Systematic measurement of total neutron cross sections for thorium isotopes is of interest both for reactor construction and for the development of nuclear theory.

Up to 1966, only the total neutron cross section for Th\(^{232}\) was measured in the thermal region. In 1966, preliminary results were published [1] for total neutron cross section measurements in this energy region for another thorium isotope, namely for Th\(^{230}\). The measurements were made by the time-of-flight method with the neutron chopper of the Institute of Theoretical and Experimental Physics [2, 3].

It was established in [1] that the total neutron cross section of Th\(^{230}\) at thermal energy (0.025 eV) was \(\sim 70\) b. If one considers that the potential scattering cross section of Th\(^{230}\) in order of magnitude must lie in the range of values \(10-20\) b, then the value given for the cross section implies that the neutron capture cross section of Th\(^{230}\) at thermal energy does not agree with the value \(23 \pm 1\) b measured by the activation method [4]. This disagreement was not unexpected because the results of measurements of the quantity \(\sigma_g\) which were obtained in other work by the activation method and by pile oscillator methods exhibited a marked spread: \(61\) b [5]; \(28\) b, \(33\) b [6]; \(26\) b [7]; and \(21.4\) b [8]. Such a spread in the data led to the necessity for an independent measurement of the total neutron cross section of Th\(^{230}\) by the time-of-flight method.

The present work was performed for the purpose of checking the results already obtained, and is a continuation of the work in [1].

New samples of thorium were prepared for the measurements; these were carefully freed of impurities, particularly those which have large neutron cross sections in the thermal region (samarium, europium, gadolinium, etc.). On the basis of the results obtained in [1], a great deal of attention was devoted to the removal of zirconium and hafnium from the samples. The chemical process for the separation of Th\(^{230}\) and its purification is described below.

The source material employed was a protactinium–ionium concentrate, which was separated from uranium ore by a sequence of processes: leaching, precipitation, and extraction. Separation of Th\(^{230}\) from the concentrate and removal of impurities was accomplished by ion exchange in a mineral acid medium on AB-17 and KU-2 sorbents [9]. As the result of repeated anion exchange operations in a hydrochloric acid medium, the thorium isotopes were separated from the main mass of such elements as zirconium, hafnium, iron, titanium, etc. Supplementary removal of zirconium from Th\(^{230}\) was carried out on a cationite with oxalic acid. Cation exchange in hydrochloric and nitric acid media facilitated the separation of thorium isotopes from uranium, iron, and protactinium. Removal of traces of manganese, rare-earth elements, and other impurities from the samples was performed by means of ion exchange in sulfuric acid media. The principal steps in the process of Th\(^{230}\) separation and purification are shown in the diagram.

The final prepared samples were in the form of the oxide ThO\(_2\). The isotopic composition of the samples and their impurity content were determined by mass-spectrometric methods. The absolute Th\(^{230}\) content in a sample was determined with a mass spectrometer by means of isotopic

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**TABLE 1. Impurity Content in the Thorium Sample**

<table>
<thead>
<tr>
<th>Element</th>
<th>Content, %</th>
<th>Element</th>
<th>Content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nd</td>
<td>&lt; 10(^{-5})</td>
<td>Sm</td>
<td>&lt; 10(^{-5})</td>
</tr>
<tr>
<td>La</td>
<td>&lt; 10(^{-5})</td>
<td>Eu</td>
<td>&lt; 10(^{-5})</td>
</tr>
<tr>
<td>Ce</td>
<td>&lt; 10(^{-6})</td>
<td>Gd</td>
<td>&lt; 2 \times 10(^{-4})</td>
</tr>
<tr>
<td>Pr</td>
<td>&lt; 10(^{-5})</td>
<td>Zr</td>
<td>&lt; 5 \times 10(^{-3})</td>
</tr>
</tbody>
</table>

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Diagnosis of Th\textsuperscript{230} Chemical Separation and Purification from Uranium Ore

1. Ore → Pa-10 concentrate
   - Extraction from HNO\textsubscript{3} solution with isoamylphosphoric acid
   - Re-extraction with (NH\textsubscript{4})\textsubscript{2}CO\textsubscript{3}

2. Desorption with 4NH\textsubscript{2}SO\textsubscript{4}
   - Sorption from concentrated HCl, AB-17 anionite
   - Sorption from 1N HCl, KU-2 cationite

3. Desorption with 3N H\textsubscript{2}SO\textsubscript{4}
   - Removal of impurities by washing with 2M HCl; 3M HCl; 2M HNO\textsubscript{3}; 0.1M H\textsubscript{2}C\textsubscript{2}O\textsubscript{4}

4. Th\textsubscript{2}O\textsubscript{2} (1.059 g Th\textsuperscript{230})

The results of the measurements established that the ratio of the amount of Th\textsuperscript{232} to the amount of Th\textsuperscript{230} in the sample was 1.463 ± 0.003 and that the sample contained 1.64 ± 0.021 g Th\textsuperscript{252} oxide and 1.12 ± 0.011 g Th\textsuperscript{230} oxide. Data for the mass-spectrometric analysis of impurity content in the sample is shown in Table 1.

A sample of (1.90 ± 0.057).10\textsuperscript{21} atoms/cm\textsuperscript{2} thick was used to determine the total neutron cross section of Th\textsuperscript{230} in the thermal region. For "without sample" measurements, a sample of Th\textsuperscript{232} was placed in the neutron beam in an amount equal to the content of that isotope in the thorium sample under study. In this way, measurements of the Th\textsuperscript{230} cross section were obtained after correcting the results for the cross section of the oxygen directly bound to the Th\textsuperscript{230}. The cross section of oxygen was assumed to be 4.2 ± 0.3 b [10].

During measurement of a ThO\textsubscript{2} sample, effects associated with the crystalline structure of the sample had a noticeable influence on transmission in the thermal region. These effects were partially cancelled in the method adopted for the measurement of transmission relative to that of Th\textsuperscript{232} oxide. In addition, the original experimental results, which were obtained with a resolution of 1 msec/m, were averaged in order to smooth out discontinuities in the transmission curve associated with reflection at the Bragg angle.

In order to check experiments made in the 0.02-0.15 eV energy range, the transmission was measured for Th\textsuperscript{235} oxide, relative to which Th\textsuperscript{231} transmission was calculated, simultaneously with the sample measurement. During transmission measurements in this energy range, the Th\textsuperscript{230} sample under study, Th\textsuperscript{232} oxide, and an empty container were successively located in the neutron beam. In the first set of measurements, the samples were changed after 30 min, and in the second set, after 10 min.

As the result of mass-spectrometric analysis of natural thorium, it was established that it contained as many impurities as were in the thorium sample under study, the data for which is given in Table 1.

For additional checking of the equipment, the total neutron cross section of boron in a D\textsubscript{2}BO\textsubscript{3} sample was measured; in addition, the total neutron cross section of Th\textsuperscript{230} at three energy values — 0.0144, 0.0253, and 0.070 eV — was measured with a single-channel time analyzer.

The results are shown in Figs. 1 and 2. The errors indicated on curve 1(see Fig. 1) include both systematic and statistical errors. The accuracy of the measurements was 5-8%. The results of the measurements of the total neutron cross section for boron are shown in Fig. 2.

One should note the excellent agreement of the data regardless of whether obtained with a single-channel or multichannel time analyzer (see curve 1 in Fig. 1) and the agreement of the total neutron cross section for boron with the tabulated results in [10]. The excellent agreement of the total neutron cross section for Th\textsuperscript{232} with published data (see curve 2 in Fig. 1) is evidence that the oxygen correction, made identically in the determination of the cross sections of both Th\textsuperscript{232} and Th\textsuperscript{230}, was valid in both cases. However, it is necessary to consider the following. The measurements of the total neutron cross section for Th\textsuperscript{232} were accomplished with a sample in which isotopic incoherent scattering was absent, and in which the coherent scattering was determined by Th\textsuperscript{232} and oxygen with identical signs of the scattering amplitude (positive). In the case of Th\textsuperscript{230} sample measurements, isotope incoherence was present. The coherent scattering of such a