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Replacement of Angra 1 NPP Steam Generators: Evaluation of Results Obtained After 10 Years

Matheus de Almeida Silva[1], e Fernando Mendonça Soares Filho[1]

Eletrobrás Termonuclear S.A – ELETRONUCLEAR
Departamento de Proteção Radiológica
Central Nuclear Almirante Álvaro Alberto
Rodovia Procurador Haroldo Fernandes Duarte, BR101/RJ,S/N km 521,56
CEP: 23948-000, Itaorna, Angra dos Reis, RJ, Brazil
[1]matheus@eletronuclear.gov.br, [1]fermsf@eletronuclear.gov.br

1. Introduction

The Angra 1 NPP Steam Generators are the equipment responsible for exchanging heat between the primary and secondary circuits. They have a useful life, which implies their replacement over time. At the Angra 1 Nuclear Power Plant, this service took place in 2009, from January to June of that year, in the task that became known as SGV, a portuguese acronym for Steam Generators Replacement.

From a radiological point of view, the replacement of the Steam Generators was justified by the increased risk of an eventual rupture of the steam generator tube. As well as the reduction of collective doses resulting from the reduction of ambient dose rates, the reduction of exposure and individual doses for workers, and the reduction in maintenance time of steam generators during refueling stops at the Angra 1 Nuclear Power Plant.

This work includes a comparative analysis through the values obtained from Collective Dose of refueling and operation, task execution time (Man-Hour), and average dose rate. The data referring to the main inspection and maintenance works, from the point of view of radiological protection, performed in the steam generators were also analyzed. The values were obtained at the Angra 1 NPP, with the support of the facility's Radiological Protection Department.

2. Methodology

In order to evaluate the results, from a radiological point of view, collective dose and task execution time data were collected and analyzed. Independent analyzes of the periods of the Angra 1 NPP in operation and refueling were performed. For this last condition, the main works related to steam generators were emphasized: the Eddy Current Test (ECT), which deals with the inspection of the steam generator tubes, and the Sludge Lancing, which deals with the removal of mud from the mirror of the Steam Generators.

Table I shows the values collected for collective dose, from 1998 to 2020. The collective dose for the period of operation of the plant and the collective dose for the refueling period are detailed in the table.

Table I: Collective Dose Data.

Year	Total Collective Dose (person-mSv)	Refueling Collective Dose (person-mSv)	Operation Collective Dose (person-mSv)
1998	1091,77	1040,20	51,57

1999	169,11	0,00	169,11
2000	1352,25	1212,80	139,45
2001	1111,34	1025,10	86,24
2002	1192,59	931,13	261,46
2003	2040,64	1846,02	194,62
2004	607,41	443,30	164,11
2005	1156,12	1006,70	149,42
2006	938,23	837,07	101,16
2007	1826,88	1593,30	233,58
2008	1108,89	947,10	161,79
2009	1876,11	1833,94	42,18
2010	745,34	711,78	33,56
2011	720,33	683,60	36,73
2012	21,62	0,00	21,62
2013	814,77	787,49	27,28
2014	454,78	424,57	30,21
2015	389,32	364,39	24,93
2016	367,02	341,15	25,87
2017	487,42	463,13	24,29
2018	396,71	372,15	24,57
2019	21,86	0,00	21,86
2020	427,36	404,66	22,70

Table II follows the same data collection criteria used in table I. However, this table describes the man-hour values obtained in the years evaluated.

Table II: Man-Hour Data.

Year	Total (Man-Hours)	Refueling (Man-Hours)	Operation (Man-Hours)
1998	158476	50020	108456
1999	53541	0	53541
2000	120167	78910	41257
2001	104025	39815	64210
2002	135473	65038	70435

2003	157485	97752	59733
2004	88826	30698	58129
2005	137981	76776	61205
2006	142982	70374	72608
2007	201206	144766	56440
2008	194884	111599	83285
2009	456555	393685	62870
2010	139088	72128	66960
2011	138392	72702	65690
2012	65097	0	65097
2013	167337	116294	51043
2014	144450	70975	73475
2015	122692	72078	50614
2016	115897	62746	53151
2017	118907	80461	38446
2018	106862	65185	41677
2019	46187	0	46187
2020	104718	69854	34864

With the data obtained, linear trend lines were plotted. A linear trend line usually shows that something is increasing or decreasing at a constant rate. In addition, the average dose rate indicator was used, which indicates the evolution in dose rates during specific periods in Angra 1. This indicator is calculated by the following formula:

$$T_{méd}^{x} = \frac{D \times 1000}{\Delta t} \quad (1)$$

Where,

$T_{méd}^{x}$ = Average Dose Rate, in μSv/h;
D = Collective Dose, in person-mSv;
Δt = Activity Runtime, in Man-Hour.

3. Results and Discussion

The values obtained from collective dose in Angra 1 were analyzed, it is noted that after replacing the steam generators there was a significant drop in this indicator. This downward trend can be observed in Fig. 1.

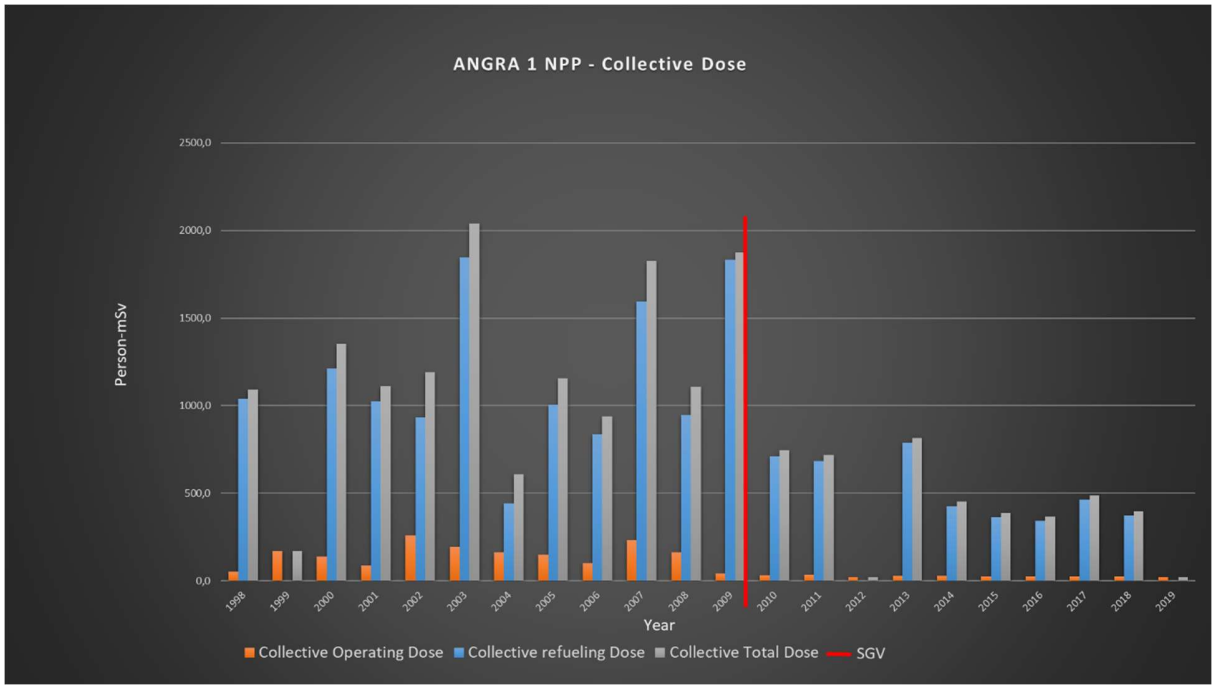

Figure 1: Angra 1 NPP Collective dose per year.

The indicator shown in Fig. 1 suffers interference from other factors and activities that do not contribute to this study. Therefore, it was decided to evaluate the values obtained in maintenance and refueling outages.

The collective dose of outages for refueling and maintenance shows a strong reduction, as demonstrated in Fig. 2. The linear trend line applied to the graph demonstrates the reduction in the actual collective dose after the outage to replace the steam generators, which occurred in 2009. This fact directly interferes with the estimates used in the subsequent outages, noting that the estimates are generated through the realization preview of the ALARA (As Low As Reasonably Achievable) Planning of activities.

The data for man-hours were also analyzed. Even though this indicator shows a trend of stability before and after the replacement of the steam generators, as demonstrated in Fig. 3, the reduction in the collective doses shows how the task had a great impact on the reduction of the total collective dose of the outages in Angra 1 NPP.

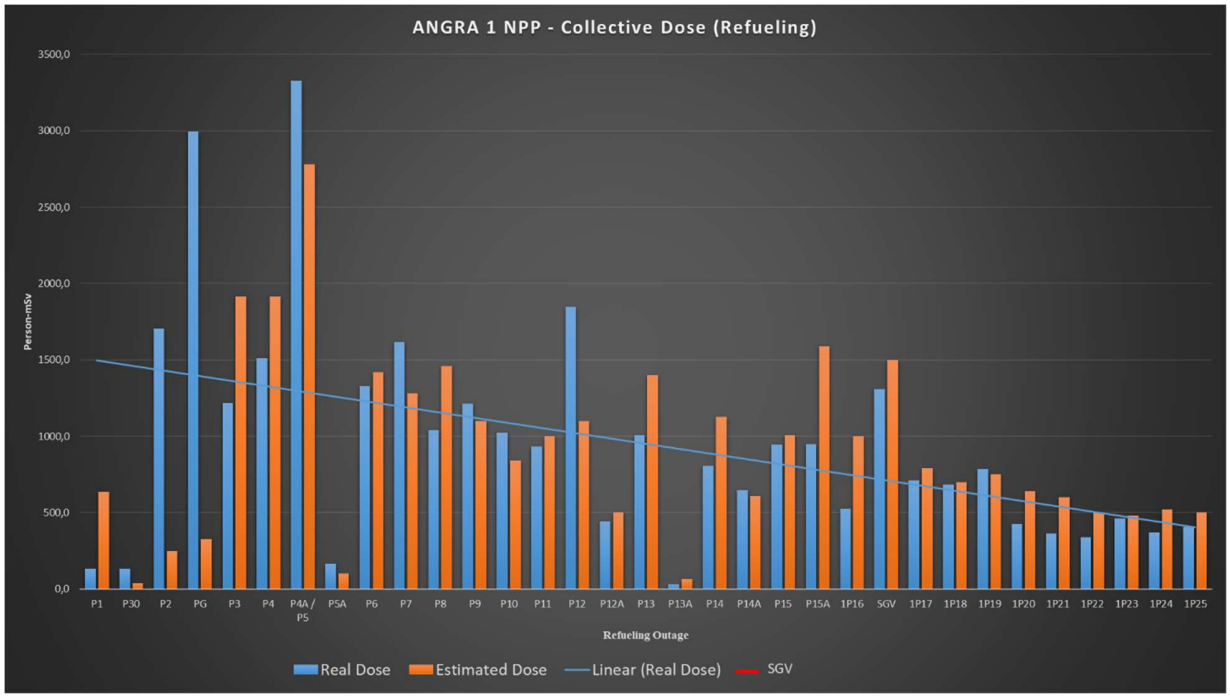

Figure 2 : Angra 1 NPP Collective dose during refueling and maintenance outages.

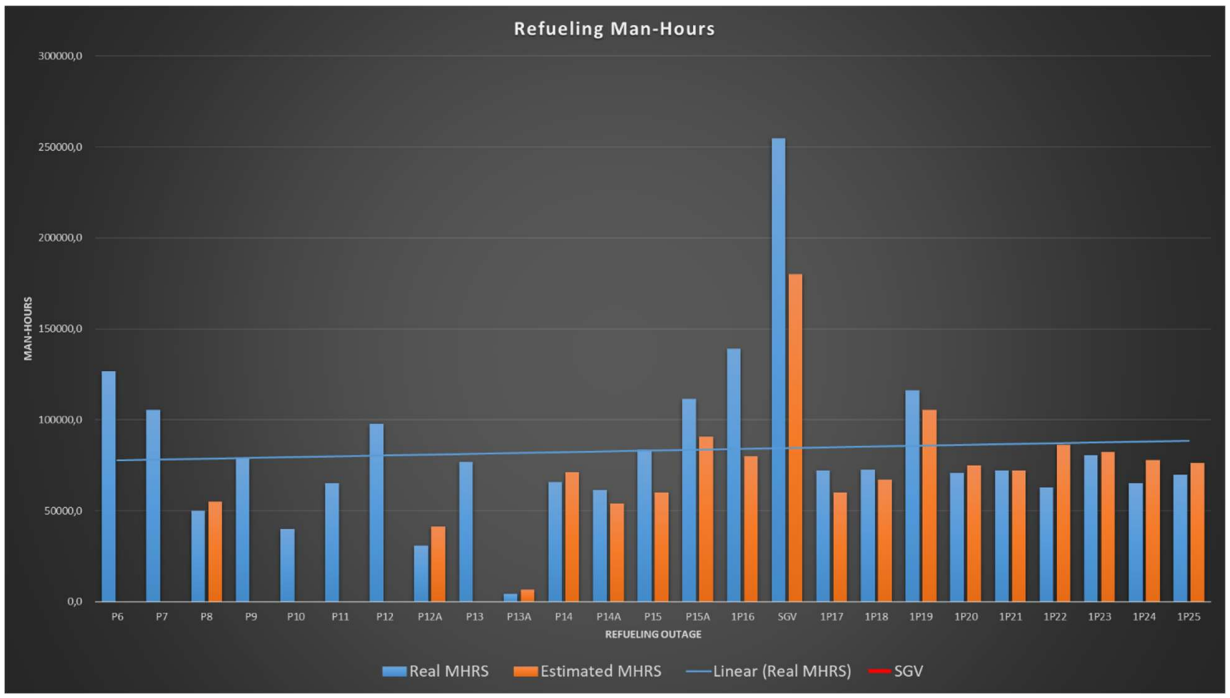

Figure 3 : Angra 1 NPP Man-Hours during refueling and maintenance outages.

When comparing the values of collective dose with the plant operating at full power, it was identified that the replacement of steam generators resulted in a reduction in this indicator, as demonstrated in Fig. 4. Ambient dose rates in rooms with components from the primary and secondary systems showed a significant reduction. Routine activities performed at these sites described above had reduced average dose rate results, as seen in Fig. 5. These data were calculated using Eq. 1.

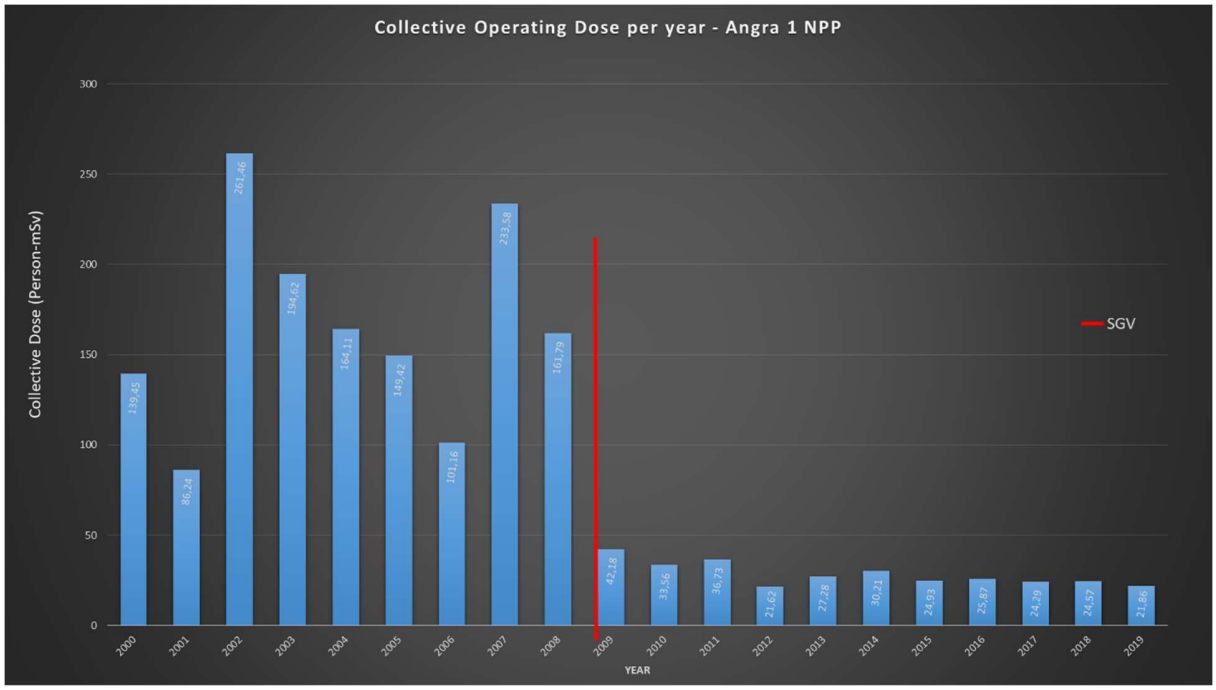

Figure 4 : Angra 1 NPP Collective Operating Dose per year.

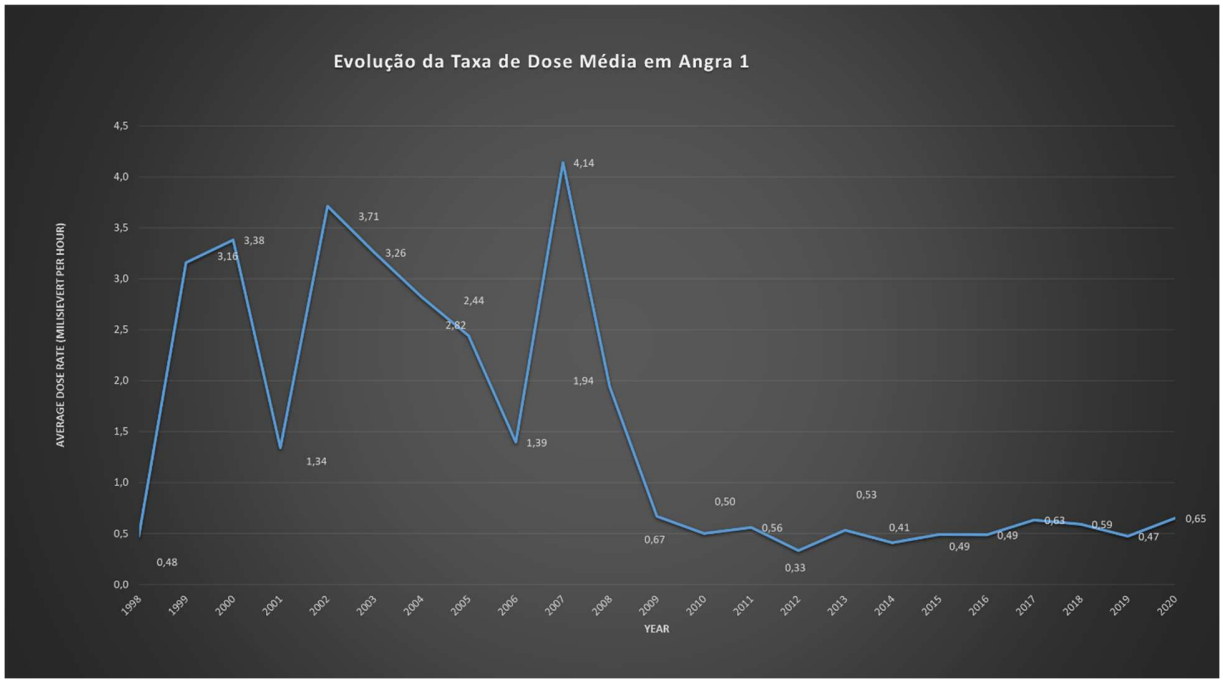

Figure 5 : Angra 1 NPP Evolution of Average Dose Rate during operation at full power.

In the evaluation of the man-hour and the collective dose of Sludge Lancing, it was found that even with the increase in the man-hour after the replacement of the GVs, the service doses decreased. When analyzing the data referring to the Eddy Current Test, it was evaluated that both indicators, man-hour and collective dose, suffered reductions. In this case, the reduction of man-hour can be attributed to the improvement in the conditions of the place for the execution of the service, considerably reducing the opening and closing time of the steam generators for inspection of the steam generator tubes. The

collective dose of this activity was greatly reduced, also because of the reduction in man-hours, but mainly because of the better radiological condition found in the steam generators after replacement. In both cases, it was verified that one of the objectives of replacing the steam generator was met: the reduction of collective doses resulting from the Steam Generators.

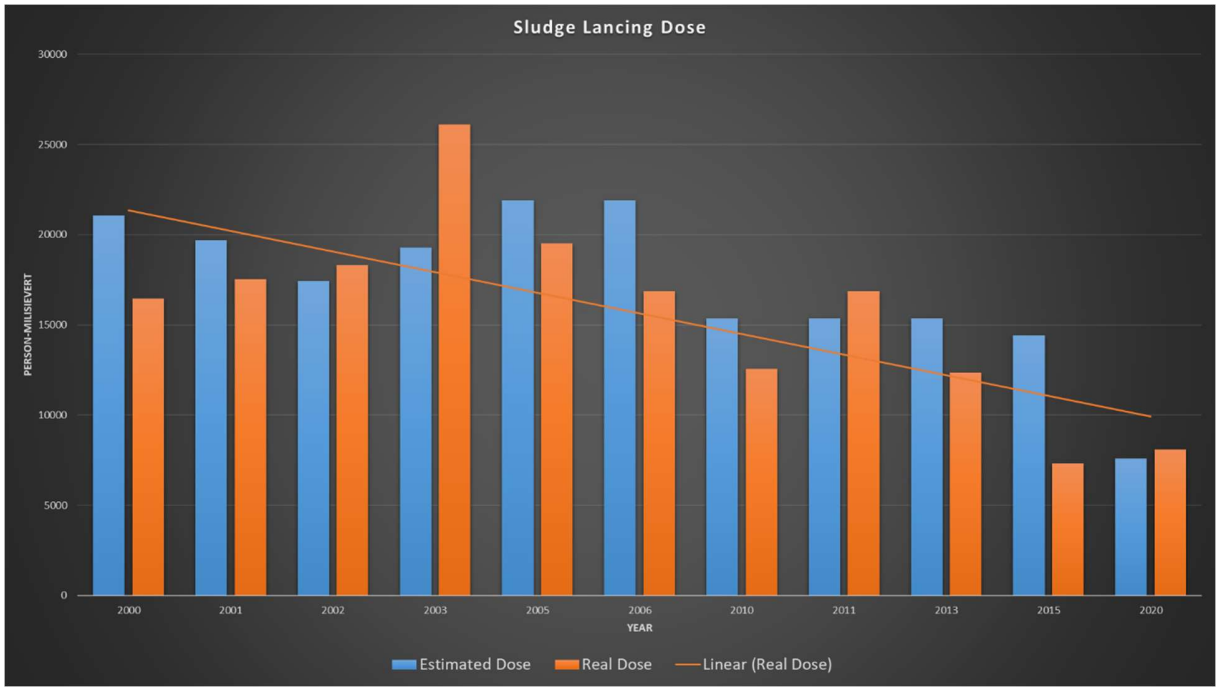

Figure 6 : Angra 1 NPP Sludge Lancing Dose per year [3, 5, 8, 10, 12, 14, 19, 20, 21, 23, 26].

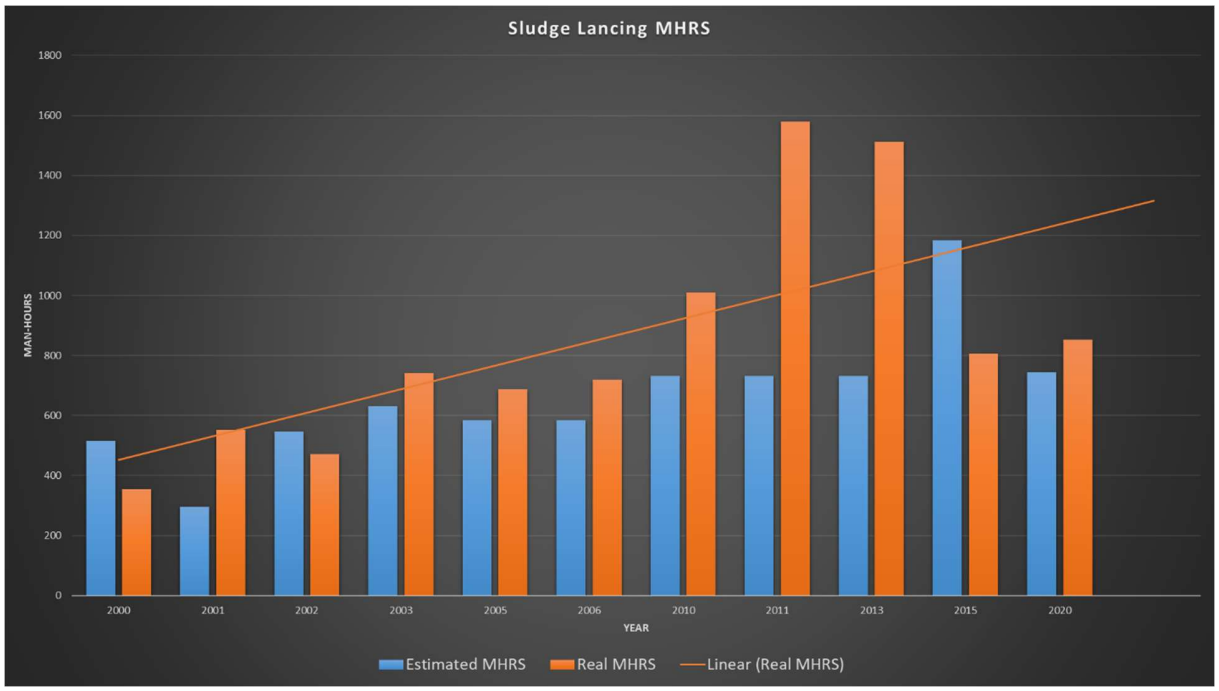

Figure 7 : Angra 1 NPP Sludge Lancing Man-Hours [3, 5, 8, 10, 12, 14, 19, 20, 21, 23, 26].

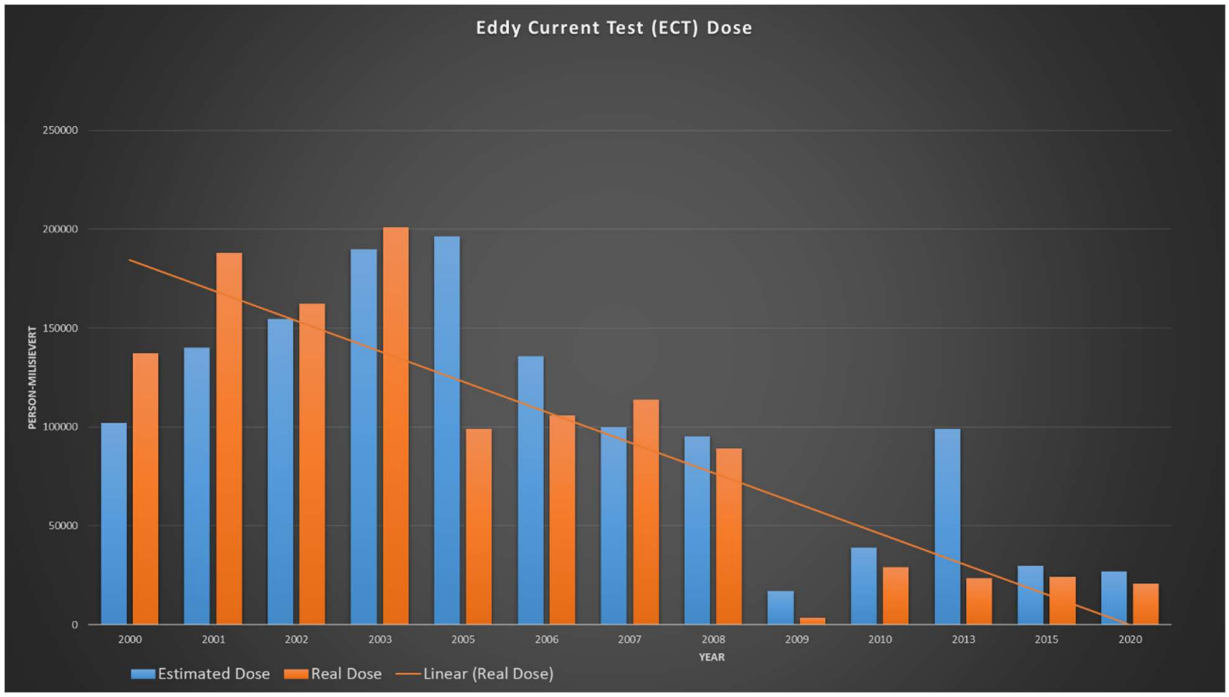

Figure 8 : Angra 1 NPP Eddy Current Test Dose per year [4, 6, 7, 9, 11, 13, 15, 16, 17, 18, 22, 24, 25].

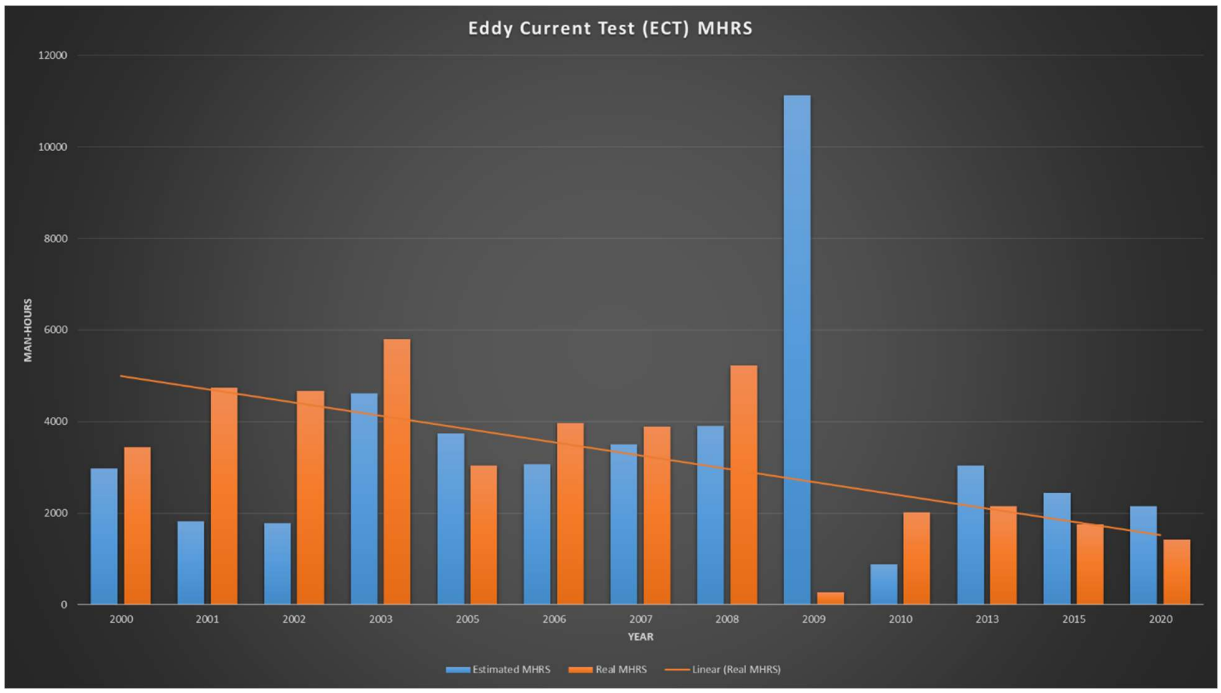

Figure 9 : Angra 1 NPP Eddy Current Test Man-Hours [4, 6, 7, 9, 11, 13, 15, 16, 17, 18, 22, 24, 25].

4. Conclusions

During the planning phase for the replacement of steam generators, the radiological protection plan presented as a justification for carrying out the activity the reduction in collective doses, the reduction in ambient dose rates, and lower individual doses for workers. After completing the task and today, with the plant data, it was possible to compare the values before and after the Replacement of Steam Generators.

It is concluded that, after comparing the radiological protection data found in Angra 1, before and after replacing the steam generators, the effectiveness of carrying out the task from the point of view of radiological protection was proven.

5. Acknowledgements

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6. References

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