INVESTIGATION OF THE POWER SENSITIVITY
OF FAST-NEUTRON RADIOMETERS

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In connection with the development of nuclear power engineering, the metrological problems of dosimetric testing and, in particular, of testing the value of maximum permissible neutron fluxes, as well as the problems related to the evaluation of the precision of neutron measurements, both under industrial and laboratory conditions are acquiring an increasing practical value.

At present, fast-neutron fluxes are measured on a wide scale by means of commercial neutron radiometers RUP-1 [1], RN-3, KPN-2 [2], etc. The fast-neutron detectors in the above instruments consist of scintillation pellets B-1 and B-2 which comprise a compressed mixture of Plexiglas powder and luminous compound K-5 (zinc sulfide and activate silver) [3].

The calibration and testing of such fast-neutron radiometers is made, as a rule, by means of PoBe or PuBe sources whose emitted-neutron energy spectrum is in the range of 0 to 11 MeV with a mean neutron energy of the sources amounting to 4.5 MeV (PoBe) and 4.2 MeV (PuBe).

However, in using such radiometers it is normally necessary in practice to measure neutron fluxes with energies differing from those at which instruments were calibrated. Most frequently it is necessary to measure neutron fluxes with energies approaching the fission-neutron spectrum (in which the maximum number of neutrons is in the range with energies of about 0.8 MeV with a mean fission-neutron energy of 1.9 MeV), or with an energy of about 1 MeV or lower (measurement of dissipated neutron radiations, measurements behind shielding, etc.).

Since the sensitivity of instruments which measure neutron flux densities depend on the energy of neutrons, a possible source of errors in practical measurements may consist of nonuniform sensitivity of radiometers to neutrons with different energies. In order to evaluate the error in such measurements, we have investigated the energy sensitivity of fast-neutron radiometers RUP-1, KRAN-1, and SCH-3 [4].

The calibration of the above instruments was made by means of neutron sources with different mean energies of neutrons (see Table 1).

Sources with mean energies of 1.3 and 1.9 MeV consisted of PoBe and PuBe sources located at the center of a pure graphite sphere 20 cm in diameter. All the sources with the exception of RaBe (γ, n) had a neutron output of about 10^6 neutrons/sec, which was evaluated by the method of activating a solution of manganese sulfate.

In the course of measurements we checked the implementation of law 1/R^2 and took into consideration corrections for scattered radiations and the effective center [5, 6]. Calibrations were carried out with an open geometry and accounting for the asymmetry of the neutron output of each source.

In order to reduce the statistical error in calibration radiometers RUP-1 and KRAN-1, we replaced the pointer instrument by a scalar instrument which was connected to the output of the normalizer's emitter follower. Before calibration and in the course of it, all the instruments were tested for stable operation and reproducibility of measurements. For this purpose, a small PuBe source was used.

A working stability graph of radiometer KRAN-1 for a prolonged and continuous operation is shown in Fig. 1a. It will be seen that the dispersion of experimental points does not exceed ±25%. On the other hand, prolonged and continuous measurements with short-duration switching over

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the same time interval have shown that the dispersion of readings is reduced to ±10% (Fig. 1b).

In a general case, if the response of the detector to the energy of neutrons is known, the radiometer sensitivity \( S(E) \) can be evaluated from the formula

\[
S(E) = \eta(E) \cdot s, \tag{1}
\]

where \( \eta(E) \) is the response of a detector to neutrons with a given energy \( [6] \); \( s \) is the area of the detector's front surface.

In measuring a flux of nonmonochromatic neutrons it is possible to consider a radiometer's mean sensitivity \( \bar{S} \) referred to an energy spectrum and represented as

\[
\bar{S}(E) = \bar{\eta}(E) \cdot s, \tag{2}
\]

where

\[
\bar{\eta}(E) = \frac{\int n(E) \cdot dE}{\int n(E) \cdot dE} = \frac{\int n(E) \cdot dE}{1}. \tag{3}
\]

\( n(E) \) is the number of neutrons with energies in the range of \( E \) to \( E + dE \), provided that

\[
\int n(E) \cdot dE = 1. \tag{4}
\]

TABLE 2

<table>
<thead>
<tr>
<th>Neutron energy, MeV</th>
<th>( 1 - f(E_0) ), %</th>
<th>PoBe</th>
<th>Fission-neutron spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>22</td>
<td>5</td>
<td>22</td>
</tr>
<tr>
<td>1.0</td>
<td>25</td>
<td>10</td>
<td>31</td>
</tr>
<tr>
<td>1.7</td>
<td>64</td>
<td>25</td>
<td>64</td>
</tr>
</tbody>
</table>

In our measurements the mean sensitivity was calculated on the basis of experimental values from formula

\[
\bar{S}(E) = 4\pi \cdot \frac{N - N_\Delta(E)}{Q \cdot \alpha} \cdot [R + \Delta r(E)]^2, \tag{5}
\]

where \( N \) is the counting speed in pulses/sec; \( N_\Delta(E) \) is the counting speed in pulses/sec corresponding scattered radiations; \( Q \) is the neutron output in neutrons/sec; \( \alpha \) is the asymmetry factor; \( R \) is the distance between the center of the source and the detector; and \( \Delta r(E) \) is the effective-center correction. The technique of evaluating \( \alpha \), \( N_\Delta(E) \), and \( \Delta r(E) \) is described in [6].

The calibration of instruments with respect to neutron energies is shown in Fig. 2 (a represents radiometer RUP-1 and b, radiometer SC-3). In Fig. 2, sensitivity is expressed in relative units. The sensitivity curves for instruments RUP-1 and KRAM-1 are identical, and, therefore, this relationship is shown only for radiometer RUP-1. It will be seen from Fig. 2 that the radiometer sensitivity decreases noticeably in the range of small energies. Moreover, for radiometer RUP-1 it decreases for \( E = 1 \) MeV by 65% as compared with its sensitivity for \( E = 4.5 \) MeV (PoBe source).

For radiometer SC-3, the corresponding variations in sensitivity amount to about 45%. In this connection, it is interesting to compare the fraction of neutrons \( 1 - f(E_0) \) with energies lying below a given threshold \( E_0 \) in an energy spectrum of a PoBe source and in the spectrum of fission neutrons (Table 2).

The value of \( f(E_0) \) is determined by implementing (4)

\[
f(E_0) = \int_{E_0}^{\infty} n(E) \cdot dE. \tag{6}
\]

It is obvious that source spectra \( E_0 \) have particularly large differences in the range of small energies. It is an essential fact that this difference increases still further when fission neutrons pass through a biological shielding (a case most commonly encountered in practice of radiometric testing of a fast-neutron flux behind a shielding).