A CRITICAL REVIEW OF AN EXTREMITY MONITORING PROGRAM AT THE INSTITUTO DE ENGENHARIA NUCLEAR IN BRAZIL

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Abstract

Eventually, the cyclotron of the Instituto de Engenharia Nuclear (IEN) may need maintenance. Its components are made of copper and they became highly activated after irradiations producing extensive $^{65}\text{Zn}$ sources. The individual monitoring of the maintenance workers is based on film badges and TLD rings. Both systems are calibrated in terms of "Photon Dose Equivalent" and the extremity dosemeter is not able to discriminate the gamma and beta contributions to the total dose. Conservatively, it was possible to estimate, using another extremity dosemeter, that beta doses received by the workers' hands are three times higher than the gamma doses. Considering this result, and the ring TL responses, it was possible to estimate $Hp(0.07)$, in the case of the hands, for all the IEN cyclotron maintenance workers, since 1983. The results show that $Hp(0.07)$ values are about 2.88 times higher than the previous reported extremity doses in mSv.
INTRODUCTION

The Instituto de Engenharia Nuclear (IEN) is one of the operational units of the Comissão Nacional de Energia Nuclear (CNEN) and it is located at the Federal University site, Rio de Janeiro. Research and development on several nuclear areas are performed at IEN. The controlled areas of IEN are the research Argonaut Reactor, the cyclotron CV-28, the radioisotope processing laboratories, the alpha laboratory, the radioactive waste laboratory and the radioprotection equipment calibration laboratory. The activity that presents the highest collective dose is the cyclotron maintenance, which contributes with 59\% of the IEN's collective dose\(^1\).

The cyclotron CV-28, operates mainly for \(^{123}\)I and \(^{67}\)Ga production for Nuclear Medicine with proton beam and as a fast neutron source through \(D(d,n)^{3}\)He reaction. As most of the internal components of the cyclotron are made of copper, the proton and deuteron irradiation produce undesirable extensive \(^{65}\)Zn sources\(^2\). Eventually, the cyclotron needs preventive or corrective maintenance, which, most of the times, consists of ion-source cathode exchange, water leakage repair, vacuum problems and deoxidisation of components. The maintenance is more complex as there are few spares parts available. The maintenance of the internal component parts of the cyclotron is always made on Mondays to permit the decay of the short half-life radionuclides during the weekend. At this time, the main radionuclide found is the \(^{65}\)Zn, which decays by electron capture and positron emission and emits photons of 1115.5keV and 8keV and positrons of 325keV, with a half-life of 244.1 days\(^3\). The radiological risks associated with these activities result from exposure to gamma-rays, beta particles and due to contamination.

The radiation protection quantity for individual monitoring recommended by the International Commission on Radiation Units and Measurements (ICRU) is defined as the Personal Dose Equivalent, \(H_p(d)\), in soft tissue at a depth \(d\) below a specified point on the body. The recommended depth \(d\) for strongly penetrating radiation is 10mm and for weakly penetrating radiation is 0.07mm for the skin and 3mm for the lens of the eye\(^4\).

The Brazilian individual dosimetry system, provided by the Instituto de Radioproteção e Dosimetria (IRD) is calibrated only for photon fields in terms of "Photon
Dose Equivalent". The objective of this work is to reassess the extremity doses of the cyclotron maintenance workers, considering the beta component of the external irradiation and so, estimating the $Hp(0.07)$ values since 1983 and to analyse its impact on the current radiological protection procedures.

THE RADIATION PROTECTION PROGRAM FOR EXTERNAL IRRADIATION

The radiological protection program$^5$ for external irradiation for the cyclotron maintenance of the cyclotron was designed by the Radiological Protection Service of IEN and it is implemented and improved whenever needed. It consists of a preventive procedure including survey of the cyclotron and the component parts, workplace survey, wipe test and air monitoring. The maintenance is always followed up by a radiation protection technician that takes care of operational radiation protection procedures such as: checking the use of appropriate protective clothing and individual monitors, timing the operations that involve high dose rates and suggesting special procedures and gaskets to reduce radiation doses. Figure 1 shows a schematic representation of the cyclotron CV-28 with indications of some component parts. The typical results of the cyclotron survey during maintenance are presented in table 1. The measurements were made with a Babyline 20 with and without the external envelope in order to assess respectively the deep and shallow dose. Routinely, quite only $^{65}$Zn is detected in wipe tests and in liquid effluent. Very seldom $^{184}$Re is found. The personal monitoring is performed with film badges, TLD rings and direct reading pen dosemeter. Except for the last one, the dosemeters are provided monthly by the IRD. The extremity monitoring at the cyclotron was introduced by 1983. The contamination control is performed with the use of radiation protection clothing and there are contamination monitors at the exit of these areas.

Brazilian Extremity Dosimetry System

For extremity individual monitoring, the IRD uses a very simple ring dosemeter. It is manufactured in plastic and has a small cavity where a commercial LiF:Mg,Ti (TLD-100) $3x3x0.9\text{mm}^3$ chip from the Harshaw Chemical Company is placed. The TL
detector is covered with a small piece of paper and a very thin aluminium adhesive label with the IRD logotype.

IRD's extremity dosemeter is calibrated in a Plexiglas finger phantom, with a $^{60}$Co calibrated source, in terms of "Photon Dose Equivalent" (6). Therefore, considering the thickness of the TLD-100 chips for low energy beta radiation, this dosemeter presents a high energy dependence, as it is shown in Figure 2, where its response to beta rays with energies between 60 and 800keV in terms of $Hp(0.07)$ is presented.

REASSESSMENT OF EXTREMITY DOSES DUE TO $^{65}$Zn

The present TL ring dosemeter used at IEN, manufactured by IRD, does not allow to discriminate the gamma and beta contributions to the total $Hp(0.07)$. Using another TL extremity dosemeter (7), based on four CaSO$_4$:Dy.PTFE 0.20mm thick pellets, produced at Instituto de Pesquisas Energéticas e Nucleares (IPEN), but capable to discriminate gamma and beta doses, it was possible to estimate, conservatively, that beta doses, $Hp_\beta(0.07)$, received by the workers' hands are three times greater than gamma doses, $Hp_\gamma(0.07)$ (8).

$$Hp_\beta(0.07) = 3.Hp_\gamma(0.07) \quad (1)$$

The total thermoluminescence yielded by the TLD-100, $TL_T$, is composed by a component due to gamma radiation, $TL_\gamma$, and another one due to beta radiation, $TL_\beta$.

$$TL_T = TL_\gamma + TL_\beta \quad (2)$$

The $Hp_\beta(0.07)$ and $Hp_\gamma(0.07)$ may be written, respectively, as:

$$Hp_\beta(0.07) = f_\beta . TL_\beta \quad (3)$$

and

$$Hp_\gamma(0.07) = f_\gamma . TL_\gamma \quad (4)$$

where $f_\beta$ and $f_\gamma$ are, respectively, the calibration factors for beta and gamma radiation, in terms of $Hp(0.07)$.

Using equations (1), (2), (3) and (4), one gets, with a little algebra,

$$TL_\beta = \frac{3.f_\gamma . TL_T}{(f_\beta + 3f_\gamma)} \quad (5)$$
Considering the relation (5) and the fact that $f_{c\beta}^{(65Zn)} = 7.69.f_{c\gamma}^{(60Co)}$ (6):

$$T_{L\beta} = 0.2806. T_{LT}$$
$$T_{L\gamma} = 0.7194. T_{LT}$$

The personal dose equivalent, $H_p(0.07)$ is the sum of $H_p\beta(0.07)$ and $H_p\gamma(0.07)$. Since the effective energy of the gamma radiation of $^{65}$Zn is high, $f_{c\gamma}^{(65Zn)}$ may be assumed as being equal to $f_{c\gamma}^{(60Co)}$. According to (3), (4) and (6):

$$H_p(0.07) = 7.69 x 0.2806. T_{LT}. f_{c\gamma}^{(60Co)} + 0.7194. T_{LT}. f_{c\gamma}^{(60Co)}$$

(7)

Following ICRP 60(9) and ICRU 43(10), for the $^{60}$Co energy, $H_p(0.07)$ value approaches the effective dose, $E$, value for AP geometry. Therefore, considering, for simplicity, $f_{c\gamma}^{(60Co)}$ equal to one, it follows:

$$H_p(0.07) = 2.88. E$$

(8)

where $E$ is estimated conservatively through the assessment of "Photon Dose Equivalent".

RESULTS

The multiplication factor obtained in equation 8 was applied to the extremity photon dose equivalent received by the cyclotron's workers. The results presented in table 2 show the annual extremity superficial doses, $H_p(0.07)$, since 1983 for two engineers and five technicians. The doses are clearly higher in the first year of the monitoring due to the frequency of maintenance and to gradual implementation of radiation protection procedures.

CONCLUSIONS

The extremity doses in terms of photon dose equivalent received by the cyclotron maintenance workers were reassessed in view of the $H_p(0.07)$ quantity, considering exposure to $^{65}$Zn source. The results obtained when taking into account the contribution of beta radiation show that the $H_p(0.07)$ doses are about 2.88 times higher the previous reported extremity doses. Although the workers annual dose didn't exceed the respective limit, these results should be taken into account in order to optimise the radiological protection procedures during IEN cyclotron maintenance. The present simple TL
dosemeter used at IEN should be improved or changed to another dosemeter with at least
two components, to be able to discriminate the beta and gamma radiation contributions and
to evaluate more accurately \( H_p(0.07) \).

REFERENCES


FIGURE CAPTIONS

FIGURE 1 - Schematic representation of the cyclotron CV-28. (1) Deflector; (2) D's; (3) Probe; (4) Ion source.

FIGURE 2 - Energy response of IRD extremity monitor in beta radiation fields. Calibration in terms of Hp(0.07).
TABLE CAPTIONS

TABLE 1 - Typical dose rates inside the cyclotron three days after the last irradiation.

TABLE 2 - Annual extremity doses (mSv) of the cyclotron maintenance workers, estimated in terms of Hp(0.07).
Relative response to $^{90}\text{Sr}/^{90}\text{Y}$

Mean energy (keV)
<table>
<thead>
<tr>
<th>Component</th>
<th>Distance from the surface (cm)</th>
<th>Shallow dose (mSv/h)</th>
<th>H*(10) (mSv/h)</th>
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<tbody>
<tr>
<td>Deflector</td>
<td>5</td>
<td>41.2</td>
<td>14.7</td>
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<tr>
<td>D's</td>
<td>10</td>
<td>3.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Probe</td>
<td>10</td>
<td>7.5</td>
<td>3.7</td>
</tr>
<tr>
<td>Ion source</td>
<td>15</td>
<td>2.2</td>
<td>1.6</td>
</tr>
<tr>
<td>-----------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>J.A.D.F. (Eng.)</td>
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<td>7.37</td>
<td>2.02</td>
</tr>
<tr>
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<td>R.G.S. (Tech.)</td>
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