DESIGN AND CONSTRUCTION OF THE Co-60 MULTIPURPOSE INDUSTRIAL IRRADIATOR VINAGA1

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Abstract: A Cobalt-60 Multipurpose Industrial Irradiator has been designed and constructed by the Research and Development Center for Radiation Technology (VINAGAMMA). It is called VINAGA1 and is the first Co-60 Industrial irradiator made in Vietnam. VINAGA1 is a Water pool-Tote box-Car on rails irradiator type, categorized as Category IV Panoramic irradiator by the International Atomic Energy Agency (IAEA). The irradiator fully meets the technical and safety requirements of Vietnam standards and IAEA safety guides. It is built with 52 tote boxes (dimensions of 50 x 67 x 90 cm) and can be maximally loaded with 2 MCi Co-60 activity. The maximum processing rate of the irradiator is 36 boxes per hour. It can be used for sterilization of healthcare products and food processing as well. The report presents the main specifications, design and construction of the irradiator. It is a great achievement of VINGAMMA efforts to localize the design and building of Co-60 irradiators to meet the economic development demands in Vietnam.

Keywords: *Cobalt-60, Irradiator, Dose uniformity ratio, Utilization efficiency*

1. INTRODUCTION

As the demands of healthcare product sterilization and food processing have been increasing with the development of the national economy, the irradiation method using ionizing radiations has been quickly found its application in Vietnam. Co-60 industrial irradiator is the main type of irradiator for sterilization of healthcare products and food processing worldwide but the cost for importing a complete system is still rather high. Therefore, the localization of designing and building Co-60 irradiators has been one of main duties assigned to research organizations of Vietnam Atomic Energy Institute (VINATOM). As a pioneer for radiation technology applications of industrial scale in Vietnam, VINAGAMMA has successfully exploited the Hungarian Co-60 industrial irradiator SVST-Co60/B in both technical handling and also economical aspects. VINAGA1 has been designed and constructed with the rich experience of VINAGAMMA in nearly 20 years of operating Hungarian irradiator. The design process has made good use of the calculation packages such as MCNP4C2 and AUTODESK INVENTOR 2015. The MCNP code has been used to calculate dose distributions inside tote box for selection of source-product configuration and tote box dimensions; AUTODESK INVENTOR 2015 has been used to calculate Young's modulus, yield strength, Poisson ratio, etc. for mechanical structure designs, material selections and cost evaluation.

2. DESIGN AND CONSTRUCTION OF VINAGA1 IRRADIATOR

2.1. Research subjects and methodology

The main designs of the source-product configuration and the principle structure of the Tote Box Mechanical System (TBMS), especially the Moving Subsystem inside the irradiation room have been done by using MCNP code.

The engineering calculation has been implemented for verifying the design of the irradiator biological shielding.

The mechanical designs of TBMS system and the Source Hoist System have been carried out by using the AUTODESK INVENTOR 2015 software.

The following design and construction tasks have been completed for VINAGA1 irradiator:

- Control System and Interlock Circuit (CS&IC)
- Radiation Monitoring System (RMS)
- Indication System (IS)
- Tote Box Mechanical System (TBMS), consisting of Moving Subsystem (MSS), Loading-Unloading Subsystem (LULSS) and Transport Subsystem (TSS);
- Source Hoist System (SHS), consisting of the source module, source racks and the hoisting mechanism;
- Water Treatment-Level-Cooling System (Water System)
- Ventilation System (VS)
- Compressed Air System (CAS)

The technological block diagram of VINAGA1 irradiator is presented in Figure 1

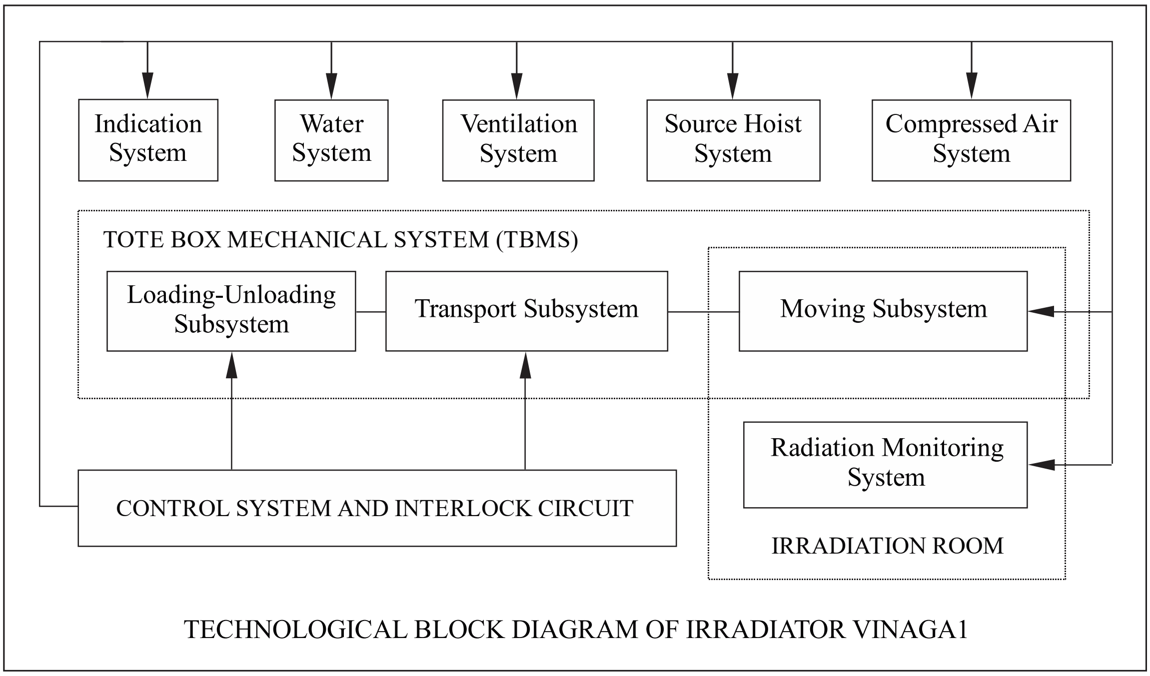

Fig. 1: Technological block diagram of VINAGA1

2.2. Results

2.2.1. Design selection [2], [4], [5]

For a Co-60 industrial irradiator the Dose Uniformity Ratios (DUR, the ratio of the maximum absorbed dose to the minimum absorbed dose in a product container) and energy utilization efficiencies (η, the ratio of the absorbed energy at the required absorbed dose in product to the energy emitted from the source) with various product densities are the most important parameters. The design objectives for the new irradiator are as follows:

- The new irradiator can be used for sterilization of healthcare products (average density in the range from 0.1 to 0.15 g/cm^3) and food processing (average density in the range from 0.3 to 0.35 g/cm^3);

- The product container of the irradiator should be suitable for the popular product dimensions nowadays. The tote box of Hungarian irradiator at VINAGAMMA is not suitable for the present product dimensions.
- The processing rate should be as high as possible in order to cover the absorbed dose range as large as possible.

MSS is a nucleus of a Co-60 industrial irradiator. MSS structure and source-product configuration have the greatest effect on the irradiator parameters. The MSS has 8 moving rows arranged in two levels with 52 tote boxes. The MCNP4C2 package has been used to calculate the irradiator parameters with several tote box dimension sets and different product densities. The calculation results have been obtained for three suggested tote box dimensions (50 x 67 x 90 cm, 55 x 67 x 90 cm and 60 x 67 x 90 cm) filled with material of five different density values (0.1, 0.2, 0.3, 0.4 and 0.5 g/cm^3).

With the compromise between DUR and energy utilization efficiency in the multipurpose requirement of the designed irradiator, the dimension set of 50 (W) x 67 (L) x 90 (H) cm has been chosen. Table 1 presents the calculated values of dose uniformity ratio with the error of ± 0.01 and energy utilization efficiency (η) with the error of ±0.2%.

Table 1: Calculation results for three suggested tote box dimensions

Density (g/cm^3)	50x67x90 cm		55x67x90 cm		60x67x90 cm	
	DUR	η (%)	DUR	η (%)	DUR	η (%)
0.1	1.36	15.3	1.38	17.3	1.41	17.7
0.2	1.43	26.4	1.47	29.5	1.51	29.9
0.3	1.50	34.4	1.57	37.4	1.65	38.0
0.4	1.59	40.4	1.68	42.2	1.76	42.7
0.5	1.75	44.9	1.86	45.6	1.99	45.1

2.2.2. Verification of the biological shield design [3], [6], [7], [9]

The shielding design has been carried out with the data similar to the ones of the Hungarian Co-60 irradiator at VINAGAMMA. Engineering method has been used for verification of VINAGA1 shielding design using ordinary concrete (density of 2,300 kg/m^3). The calculated dose rate at a point is a sum of transmitted and scattered radiation dose rates at the height of 1 m from the floor. The calculation accuracy is better than 20%. The calculation results show that the shielding design for VINAGA1 with the maximum 2 MCi activity is adequate to give the dose rate less than the occupational dose limit specified in the radiation regulation of Vietnam. Figure 2 shows the irradiator shielding plan for 2 MCi of Co-60 activity. The dose rate calculation data for 8 specific points in the plan are given in Table 2.

Table 2: Calculation data of the biological shielding of VINAGA1 irradiator

Point	1	2	3	4	5	6	7	8
μSv/h	7.5E-02	2.7E-03	3.7E-06	6.8E-11	6.8E-03	2.3E-04	1.2E-08	9.6E-01

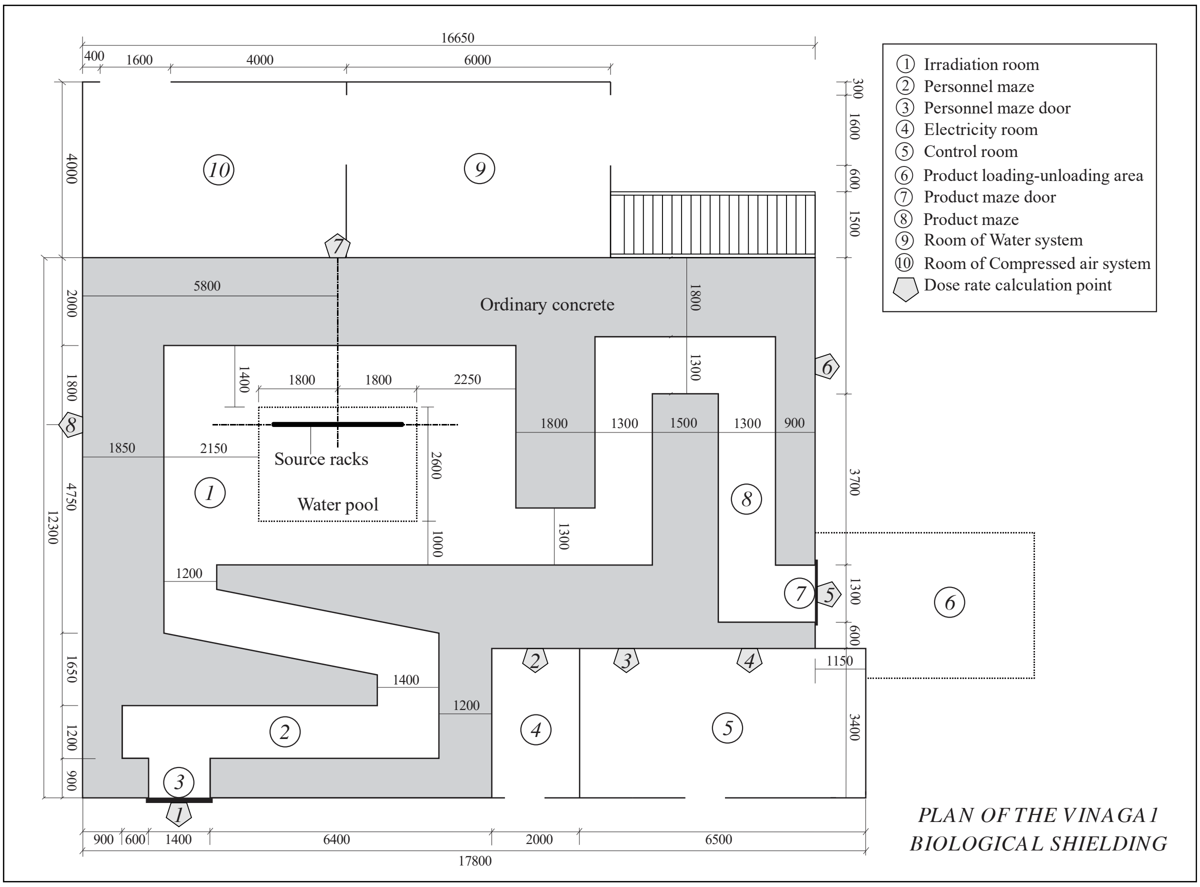

Fig. 2: VINAGA1 shielding plan and points of dose rate calculation

2.2.3. Control System and Interlock Circuit [1], [4], [5], [9]

The control system and interlock circuit have been designed to meet safety criteria of the Vietnam Standard (TCVN 8289) and Safety Guide of IAEA (Safety Series 107). The main safety philosophies in design such as Defense in Depth, Redundancy, Diversity and Independence are applied in the design. The block diagram of the Control system is illustrated in Figure 3.

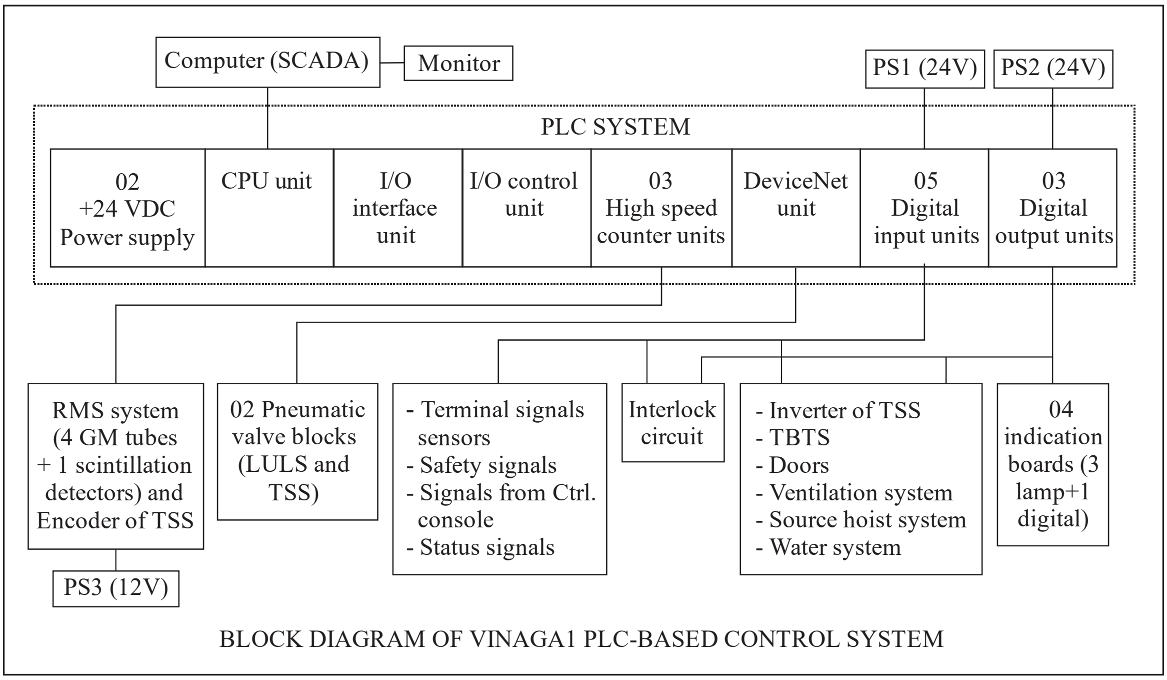

Fig. 3: Block diagram of the control system

The control system has been designed and built on OMRON Industrial PLC system (Programmable Logic Control) and SCADA software (Supervisory Control and Data Acquisition) running on a Personal Computer. The PLC handles 134 digital inputs, 77 digital outputs, 6 high speed counting lines and 3 data transmission lines.

The Interlock circuit composes of 12 safety devices such as Watch-dog, emergency buttons, emergency plugs and safety switches. These devices are serially connected in a line so that the source racks immediately fall down into the storage water pool if this line is broken due to activation of any safety device.

2.2.4. Tote Box Mechanical System and Source hoist system [2], [4], [5]

The Tote Box Mechanical System (TBMS) consists of three subsystems namely Loading-Unloading Subsystem (LULSS), Transport Subsystem (TSS) and Moving Subsystem (MSS). The MSS system, which is located in the irradiation room, contains 52 tote boxes arranged in two levels (Upper level and Lower level) with 4 rows for each level. Therefore, when a tote box comes in, at first it will be moved through 4 rows of the upper level (two rows for each side of the source) and then through 4 rows in the lower level. This sequence allows all boxes in MSS get an equal absorbed dose.

The MSS is made of SUS 304 stainless steel structure. It is built on six beams with the dimensions of 6.0 x 1.20 x 0.4 cm (σ_k = 540 MPa) above the water pool. The bottom and upper rails (3 x 5 x 0.3 cm) are hold on six U-shape stainless steel frames (262 x 250 cm). The dimensions of MSS are 260 cm (W) x 575 cm (L) x 250 cm(H) and the maximum load is 10,400 kg. The subsystem has been certificated by the Quality and Testing Center 3.

The LULSS consists of three sections. In the first section the new tote boxes are automatically pushed to the tote box car. In the second section the tote boxes are semi-automatically pushed to the unloading station. In the third section the tote boxes must be pushed by hand. As the sections are perpendicular to each other so the tote boxes must go through four corners. These corners are made of CT3 steel plates (thickness of 8 mm, σ_k = 345 Mpa) with ball rollers. The dimensions of the LULSS are 352 cm (W) x 528 cm (L) x 285 cm (H).

The TSS is designed to transport new boxes from the LULSS to the MSS through the product maze and to carry irradiated boxes back to the LULSS. The system has the following parts: tote box car, cable winding drum, cable stretching unit, rails, cable turning and guiding pulleys. The rails, which are fixed on the floor, are made of CT3 steel (65 cm in width, 9 cm in height, σ_k = 345 Mpa) and have the length of 20 meters. The going-in and going-out speeds of the car are controlled by PLC and powered by the 3.7 kW VFD device.

A tote box has dimensions of 50 cm (W) x 67 cm (L) x 90 cm (H) and maximum load of 180 kg.

VINAGA1 can be operated in three irradiation modes namely Continuous, Batch and Stationary. The minimum irradiation time for the continuous mode and the batch mode are 1h25’ and 1h15’ respectively. One VINAGA1 irradiator has been installed in Danang irradiation center and its TBMS is illustrated in Figure 4 and its real MSS system picture in the irradiation room is shown in Figure 5.

The source hoist system has the functions to hoist the source racks for irradiation from the storage position in the water pool to the middle height of the Tote box moving subsystem and lower them into the water pool when irradiation stops or any emergency happens. Co-60 sources are kept in three racks with modules. Each rack contains four modules and each module can be loaded with 38 source rods of C-188, RSL2089 or GIK-A6 type. These racks can be independently hoisted upon the requirement of irradiation dose rate. The system consists of a pulley mechanism with 03 pneumatic cylinders, a guiding mechanism for source rack moving and terminal sensors. The positions of source racks at two terminals are monitored by reed relays attached on the cylinders, by mechanical switches and by proximity sensors.

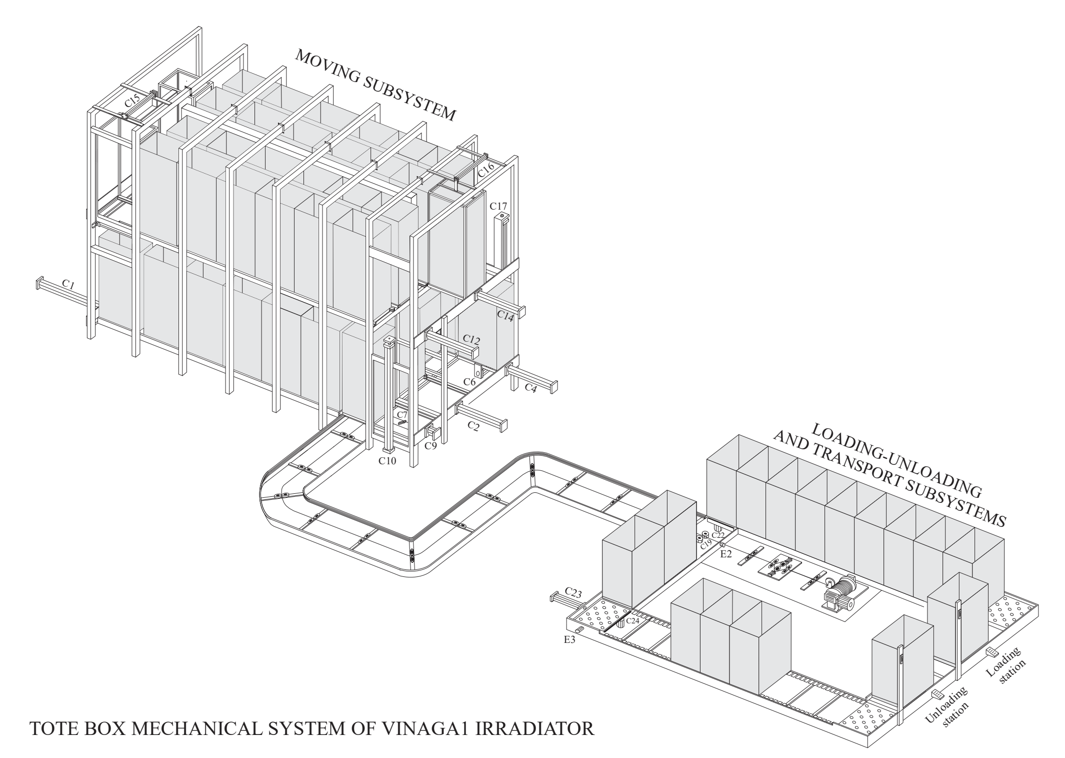

Fig. 4: Principle scheme of the Tote Box Mechanical System

Fig. 5: The moving subsystem of VINAGA1 at the Danang irradiation center

2.2.5. Technological systems [1], [4], [8], [9]

The technological systems of VINAGA1 irradiator are the Radiation Monitoring System (TMS), the Indication System, the Water Treatment-Level-Cooling System (Water system), the Ventilation System (VS) and the Compressed Air System (CAS).

The RMS consists of 5 gamma detectors for control of radiation inside the biological shielding and radioactive contamination in the pool water. The signals of these detectors are connected to the control system. The control system gives out warning signals or stops irradiation if count rate of any detector exceeds the warning or emergency setting levels. In order to enhance the safety feature an independent radiation monitoring unit has been added. This unit is independent of the control system. It gives out signals by lamps “Detector OK”, “Irradiation” and “No irradiation” at the door of the control panel.

The indication system has three lamp indication boards and one digital indication board. The system shows the status of the irradiator such as irradiation, no irradiation, tote box moving, source rack moving by lamps and indicates the number of tote boxes in the irradiation process.

The water system has the function to purify and add water, to control water level and to cool water in the water pool. The signals of conductivity, high level, low level and emergency low level of water are fed to the control system. The control system automatically controls the water supplement when the water level is lower than the set value. The system consists of water pumps, mechanical filters, ion exchange columns, valves, water conductivity meter, water level sensors, rotameters, manometers and gamma monitoring unit. The gamma monitoring unit with a scintillation detector is designed for monitoring the gamma background of water in order to detect any leakage of Co-60 from source rods into the water pool (accident of source capsules). The control system immediately stops irradiation if the count rate of this unit exceeds the set level. The water quality in the water pool is continuously maintained so that its conductivity is always less than 20 μS/cm, total salt concentration less than 20 mg/l and pH in the range of 6 – 8. The maximum treatment flow rate of the system is 1000 l/h.

Table 3: Main specifications of VINAGA1 irradiator

Name	Value
Source rack type/number of rack	Plane, Rectangular/3
Number of module in a rack/ rods in a module	4/38
Source rod type (ϕ11x451 mm)	C188, RSL2089, GIK-A6
Maximum of Co-60 source activity	74PBq (2MCi)
Dose rate at outside the irradiator shielding	$<2\mu$Sv/h
Tote box dimensions	50 (W) x 67 (L) x 90 (H) cm
Maximum processing rate	36 boxes/hour

Density (g/cm^3)	DUR	Efficiency (%)
0.1	1.36	15.3
0.2	1.43	26.4
0.3	1.50	34.4
0.4	1.59	40.4
0.5	1.75	44.9

The ventilation system has the function to exhaust ozone created by air ionization of gamma ray from the irradiation room and discard them through a chimney. The system is designed to ensure ozone concentration in the irradiation room after the irradiation stops for 10 minutes and ozone concentration in the environment outside the irradiation center are lower than the safe level stipulated by Vietnam environmental standards, QCVN 05:2009/BTNMT. The system consists of two fans (one in operation, one in standby) with the flow rate of 3,000 m^3/h. The system can be operated manually or by the control system.

The compressed air system has the function to provide compressed, oil-less and dried air with stable pressure for cylinders used in the Tote box mechanical system and the Source hoist system. The system delivers the compressed air with the pressure in the range of 4.5 ÷ 5.5 atm and with the air supply capacity of more than 150 l/min.

2.3. Discussion

VINAGA1 irradiator has been successfully designed and constructed and met safety requirements for operation and radiation safety. As it is the first irradiator made domestically, VINAGA1 irradiator is applicable and suitable for the sterilization of present healthcare product and food processing demands. However, for the food processing purpose it is better to build an irradiator with product container of larger dimensions. VINAGAMMA is working on new design of an irradiator specially used for food processing purpose.

3. CONCLUSION

VINAGA1 irradiator is the first Co-60 multipurpose and industrial irradiator made in Vietnam. It is a great achievement of VINAGAMMA sustained efforts on the way to handling and localizing the irradiation technology. The irradiator parameters show that it has high quality of technical specifications and competitive price in comparison with other overseas irradiators. As the domestic-made irradiator, VINAGA1 has several advantages over imported irradiators, typically the procurement of spare part, maintenance, repair, renovation and so on.

Two irradiators of VINAGA1 type have been installed in two different irradiation centers in Danang and Dongnai province. The Danang irradiator has been commissioned and put into operation since January 2019. The Dongnai irradiator is in the source procurement phase and hopefully could be put into operation next year.

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