FEASIBILITY STUDY OF EXTREMITY DOSEMETER BASED ON POLYALLYLDIGLYCOLCARBONATE (CR-39) FOR NEUTRON EXPOSURE

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In nuclear facilities, some activities such as reprocessing, recycling and production of bare fuel rods expose the workers to mixed neutron–photon fields. For several workplaces, particularly in glove boxes, some workers expose their hands to mixed fields. The mastery of the photon extremity dosimetry is relatively good, whereas the neutron dosimetry still raises difficulties. In this context, the Institute for Radiological Protection and Nuclear Safety (IRSN) has proposed a study on a passive neutron extremity dosemeter based on chemically etched CR-39 (PADC: polyallyldiglycolcarbonate), named PN-3, already used in routine practice for whole body dosimetry. This dosemeter is a chip of plastic sensitive to recoil protons. The chemical etching process amplifies the size of the impact. The reading system for tracks counting is composed of a microscope, a video camera and an image analyser. This system is combined with the dose evaluation algorithm. The performance of the dosemeter PN-3 has been largely studied and proved by several laboratories in terms of passive individual neutron dosemeter which is used in routine production by different companies.

This study focuses on the sensitivity of the extremity dosemeter, as well as its performance in the function of the level of the neutron energy. The dosemeter was exposed to monoenergetic neutron fields in laboratory conditions and to mixed fields in glove boxes at workplaces.

INTRODUCTION

Some activities in nuclear industry and particularly at specific workplaces in glove boxes expose the workers’ hands to mixed neutron–photon fields. The extremity dosemeters are mostly needed to optimise the exposure of the workers’ hands at workplaces. Even if the lithium fluoride TLD (FLi-700) dosemeter seems well adapted for photon extremity dosimetry, the neutron extremity dosemeter needs to be developed. To meet those needs, the Institute for Radiological Protection and Nuclear Safety (IRSN) in association with Atomic Energy Commission (CEA) has been studying a passive neutron extremity dosemeter based on chemically etched CR-39 (named PN-3). The prototypes of neutron extremity dosemeters were tested during measurement campaigns at IRSN and CEA in their neutron metrology laboratories and at AREVA NC-Cadarache in its mixed fields in glove boxes at workplaces during the year 2005. Today in this kind of workplaces, the extremity dosimetry proposes to workers is the wrist photon dosemeter.

This paper presents the experimental results in laboratory conditions and at the different facilities. In a first stage, the result of the extremity dosemeter PN-3 irradiated by monoenergetic neutron fields and ISO neutron sources was compared to the reference values. In a second stage, the evaluation of the neutron and photon dose equivalent was studied to define the gradient of doses for the hand.

MATERIAL AND METHODS

Description of the dosemeter

The neutron dosemeter named PN-3 is based on the chemical etching process of polyallyldiglycolcarbonate (PADC) material. This detector made of solid plastic material is sensitive to recoil protons which create damage tracks inside. The tracks are amplified by chemical etching attack process. The number of tracks is assessed by an image analysis reading system, which is composed of a microscope, a video camera and an image analyser. For each dosemeter, the system which collects the number of tracks is combined with an algorithm in order to evaluate the radiation protection quantity dose equivalent.

Concerning the evaluation of photons, the extremity dosemeter lithium fluoride, named FLi-700, is employed. The detection principle is widely known by several laboratories. The small size of this kind of dosemeter was well suitable to fingers.

Description of the campaigns

The dosemeters PN-3 and FLi-700 have been tested in two phases since 2005. The first one consisted in the measurement of monoenergetic neutron fields for PN-3 at CEA Bruyères le Châtel (Figure 1) and of photon fields for FLi-700 at IRSN and also of
fields generated by a thermal facility (SIGMA)\(^{1}\), realistic spectrum (Canel/T400)\(^{2,5}\), radionuclide ISO sources\(^{4}\) (\(^{241}\)Am–Be; \(^{252}\)Cf; \(^{252}\)Cf(D\(_{2}\)O)/Cd, \(^{137}\)Cs and \(^{60}\)Co) in IRSN laboratory. The second phase was carried out at AREVA NC-Cadarache in a fuel processing factory. Measurements were performed in glove boxes (Figure 2), at the production of bare fuel rods, near a rack of storage fuel and close to the storage pot of fuel. Eight tests were performed at workplaces (four measurement at storage pot of fuel PuO\(_{2}\), two at bare fuel rods, one with a pastille fuel and one in a glove box with contamination of U, PuO\(_{2}\)). At those specific workplaces which were composed of mixed fields, the part of neutrons and photons was evaluated with extremity dosemeters.

The dosemeters were fixed on an ISO finger phantom or wrist phantom made of polymethylmethacrylate (PMMA) in order to define the sensitivity of dosemeters and on a hand made of tissue equivalent material MIXD water\(^{5}\) in order to represent the gradient dose equivalent of the hand of workers. These dosemeters were irradiated in the experimental conditions as close as possible to the routine operations.

The result of the analysis proposed a method in order to evaluate the fingers dose equivalent for neutrons and photons and to define the ratio between the experimental results for fingers and wrist.

### RESULTS AND DISCUSSION

For the extremities, the radiation risk is evaluated at a depth of 0.07 mm inside the tissue. For this purpose, the operational quantity appropriated, as defined by ICRU, is named the personal extremity equivalent dose \(H_p(0.07)\). \(H_p(0.07)\) is widely known and applied to evaluate the photon fields\(^{6}\). However, for the neutrons, the extremity quantity\(^{7}\) has not, as yet, been completely defined by the ICRU\(^{8}\). In this context, \(H_p(0.07)\) is used for photons and \(H_p(10)\) is applied for neutrons. Consequently in the case of a feasibility study, the analysis of measurement results remains relative.

#### Measurement in laboratory condition

Figure 3 presents the extremity photon and neutron dosemeter results of monoenergetic fields. The response corresponds to the ratio between the values of the dosemeter and the reference. The response obtained with photon dosemeter is acceptable in terms of radiation protection condition (±30% for photons and ±50% for neutrons). The response ranges from 0.8 to 1.2 for reference extremity dose equivalent. Regarding the response with neutron dosemeter, the ratio can be from 0.6 to 1.1 for energies ranging between 565 and 2500 keV and from 0 to 0.5 for energies ranging between 0 and 565 keV.

Figure 4 presents the result of ISO source photon and neutron fields. The response is correct, ranging from 0.5 to 1.3 for neutron dosemeter and from 0.7 to 1 for photon dosemeter.
Measurement at workplaces

The second phase consisted in the measurement of the eight specific workplaces which were composed of mixed fields. Out of eight tests performed, only one measurement is presented with all experimental values. The same method of analysis was applied to the seven others measurements, in order to propose a synthesis of the results.

Figure 5 presents the results of dosemeters fixed on a hand made of tissue-equivalent material MIXD that simulates the position of the hand about to catch the Pu storage pot. This figure shows the photon and the neutron dose equivalent rate. These values of the fingers are overall relatively homogeneous. For the photons, the middle value corresponds to 28 mSv h\(^{-1}\) for the face of the hand and 14 mSv h\(^{-1}\) for the back. Concerning the neutron, 0.9 mSv h\(^{-1}\) was obtained for the back of the hand and 0.8 mSv h\(^{-1}\) in the palm of the hand. The ratio between face and back of the hand is a factor 3 for photons and 1.6 for neutrons. The contribution of photons represents a factor 16 compared with neutrons. The value obtained on the wrist is 2 mSv h\(^{-1}\) for photons and 0.08 mSv h\(^{-1}\) for neutrons. The ratio between the fingers and wrist corresponds to a factor 7 for photons and 10 for neutrons. These values are especially high compared with the seven other results. The values of the first measurement need to be confirmed by future measurement and Monte-Carlo calculations in order to better understand the results.

Table 1 presents a synthesis of the results obtained at eight different workplaces. For each workplace, the middle dose equivalent value for the fingers was given for photons and neutrons. For each workplace studied, the values obtained with dosemeters placed on several fingers were relatively homogenous and the deviation was under 20%. For all the workplaces studied, the ratio between face and back of the hand

<table>
<thead>
<tr>
<th>Source</th>
<th>(Hp) middle of fingers ((\mu)Sv h(^{-1}))</th>
<th>Ratio photon/neutron</th>
<th>Ratio face/back of hand</th>
<th>Ratio finger/wrist</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Neutron</td>
<td>Photon</td>
<td>Neutron</td>
<td>Photon</td>
</tr>
<tr>
<td>Storage pot of fuel PuO(_2)</td>
<td>851 (\pm) 114</td>
<td>13712 (\pm) 3218</td>
<td>16</td>
<td>1.6</td>
</tr>
<tr>
<td>Storage pot of fuel PuO(_2)</td>
<td>673 (\pm) 80</td>
<td>13395 (\pm) 1999</td>
<td>20</td>
<td>1.7</td>
</tr>
<tr>
<td>1 bare fuel rods</td>
<td>6.3 (\pm) 38</td>
<td>142 (\pm) 14</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>Pastille fuel</td>
<td>133 (\pm) 23</td>
<td>1118 (\pm) 286</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Storage pot of fuel U, PuO(_2)</td>
<td>191 (\pm) 23</td>
<td>230 (\pm) 57</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>Storage pot of fuel U, PuO(_2)</td>
<td>204 (\pm) 80</td>
<td>900 (\pm) 140</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Contamination U, PuO(_2)</td>
<td>65 (\pm) 23</td>
<td>5108 (\pm) 1569</td>
<td>79</td>
<td>1</td>
</tr>
<tr>
<td>in glove box</td>
<td></td>
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</tr>
</tbody>
</table>
ranges from 1 to 2 for neutrons and from 1 to 3 for photons. Except the first measurement, the ratio between fingers and wrist is from 1 to 4.5 for neutrons and from 1 to 3 for photons. Nevertheless, the values obtained for the dose equivalent rates for the eight different experiments showed large differences arising from the several source terms and environments used for each workplace condition. In all those cases, the photons’ contribution was higher than the neutron, ranging from 1 to 20 times. Whereas for the last measurement, the ratio on photon per neutron reached 79 due to the term source which represented the contamination of Pu inside the glove box.

CONCLUSION

The photon dosemeters FLi-700 can be well suited to the radiation fields at laboratory condition and at the workplaces in nuclear industries. The prototype neutron dosemeters PN-3 is adapted to fields for energy ranging from 565 keV to 1 MeV. These dosemeters PN-3 can be adapted in the workplaces studied, because the energy fields emitted by Pu is around 1 MeV. At this stage of the study, the preliminary results show some discrepancies that will lead to further study concerning the prototype.

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REFERENCES