SEWAGE SLUDGE DISINFECTION BY IRRADIATION (ENEA-ACEA COLLABORATION)

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Abstract

The Municipal Association for Electricity and Water (ACEA) of Rome and the Lazio Regional Administration are implementing a programme of intervention aimed at protecting the water quality of the hydrogeological basin of Lake Bracciano. With support from ENEA, a pilot plant is being constructed for sewage-sludge disinfection by irradiation with accelerated electrons, in order to use the sludge as fertilizer for agriculture, as is practised abroad mainly in Germany and the United States. The work to be carried out within the ENEA-ACEA agreement includes: sludge digestion, drying, and sterilization by irradiation. Results achieved so far, including preliminary analyses of irradiated sludge, are presented. The irradiation plant and processes involved are also described.

1. INTRODUCTION

The Municipal Association for Electricity and Water (ACEA) of Rome and, more recently, the Lazio Region Administration, have initiated studies and research activities to plan a programme of intervention that will protect the hydrogeological basin of Lake Bracciano.

Lake Bracciano is designated as a drinking-water reservoir in the Rome Urban Water Supply Plan. The reservoir is intended to help cover the peak demand for water (projected as being about 8 $m^3 s^{-1}$ above the average summer flow in 2015) and to cope with emergencies when one or other of the aqueducts supplying the city has to be closed for maintenance.

As a source of drinking water, the lake must be protected from pollution by raw sewage from urban and tourist developments on its shores. It should be stressed that the rate of renewal of lake water is slow, since the source of recharge consists almost exclusively of sub-lacustrine springs.

Therefore, ACEA devised an Action Plan to prevent pollution of the lake and comply with the highest drinking-water standards. Financed by the Lazio Regional Administration, the plan is almost fully implemented: most of the construction is at or near completion. About 27 km of circumlacustrine pipe has been laid and connected to the terminal treatment plant (main contractor: the S.I.T.A. Company in Rome). ENEA is assisting in the construction of a pilot plant for sewage-sludge disinfection by irradiation with accelerated electrons, to render it useful as fertilizer in agriculture, a practice that has been adopted abroad, mainly in Germany and the United States [1].

2. THE SEWAGE-TREATMENT PLANT AT BRACCIANO

The sewerage system, aimed at protecting the waters of Lake Bracciano from pollution, consists of a main that encircles the shore, collecting sewage from residential and tourist developments in the region. The sewage is pumped to the Consorzio Bracciano Idrico Sabatino (CoBIS) treatment plant by 21 booster stations and purified effluent is piped into the Arrone River, which flows out of the lake at a point outside the basin.

The CoBIS plant started operations in July 1983 and currently has the capacity to serve 45,000 (25,000 residents and 20,000 visitors). It is envisaged that it will eventually serve a population of 90,000. The treatment process consists essentially of: sand removal; oil and grease removal; aeration; primary settling in tanks tanks; oxidation and aeration; secondary settling; sludge recycling; sludge thickening; dewatering.

One multi-processor system controls the main sewer around the lake and transmits pre-processed information to the data-acquisition and storage system. A similar system provides process control of plant operations, and also transmits data to the acquisition system. The third system is concerned essentially with the acquisition of operating data (consumption, maintenance, storage, etc.), using pre-processed data transmitted from the first two systems.

Instruments for measuring chemical oxygen demand (COD), conductivity, redox potential, dissolved oxygen, and residual chlorine and ammonia, were installed to acquire a historical record of plant-operating data and to provide warning if any of the parameters moves outside pre-set limits.

3. THE SEWAGE-SLUDGE PROBLEM

After treatment of sewage, residual sludge must be disposed of by storage and/or incineration; both present problems, the most important of which are related to spatial and environmental impact.

When the CoBIS plant was under consideration, the following values were predicted for the incinerator:

- throughput capacity: 400 L h^{-1}
- ashes: 35 kg h^{-1}
- fuel consumption: 19 L h^{-1}.

The possibility of using sewage sludge as agricultural fertilizer was considered to be an attractive alternative, provided that bacteria and viruses could be destroyed by treatment with γ rays or accelerated electrons, using irradiation technologies similar to those employed for the sterilization of medical products (syringes, gauzes, cotton, etc.).

Gamma rays used in industrial radiation processing are generated by radioisotopic sources (Cobalt-60 or Caesium-137). Electrons are produced in acceleration machines and can be employed directly, or be converted into X-rays by means of a metallic target.

Microorganisms are damaged when exposed to electrons or γ-rays. The extent of damage is proportional to the radiation dose (measured in Gray) absorbed by the organism. With sufficiently high doses, commercial sterilization becomes possible. Irradiation plants for sewage-sludge disinfection have operated abroad with excellent results. A Miami (USA) plant uses an electron-accelerator source, and one near Munich used a 60-Co source for sewage-sludges treatment in the liquid phase.

A pilot system, which provided much of the basic data for the planning of other γ-irradiation plants, was operated at Sandia National Laboratories in Albuquerque, New Mexico, where sewage sludge was irradiated at various levels of dehydration including the dry state.

4. THE ENEA IRRADIATION FACILITY

The choice of irradiation method depends above all on economic considerations and on the particular context in which a plant is to operate. The ENEA facility at the CoBIS plant will use a linear electron accelerator ($E=6$ MeV; $P=4$ kW maximum) [1].

The plant will process the sewage sludge by digestion, drying, and sterilization by irradiation, and have the following components:

- a primary sludge thickener
- an anaerobic digestion system with bio-gas production
- a second sludge thickener
- a dewatering station
- a bunker of reinforced concrete (biological shielding) with a thickness of 200-220 cm; the inner space of the bunker constitutes the irradiation cell
- safety systems connected to the control console, photo-electric cells, personnel indicator footboard, "scram" systems for the source, visual and acoustical systems that mark the beginning and the end of irradiation processing
- a ventilation system in the irradiation cell
- water and powder fire-extinguishing systems
- a control room with an operating console, where visual and aural alarms signal any malfunctioning in the various sectors
- a sewage-sludge transportation system, with transporter rollers for automatic insertion and outlet of materials
- a drying station
- central services, warehouses
- a loading and unloading area, with systems for automatic transfer of sludge
- a packaging and shipping section.

5. MATERIALS AND METHODS

Within the research programme defined by the ENEA-ACEA agreement, preliminary studies were carried out on the degradation, by electron-bean irradiation, of halogenated organic compounds and pesticides that are often present in sewage sludges [2, 3].

The compounds were placed in glass containers and irradiated both dry and in solution (of distilled water). For the irradiation, a 5 MeV LINAC accelerator (Fig. 1) was employed, with a 10-Hz repetition frequency; the doses were in the range of 0.5 - 8 Mrad (5 - 80 kGy) [4]. The irradiation dosimetry was determined with perspex slides and the calorimetric method, and analyses were performed by gas chromatography. The initial concentrations of the treated compounds are shown in Table I.

Municipal sewage sludges from the CoBIS water-treatment plant were γ-irradiated (Co-60) at ENEA's Calliope plant at Casaccia, to determine effects on physico-chemical characteristics and microbial populations.

6. RESULTS

The results for radiation-induced degradation of atrazine, 2-ethilexylphthalate (D2EHP), hexachlorobenzene (HCB) and parathion are shown in Table I and in Fig. 2. Maximum degradation was achieved when the compounds were dissolved in water. Atrazine and parathion were easily degraded, even at low doses of accelerated electrons (5 kGy).

Analytical determinations of heavy metals (Pb, Hg, Cd, Zn, Cr), halogenated organic compounds, detergents, infestant seeds and other chemical parameters (Table II) demonstrate that irradiated sewage sludge from the CoBIS plant can be used for agricultural land application, as defined by current national standards.

Table II also shows the marked reductions in microbial counts with γ-irradiation, for the principal pathogens often present in sewage sludge. Destruction of the microbial populations was almost complete, with more than 99% reduction in total counts. Salmonella contamination, detected only in two samples, was eliminated by radiation.

Fig. 3 charts the flow of the activities started in 1985; "experimental operations" refers to the optimization of plant parameters, both conventional and in the irradiation unit. The plant is self-sufficient in energy through bio-gas production.

Field experiments near the plant will follow the product to its final application, in collaboration with the local farmers and colleagues in agronomical research.

7. CONCLUSION

The Lake Bracciano project has fostered the acquisition of knowledge necessary for the development of radiation technology that is needed at the national level for the processing and safe utilization of sewage sludge.

TABLE I. EFFECTIVENESS OF ELECTRON-BEAM RADIATION FOR DEGRADATION OF ENVIRONMENTAL POLLUTANTS

Substance	Quantity or concentration treated	Doses of radiation (MRad)	Degradation (%)
Atrazine	21.2 μg (dry)	0.5 - 8	4 - 89[a]
	1.9 ppm (water)	0.5 - 8	99.9[b]
D2EHP	18.8 μg (dry)	0.5 -14	5 - 54[c]
	1.0 ppm (water)	0.5 -15	54 - 70
HCB	23.8 μg (dry)	0.5 - 8	0 - 7[c]
	3.6 ppb (water)	0.5 - 8	66 - 77[c]
Parathion	23.8 μg (dry)	0.5 - 8	18 - 89[a]
	1.4 ppm (water)	0.5 - 8	99[b]

[a]Linear dose/effect relationship.

[b]At the minimum dose of 0.5 Mrad.

[c]No linear dose/effect relationship.

TABLE II. PHYSICO-CHEMICAL AND MICROBIOLOGICAL EFFECTS OF γ-IRRADIATION OF SEWAGE SLUDGE PRODUCED AT THE CoBIS PLANT

Physico-chemical component	06-19-90		07-03-90	
	Unirradiated	Irradiated	Unirradiated	Irradiated
pH	6.2	6.6	6.3	7.5
Density	0.96	1.06	0.99	1.06
Total Solids at 105°C	25.4	20.9	19.7	23.3
Volatile Solids at 550°C	69.3	70.6	69.8	70.8
Organic Carbon	45.2	41.6	44.3	39.5
Total Nitrogen	2.5	2.4	5.4	3.4
Total Phosphorus	1.09	1.58	2.79	1.53
Potassium	0.45	0.40	0.44	0.60
Carbon/Nitrogen Ratio	18.1	17.3	8.2	11.6
Cadmium	<1	<1	1.3	1.5
Copper	285.1	189.9	177.2	293.5
Nickel	<1	<1	16.8	19.7
Lead	73.2	32.1	101.0	135.9
Zinc	1238	1309	1364	1236
Chromium	18.2	23.0	27.2	24.7
Mercury	<1	<1	8.6	2.8
Total Phenols	61.6	19.7	<1	<1
Anionic Detergents	3750	6728	4863	4248
Total Fats	4900	4869	4920	3186
Chloroform	<1	<1	327	633
Dimethylketone	-	-	14.3	18.8
Trichloroethylene	<1	<1	<5	<5
Benzene	<1	<1	<5	<5
Tetrachloroethylene	80	20	-	-
Polychlorodiphenyl	<0.5	<0.5	<0.5	<0.5
Hexachlorobenzene	<0.5	<0.5	<0.5	<0.5
Parathion	<0.5	<0.5	<0.5	<0.5

TABLE II. (continued)

Microbiological component	06-19-90 Unirradiated	06-19-90 Irradiated	07-03-90 Unirradiated	07-03-90 Irradiated
Infestant Seeds	0	0	0	0
Total Coliforms	3.10^{9}	200	2.10^{10}	0
Fecal Coliforms	4.10^{8}	100	8.10^{9}	0
Fecal Streptococci	2.10^{8}	120	7.10^{9}	0
Total Bacterial Count at 22°C	8.10^{10}	7.10^{4}	5.10^{10}	8.10^{3}
Total Bacterial Count at 36°C	4.10^{10}	5.10^{4}	3.10^{10}	6.10^{3}
Parasites (eggs)	0	0	0	0
Salmonella	0	0	5.10^{3}	0

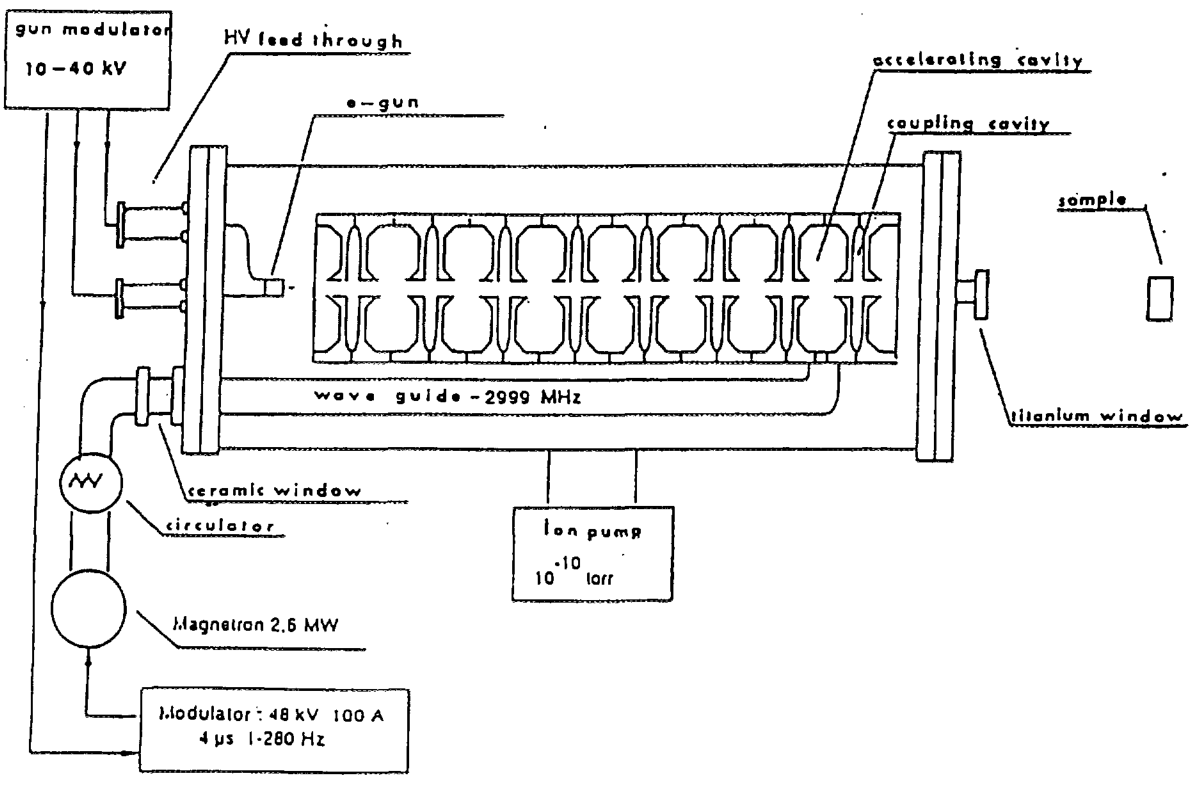

FIG. 1. Drawing of the linear accelerator.

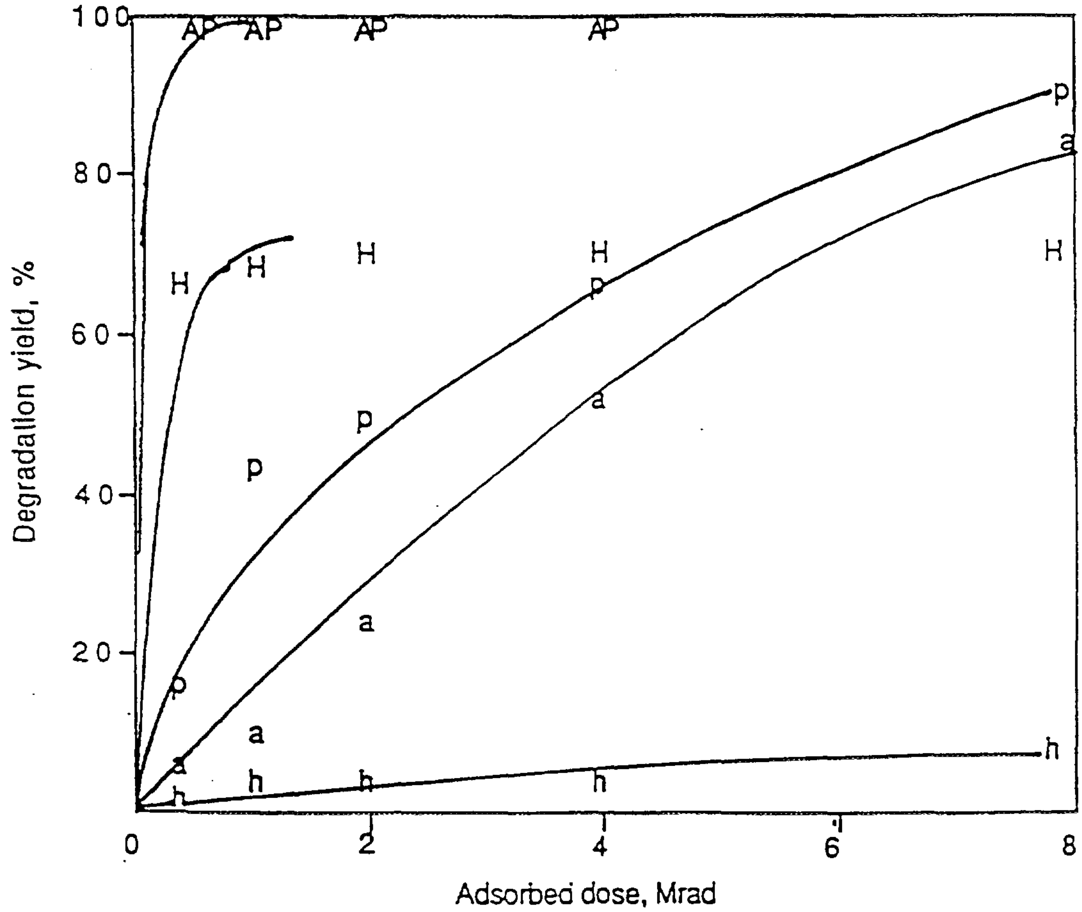

FIG. 2. Degradation of selected pesticides by electron-beam irradiation.

Legend: *Atrazine: a - solid, in air (20 μg), A - in aq. solution (1.9 mg/l)*
Hexachlorobenzene: h - solid, in air (24 μg), H - in aq. solution (5.5 mg/l)
Parathion: p - solid, in air (24 μg), P - in aq. solution (1.4 mg/l)

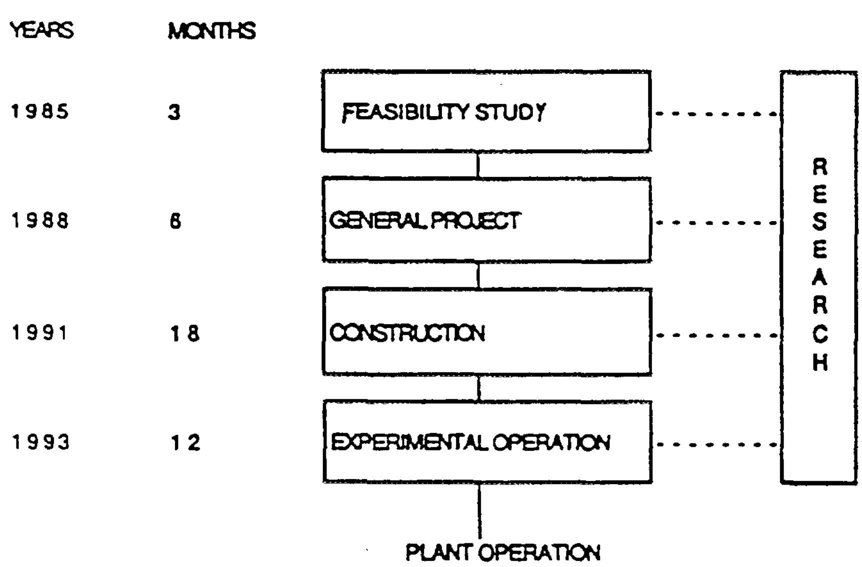

FIG. 3. Flow-chart of project activities.

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