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A NEW SEMI-MOBILE PLANT FOR RADIATION PROCESSING OF WASTE

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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 in order to propose and explore new technological opportunities, based on an "in-situ" effective cleaning process. The main general goal is to face increased problems and concerns related to the treatment/disposal of different solid-liquid wastes, particularly with reference to emergency situation (e.g. need of a quick environment restoring operation following an accident with 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. A highly flexible automatic system allows materials (solid or liquid wastes) transporting and handling, being equipped a belt conveyor and a piping net.

Scattered radiation shielding is performed by a water pool surrounding the EB-machine head, filled up before operations. Auxiliary systems, control console and analytical chemical laboratories are hosted in suitable containers near the plant and easily transportable.

The whole plant and annexed systems disassembling and reassembling in a new site can be easily carried in a short time (few days).

The plant, that is located by 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 polyciclic aromatic compounds (180 to 35 kg/h in the 10 to 50 kGy dose range).

The paper describes and illustrates the plant in details and presents first available operating results so far performed by the installed plant.

1. INTRODUCTION

TRIRIS is a transportable plant that performs accelerated electrons beam irradiation in order to allow a wide range of treatments, like to contaminated solid and/or liquid substances, including hospital, industrial and toxic/hazardous wastes sterilizing or treatment.

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 before the end of the year.

The plant is defined as transportable because the parts are preassembled at the factory and final assembly is 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, 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 to 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 applied);
- flexible operating process (sterilization/treatment), enabling 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 treatment.
- technology and processes developed to:
  - sterilize infected liquid and/or solid waste, in particular 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.

2. PLANT DESCRIPTION

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

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; all that is needed is an appropriately outfitted platform, power supply and industrial water availability. The system is divided into three parts: the radiating head, which contains the accelerator; the radio-

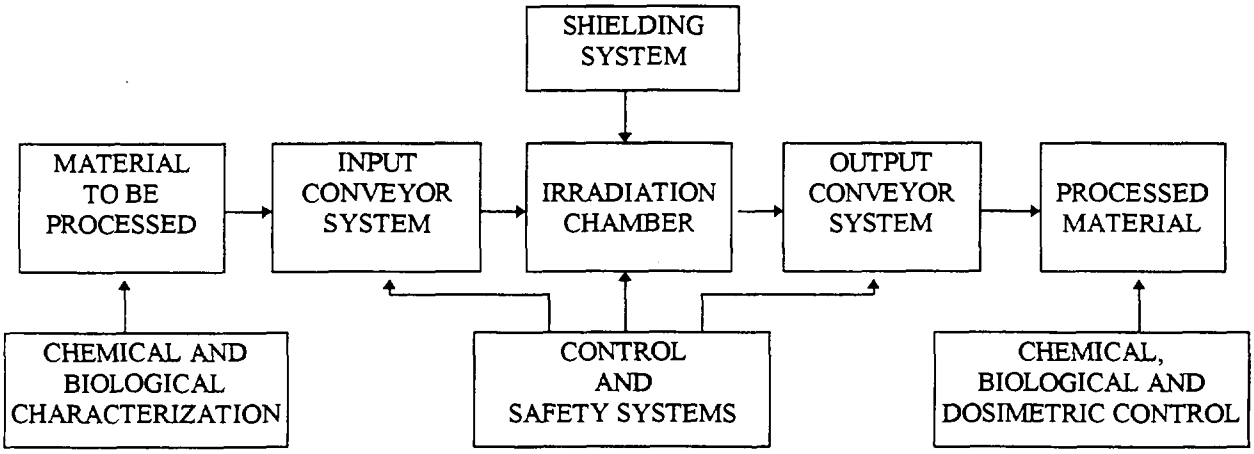

Fig. 1 - Plant Block Diagram

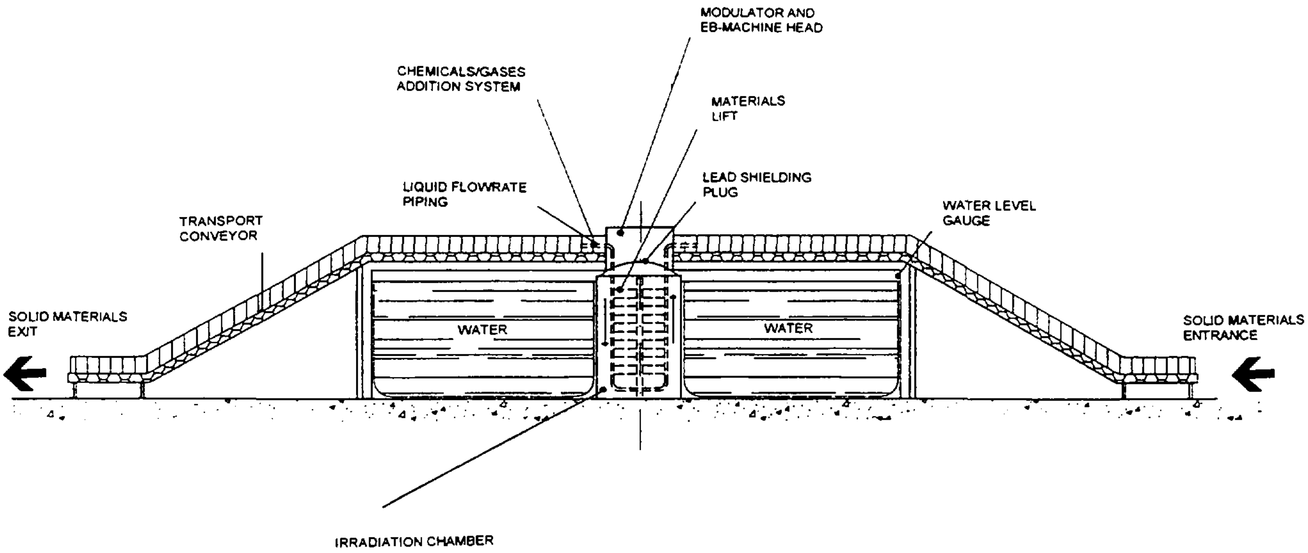

Fig.2 - Plant Vertical Section

TABLE I. PROCESSING CAPACITY

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

frequency generator, including magnetron, RF circuitry and pulse generator; and the cabinet, containing further power supplies and the control system.

The plant complete 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 has an independent power generating circuit that enables input to the 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 electron accelerator coupled on its axis with a cathode and having a titanium window.

Beam Energy	4 to 6 MeV
Beam Power	600 to 1000 W
Frequency	3000 MHz
Pulse repetition	frequency max. 300 Hz
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.

3.2 Modulator

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 functions with computer-controlled apparatuses:

Measurement range 2 to 100 kGy

Readout by optical transmission.

3.4.2 Chemical/physical characterization laboratory

The laboratory performs certain relevant tests, to be completed later in a specialized laboratory. By way of example, this lab determines:

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

The main laboratory instruments are:

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

3.4.3 Biological/bacteriological characterization laboratory

This lab too performs the most important relevant biological tests, to be completed later in a specialized laboratory.

In particular, this lab tests contaminated wastewater for:
- fecal coliforms
- total coliforms
- fecal streptococci.

The laboratory is equipped with portable apparatuses for microbiological analysis of aqueous fluids.

3.5 Waste conveyor systems

Liquids to be treated enter the shielding structure through a ∅ 25 mm stainless-steel pipe.

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

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 limit 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 industrial water.

The shielding structure meets all the requirements specified in the applicable IAEA, ICRP and Italian Standard Regulations for the protection of personnel and the general population against radiation hazards.

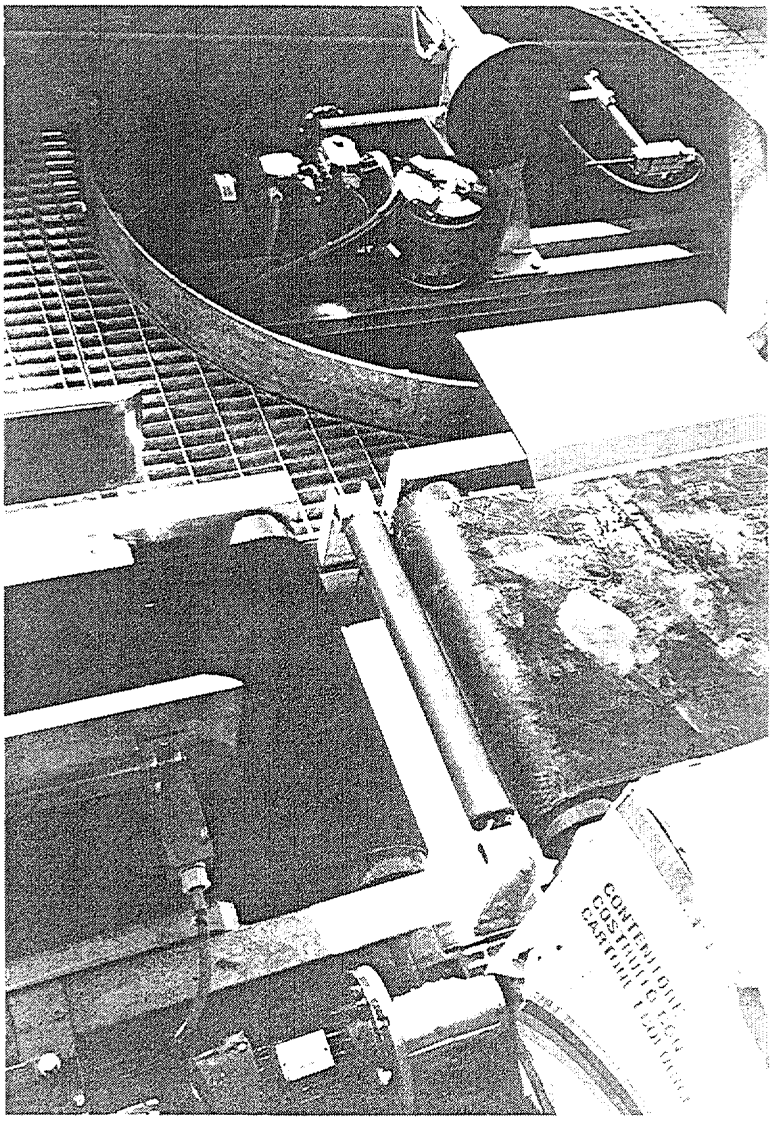

Fig.3 - EB-machine Top Area

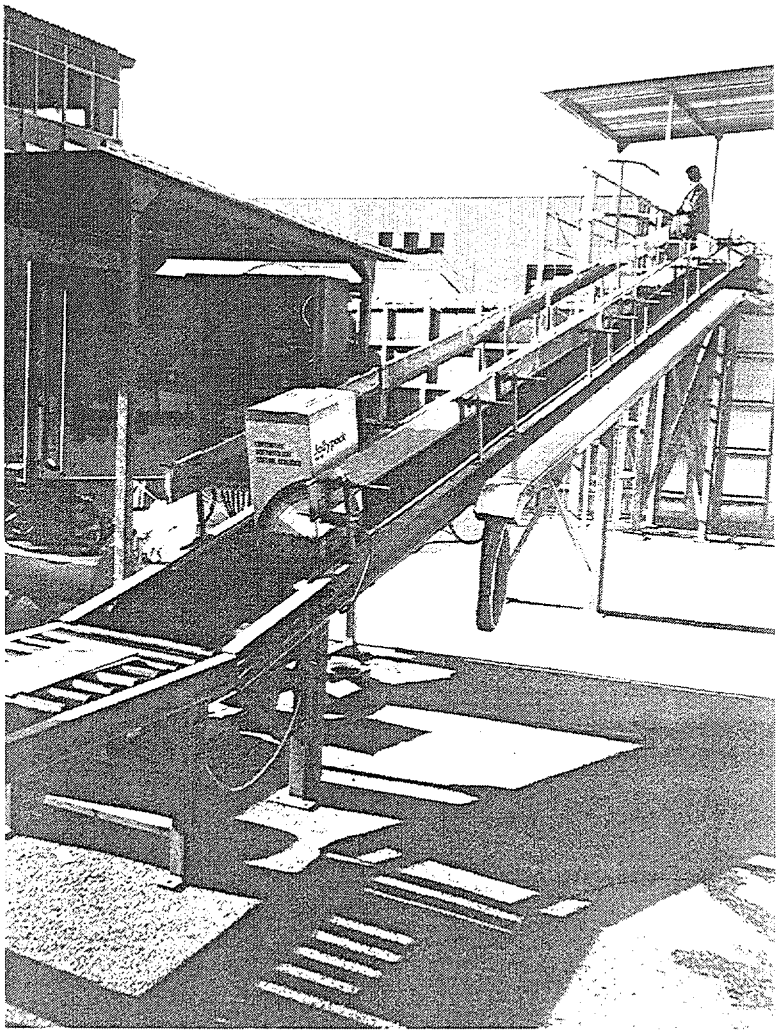

Fig.4 - Solid Material Conveyor System

4. WASTE PROCESSING CAPACITY

Processing capacity can be calculated in different ways, depending on the actual operating situation.

(a) 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 loss or secondary emissions. It describes the accelerating machine, regardless of the configuration in which the machine is actually used.

(b) Short-term processing capacity (SPC): This factor takes into account the efficiency of the irradiation process, which ranges from 0.4 to 0.7, depending on the process parameters (irradiation on one or two sides, size and density of the target material); it neglects machine down time, so it allows future assessments of experimental or pilot operations, process characterization, or small production runs.

(c) Long-term processing capacity (LPC): this factor is lower than the short-term one, because it takes into account the machine down time (for instance, to perform maintenance operations). It applies to large runs that require the plant to operate for longer than a few days.

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

REFERENCES

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

Appendix 1

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:

(a) high irradiation rate of components (some accelerators are known to have failed after only 50 hours, as against the 20,000 hours warranted by the manufacturer);

(b) 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 diagonal 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 prudently not taken into account in the calculations.

The basic assumptions regarding the electron beam were:

(a) The electron beam is emitted in the downward direction.

(b) The point where the braking X-ray beam is generated (by interaction between the electron beam and the target material) is 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. This translates into a damping factor of 1/1,000,000; i.e., the radiation emitted at ground level must be one millionth of the amount 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 using lead (nominal density of 11.3 g/cm^3) the structure would have the smallest possible volume. At the assumed 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 it is used only to treat liquids conveyed under the beam through a simple pipe whose section diameter, given the power of the accelerator, would be no larger than one inch), the theoretical prism would be clad with 30 cm along one height of 80 cm. In this 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's flexibility being the plant suitable only for liquids treatment.

If the lead-cladding solution were 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 "normal 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

To provide the same radiation absorption capacity, a layer of the type of sand commonly used in the construction industry would have to be 150-200 cm thick.

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 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 to pour concrete. The outer form is simpler to make because it has no function other than to contain the sand (leaving space for a stairway leading to the accelerator pit and openings for the conveyor system). The inner form is obviously more complicated because it must accommodate not only the accelerator but also the conveyor system, the ventilation system and the chamber monitoring system.

The assembly of this type of shielding system is more complicated 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 the shielding material makes it possible to provide a transportable structure that can be set up on site in about two days by a team made up of machine technicians and local labour.

The installation requires one or two truckloads of sand. As this is fairly large quantity, plants for its eventual reuse or disposal should be made beforehand.. The characteristics of the material are every simple and it lends itself to use over long periods of time as well as it is not damaged by exposure to radiation.

Solution 3: WATER

Because of the low density of water, a shield made of this substance must be very thick in order to damp the X-rays generated by the machine by the considered factor of 1/1,000,000. The effect achieved 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 by 2 m in height.

In this case too, 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 may be circular.

The system used to contain the water is similar to the one 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 that prevents the cylindrical shape of the tank from being deformed by the pressure of the water it contains. The circular shape of the structure allows it to operate by traction only, fully exploiting the properties of the material.

The drawback of this solution is that it exposes a radiation-sensitive material (as thermoplastics generally are) to large amounts of radiation. Moreover, the exposure occurs in the presence of water, which facilitates 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 would be to use a number of collapsible PCV or neoprene tanks and fill them up one by one.

Either way, this solution has the advantage of very easy installation.

Based on the above considerations, the final choice of shielding material was Solution 3, i.e. the use of industrial water filling a suitable pool surrounding the irradiation chamber.