Radiological risks from irradiation of cargo contents with EURITRACK neutron inspection systems

E. Giroletti a,*, G. Bonomi b, A. Donzella b, G. Viesti c, A. Zenoni b

a Dipartimento di Fisica Nucleare e Teorica dell'Università di Pavia and INFN Sezione di Pavia, 8 Via Bassi, I-27100 Pavia, Italy
b Dipartimento di Ingegneria Meccanica e Industriale dell'Università di Brescia, 38 Via Branze, I-25123 Brescia, Italy
c Dipartimento di Fisica ed Astronomia dell'Università di Padova, 8 Via Marzolo, I-35131 Padova, Italy

Abstract

The radiological risk for the population related to the neutron irradiation of cargo containers with a tagged neutron inspection system has been studied. Two possible effects on the public health have been assessed: the modification of the nutritional and organoleptic properties of the irradiated materials, in particular foodstuff, and the neutron activation of consumer products (i.e. food and pharmaceuticals). The result of this study is that irradiation of food and foodstuff, pharmaceutical and medical devices in container cargoes would neither modify the properties of the irradiated material nor produce effective doses of concern for public health. Furthermore, the dose received by possible stowaways present inside the container during the inspection is less than the annual effective dose limit defined by European Legislation for the public.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

The passage across borders of illicit materials such as drugs and explosives in cargo containers poses a serious threat to civil populations. The European EURITRACK 6th Framework Program project (2004–2008) was aimed at developing a cargo inspection system based on the innovative tagged neutron inspection system technique (TNIS; Nebbia et al., 2004; Pesente et al., 2007; Viesti et al., 2005). The EURITRACK inspection portal, in the following referred to as “EURITRACK system”, consists of a source of 14 MeV tagged neutron beams and a large gamma detector array positioned around the container.

Different from commercial systems based on X-ray or γ-ray radiography, the EURITRACK system is able to directly determine the chemical composition of suspect goods by looking to the spectrum of the neutron induced gamma rays. A prototype of the EURITRACK system has been constructed (Donzella et al., 2007; Lunardon et al., 2007; Perot et al., 2007), installed in 2007 and subsequently operated until 2010 at the Rijeka seaport, Croatia, also in the frame of the follow-up European Erirtr@C project (2008–2010; Carasco et al., 2008; Obhodas et al., 2010).

One of the aims of the Erirtr@C project, subject of this work, has been to assess the hazard associated with the irradiation by 14 MeV neutrons of goods, in particular foodstuff, pharmaceuticals and medical devices. Possible effects induced by the ionizing radiation, posing risks to the public health, are of two types. The first one concerns possible modifications of the nutritional and organoleptic properties of the irradiated materials, especially foodstuff. The second one derives from the radio-nuclides produced via neutron activation inside the inspected goods. This radioactivity can give an effective dose to the population either via ingestion or via irradiation (e.g. in the case of medical devices).

In this work the irradiation levels, calculated with the MCNP Monte Carlo code (X-5 Monte Carlo Team, 2003) for a second generation EURITRACK system, are compared with the limits stated by international and European regulation for the irradiation of foodstuff. Calculations by MCNP for activation of container goods occurring during irradiations are also performed. A comparison of the results obtained in this work with the ones obtained for a similar system, namely the Pulsed Fast Neutron Analysis (PFNA) inspection system (Brown et al., 1994; Brown and Gozani, 1995; Rynes et al., 1999), is also presented.

Finally, the dose received by an inadvertently exposed individual (stowaway) present inside the inspected truck is evaluated.

2. EURITRACK system

The main elements composing the EURITRACK system, as in the prototype installed at the seaport of Rijeka, are presented in Fig. 1. The mechanical structure of the portal supports a set of 16 12.5 cm × 12.5 cm × 25 cm NaI(Tl) gamma detectors (top detectors) placed above the container. A neutron source with two cylindrical...
as previously reported, two aspects have been investigated in this work. the first one concerns possible modifications of the properties of the irradiated goods. This aspect is relevant for foodstuffs, whose nutritional and organoleptic properties must not be altered or modified by any treatment. the second concerns the possibility to induce activation, which may result in contamination and committed doses to individuals after irradiated food ingestion.

3. Monte Carlo calculations

The effects of container irradiation with X-rays, electron beams or neutrons have been investigated in the past (Easterly et al., 2003; Findlay et al., 1992; Food and Drug Administration, 1977; Reports of the Scientific Committee for Food, 1997; Ryge et al., 1992; Slater et al., 2000; Tenforde, 2002). Following the studies performed to assess effects and risks for the public health, public authorities in different countries and in particular in Europe have adopted norms to regulate the use of ionizing radiation (Directive 1999/2/EC, 1999; Directive 1999/3/EC, 1999; Food and Drug Administration, 1977; List of Member States’ Authorizations, 2006).

As previously reported, two aspects have been investigated in this work. The first one concerns possible modifications of the properties of the irradiated goods. This aspect is relevant for foodstuffs, whose nutritional and organoleptic properties must not be altered or modified by any treatment. The second one concerns the possibility to induce activation, which may result in contamination and committed doses to individuals after irradiated food ingestion.

4. Irradiation of consumer products

The EURITRACK system is intended to be a second level control portal, to perform an interrogation of a specific region of interest identified in first level X-ray or γ-ray images of the cargo. At the first level, custom agents verify that the shape and apparent density of items inside the cargo container, as they appear in the X-ray image, are consistent with the custom declaration. In cases of suspect items, the truck moves towards the EURITRACK system, where the tagged neutron beam axis crosses the suspicious volume in the container, as defined by the X-ray first level scanning. The EURITRACK system works with a typical interrogation time on the order of 600 s.
4.1. Alteration of foodstuff nutritional and organoleptic properties

The European Union adopted the Directives 1999/2/EC (Directive 1999/2/EC, 1999) and 1999/3/EC (Directive 1999/3/EC, 1999) to regulate the irradiation of foodstuff for preservation. An implementation of the Directive 1999/2/EC defines the list of foodstuffs which may be treated with ionizing radiation and the maximum absorbed doses authorized in different Member States (List of Member States’ Authorizations, 2006). It is important to note that these Directives do not apply to “foodstuffs exposed to ionizing radiation generated by measuring or inspection devices, provided that the dose absorbed is not greater than 0.01 Gy for inspection devices which utilize neutrons and 0.5 Gy in other cases, at maximum radiation energy level of 10 MeV in the case of X-rays, 14 MeV in the case of neutrons and 5 MeV in other cases” (Directive 1999/2/EC, 1999).

In the USA, the norms are contained in the US Food and Drug Administration Report 21 CFR Part 179 (Food and Drug Administration, 1977). US-FDA norms are coherent with the European directives.

In the EURITRACK prototype, equipped with a single neutron source, the irradiation with 14 MeV neutrons causes an absorbed dose of less than 0.01 Gy that has been considered safe for preservation of nutritional and organoleptic properties of foodstuff. In the case of the second generation design, the dose absorbed in a typical irradiation with the EURITRACK system will be larger. Consequently, the absorbed dose has been estimated by MCNP calculation of a container filled by Red Delicious apple crates, indicated with yellow boxes in Fig. 2.

The elemental composition of the Red Delicious apples has been simulated, with a density of about 1.0 g/cm³, using the prescription in Rivadeneira et al. (2007). The absorbed dose has been assessed for different positions inside the container using a MCNP “type 6 tally” estimator (X-5 Monte Carlo Team, 2003), that calculates the neutron energy deposition averaged over the volume of the crate containing the apples (gray boxes and corresponding MCNP tally numbers in Fig. 2). The calculation has been performed both in proximity of the tagged monochromatic neutron beam source, where a larger component of fast neutrons emerging through the polyethylene collimators is expected (gray boxes 16 and 36), and in positions far from the tagged beam axis (gray boxes 6 and 26), where the beam spectrum is affected to a larger extent by a low energy neutron component caused by the moderation inside the polyethylene shield. A smaller further box (46), centered on the beam axis, has been added to calculate the dose in a critical position where the fast neutron flux reaches its maximum. Samples of the results from Monte Carlo calculations are shown in Fig. 3, where the absorbed dose in a given energy bin, received by foodstuff in positions 26 and 36 in 600 s irradiation time, is plotted as a function of the neutron energy. Moreover the absorbed doses are also listed for the different positions in Table 1.

As expected, the absorbed dose is larger at the positions along the tagged beam directions, that is in the gray boxes 16, 36 and especially 46, where the fast neutron beam intensity is not lowered by the polyethylene collimators. In all the cases, however, sampled values of the absorbed doses are safely orders of magnitude lower than the 0.01 Gy limit stated in the European Community and in the USA. This result assures that the absorbed dose will be lower than the 0.01 Gy limit also in the case of more than one neutron inspection, as when a few voxels are suspect in the same container.

4.2. Induced activation in goods and foodstuff

Several studies on the effects of neutron irradiation on goods are available, with reference to the PFNA neutron irradiation system (Easterly et al., 2003; Findlay et al., 1992; Food and Drug Administration, 1977; Reports of the Scientific Committee for Food, 1997; Ryge et al., 1992; Slater et al., 2000; Tenforde, 2002).
Concerning irradiation of foodstuff, a common result of the PFNA studies is that the committed dose induced by irradiation is lower than the one characteristic of non-irradiated food and only due to the natural radioactivity in the same food. On the basis of some of these studies, Food and Drug Administration concluded that consumption of food inspected by a source of monoenergetic neutrons between 1 MeV and 14 MeV in the PFNA conditions is safe (Food and Drug Administration, 1977). The European Scientific Committee for Food concluded, based on the same studies, that surveillance devices using neutron scanning, in particular PFNA systems operating at up to 14 MeV, which during interrogation do not impart to foodstuff radiation doses greater than 0.01 Gy, raise no safety concerns because of the negligible induced radioactivity on the neutron irradiated foodstuffs (Reports of the Scientific Committee for Food, 1997). Furthermore, the opinion of the National Council on Radiation Protection and Measurement (NCRP) for irradiation of pharmaceuticals and medical devices by PFNA systems is that activation would not result in effective doses of concern for public health (Tenforde, 2002).

Although different in a number of technical aspects, the two systems, PFNA and EURITRACK, are based on the same principle of fast neutron interrogation. Therefore, in spite of the differences, it is possible to establish a quantitative comparison, considering that the results obtained for the PFNA system in Tenforde (2002) are referred to a specified total fast neutron fluence of $6.4 \times 10^5$ n/cm$^2$ at the surface of the scanned container. In addition, an equivalent fluence of thermal neutrons has been considered inside the container cargo for the PFNA system, that is equivalent to assuming that every fast neutron is reduced to thermal energy in the container, or is scattered back into it after being thermalized in the surrounding shielding. By scaling the conditions in which these results have been obtained for the PFNA system with the parameters characterizing the second generation EURITRACK system, the conclusions drawn for the PFNA system can be considered valid also in our case.

In the configuration described in Section 3, the neutron fluencies in different positions inside the container have been calculated using a MCNP "type 5 point detector tally", an estimator that gives the particle flux value in a specific position in space (X-5 Monte Carlo Team, 2003). The positions where the neutron fluencies are sampled are shown in Figs. 4 and 5, with the corresponding MCNP tally number.

In Fig. 6 the spectral neutron fluencies at the two extreme positions of Figs. 4 and 5 where the integrated values are respectively the lowest (point 5) and the highest (point 15) are shown. Total fluence and thermal contribution (on left of the dotted line) are reported on the plots.

Finally, neutron fluencies are reported in Table 2 for all the different positions shown in Figs. 4 and 5. At the positions 15, 55, and 115, which are aligned with the beam axis, the fluence is higher and the maximum of $6.4 \times 10^5$ n/cm$^2$ is reached for the position 15, where a large fast neutron component is present. On the contrary, at positions located off axis inside the container, as in positions 5, 25 and 35, the spectrum has a lower fast neutron component (see Fig. 6 for position 5). In general, the fluence decreases rapidly, as expected, from near on axis positions to far off axis positions.

These results show that values of neutron fluencies in our case are comparable to or lower than the fast neutron fluence value of $6.4 \times 10^5$ n/cm$^2$ taken as a reference by NCRP (Tenforde, 2002) for the PFNA project. It is worth recalling that, in the PFNA calculations, the same fluence was assumed for the thermal components of the neutron beam, too. Therefore, the same results obtained for the PFNA system may be reasonably considered valid also for our system.

### 4.3. MCNP direct calculation of induced activation

To confirm our assessment, a direct evaluation by MCNP of the activation during irradiations has been performed in two relevant cases of nuclear reactions producing the $^{24}$Na$^1$ radionuclide.

The NCRP report on PFNA systems (Tenforde, 2002) addresses the question as to whether the levels of activation products in

---

Table 1

<table>
<thead>
<tr>
<th>Position inside the container</th>
<th>Absorbed dose in a 600 s irradiation (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box 6</td>
<td>$8.1 \times 10^{-9}$</td>
</tr>
<tr>
<td>Box 16</td>
<td>$1.2 \times 10^{-6}$</td>
</tr>
<tr>
<td>Box 26</td>
<td>$1.8 \times 10^{-9}$</td>
</tr>
<tr>
<td>Box 36</td>
<td>$4.2 \times 10^{-6}$</td>
</tr>
<tr>
<td>Box 46</td>
<td>$2.1 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

---

Footnote 1: The $^{24}$Na nucleus is a beta emitter with a half-life $T_{1/2} = 15$ h, which decays into $^{24}$Mg, mainly emitting an electron with 0.554 MeV average energy (end point 1.39 MeV) and two gamma rays in cascade, 2.754 MeV and 1.369 MeV energy.
Fig. 4. Top view of the EURITRACK long tunnel design with the container filled with apple crates. The little circles indicate the positions where the neutron fluences are sampled.

Fig. 5. Side view of the container filled with apple crates. The little circles indicate the positions where the neutron fluences are sampled.

Fig. 6. Spectral fluences calculated inside the container at positions 5 and 15 of Figs. 4 and 5. The irradiation time is 600 s. In the plots total fluence and thermal contribution (on left of the dotted line) are reported, as well as the height of the point inside the container.
pharmaceuticals and medical devices might be of concern to public health. In the case of pharmaceuticals, the $^{24}\text{Mg}(n,p)^{24}\text{Na}$ fast neutron reaction is likely to produce the highest absorbed dose from $^{24}\text{Na}$ activated product, because relatively large amounts of magnesium may be consumed in one day by a person as MgOH (milk of magnesia). The highest absorbed dose from $^{24}\text{Na}$ in a thermal neutron capture reaction results from $^{23}\text{Na}(n,\gamma)^{24}\text{Na}$, because of the relatively high amount of natural sodium contained as, for example, in isotonic saline solution administered intravenously. In the case of food, the highest dose is associated to $^{24}\text{Na}$ produced in the same capture reaction in salty processed food such as potato chips, but the doses will be less than those found for pharmaceuticals. Other fast or thermal neutron reactions may occur with similar absorbed dose rates, but the consumed amounts of these elements in the public are supposed to be much lower (Tenforde, 2002).

To study the production of the $^{24}\text{Na}$ radionuclide during irradiation in the second generation EURITRACK system, the same set-up configuration and conditions described in Section 3 have been considered. In addition, ten 5 cm radius spheres have been distributed within the Red Delicious apple crates inside the container. Five of them were made of natural Mg ($^{24}\text{Mg}$ 78.99%, $^{25}\text{Mg}$ 10%, $^{26}\text{Mg}$ 11.01%, 1.74 g/cm$^3$ density) and the remaining of $^{23}\text{Na}$ (0.97 g/cm$^3$ density), which is the only isotope present in the natural sodium composition. In Fig. 7 the positions of the ten spheres inside the container are shown, with the corresponding MCNP tally number.

In Table 3 the results of the simulated activation of natural Mg and $^{23}\text{Na}$ are summarized. The average fluence in the Mg and $^{23}\text{Na}$ spheres has been calculated by MCNP with a “type 4 tally”. Using the cross sections for the $^{24}\text{Mg}(n,p)^{24}\text{Na}$ and $^{23}\text{Na}(n,\gamma)^{24}\text{Na}$ reactions imbedded in MCNP (X-5 Monte Carlo Team, 2003), the total number $N_0$ of generated $^{24}\text{Na}$ radionuclides per unit mass in the different spheres has been estimated for a 600 s irradiation.

The spheres at positions 4 (Mg) and 54 ($^{23}\text{Na}$) are placed along the neutron beam axis, where the neutron fluence is the largest. As expected, activation in spheres positioned off axis is much lower, in particular for Mg, since the fast neutron component is strongly reduced. In each case the number of generated $^{24}\text{Na}$ radionuclides per milligram inside the spheres is less than unity.

Assuming a conservative hypothesis that during the 600 s irradiation no activated $^{24}\text{Na}$ radionuclide disintegrates, $N_0$ radionuclides per unit mass are still present in the spheres immediately after the irradiation. The number of the remaining radionuclides per unit mass after 24 h from irradiation time has been calculated using the radioactive decay law; the corresponding activity per unit mass (concentration) is also reported in Table 3.

Finally, the absorbed dose received by an individual in the case of ingestion of the activated material has been evaluated, following the same calculations performed by NCRP (Tenforde, 2002), i.e. supposing a uniform distribution of the radioactivity in the body (whole body irradiation). In Table 3 the absorbed doses are reported for an individual of 50 kg weight in the case of ingestion.

Table 2

<table>
<thead>
<tr>
<th>Position and height inside the container</th>
<th>Fluence in a 600 s irradiation ($n/cm^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point 5, h2</td>
<td>$7.3 \times 10^2$</td>
</tr>
<tr>
<td>Point 15, h2</td>
<td>$6.4 \times 10^3$</td>
</tr>
<tr>
<td>Point 25, h1</td>
<td>$7.7 \times 10^2$</td>
</tr>
<tr>
<td>Point 35, h2</td>
<td>$7.8 \times 10^2$</td>
</tr>
<tr>
<td>Point 45, h2</td>
<td>$3.8 \times 10^2$</td>
</tr>
<tr>
<td>Point 55, h2</td>
<td>$3.2 \times 10^2$</td>
</tr>
<tr>
<td>Point 65, h1</td>
<td>$3.6 \times 10^4$</td>
</tr>
<tr>
<td>Point 75, h2</td>
<td>$1.3 \times 10^4$</td>
</tr>
<tr>
<td>Point 85, h2</td>
<td>$1.4 \times 10^3$</td>
</tr>
<tr>
<td>Point 95, h2</td>
<td>$1.7 \times 10^3$</td>
</tr>
<tr>
<td>Point 105, h1</td>
<td>$1.1 \times 10^4$</td>
</tr>
<tr>
<td>Point 115, h2</td>
<td>$3.2 \times 10^2$</td>
</tr>
<tr>
<td>Point 125, h2</td>
<td>$1.8 \times 10^4$</td>
</tr>
</tbody>
</table>

Fig. 7. Top view of the EURITRACK long tunnel design with spheres made of natural Mg and $^{23}\text{Na}$ inside the container. Spheres have 5 cm radius; nos. 4, 34, 44, 54 and 84 are positioned at the neutron source height, nos. 14, 24, 64 and 74 are positioned 50 cm below the neutron source level.
Table 3
Neutron activation of natural Mg and Na spheres, dispersed inside the container, during a 600 s irradiation with the second generation EURITRACK system. The position of the sphere inside the container is reported in the first column; the material composition of the sphere and the corresponding weight are reported, respectively, in the second and in the third columns; the total number \( N_0 \) of \( ^{24}\text{Na} \) radionuclides per unit mass generated in the sphere during a 600 s irradiation and the \( ^{24}\text{Na} \) concentration after 24 h from irradiation are reported in the fourth and in the fifth columns; the absorbed doses due to possible ingestion of 10 g of activated magnesium or 10 g of activated sodium uniformly distributed in the body of an individual of 50 kg weight are reported in the sixth column (according to the NCRP method; Tenforde, 2002).

<table>
<thead>
<tr>
<th>Sphere position</th>
<th>Composing material</th>
<th>( W ) (mg)</th>
<th>( N_0 ) (nuclei/mg)</th>
<th>Concentration ( A_{24\text{Na}} ) (Bq/kg)</th>
<th>Absorbed dose ( (\mu\text{Gy}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>( ^{24}\text{Mg} )</td>
<td>( 9.12 \times 10^5 )</td>
<td>0.78</td>
<td>3.3</td>
<td>( 3.8 \times 10^{-8} )</td>
</tr>
<tr>
<td>14</td>
<td>( ^{24}\text{Mg} )</td>
<td>( 9.12 \times 10^5 )</td>
<td>( 9.0 \times 10^{-4} )</td>
<td>( 3.8 \times 10^{-3} )</td>
<td>( 4.4 \times 10^{-11} )</td>
</tr>
<tr>
<td>24</td>
<td>( ^{24}\text{Mg} )</td>
<td>( 9.12 \times 10^5 )</td>
<td>( 1.9 \times 10^{-3} )</td>
<td>( 8.0 \times 10^{-5} )</td>
<td>( 9.3 \times 10^{-11} )</td>
</tr>
<tr>
<td>34</td>
<td>( ^{24}\text{Mg} )</td>
<td>( 9.12 \times 10^5 )</td>
<td>( 1.3 \times 10^{-3} )</td>
<td>( 5.5 \times 10^{-5} )</td>
<td>( 6.4 \times 10^{-11} )</td>
</tr>
<tr>
<td>44</td>
<td>( ^{24}\text{Mg} )</td>
<td>( 9.12 \times 10^5 )</td>
<td>( 1.9 \times 10^{-3} )</td>
<td>( 8.0 \times 10^{-3} )</td>
<td>( 9.3 \times 10^{-11} )</td>
</tr>
<tr>
<td>54</td>
<td>( ^{23}\text{Na} )</td>
<td>( 5.08 \times 10^6 )</td>
<td>0.60</td>
<td>2.5</td>
<td>( 9.6 \times 10^{-9} )</td>
</tr>
<tr>
<td>64</td>
<td>( ^{23}\text{Na} )</td>
<td>( 5.08 \times 10^6 )</td>
<td>( 6.6 \times 10^{-2} )</td>
<td>( 2.8 \times 10^{-1} )</td>
<td>( 1.1 \times 10^{-9} )</td>
</tr>
<tr>
<td>74</td>
<td>( ^{23}\text{Na} )</td>
<td>( 5.08 \times 10^6 )</td>
<td>( 7.2 \times 10^{-2} )</td>
<td>( 3.0 \times 10^{-1} )</td>
<td>( 1.2 \times 10^{-9} )</td>
</tr>
<tr>
<td>84</td>
<td>( ^{23}\text{Na} )</td>
<td>( 5.08 \times 10^6 )</td>
<td>( 1.4 \times 10^{-2} )</td>
<td>( 5.9 \times 10^{-2} )</td>
<td>( 2.3 \times 10^{-10} )</td>
</tr>
<tr>
<td>94</td>
<td>( ^{23}\text{Na} )</td>
<td>( 5.08 \times 10^6 )</td>
<td>( 1.7 \times 10^{-2} )</td>
<td>( 7.2 \times 10^{-2} )</td>
<td>( 2.8 \times 10^{-10} )</td>
</tr>
</tbody>
</table>

Therefore, considering an uniform irradiation, the dose received in one single inspection of 600 s is not larger than 0.25 mSv. Even if the minimum distance source–individual were 50 cm, the corresponding neutron dose would be about 1 mSv.

When the container is filled with an organic, inorganic or mixed matrix, the dose received by an individual inadvertently exposed may depend on the shielding effect of the interposed materials, on the diffusion and degradation of the direct neutron beam by hydrogenated materials and on the exact position of the individual inside the container. Nevertheless, a provisional calculation for a container partially filled with organic stuff stacked in columns gives, at different positions close to the beam axis, doses not very different from the ones obtained with a void container.

Considering that, in the case of uniform irradiation and for all the ISO geometries, \( f^*(10) \) represents quite well the effective dose, the dose assessed is less than the annual dose limit stated by international and European regulations for the population (1 mSv of effective dose; Council Directive 96/29/Euratom, 1996).

Because the calculated dose values are of the order or less than \( 10^{-6} \) mSv, it has not been considered sensible to proceed with further studies in this field.

5. Inadvertently exposed individual (stowaways)

The probability of a stowaway irradiation in the cargo is low in our case, given the availability of the prior X-ray image of the container content. Nevertheless, the radiological risk also has to be considered.

With the irradiation set-up described in Section 3, the energy dependent neutron and photon fluences have been calculated at the center and close to the wall of a container by means of a “type 5 point detector tally” (X-5 Monte Carlo Team, 2003). The fluences have been then converted into ambient dose equivalent \( H^*(10) \), using the ICRP conversion coefficients (ICRP, 1996). The cargo has been simulated both void and full of organic, to have fast and low energy neutrons (Chichester, 2007).

In the extreme case of a stowaway hidden at the center of a void container, the resulting value for the neutron dose rate is about 750 mSv/h, whereas the contribution from photons is at least a factor of 100 lower and may be neglected. Close to the container walls, on the axis of the neutron beam to about 1 m distance from the neutron generator, the dose rate increases by about a factor of 2.

These coefficients may slightly change according to new statements of the ICRP (ICRP, 2007).

6. Conclusions

In the present work, possible risks connected with the irradiation of goods and in particular foodstuff, pharmaceuticals and medical devices, by tagged neutron inspection systems as in the case of EURITRACK portals have been assessed, in view of the development of second generation systems in which two neutron generators will be used. Two aspects of the problem have been analyzed. The first one concerns the possible modifications of the properties of irradiated goods. The second one concerns the activation induced by neutrons in goods and in particular in foodstuff and pharmaceuticals.

Norms adopted by the European Union and by the USA state that irradiation with neutron beams of 14 MeV, which cause an absorbed dose of less than 0.01 Gy, can be considered safe for preservation of nutritional and organoleptic properties of foodstuff. Calculations of the absorbed dose, after neutron irradiation, by food at different positions inside a container in typical conditions for the second generation EURITRACK system, show amounts, in the worst case, several orders of magnitude lower than the above limit of 0.01 Gy.

Common results of studies on the effects of activation from inspected foods, pharmaceuticals and medical devices performed...
specifically for the PFNA system indicate that the effective doses to the population resulting from inspection (ingestion of irradiated goods) are not harmful to public health. By means of Monte Carlo calculations, these comfortable results have been successfully scaled to our system conditions. The committed dose potentially received by a person of the public is many orders of magnitudes less than the annual dose limit (1 mSv). So, the conclusion that cargo containers can be inspected with the second generation EURITRACK system without any limitation due to the type of transported goods may be drawn.

Finally, the possible irradiation of inadvertently exposed individuals (stowaways) has been considered, even though such an event is extremely unlikely in a second level control portal, as the EURITRACK system follows an X-ray imaging device. The calculations show that, in the extreme case of a stowaway hidden in a container, the maximum effective dose received is less than the annual dose limit internationally stated for the population.

Acknowledgments

This work is supported by the European Commission, Directorate General Justice, Freedom and Security under the program Prevention and Fight against the Crime 2007, through the Eritrac project, JLS/2007/ISEC/55030-CE-0179232/00-41.

References


List of Member States’ Authorizations of Food and Food Ingredients Which may be Treated With Ionizing Radiation. 2006/C 112/05.


