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A NEW SEMI-MOBILE PLANT FOR RADIATION PROCESSING OF WASTE

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RIASSUNTO

Un nuovo impianto di irraggiamento semi-mobile pilota/dimostrativo, denominato TRIRIS (TRIsaia-RIfiuti-Sterilizzazione), É stato progettato e realizzato con finalità di proposizione e valutazione di nuove opportunità tecnologiche di trattamenti "in-situ" di rifiuti solidi e liquidi, in particolare con riferimento a situazioni di emergenza (es. necessità di un veloce recupero ambientale a seguito di un evento accidentale con effetti di inquinamento della falda acquifera).
Il progetto, che è stato condotto congiuntamente da ENEA e dalla Soc. Hitesys SpA, azienda italiana di fabbricazione di acceleratori di elettroni, prevede l'utilizzo di una macchina acceleratrice del tipo LINAC (in banda s) avente come energia e potenza di fascio rispettivamente 4-6 MeV e 1000 W. Lo schermaggio della radiazione diffusa è realizzato mediante una piscina ad acqua, riempita prima delle operazioni, che circonda la testa dell'acceleratore di elettroni.
L'impianto, che troverà collocazione definitiva presso il Centro Ricerche ENEA-Trisaia (Basilicata, Sud-Italia), permette una larga flessibilità operativa: decontaminazione di acque di falda e di scarico (da 1800 a 70 kg/h con dosi da 1 a 25 kGy), reflui organici e composti clorurati (25 kg/h a 75 kGy), rifiuti solidi ospedalieri (50 kg/h a 35 kGy) o rifiuti speciali tossico-nocivi come i composti aromatici policiclici (da 180 a 35 kg/h con dosi da 10 a 50 kGy).

ABSTRACT

A new pilot/demonstrative semi-mobile irradiation plant, named TRIRIS (TRIsaia-RIfiuti-Sterilizzazione, namely "Trisaia Res. Center - Wastes -Sterilization"), has been designed and erected. The plant goal is recognized in proposing and exploring new technological opportunities, based on an "in-situ" effective processing of solid or liquid waste, mainly with reference to emergency situations (e.g. need of a quick environmental restoring operation following an accidental groundwater pollution).
The project, which was jointly carried out by ENEA and Hitesys Co., an Italian electrons accelerators manufacturer, foresees a LINAC type EB-machine (s band) having 4-6 MeV and till 1000 W as beam features. Scattered radiation shielding is performed by a water pool surrounding the EB-machine head, filled up before operations.
The plant, that is to be located at ENEA-Trisaia Res. Center (Basilicata, southern of Italy), allows a large operative flexibility: groundwater and wastewater decontamination (1800 to 70 kg/h in the 1 to 25 kGy dose range), organic and chlorinated waste streams (25 kg/h at 75 kGy), solid hospital wastes (50 kg/h at 35 kGy) or hazardous wastes like polycyclic aromatic compounds (180 to 35 kg/h in the 10 to 50 kGy dose range).

1. INTRODUCTION

TRIRIS is a transportable plant performing accelerated electrons beam irradiation in order to allow a wide range of treatments (cleaning, decontamination, sterilization, detoxication, etc.), of contaminated solid or liquid substances, including hospital, industrial and toxic/hazardous wastes.

The plant is based on an electron accelerator set up inside a semi-fixed shielding structure.

ENEA, the Italian National Agency for New Technology, Energy and the Environment, commissioned Hitesys to design and build the facility for use at its Trisaia Research Center, in southern Italy. Work began at the beginning of 1996 and was completed in April 1997.

At present TRIRIS is being tested at the Hitesys workshop in Aprilia, and the company expects to transfer it to Trisaia as preparation works of the site there are fully performed.

The plant is defined as transportable being most parts preassembled at the factory and only final assembly to be accomplished on site.

The entire plant can be packed in two containers, for easy transport by road, rail or sea.

TRIRIS can also be moved from site to site for short-term operations, also for instance to demonstrate the technological capabilities of electron beam irradiation in sterilizing/treating contaminated liquid and solid wastes, or if necessary to meet specific local needs.

The main features of the plant are:

- easy transport to the operating site by truck railway car;
- treatment capability of hospital, industrial and toxic liquid or solid waste at speeds ranging from 20 to 1800 kg/hour (depending on the type of waste and the radiation dose required);
- technology and processes particularly developed to:
  - sterilize infected liquid and/or solid waste, mainly solid hospital waste (SHW), thereby allowing the destruction or reproduction inhibition of the microbial charge present down to a residual concentration of 10^{-6} CFU (Colony Forming Units) per gram;
  - treat industrial and/or agriculture originating wastewater (containing, e.g., pesticides, herbicides, fungicides, hydrocarbons, surfactants, PCBs, PCTs or polychlorophenol), transforming it into a flowrate legally dischargeable into surface or coastal waters;
  - sanitize water for human use within the limits established by law;
- flexible operating process (sterilization/treatment), allowing easy and fast switching from one type of waste to another;
- compliance with applicable radiological and conventional safety regulations for the protection of personnel and population health;
- autonomous capacity to verify and analyze the characteristics of waste before and after the treatment.

2. PLANT DESCRIPTION

According to block diagram shown in Fig. 1 and the plant vertical section shown in Fig. 2, the plant main components are:

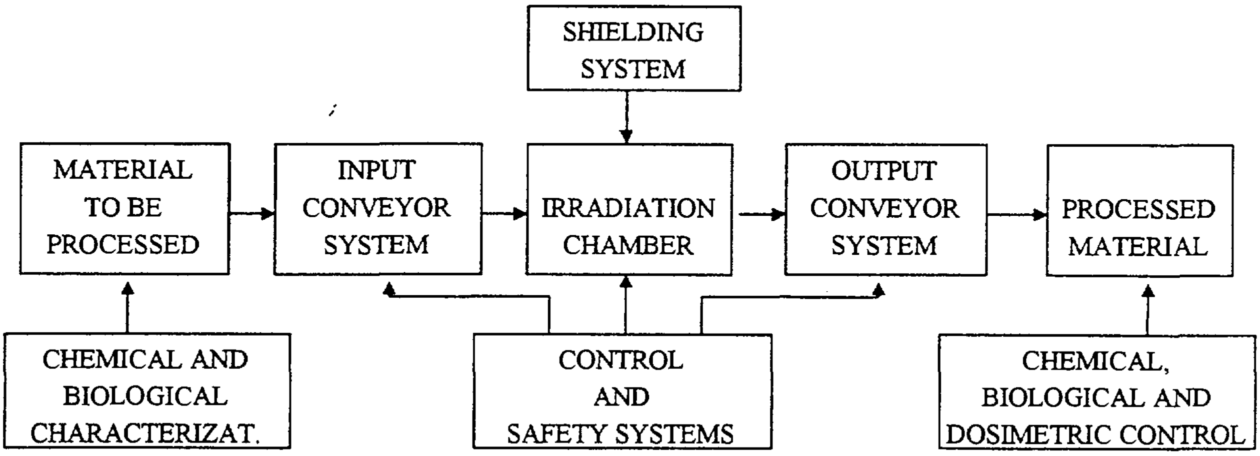

Fig. 1 - Plant Block Diagram

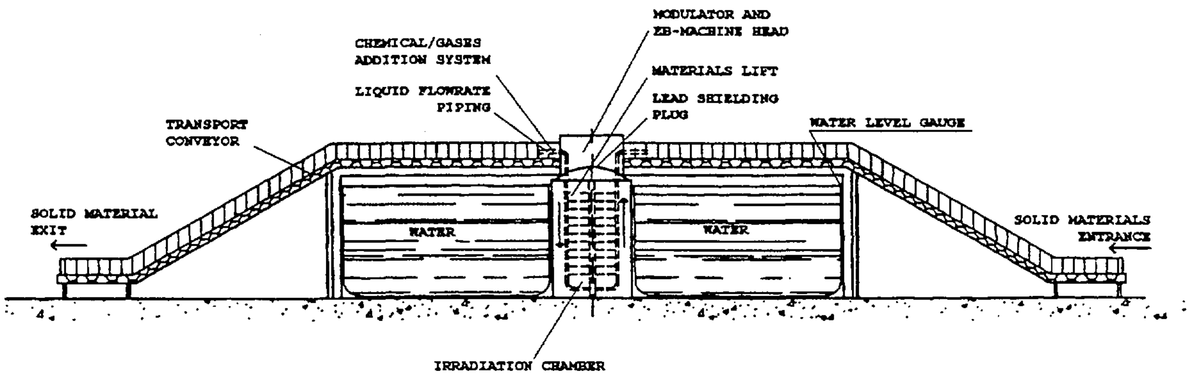

Fig. 2 - Plant Vertical Section

1. accelerator
2. modulator
3. control cabinet/console
4. mobile pre/post irradiation control laboratory
5. waste conveyor system
6. semi-fixed shielding structure.

The plant is designed to be easily transported to and assembled at user sites. The site requires minimum preparation: only an appropriately outfitted platform, power supply and industrial water availability. The EB-machine system could be divided into three parts: the radiating head (which contains the accelerator), the radio-frequency generator (including magnetron, RF circuitry and pulse generator), and the cabinet (containing further power supplies and the control system). The complete plant, including remaining mechanical and control equipment, can be transported by a small truck or other mobile unit having maximum transportable load of 3.5 tons. The maximum operating distance between the accelerator and the power supply located in the mobile unit is 50 meters.
The system is equipped with an independent power generating circuit enabling input to vacuum pumps connected to the accelerator during down time.
The accelerator control system performs the following functions:
- measurement and programming of emitted radiation
- measurement and programming of absorbed dose rate
- measurement and programming of functioning time
- counting and programming of number of emitted pulses.

The command console is located in the mobile unit and the control system displays all analogical and digital data related to accelerator operations.

3. COMPONENTS

A general description of the main components of the TRIRIS plant follows.

3.1 Accelerator

The selected EB-machine (see Fig. 3) is an s-band stationary-wave linear electron accelerator, coupled on its axis with a cathode and equipped with titanium window.
Main accelerator features are:

Beam Energy	4 to 6 MeV
Beam Power	600 to 1000 W
Frequency	3000 MHz
Pulse repetition	300 Hz as max. frequency
Peak RF power	2.6 MW
Average RF power	3 kW
Pulse duration	4 μs
Flow deflection	by electromagnet

Deflection frequency	adjustable and synchronized with pulse emission
Window cooling	forced air
Head maximum dimensions	70x23x27 cm
Head maximum weight	50 kg.

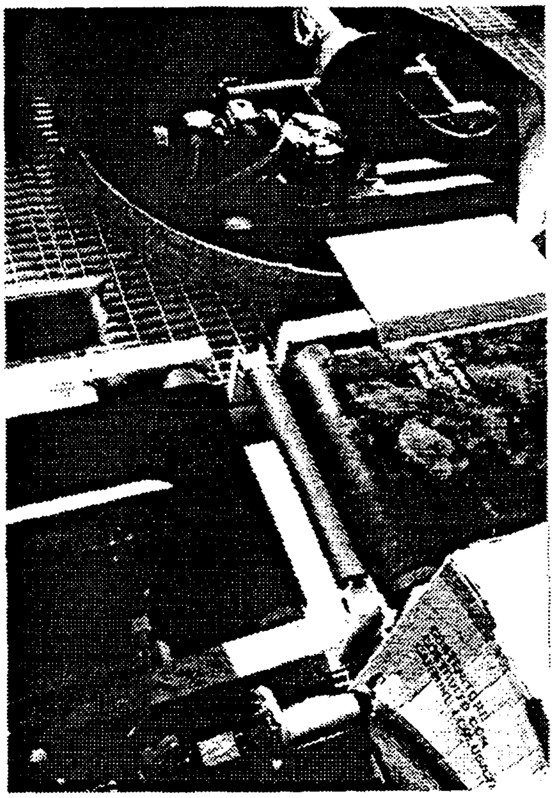

Fig. 3 - EB-machine Top Area

3.2 Modulator

Main modulator features are:

RF generator	EEV Magnetron, model m 5193
Insulation	circular, 4-gates ferrite insulator
Pulse generation	by forming line and thyratron
Pulse transformation	47 kV
Resonance frequ. control	automatic, by dedicated circuit
Weight	less than 130 kg.

3.3 Control cabinet/console

The console includes:

- cooling system

- low and high voltage power supplies
- measurement interfaces
- process computer
- super VGA display
- PC keyboard and separate beam ON/OFF switch.

3.4 Pre/post irradiation control laboratory

3.4.1 Dosimetric laboratory

The laboratory performs all dosimetric control measures utilizing computer-controlled apparatuses; main features are:

Measurement range	2 to 100 kGy
Readout	by optical transmission.

3.4.2 Chemical/physical characterization laboratory

The laboratory performs a number of relevant preliminary tests, to be completed later in a specialized laboratory. The plant laboratory allows the following measures:

- BOD_5
- COD
- NO_2
- NO_3
- colour
- turbidity.

The laboratory main instrumentation set includes:

- pH, mV and temperature measuring instrument
- photometer and/or spectrophotometer
- thermostatic refrigerator
- lab heater.

3.4.3 Biological/bacteriological characterization laboratory

The laboratory allows to perform the most important relevant biological tests, to be completed later in a specialized laboratory.
In particular, the lab tests performed with reference to contaminated wastewater regard:

- faecal coliforms
- total coliforms
- faecal streptococci.

The laboratory is also equipped with portable apparatuses for microbiological analysis of liquid streams.

3.5 Waste conveyor systems

Liquids to be treated penetrate the shielding structure through a ∅ 25 mm stainless-steel pipe network. Solids (packed in standard SHW boxes) are conveyed into the chamber by a driven belt complete with down/up carriers and handling systems (see Fig. 4). The operating structure is surrounded by a safety area (radius 10 meters) accessible only to authorized personnel during plant functioning.

Fig. 4 – Solid Material Conveyor System

3.6 Shielding structure

As mentioned above, the TRIRIS plant is based on an electron accelerator set up inside a semi-fixed shielding structure. This structure is easy to assemble, dismantle and transport.
To reduce costs and make the TRIRIS plant easy to transport, the shielding structure, which includes the irradiation chamber and the waste conveyor systems, is designed to be assembled at the operating site.
The irradiation chamber, with the radiating head and the conveyor systems, is placed inside a semi-fixed bunker.

Pursuant to the criteria and calculations described in Appendix 1, the shielding medium used is row filtered industrial water.
The shielding structure comply at all with requirements specified in the applicable IAEA, ICRP and Italian Standard Regulations for the protection of personnel and the general population against radiation hazards.

4. WASTE PROCESSING CAPACITY

Processing capacity can be estimated in three main different ways, depending on several allowed operating situation:

- Theoretical processing capacity (TPC): this factor is based on the assumption that the whole energy associated with the beam is absorbed by the irradiated substance, with no radiation loss or secondary emissions. It evaluates the accelerating machine theoretical maximum performance, regardless of the EB-machine operating configuration;
- Short-term processing capacity (SPC): this factor takes into account the efficiency of the irradiation process (ranging from 0.4 to 0.7), depending on the process parameters (irradiation on one or two sides, size and density of the target material, etc.); it neglects machine down time, so it allows an evaluation also of future assessments of experimental or pilot operations, process characterization, as well as small production runs;
- Long-term processing capacity (LPC): this factor is lower than the short-term one, as it takes into account the machine down time due to, for instance, the maintenance operations. It refers to large processing runs requiring the plant to operate continuously for very long periods (longer than few days).

Tab.1 summarizes above referred parameters, calculating TRIRIS throughput capacity assuming a total irradiation efficiency factor of 0.5.

Type of treatment	*Dose* kGy	*TPC* kg/hr	*SPC* kg/hr	*LPC* kg/hr
Water sanitization	1	3600	1800	1500
	5	720	360	300
	10	360	180	150
Water sterilization	25	140	70	60
Solid Hospital Wastes	35	100	50	40
Organochlorines	75	50	25	20

Tab.1 – Plant Throughput Capacity

REFERENCES

[1] TRIRIS Plant Detailed Design - HITESYS-ENEA internal doc. No. 335/21-06-96 rev.0

APPENDIX : DESIGN CRITERIA FOR SHIELDING STRUCTURE GEOMETRY AND MATERIALS

The type and characteristics of the shielding structure were chosen in light of the need to make the plant safe, easy to transport and assemble, and to keep down construction costs.
As a reasonable starting point, it was assumed that the accelerator would consist of the accelerating structure alone, without the surrounding electronics. This would avoid the risk of failures due to:

- high irradiation rate of components (some accelerators are known to have failed after only 50 hours, despite of the 20,000 hours warranted by the manufacturer);
- chemical oxidation by large quantities of ozone released by ionization of the air between the electron source and the target.

It was also decided to keep beam energy below 6 MeV; this would limit braking ("*bremsstrahlung*") X-ray effects, while assuring good penetration into the target materials.
In calculating the necessary shielding, the accelerator was reduced to a simple radiating geometric structure simulated by a prism having a 30-cm square base and a scanning cone lined to the base.
It was further assumed that the electron beam action would occur as close as possible to ground level. The size of the transportable components could be considerably reduced if the shielding structure were installed partly underground, but this assumption was conservatively not taken into account in performed calculations.
The basic assumptions regarding the electron beam were:

- electron beam emission in downward direction;
- braking X-ray (due to interaction between the electrons and target material) beam generation point located at ground level.

Based on these assumptions, it was reasonable to think that the shielding structure would have to lower the lateral component to 90 degrees, that is a damping factor of 1/1,000,000 (i.e. the radiation emitted at ground level must be one millionth of the beam flowing parallel to the ground around the irradiation chamber).
At this point, three alternative shielding solutions were considered.

Solution 1: LEAD

In the case of lead (nominal density of 11.3 g/cm^3) the structure would have the smallest possible volume. Referring to considered energies, a 30 cm layer could allow a 10^6 beam attenuation.
Assuming that the accelerating structure is surrounded by lead and the irradiation chamber is very small (e.g., if the plant purpose is only to treat liquids conveyed under the beam through a simple pipe whose nominal diameter, given the power of the accelerator, would not to be larger than one inch), the theoretical prism would have a 30 cm cladding along the 80 cm height). In such case, the shielding structure, though assembled with relatively lightweight parts, would weight around 6500 or 7000 kilograms.
However, this solution would greatly penalize the plant flexibility being the plant suitable only for liquids treatment. As a matter of fact, if the lead-cladding solution would be applied to a

chamber large enough to contain the solid waste conveyor system, the amount of lead needed would put the TRIRIS plant out of the range of a feasible transportability.
Accordingly, the shielding material should be something that can be easily sourced at the operating site and easily shaped to shield the X photons.

Solution 2: SAND
In order to provide the same above referred radiation absorption capacity, a thickness of sand (having same features of commonly used civil works materials) would be in the 150 to 200 cm range.
In this case, the shielding structure is pictured as a prism with a 4-meter square base and 2 meters in height.
The irradiation chamber can be much larger than in the previous case of lead shielding. If the base is increased from 30 to 100 cm square, the effect of 2 meters of shielding on the total volume, though not negligible, will certainly be secondary.
In order to use sand as shielding material, would make necessary to build forms like the ones used for concrete pouring. The outer form is simpler to make as it has no other function than containing the sand (leaving space for a stairway leading to the accelerator pit and openings for the conveyor system). The inner form is obviously more difficult because it must host not only the accelerator but also the conveyor system, the ventilation system and the chamber monitoring system.
The assembly of described shielding system is more difficult to arrange than in the case of lead cladding, where the operators, using a small truck-mounted crane, simply assemble the various components of the shielding structure. In the case of sand, the operators put the forms in place with the crane, then unload the sand brought in by truck and fill up the forms.
To dismantle the plant, the same operations have to be done in reverse.
In short, using sand as shielding material it is possible to provide a transportable structure that can be set up on site in a couple of days by a team of machine technicians and local labour.
The installation would likely require one or two truckloads of sand. As this is a fairly large quantity, plants for its eventual reuse or disposal should be made beforehand. The material characteristics are quite satisfactory and it lends itself to be used over long periods of time, as well as it is not damaged by exposure to radiation.

Solution 3: WATER
Water density is considerably low in comparison with previous mentioned materials, and, consequently, a shield made of this substance must be thicker in order to damp the X-rays generated by the machine by the considered factor of 1/1,000,000: the effects reached with 30 cm of lead requires 3.5 to 4 m of water.
Accordingly to the defined irradiation geometry, the dimensions of a possible water shield would be 8x8 m (square base) by 2 m in height.
In this case too, like for sand, the transportable structure consists of an inner and an outer containment system. To limit stress, the outer system can be circular. As in the previous case, the inner structure contains the accelerator, the conveyor system, the ventilation system and the chamber monitoring system. To better exploit the mechanical features of the containment materials, the inner structure too would be circular.
The system used to contain the water is similar to those commonly used in building above-ground swimming pools (which are often as large as the structure described here): a seamless

polyethylene sheet supported by a metal or Fiberglas framework able to prevent damages due to the water pressure on the cylindrical shape tank. The circular shape structure allows to fully exploiting the properties of the material.
The drawback of this ,solution is the exposure of a radiation-sensitive material (as thermoplastics generally are) to large amounts of radiation. Moreover, the exposure occurs in the presence of water, which make easy oxidation reactions caused by the generation of free radicals. Since the inner side of the pool sheet receives the highest dose rate, its service life will be shorter, though it cannot be quantified objectively at this time.
An alternative solution would be to use a number of collapsible PCV or neoprene tanks, filling them up one by one, with advantages of a very easy installation.
Based on the above considerations, the final choice of shielding material was Solution 3, i.e. the use of industrial filtered raw water, filling a suitable pool surrounding the irradiation chamber.

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