RADIOLOGICAL PROTECTION FOR THE ANGRA 1 STEAM GENERATOR REPLACEMENT OUTAGE

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ABSTRACT

The Angra 1 Nuclear Power Plant (NPP) is a Westinghouse two-loop plant with net output before its 1P16 Outage of 632 MWe, with the Old Steam Generators (OSG) type model D3, which were replaced by two new Steam Generators with feed water-ring system. Localized in Angra dos Reis, Rio de Janeiro – Brazil, Angra 1 started in commercial operation in 1985 and, from the beginning problems about corrosion have appeared in the inconnel 600 alloy of the tubes. The corrosion problems indicated the necessity for a strong control of the tubes thicknesses and, after a time, the Eletronuclear decided to replace the OSG. In 2009, Eletronuclear initiated in January 24, the actions for the Steam Generators Replacement – SGR. During the SGR process, several controls were applied in field, which made possible to have no radiological accidents, no dose limits exceeded, and permitted to achieve a very good result in terms of Collective Dose. This paper describes the radiological controls applied for the Angra 1 Steam Generator Replacement Outage, the radiological protection team sizing and distribution and the obtained results.

1. INTRODUCTION

The Angra 1 Nuclear Power Plant (NPP) is a Westinghouse two-loop plant with net output before its 1P16 Outage of 632 MWe, with the Old Steam Generators (OSG) type model D3, which were replaced by two new Steam Generators with feed water-ring system. Localized in Angra dos Reis, Rio de Janeiro – Brazil, Angra 1 started in commercial operation in 1985. Since 2003, Angra 1 NPP slowed the process for reduction of the Collective Radiation Exposure, sometimes increasing this indicator, due to degradation in the steam generators which caused more than one outage per year.

The primary water stress corrosion cracking – PWSCC was, in most of the cases, responsible for the corrosion in the tubes of the OSG which caused the thickness reduction of many tubes. The consequences were the plugging of the failed tubes or those with a high probability to becoming failed, the reduction on generating power and an increase in the probability of a tube rupture event related.

To perform tests and maintenance for the defective OSG it was necessary to shutdown the Plant in mid cycle's outages. Those outages contributed to increase the collective radiation exposure indicator, as well as the skilled workers dose and the personnel contamination events indicator number.

Electronuclear decide to correct definitely the problem by replacing the OSG, which was planned for 2009. This task was taken as a challenge for the Electronuclear Radiological Protection Organization to make this high risk endeavor without any accident or significant incident. The Radiological Protection Management was also concerned to minimize the collective dose for the project and keeping the individual doses As Low As Reasonable Achievable – ALARA.

The main objective of this paper is to present the radiological controls applied for the Angra 1 Steam Generator Replacement Outage, the radiological protection team data, collective dose distribution and also the experience gathered in this challenging operation.

2. CHRONOLOGY

August 7, 2003 – a sudden increase in the OSG primary-to-secondary leak rate causes the plant shutdown according the operating procedures, based on the guidelines from Electrical Power Research Institute – EPRI. In that moment, it was also initiated the Angra 1 1P12 outage. Until November 5, 2003, a full scope eddy current test was performed (100% the Steam Generators – SG tubes were examined and also was installed the retainer ring for the nozzle dams inside the primary bowl of the Steam Generators. All evolutions produced 2,041 man.mSv and 157,485 worked hours inside Controlled Area in the year, with an Annual Dose Index of 13.0 μSv/h.

July 10, 2004 - the 1P12A planned shutdown is done to perform the non-destructive tests in the OSG and plugging the failed tubes. The 1P12A outage had no refueling, and until August 12, 2004, 607 man.mSv and 88,826 worked hours inside Controlled Area in this year, produced an Annual Dose Index of 6.8 μSv/h.

February 26, 2005 – the 1P13 outage begins with 3,940 tasks to be performed. Until April 24, were produced 1,157 man.mSv and 84,804 worked hours inside Controlled Area in the year, with an Annual Dose Index of 13.6 μSv/h.

February 3, 2006 – the 1P13A planned shutdown to perform maintenance in the low pressure turbine of the electrical generator. Until February 20, 2006, only one ALARA planned work was performed in this outage without refueling.

May 5, 2006 – the 1P14 outage with 3,655 tasks is initiated and finished in June 26, 2006. For this year, a dose of 938 man.mSv and 77,925 worked hours inside the Controlled Area produced an Annual Dose Index of 12.0 μSv/h.

January 12, 2007 – the 1P14A outage had to start before the original date, due the combination of fuel failure and the increasing in the OSG primary-to-secondary leak rate. Following a decision making based process, the plant was shut down and in March 4, 2007 was reconnected to the grid. After opening the OSG primary man way, a broken steel cable designed to stabilize a plugged tube was found inside the primary circuit, and was the responsible for the damages in the fuel. The recovery work and maintenance in the OSG caused a dose of 646 man.mSv and 61,200 worked hours inside the Controlled Area.

June 6, 2007 – the 1P15 outage started in June, 6 and finished in August, 3. The dose of 1,827 man.mSv and 201,207 worked hours inside Controlled Area produced in 2007 was most because 1P14A and 1P15, with an Annual Dose Index of 9.1 μSv/h.

February 16, 2008 – the 1P15A was the last outage before the SGR outage, including 2,909 tasks, many of them related to the upcoming SGR operations planned for the 1P16. Finishing in April 16, 2008, the 1P15A produced a dose of 1,109 man.mSv and 194,929 worked hours inside Controlled Area, with an Annual Dose Index of 5.7 μSv/h. In this outage, several improvements in terms of shielding were installed previously to the SGR outage, showing highly favorable results in reducing the outage collective dose.

January 24, 2009 – the 1P16 refueling outage started, in which the main task was the Angra 1 Steam Generator Replacement and its subtasks. Although the fact that the SGR is said to have started in March 2, for contractual reasons, effectively several SGR tasks related began with the breaker off, like scaffolding, containment opening, shield installation etc. the 1P16 finished in June 4, 2009.

The results of this last outage are here presented, in the next lines, and the conclusions will bring the expectations for the upcoming operating cycles for Angra 1 NPP, with the consequent challenges for the Eletronuclear Radiological Protection Division: less outage duration, lower collective dose, lower individual doses – how to achieve this still maintaining a reasonable cost effective for saving doses?

Fig. 1 shows the evolution for the main outages tasks ranging from 2000 to 2008. Because it is an original figure produced directly from the ISOE – International System On Occupational Exposure website [1], the graphical patterns are made in a non editable way, as some other graphs in this paper.

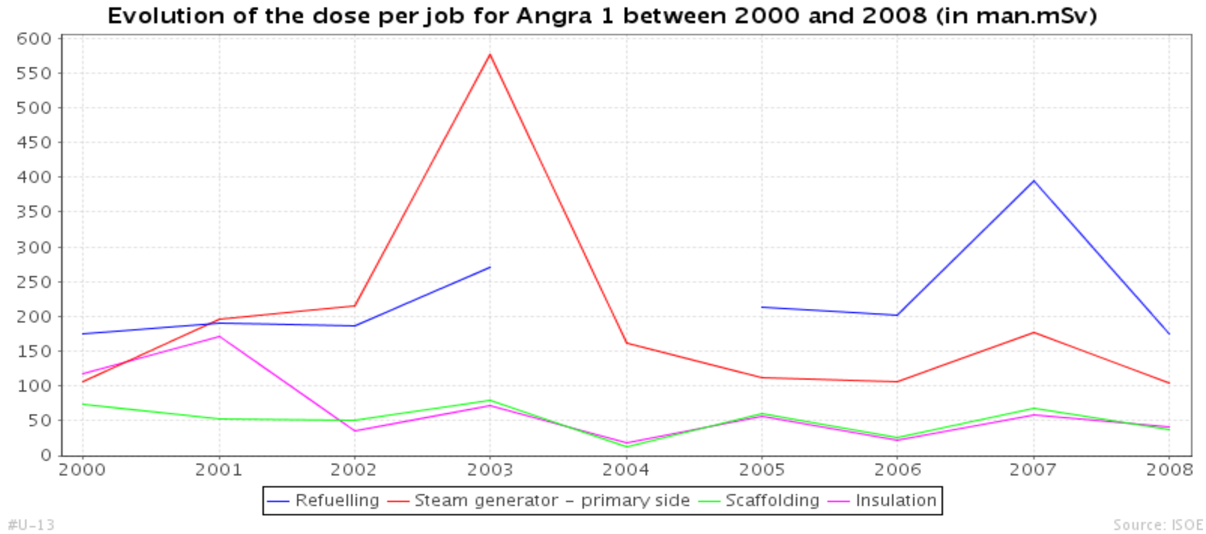

Figure 1 – Evolution of the dose per job for Angra 1

3. STEAM GENERATOR REPLACEMENT

3.1. SGR Radiological Protection Plan and ALARA Plans

The first document written to address radiological issues was the "Technical Specifications for Angra 1 Steam Generators Replacement" [2], but the most important document with radiological focus prepared was "Angra 1 Steam Generator Replacement Radiological Protection Plan" [3], developed by Eletronuclear Radiological Protection Division and submitted to the Brazilian Nuclear Regulatory Commission – CNEN, receiving comments from CNEN before to be finally approved.

During the planning phase, an expert assessment mission from EPRI was contracted by Eletronuclear RP Division to evaluate the Radiological Protection Plan for Angra 1 SGR. The EPRI Final Report [4] proved to be very useful and the main recommendations were implemented, emphasizing the reduction dose methods, using technologies to control dose, highly visible postings and signs, effective communication and coverage for field tasks.

Some facilities were built, like the Containment Access Facility – CAF as a secondary access to the Reactor Building via North Auxiliary Building, the Decon Area – a tent to permit low level and dry decontamination outside the plant buildings, and the Extended Controlled Area – ECA giving more space to handle insulations and pipes before install it and directly connected to the Containment Equipment Hatch in a posted Contaminated Controlled Area. All they worked well and effectively in the yard of Angra 1.

The accomplishment of the ALARA Plans and the measures to reduce and control the workers' doses were determinant to achieve the collective dose of 1,310 man.mSv, 8% below from the initially estimated value of 1,417 man.mSv, and below the target of less than 1,500 man.mSv, contractually defined.

Nineteen ALARA Plans were produced, followed-up and finished according the plant's ALARA procedure. The final collective dose was 81% originated from the tasks covered by specific ALARA plans and the remaining 19% from non-ALARA tasks, i.e., below the threshold to start an ALARA specific job plan.

3.2. SGR RP Plan and ALARA Plans Implementation

Following the SGR Specifications, The Eletronuclear RP Division issued a SGR Radiological Protection Plan, submitted it to the Brazilian Nuclear Regulatory Commission – CNEN and received approval. Also, the expert mission from EPRI evaluated the global scope for Angra 1 SGR Project and issued several recommendations, most of them were incorporated in the SGR RP Plan or in the derived procedures and instructions made specifically for the Project.

The SGR ALARA Plan was initially accomplished by carrying out the dosimetric phase in the 1P15A outage, which involved radiation surveys, source term characterization, job scope and working areas definition, designation of methods to lower the doses, doses estimates and specific ALARA planning for the main activities.

Immediately before the 1P16 outage were defined all the tasks and subtasks for each ALARA Plan, the respective Radiological Work Permit – RWP, with instructions, precautions, alarm settings. A very comprehensive training structure was established, for the radiation workers in general, RP technicians and special trainings. Also, the documents for temporary shielding were fostered, allowing the shielding installation in field.

3.3. Dose Reduction Methods

The main methods to reduce the collective doses and the individual doses were the source term reduction, lead shielding, water management as shielding and mockup training. The effective control over the people entering to the Controlled Area, strong postings, lights and signs used, all together made favorable the achieved results for Angra 1 SGR.

3.3.1. Source term reduction

The source term reduction, through the activated corrosion products removal, was one of the most important points to reduce the doses for the SGR. Since 2004, Angra 1 was performing the zinc addition in the Reactor Coolant System – RCS in its operation cycles. Due its higher binding energy value, the zinc composes the most stable layer in the oxide film, occupying the inner position and the other oxides with less energy, like cobalt, will occupy only a thin layer in the internal surface of piping and equipments of the reactor coolant system. The zinc is depleted from the isotope ^{64}Zn, to avoid the formation of radionuclide ^{65}Zn.

Other than zinc, a chemical decontamination using hydrogen peroxide is carried out to remove the corrosion products, with a target for ^{58}Co of 1.85 MBq/kg immediately after each refueling shutdown. In the 1P16, the H_2O_2 process initiated with 80 ^oC in the reactor coolant system. It has shown effective and the target was achieved in less time than was initially estimated. This operation removed a total of 23 TBq, minimizing the dose for the workers.

3.3.2. Lead shielding

The use of lead blankets with several sizes was intensive, aiming to reduce the ambient dose rates and hot spots. Two concepts were adopted: first, the shielding was installed to protect individuals working in high radiation areas against unplanned doses; second, to reduce the low dose rates in the working environments – for example, in a transit area in which is estimated 1 minute per person passing through, if a thousand evolutions are counted in a day, it means 1,000 man.minutes in a day; then, if the shielding reduces 30 μSv/hour in the dose rate, or 0,5 μSv/min, it would save about 500 man.μSv in a day or 15 man.mSv after 30 working days.

Approximately 40,000 kg of lead shielding was installed inside the Controlled Area, especially in the Reactor Building, RCS pipes, OSG platforms etc, according the following criteria:

Special Places – this type of shielding was installed directly over the RCS lines, Pressurizer Surge Line, Residual Heat Removal system lines and others piping and components.

Normal Places – this shielding was installed in places normally used during the plant outages, by using definitive hangers installed in 1P15A outage, tied with strong plastic tie wraps.

New Places – this shielding was mounted on scaffolding covering piping and components which showed high doses rates, with the shapes modeled adequately to permit people's transit inside the areas. Also, this type of shielding was installed punctually where relevant dose rates could impact the collective doses, like hepa filters, pipe end decontamination sponges, removed external neutron detectors, "shielded bunkers" etc.

The duration of the installed shielding was optimized in the hot leg, cold leg and intermediate leg of the RCS, before feeding water for the intermediate leg. Therefore, it assured the ambient dose rates reduction in the elevation 3.85 m of the cubicles of the new Steam Generators, before removing the shielding to install the thermal insulation.

The dose rates reduction after the shielding installation, have achieved values ranging from 25% to 50% in the hot leg, cold leg and intermediate leg and the safety injection lines, and ranging from 25% to 30% in the resistance temperature detectors – RTD's manifold. Shield blankets were installed over the grid floor of the Steam Generators platforms, in the elevations 7.60 meters and 10.02 meters, assuring minimum values for the dose rates in the staying areas.

3.3.3. Water shielding

Water management inside the systems was a strong tool to minimize doses. The RCS and the OSG were full most of the time, according was possible, to take advantage of the water attenuation effect over the radiation. It was considered, both by RP Team and EPRI Mission, as a key for the dose reduction during SGR planning phase.

After the final OSG secondary side drainage to allow to cut the main feed water piping, OSG purge lines and drain systems lines, it was noted an increase of about 100% in the vicinities dose rates of the OSG. Therefore, only the required tasks were authorized to proceed in this situation. Most of the tasks were planned to be done with the secondary side of OSG and the RCS with water as much as possible.

3.3.4. Mock up and training

A very detailed and true dimension mockup with associated piping was specified to perform test of tools and for the training to the crews in the tasks of shielding installation, cutting pipes, tripod and shielding supports for cutting primary lines, welding pipes and Foreign Object Search And Retrieval – FOSAR operations. Unfortunately, this mockup was not released in a timely manner to be used before the SGR.

Then, the Angra 1 old mockup was decontaminated by RP decontamination workers. This mockup is a partial reproduction of primary internal chamber of the Steam Generators, but had not the connections with the primary pipe legs.

The trainings were performed, but out of the desired conditions. Despite the success obtained with the broad project, the mockup issue should be treated carefully, because its inadequacy meant much more improvisation, sometimes wasting time and doses, contribute to higher the probabilities for any incident or personal injury.

For better illustration of the dose evolution during SGR, Fig. 2 shows the daily doses and the integrated doses, associated with the major tasks evolutions with impact on doses.

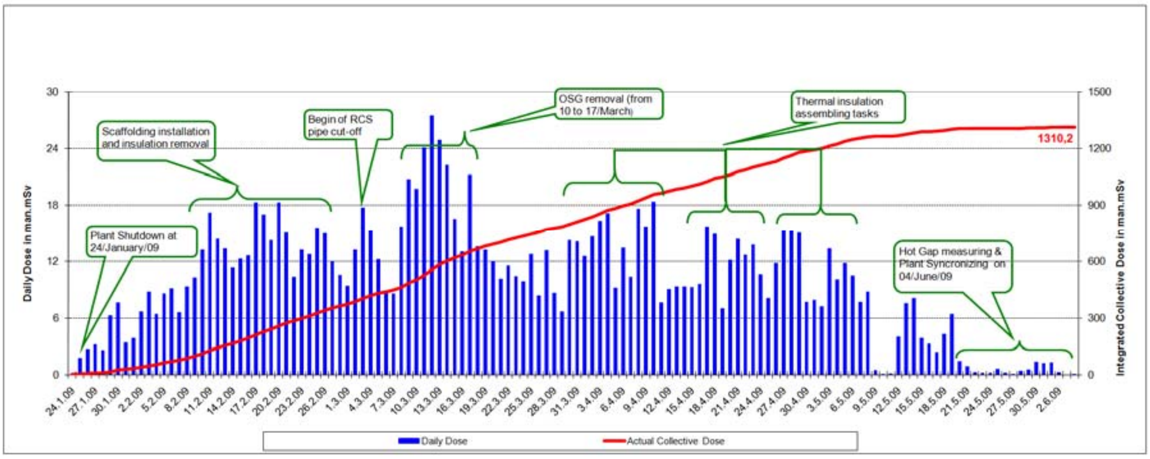

Figure 2 –Evolution of the collective dose during Angra 1 SGR

3.4. Radiological Protection Organization

3.4.1. Structure and organization

The organization chart for the Eletronuclear Radiological Protection Division is shown in Fig. 3. All the radiological safety efforts were distributed among this organization, and the contracted field technicians were directly coordinated by the Angra 1 RP Supervision. The

ALARA Supervision conducted the contact with Westinghouse (WEC) and its subcontractors, giving to them directions and establishing Eletronuclear specific RP requirements.

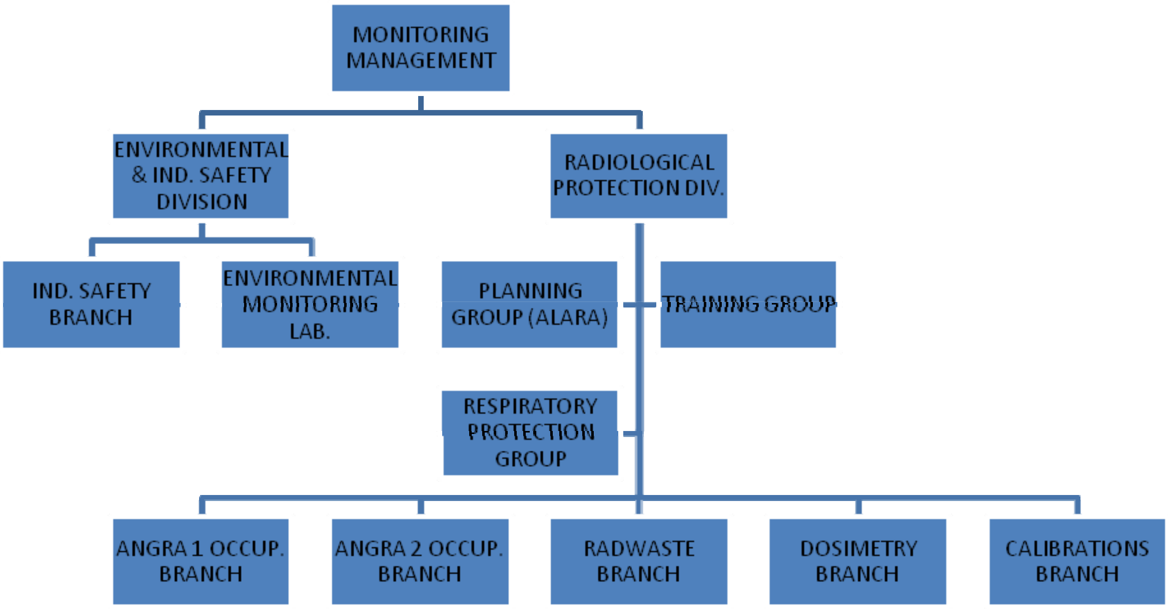

Figure 3 – RP organization chart

The Division had 253 persons for the SGR, distributed between helpers, auxiliary technicians, decontamination technicians, junior and senior RP technicians, supervisors and RP Supervisors, with employees of Eletronuclear and contracted people.

Table 1 show the total effort used in the peak of the outage, when the human resources were the maximum quantity to cover the several working fronts.

Table 1 – Total effort of RP Division during SGR

Function	ETN	Brazilian Contractor	International Contractor
Manager	1		
Coordinator	3		
Supervisor	5		8
Senior Technician	12		35
Junior Technician	4		20
Aux. Technician	5	40	
Decon Technician		25	5
Helper		90	
Total	30	155	68

The mobilization and demobilization of the personnel were ramped up and ramped down, in order to optimize the human resources. Due to the delay for visa passports, the international workers from Bartlett Nuclear Inc., the contractor hired to supply SGR skilled RP technicians, only started to arrive in Brazil in the third week of February, but the total were in field by the first week of March, the 7th week of 1P16 Outage, as shown in Fig.4.

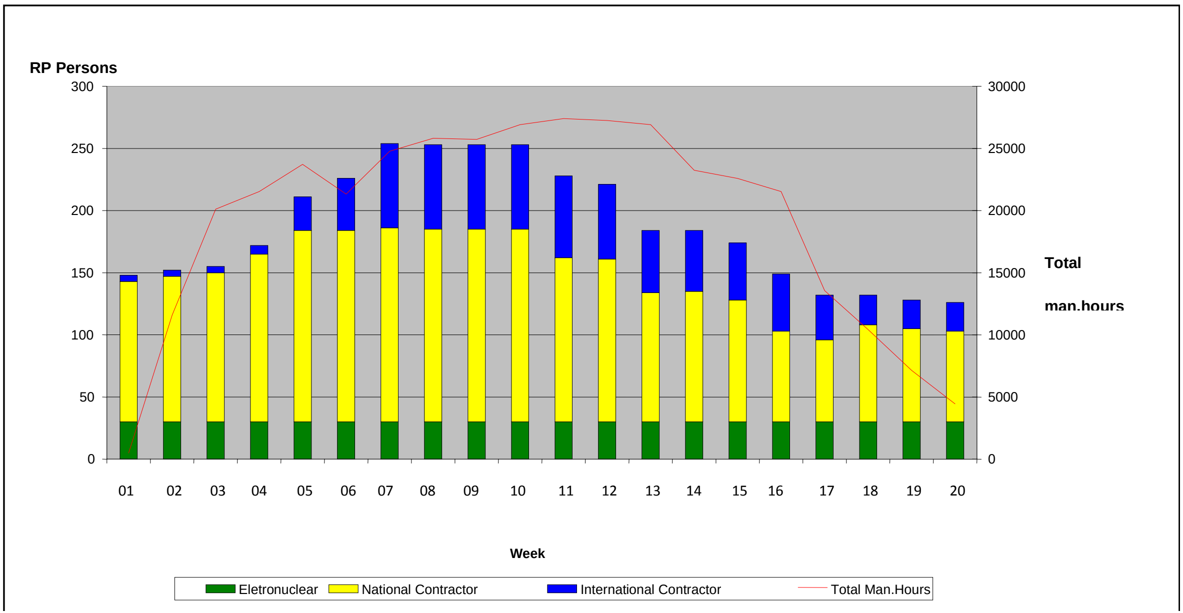

Figure 4 – RP effective mobilization and demobilization

All the supervisors and technicians received specific instructions for the 1P16 Outage Program, especially those tasks related to the SGR with ALARA Planning. Additionally, the international technicians received training about the radiation instruments used by Angra 1 RP Techs and about the specific RP criteria applicable to Angra 1.
The organization used two daily schedules, some working with two teams of twelve hours a day and some working with three teams of eight hours a day.

3.4.2. Dose control, job coverage and communication

The worker's dose control was done by using the Electronic Access Control System – EACS, with electronic dosimeters made by Rados™ and MGP™. This system was designed specially for Angra site, with an Oracle database system using SQL language. With this system, the requirements for the radiation workers are verified online; if necessary, the system block the access in case of any requirement missing, or alarm and inform to the RP Control Point in case of dosimeter alarm inside field. The dosimeter can alarm because the dose constraint was exceeded, or a high dose rate in field, or an excessive time spent inside Controlled Area. Also, the system detects any attempt of battery removal or bad contact with the battery terminals, alarming it when the user performs the exit operation.

The job coverage for the SGR was done with an exclusive Control Point, named Containment Access Facility – CAF, for WEC and its subcontractors, and with the establishment of

Advanced Control Points inside area. The CAF was dimensioned to store 2000 dosimeters TLD and 750 electronic dosimeters. Inside the meeting room, two TV monitors were controlling 14 cameras with pan zoom and tilt, with a senior technician permanently covering the job details and directing RP rover efforts according required.

The communication process among supervisors was defined by the RP Manager to be immediately between the daily meeting “Plan of the Day – POD” and the daily Plant Outage Meeting. The use of radios, with a specific ALARA channel, made possible the online communication among the team leaders according required. To make the communication successful, the use of 3-Way Communication and Phonetic Alphabet was always reinforced and extensively practiced [6,7].

3.4.3. Techniques and technologies

- Emergency lights – red lights were used during high risk evolutions, blinking to warn the workers about the risks in the area, like in the job of radiography, “sand boxes” in the reactor cavity, primary legs cutting out and others.

- Teledosimetry – the MGP teledosimetry system was used, with availability to monitor simultaneously 150 workers. This system permitted the real time monitoring of the workers executing jobs inside Controlled Area, where the dose rates were high and or subject to sudden variations, allowing identifying and taking actions to avoid the unplanned workers exposure.

- CCTV / Radio System – a CCTV composed by 14 cameras installed in the Reactor Building, Temporary Containment Opening and Reactor Equipment Hatch. This system, integrated with the radio system and area telephones, have made possible to interchange information during the tasks evolution, giving the opportunity for saving time, to coach the worker both in terms of RP and maintenance practices, permitting to correct eventual bad practices on time.

- Material’s clearance management – a special RP Team was created, during SGR, to perform the materials release from the Controlled Areas of the Plant buildings to the Decon Area, monitoring, segregating, monitoring again and clearing the clean materials for free release or for warehouses in free area.

- Colored postings and warning messages – “Waiting Areas” green colored postings and “Do No Stay in This Area Without Necessity” red colored postings which were distributed inside Controlled Area, allowing workers to visually and identify the areas planned to rest or wait another action, whereas the RP Techs could act promptly and remove the unneeded workers from the red colored areas.

- RP Personnel Identification – red jackets, with reflective letters writing “Radiological Protection” were used by RP personnel both in contaminated and non-contaminated areas, allowing the workers to promptly identify the RP Techs and Aux Techs in field. It fastened the job execution and also served to hold off workers bad behaviors.

4. RESULTS [5]

The results for the Angra 1 SGR are below presented in the next graphs, but the synthesis is that the OSG were removed and brand new ones were installed in its place, bringing opportunities for Angra 1 to really start to be within the best plants indicators in the world, in its category.

Fig. 5 shows the historical Collective Dose and, after the 7th Outage of Angra 1 (1P7), also the manpower was given in order to permit a comparison of the magnitude of the SGR. For better understanding, the outages are named as follows: the first component represents the Plant Unit number, 1 for Angra 1 or 2 for Angra 2; the second is the letter P from “Parada”, the Brazilian term in Portuguese to designate “Outage”, and the third component is the number of the outage; if it is a mid cycle’s outage, than a letter A for the first, B for the second is used. As an exception, a term is used to express the reason for the outages, like “30 Days” post- commissioning and “G” due to an Electrical Generator failure.

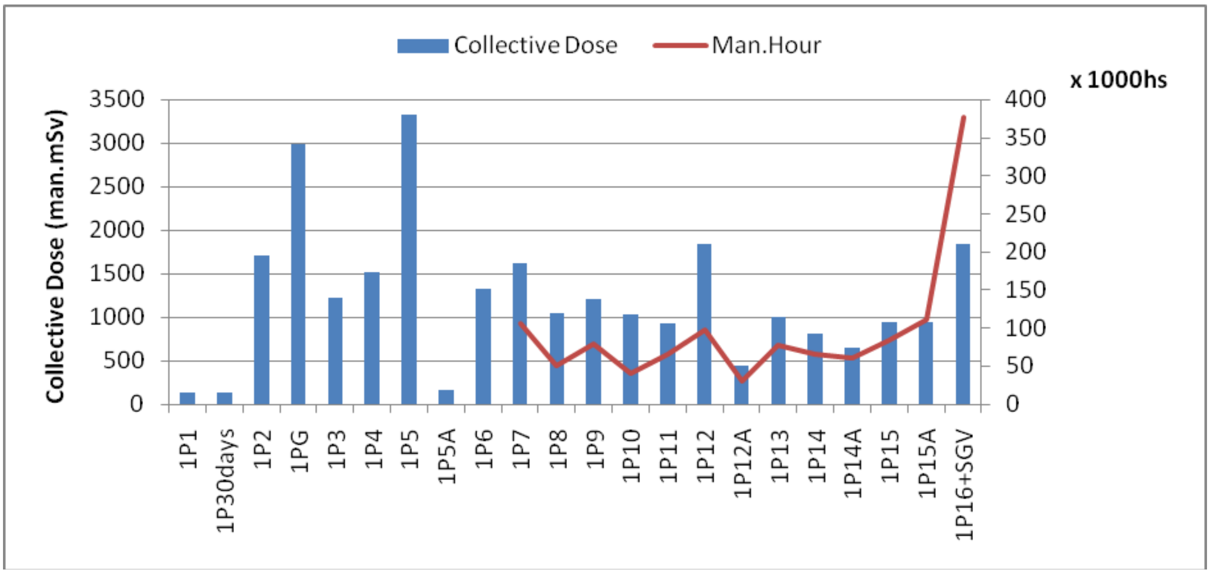

Figure 5 – Angra 1 Collective Dose in outages

The Fig. 6 shows the evolution of the average collective dose index in µSv/h, demonstrating that mostly happened because of a large increase in the hours worked inside Controlled Area, and some improvements were made to reduce this ALARA index, despite the fact that some years had an increase in the collective dose.

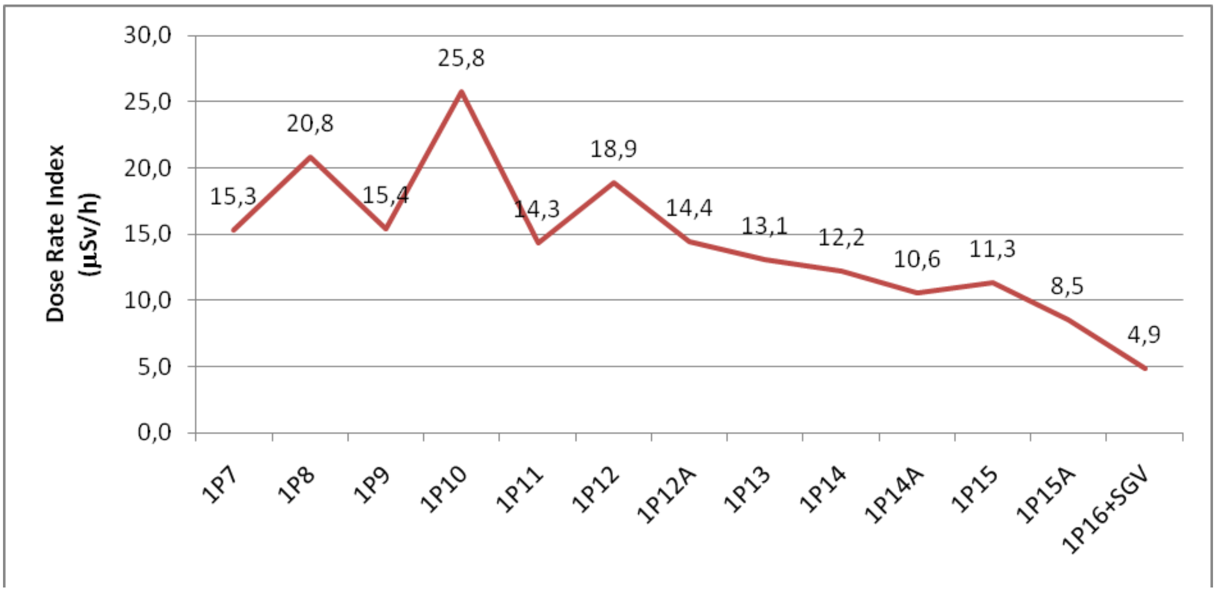

Figure 6 – Angra 1 dose rate index in outages

The Fig. 7 presents the daily numbers both for people and entries inside Controlled Area. The peak was 1,401 persons inside Controlled Area and 3,060 entries in Controlled Area in a day. The average number of people and entries of entire outage were, respectively, 767 persons and 1,697 entries per day. It illustrates the RP concerns, considering that the main quantity of workers were Brazilian contractors, not skilled in working in radiological Controlled Areas, as some international contractors.

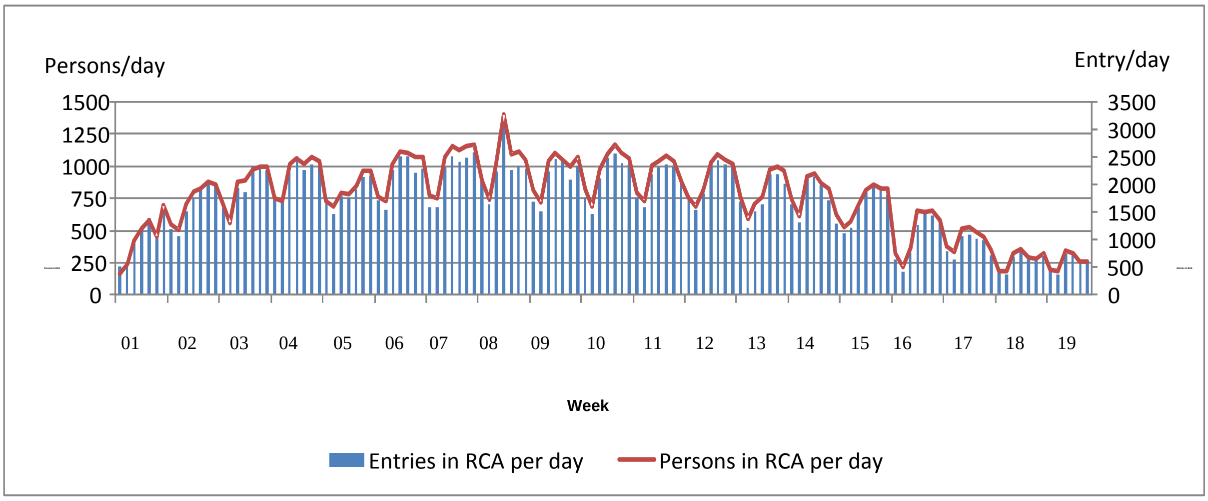

Figure 7 – Angra 1 – trend for people and entries in the Radiological Controlled Areas

The Fig. 8 shows the reduction achieved in the collective dose index, as the shielding was installed; the controls were in place and, by last, after the removal of the OSG.

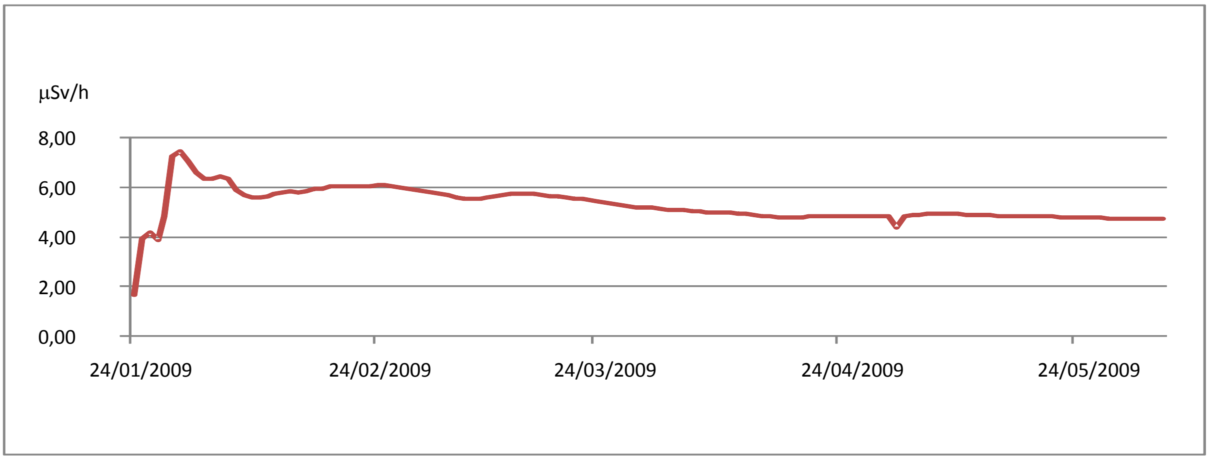

Figure 8 – Angra 1 – Dose rate index for SGR

Fig. 9 shows the average dose per person and per entry. Again, it is visible in the end of outage the effect of the source term reduction due the removal of the OSG.

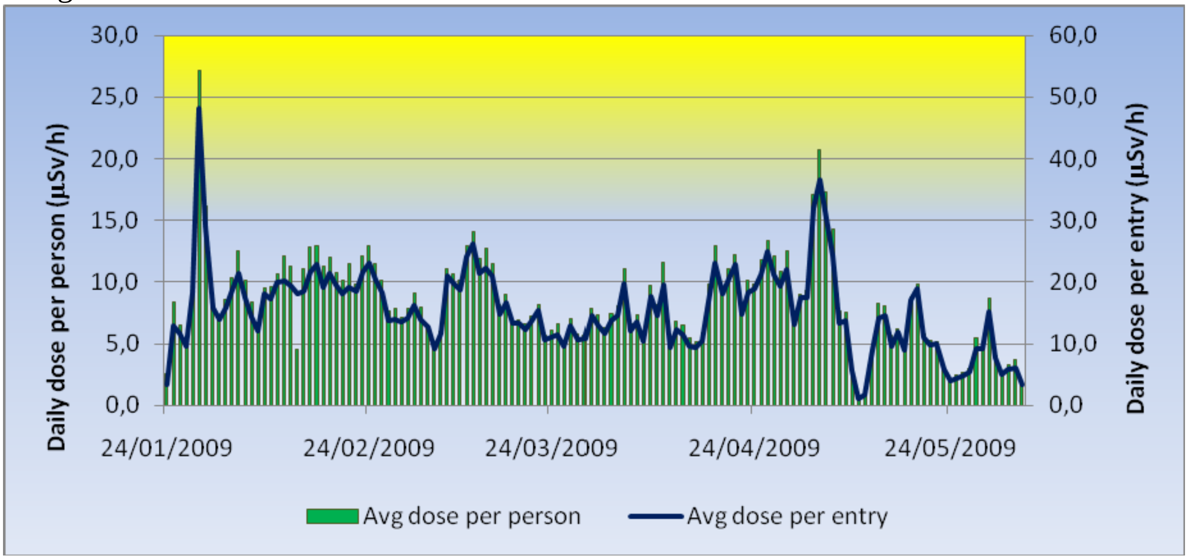

Figure 9 – Angra 1 – Average dose per person and per entry in the SGR

5. CONCLUSION

The Angra 1 Steam Generator Replacement represented an enormous challenge for the Eletronuclear RP Organization. Not only because it was a really big job, but also because some changes in the managerial posts. The Angra 1 RP Supervisor, in 2006, was promoted to RP Manager so, it was also necessary to prepare a new RP Supervisor of Angra 1. It was done with success, the RP Plan for SGR was evaluated by EPRI and considered a strong set of plans; almost all the provisions in the RP Plan were implemented before or during the SGR.

The SGR completed brought new challenges for the Angra 1 organization. First, the Plant Superintendent established for the new outages a term no more than 30 days. Second, the Eletronuclear Operations Directorate established a target in three years to achieve the median value for WANO collective radiation exposure indicator.

For the Eletronuclear RP organization, the two targets of Operations Directorate mentioned above has the meaning that much more manpower will be involved in tasks inside the Controlled Area at the same time. Anticipating this situation, the RP Manager started a process to install the remote monitoring technology, which was partially used during the SGR and was successful. A complete system of CCTV was planned to be installed until the 1P18 Angra 1 outage, but for the next outage the RP organization intends to install temporary cameras and radio system, in order to face the outage reduction term challenge.

Another powerful tool is the use of temporary shielding, not more only intending to shield the high dose rates, but now aiming to reduce the low dose rates fields in areas with high occupation rate and elevated people transit.

The post SGR primary chemistry also is a matter of attention, considering that some plants faced an increase in source term related to the ^{58}Co. Those experiences are being considered for the present cycle and the next plant outage shutdown.

By last, the new RP Technicians need to be trained accordingly, much more now when the new Plant – Angra 3 is again in construction, and the RP Training Group will play a fundamental role for the RP Technicians quality for the incoming years.

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