RADIATION TECHNOLOGY FOR SEWAGE SLUDGE TREATMENT: THE ARGENTINE PROJECT

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Abstract. Within the environmental applications of ionizing radiation, disinfection of wastewaters or sewage sludges is one of the most best known. Argentina based the project of a full scale irradiation plant on the gamma irradiation application, utilizing Argentine made Cobalt-60 sources. The design characteristics, process descriptions and costs are included.

The research project developed information about the irradiation effects on the sludges with respect to plant performance. For the purpose of oxi-irradiation experiments, a lab-scale pool irradiator was constructed and is described.

1. INTRODUCTION

There are many examples of commercial on-line irradiation plants as well as laboratory experiments [1], when irradiation technology is used to solve problems in water contamination, wastewaters and sludge, using radioactive sources of Co-60 or electron beam accelerators with energy above 1.5 Mev. Decontamination, degradation and reuse of material must be analysed bearing in mind not only technological aspects. Public acceptance, environmental laws, engineering, replacement and operation costs must be considered for the final balance of every project.

The Project in Argentina, conducted by PIBA, was created using nuclear technology to solve environmental problems associated with the treatment and final disposal of sewage sludge. Therefore radiation application is used for biological and physicochemical modifications in semisolid material obtained by conventional treatment of wastewaters.

In all big cities the demographic pressure creates distortions and environmental problems, one of them the effluent and waste treatment, which must be solved by closed cycles that allow maximum degradation and re-utilization and then, minimum loss of energy and investment. In the case of sewage sludges reused in agriculture, for example, the organic material may be degraded in soil by natural oxidation cycles, and the nutrients reutilized by the plants [2]. But control for human health risks avoiding pathogen microorganisms back into the food chain by means of the contaminated crops or agriculture workers is required [3].

Ionizing radiation of radioactive sources or accelerators causes alteration in cell membranes and then destroy bacteria, fungi, viruses, etc. as well as breaks chemical chains in some organic toxic substances like pesticides, herbicides, PCBs, etc., included in the sludge contents.

The design parameters and main features of a full scale gamma irradiation plant projected for the treatment of sewage sludges of a populated city (Tucumán: 600,000 inhabitants) in the Northwest Argentina, and some research about irradiation effects on the sludges are described. Also shown are the design and construction of an experimental irradiator of a hundred litres to be used for irradiation experiments in sludges, wastewaters or effluents.

2. PRELIMINARY CALCULATIONS

After a review of previous work [5,6] the Argentine project was based on the batch process type, with anaerobically digested sludges, 5% to 8% solids concentration. The Wastewater Treatment Plant at Tucumán, which the irradiation plant was designed for, accomplishes primary treatment processes on the wastewaters (grids, sand exclusion, clarifiers, and chlorination before being dumped into the river) and anaerobic digestion on the thickened sludges. According to the reported data summarized in the table below, it is assumed that the quantity of anaerobically digested sludges is 0.35 lt/day.inh (Table 1) [7].

TABLE 1. SLUDGE AMOUNT PRODUCED BY DIFFERENT TREATMENTS

Treatment	Dried Sludge g/inh.day	Dried Sludge %	Sludge Amount L/inh.day
Primary Raw Sludge	54	5	1.08
Primary Digested Sludge	34	10	0.34
Secondary Raw Sludge	74	5	1.48
Secondary Digested Sludge	48	8	0.60
Biological Treatment Raw Sludge	85	4.5	1.87
Biological Treatment Digested Sludge	55	7	0.79

The facility was designed for a population of 100,000 to 400,000 inhabitants served, and therefore the maximum processing capacity should be 140 m^3/day. It was already concluded that the required dose for satisfactory decontamination is 3 kGy without oxygen addition, and 2 kGy with oxygenation [8]. Then, it is possible to calculate the required energy and also the radioactive charge of the irradiation plant to accomplish the process.

2.1. Plant power and activity calculation

The total activity of an irradiation plant is proportional to the annual volume of treated material and to the required radiation dose as follows:

$$P(kw) = \frac{D\,(kGy) \times M\,(kg/h)}{\mu \times 3600\,(s/h)}$$

$$13\,(kw) = \frac{3\ (kGy) \times 6270\ (kg/h)}{0.4 \times\ 3600\ (s/h)}$$

where

P is source power,
D is absorbed dose required,
M is mass to be treated by hour in 8150 h/operational year,
μ is energy transference yield.

The expression represents the rate of absorbed energy in the required treatment by the available energy in the radioactive sources.

Now, Co-60 disintegration produces two photons with isotopic yield of 100%; the total released energy is the sum of: 1.17 MeV + 1.33 MeV = 2.5 MeV.

Then, the source activity is:

$$2.5\text{MeV/dis} \times 1.6 \times 10^{-13}\ \text{w.seg/MeV} \times 3.7 \times 10^{10}\ \text{dis/seg.Ci} = 14.8 \times 10^{-3}\ \text{w/Ci}$$

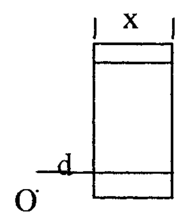
$$\frac{13 \times 10^{3}\, w}{14.8 \times 10^{-3}\ w/Ci} = 0.878\ MCi$$

For Co-60 sources the attenuation in water may be calculated by the expression:

$$D = Do \times B \times (e^{-0.063.x})$$

being $Do = A(Ci) \times Kr(1.34\ R.m^2/h.Ci)$

$B = B\ f(u.x)$



where

μ is attenuation coefficient 0.063 (cm^{-1}),
A is source activity,
Kr is gamma radiation specific constant,
d is distance from the source to the object point,
B is multiplication factor,
X is shielding thickness: 30 cm.

The attenuation in 20 cm water results are greater than 70%. This is conditioning for the tank diameter not to be exceeding 1.6 m if the irradiator is composed with the source distribution in a circular shape, like it is shown in the Fig. 1a/1b.

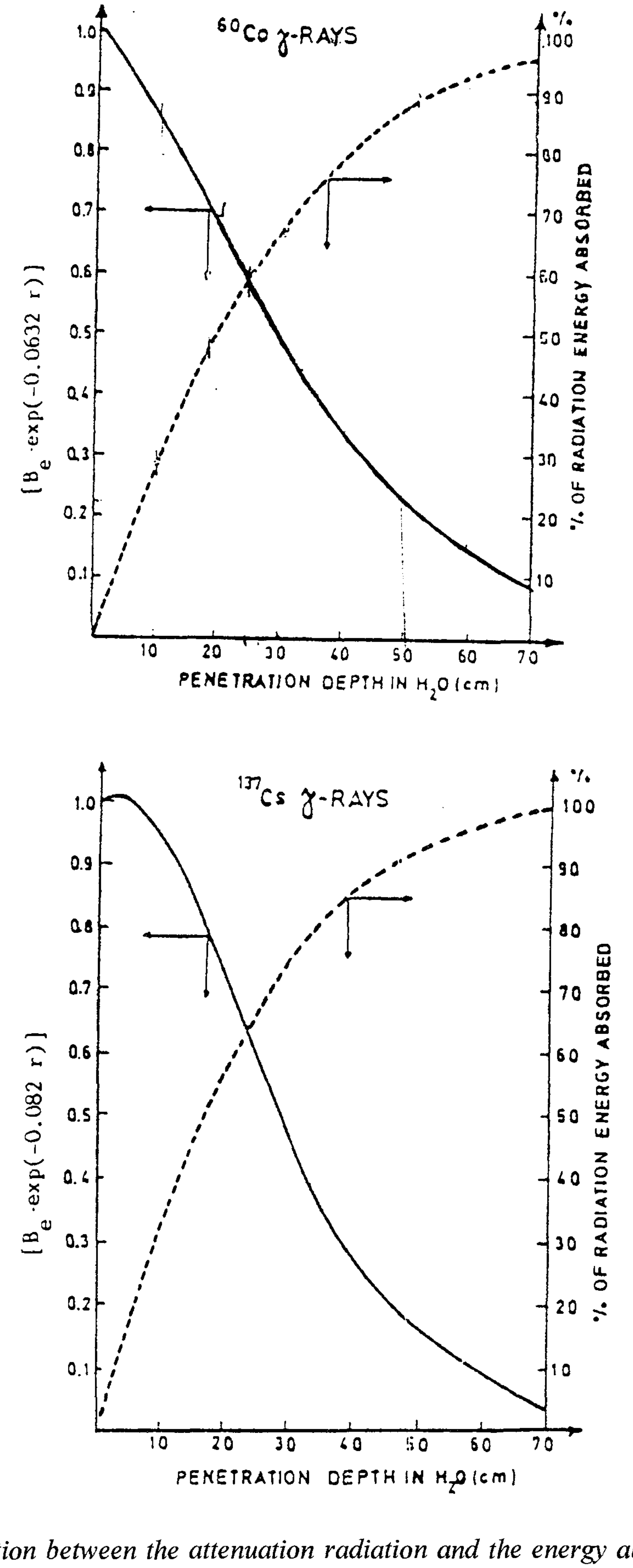


FIG. 1a-1b. Relation between the attenuation radiation and the energy absorbed at various water thickness.

3. CHARACTERISTICS OF DESIGN AND OPERATION

The plant core is the cylindric irradiator tank surrounded by shielding concrete; the other tanks, intake and outlet tanks, are conveniently located within the installations which cover an area of about 200 m^2 [9] Fig. 2.

The irradiator has 304 L capacity, two concentric stainless steel of 1m and 1.60 m, respectively. The interior tank lodges the radioactive sources, keeping them separated from the sludges; it has also a chamber containing deionized water for refrigeration and control of the cobalt-60 sources.

The refrigeration system recycles the water and allows any possible radioactivity coming from any source to be measured in case of eventual failure or original weakness. The permanent and continuous control of the refrigeration water is automatically made and watched from the computer video display at the control desk.

The digested sludges are previously pumped to the intake tank and are discharged by gravity into the irradiator tank as soon as a 10 inch electromechanical valve is opened, and in very short time (less than 1 minute). The intake way is by the central tube and simultaneously by the periferic distributor tube; in this way the sludges could best receive radiation coming from the cylindric distributed sources, see Fig. 2. Once the opening valve is closed a pump 240 m3/h is activated to make the sludges recirculate during the necessary time to achieve the required disinfection dose (about 30 minutes). Once the irradiation time is over and 20 recirculation cycles are accomplished, the recirculation pump is automatically stopped and the sludges are discharged into the outlet tank. This cycle might be modified for the complete operation during 24 hour a day.

For the source charges and redistribution, a transference well five meters deep is available next to the irradiation room and connected by a channel. The container with new source material enters the pool of the transference well using a crane 10 t maximum charge.

Source movements, for recharge as redistribution, are made under protection of a five meter water column, guaranteeing the required biological shielding; these operations are made only when the radioactive charge is not enough to carry out the total available amount of sludges processed.

The system software automatically determines what activity of the source is needed in case of increasing the sludge amount to be processed, and, on the other hand, controls and tests the sludge levels in the three tanks, opening and close of the valves, warning to the operator every possible failure that might be happening.

The entire installation is located within the Wastewater Treatment Plant; the sludges are directly pumped from the digesters to the Irradiation Plant, and the charge cycle is automatically controlled. Once the sludges are sufficiently irradiated, they are spread unto drying beds, or are eventually applied in liquid form.

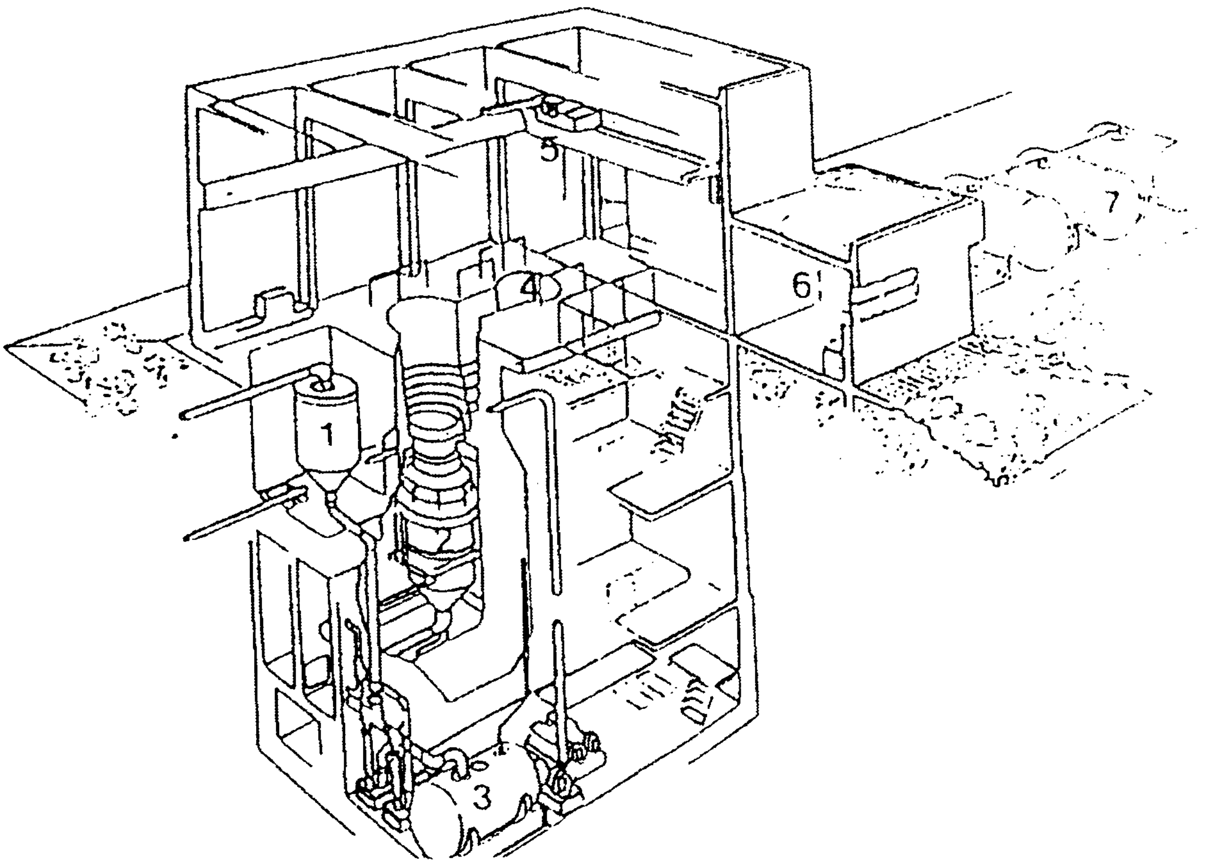


FIG. 2. Drawing of the installations. 1- Intake tank. 2- Irradiation tank. 3- Outlet Tank. 4- Transference well. 5- Grantry crane. 6- Repair work and lab. 7- Storage tanks of deionized water.

3.1. Details of the source loading tank

The concentric source loading tank, located inside the irradiation tank, is a separate unit, thus allowing any repair, if necessary, Fig. 3. This unit has 32 locations, where a specially designed support lodges nine sources in vertical position. These are industrial Co-60 sources, model FIS 60-05 with an averaged activity of 7,000 to 10,000 Ci each.

As the maximum radioactivity capacity is 700,000 Ci, it would be necessary to have 70 sources of maximum activity which would initially occupy eight locations; then, approximately 24 positions would be free for new charges or arrangements. Thus, the total amount and homogeneity of activity is conserved for more than 20 years, without the necessity of taking off exhausted sources. The ensemble is refrigerated by demineralized water circulation, as mentioned before.

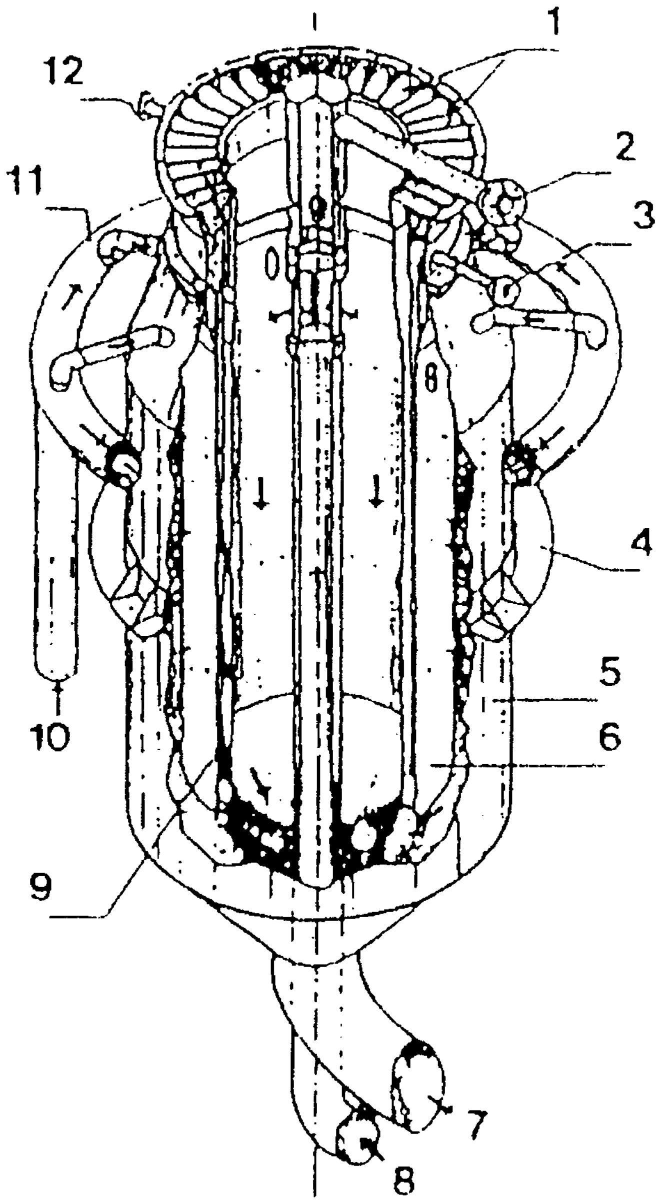


FIG. 3. Irradiation Tank. 1- Source lodging rail. 2- Ventilation. 3- Refrigeration water intake. 4- Support. 5- Tank. 6- Source holder. 7- Sludge outlet. 8- Sludge intake. 9- Sources. 10- Sludge intake. 11- Distribution pipe. 12- Refrigeration water outlet.

3.2. Auxiliary installations

The installations include several other facilities and systems like electromechanical work, chemical laboratory, radioactive dose testing systems, gas ventilation systems, oxygenation system, flood system, alarms and warnings systems.

The existence of auxiliary installations makes this plant to be autonomous but more expensive; this plant was designed as a prototype but future ones would be constructed with lower costs.

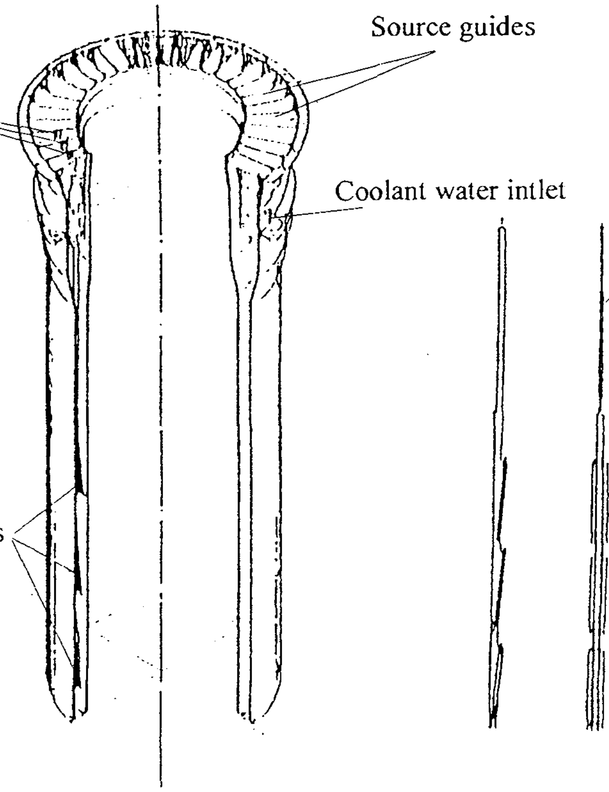


FIG. 4. Internal loading tank.

DESIGN PARAMETERS

Served population	100,000 to 400,000 inhabitants
Amount of produced sludges	0.35 l/inh.day
Annual volume treated	47,500 m^3
Annual operational time	8,150 h
Maximum radioactive capacity	700,000 Ci
FIS 60 type source activity	7,000 to 9,000 Ci
Irradiation time	30 min
Absorbed dose without oxygenation	3 kGy
Absorbed dose with oxygenation	2 kGy
Batch volume	6 m^3
Volume of treated sludge	140 m^3/day
Annual amount of sludge (dry weight)	4,750 tn
Energy transference yield	40%
Tank diameter	1.60 m
Amount of Source lodging	32
Recirculation Rate	240 m^3/h

4. COSTS

The construction of the first full-scale Sewage Irradiation Plant was bided at auction, both the civil work and the electromechanical installations. As result of the auction process, the following amounts were estimated (in US $):

Investment:	
Civil works	900,000
Electromechanical works	1,600,000
Subtotal	2,500,000
Co-60 sources (700,000 Ci)	700,000
Total	3,200,000

Operational costs:	
Personnel	70,000
Co-60 recharge (average)	50,000
Maintenance and repair	28,000
Electric power	25,000
Sludge transport	50,000
Oxygen	10,000
Subtotal	233,000
Unforeseen (5%)	11,000
	244,000
Amortization (25 years 5%)	225,000
Total	469,000
Annual cost by inh. (400,000 inh)U$S	1.17
Cost by dry ton (4,750 ton)	99
Cost by wet ton	9.9
Sludges amendment	3,400 kg /ha
Total capacity of use	1,400 ha /year
Cost by hectare	US $ 336

The resulting cost by hectare is also high, but again it must be considered that this is a case of a demonstrative project; some systems that are redundant should be omitted in further constructions. It is estimated that the cost of a new plant might be decreased by approximately 30%.

5. IRRADIATION EFFECTS

5.1. Pathogen elimination

The main purpose of the radiation technology treatment on the sewage sludge is to inactivate the pathogenic microorganisms and then to allow the reuse in agriculture without any sanitary risk. Several research programmes have already determined the effective absorbed dose for the elimination of the most known pathogenics. The effectiveness in the faecal or hydric transmission of pathogenic agents was verified in the Argentine project. Bacteria, fungi and parasite ova were inactivated by an absorbed gamma irradiation dose of 2 kGy [10].

The Argentine environmental regulations are still not complete and the limitations for the reuse of sludges in agriculture have not been pronounced, but the project is following foreigner regulations such as the USEPA or the European Community regulations. For example, survival of faecal coliform bacteria after irradiation treatment is still less than the maximum of 1000 MPN/g of the EPA regulations.

However, the recommended absorbed dose is 3 kGy because of the virus inactivation requirement. Enteric pathogenic viruses, like all viruses in general are more radioresistant, and some of them are surviving on land for a long time. One of the topics of the project was the investigation of this type of pathogen control.

Some technical difficulties were solved first about the isolation of the virus species, after that, the species identified were tested after irradiation of maximum 3 kGy abs. dose. A positive result was found in only one of the six tests on the main types of enteric viruses, i.e. Cocksakie virus, Echovirus, etc. It is still necessary to confirm the minimum dose to guarantee virus inactivation below the acceptable limits.

5.2. Detoxification effects

Aqueous solutions of organic toxic compounds are destroyed by ionizing radiation because of the decomposition secondary effects due to irradiation. There are many examples in literature about organochlorinated pesticides, phenols, etc. Purely domestic sludges should not have significant concentration of these substances but the existence of them in the sewage sludges is known, increased by the industrial effluents dumped sometimes into the sewerage.

Some organochlorinated pesticides were detected in low concentration in the sludges at Tucumán where the project will be located: Chlorpyrifos, Heptachlor, etc. Experimental irradiations were carried out to measure decomposition, and this was really proved. But the identification of by-products of the modified compound and their toxicity is still to be accomplished according to the plan for future steps.

5.3. Physicochemical effects

It is known that ionizing radiation may cause some changes in the physicochemical characteristics of the sludges. The project has determined the decrease in the viscosity with dose level surrounding the recommended dose for the project [11].

The simple tests of sedimentation velocity have demonstrated the effect of irradiation, more evidently in diluted samples of the irradiated sludges than in the pure ones.

Also, the test of "filtration specific resistance: r" has been carried out to evaluate the possible changes of the material due to irradiation. The decrease of r value as the dose is increasing is evident up to 3 kGy of absorbed dose, reaching a difference of 60% less than the non-irradiated sludge. This was tested in three different sludges, and the results are shown in Fig. 5.

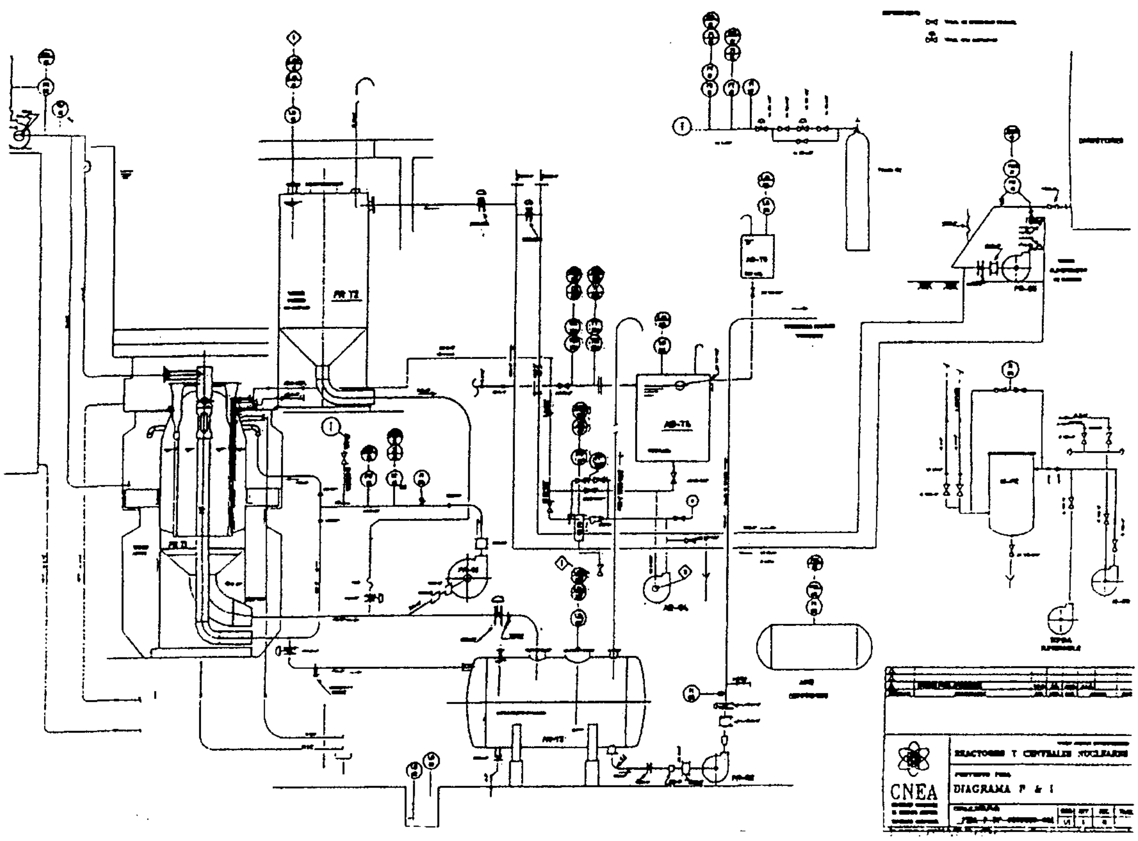


FIG. 5. Flowsheet.

These changes on the physicochemical characteristics of the sludges can be important in connection with the sludge movement into the mechanical systems of the plant. Even if they are not enough to improve the sludge sliding, they are, on a positive sense, for the sludge managing.

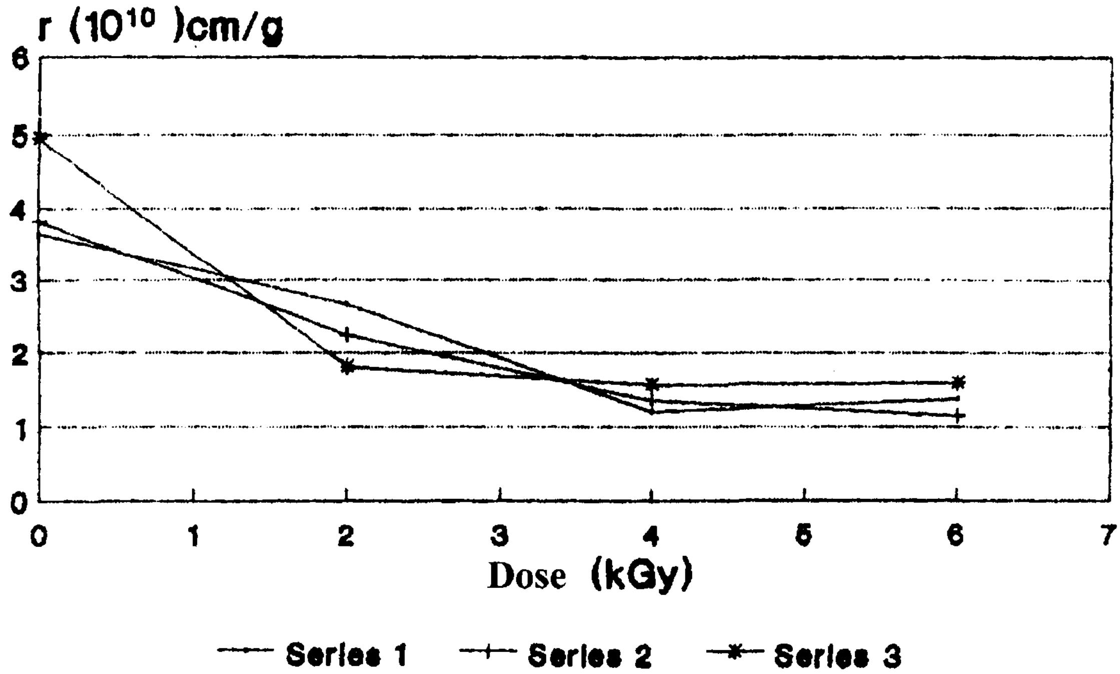


FIG. 6. Filtration Specific Resistance In Irradiated Sewage Sludges.

6. IP-100 EXPERIMENTAL IRRADIATOR

The Pool Irradiator, 100 L capacity (IP-100) is an irradiation facility for the purpose of the study about the irradiation effect on several liquid materials. The main feature is that the radioactive sources are included in the liquid core with the benefit of:

- minimum loss of energy
- high dose homogeneity due to recirculation systems
- addition of other fluids (oxygen, gases, etc.)
- possibility of heating for technical effects
- easy accessibility for cleaning and repair.

The IP-100 was created for experimental purposes concerning the oxi-irradiation of sewage sludges; however, is might also be used for dyes, pesticides solutions, hydrocarbons, latex, liquid industrial effluents in general; and it may be adapted and dimensioned for semi industrial purposes.

The IP-100 consists in a stainless steel cylindric tank, with a centrifuge pump that recirculates the liquid volume from the bottom to the third upper part. The radioactive elements are in tubes, and these are fixed to the stopper. The gases or additions may be injected by a connecting tube with a valve and a second valve on the upper side of the tank for ventilation [12].

For operation it is submerged in a pool no more than five m deep. The water column makes the needed shielding. The movements for the sources charge and discharge are carried out under water at the bottom of the pool, with direct vision and illumination. Usually there are pools in simple nuclear research installations for storage or replacement of sources that may be used for the IP-100 operation, avoiding the construction of expensive concrete shielding.

Main design parameters are:

Irradiation volume:	100 lt
External diameter:	450 mm
Thickness:	2.5 mm
Material:	AISI 304 lt
Recirculation pump:	0.6 kw
Recirculation volume:	120 lt/min
Maximum radioactive capacity:	40,000 Ci (Co-60)
Verification to the interior pressure:	P max: 20 N/cm^2
Verification to the external pressure:	P max: 10.5 N/cm^2

6.1. Laboratory tests

The IP-100 was tested on hydraulic resistance and leakproof, under pressure already mentioned during 1 h, without watching any change or alteration. For control of homogeneity and death zones existence, a radioactive solution of I-131 was used. The tracer was detected by INa-Tl scintillator on the entrance of the pump, and the recorded data were graphed. The mixing time resulted to be very low as compared to the total expected irradiation time, so as to have high dose homogeneity.

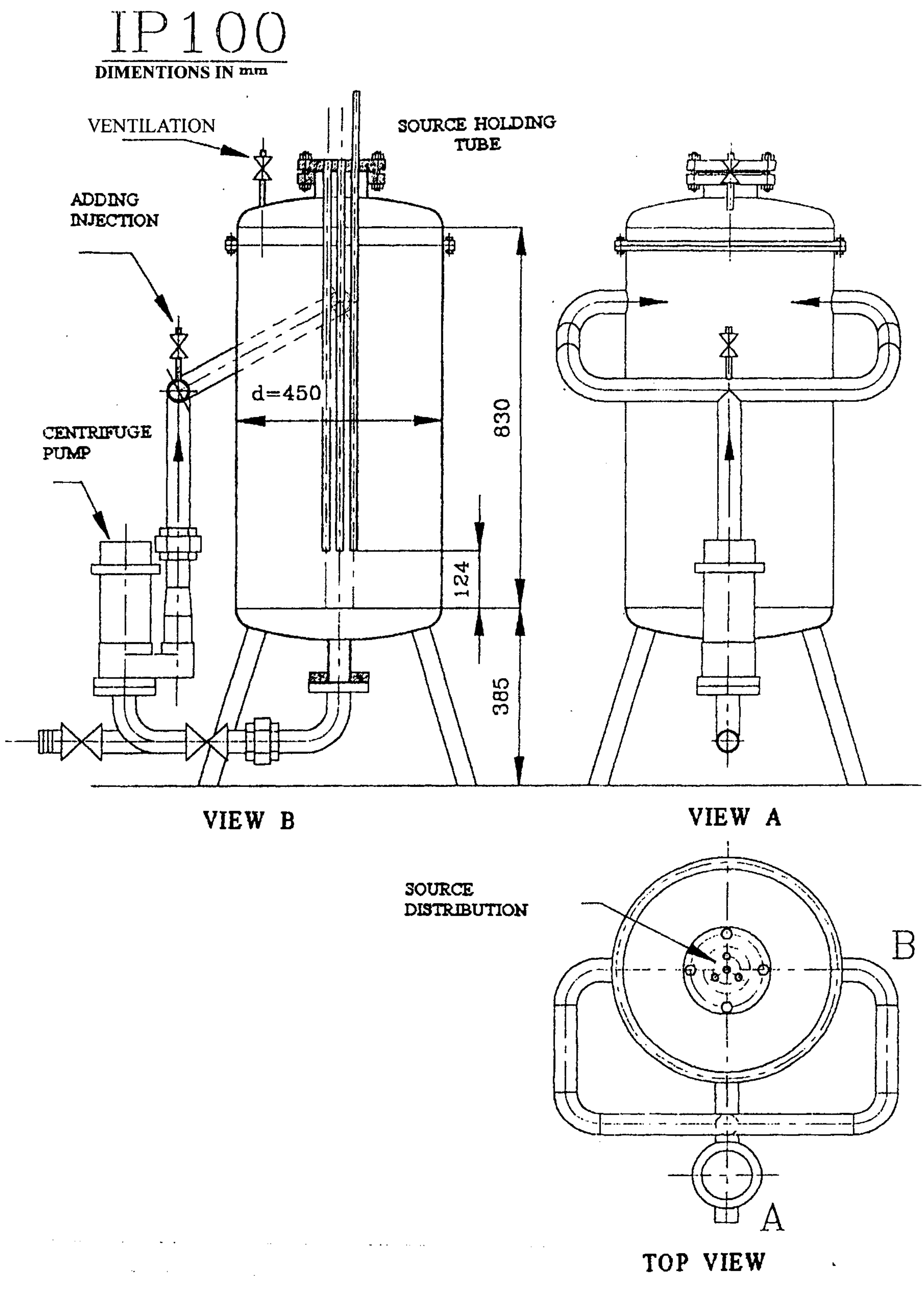


FIG. 7. Irradiator schematic diagram.

7. CONCLUSIONS

The basic concepts of irradiation facilities have been reported in the last decades; at the present, the aim of radiation processing development is the optimization of the rate: cost over absorbed energy. For this purpose, the factors that may participate are: the design improvements and the combination with other processes (heat, oxygenation, etc.). Mathematical or physics models in lab-scale facilities like the IP-100, will lead to find out the best irradiation conditions. In this sense, and based on the 20 years German experience, the Sewage Sludge Irradiation Project is being developed.

As the project has been planned as full-scale plant, to treat the sludges coming from a big city and to reuse them for Agriculture, many topics has to be considered. The first of them is the protection of the Public Health, and life quality improvement, taking into account the pathogen elimination, toxic decontamination and agronomic value of the use on land. These factors imply also a benefit and they have to be taken into account whenever a project is evaluated.

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Dr. Cecilia Magnavacca in the conduction of research about the irradiated sludges, and all the personnel of CNEA involved in different aspects of the project. The Tucumán City, the National University of Tucumán, the Agro Industrial Experimental Station O. Colombres, professionals and colleagues. The IAEA, by means of the Co-ordinated Research Programme and Technical Co-operation Assistance.

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