Application of a Calculational Model for Thermal Neutrons Through Biological Shields

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Abstract

In this work a computational program, based on the Boltzman transport integro-differential equation, is applied. The scattering kernel is represented by the synthetic scattering model.

The behaviour of thermal neutrons in hydrogenous materials, which can be used as biological shields, are studied. These materials are water, polyethylene, Oak-Ridge concrete, ordinary concrete and manganous concrete.

The data obtained are presented in tables. The results are analysed and compared with similar experimental values. Safety evaluation and environmental impact are discussed.
Introduction

The detection and calculation of thermal neutrons are straightforward. Many theoretical and experimental techniques are used. Most methods were developed for reactor physics and radiation shielding design.

The study of the behaviour of thermal neutrons through hydrogenous shielding materials, which can be used as biological shields, is very important. It has many applications in medicine and nuclear safety.

The case of an infinite homogeneous shielding system will be studied as function of energy. The Boltzmann transport equation is written as, (1,2):

\[ \hat{L} \hat{\varnothing} = S \hat{\varnothing} \quad (1) \]

where the operators \( \hat{L} \) and \( \hat{S} \) are defined as :

\[ \hat{L} \hat{\varnothing} = (\Sigma_a + DB^2) \hat{\varnothing} \quad (2) \]

\[ \hat{S} \hat{\varnothing} = \int \Sigma_s (E \rightarrow E') \hat{\varnothing}(E') dE' - \Sigma_s (E) \hat{\varnothing}(E) \quad (3) \]

Were :
\( \varnothing \) is the neutron spectrum as function energy,
\( \Sigma_a \) is the macroscopic absorption cross-section,
\( \Sigma_s \) is the macroscopic scattering cross-section,
\( D_2 \) is the diffusion coefficient,
\( B \) is the geometric buckling, and
\[ S \Sigma_s (E \rightarrow E) \hat{\varnothing}(E') \quad (E') dE' \] is the scattering kernel.

The effect of the hydrogen content in the shielding materials is taken into consideration (3), it is essential for reactor safety. The materials studied, are frequently used in nuclear reactors. The number densities of the constituents depend upon the geographical location.

The Calculational Equations

Introducing the slowing-down density to equations (1) :

\[ \frac{dq}{dE} = S \hat{\varnothing} \quad (4) \]

\[ i-e \quad \hat{L} \hat{\varnothing} = \frac{dq}{dE} \quad (5) \]

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After some mathematical manipulations, the transport equation and the differential operator in the synthetic model has the form:

$$\frac{d}{dx} \varphi(x) = j(x)q(x) - \frac{d}{dx} \left( k(x) \frac{dq(x)}{dx} \right)$$  \hspace{1cm} (6)

where $x = M(x)$ is the Maxwellian spectrum.

$j(x)$ and $k(x)$ are two energy function depending on molecular characteristics of the medium.

$$j(x) = \frac{1}{\sum_{s}^{n} x^{2} e^{-x}}$$  \hspace{1cm} (7)

$$k(x) = \frac{1}{\sum_{s}^{n} x^{2} e^{-x}}$$  \hspace{1cm} (8)

Where $\sum_{s}^{n}$ is given in the associated Laguerre polynomials. A computer program is done on VAX 6000 to calculate the mathematical equations (6), (7) and (8).

**Inputdata**

The hydrogeneous shielding materials are mixtures of various elements of different atomic densities, the composition of these materials varies widely. The number density of the constituents are taken from ORNL -4938.

The energy dependent cross-sections are taken from references (4), (5) and (6). The number of the group energy is 40 groups. It has the range from 0.0228 to 36.44 in KT units.

**Results and Discussions**

The results are presented in tables (1) and (2). The materials are tabulated and arranged as the hydrogen atomic density decreases. The large percent of hydrogen is in the composition of water and polyethylene. It is approximately the same. But the effect of the small difference is clear due to the value of the average energy in polyethylene and water. We can say that as the hydrogen percent, or as the number density decreases, the average energy of the thermal neutron spectrum increases.

From table (1), the effect of sodium density, in addition to the hydrogen content, gives less value of the average energy. The reason for this is that Na has a resonance absorption near the upper end of the
thermal energy range. So, one can say that the addition of sodium, with suitable amounts, makes the shielding material more safe. (It is to be noted that Na is already a constituent of the shielding used concrete)

Table (2) presents the effect of hydrogen percent and the total macroscopic cross-section on the average neutron spectrum through the hydrogenous shielding materials considered. It is clear that, as the hydrogen percent decreases, the average thermal neutron spectrum decreases. This is because the hydrogen atom is a weak absorber. The total cross section is proportional with the average thermal neutron spectrum. This cross-section can be considered as the scattering cross-section.

Conclusion

The results of the present calculational model reveal the neutronic properties of different shielding materials. This computational method could be used successfully in evaluating the biological shields of nuclear and radiation facilities for safety analysis review, in their licensing.

Moreover, this method may be applied to estimate the projected exposure doses from the operating facility and to identify the requirements, if any, to reinforce shielding.

References

2- S.A. EL Wakil, A.M. Hathout & M. Yousef, "on the synthetic scattering kernel" ATKE, 24\2, (1974),
### Table (1)

<table>
<thead>
<tr>
<th>Material</th>
<th>Hydrogen at. / b. cm</th>
<th>Sodium at. / b. cm</th>
<th>Av. Energy in KT units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene</td>
<td>0.07943</td>
<td>---</td>
<td>2.0287</td>
</tr>
<tr>
<td>Water</td>
<td>0.06674</td>
<td>---</td>
<td>2.0959</td>
</tr>
<tr>
<td>Ordinary Con.</td>
<td>0.01487</td>
<td>0.000304</td>
<td>2.0083</td>
</tr>
<tr>
<td>Oak-Ridge Con.</td>
<td>0.0085</td>
<td>0.000016</td>
<td>2.0103</td>
</tr>
<tr>
<td>Manganese Conc.</td>
<td>0.00424</td>
<td>0.000079</td>
<td>2.0088</td>
</tr>
</tbody>
</table>

Table (1) : The effect of hydrogen density and sodium density on the average neutron energy through hydrogenous shield.

### Table (2)

<table>
<thead>
<tr>
<th>Material</th>
<th>Hydrogen %</th>
<th>Av. Total Macr. cr. sec.</th>
<th>Av. Spectrum (arbitrary units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene</td>
<td>66.67</td>
<td>1.414</td>
<td>0.00193</td>
</tr>
<tr>
<td>Water</td>
<td>66.44</td>
<td>1.182</td>
<td>0.017</td>
</tr>
<tr>
<td>Ordinary Con.</td>
<td>18.67</td>
<td>0.416</td>
<td>0.00015</td>
</tr>
<tr>
<td>Oak-Ridge Con.</td>
<td>10.67</td>
<td>0.468</td>
<td>0.00016</td>
</tr>
<tr>
<td>Manganese Conc.</td>
<td>5.74</td>
<td>0.332</td>
<td>0.000144</td>
</tr>
</tbody>
</table>

Table (2) : The effects of hydrogen percent and the total macroscopic cross-section on the average neutron spectrum through the hydrogenous shield.