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EXPERIMENTS PROPOSED ON LOW-ENERGY $\tilde{\nu}_e$ PHYSICS AT PIK-TYPE RESEARCH REACTORS

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It is noted that the interaction of electron antineutrinos with neutrons, protons and electrons is known with a low accuracy and the theory of electroweak interactions in this area has no quantitative verification.

It is proposed to create an intensive source of hard $\tilde{\nu}_e$ from the decay of lithium-8 on the basis of the PIK-type research reactor. Expected count rates and spectra of products of different reactions are presented. The proposed $\tilde{\nu}_e$ source displays appreciable advantages over power and industrial reactors, on which the neutrino experiments are performed at present.

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(1) The main processes of interaction of electron neutrinos with protons, neutrons and electrons are studied quite insufficiently. The laws of electroweak interaction with the participation of first-generation leptons are established on a qualitative or semiquantitative level as yet.

Processes 1-4 of absorption or scattering of reactor $\tilde{\nu}_e$, given below, are traditionally considered in connection with the problem of weak coupling investigation.

Table I

	Reaction	Type of interaction; constants
1.	$\tilde{\nu}_e + p \rightarrow n + e^+$	Charged currents of leptons and nucleons; $(g_V^2 + 3g_A^2)\cos^2\theta_c$.
2.	$\tilde{\nu}_e + d \rightarrow e^+ + 2n$	$g_A^2\cos^2\theta_c$
3.	$\tilde{\nu}_e + d \rightarrow \tilde{\nu}_e + n + p$	Semilepton neutral currents. Interference of amplitudes of scattering by a neutron and proton is included: $(g_A^o)^2$.
4.	$\tilde{\nu}_e + e^- \rightarrow \tilde{\nu}_e' + e^-$	Interference of neutral and charged currents; the Weinberg angle.
5.	$\tilde{\nu}_e + A \rightarrow \tilde{\nu}_e + A'$	Elastic scattering by a nucleus. At low energies ($p_\nu R \ll 1$) the cross section is determined by the amplitude sum squared: $\sigma = \frac{(g_V^o)^2 E_\nu^2}{\pi}\left[N/2 + (2\sin^2\theta_W - 1/2)Z\right]^2$.

Reactions 1-4 have been observed in reactor experiments. Reaction 5 has not bee studied so far.

(2) From the beginning of the eighties the neutrino investigation on nuclear reactors is being quickly developed. Several stationary neutrino laboratories were organized: two

laboratories at the Kurchatov Institute (one, at the Rovno APP /1/ and the other, on the other reactor /2/), a laboretory in France /3/, studies were resumed at the industrial reactor in the USA /4/.

Until now, real progress has been achieved only in investigating the inverse beta-decay reaction (1). In two laboratories of the Kurchatov Institute and at the reactor in the USA the study of reactions (2) and (3) of the $\tilde{\nu}_e$ interaction with a deuteron is under preparation. At the Rovno APP the Leningrad Institute of Nuclear Physics is engaged in designing an experiment on $\tilde{\nu}_e e^-$ - scattering /5/.

(3) A research reactor with the power of 50-100 MW, e.g. the PIK reactor, can successfully compete with more powerful APP reactors and even have noticeable advantages in performing neutrino studies. Below a proposal is considered, comprising two basic points.

- The ^7Li isotope is to be used as a converter of thermal neutrons in order to obtain $\tilde{\nu}_e$ with the end point energy of 13 MeV (see Fig.1) for the $^7Li + n \rightarrow {}^8Li \xrightarrow{\tilde{\nu}_e, e^-} {}^8Be \rightarrow 2\alpha$ reaction.

- A schielded measuring chamber positioned as close as possible to the $\tilde{\nu}_e$ source (see Fig.2) should be designed.

Note that the problem of using ^7Li to obtain hard $\tilde{\nu}_e$ in pulsed and stationary reactors was treated at the Kurchatov Institute in the sixties and seventies /6/ and recently at the Moscow Engineer-Physicist Institute /7/.

(4) As shown by estimates, it is technically feasible to produce the converter with the following parameters:

^7Li mass, t	- 1.5 - 2.0
^6Li impurity, %	- not more than $3\cdot10^{-3}$
Conversion ratio	- 0.2 neutron capture per fission event.

It is proposed to place lithium in the reactor heavy-water reflector in containers (ampules) made of thin-walled stainless steel, pyrographite or aluminium in the form of a metal or compounds with low parasitic absorption of neutrons: LiF, LiOD, Li_2CO_3. In producing the ampules, it should be taken into account that the neutron capture in ^7Li results in formation of two α-particles, while the capture in ^6Li, in formation of an α-particles and tritium. The total amount of helium and tritium formed in running the reactor at the power of 100 MW is a few liters per day, which, on the one hand, is a source of certain inconveniences and, on the other, may be used for exact determination of the $\tilde{\nu}_e$ flux from ^{8}Li.

Below we present the expected parameters of the $_e$ source in operating the reactor at the power of 100 MW.

Number of fission events	$3.1 \cdot 10^{18}$ s^{-1}
Power of fission $\tilde{\nu}_e$ source	$1.9 \cdot 10^{19}$ s^{-1}
Power of $\tilde{\nu}_e$ source from ^{8}Li	$0.6 \cdot 10^{18}$ s^{-1}
Flux of $\tilde{\nu}_e$ on detector at 4.7-m distance from core centre (see Fig.2):	
fission $\tilde{\nu}_e$	$6.7 \cdot 10^{12} s^{-1} cm^{-2}$
$\tilde{\nu}_e$ from ^{8}Li	$2.2 \cdot 10^{11}$ $s^{-1} cm^{-2}$

(5) The presented $\tilde{\nu}_e$ fluxes from the ^{8}Li decay and fragments are used below for estimation of the effects observed.

Inverse beta-decay (1). The $CH_{1.8}$ target has 1000 kg (liquid scintillator). The integral energy spectra of positrons are given in Fig.3 in the units: number of events per 10^5s. It is clear from Fig.3 that at low thresholds of detection the contributions of reactor $\tilde{\nu}_e$ and $\tilde{\nu}_e$ from ^{8}Li are comparable and their sum amounts to about 10^4 per day. In the energy range above 6 MeV the number of events is still large enough and is fully determined by lithium.

Interaction of $\tilde{\nu}_e$ with deuteron (2),(3)

Table 2

Cross section σ and number of events N per 10^5s in 1000 kg of D_2O

Reaction	Fission $\tilde{\nu}_e$	N	$\tilde{\nu}_e$ from ^{8}Li	N
$\tilde{\nu}_e$ d^{NC}	$2.9\ 10^{-44} cm^2$/fis.event	200	$44.10^{-44} cm^2/\ _e$	580
$\tilde{\nu}_e$ d^{CC}	$1.1\ 10^{-44} cm^2$/fis.event		$47\ 10^{-44} cm^2/\ _e$	620

The observable particles are single neutrons from the $\tilde{\nu}_e d^{NC}$ reaction and pairs of neutrons from the $\tilde{\nu}_e d^{CC}$ reaction. Note that at the Rovno APP the installation with the target of 3000 kg of D_2O and expected number of events of 600 ($\tilde{\nu}_e d^{NC}$) and 200 ($\tilde{\nu}_e d^{CC}$) per day is in the start-up stage.

$\tilde{\nu}_e e^-$ - scattering (4). The expected number of electrons versus the threshold of recoil detection (per 10^5s in a target with the mass of 1000 kg, 2.9 10^{29} of electrons) is presented in Fig.4. As the target material, one can use silicon, sodium iodide or liquid organic scintillator based on fluorobenzene C_6F_6. It is known that the main difficulty of studying the $\tilde{\nu}_e e^-$ - scattering in the fission $\tilde{\nu}_e$ spectrum is that in the energy range where the natural background is low (3-3.5 MeV) the number of useful events is also very small. The advantage of using the converter (see Fig.4) is evident.

Elastic scattering of $\tilde{\nu}_e$ by nuclei (5). The cross section is determined by a vector constant (a neutral current). One can observe only recoil nuclei. The number of recoil nuclei for 100 (normal) cubic meters of He, Ne and Ar per 10^5s is shown in Fig.5. The number of evernts is very large, however, the detection involves difficulties. In principle, wire chambers may, probably, be used. Recently, superconducting tunnel detectors recording the formation of the excess of "free" (not paired) electrons /8/ have been developed.

(6) It is doubtless that in producing the $\tilde{\nu}_e$ source from the ^{8}Li decay with the above-mentioned parameters, the cross sections of processes 1-4 (Table I) can be measured with a high accuracy. It will make it possible to verify the Weinberg-Salam theory at a quantitative level in the simplest and well-interpreted reactions and to establish strong limitations on possible deviations from its predictions.

In the $\tilde{\nu}_e$ spectrum from ^{8}Li one would also observe transitions into the excited state of nuclei.

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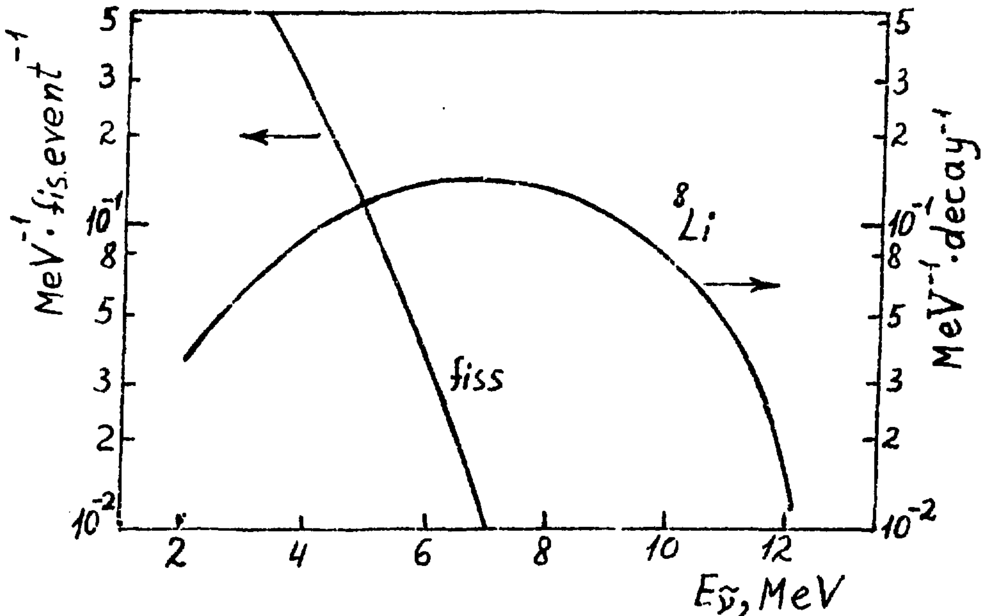

Fig. 1

Energy spectra of antineutrino: fiss- from fission fragments (MeV^{-1}·fis. event^{-1}), ^{8}Li- from decay (MeV^{-1}·decay^{-1}).

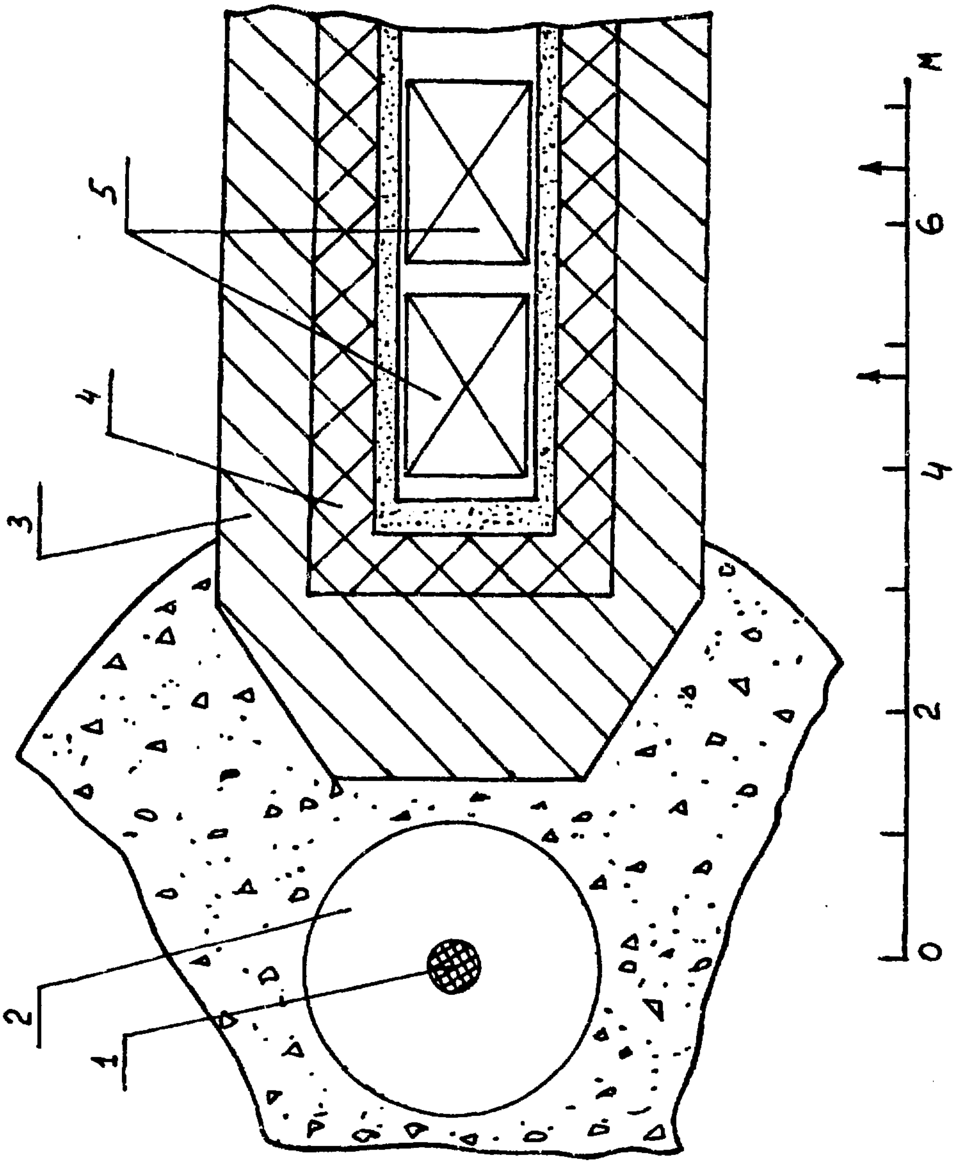

Fig. 2

Geometry:
1- core; 2- heavy-water reflector; 3- borated steel; 4- borated polyethylene; 5- detectors.
The converter with ^{7}Li is mounted in the reflector (not shown in the figure).

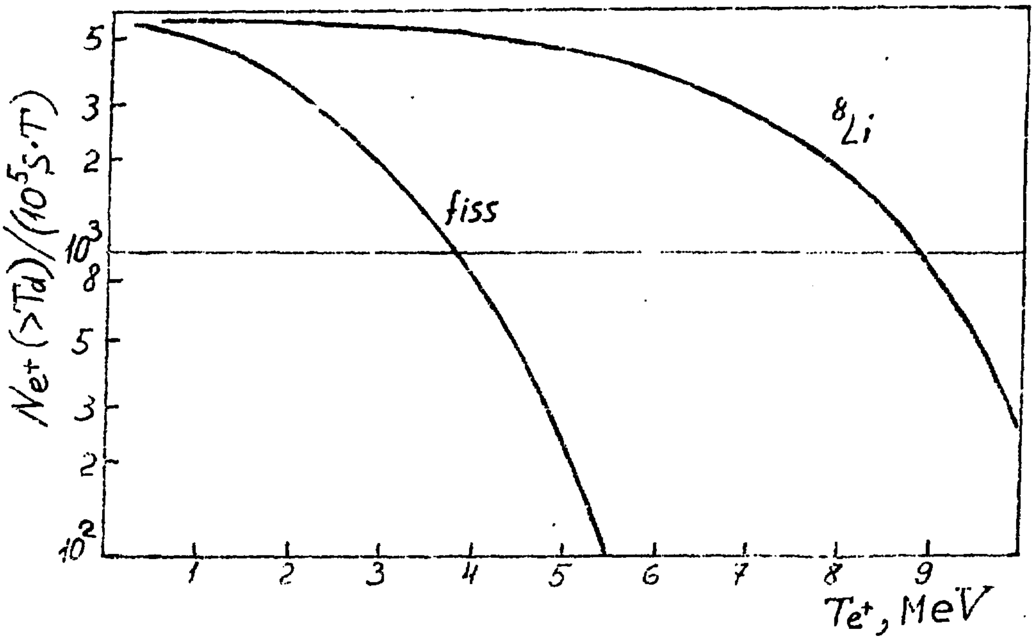

Fig. 3

Number of events of inverse beta-decay reaction at 4.7-m distance from core centre with positron energy being higher than threshold per 10^5 s in 1000 kg of liquid scintillator.

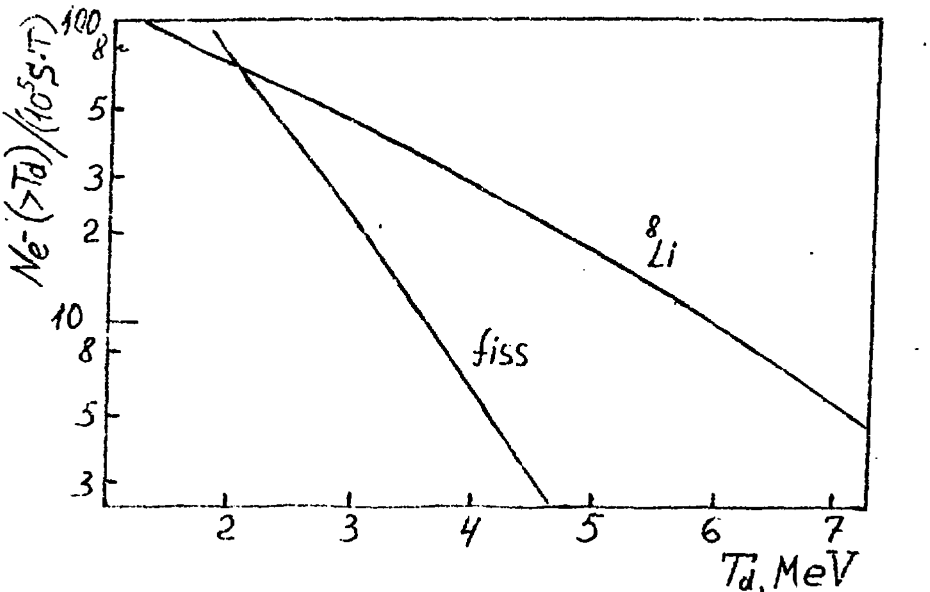

Fig. 4

Number of $\tilde{\nu}_e e^-$-scattering events at 4.7-m distance (per 10^5 s in target with 1000-kg mass) at above-threshold energy of recoil electron.

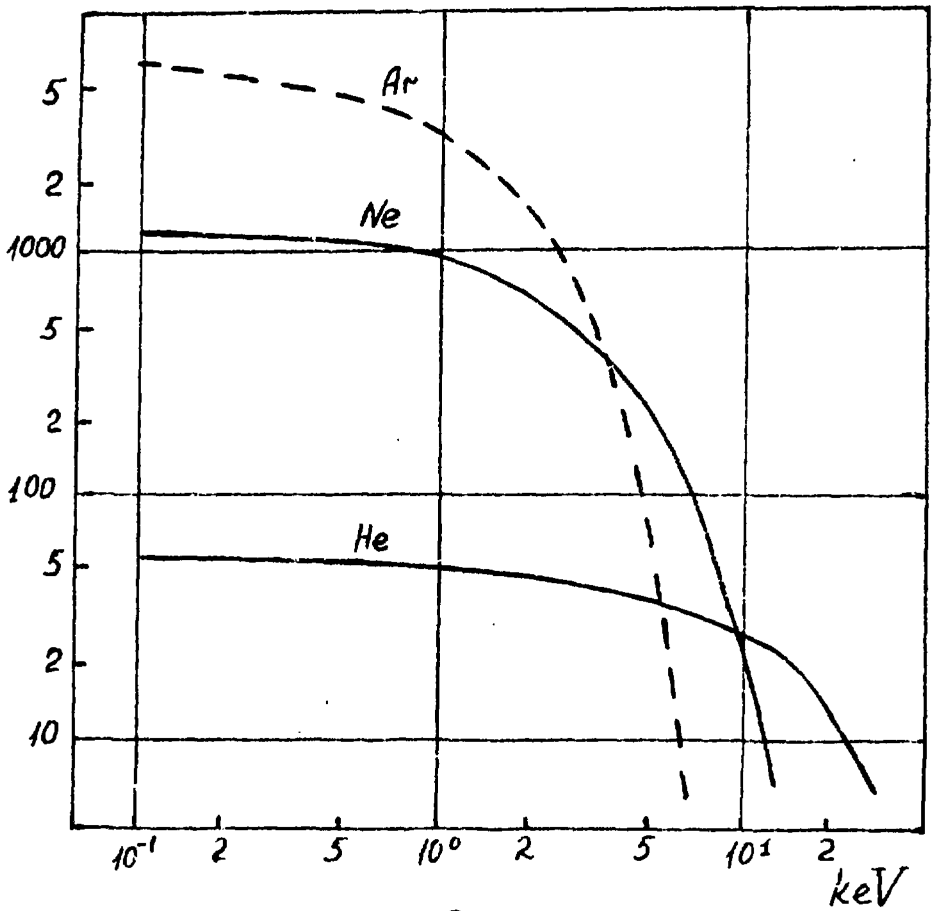

Fig. 5

Elastic scattering of $\tilde{\nu}_e(^8Li)$ by ^4He, ^{20}Ne, ^{40}Ar nuclei. Number of events with recoil nucleus above detection threshold per 10^5 s in 100 m^3 (normal) of gas.

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