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The Conception of the Powerful Dynamic Neutrino Source with Modifiable Hard Spectrum

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The CONCEPTION of the POWERFUL DYNAMIC NEUTRINO SOURCE with MODIFIABLE HARD SPECTRUM:
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Powerful dynamic antineutrino source with hard $\tilde{\nu}_e$-spectrum obtained at activation of ^{7}Li and subsequent β^--decay ($T_{1/2} = 0.84$ s) of the ^{8}Li isotope with emission of high-energy $\tilde{\nu}_e$ with energy up to 13 MeV - is discussed. In the dynamic system, lithium is pumped over in a closed cycle through a converter close by the active zone of a reactor and further - to a remote $\tilde{\nu}_e$-detector.

Expressions for $\tilde{\nu}_e$-fluxes enabling to optimize parameters of the dynamic system and to calculate the hardness of the summary $\tilde{\nu}_e$-spectrum and antineutrino reaction cross sections in the location of a detector are obtained. On examples of particular dynamic systems it is shown that owing to a large growth of the of summary $\tilde{\nu}_e$-spectrum hardness the cross section of interaction with a deuteron can increase in tens times in the neutral ($\tilde{\nu}_e+d \rightarrow n+p+\tilde{\nu}_e$) channel and up to two orders in the charged ($\tilde{\nu}_e+d \rightarrow n+n+e^+$) channel in comparison with these cross sections in the reactor $\tilde{\nu}_e$-spectrum.

Fig. - 8, ref. - 13 name.

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1. INTRODUCTION

The main difficulties of experiments on research of neutrino interaction with substance are stipulated extremely by small cross sections of these reactions. The smallness of cross sections extremely complicates separation of neutrino effect from a background. Therefore, a high neutrino flux can be a decisive factor for obtaining of reliable results. On the other hand, the probability of registration strongly depends on neutrino energy . The reaction cross section $\sigma_\nu \sim E_\nu^2$ at the neutrino energy $E_\nu \ll m_t$, where m_t - mass of the target particle. At $E_\nu \gg m_t$ the square-law growth of a cross section goes into linear.

In earthly conditions the Sun, nuclear reactors and accelerators are exceptional on intensive neutrino fluxes [1,2,3]. The solar ν_e-neutrinos fluxes are estimated as $\approx 6.6 \cdot 10^{10}$ cm$^{-2} \cdot$s^{-1}. However, the energy of 98 % of all solar neutrinos does not exceed 0.86 MeV. In experiments with artificial neutrino sources there is a certain freedom in specification of an energy and neutrino fluxes. The density of $\tilde{\nu}_e$-flux from a nuclear reactor [2] is determined by its power P and for distance R is :

$$F[cm^{-2}\cdot s^{-1}] \cong \overline{n}P/4\pi R^2\overline{E} = 1.5\cdot 10^{12}P[MW]/R^2[m], \qquad (1)$$

where $\overline{n} \cong 6$ - mean number of β^--decays of both fission fragments of ^{235}U, $\overline{E} \cong 200$ MeV - mean energy released at ^{235}U-fission. Then, at the power P =2800 MW (the Bugeu reactor, France) and distance $R \cong 18$ m (as in experiments on search of neutrino oscillations[4]) the flux is $F \cong 1.3\cdot 10^{13}$ $cm^{-2}\cdot c^{-1}$. Antineutrinos $\tilde{\nu}_e$ emited at β^--decay of fission fragments in a nuclear reactor have energy $E_{\tilde{\nu}} \leq 10$ MeV and cross sections of the interaction with protons, electrons and deuterons are in the interval 10^{-46}-10^{-43} cm^2. The interaction of neutrinos ν_μ and $\tilde{\nu}_\mu$ with energy $E_\nu \approx 10 \div 300$ MeV is studied at meson factories and at greater energy $E_\nu \approx 1 \div 200$ GeV - at high energy accelerators. The neutrino cross sections strongly grow at these energies but, however, the fluxes are on many less orders than in reactor experiments.

Alongside with the obvious advantage on a neutrino flux the nuclear reactor has a disadvantage too-small hardness of $\tilde{\nu}_e$-spectrum. This disadvantage can be filled having realized the idea to use a high-purified isotope ^7Li for engineering of a reactor neutrons-to-antineutrino converter, which is located close by the active zone of a reactor[5]. In a reactor neutrons flux a short-lived isotope $^8Li(T_{1/2}= 0.84$ s) is created in the reaction $^7Li(n,\gamma)^8Li$ and at β^--decay emits hard antineutrinos of a well determined spectrum with the maximum energy $E_{\tilde{\nu}}^{max}$=13.0 MeV and mean energy $\overline{E}_{\tilde{\nu}} = 6.5$ MeV. As a result the summary $\tilde{\nu}_e$-spectrum from the active zone of a reactor and from decays of ^8Li isotope becomes considerably more harder in comparison with the purely reactor spectrum.

The questions of constructing of intensive neutrino sources with a hard spectrum, different types of lithium converters for reactors working in a stationary mode, applications of converters for neutrino researches are considered in Ref. 6,7 and 8. In Ref. 8 the models of lithium converters with the purity on the isotope ^{7}Li P_7 = 99.99 % for a spherically-laminated geometry with the active zone in a centre were discussed. The radius of the active zone R_{AZ}= 23 cm corresponds to a volume 51 *l* as at the high-flux PIK reactor [9]. In the calculations it was assumed that one fission spectrum neutron escaped from the active zone per one fission in the active zone. It was obtained the maximum efficiency of the converter κ (number of ^{8}Li nuclei created per one neutron escaping from the active zone) for considered models is equal to 0.093. At this summary $\tilde{\nu}_e$-spectrum the cross sections of antineutrino-deuteron reactions

$$\tilde{\nu}_e+d\rightarrow n+p+\tilde{\nu}_e \qquad \text{(neutral channel) and} \qquad (2)$$

$$\tilde{\nu}_e+d\rightarrow n+n+e^+ \qquad \text{(charged channel)} \qquad (3)$$

exceed these cross sections for a purely reactor $\tilde{\nu}_e$-spectrum in 2.5 and 5 times in (n,p) and (n,n)-channels, respectively.

II. DYNAMIC MODE OF OPERATION FOR CONVERTER

It is possible to supply powerful neutrino fluxes with considerably greater hardness in a facility with a dynamic mode of operation [10]: liquid lithium is pumped over in a closed cycle through a converter and further in a direction to a remote neutrino detector (Fig. 1). For increasing of a part of hard lithium antineutrinos a being pumped reservoir is constructed near the $\tilde{\nu}_e$-detector. Such a facility will ensure not only more hard spectrum in the location of a detector but also an opportunity to investigate $\tilde{\nu}_e$-interaction at different spectrum hardness varying a rate of lithium pumping over.

However, the development of such a facility comes across serious problems connected with necessity of a temperature regime maintenance ($t_{melting}$(Li)=180.5 °C) and requirement in a large mass of a high-purified lithium. So, at the thickness of converter $L_C = 1.5$ m it is reaches the efficiency $\kappa \cong 0.077$ that requires 11.9 t. of lithium with the purity on the isotope ^{7}Li $P_7 = 99.99\%$. For realization of a dynamic mode it will required lithium about in 2÷4 times more [10].

The problem of lithium mass decrease at preservation or growth of the converter efficiency κ can be solved using in a converter the substances with a high slowing-down power $\bar{\xi}\sum_S$ and very small cross sections of absorption. Simultaneously it permits to reach a necessary level of the efficiency κ at a smaller thickness of the converter layer L_C. The different candidates for use as substance in a converter are considered in Ref. 11 and 12. For a facility with a dynamic mode of operation the perspective substance is a heavy water solution of lithium hydroxide *LiOD*. Really, at concentration (by mass) of *LiOD* equal to 5.66 % and the layer thickness $L_C = 1.0$ and 1.5 m the efficiency of such converters $\kappa \cong 0.10$ and 0.108, respectively. At the greater concentration - 9.46 % and the same values L_C the efficiency κ grows up to 0.112 and 0.120, respectively. Thus, use of heavy water *LiOD* solution permits to reduce the layer thickness L_C up to ≈1 m and sharply to reduce a required mass of a high-purified lithium. For example, at the concentration of 9.46 % for the achievement $\kappa = 0.077$ it is necessary lithium in 300 times less than for the converter filled with lithium only.

III. FLUXES OF LITHIUM ANTINEUTRINOS AND HARDNESS OF THE SUMMARY $\tilde{\nu}_e$-SPECTRUM IN A DYNAMIC MODE

The creation of the isotope ^{8}Li in a converter at (n,γ)-activation of lithium is described by the system of equations:

$$\begin{cases} \dfrac{\partial N_7(t)}{\partial t} = -\lambda_{n,\gamma} N_7(t) & (4) \\ \dfrac{\partial N_8(t)}{\partial t} = -\lambda_{n,\gamma} N_7(t) - \lambda_\beta N_8(t) & (5) \end{cases}$$

where $N_7(t)$ and $N_8(t)$ - number of nucleus ^{7}Li and ^{8}Li at the moment t, $\lambda_{n,\gamma}$, λ_β - rate of (n,γ)-reaction and β⁻- decay.

Assuming that at $t = 0$ where is N_7^0 nucleuses of starting isotope ^{7}Li and $N_8^0 = 0$, the solution is :

$$N_7(t) = N_7^0 \cdot \exp(-\lambda_{n,\gamma} t) \qquad (6)$$

$$N_8(t) = \lambda_{n,\gamma} N_7^0 \left[\frac{\exp(-\lambda_{n,\gamma} t)}{\lambda_\beta - \lambda_{n,\gamma}} + \frac{\exp(-\lambda_\beta t)}{\lambda_{n,\gamma} - \lambda_\beta} \right] . \qquad (7)$$

The rapid decay of a isotope ^{8}Li causes necessity of a maximally rapid delivery of lithium (or heavy water *LiOD* solution) to a being pumped reservoir to ensure a greater hardness of the summary $\tilde{\nu}_e$- spectrum in a location of the detector. Taking into account that $\lambda_{n,\gamma} \ll \lambda_\beta$ and the time of (n,γ)-activation is a time of pumping over of a converter volume and equally to several seconds (the time of pumping over is discussed below in the part IV), the expression (7) is simplified:

$$N_8(t) = \frac{\lambda_{n,\gamma} N_7^0}{\lambda_\beta} \left[1 - \exp(-\lambda_\beta t) \right] . \qquad (8)$$

The number of nuclei ^{8}Li $\lambda_{n,\gamma} N_7^0$ created in a time unit is the converter efficiency κ on definition in view of the accepted normalization per one fission in the active zone.

The knowledge of the $\lambda_{n,\gamma} N_7^0$-value normalized per one fission permits to calculate lithium antineutrinos fluxes from any parts of a dynamic system (including - a converter, being pumped reservoir and a channel of delivery of lithium from a converter to a reservoir) and the summary hardness of $\tilde{\nu}_e$- spectrum in a location of the neutrino detector.

Let us derive the expressions for the lithium antineutrinos fluxes emited from the volumes discussed below and assuming that all the parameters of a dynamic system were stabilized. Let us adopt the necessary assumption for the further calculations: the pumping over in considered volume is constructed so that the time of lithium nuclei movement on a trajectory inside this volume does not depend on a trajectory and equally to the time of pumping over of this volume.

$\tilde{\nu}_e$- <u>FLUX FROM A CONVERTER</u>*. Let V_c - converter volume, V_0- volume of a whole system, w - volume being pumped over in a time unit (flow rate, i.e. circulation rate), then $t_p = V_c / w$ - time of pumping over of converter volume. In a converter we shall allocate some spherical segment with a volume V_s and with a plane of the basis perpendicular to the axis of a delivery channel. The example of such a segment is hatched in Fig. 1.

During the time of a segment volume pumping over $t_s = V_s / w$, the part of ^{8}Li nuclei created within this time interval $[0, t_s]$ - decays and in view of expressions (6), (8) and $\lambda_{n,\gamma} t_s \ll 1$ these decays give $\tilde{\nu}_e$- flux:

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[*] here and below what is implied is the antineutrino flux integrated with respect to time

$$S_1=N_7^0-N_7(t_S)-N_8(t_S)=\lambda_{n,\gamma}\,N_7^0\,t_S-(\lambda_{n,\gamma}\,N_7^0/\lambda_\beta)\varphi(V_S), \tag{9}$$

where the function $$\varphi(y)=1-\exp(-\lambda_\beta y/w). \tag{10}$$

Nuclei of ^{8}Li created within the previous time intervals - decay in the same interval $[0,\ t_s]$ too. These previous intervals are: $[-V_0/w,\ t_p-V_0/w]$, $[-2V_0/w,\ t_p-2V_0/w]$,..., $[-nV_0/w,\ t_p-nV_0/w]$, corresponded to the last, penultimate,..., "*n*"-th cycle with respect to the the moment $t=0$. Taking into account that the nuclear concentration of the isotope ^{7}Li does not practically vary, the antineutrino fluxes corresponding the considered decays are following:

$$\begin{aligned} S_2&=\frac{\lambda_{n,\gamma}\,N_7^0}{\lambda_\beta}\varphi(V_C)\Big\{\exp\big[-\lambda_\beta(V_0-V_C)/w\big]-\exp\big[-\lambda_\beta(V_0-V_C+wt_s)/w\big]\Big\}\\ S_3&=S_2\exp\big(-\lambda_\beta V_0/w\big)\\ &\;\vdots\\ S_n&=S_2\exp\big[-(n-2)\lambda_\beta V_0/w\big]\,. \end{aligned} \tag{11}$$

Then the integral flux of lithium antineutrinos emited from this spherical segment for a time t is:

$$N_S(t)=\frac{t}{t_s}\left(S_1+\sum_{n=2}^{\infty}S_n\right)=\frac{t}{t_s}\left[S_1+\frac{S_2}{\varphi(-\lambda_\beta V_0/w)}\right] \tag{12}$$

At a pumping over time $t_s=t_p$ the formula (12) gives an integral flux from whole volume of a converter.

$\tilde{\nu}_e$-FLUX FROM A CHANNEL OF DELIVERY. We shall neglect (n,γ)-activation of ^{7}Li isotope in a channel of lithium delivery from a converter to a being pumped reservoir. Let t_d - time of lithium delivery, i.e. the time necessary for passage of the distance L (see Fig. 1).

As well as in case of a converter, the integral flux of lithium antineutrinos from a channel of delivery during a time t is a sum of infinite series of fluxes emited from a channel within the time intervals $[t_p,\ t_p+t_d]$, $[t_p - V_0/w,\ t_p+t_d - V_0/w]$, ... , $[t_p - nV_0/w,\ t_p+t_d-nV_0/w]$:

$$N_{cd}(t)=\frac{t}{t_p}\sum_{n=1}^{\infty}\frac{\lambda_{n\gamma}N_7^0}{\lambda_\beta}\varphi(V_C)\varphi(wt_d)\exp\left[-(n-1)\lambda_\beta V_0/w\right]=$$

$$\frac{\lambda_{n\gamma}N_7^0 t}{\lambda_\beta t_p}\cdot\frac{\varphi(V_C)\varphi(wt_d)}{\varphi(V_0)} \tag{13}$$

$\tilde{\nu}_e$-FLUX FROM A RESERVOIR. Let V_r - volume of a being pumped reservoir. The integral lithium antineutrinos flux from a reservoir is the remainder of values $N_{cd}(t,t'_d)$ for two delivery times t'_d :

$$N_r(t)=N_{cd}(t,t'_d)\Big|_{t'_d=t_d}^{t'_d=t_d+V_r/w}=\frac{\lambda_{n,\gamma}N_7^0 t}{\lambda_\beta t_p}\cdot\frac{\varphi(V_C)\varphi(V_r)\exp(-\lambda_\beta t_d)}{\varphi(V_0)} \tag{14}$$

HARDNESS OF THE SUMMARY $\tilde{\nu}_e$-SPECTRUM. Let $F_{Li}(\vec{r})$ and $F_{AZ}(\vec{r})$ - densities of lithium antineutrinos flux and antineutrino flux from the active zone, $\bar{n}_\nu=6.13\div6.14$ - number of reactor antineutrinos emited per one fission in the active zone. Let us consider that the hardness of the summary $\tilde{\nu}_e$- spectrum at the point $\vec{r}$ equals one unit of hardness if the ratio of densities $F_{Li}(\vec{r})/F_{AZ}(\vec{r})$ equals $1/\bar{n}_\nu$. Then in common case the hardness of a summary spectrum is defined as:

$$H(\vec{r})=\bar{n}_\nu\frac{F_{Li}(\vec{r})}{F_{AZ}(\vec{r})} \tag{15}$$

This definition is convenient as in so doing the summary $\tilde{\nu}_e$-spectrum hardness of a converter in a static mode (i.e. models considered in Ref.6,8, 10,11,12) is estimateed by the value of its efficiency κ.

IV. DISCUSSION OF CONVERTER PARAMETERS AND RESULTS OF CALCULATIONS

The main requirements to a dynamic system: a converter with a high efficiency κ, rather volumetric remote reservoir for maintenance of greater $\tilde{\nu}_e$-flux hardness in the location of a detector and rapid lithium delivery from a converter to a reservoir. One of possible geometries is a system with a straight delivery channel ensuring maximum distance L between a converter and a reservoir at the given delivery time t_d.

Let us define the relation between a whole system volume V_0, converter volume V_c and volume of a reservoir V_r as follows:

$$\begin{cases} V_0=(1+\alpha)V_C \\ V_r=\alpha\cdot b\cdot V_C \end{cases}, \qquad (16)$$

where α, b - some coefficients, $\alpha > 0$, $0 \le b < 1$.

For choice of converter operation parameters it is necessary to observe a variation of relative number of lithium antineutrinos emited from the converter as function of a time of lithium pumping over through the converter t_p and of a coefficient α. The information on operation parameters of a being pumped reservoir and channels, the data for determination of relation between volumes of a converter, reservoir and delivery channel can be obtained from the analysis of dependence of relative number of antineutrinos emited from the reservoir and delivery channel as function of: time t_p, koefficients α and b, and delivery time t_d.

The assemblage of dependences for relative number of lithium antineutrinos emited from a converter (i.e. $N_C(t)/N_0(t)$, where $N_0(t)=\lambda_{n,\gamma}N_7^0 t$ – number of antineutrinos emited from the whole system during the time t) as function of the coefficient α at various times of converter pumping over t_p (s) is presented in Fig. 2. The flow rates w (m^3/s) (at which the given time of pumping over t_p will be realized) are specified in the brackets . The unphysical interval $\alpha = 0 \div \alpha_{min}$ can be found at the given values t_d and w on the restrictions: $b = 0$ and $V_C\,(1 + \alpha_{min}) = V_C + 2wt_d$. As the example the unphysical range (see Fig. 2) is finished by a dotted line up to α_{min} corresponding $t_d = 0.75$ s. The choice of possible values of delivery times t_d is dictated rapid β^--decay of ^{8}Li isotope. At large times of pumping over t_p the curves rapidly go on a asymptotic behaviour and further increase of α (volumes of reservoir and channels) with the purpose to increase a part of a hard lithium component in the summary $\tilde{\nu}_e$- spectrum is unjustified. Therefore, modes with a maximally possible flow rate w are necessary.

The dependences of relative number of lithium antineutrinos emited from a delivery channel $N_{cd}(t)/N_0(t)$ are shown in Fig. 3 for different rates w and delivery times t_d . The unphysical interval of values $\alpha = 0 \div \alpha_{min}$ is found under the same restrictions. Antineutrino part emited from a channel increases rapidly with growth of a pumping over rate and it is important for increasing of $\tilde{\nu}_e$-spectrum hardness in the location of a detector.

The assemblage of dependences for relative number of lithium antineutrinos emited from a being pumped reservoir [i.e. $N_r(t)/N_0(t)$] as function of the coefficient b at various times of pumping over t_p (the corresponding flow rates are specified in the brackets), delivery times t_d and parameters α is presented in Fig. 4. The unphysical interval $b = b_{max} \div 1$ is found on the restriction $\alpha V_C = 2wt_d + \alpha b_{max} V_C$. The presence of particular values of the parameter α is the result of the particular geometry choice of the dynamic system for which the calculations of the expected $\tilde{\nu}_e$-spectrum hardness and neutrino reaction cross sections in the detector were made. It is seen that at large times of pumping over t_p the part of lithium antineutrinos emited from the reservoir rapidly goes on the asymptotic behaviour with increasing of the coefficient b, i.e. with a reservoir volume growth. On the other hand, at growth of a pumping over rate w the increase of a volume V_r gives significant growth of the antineutrino part emited from a reservoir.

In the geometry chosen for computation (Fig. 1) the spherical converter has the thickness $L_C = 1$ m and the spherical active zone with volume as at the high-flux reactor PIK [9] and the external radius $r = 24$ cm. This converter on the basis of heavy water *LiOD* solution with concentration ≥ 5.66 % and purity $P_7 = 99.99$ % possess the efficiency $\kappa \geq 0.10$. The spherical reservoir has the volume equal to the converter volume and radius $R_r \cong 1.24$ m. The channel has diameter $D = 0.40$ m and radius of turn $R_t = 1.35$ m. The computations were made at the different delivery channel length L determined from the specified delivery time $t_d = 0.5,\ 0.75,\ 1.0$ s at fixed flow rate w. The values corresponding just such geometries at flow rates $w = 1.5,\ 2.0,\ 2.5,\ 3.0$ m^3/s are marked in Figs. 2 ÷ 4 as the accepted values.

For calculations of the summary $\tilde{\nu}_e$- spectrum hardness it is necessary to compute a lithium antineutrinos flux from the whole dynamic system in a detector remote on a distance S from the reservoir centre (Fig. 1). The numerical integration of fluxes from small volume elements of a converter, reservoir and channels (by the code NDS) were carried out on the part III technique taking into account the radial density of ^{8}Li nucleus creations in the heavy water *LiOD* solution. It was obtained the values of the summary $\tilde{\nu}_e$- spectrum hardness for the detector remote on the distances $S = 2 \div 30$ m.

Computation results of the summary $\tilde{\nu}_e$- spectrum hardness $H(\vec{r})$ as function of the distance S at the different flow rates w are presented in Fig. 5 for the delivery time $t_d = 0.5$ s, in Fig. 6 - for $t_d = 0.75$ s and in Fig. 7 - for $t_d = 1.0$ s. The delivery channel length, corresponding the given values of t_d and w, is specified in brackets. All results are presented for the converter efficiency $\kappa = 0.10$. For other efficiency κ' the value $H(\vec{r})$ should be multiplied on the ratio $\left(\kappa'/\kappa\right)$ as far as the efficiency enters in the summary hardness as a coefficient. Cross sections of the $(\tilde{\nu}_e, d)-$ reaction in the neutral (n, p) and charged (n,n)- channels corresponding reached hardness are laid off on the right axes taking into account linear dependence of neutrino cross sections on the summary spectrum hardness ^{8}.

Near by the reservoir the hardness rapidly drops with an increase of a distance S and asymptotically tends to the value $H = 0.10$, - i.e. the summary $\tilde{\nu}_e$- spectrum hardness for the converter in a static mode of operation. At a dynamic mode the increase of summary spectrum hardness in the location of a detector is based on the geometrical factor - lithium $\tilde{\nu}_e$-sources and reactor $\tilde{\nu}_e$-sources are spaced at different distances from the $\tilde{\nu}_e$-detector . Therefore, the greatest effect is reached at small distances from the reservoir S, maximum flow rate w and greater time of delivery t_d . At a detector position nearby a being pumped reservoir it is possible to increase cross sections in (n, p) and (n,n)-channels at the order and more in comparison with cross sections at $H = 0.10$ in a static mode of operation of a converter. In comparison with cross sections of these reactions in the purely reactor $\tilde{\nu}_e$-spectrum (see Ref. 8) the cross sections in the neutral channel of $(\tilde{\nu}_e, d)-$ interaction grow in tens times and in the charged channel - up to two orders.

In order to reach rapid pumping over of a converter and to provide the lithium delivery on the distance $L \approx 15 \div 25$ m in the time $t_d \leq 1$ s it is necessary to ensure a very significant flow rate w and linear speed $\boldsymbol{V}$ of moving in a channel. Examples of the successful resolution of these serious technical questions are the reactors [13]: ATR (Idaho, USA) - flow rate of water coolent - 170 - 200 m^3/min, GHFR (Grenoble, France) - linear speed of D_2O-coolent -15.5 m/s, SRHFD (Savannah River, USA) - flow rate of D_2O-coolent - 5.65 m^3/s at linear speed 19.8 m/s.

The other advantage of a dynamic system is a possibility to modify a spectrum shape and investigate neutrino reactions at the different summary $\tilde{\nu}_e$- spectrum hardness varying flow rate w from a zero up to maximum. The shapes of a summary $\tilde{\nu}_e$-spectrum at the hardness $H = 0.1 \div 10$ are presented in Fig. 2 of Ref. 8 according to the hardness definition in the part III . Dependence of the summary hardness and cross sections for the channels of $(\tilde{\nu}_e,d)$-reaction are shown in Fig. 8 at the fixed length of the delivery channel $L = 17.90$ m. This length corresponds to the delivery time $t_d = 1.0$ s at the flow rate $w = 2.25$ m^3/s - the average rate among the considered w-values. The construction of this facility requests 22.0 m^3 of 5.66 % *LiOD* heavy water solution. That is necessary 412.8 kg of ^{7}Li isotope with the purity $P_7 = 99.99$ %. The figures are presented for detectors remote for the distances S from 2.5 up to 6.0 meters. Linear speeds $\boldsymbol{V}$ corresponding flow rates w are presented on the bottom axis. Fair growth of cross sections with increase of a flow rate and simple approximation for cross sections at various distances S will give an opportunity to obtain more reliable experimental results.

V. CONCLUSION

The purpose of given work was development of a powerful antineutrino source with a hard spectrum. This problem is solved in a dynamic system where the high-purified ^{7}Li isotope (or lithium-containing substance, for example, heavy water solution of *LiOD*) is pumped cyclically through a converter close by the active zone of a reactor and further over a channel to a remote voluminous reservoir near to the $\tilde{\nu}_e$-detector. The dynamic system allows to locate β^--decays of ^{8}Li isotope near to a detector and it is basic difference and advantage in comparison with a converter operating in a static mode.

The expressions for lithium antineutrino fluxes from dynamic system volumes are derived. It were analysed variants of operation modes that permits to estimate parameters of a designed facility and the hardness of the summary $\tilde{\nu}_e$-spectrum. For dynamic systems with the heavy water *LiOD* solution in the particular geometries it was calculated the hardness and cross sections of antineutrino reactions with a deuteron as function of a flow rate and distance to the $\tilde{\nu}_e$-detector. Is shown that at arrangement of a detector near to a being pumped reservoir and significant flow rates (up to ~ 3 m^3/s) the cross sections in (n, p)-channel of the reaction with a deuteron grow in tens times and in (n,n)-channel - up to two orders in comparison with these cross sections in the spectrum of reactor antineutrinos.

The other advantage of a dynamic system consists is an opportunity to vary a lithium flow rate that allows to modify the summary $\tilde{\nu}_e$-spectrum and to investigate neutrino interactions at the different hardness in the continuous interval $H = \kappa \div H(w_{max})$.

ACKNOLEDGMENTS

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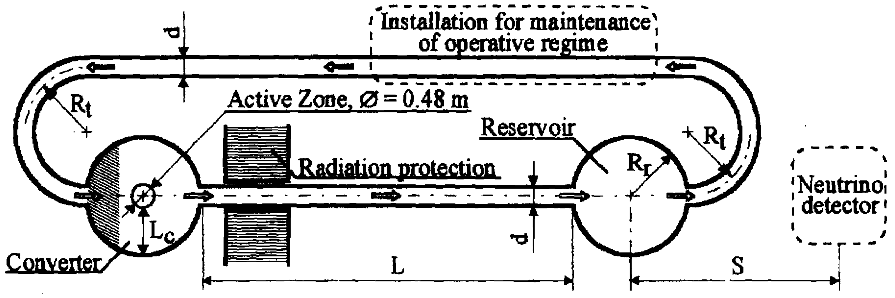

Fig.1. Scheme of the neutrino source facility operating in a dynamic mode

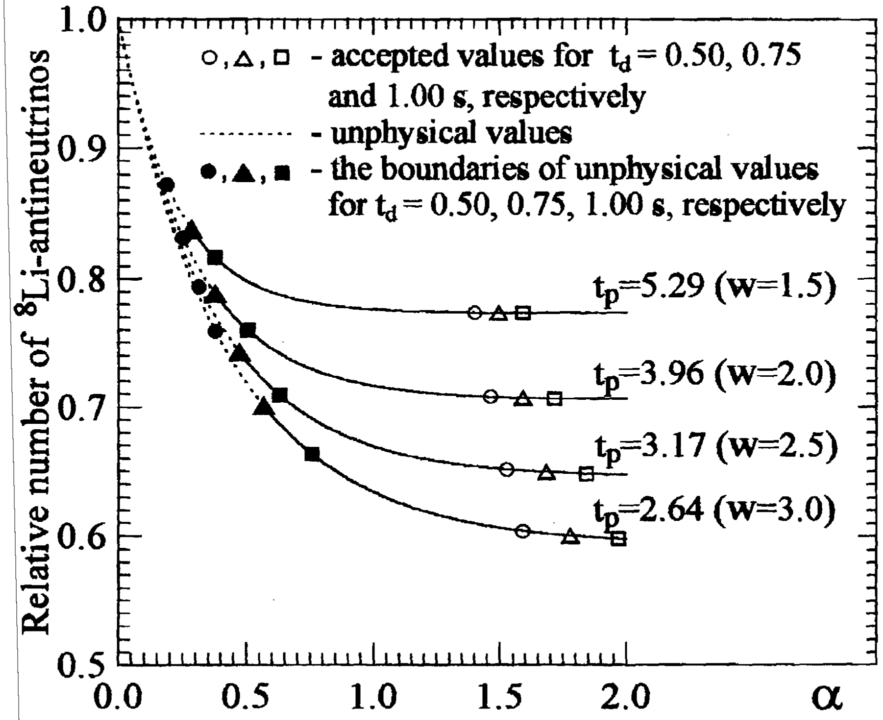

Fig. 2. Relative number of lithium antineutrinos emited from a converter as function of the dynamic system volume parameter α at different times of converter pumping over t_p (s).

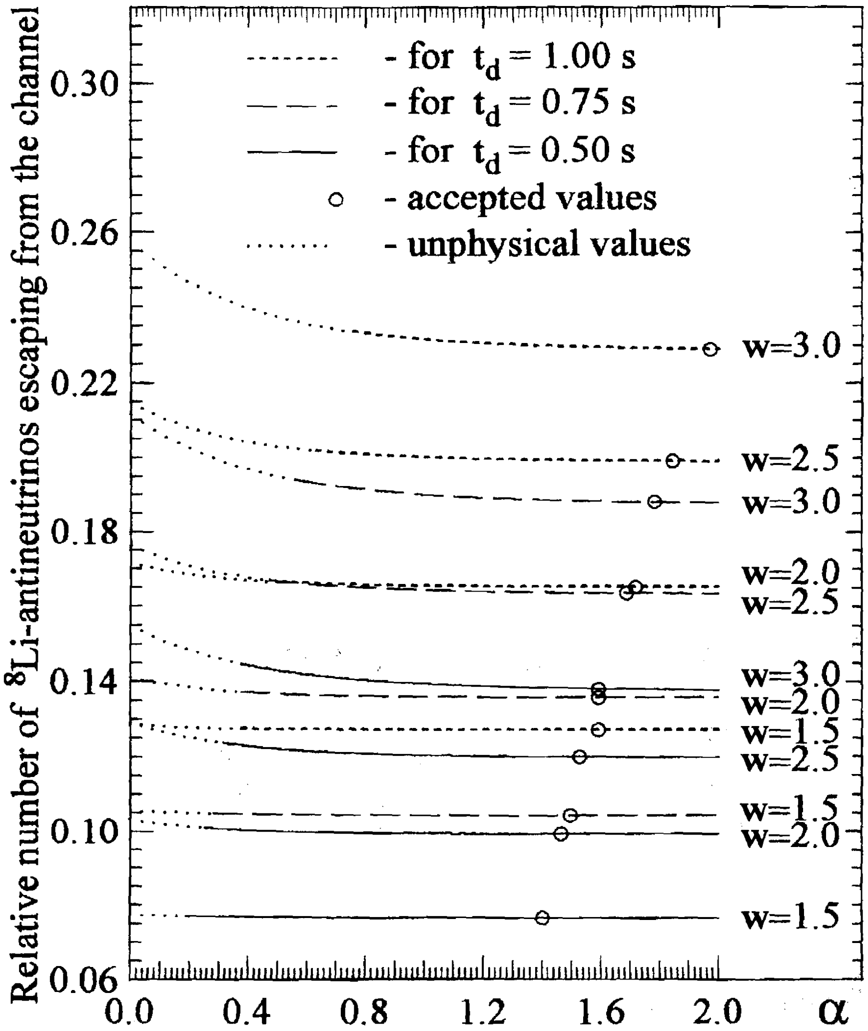

Fig.3. Relative number of lithium antineutrinos emited from a delivery channel as function of the dynamic system volume parameter α at different values of the flow rate w (m^3/s) and time of lithium delivery from a converter to a reservoir - t_d.

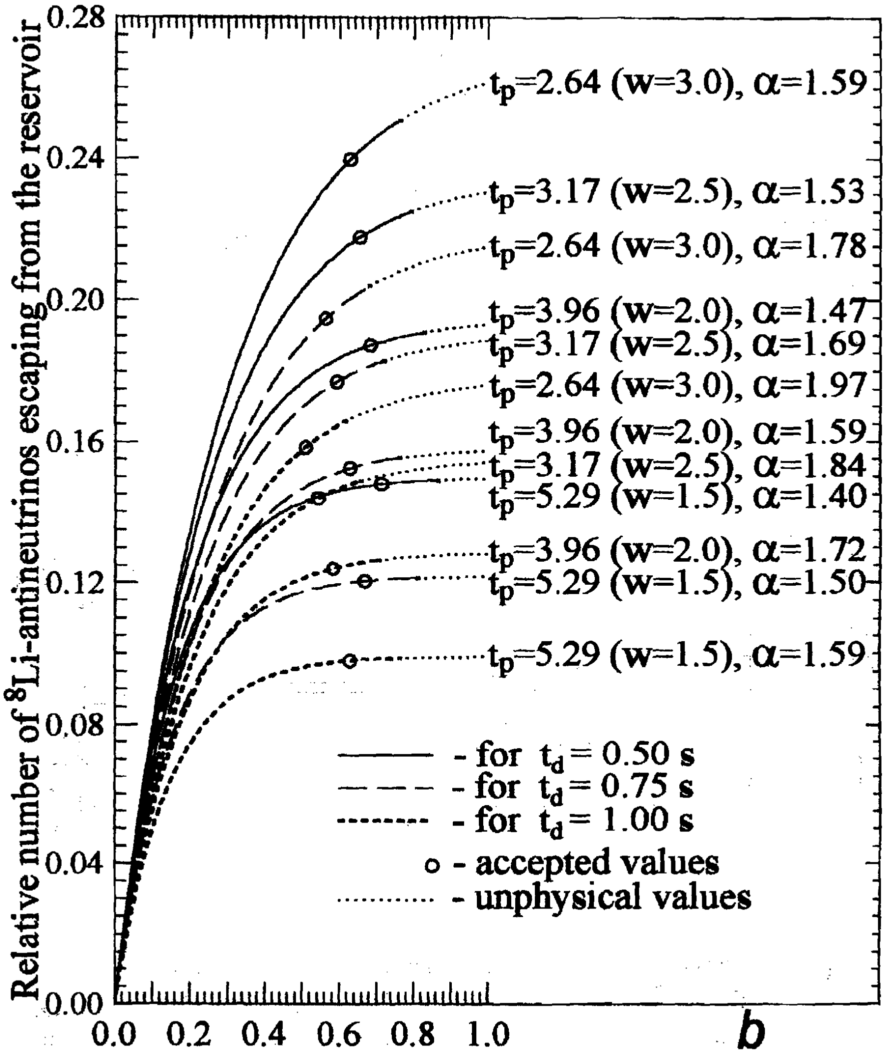

Fig.4. Relative number of lithium antineutrinos emited from a being pumped reservoir as function of the dynamic system volume parameter b at different values of: time of converter pumping over t_p (s), dynamic system volume parameter α, time of lithium delivery from a converter to a reservoir t_d.

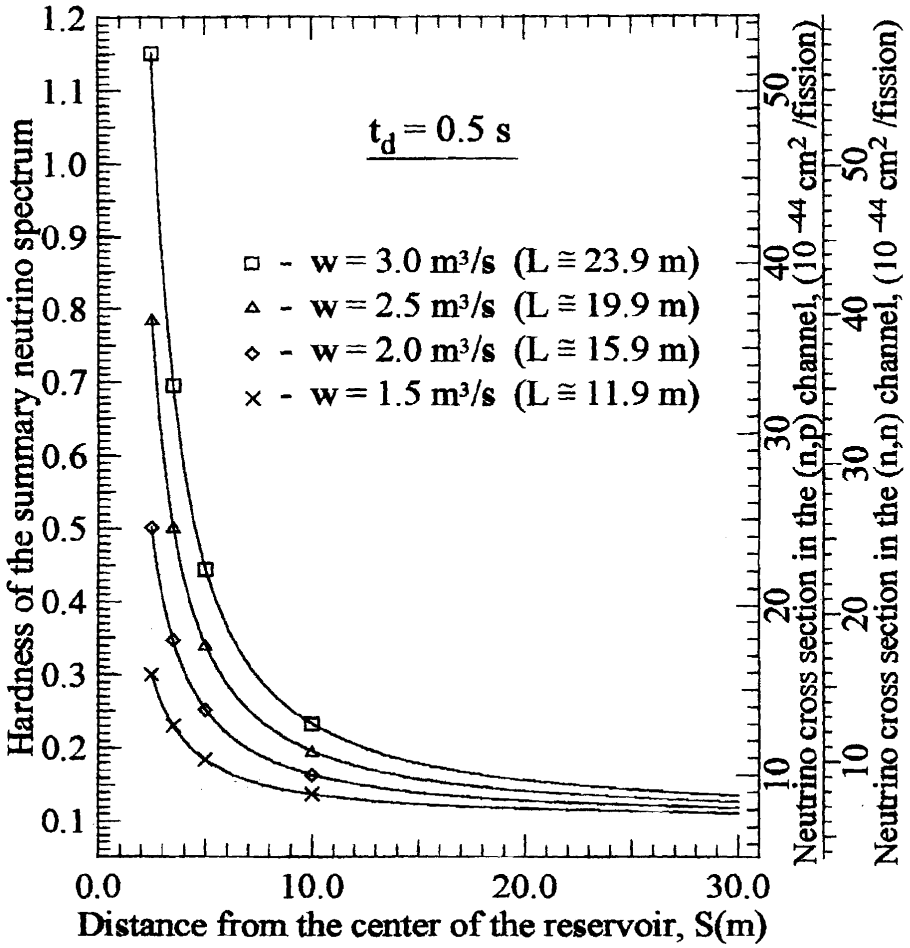

Fig.5. Hardness of the summary $\tilde{\nu}_e$ -spectrum of ($\tilde{\nu}_e$, d)-interactions in (n, p) and (n, n)-channels as function of the distance S from the reservoir center. Curves are presented for different flow rates w at the lithium delivery time from a converter to a reservoir $t_d = 0.5$ s .

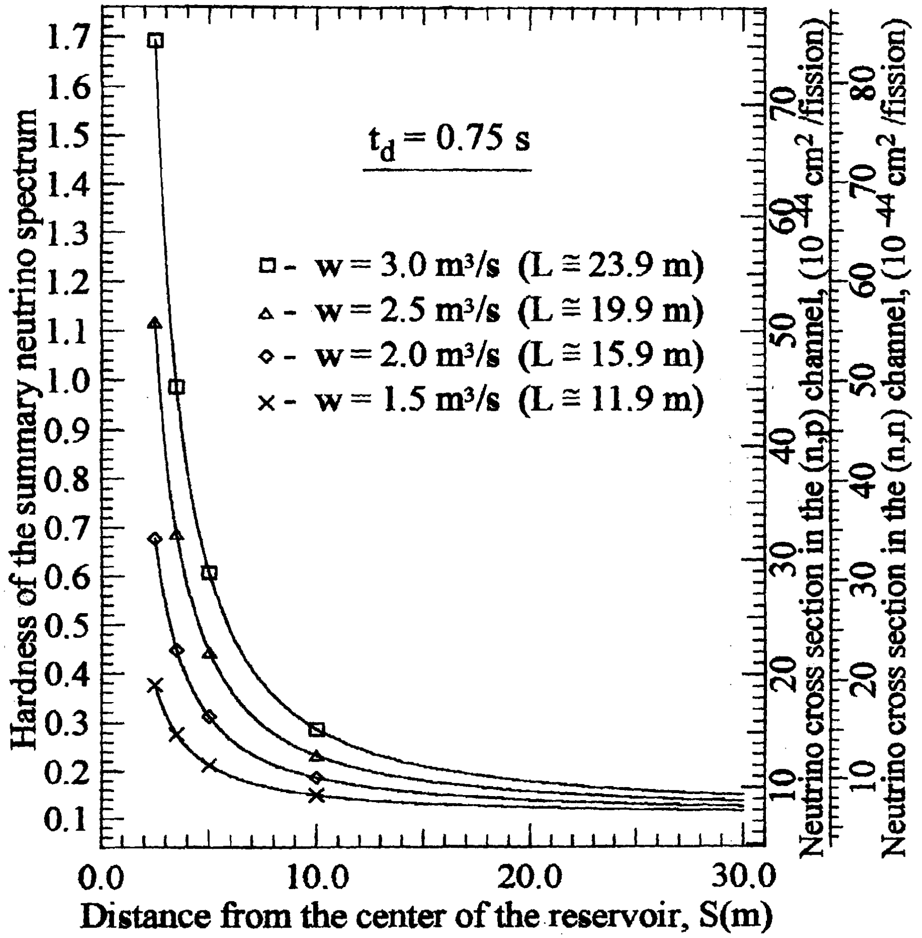

Fig.6. Hardness of the summary $\tilde{\nu}_e$ -spectrum of ($\tilde{\nu}_e$, d)-interactions in (*n*, *p*) and (*n*, *n*)-channels as function of the distance *S* from the reservoir center. Curves are presented for different flow rates *w* at the lithium delivery time from a converter to a reservoir t_d = 0.75 s .

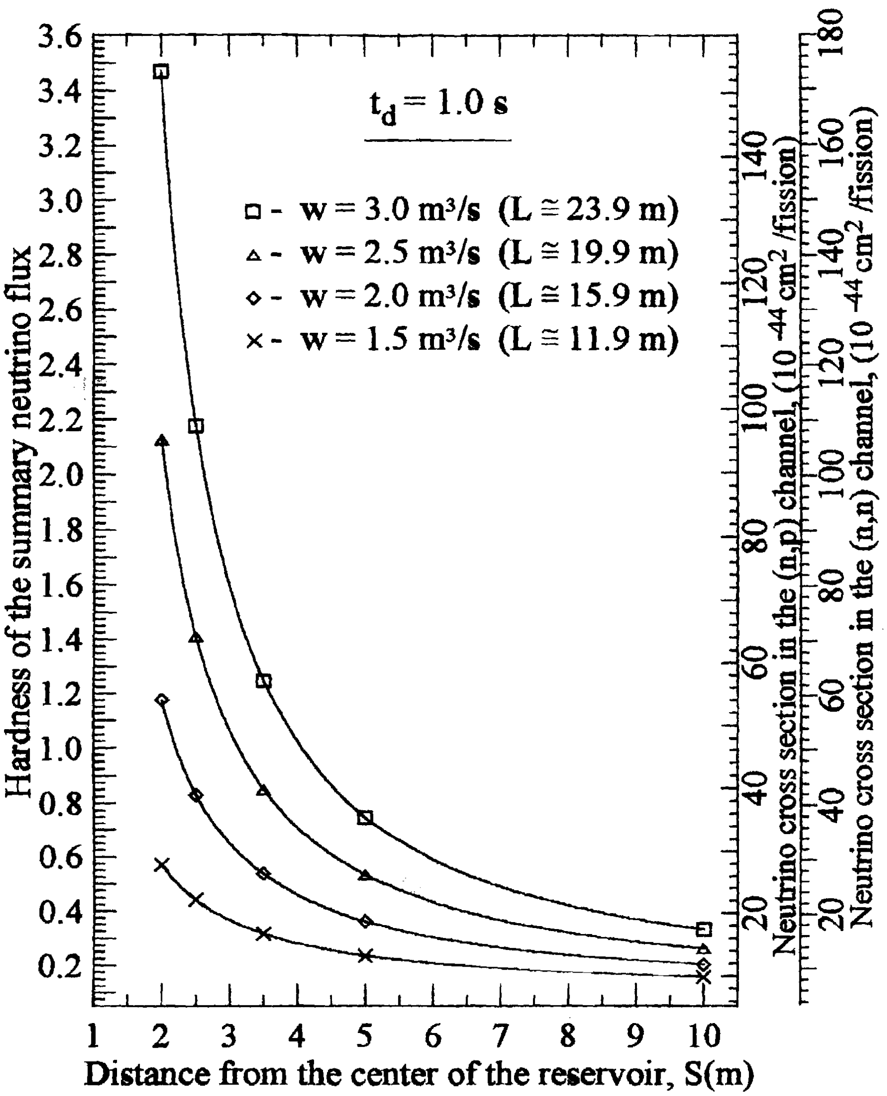

Fig.7. Hardness of the summary $\tilde{\nu}_e$-spectrum of ($\tilde{\nu}_e$, *d*)-interactions in (*n*, *p*) and (*n*, *n*)-channels as function of the distance *S* from the reservoir center. Curves are presented for different flow rates *w* at the lithium delivery time from a converter to a reservoir t_d = 1.0 s.

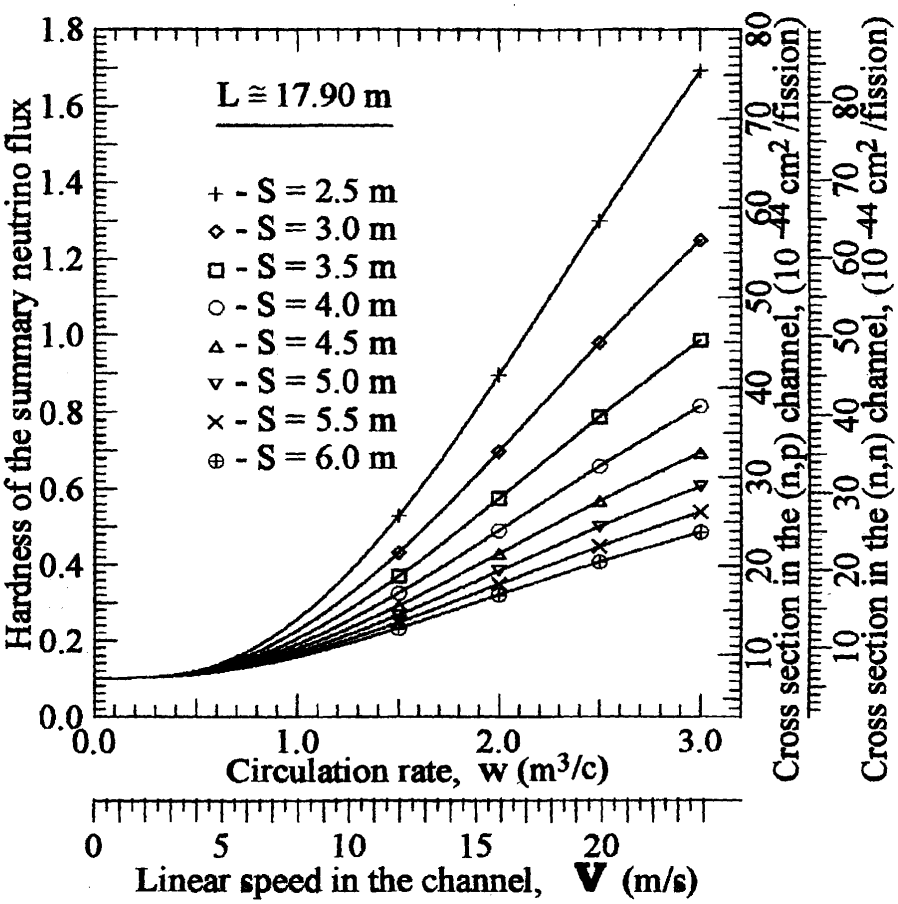

Fig.8. Hardness of the summary $\tilde{\nu}_e$-spectrum of ($\tilde{\nu}_e$, *d*)-interactions in (*n*, *p*) and (*n*, *n*)-channels as function of the circulation rate *W* . Curves are presented for different distances *S* from the reservoir center and at the fixed length of delivery channel - *L* = 17.90 m .

Linear speeds **V** corresponding flow rates *W* are presented on the bottom axis.

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