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Dose profile modeling of the Gamma Irradiation Facility at Biotechnology and Nuclear Agriculture Research Institute of Ghana using MCNP5

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ABSTRACT

Dose rates distribution through the ^{60}Co Gamma Irradiation Facility (GIF) at the Biotechnology and Nuclear Agriculture Research Institute (BNARI) was studied using the Monte Carlo code MCNP5. The MCNP5 code was used to model the GIF structure. The dose rates for selected dwell positions throughout the facility was calculated and analyzed. The absorbed dose rate distribution calculated ranged from as high as 1.82E05 mGy/s to as low as 4.14E-06 mGy/s. These simulated dose rates is essential to the irradiator operators in scheduling products and time needed for irradiations.

Keywords: *Monte Carlo simulation, MCNP5, Dose rates, Dose Profile, Air kerma rate.*

1. INTRODUCTION

The dose rates distribution inside a ^{60}Co Gamma Irradiation Facility is important for a lot of reasons and subsequent applications. It helps in designing the irradiator source rack configuration and loading system. It also assists the operators of the facility with planning and scheduling products of different densities for irradiations with the requisite doses. The facility operators are also able to calculate the time required for each irradiation positions within the irradiator.

Monte Carlo modeling is, in principle, the most detailed modeling method for particles transport analysis [1] and involves tracking simulated particles through a geometrical model of the physical system, taking account of scattering and energy absorption. A large number of histories are simulated to estimate outcomes of interactions based on probability distributions [2]. The use of mathematical modeling has begun to establish itself as a useful and cost-effective tool for process design, validation, and quality control. The technology extends itself across various professions and disciplines within the industrial irradiation processing community [3].

The ^{60}Co Gamma Irradiation Facility (GIF) at the Biotechnology and Nuclear Agriculture Research Institute (BNARI) which was commissioned in March 1995 was designed with a maximum loading capacity of 18.5 GBq of Cobalt-60 for the irradiation facility [4]. The radiation source was supplied by the Institute of Izotope of the Hungarian Academy of Sciences (INISO) Budapest, Hungary. The primary purpose of the GIF in Ghana is the sterilization of products and medical devices and research applications

The purpose of this work is to model the GIF with the Monte Carlo code MCNP5 and simulate the particles transport throughout the irradiator during an irradiation process. The absorbed dose rates in Milligray/seconds (mGy/s) at selected positions with the facility was calculated and analysed.

2. MATERIALS AND METHODS

2.1 Description of the Facility

Figure 1 and 2 is the plan and cross-section view of the multipurpose Gamma Irradiation Facility (GIF) at the Biotechnology and Nuclear Agriculture Research Institute (BNARI). The facility is a Cobalt-60 source with an initial activity of 18.5 GBq installed in March 1994[4]. The water pool shields the personnel in the irradiation chamber when the source is at rest or storage position. The shielding design is made of 1.7m thickness of re-enforced concrete. The goods and personnel doors are lead lined (9mm Pb) and encased within iron frame and opens into a maze. The size of the irradiation chamber is approximately 5m long by 4m wide and 4m high. In the floor of the irradiation chamber is a de-ionized water pool measuring 3m long by 2m wide by 5.7m deep which is covered with re-enforced stainless steel plates. The pool serves as a biological shield for the source when the source is at its rest position. The 18.5 GBq of the cobalt-60 source is distributed equally among a rectangular plaque of dimension 1 m x 1 m. The rectangular plaque is divided into four module with seventeen (17) active or dummy sources arranged in each module. Each source pencil is 0.065m diameter by 0.451m in length. A hoist motor system located on the roof of the irradiation chamber made of 1.6m concrete with two steel rods brings the source rack from the de-ionized water pool to the irradiation position. Two ventilation units located on the roof of the irradiation chamber have nozzle within by which noxious gases produced by interaction of radiation with air are drawn through filters out of the chamber. The irradiator has a mechanized conveyor tote box system for movement of goods into and out of the chamber during irradiation processes.

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THE MULTIPURPOSE GAMMA IRRADIATION FACILITY AT THE BIOTECHNOLOGY AND NUCLEAR AGRICULTURE RESEARCH INSTTUTE (BNARI)

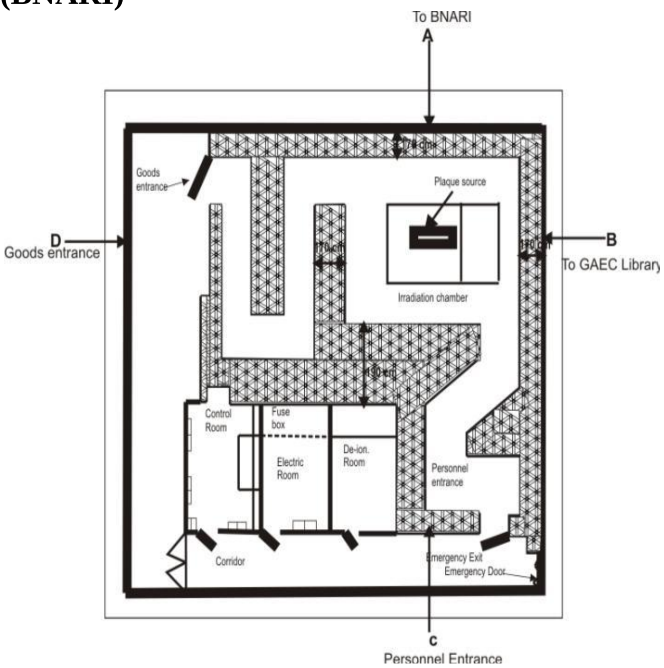

Figure 1: Plan view of the Gamma Irradiation Facility at BNARI

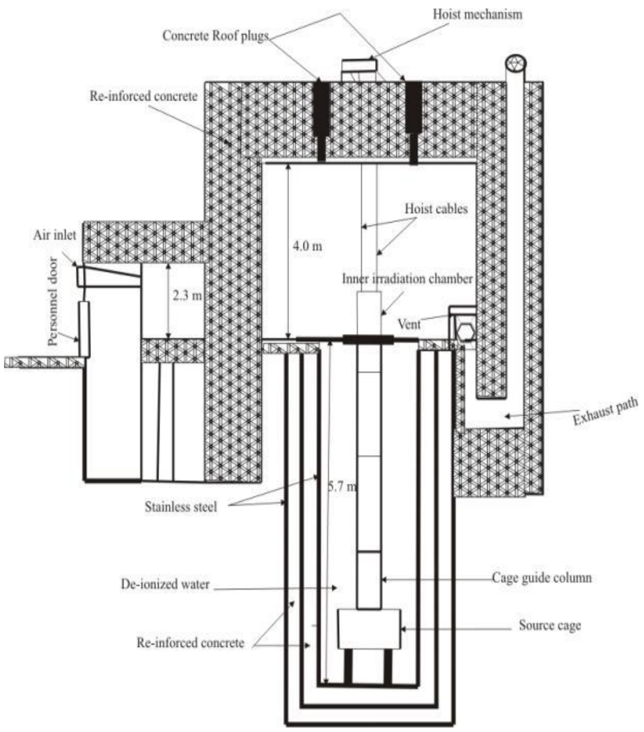

Figure 2: Vertical cross section through part of the facility showing the irradiation chamber, water pool, hoist motor system and roof Plugs

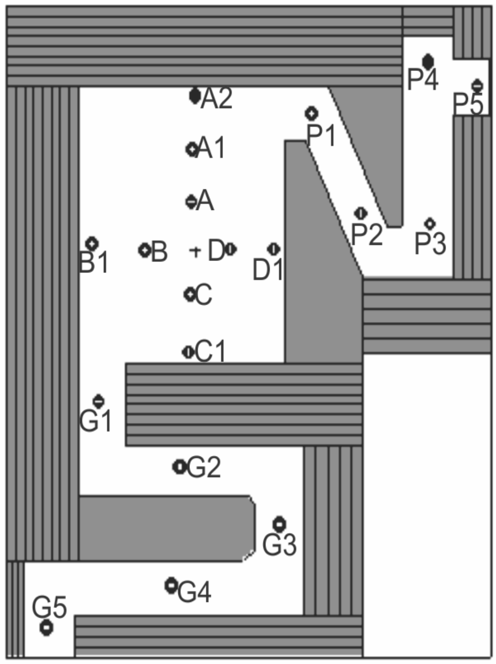

Figure 3: Layout of Mcnp5 Modeled GIF facility showing detectors locations around the $^{co}60$ source.

MCNP5 MODELING

The plaque ^{60}Co source of rectangular array of 1 m x1 m was module into a rectangular rack with the assumption of a negligible source attenuation and attenuation by the metallic steel rack. The first two top modules joind to the bottom two source modules, creating a single rectangular module with the top joined to the bottom. Each source pencil now becomes 0.065 m in diameter and 0.902 m in length. The total active source pencil in the plaque was 34. Each pencil was made up of an average energy of 1.25MeV. The source was located 0.5 m above the ground during irradiation. A physics card was deployed to eliminate bremsstrunlung radiations. The photon interactions considered were; photoelectric, Compton scattering and pair annihilation. The variance reduction technique used was cell splitting and importance which increases particle interactions toward regions of importance. The irradiation room was also modeled with the help of the visual editor within the code according to the design specification of the room. The material used was an ordinary concrete of density 2.3 g/cm^3 was obtained from "Compendium of Material Composition Data for Radiation Transport Modeling" [5].

The maze walls are typically sufficiently thick to eliminate transmission as a concern, leaving scattered radiation streaming through the maze opening as the primary exposure pathway [6]. Small spherical surfaces flux detectors were modeled with sensitive areas of 1.8 cm each and were placed at the various dose locations of A,

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B, C, D, A1, B1, C1, D1, A3, G1 ,G2, G3, G4, G5,P1, P2, P3, P5 and P4 respectively as shown in figure 3. The activity of the source was normalized to source per starting particle. Enough particles were run. The resulting flux was then modified by an ambient dose equivalent response function obtained from the compilation of the International Commission on Radiological Protection (ICRP) Publication 74[7] which was converted to absorbed dose in mGy/s for the purpose dose profiling throughout the facility.

3. RESULTS AND DISCUSSIONS

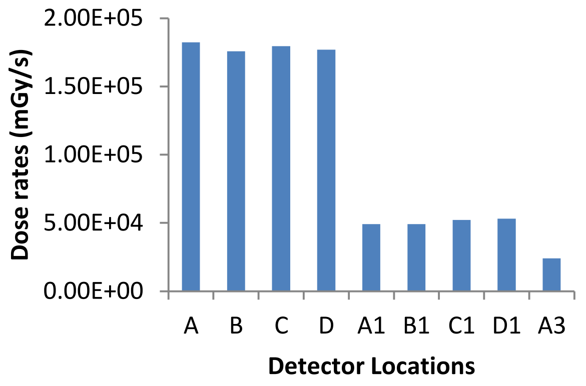

Figure 4: Dose distribution within Main Room

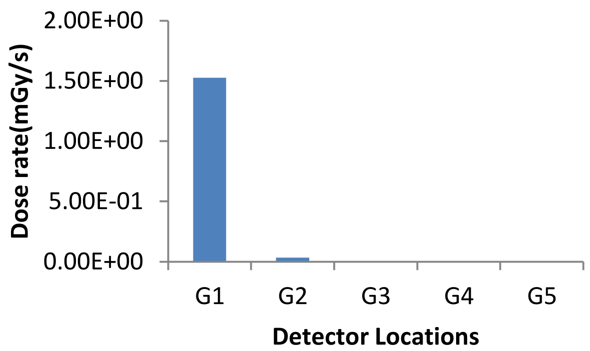

Figure 5: Dose distribution within Goods Maze

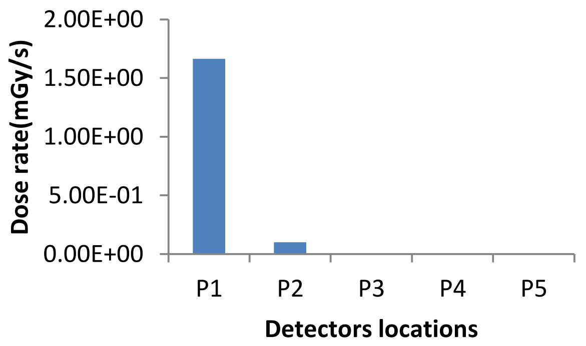

Figure 6: Dose rates distribution within Personnel Maze

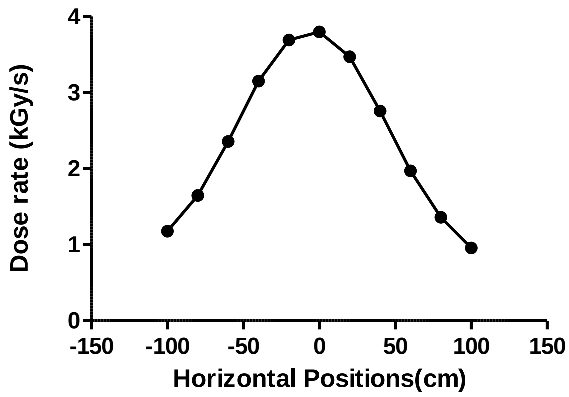

Figure 7: Air Kerma rate profile at source location as a function of height above the floor level

For normal or routine operation of the irradiator, the average dose rates distribution varies linearly with the source activity. For figure 4 the detectors locations as shown from figure 3 are located very near the source. The absorbed dose rates calculated at points A, B, C and D were highest (1.82E05 - 1.77E05) mGy/s. These dose rates significantly drop from A1 to A2 (4.92E04 - 2.42E+04) mGy/s from the source as distances increased.

Figure 5 shows the dose distribution (1.53-4.14E-06) mGy/s at locations from G1 to G5 within the Goods Maze. The design of the maze here significantly attenuates the dose rates obtained here. Also as in the case of Goods Maze, the Personnel Maze dose rate calculated (1.66E3-59E-04) mGy/s from locations P1 to P5 as displayed in figure 6 were attenuated by the Maze structure thereby giving very low doses which is good for achieving ALARA doses for the personnel at the facility.

The air kerma rate profile at horizontal positions simulated at the source location was also calculated as seen in figure 7. The maximum location value is calculated at a height almost at the midpoint of the source. The air kerma rate as a function of the distance from the source, showing gradient of the order of 1 mGy s^{-1} cm^{-1}[8] from figure 7.

4. CONCLUSION

The Mcnp5 Monte Carlo was successfully used to model the GIF at BNARI. Absorbed dose rates distribution in Milligray per seconds (mGy/s) from specified locations within the facility was calculated. The air kerma rates at horizontal points at the source location were also calculated with the maximum value attained at the midpoint of the source location. The dose rates obtained will assist the operators with planning and scheduling goods for irradiations. Further work on dose rates determination by experimental procedure must be done to compare the simulated results with the experimental results.

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