research and Development Administration (ERDA) has prophesied as follows:

> It is expected that the current national coal production of 648 million tons will double by the year 2000. The major share of this projected increase will probably come from surface coal mining, because surface, or strip, mining is more economical than underground, or deep, mining.

> In several ways, however, surface mining of coal can be more disruptive environmentally than deep mining. Surface mining can disturb existing ecosystems, affect water quality through drainage of acidic mine spoils, and alter patterns of land usage. There is, therefore, a great need to better understand and evaluate the costs and potential effectiveness of alternate methods for reclaiming and rehabilitating strip-mined lands. [14]

In May 1971, before the National Academy of Science [15], I suggested that the many unit-trains of 100 carloads of coal on eastbound trips from strip mines in the West could return with ashes, municipal solid wastes, and reclaim the land. The sludge would serve as a soil conditioner for the covered and resealed mine areas and give them better soils than they originally had.

This country will soon be producing tremendous quantities of sludge. Could it be used as a valuable export — stabilized sludge, with its humus and nitrogen content, in exchange for oil? This may not be too far-fetched an idea for sludge management of the future!

C.E. Pound and R.W. Crites, vice president and project manager, respectively, of Metcalf & Eddy, Inc., in Palo Alto, California, have published the results of considerable work in the field of land treatment of wastewaters from municipalities and industries [16]. One of their current assignments is to apply these techniques to an agricultural development program for the State of Qatar — a country that is rich in oil but poor in agricultural production [17]. Qatar has a total land area of 10,000 square kilometres, but only about 3 percent has been classified as potentially arable. Of this 3 percent, only a little more than 10 square kilometres are under cultivation at the present time. Consequently, that country of 200,000 people must import all its food.

Why not import stabilized sludge to enrich its barren soils? Why should the oil tankers run full from Qatar to the United States and run empty on their return trips, except for ballast? Why not fill the ballast tanks with stabilized sludge and deliver it to Qatar? Qatar's municipal and industrial wastewaters could also be reclaimed and used for irrigation. Start with the small State of Qatar and then think of reclaiming the desert sands of Arabia and the barren lands of other large oil-producing nations to help them approach self-sufficiency in agriculture. Their oil may be like gold to us, but our stabilized sludge might be like platinum to them!

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