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Alleviation of Environmental Pollution Using Nuclear Techniques Recycling of Sewage Water and Sludge in Agriculture: a Case Study

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ABSTRACT

Agriculture soil has always been the disposal site for sewage effluent and solid sewage sludge. In Egypt, the use of raw sewage effluent as a source of irrigation and fertilization has been practiced for almost 80 years at ElGabal ElAsfar farm. At Helwan sewage effluent has started to be used in agriculture since 1992.

Raw sewage sludge and sewage water are considered to be a valuable source of plant nutrients and organic matter. However, it contain several pollutant which can adversely affect the environment (water resources, plants, soils, animal and human health). The continuation of using raw sewage water and effluent in irrigation could result in environmental pollution, which is reflected in the accumulation of the following dominant pollutants:

- 1) Heavy metals (e.g. Cd, Pb, Ni, Co, Cr, Zn, Cu, Fe, Mn) which is found in soil, plant and water table. As such metals enter the food chain it create hazards to animals and human health. In addition, heavy metals affects plant growth, soil microbial activity and soil fertility
- 2) Toxic organic compounds (e.g. detergents, pesticides, dyes, phenolic compounds, chlorinated hydrocarbones) which are biologically resistance to degradation, highly toxic and carcinogenic
- 3) Harmful pathogens (parasites, bacteria and viruses) which transit significance diseases to animal and human
- 4) Sewage water from industrial area are always mixed with industrial waste, in particular waste of nitrogen fertilizer factories contain high concentration of nitrate salts. The leached nitrate represent a hazards to the environment, human and animal health

Such pollutants could reach groundwater; through direct leaching from contaminated soil, human food; through the food chain, reating environmental and health problems. This situation started to cause governmental and public concern.

Nuclear techniques (gamma radiation and electron beam) has been recently introduced for sewage sludge treatment. This method is gaining world wide recognition as a means of pathogen disinfection, organic pollutants degradation and improving sewage water quality. The use of gamma radiation has proved to be more effective in sewage sludge treatment than the conventional methods.

Keywords: Gamma Radiation, Electron Beam, Heavy Metals, Pathogens, Organic Pollutants, Nitrate, Nitrogen, Phosphorus, Management

INTRODUCTION

Reclamation of desert land is one of the main objectives of the government strategy to increase food production and insure food security. The cultivated area in Egypt existing around the Nile valley and delta represents only 4% of the total area, the remaining 96% are barren deserts. Reclamation of such desert lands require water and fertilizer input.

Egypt being in the semi-arid region of the world, is exposed to water shortage. This is considered the main constraints that threaten the agriculture expansion. The River Nile provides the main source of water, additional water is provided by groundwater. Almost 90% of the current total water demand of the country (55,000 Mm³) is used for irrigation purpose. On per capita basis, about 860 m³/year is available, whereas the least amount is estimated to be 1000 m³/year.

The continuing drought in Africa has resulted in decreasing volumes of Nile water over the past 6 years. In the meantime, there is an increasing demand of the Nile water. Away from the demands created by the rapid growth of population in the country and increased urbanization it has been suggested that industrial development alone will double its demand for water by the year 2001.

Ambitious and very necessary desert reclamation for agriculture is proving an ever increasing burden on water resources. Water conservation is of prime concern, it is undoubtedly become imperative to conserve water used by urbanization. To do this the main effort must be made towards conservation and re-use of urban wastewater.

Sewage wastewater, if properly treated, must be considered an important non-conventional water resource for irrigation, especially for the newly reclaimed land. In Greater Cairo alone, the production of sewage wastewater is estimated to be about 2 billion m³ /year. This wastewater must go somewhere and should be considered a resource as it is sufficient to irrigate 208,000 ha (Abo Soliman, 1997). Sewage sludge generated from such water is a good source of organic fertilizer. However, treatments should be applied in order to achieve the following: pathogens disinfection, organic pollutants degradation, less available heavy metals and seed weeds destruction. In addition, sewage sludge loading to agriculture land should be monitored as excessive application may result in nitrate pollution of the ecosystem. El-Motaium and Abdel-Monem (2000), found considerable increase in nitrate concentration in water table, ground water, soil and orange fruits, after 80 years of irrigation using sewage wastewater at El-Gabal El-Asfar farm.

Gamma radiation has been used in sterilization of medical products and preservation of food. Gamma radiation and electron beams have been successfully used on sludges and wastewater treatment to eliminate pathogenic organisms and toxic organic chemicals. Sufficient data are available for gamma radiation treatment of sludges, permitting its application on commercial scale.

Sewage sludge disposal and utilization has become a subject of great concern to environmentalists. Several international organizations are involved in studies and projects and devoted financial support for processing of sewage sludge to insure its safe land application. Among these organizations are:

- 1) United States Environmental Protection Agency
- 2) International Atomic Energy Agency
- 3) United Nations Development Program
- 4) United States Agency for International Development

Management of Sewage Wastewater and Sewage Sludge in Egypt: After collection of sewage wastewater at the main collectors, it is pumped, through lifting stations, to the wastewater treatment plants (WWTP). Then, the wastewater is exposed to the following treatment: 1) screening 2) sand removal 3) primary treatments 4) aeration 5) secondary treatment 6) chlorination. After separation into liquid and solid phases at the WWTP, effluent and sludge follow one of the following pathways:

- 1) Discharge in water bodies (Rivers, Sea, Lakes) or irrigation for sewage effluent
- 2) Incineration, landfill or land application for sewage sludge

At El-Gabal El-Asfar farm raw sewage water has been the sole source of irrigation and fertilization for almost 80 years. The farm is mainly cultivated with different species of citrus trees. Sewage effluent has been used for irrigation for about 20 years at Abou Rawash WWTP, whereas the sludge is pumped to the lagoons in western desert for drying by solar heat. At Helwan WWTP the process includes primary treatment, secondary treatment and tertiary treatment. Sewage effluent is pumped to adjacent, man made, reservoir for irrigation of olive orchard since 1992 and the sewage sludge has been thickened and dried on

sand beds to be sold to farmers as organic fertilizer. In Alexandria WWTP sewage water is exposed to primary treatment then the effluent is discharged into lake Marriout for final disposal. The lake being adjacent to the Mediterranean Sea, such disposal creates a heavy pollution in the sea. The sludge generated in the East Plant is pumped to the West WWTP. The combined sludge is dewatered by belt filters and transported to the desert for land filling.

At this stage sewage sludge and effluent contain several contaminants such as pathogens, heavy metals, toxic organic compounds, seed weeds. These contaminants has to be eliminated before safe utilization of such materials.

Justification of Using Sewage wastewater and sewage sludge in Agriculture in Egypt:

- 1) Shortage of water: provide non-conventional water source for irrigation
- 2) Sandy desert soil: provide O.M., WHC, CEC
- 3) Egyptian sewage sludge is low in heavy metal content
- 4) Desert soils are high in CaCO_3 and pH: less heavy metals availability from sewage sludge

Sewage Sludge Stabilization. Several methods are available at present, and has been in use for a long time, for sludge stabilization and disinfection. These methods are aerobic digestion, anaerobic digestion, composting, liming and heat treatment (Strauchtrauch et al., 1985). Recently gamma radiation and electron beam has been introduced for sewage sludge stabilization.

Brandon (1979) evaluated the different methods of sludge stabilization and found that aeorobic and anaerobic digestion are not very effective in reducing pathogens, lime tretment requires that a high pH be reached and maintained, heat treatment is effective but is expensive and is energy intensive, composting requires all of the composting sludge reaches an adequate temperature for pathogens inactivation. It is obvious that irradiation of sewage sludge ensure the safe recycle of sewage sludge.

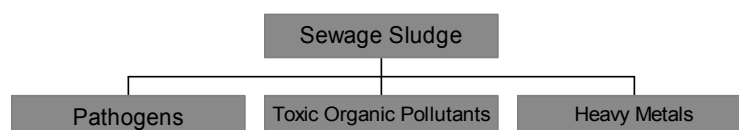
Advantage of using Gamma Radiation in Sewage Sludge Treatment:

- 1) Excellent penetration power
- 2) Environmentally clean
- 3) Uniform dosage in materials
- 4) Small energy consumption
- 5) Neither toxic chemicals nor residual radioactivity are produced in the material

Expected Mechanisms of Gamma Radiation Effect on Sewage Sludge:

- 1) Degradation
- 2) Oxidation
- 3) Bond Rupture
- 4) Conditioning
- 5) Denaturation

Gamma Radiation Effect on Sewage Sludge Contaminants



1) Pathogens. Sewage sludge contains various pathogenic organisms that are capable to induce several human diseases. Bacteria: *Salmonella typhi* (Enteric fever, typhoid); *Vibrio cholerae* (Cholera); *E. coli* (Infantile diarrhoea). Parasites: *Ascaris Lumbricoides* (Ascariasis); *Taenia* spp. (Abdominal); *Giardia Lamblia* (Giardiasis). Viruses: Reovirus (Fever, Respiratory infections, Diarrhoea); Echovirus (Rash and Fever); Adenovirus (Respiratory and Eye Infections); Rotavirus (Diarrhea, Vomiting).

Gamma radiation has been recognized as a new method to eliminate pathogens in sewage sludge (Lessel 1988, Ward et al., 1984; USEPA 1993). The dosage of gamma radiation required for pathogens inactivation may vary with pathogen types, initial population, previous treatment and moisture content. A dose range from 3 to 10 Kgy has been reported as an adequate for sewage sludge disinfection. In the opinion of radiation scientists, 3-5 Kgy of ionized radiation is adequate to completely inactivate pathogens in sewage sludge (Pikaev, 1997).

Suess (1977) has reported a dose of 3 Kgy for sludge decontamination but Takehisa (1980) and Hashimoto et al., (1988) found that 5 Kgy is the appropriate disinfection dose for dewatered sludge, whereas El-Motaium et al., (2000) found that a dose of 1 Kgy and 6 Kgy are sufficient for disinfection of sewage water and sewage sludge respectively. McCaslin and Sivinski (1980) found that 1 Mrad of gamma irradiation effectively destroys pathogenic bacteria and parasites in dried sewage sludge.

Viability of *Ascaris* ova is an important criterion for safe sludge disposal. It has been chosen as indicator organism for inactivation studies. This is because *Ascaris* ova is the most resistant species to most forms of treatments (Gaspard, 1995). A dose of 10 Kgy is required by USEPA (1993) for *Ascaris* ova elimination from sludge. Brandon (1979) indicated that 1 Mrad was a sufficient dose to ensure the inactivation of *Ascaris* eggs naturally present in digested sludge filter cake and in composted sludge.

The reduction of pathogens in sewage sludge by radiation is a function of the absorbed dose and may be described by a first –order reaction equation. Chang (1997) has reported the mechanism by which gamma radiation inactivate pathogens. He concluded that gamma radiation induces ionization in biological tissue resulting in the production of free radicals that cause denaturation of cell protoplasm and damage of membranes and cell walls causing lysis. Protoplasm damage cause inactivation of most pathogens, being single-cell organisms.

2) Toxic Organic Pollutants. Sewage sludge is often contaminated with mixture of toxic organic

compounds such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), dyes, pesticides, herbicide (monuron), detergents, phenolic compounds. These compounds, even non-polar ones, can be assimilated by intact plants or in-vitro cell culture system (Harms, 1995). The amount taken up by plant depends on plant species and the physico-chemical properties of the compound (Harms, 1995). The uptake rate are higher with low-molecular weight and polar compounds.

These compounds are very toxic, carcinogenic and highly resistant to degradation. The lipid soluble class of these compounds are the most dangerous when ingested by animals or humans (M.I.T. , 1980). In raw or digested sludge, the concentration of PCB types should be highest in the lipid phases.

Pandya et al., (1989) in their study on Chickpea (*Cicer arietinum*) found that plant grown in gamma irradiated sludge have higher growth and yield than those grown in unirradiated sludge. They suggests that gamma radiation induced inactivation of toxic substance(s) in sludge.

The effect of ionizing radiation on water results in the formation of hydroxyl radicals (OH[•]) and solvated electrons (e⁻aq, H[•]). Therefore, gamma radiation can be used to study the effect of free radicals species on solutes or pollutants in water.

Research conducted by (M.I.T.) demonstrate that trace amounts of polychlorinated biphenyls (PCBs) in pure water and of water-dissolved herbicide of the urea type-monuron were 96% destroyed using

dosages as low as 10 Krad. Their destruction was explained by the attack of hydroxyl radicals (OH \cdot) formed by dissociation of water molecules by the ionizing electron energy.

The formation of free radicals is given by the following reaction (Thomas, 1969):

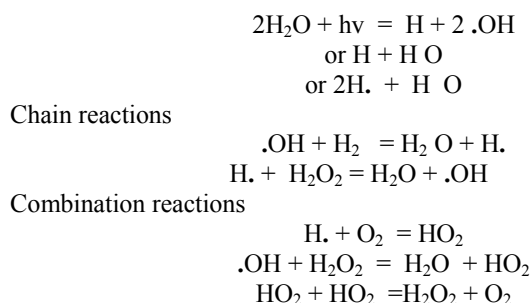


Table (1): Effect of Radiation on Organic Pollutant Degradation (Monuron, 4.2 mg/L)

Radiation Treatment	% Degradation
0 Krad	0
2 Krad	15.6
4 Krad	36.5
6 Krad	52.1
8 Krad	62.8
10 Krad	73.1
15 Krad	82.6
20 Krad	93.4
25 Krad	95.8
30 Krad	98.0

Merrill (1977)

3) Heavy Metals. Sewage wastewater and sludge, particularly when mixed with industrial waste, contain a large amount of potentially toxic metals such as Hg, Cr, Pb, Cd, Ni, Co, Cu, Zn, Fe, Mn. Heavy metals exist in different forms (water soluble, exchangeable, organically complexed, adsorbed in organic sites, occluded or held in primary minerals). These forms differ in their mobility in soils and extractability by plants.

Several metal uptake studies have shown that, the water soluble fraction of metals, such as cadmium, lead, mercury and chromium that can be accumulated by living plants and thus enter the animal and human food chain. Some of these heavy metals are essential plant nutrients (Fe, Cu, Mn, Zn) while others (Cd, Pb, Cr, Hg) are not. The heavy metals have no known beneficial physiological function and are considered toxic to plant.

Cadmium is toxic to human and animals. Cadmium toxicity affects primarily kidneys thus disturb P & Ca metabolism, other organs can also be affected (e.g. cause bone diseases). Lead is of primary health concern. The effect of lead toxicity in human health is through causing brain damage. The main source of toxicity by lead is from direct ingestion of soil by humans and grazing animals.

Very few studies have addressed the topic of the effect of irradiation on the bioavailability of heavy metals. Based on work of Massachusetts Institute of Technology (1980), they concluded that electron disinfection dosage does significantly reduce the water-soluble fraction of several potentially toxic metals. This effect would tend to render metals less available for plant uptake. They suggests that electron treatment can bind water-dissolved metals to sludge components. Some workers in the U.S. have

claimed decreased solubility of metals in irradiated sludge (Sheppard and Mayoh, 1986). In the same line, Ahlstrom (1985) found that irradiation did not increase the extractability and plant uptake of a broad range of nutrients and heavy metals from sludge-amended soils. This finding was supported by our results in Egypt (El-Motaium and Badawy, 2000). However, more studies are required in order to quantify this finding and understand the mechanisms involved.

4) Seed Weeds. Seed weeds can represent a kind of contaminant in sewage sludge. McCaslin and Sivinski (1980), found that 1 Mrad (1000 Krad) of gamma radiation effectively destroys plant seeds in dried sewage sludge.

Nuclear Techniques in Use for Sewage Sludge Treatment

- 1) Gamma Radiation (^{60}Co)
2-10 Kgy
- 2) Electron Beam Accelerator
1.5-3 MeV
- 3) Combined Processes
 - oxyradiation
 - ozon-plus irradiation
 - thermoradiation

Examples of Types of Irradiators for Sewage Sludge Treatment in the World:

- 1) The Facility at Geiselbullach (Germany)
Uses coblt-60 to irradiates anaerobically digested liquid sludge in a batch process
- 2) The Facility at Deer Island (Boston, USA)
Irradiates a continously flowing thin film of liquid digested sludge with an electron beam
- 3) The Facility at Baroda (India)
Uses coblt-60 to irradiates anaerobically digested liquid sludge in a batch process
- 4) The Facility at Tucuman (Argentina)
Uses coblt-60 to irradiate anaerobically digested, liquid sludge in a batch process
- 5) The Nordion International Inc. Facility (Canada)
Uses coblt-60 to irradiate dewatered sludge in a continous flow process

IMPORTANT RESULTS

Sewage Sludge Characteristics of El-Gabal El-Asfar Farm. Data in Table (2) show that domestic Egyptian sewage sludge of El-Gabal El-Asfar Farm contain high organic matter content (45%), NPK and micro-nutrients (Fe, Zn, Cu, Mn). The 503 regulations issued by the USEPA (1993), regarding the maximum permitted concentrations of heavy metals in sewage sludge, show that Egyptian sewage sludge is far belowe this limit. This indicate its safe utilization in agriculture land.

Table (2): General characteristics and heavy metals contents of sewage sludge collected from El-Gabal El-Asfar farm

Variables	Irradiated sewage sludge	Non-irradiated sewage sludge	U.S.EPA
PH (1: 2.5)	6.80	6.64	
EC mmohs/cm (1:2.5)	4.11	4.27	
CaCO ₃ (%)	3.01	3.25	
O.M. (%)	44.50	44.90	
Total-N (%)	2.10	2.00	
C/N Ratio	12.40	13.02	
Available-P (µg/g)	63.60	62.70	
Available-K (µg/g)	389.50	379.60	
Total Metal Content (µg/g)			
Fe	5881	5607	
Mn	388	380	
Cu	219	203	1500
Zn	760	756	2800
Cd	5.20	5.10	39
Co	33.50	34.20	
Ni	44.30	43.80	420
Pb	278.50	284.50	300
DTPA-extractable metals (µg/g)			
Fe	76.60	71.33	
Mn	21.10	20.29	
Cu	69.19	65.44	
Zn	367.93	308.30	
Cd	0.94	0.89	
Co	2.10	1.95	
Ni	1.81	1.87	
Pb	6.14	7.50	

- 2) **Isotopes techniques for detecting the bioavailability of nitrogen and phosphorus from sewage sludge.** In this study ¹⁵N-labelled ammonium sulphate was used to detect the availability of nitrogen (El-Motaium 2000) and ³²P for detecting the availability of phosphorus from sewage sludge (El-Motaium 2000). The data indicate an increase in plant dry matter production, plant tissue N&P, plant uptake and recovery of N&P, soil N&P with the application of irradiated sewage sludge to sandy soil. Most nitrogen (90% average) and phosphorus (71.5 % average) was derived from sewage sludge, sandy soil did not contribute well toward total nitrogen or phosphorus in plant.
- 3) **Effect of irradiated sewage sludge on yield and plant nutritional status.** Our studies show that sewage sludge at (80t/ha) application rate increased tomato yield dramatically (7 fold) in sandy and (6 fold) in calcareous soils. As for Fennel seeds the increase in production was 4 time greater than the control (chemical fertilizer). In addition, the increase in soil NPK and micro-nutrients (Fe, Zn, Cu, Mn) have resulted in providing plants with their requirements of these essential nutrients necessary for their growth and development.
- 4) **Effect of irradiated sewage sludge on soil characteristics.** Improvement in soil physical, chemical characteristics always accompany the addition of sewage sludge to sandy soil. Increase in soil organic matter (O.M.), water holding capacity (WHC), cation exchange capacity (CEC) and decrease in soil pH and bulk density (BD) was reported by several investigators (Hinesly et al., 1979; Epstein et al., 1976 and Badawy and El-Motaium 1999). The organic matter in sewage sludge, may have more value, as a soil conditioner, than the nutrients content.

Economic and Social Impact of Using Irradiated Sewage Sludge in agriculture:

- 1) Environmental preservation
- 2) provide alternative source for irrigation and fertilization
- 3) reduce the use, production and/or importation of chemical fertilizer
- 4) lessen dependence on imported organic amendment, have shown significant potential as a substitute for peatmoss
- 5) reduce water consumption
- 6) reduce the production cost
- 7) increase the national income (increase the cultivated area and yield)
- 8) production of highly priced organic commodities for national and international markets

CONCLUSION AND RECOMMENDATIONS

- 1) Radiation technology is recommended for sewage sludge disinfection, a dose of 6 KGy is for sewage sludge and a dose of 1 KGy for sewage water
- 2) Radiation disinfection can replace chlorine which form carcinogenic compounds
- 3) The use of irradiated sewage sludge is environmentally safe for recycling in agriculture and it preserve human health
- 4) Irradiated sewage sludge at a rate of (80t/ha) proved to be a good organic fertilizer for sandy and calcareous soils
- 5) Irradiated sewage sludge is considered a good substitute for peatmoss and chemical fertilizer
- 6) Irradiated sewage sludge resemble a slow release fertilizer capable for sustaining crop production without harming the environment

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