Commissioning Test of the Iradiator Gamma Merah Putih

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Abstract. Initialized with design phase in 2015, BATAN developed a gamma irradiator, namely the Iradiator Gamma Merah Putih (IGMP). Located in Puspiptek Serpong, the IGMP finished its construction in 2017. Commissioning test was performed for assuring that the installation is designed, constructed and installed according to the operational requirements. The commissioning test consists of cold and hot commissioning. Cold commissioning refers to testing the operation of the irradiator without radioactive sources. The test was carried out by doing a checklist on the operating table list. The test showed that in all operations, all irradiator equipment and systems are functioning well as per the requirements. It was then concluded that the irradiation facility was ready to receive radioactive sources. In July 2017, the gamma irradiator was loaded with 301 kCi of Cobalt-60 sources provided in 29 source rods distributed into three racks individually controlled by hoist mechanism. Hot commissioning was carried out by lifting up all radioactive sources, and then radiation exposures were measured. In the preliminary tests, there were some locations at the third floor, where the radiation exposures were too high. It was then be minimized by correcting the roof plugs positions and by adding lead material as additional shielding. Finally, measurements show that all radiation exposures were less than 1 µSv/h and safe for public.

1. Introduction

In 2015, BATAN began to design a panoramic gamma irradiator. In the following year, the programme was continued with its construction in Puspiptek Serpong, which ended in June 2017. The gamma irradiator, then called as Iradiator Gamma Merah Putih (IGMP), was designed up to 2 MCi by using Cobalt-60 as radioactive sources. It was for multi-purpose uses such as for phytosanitary, food preservation, medical device sterilization, and so on.

As Category IV, the irradiator stores its radioactive sources in a water pool with dimension of 3.6x2.8x6.0 m³. The pool is fulfilled with demineralized water both as coolant and as shielding. When the irradiator is operated, the radioactive source is lifted up above the pool. The pool itself is within a bunker in irradiation room as shown in figure 1 [1]. The bunker is confined by concrete with a thickness more than 1.8 m as shielding. A labyrinth provides an access for goods going into the bunker. Another access, strictly controlled, is also provided for maintenance work.

Products to be irradiated are packaged in carton boxes. In the loading-unloading area, the carton boxes are inserted into tote boxes. Tote boxes are shipped one by one into the bunker using a couple of box cars withdrawn by an electric motor through a chain. Enter and exit the bunker pass through a single
goods access. In the irradiation room, tote boxes undergo source pass mechanism, in which the tote boxes move through a trajectory around the radioactive sources.

In the middle 2017 the IGMP is ready to be operated. Cobalt-60 sources with a total activity of about 300 kCi are installed in the irradiator. The experience during its construction processes becomes lesson learns for the future gamma irradiator development. This paper discusses both cold and hot commissioning tests of the IGMP.

2. Theory

2.1. Commissioning test [2]
Commissioning activity should be setting plant and equipment to work. Commissioning should provide evidence and demonstrate that all aspects of the infrastructure operate as planned in both normal and fault conditions to confirm operational resilience. Commissioning is typically broken into two parts usually termed cold and hot commissioning. The cold commissioning usually demonstrates the completeness of the plant and systems. It confirms that all components are installed, connections made and plant labelled. Evidence should be available to show this process has been appropriately undertaken. The hot commissioning refers to a phase when the plant and systems are energised. It is when the actual performance of the individual plant components is demonstrated against their specified performance. This is followed by component integration into systems together with the human response elements. The final combination of the different systems into the overall infrastructure should prove the overall effectiveness of the installation and whether it meets the intent and success criteria described in the operational requirements.

2.2. Controlled and supervised areas
The irradiator shall adopt a Radiation Protection Programme (RPP). Due to potential occupational exposure to radiation, working areas should be considered and classified [3,4]. Two types of area may be defined: controlled areas and supervised areas. Certain and different measures should be adopted in both controlled and supervised areas, such as providing equipment for radiation monitoring and radiation protection.

IAEA states explicitly that for panoramic gamma irradiators (Categories II and IV), the controlled area includes both the radiation room and roof of the radiation room [3]. Meanwhile, BAPETEN considers the controlled area with criterion having a potential radiation exposure exceeding 3/10 of allowable limit for radiation worker [4]. The area is considered as supervised area when its potential radiation exposure is exceeding the allowable limit for individual members of the public, but less than 3/10 of the allowable limit for radiation worker. The allowable limit for radiation worker and for members of
the public are respectively 20.0 and 1.0 mSv/year which are equivalent in average to 10.0 and 0.5 µSv/hour. Thus, the area will be considered as controlled area if its potential radiation exposure is more than 3.0 µSv/hour and it will be considered as supervised area if its potential radiation exposure is more than 0.5 µSv/hour but less than 3.0 µSv/hour.

3. Method
The irradiator is developed step by step as follows: design, construction, and commissioning test. Commissioning test is to assure that the installation including building, mechanical system, process and other system is designed, constructed and installed according to the operational requirements. So, before discussing the commissioning test itself, this paper will discuss first the design the IGMP.

The commissioning test consists of 2 steps: cold and hot. Cold commissioning refers to testing the operation of the irradiator without radioactive sources. Testing is done by doing a checklist on the operating table list. Observations are made directly in the field by observing the phenomena that arise during testing. Testing is stated as acceptable if the results of observations show performance in accordance with the requirements. Hot commissioning test is done after the radioactive sources is installed. Tests similar to cold commissioning were also carried out. In addition, in hot commissioning, measurement of radioactive exposure is also carried out using calibrated surveymeters and the results are compared with the requirements that must be obtained.

4. Results And Discussion

4.1. Design of the IGMP

4.1.1. Radiation shielding
The Hungarian design as reference plant states that the dose rate permitted on the outer surface is maximum 2 µSv/h [5]. Meanwhile, the allowable limit of radiation exposure for public area in Indonesia is 0.5 µSv/h. Due to difference point of view, pool water and wall concrete as radiation protection shielding are evaluated.

The Irradiator Gamma Merah Putih is designed up to 2 MCi using Cobalt-60 as radioactive sources. As required by national regulation, calculation or simulation shall show that, as shielding, pool water and wall concrete as radiation protection shielding are evaluated. Analysis was performed using MCNP software [6]. The configuration of building concrete (i.e. form and dimension) refers to the reference plant. A total activity 3 MCi of Cobalt-60 is modelled. Radiation exposures at many locations outer the wall are evaluated. Its maximum radiation was 0.485 µSv/hour in the front of goods maze door. It was then confirmed that all areas close to the wall has radiation exposure not more than the limit value, i.e. 0.5 µSv/hour as public area. This means that all areas outside bunker are safe for public.

When the irradiator is not operated, the sources must be stored at the bottom of the water pool. As shielding, the pool water was analyzed using MCNP software [7]. The pool dimension is 3.6x2.8 m2 in width and 6.0 m in depth. The pool was modeled in layers as function of depth. The sources with total activity of 3 MCi are configured. From the MCNP results and combined with extrapolating method, it was found that at a water depth of -163 cm from the pool surface, the irradiation rate is near zero, or radiation exposure is not detected. It is much lower than the allowable limit of 10 µSv/h as controlled area. This means that the area above the pool is very safe.

4.1.2. Mechanical design
The main mechanical parts related to irradiation process are the source rack hoist mechanism and the source pass mechanism as part of the product transport system [8]. The source rack hoist mechanism serves to up-and-down the position of the radioactive sources. The product transport system plays a role in the irradiation process by bringing the target product closer and away from radioactive sources. The Cobalt-60 sources are in cylinder rod with diameter of about 11 mm and length of 451 mm. 41 source (or dummy) rods are placed in a source module. Four modules are placed on a source rack with
2x2 configuration. Three racks (R1, R2 and R3) are available. Each source rack is equipped with a hoist mechanism driven by pneumatic cylinder. The irradiator provides three independent source rack hoists which means each rack can independently be moved upward (see figure 2). There are then many combinations of lifting source racks.

![Figure 2. Source rack configuration](image)

In operation mode, the source racks are lifted up. The product within tote boxes is transported into the bunker. Tote boxes will be brought close and away from radioactive sources by undergoing a process called source pass mechanism (see figure 3).

![Figure 3. Source pass mechanism](image)

Once entering the bunker, a tote box goes into the irradiation mechanism at the lower story (position 1), but is directly dropped to right side and sent to the top story using a lift (+) so it moves to position 2. At the top story, the tote box undergoes a path starting from lane 1, to lanes 2, 3 and 4. Then the tote box goes down to the lower story with another lift (-) and then runs through lane 4, moves to lanes 3, 2 and 1. In position 72, the tote box is ready to shift to position 1 and removed from the bunker after finishing irradiation process. All tote box movements are provided by pneumatic systems. The source pass mechanism has a purpose in order that all products in the tote box get a uniform irradiation absorbed dose. There are 84 tote box positions inside the bunker, but only 72 positions are irradiated positions. The rests are transit or temporary positions. Thus once irradiation process, the bunker can contain as many as 72 tote boxes. In each irradiation position, the movement of the tote box can be stopped for time delay. A cycle is a process in which all 72 tote boxes move from one irradiation position to the next irradiation position. The minimum time is needed to complete a cycle. It is mechanical characteristic. It determines the minimum absorbed dose received by product within tote box.

4.1.3. Safety system
The safety system implements the safety philosophy recommended by IAEA: defence in depth, redundancy, diversity and independence [9]. The defence in depth has 3 levels: the first level is preventing deviation from normal operation; the second level is detecting and responding to deviations from normal operating conditions; and the third level is mitigating the consequences of a failure or an accident.
One example of implementation of the defence in depth is concerning source racks. At first level, the source racks are constructed in such a way that the sealed sources are firmly fixed within them. The sources cannot be dislodged from them. Source hoisting units are operated from outside the radiation shielding. Different types of deviation can occur originating from various phenomena. At second level defence, the principles of redundancy, diversity and independence are implemented: sensors are used to detect the position of source racks in the bottom of pool or in the irradiation position, times to moving up or lowering source racks are limited, and radiation monitoring detectors are also available. In the case of source racks stuck and their own weight can not lower the racks by gravitation, at the third level of defence, pushing bars are available to push down the source racks manually through the provided ceiling holes. Detectors or sensors, buttons, and other safety functions are located in different rooms or areas: bunker, above ceiling, hall, control room, etc. All safety items must be connected to control room where the PLC module is located. The irradiation facility can be operated only if all levels of defence are in place and functioning.

4.1.4. Control system
All operational information are processed by PLC module. Interaction between operator and PLC is provided via touchscreen monitor. All commands are given by this screen. Various menus are provided [10]. Figure 4 shows an example display for operating the irradiator. Some parameters should be input or choosen: total irradiation time, operating mode, rack option, etc.

The source hoist mechanism is controlled by PLC programme. There are many combinations of lifting source racks, but only 4 options are are provided by the control system:
- Option 1: R1 (only Rack 1 is lifted)
- Option 2: R1-R3 (Rack 1 and Rack 3 are lifted)
- Option 3: R2 (only Rack 2 is lifted)
- Option 4: R1 R2 R3 (all racks are lifted)
A menu for safety system is also available. When safety functions are in normal condition, the green lamp will be on. But if an abnormal conditions is detected, the appropriate lamp is in grey. Under this condition, the irradiator can not be operated until the abnormal condition is repaired and reset. In every case, the control system informs the operator about the failure on the screen and prints this message in a log file.

4.2. Commissioning of Irradiator
During about 18 months, the Irradiator Gamma Merah Putih was constructed referring to the design described above. As governmental building, the construction phase involved supervising consultant,
design consultant, construction contractor and other private companies. After completing the construction, the following phase is commissioning. Commissioning process is to assure that the installation including building, mechanical system, process and other system is designed, constructed and installed according to the operational requirements. Cold and hot commissioning refers to test respectively without and with radioactive sources.

4.2.1. Cold commissioning
After all items (components, equipments, modules, subsystems and systems) are well tested independently, the installation with fully integrated systems is operated. Cold commissioning testing is done by operating the irradiator via control console. All systems including water treatment plant, blower system, utilities systems, etc are tested, but, only normal and abnormal operations related to irradiation process are discussed. Normal operations show the irradiation process as it should be. Abnormal operations indicate the function of safety system. The irradiator is operated in batch mode. In preliminary step, all tote boxes are loaded with sand (60 kg for each tote box) as dummy product and then are fed into the bunker. The source racks are then lifted and the tote boxes undergo the source pass mechanism. After pseudo-irradiation is completed, the source racks are moved down. The tote boxes are removed from the bunker and the dummy products are unloaded.

In continuous mode, operator must load and unload dummy products into the tote boxes continuously. A pre-irradiated tote box enters to the irradiation room one by one, and at the same time, a post-irradiated tote box is removed from the bunker. Inside the bunker, tote boxes undergo the source pass mechanism like in batch mode. After irradiation is completed, the radioactive source racks are moved down.

In both batch and continues modes, the test showed that both of the source rack hoist mechanism and the source pass mechanism function well as operational requirements.

To test the safety system, the irradiator is operated in continuous mode. After then, all safety items (emergency buttons, roof plug, motion detectors, etc) are activated one by one as if there were an incident of abnormal conditions. The incident is carried out by manual intervention. In general, safety items are divided into two groups: Case 1 and Case 2. In Case 1, the source racks are automatically moved down just after the system recognizes abnormal condition (emergency button, roof plug, personal door, emergency rope, etc). In Case 2, the system still continues the irradiation after recognizing abnormal condition (stop buttons, anomalies in loading-unloading area, with the absence of pressure, absence of electricity, etc.), but, the source racks are automatically moved down, just after completing one cycle of the source pass mechanism.

The tests show that in all operations, all irradiator equipments and systems are functioning well as per the requirements. It is then concluded that the irradiation facility is ready to receive radioactive sources.

As part of cold commissioning, background radiations are measured before the arrival of the Cobalt-60 sources. Surveymeters Miniray and Inspector are used. Four areas are examined:
- Irradiator Building (including hall and bunker): more than 50 location points are measured with the maximum of 0.156 µSv/hour,
- Utility Building: 14 location points with the maximum of 0.135 µSv/hour,
- Marketing Office Building: 4 location points with the maximum of 0.146 µSv/hour,
- outside Irradiator Building: 28 location points with the maximum of 0.184 µSv/hour.

The above values will be useful as a reference to be compared with future measurements after the installation of Cobalt-60 sources.

4.2.2. Installation of Cobalt-60 sources
Cobalt-60 sources are imported from Russia and transported using two containers in lead material. The containers are loaded into bunker through ceiling holes. The hole plugs are lifted by using crane. One container is moved down until the bottom of the pool. Cobalt-60 sources are then loaded to temporary source basket. The first container is lifted out and changed with the second container. With the same
procedure, the second temporary source basket is used. All cobalt-60 sources are then loaded into source racks and ready to be used. In total, the IGMP is loaded with 301 kCi of Cobalt-60 sources [10]. This activity is provided by 29 rods, each of which contains 10 to 11 kCi. The list of the Cobalt-60 rods is shown in Table 1.

| No | Serial number | Activities (kCi) | No | Serial number | Activities (kCi) |
|----|---------------|-----------------|----|---------------|-----------------|
| 1  | 73H           | 10,627          | 16 | 97H           | 10,547          |
| 2  | 81H           | 10,334          | 17 | 38H           | 10,437          |
| 3  | 03P           | 9,913           | 18 | 85K           | 10,629          |
| 4  | 06P           | 10,928          | 19 | 60H           | 10,501          |
| 5  | 15P           | 10,590          | 20 | 53H           | 10,254          |
| 6  | 91K           | 10,508          | 21 | 67H           | 10,437          |
| 7  | 23H           | 10,718          | 22 | 27H           | 10,327          |
| 8  | 57P           | 9,872           | 23 | 20H           | 10,583          |
| 9  | 40H           | 10,544          | 24 | 34H           | 10,281          |
| 10 | 84H           | 10,133          | 25 | 13P           | 10,180          |
| 11 | 96H           | 10,206          | 26 | 75H           | 10,354          |
| 12 | 88K           | 10,206          | 27 | 52H           | 10,711          |
| 13 | 89K           | 10,590          | 28 | 18H           | 10,400          |
| 14 | 69H           | 9,987           | 29 | 08H           | 10,382          |
| 15 | 25H           | 10,334          | Total | 301,513 | Total |

With respect to both dose uniformity and efficiency, all radioactive sources are ideally placed on the middle rack. However, since the irradiator is designed to be multi-purpose, it should allow the use of low to high irradiation doses. For this reason, the source rods are distributed on all three racks. If possible, the source rods are placed symmetrically at the center. Based on various combinations of placement of the source rods on the racks, it is finally decided to use the 4-21-4 configuration, which is 4 rods placed on the left rack (R3) with total capacity of 41.25 kCi, and 4 rods placed on the right rack (R1) with total capacity of 41.22 kCi. The other 21 Cobalt-60 sources are placed on the middle rack (R2) with a total activity of 219.04 kCi. Figure 5 shows the sources configuration in the source racks.

Figure 5. Source racks at the bottom of the pool

Since there are 4 operational options, the activity of each option is as follows:
- Option 1: 41.25 kCi (only Rack 1 is lifted)
- Option 2: 82.48 kCi (Rack 1 and 3 are lifted)
- Option 3: 219.04 kCi (only Rack 2 is lifted)
- Option 4: 301.51 kCi (all racks are lifted)

The first and second options are intended for low irradiation doses, while options 3 and 4 are used for high irradiation doses.

4.2.3. Hot commissioning

The irradiator is operated by lifting all source racks, i.e. the total activity is 301 kCi. Radiation exposures around the irradiator are measured, as shown in Table 2. Measurements used Miniray 2000 surveymeter.
At the first floor, all measurements give values not more than 0.27 µSv/h such as in water treatment room, in goods maze door, and in personal entrance door. At the outside building, the maximum radiation is 0.5 µSv/h. At the third floor, the dose measurements give not more than 0.37 µSv/h such as on the surface of ceiling, compression room, and in the lift moving cylinder area, but for certain location points, the radiation exposures are high: above source racks (maximum: 2000 µSv/h), around gap between ceiling plugs (32.2 µSv/h), and above ducting hole (53.9 µSv/h).

Table 2. Preliminary radiation exposures measurements

| No | Locations                          | Max. dose rate (µSv/h) | No | Locations                          | Max. dose rate (µSv/h) |
|----|-----------------------------------|------------------------|----|-----------------------------------|------------------------|
| 1  | Outside building                  | 0.5                    | 9  | Outside building wall             | 0.5                    |
| 2  | Holes related to Rack R1          | 320                    | 10 | Lift cylinder 1                   | 0.17                   |
| 3  | Holes related to Rack R2          | 1700                   | 11 | Lift cylinder 2                   | 0.18                   |
| 4  | Holes related to Rack R3          | 2000                   | 12 | Personal entrance door            | 0.07                   |
| 5  | Surface of ceiling                | 0.37                   | 13 | Ventilation ducting               | 53.9                   |
| 6  | Roof plug (left side)             | 0.33                   | 14 | Hole of Goods maze door           | 0.06                   |
| 7  | Roof plug (right side)            | 0.22                   | 15 | Water treatment room              | 0.26                   |
| 8  | Compressor room                   | 0.13                   | 16 | Wall of source sym                | 0.25                   |

The preliminary commissioning shows that all shieldings work apparently well. Some radiation exposures are high just in three areas: around roof plugs area, above ducting hole and above source rack. It is decided to minimize radiation exposure using lead material in order that its values are in the range of supervised area.

Around roof plugs, the detailed analysis showed that the high exposures are due to lowest gap between ceiling hole and its first plug. HVL of lead needs more than 48 mm of thickness. Alternative solution is considered. The plugs are moved to the right side so that the gap is moved from right side to the left side. By this solution, the gap is no longer directly in line to the sources. The dose measurements give good values less than 1 µSv/h at the right side of the roof plugs and about 3 µSv/h at the left side of the roof plugs due to scattered phenomenon. By adding 2 mm of lead sheet at the left side, the radiation doses dropped significantly, under 1 µSv/h.

Above ducting hole, the high exposure radiation is well known due to the scattering phenomena. Adding 2 mm of lead sheet reduces radiation leak significantly under 1 µSv/h. For the above source rack, the problem is more difficult. The radiation leak is too high. It is calculated that the lead thickness should be around 7 cm. Lead in bricks are used as shown in figure 6. After measurement, it is found that all radiation exposures are less than 1 µSv/h.

![Figure 6. Additional lead in bricks as shielding](image)

The test like in cold commissioning is also performed. The result leads to conclude that the installation including building, mechanical system, process and other system was designed, constructed and installed in accordance with the operational requirements.

5. Conclusion

Commissioning phase is performed for assuring that the irradiator is designed, constructed and installed according to the operational requirements. The irradiator is loaded with a total of 301 kCi of Cobalt-60 sources provided by 29 source rods. These rods are distributed to three source racks in such that the control system provides 4 combinations of sources activity: 41.25, 82.48, 219.04, and 301.51 kCi. Both low and high irradiation dose rates are then disponible. Commissioning tests show that all equipment and systems run well. By operating all radioactive sources with the activity of 301 kCi, measurements show that outside bunker all radiation exposures are less than 1 µSv/h.
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