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Comparative Analysis of Radiation Dose Rate on Brachytherapy Commissioning Data and Radiation Safety Evaluation at R.T Notopuro Sidoarjo Hospital

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ABSTRACT

Brachytherapy is a modality of internal radiotherapy that utilizes radioactive sources placed close to the target to increase treatment effectiveness. Before clinical operation, the brachytherapy unit must undergo commissioning to ensure that the system meets manufacturer specifications and radiation safety requirements. This study aims to analyze the differences in radiation dose rate between the commissioning data obtained in 2022 and radiation exposure measurements conducted in 2026 on the SagiNova brachytherapy system using a Cobalt-60 radioactive source at the Integrated Cancer Service Installation of R.T Notopuro Sidoarjo Hospital. The measurement was performed using a Gamma RadEye G20-10 surveymeter at several points around the Transfer Device Unit (TDU) with distances of 5 cm and 1 m. The results showed that radiation dose rates in 2026 were lower than the commissioning values due to the decrease in Cobalt-60 source activity caused by radioactive decay. The measured dose rates remained within applicable radiation protection criteria for radiation workers.

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1. INTRODUCTION

Brachytherapy is a type of internal radiotherapy treatment, where there is a radioactive source fired close to the target to kill tumor cells (Juari et al., 2023). Radiotherapy is one of the effective and efficient treatments compared to surgery followed by chemotherapy. However, there are still not many hospitals in Indonesia that implement treatment using the Brachytherapy modality. This is because there are constraints on the cost of Brachytherapy equipment. Brachytherapy equipment that will be used for clinical services must undergo a commissioning process to verify that the system operates properly and complies with manufacturer specifications and radiation safety requirements. Commissioning is a series of tests carried out to ensure that the tool functions properly and appropriately with the manufacturer's specifications. In this commissioning test, the activity is in the form of collecting all radiation file data and output files needed in clinical services. The data that has been obtained will then be documented in a book so that it can be easier to use as reference material (Podgorsak, Ervin, 2005).

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After commissioning, periodic radiation exposure measurements are also needed to maintain radiation safety. This measurement is one part of Quality Assurance (QA) and radiation protection. This measurement is carried out to ensure that the level of radiation exposure around the brachytherapy machine is still within safe limits in accordance with applicable radiation safety regulations. Based on the regulation of the Nuclear Energy Supervisory Agency (BAPETEN) Number 4 of 2013 concerning radiation protection and safety, it is stated that the average dose limit value (NBD) for radiation workers is 20 mSv/year for 5 consecutive years, so that the cumulative dose for 5 years does not exceed 100 mSv, provided that the effective dose does not exceed 50 mSv in a given year. Meanwhile, the dose limit value (NBD) for the community is set not to exceed 1 mSv/year (BAPETEN, 2015)

Although commissioning tests are performed before clinical implementation, periodic evaluation of radiation dose rate after several years of operation remains necessary because radioactive source activity changes over time. Therefore, comparing initial commissioning data with recent radiation exposure measurements provides important information regarding the performance consistency and radiation safety condition of HDR brachytherapy systems. Therefore, it is necessary to analyze the dose rate value between the commissioning data and the results of radiation exposure measurements in 2026 in order to find out the factors that affect the difference in the dose rate value that has been obtained, as well as to find out whether the results obtained are still within safe limits. This analysis is expected to be used as an evaluation of the radiation protection system from the information that has been obtained from this measurement and can improve the quality of safety supervision in the use of brachytherapy at the Integrated Cancer Service Installation of R.T Notopuro Sidoarjo Hospital. In addition, this study also aims to prove the suitability of measurement results with the theory of inverse square law (Inverse Square Law) through theoretical analysis and mathematical calculation approaches.

2. METHOD

The method used in this study is direct measurement with an observational approach to evaluate the radiation dose rate around the SagiNova brachytherapy device with the radioactive source Cobalt-60. The measurement will be carried out in 2026 at the Integrated Cancer Service Installation of R.T Notopuro Sidoarjo Hospital as part of radiation exposure tests to ensure the level of radiation safety in the work environment. Radiation dose rate measurement was carried out using the Gamma Rad Eye G20-10 Surveymeter with a calibration factor of 1.00 and when commissioning using a surveymeter with a calibration factor of 0.95. The measurement point is determined on several sides of the brachytherapy device around the Transfer Device Unit (TDU). Measurements are made at two different distances from the TDU surface, namely 5 cm and 1 meter, according to the test standards set by the manufacturer. The measured radiation dose rate value is recorded in μSv/h at each measurement point.

Before the measurement is taken, the background radiation value is measured to ensure that the measurement results obtained come from the radiation source of the brachytherapy device. The measured background value is 0.1 μSv/h. The measurement data is then compared with the device commissioning data that has been carried out previously. Data analysis was carried out in a comparative descriptive manner, namely by comparing the radiation dose rate value of the 2026 exposure test results with commissioning data to identify differences in measurement values and evaluate the suitability of measurement results with applicable radiation safety standards.

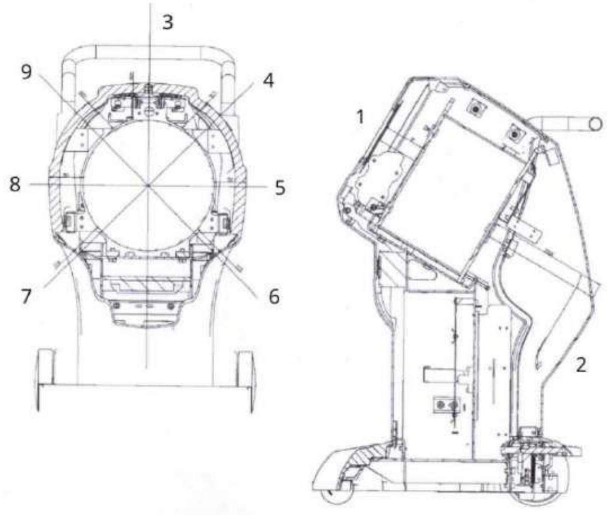

Figure 1. Measurement Point in the Area of the SagiNova Brachytherapy Machine

In addition to the comparative analysis of the measurement data, this study can also be complemented by theoretical analysis using the inverse square law. This calculation is performed to predict the value of the radiation dose rate at a certain distance based on the measurement results at the initial distance. Mathematically, the law of inverse squares can be written with the following equation:

$$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2} \tag{1}$$

In this equation, I_1 represents the radiation dose rate at the initial distance from the radiation source, expressed in $\mu Sv/h$, while I_2 represents the radiation dose rate measured at the second distance, also expressed in $\mu Sv/h$. The variables r_1 and r_2 denote the initial and second distances from the radiation source, respectively, expressed in centimeters (cm) (Podgorsak, 2005).

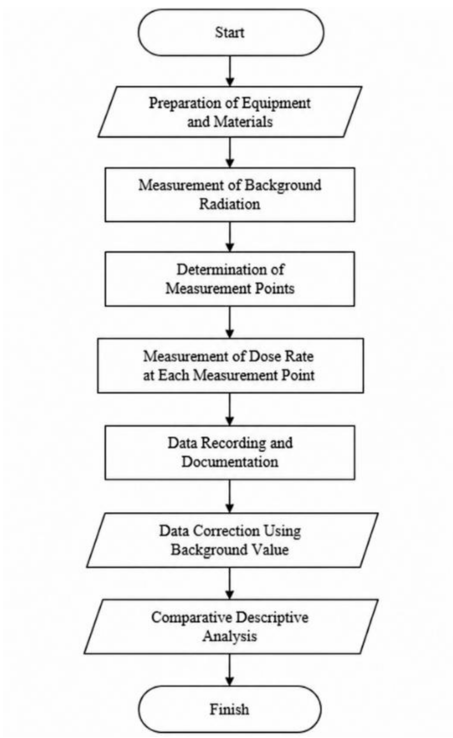

Figure 2. Research Flow Diagram

3. RESULTS AND DISCUSSION

The results of radiation exposure measurements were then compared with the equipment commissioning data carried out during the initial installation of the brachytherapy machine. Data commissioning is a reference data used to ensure that radiotherapy devices meet safety standards before being used in clinical services.

Table 1. Results of Radiation Exposure Measurement Around Brachytherapy Machine at a Distance of 5 cm

Side	Commissioning Data in 2022 (µSv/h)	Exposure Test in 2026 (µSv/h)	Difference (µSv/h)
1	10,1	6,76	3,34
2	8,56	3,46	5,1
3	8,05	3,23	4,82
4	16,79	2,49	14,3
5	13,98	2,45	11,53
6	15,01	1,12	13,89
7	20,41	1,07	19,34
8	14,21	2,59	11,62
9	13,6	2,19	11,41

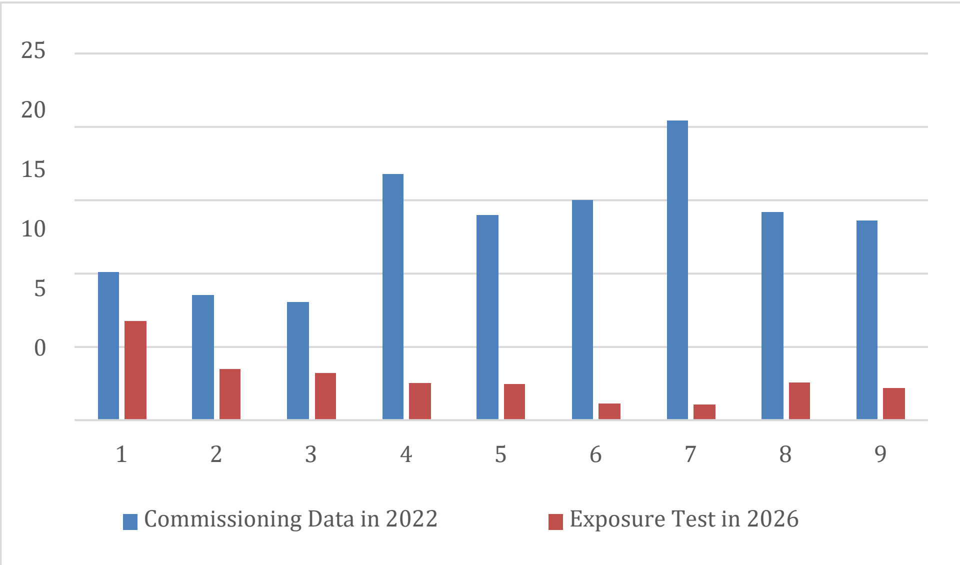

Figure 3. Results of Radiation Exposure Measurement in Brachytherapy Machine at a Distance of 5 cm.

Table 2. Results of Radiation Exposure Measurement Around Brachytherapy Machine at a Distance of 1 meter

Side	Commissioning Data in 2022 (µSv/h)	Exposure Test in 2026 (µSv/h)	Difference (µSv/h)
1	0,49	0,45	0,04
2	1,37	0,62	0,75
3	0,67	0,3	0,37
4	1,01	0,35	0,66
5	0,71	0,59	0,12
6	0,67	0,4	0,27
7	0,67	0,22	0,45
8	1,2	0,58	0,62
9	0,57	0,54	0,03

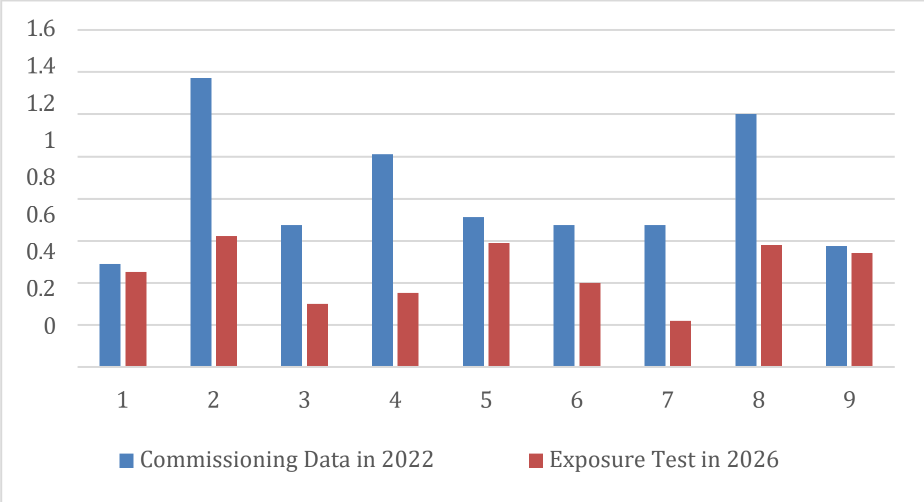

Figure 4. Results of Radiation Exposure Measurement in Brachytherapy Machine at a Distance of 1 meter.

Based on the above research data, in the commissioning data with a distance measurement of 5 cm, the difference value ranged from 3.34 μSv/hour to 19.34 μSv/hour. The biggest difference is found at point 7 where the dose rate is valued at 20.41 μSv/hour, while the measurement results in 2026 are 1.07 μSv/hour, so a difference of 19.34 is obtained μSv/hour. This shows that the measured radiation exposure value in 2026 is likely to be lower than the commissioning data. Meanwhile, in the measurement of a distance of 1 meter, the value of the difference obtained is relatively smaller, ranging from 0.03 μSv/hour to 0.75 μSv/hour. This is in accordance with the principle of reducing radiation intensity to distance, where the radiation dose rate will decrease significantly as the distance from the radiation source increases (Mahanani et al., 2024).

Table 3. Measurement Calculation Results for 2026 at a Distance of 1 meter

Side	5 cm (μSv/h)	1 meter Measurement (μSv/h)	1 meter Theory Calculation (μSv/h)
1	6,63	6,76	0,025
2	3,55	3,46	0,021
3	3,29	3,23	0,020
4	2,41	2,49	0,042
5	2,48	2,45	0,035
6	1,24	1,12	0,038
7	1,04	1,07	0,051
8	2,53	2,59	0,036
9	2,20	2,19	0,034

The theoretical dose rates calculated using the inverse square law were lower than the measured dose rates at a distance of 1 meter. The theoretical values ranged from 0.020 μSv/h to 0.051 μSv/h. This difference indicates that the inverse square law calculation represents an idealized condition and does not fully describe the actual measurement environment. The inverse square law assumes an ideal point source and propagation without scattering. In the actual brachytherapy room, radiation detected by the survey meter may include scattered radiation from walls, floors, and surrounding equipment. Room geometry and the position of the measurement points may also contribute to differences between theoretical and measured values. Therefore, the theoretical calculation is used as a reference for evaluating the distancedependent trend, while the direct measurement represents the actual radiation dose rate at each measurement point.

In the results of the measurements that have been carried out, it was found that there are several value differences between the current measurement data and the commissioning data. This difference is still acceptable because there are factors that can affect the results of radiation exposure measurements, namely changes in the activity of radiation sources. The radiation source used in the brachytherapy system is Cobalt-60 (Co-60). Like other radionuclides, Cobalt-60 undergoes radioactive decay naturally so that the activity of the source will decrease over time. Cobalt-60 has a half-life of about 5.27 years, which means that during that period the source activity will be reduced to half of its initial activity. This means that the rate of radiation dose produced will also decrease by a similar ratio, because the dose rate is proportional to that of the straight with the source activity. Therefore, if radiation exposure is measured at different times, it is likely that there will be differences in the measured radiation dose rate values (Miftahul Aziz, 2015).

In addition to the influence of source distance and activity, radiation safety was evaluated by comparing the measured dose rates with the applicable annual dose limits. Because the field measurements were expressed in μSv/h, the annual dose limits were converted into hourly dose rate values to allow direct comparison. Based on a total working time of 2100 hours per year, the occupational dose limit (NBD) of 20 mSv/year is equivalent to 9.52 μSv/h, while the dose limit for the public (NPD) of 5 mSv/year is equivalent to 2.38 μSv/h. These converted values were used as reference values for evaluating the measured radiation dose rates at each measurement point.

Table 4. Results of Dose Rate Against NBD at a Distance of 5 cm

Side	Commissioning Data in 2022 (μSv/h)	Exposure Test in 2026 (μSv/h)	NBD (μSv/h)
1	10,1	6,63	9,52
2	8,56	3,55	9,52
3	8,05	3,29	9,52
4	16,79	2,41	9,52
5	13,98	2,48	9,52
6	15,01	1,24	9,52
7	20,41	1,04	9,52
8	14,21	2,53	9,52
9	13,6	2,20	9,52

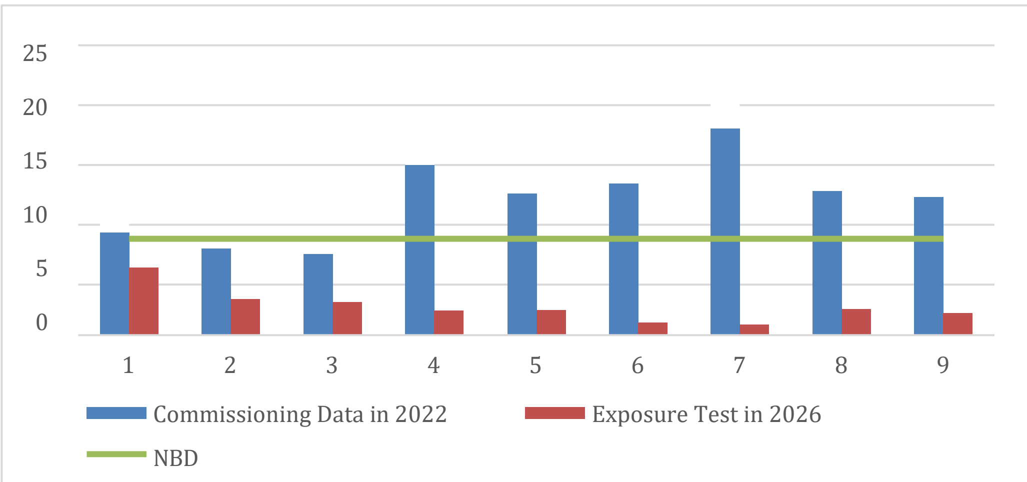

Figure 5. Dose Rate Against NBD at a Distance of 5 cm

Based on Table 4. Results of Dose Rate Against NBD at a Distance of 5 cm, The dose rate value in the 2026 exposure test has a value in the range of 1.04 μSv/hour to 6.63 μSv/hour, while the set NBD value is 9.52 μSv/hour. Table 3 shows that the value of the dose rate in the 2026 exposure test from points 1 to 9 is still below the set limit. However, if analyzed through Figure 5, namely the diagram.

The dose rate, in the 2022 commissioning data shows that at several points, namely points 1, 4, 5, 6, 7, 8, and 9 have values that tend to be higher than the set NBD values. This indicates that the area at the measurement point has the greatest radiation intensity. This condition confirms that the area near the source is not designed for prolonged exposure and is only used for purposes such as testing or maintenance.

Table 5. Results of Dose Rate Against NBD at a Distance of 1 Meter

Side	Commissioning Data in 2022 (μSv/h)	Exposure Test in 2026 (μSv/h)	NBD (μSv/h)
1	0,49	0,38	9,52
2	1,37	0,59	9,52
3	0,67	0,28	9,52
4	1,01	0,39	9,52
5	0,71	0,51	9,52
6	0,67	0,37	9,52
7	0,67	0,23	9,52
8	1,2	0,49	9,52
9	0,57	0,47	9,52

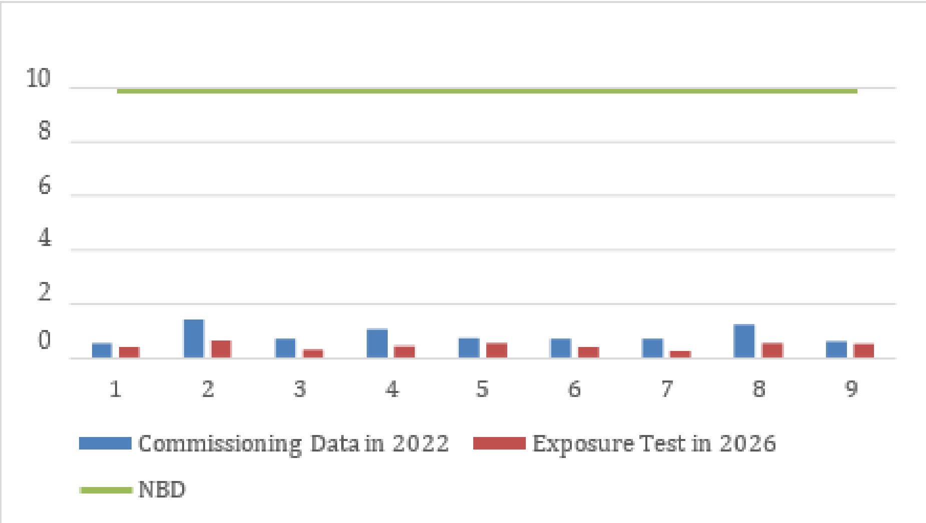

Figure 6. Dose Rate Against NBD at a Distance of 1 Meter

Based on Table 5. Results of Dose Rate Against NBD at a distance of 1 meter, the dose rate value in the 2026 exposure test has a value in the range of 0.23 μSv/hour to 0.59 μSv/hour, with a set NBD value of 9.52 μSv/hour. Meanwhile, in the 2022 commissioning data, the dose rate value ranges from 0.49 μSv/hour to 1.37 μSv/hour. Figure 6 shows that the dose rate values at the 2022 commissioning and the 2026 exposure test have a very low level of radiation exposure, so the values obtained are below the safe limit that has been set. This is in accordance with the principle of the inverse square law, where the intensity of radiation will be reduced by the squared value of the distance of the radiation source. Thus, exposure to radiation at a distance of 1 meter can be said to be safe for radiation workers.

Table 6. Results of Dose Rate Against NPD at a Distance of 1 Meter

Side	Commissioning Data Year 2022 (μSv/h)	Exposure Test Year 2026 (μSv/h)	NPD (μSv/h)
1	0,49	0,38	2,38
2	1,37	0,59	2,38
3	0,67	0,28	2,38
4	1,01	0,39	2,38
5	0,71	0,51	2,38
6	0,67	0,37	2,38
7	0,67	0,23	2,38
8	1,2	0,49	2,38
9	0,57	0,47	2,38

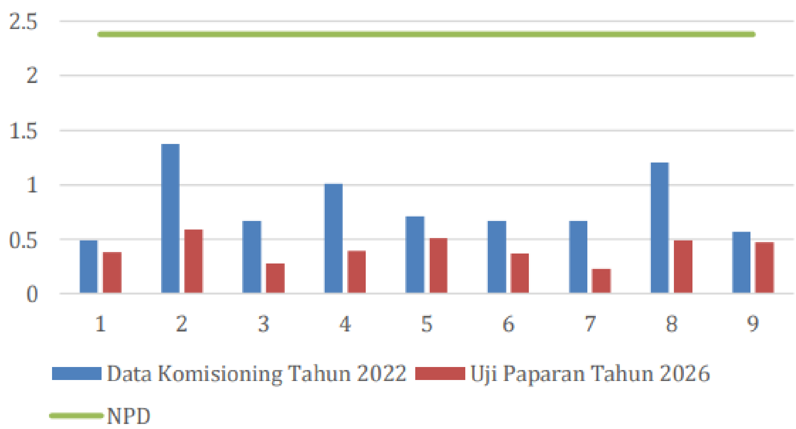

Figure 7. Dose Rate Against NPD at a Distance of 1 Meter

Based on Table 6. Results of the Dosing Rate Against NPD at a distance of 1 meter, the dose rate value in the 2026 exposure test has a value in the range of 0.23 μSv/hour to 0.59 μSv/hour, while in the 2022 commissioning data, the dose rate value ranges from 0.49 μSv/hour to 1.37 μSv/hour, with a set NPD value of 2.38 μSv/hour. Figure 7 shows that the dose rate diagram is still below the NPD limit that has been set. This indicates that the radiation exposure received by the community or the surrounding environment is still within the permissible safe limits.

Overall, these results show that all dose rate values measured in 2026 at measurement points 1 to 9 are still within the safe limits set by the NBD and NPD for radiation workers, but do not fully meet the safe limits for the general public. Periodic monitoring is also required for the establishment of clear safe zones to ensure that operational activities are carried out under safe conditions and in accordance with applicable radiation safety standards.

4. CONCLUSION

Based on the results of the analysis that has been carried out, it can be concluded that the value of the radiation dose rate around the SagiNova brachytherapy machine in 2026 shows that the value tends to decrease according to the inverse square law of distance from the source radiation. A comparison between the commissioning data and the measurement results shows a decrease in the value of Cobalt-60 source activity which leads to a difference in exposure values around the engine in 2022 and 2026. The annual dose value calculated at all measurement points is still below the dose limit set by radiation safety regulations. The measured radiation dose rates around the Sagi Nova brachytherapy system remain within the applicable radiation protection criteria. Therefore, periodic radiation monitoring is important to ensure continuous compliance with radiation safety requirements. Therefore, commissioning testing and regular dose monitoring are essential to ensure the safety of patients, radiation workers, and the general public.

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