lished for an arbitrary scattering law, the degree of anisotropy of which is determined by the smallness of the parameter

$$\varepsilon = \frac{1}{2}\int_{-1}^{+1} (1-\mu)\mathscr{F}(\mu)\,d\mu,$$

i.e., by the smallness of the rms angle upon single scattering. The small-angle approximation is represented by the sum

$$\delta(\mu-1)\,e^{-\tau/\mu} + I_0(\mu, \tau),$$

where $I_0(\mu, \tau)$ is close to the Gauss function $\exp(-\theta^2/\overline{\theta^2})$, $\overline{\theta^2} \approx h$, at small angles $(\theta^2 \lesssim \epsilon h)$. If $\mathscr{F}(\cos\chi)$ is taken in the form (2), the asymptotic expression at large angles is

$$2^{\eta} A_{\eta} h\,\theta^{-2\eta}, \quad \eta = \min k_i.$$

The free term in Eq. (3) is a quantity of the order of ϵ. The function $\psi_1 = O(\epsilon h \psi_0)$ at small angles $(\theta^2 \lesssim h)$, and $\psi_1 = O(\theta^2\psi_0/2)$ at greater angles. Thus, at $\epsilon h \ll 1$, as expected, the correction ψ_1 is small in the region $\theta^2/2 \ll 1$. On the other hand, the comparatively large value of the correction $\psi_2(\mu, \tau)$ in this example limits the range of validity of the small-angle approximation to the inequality $\psi_0 \gg \psi_2$, i.e., $\theta^4 \ll \epsilon h$. Since in this problem $\epsilon = x_0 \ln x_0$, one would expect that the approximation here is good in the region $\theta \lesssim 1/10$ and is acceptable at $\epsilon h \ll 1$. To obtain solutions with a sufficient degree of accuracy at large angles it is proposed to use the interpolation method developed in Refs. 2 and 5.

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COMPARISON OF NEUTRON SPECTRA IN THE FISSION OF U^{233}, U^{235}, Pu^{239}

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THE spectra of fission neutrons from U^{235}, U^{233}, and Pu^{239} have been reported in a number of papers.[1-10] Measurements of the fission neutron spectrum from U^{235} (Refs. 1 – 8) are in satisfactory agreement with the semi-empirical formula of Watt.[3]

According to the data of Mukhin, Barkov, and Gerasimov,[8] the fission neutron spectra from U^{233} and Pu^{239} are the same as the spectrum from U^{235}, within experimental errors of 10 – 20%. The data of Nereson[9] and of Grandl and Neuer[10] indicate that the neutrons from Pu^{239} are somewhat harder than those from U^{235}.

This note presents a comparison of the neutron spectra from the fission of U^{233}, U^{235}, and Pu^{239}. Various neutron detectors were used.

The fission neutrons were obtained by irradiating samples of U^{233}, U^{235}, and Pu^{239} with thermal neutrons from a reactor. In the first series of measurements, the neutrons were detected by using the thresholds of the reactions $Pr^{141}(n, 2n)Pr^{140}$, $Al^{27}(n, p)Mg^{27}$, $P^{31}(n, p)Si^{31}$, and $Au^{197}(n, \gamma)Au^{198}$. To compare the intensities of the fission neutron sources, we used a fission camera with U^{233}. The irradiation took place inside a cavity 20 × 20 × 40 cm in the thermal column of the reactor.

In the second series of measurements, the neutrons were detected with fission cameras using U^{233}, U^{238}, and Np^{237}.

In the third series of measurements, the neutrons were detected with fission cameras using U^{238}, Np^{237}, and Th^{232}. A fission camera with U^{235} was used to compare the fast neutron fluxes.

The reactor power was controlled in all three series of measurements. The results obtained are shown in the table. These results include small (< 2%) corrections for inelastic neutron scattering in the converters. A_{233}, A_{235}, and A_{239} are the counting rates in the various detectors, normalized to unit flux of fission neutrons from the corresponding converter, indicated by the index subscript of A. E_{eff} is the effective threshold of the reaction.

Detector	A_{239}/A_{235}	A_{233}/A_{235}	E_{eff} (Mev)	Measurement Series
$Pr^{141}(n, 2n)Pr^{140}$	1.42 ± 0.08	1.30 ± 0.03	11.5	I
$Al^{27}(n, p)Mg^{27}$	1.13 ± 0.02	1.11 ± 0.03	4.6	I
$P^{31}(n, p)Si^{31}$	1.07 ± 0.03	1.07 ± 0.05	3.5	I
$Th^{232}(n, f)$	1.034 ± 0.017		1.6	III
$U^{238}(n, f)$	1.015 ± 0.013	1.02 ± 0.017	1.4	II
$U^{238}(n, f)$	1.04 ± 0.01		1.4	III
$Np^{237}(n, f)$	0.985 ± 0.01	1.01 ± 0.017	0.7	II
$Np^{237}(n, f)$	1.028 ± 0.014		0.7	III
$Au^{197}(n, \gamma)Au^{198}$	1.02 ± 0.03	1.01 ± 0.02	—	I

The data show that the fission neutrons from U^{233} and Pu^{239} are harder than those from U^{235}. The temperature differences between the fission fragments of U^{233} and Pu^{239} compared with those of U^{235} are estimated to be 0.04 ± 0.01 and 0.05 ± 0.01 Mev.

On the basis of models for the evaporation of neutrons from moving fragments, and assuming that the excitation energy of the fragment is connected with the mean number ν of neutrons evaporated through the relation $\Delta\nu/\Delta E = 0.120$ Mev^{-1} (Ref. 6), temperatures T of 1.02 ± 0.01 and 1.06 ± 0.01 Mev are found for the fragments of U^{233} and Pu^{239} respectively. The uncertainty in T corresponds to the uncertainty in ν.[11] The temperature T = 1.00 Mev was adopted for the fragments of U^{235}.

The difference between the average energy of neutrons from the spontaneous fission of Cf^{252} and those from U^{235} can be estimated using the values $\nu = 3.53 \pm 0.15$[12] and $\nu = 3.82 \pm 0.12$[13] for Californium. The result is a figure of 9 — 11%. This agrees well with the experimental value 8% found in Ref. 14.

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