2015 International Nuclear Atlantic Conference - INAC 2015
São Paulo, SP, Brazil, October 4-9, 2015
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: **978-85-99141-06-9**

PROCEDURE TO EVALUATE THE IONIZING RADIATION INFLUENCE OVER LED AND MAGNETIC INDUCTION LAMPS

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ABSTRACT

The goal of this paper is to present a methodology to evaluate the ionizing radiation influence over Lighting Emitting Diode (LED) and Magnetic Induction (MI) lamps as they use a lot of electronic in their power supply. Considering they have a huge lifetime it is interesting to apply this technology into environments under ionizing radiation, such as a nuclear facility. Thus, it is possible to increase the period between two consecutive maintenances, reduce the repair and global maintenance costs and reduce the operational personnel exposure to ionizing radiation.

In this context it is going to be presented a scheme to select different LED and MI lamps available in the Brazilian market, a methodology to irradiate several lamp samples according various radiation levels that can be found in the facilities and the electrical and photometric evaluation to be performed. Considering this methodology it will be possible to analyze the lamps capacity to withstand ionizing radiation, under regular operating conditions of the facilities and its effects in the performance and lifetime of the selected lamps.

Thus, the procedures suggested in this work can be used as a guide to perform experiments and analysis to find specific lamps that can reduce the global maintenance costs and the personnel exposure. Hereafter, several lamps are going to be acquired and the tests performed, according the procedures here described.

1. INTRODUCTION

Two specific types of lamps, known as Lighting Emitting Diode (LED) and Magnetic Induction (MI), have called attention as they are considered a technological trend in illumination systems [1]. In most of the cases they comply with the required quality in illumination and energy efficiency as well. Considering they have a huge lifetime it is interesting to apply this technology into environments under ionizing radiation, such as nuclear facilities. Thus, it is possible to increase the period between two consecutive maintenances, reduce the repair and global maintenance costs and reduce the operational personnel exposure to ionizing radiation.

The first high power LED was developed in the beginning of 1990 decade. At that time it had a lower efficiency than the currently existing solutions, but it paved the way to the development and application of this technology [2]. In the beginning it was aimed to indoor use and most of the available products, in the Brazilian market, were used for decoration purposes [2]. Nowadays it is possible to find several products for industrial environment from suppliers' portfolio.

In industrial applications LED lamps are being used in such places where many hours of daily utilization are required or the replacing process is cumbersome or expensive (in an operational point of view) [3]. Usually, this category of equipment presents a higher cost when compared to regular ones, so the benefits, besides the lifetime, are associated to the low power consumption, allied to an energy bill reduction [4, 5].

All the above aspects can be applied to the MI lamps, as they also have a higher cost but a higher lifetime, even more than the LEDs one. In the same way they are very well suited in such places where maintenance aspects are demanding or expensive [6].

The MI lamps were first described in 19th century, when Nikola Tesla demonstrated its working principle, in 1891 [7]. Just at the beginning of 2000 decade this type of lamps has become commercially interesting. The reasons are related to the power electronics improvements in the equipment supply [8] associated to the acquired knowledge about plasma behavior and providing efficient ways to excite the confined gas [9].

During the development of this work many LED suppliers in the Brazilian market were found, but only one when it comes to MI lamps. In both cases it is important to highlight solutions that can be directly applied to existing facilities, which can reduce global costs of retrofit projects.

As any other illumination technology LED and MI lamps have both positive and negative aspects. Thus, their main characteristics are going to be presented in the next topic with focus on the potential effects of ionizing radiation on these equipments.

2. LED AND MI LAMPS CHARACTERISTICS

Extensive literature about LED and MI lamps is available. It covers many aspects of these devices, such as constructive details [3, 10, 11, 12], energy efficiency [3, 4, 5, 13], lifetime [9, 14], practical applications [3, 4, 5, 15], retrofit projects [3, 10, 11, 16], environmental issues, financial analysis [10, 13, 15, 16] and electromagnetic compatibility [6, 9].

In this context the main characteristics of these equipments are presented as a guide to the concerns related to the ionizing radiation equipment exposure.

2.1. LED Lamps

It must be clear that LED lamps are devices/equipments that use lighting emitting diodes as a light source.

The white light production can be obtained by 3 different methods. The first one consists in mixing the light produced by 3 or more monochromatic substrates, which are usually red, green and blue (RGB). The others methods use the light conversion through using phosphors, in the same way fluorescent lamps do. One of them uses an ultra violet band emitting diode, which is absorbed by phosphor and reemitted into the visible spectrum band. Another one uses a blue LED (InGaN chip) plus a phosphor coating. In this case part of the blue spectrum band passes directly through the phosphor coating and the other part is absorbed and reemitted into the green, yellow and red spectrum bands [10, 12, 17].

In general the basic ballasts to supply the LED lamps are DC-DC power converters. Usually, Buck, Boost or Buck-Boost converters are used. The power supply, used in RGB equipments, can individually control each light source (red, green and blue LEDs) to produce white light. It provides additional degrees of freedom towards a continuous emission spectrum [11].

The basic parts that constitute a LED lamp are the LED itself (solid state component), the printed circuit board (PCB) which can contains several light sources, heat exchangers, an optical apparatus, control circuits and the power supply [3].

2.2. Magnetic Induction Lamps

The light production process in the MI lamps is, basically, the same as in the regular discharge lamps, through a gas. The fundamental difference is that the MI lamps operate without electrodes [8, 9].

Regular discharge lamps use the electrodes as a physical way of connection with an exterior power source, then supply the plasma with electrons. Existing electrodes are the most fail prone components in this kind of equipment, limiting their lifetime [6, 8, 9].

The MI lamp can be regarded as a kind of transformer where the plasma, confined, is the secondary winding with one turn [8, 9].

To create the discharge, within the vessel, and activate the lamp it is necessary to use electronic ballast, which can induce the discharge through 3 different ways. The first one is the capacitive radio frequency discharge (CRFD) where RF electrodes can be placed inside or outside the vessel and produce a displacement current ($\partial D / \partial t$) through the plasma using frequencies less than 1GHz. The second one is to produce and maintain the discharge through the plasma using the electric and magnetic field produced by induction coils (inductive RF discharge – IRFD) at frequencies of some MHz. These coils can be mounted outside the vessel. The third method is the wave sustained discharges (WRFD) where the electric and magnetic waves are incident on the plasma surface. Typical work frequencies are about GHz [9]. The method to be used depends on the application of the lamp, but it must be clear that the electronic ballast is an essential component of this kind of illumination equipment.

2.3. Concerns about Ionizing Radiation Potential Damages

Both technologies use electronic ballasts to supply the lamp itself. It is know that ionizing radiation can damage (or reduce the lifetime) electronic equipment, so the first concern is related to potential damages to the ballast.

It is important to observe the amount of available information of ionizing radiation effects in several electronic components found in ordinary ballast [18, 19, 20, 21]. In the present step of this work there is no interest in the effects over a specific component, but the overall effects over the whole equipment.

In case of induced damages to the ballast disturbances are expected in the input rated voltage (V) and current (A). The same can occur to the output voltage (V), current (A) and frequency (Hz).

Another point of concern is related to the light source in LED equipments. As the source is a solid state element it can be damaged by ionizing radiation exposure, with consequent variations in the output radiant flux (lm) of the equipment.

In the same way there are concerns about variations in the radiant flux (lm) caused by damage (or modifications) in the fixture structure. It is known that long exposure to ionizing radiation can reduce the transmittance of the glass [18] therefore reducing the efficiency of the fixture.

3. UTILIZATION AREAS AND ITS REQUIREMENTS

This work aims to contribute specifically to the Brazilian facilities. So, illumination Brazilian standards [22] and some specific facilities were considered, as described below.

3.1. Angra 1 – Nuclear Power Plant

The area of interest is composed, basically, by the contention area of Angra 1. In this area it is possible to find the nuclear reactor itself, two steam generators, a pressurizer and many other auxiliary equipments as well.

The pool hall is located at the top of the reactor pool and its illumination is provided by the equipments installed at the contention ceiling (20m high). They are responsible to produce a minimum illuminance of 200lux [22] at the reactor pool hall and the worst expected environmental conditions are 50ºC and 95% of humidity.

Another area of interest, within contention, is the underwater illumination system. Each equipment provides a radiant flux of 19400lm to supply the reactor pool.

It must operate under environmental conditions between 40ºC and 58ºC and 10m maximum depth (underwater equipment). It is important to observe that these requirements are complied by most of illumination equipments.

The underwater radiological environment to be considered brings a total dose of $4x10^4$Gy ($4x10^6$rad) integrated over a period of 40 years. In the other hand the total dose to be considered in the ceiling is $4x10^2$Gy ($4x10^4$rad) during the same 40 years. So, a linear dose rate will be assumed along the lifetime of the equipment (which is smaller than 40 years) to establish the total dose to be applied.

All of these requirements have guided the performed equipments selection.

3.2. Brazilian Multipurpose Research Reactor

In the reactor building the area of interest, within confinement, is the level -6.0m. In this level is possible to find the primary cooling pumps and its associated pipes. In the same way there are equipments related to the heavy water systems, resins system, decay tank and others.

The required illuminance is about 200lux (minimum value), as it is similar to an industrial area [22]. The environmental conditions are regular and temperatures above 40ºC and humidity higher than 85% are not expected to be found. Most of illumination equipments comply with those requirements.

According the calculations developed during the preliminary design a typical radiological environment (-6.0m level) with a dose rate of $250x10^{-6}$Gy/h was considered [23]. Such dose rate only applies during reactor operation, corresponding to 28 days per month, so it is necessary to attenuate this number in order to reproduce the total dose during the equipments lifetime.

Thus, $240x10^{-6}$Gy/h (28 days per month) was used to calculate to the total dose in a whole year, which leads us to about 2Gy. So, this value will be used to calculate the equivalent dose rate.

All of these requirements have guided the performed equipments selection.

3.3. Radiopharmacy Facility at IPEN

In this facility the area of interest is the inner part of the existing hot cells. In this case the main concern is to reduce the personnel exposure due maintenance activities [24].

The minimum required illuminance of 200lux in the manipulation area (inside the hot cell) is easy to be achieved as the maximum hot cell high is about 1,5m. The environmental conditions are regular temperatures above 40ºC are not expected to be found. Most of illumination equipments comply with those requirements.

Considering the existence of many hot cells, to produce various products, it was considered the harshest radiological environment (^{99}Mo hot cell). A simulation has been performed by IPEN's Shielding Group using SCALE [25] software considering an activity of 17TBq inside a 3,4cm x 3,4cm x 10cm vessel. It results in a simulated dose rate of $230x10^{-3}$Gy/h. Such dose rate only applies during production (6 hours per week), so it is necessary do attenuate this number in order to reproduce the total dose during the equipments lifetime.

Thus, 230×10^{-3}Gy/h (6 hours a week) was used to calculate the total dose in a whole year, which leads us to about 72Gy. So, this value will be used to calculate the equivalent dose rate.

All of these requirements have guided the performed equipments selection.

4. EXISTING AND SELECTED EQUIPMENTS

According the photometric and physical requirements above described several equipments were analyzed from 9 different suppliers and 4 equipments were selected. The equipments already used in the facilities were considered as a reference.

Table 1 presents information about the existing illumination system in the areas previously described. The different suppliers were identified by numbers.

Table 1: Characteristics of the existing equipments

Facility	Supplier	Fixture utilization	Power (W)	Type	Radiant flux (lm)	Lifetime (h)
IPEN Radiopharmacy	1	No	42	Compact Fluorescent Integrated	2650	8000
	1	No	20	Fluorescent Tubular	1300	7500
Angra 1	2	Yes	500	Incandescent	10850	1000
	2	Yes	1000	Halogen (underwater)	19400	4000

Analyzing the areas of interest is possible to define two different kinds of illumination system, independently of the facility, plus the underwater.

The first one (group 1) considers equipments (fixture and lamps) to be used in places with a minimum high of 20m. So, the equipments that match this requirement were selected.

The second group (group 2) considers equipments to be used in places with a reduced high, such as laboratories, offices corridors or hot cells. The equipments that match this requirement were selected as well.

Table 2 presents information about the LED and MI selected equipments of illumination systems that could be applied to the facilities (and environments) here considered.

Table 2: Characteristics of the selected equipments

Group	Fixture utilization	Power (W)	Type	Radiant flux (lm)	Lifetime (h)
1	Yes	220	LED	18075	50000
1	Yes	200	MI	17000	100000
2	Yes	23	LED Tablet	1480	30000

2	No	40	MI Bulb	3000	30000
Underwater	Yes	510	LED	30000	36000

5. IRRADIATION TESTS

After the illumination equipments selection it was important to organize information about the total dose of each area or facility. Thus, Table 3 presents the calculated equivalent dose rate (Gy/h) of each facility of interest, which represents an average dose rate during the lifetime of the facility.

Table 3: Equivalent dose ratio (Gy/h) of each facility

	Angra 1 Ceiling	Angra 1 Underwater	RMB -6.0m level	IPEN Radiopharmacy
Total dose (Gy)	400	40000	2	72
Period (years)	40	40	1	1
Equivalent dose rate (Gy/h)	0,0011	0,1142	0,0002	0,0082

Considering the rated lifetime of the equipments and the equivalent dose rate they are going to be submitted it was possible to calculate the total dose (Gy) accumulated in it during its entire utilization period within the facility.

Table 4 consolidates the total dose to be accumulated in the equipments of the selected illumination systems.

Table 4: Total dose accumulated in the equipments

Lamp lifetime (h)	Angra 1 Ceiling (Gy)	Angra 1 Underwater (Gy)	RMB -6.0m level (Gy)	IPEN Radiopharmacy (Gy)
30000	34	3425	7	246
36000	41	4110	8	296
50000	57	5708	11	411
100000	114	11416	23	821

The highlighted cells correspond to those to be used in the facility identified by the column. So, only these total doses are going to be considered to organize a schedule to irradiate the illumination equipments previously selected.

Through the analysis of the highlighted doses it was possible to define the following methodology to evaluate the capacity of the equipments withstands the ionizing radiation. The goal is to irradiate the equipments at the IPEN’s ^{60}Co Multipurpose Irradiator according the pre defined total doses.

According Table 4 there are 5 different total dose values of interest. They were approximated to establish different levels of total dose to be applied to the equipments. The values are 60Gy, 120Gy, 250Gy and 4110Gy. The 7Gy value is not going to be used as it corresponds to a low dose to the equipments here considered [26].

It is important to note that equipments of group 2 (places with a reduced high) are going to be tested for a Radiopharmacy conditions and the values of total dose to be applied are greater than Angra 1 ceiling. So, during the results analysis it is essential to observe that if they are approved they can be applied to Angra 1 contention area (access areas, platforms, etc.).

To perform the irradiation tests it was defined to use 4 samples of each equipment. The first equipment will serve as a reference and will be evaluated (electrical and photometric tests) without being irradiated. The other 3 samples will be irradiated in a staggered way, so it was defined 3 stages of accumulated dose to each sample.

The Fig. 1 presents the organization of the irradiation tests to be done at the IPEN's ^{60}Co Multipurpose Irradiator.

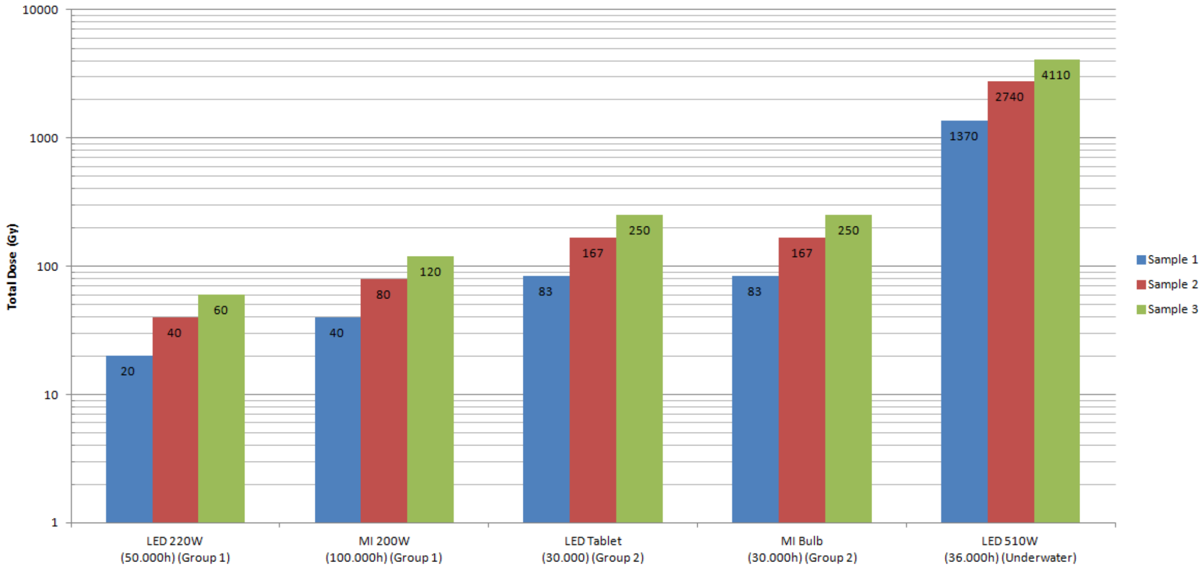

Figure 1: Organization of the irradiation tests to be done.

As soon as the doses are reached for specific equipment it is necessary to evaluate the electric and photometric parameters to verify potential damages or degradation.

6. ELECTRICAL AND PHOTOMETRIC EVALUATION

Considering the main characteristics of LED and MI lamps it was defined some parameters to perform the electrical and photometric evaluation, such as input/output voltage (V) and current (A) wave forms, power factor (cos(φ)), active power (W), reactive power (VAr) and apparent power (VA) as well. In the same way it will be necessary to measure the radiant flux (lm) produced by the lamps (with fixture), illuminance at 1m (lux) and luminous efficiency (lm/W) as well.

This evaluation will be performed for the 4 samples of each equipment. Thus, it will be possible to construct a graph comparing each electrical and photometric parameter as a function of total dose absorbed by the sample, which will allow evaluating potential damages or degradation in the samples.

After the comparison process will be possible to verify what equipments could operate in a specific ionizing radiation environment and support the environmental conditions without degradation. It is important to detach that even with a potential reduction in some equipment lifetime is important to compare the measured lifetime with the one of the existing equipment. In case to find a greater lifetime it can be interesting to use this equipment to increase the maintenance period and, consequently, reduce the personnel exposure.

As soon as the selected equipments were acquired all the evaluation here described will be performed and the details of the electrical and photometric tests are going to be addressed in a future work.

7. CONCLUSIONS

This work has presented a scheme to proper select illumination equipments as a function of the existing one in various nuclear and radioactive Brazilian facilities.

It was shown the total dose to be applied in each equipment and simulate its lifetime effects in an ionizing radiation consequences point of view. In the same way electrical and photometric variables to be analyzed after the irradiation process (considering the main characteristics of LED and MI lamps) were indicated.

Finally, the acquisition of electrical and photometric parameters, before and after the irradiation will allow verifying the capacity of the equipments to withstand the ionizing radiation environment.

The next step of this work is ongoing and the authors are acquiring the illumination equipments to apply the methodology here described. The expectation is to irradiate the equipments in the second semester of 2015 and produce the final results in the beginning of 2016.

The results to be obtained can contribute to increase the period between two consecutive maintenances, reduce the repair and global maintenance costs and reduce the operational personnel exposure to ionizing radiation in the facilities here cited.

ACKNOWLEDGMENTS

The authors thank Eletrobrás Termonuclear, IPEN’s Radiopharmacy Radiological Protection and Infrastructure team by the information about the dose rates in the facilities. The authors also thank the IPEN’s Nuclear Engineering Center Shielding Group by the simulations performed, IPEN’s ^{60}Co Multipurpose Irradiator for the information exchanged during the development of this work and IPEN/MB-01 staff for many useful suggestions made to this work.

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