Shmatov *Energy, Sustainability and Society* (2024) 14:39
https://doi.org/10.1186/s13705-024-00470-3

Energy, Sustainability
and Society

CORRESPONDENCE **Open Access**

Analysis of some of the statements of L. Holmlid about T + D fusion, D + D fusion and ultra-dense hydrogen

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Abstract

Background Thermonuclear fusion is a widely discussed approach to energy production. In 2022, Energy Sustain. Soc. published L. Holmlid's paper (Energy Sustain Soc 12:14, 2022, 10.1186/s13705-022-00338-4) containing, in particular, critical statements about the plans for use of the T + D fusion in energy production. An analysis of these and several other statements of L. Holmlid is presented. This analysis complements a similar analysis performed by K. Hansen and J. Engelen (Energy Sustain Soc 13:14, 2023, 10.1186/s13705-023-00403-6).

Main text It is shown that several statements of L. Holmlid about D + T fusion and D + D fusion are mistaken or ungrounded. It is also shown that the statement of L. Holmlid about the products of annihilation of low-energy antiprotons with protons in ultra-dense hydrogen differs strongly from the data on the products of annihilation of stopped antiprotons with protons in liquid hydrogen and with nucleons of the nuclei of elements heavier than hydrogen.

Conclusion The statement "The use of all resources for fusion research on non-sustainable D + T fusion instead of sustainable muon-induced fusion may be a fatal mistake for humanity", made by L. Holmlid in his Reply (Energy Sustain Soc 13:25, 2023, 10.1186/s13705-023-00404-5) to the aforementioned paper by K. Hansen and J. Engelen, is mistaken.

Keywords Thermonuclear fusion, Inertial fusion energy, Breeding of tritium, Ultra-dense hydrogen, Antiproton

Background

In 2022, Energy Sustain. Soc. published L. Holmlid's paper [1] containing statements about the possibility of energy production with the use of a material called ultra-dense hydrogen, which arises in his experiments, having a very short interatomic distances of, for example, 2.3 ± 0.1 pm and is "the densest form of matter that exists on Earth and probably also in the Universe". In Ref. [1] and several other papers (see, e.g., Refs. [2–4]) L. Holmlid declares in particular, that laser irradiation of this materials results in generation and subsequent annihilation of antiprotons and negative muons, arising due to these processes after decay of negative pions, can be used for muon catalyzed D + D fusion. The energy cost of negative muon, generated by this method, is estimated as 0.25 MeV [1], i.e., as a value which is about 400 times less than the muon rest energy [5]. The negative results of analysis of these statements of L. Holmlid were published by K. Hansen and J. Engelen [5]. Ref. [1] also contains critical statements about the plans for the use of the T + D fusion in energy production. An analysis of some of these statements and several other statements made by L. Holmlid is presented below. This analysis complements that presented in Ref. [5].

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Statements about breeding of tritium, the risk of explosive process and D + D fusion

When discussing breeding of tritium, L. Holmlid declares in particular, that "laser based ICF has no such option" [1] (the abbreviation ICF means Inertial Confinement Fusion). This statement is ungrounded, because Ref. [1] contains no analysis of any scenario of breeding of tritium in power plants utilizing laser thermonuclear fusion, while such scenarios have been discussed in the scientific literature for many years (see, e.g., Refs. [6–13] and bibliography therein; Refs. [6–10] were published before the submission of Ref. [1] to Energy Sustain. Soc.). Note that Refs. [11, 12] contain information about a recent success of the Lawrence Livermore National Laboratory in ignition of thermonuclear microexplosions at the National Ignition Facility and the importance of this success for studies on Inertial Fusion Energy (IFE), and Ref. [12] also contains a recent review of several important problems related to IFE.

The Section "Fusion accidents" of Ref. [1] starts with the following statement: "Another problem with high temperature D + T fusion is of course the risk of explosive process in the fusion reactor. Plasma based methods have such risks, since the fusion process is thermonuclear and it may support itself in an ignited mode. Of course, using picomol quantities of the fuel, the risks are smaller but the usefulness for large-scale energy generation also disappears." We will limit the analysis of this fragment of Ref. [1] by the analysis of the situation with respect to ICF.

Ref. [1] contains no analysis of the influence of a microexplosion on the walls of a reactor chamber, i.e., of the chamber in which the microexplosions occur, or other construction elements of any IFE power plant described in the literature (see, e.g., Refs. [6–8, 10, 14], published before the submission of Ref. [1] to Energy Sustain. Soc., and Refs. [11, 13], published later; the term "IFE power plant" is a synonym of the term "power plant utilizing ICF"). From this point of view, the situation is similar to tritium breeding. However, the statement under consideration overlaps with L.P. Feoktistov's assumption, presented in Ref. [15], and worths special consideration.

L.P. Feoktistov discussed the possibility of a situation where yield Y of some microexplosion, ignited in the power plant, significantly exceeds the average value $\langle Y \rangle$ of Y of other microexplosions, ignited in this power plant [[15] (page 112)]. According to Ref. [15], such a situation will arise if implosion of the fuel occurs without growth of instabilities. An increase in the density of the fuel at the stage of its maximum compression due to the absence or relatively weak growth of instabilities will result in an increase in the fuel burning efficiency η, i.e., in the ratio of the mass of the fuel that undergoes fusion due to one microexplosion to the total mass m_{tot} of this fuel in the target used to perform the microexplosion (see also Refs. [6, 8, 16]; the parameter η is also described by other terms, in particular, "burn efficiency", "burn-up", "fuel burn-up" and "burn-up fraction" [6, 8, 12]). An increase in η corresponds to an increase in Y. L.P. Feoktistov discussed the realization of $Y = 1000\langle Y \rangle$ and assumed that this effect could have catastrophic consequences [15]. It is easy to show that for the power plants utilizing only the DT microexplosions (i.e., microexplosions for which only the T + D fusion reaction is physically important), this assumption and the statement of L. Holmlid about the risk of an explosive process are not realistic and the extraordinary safety measures are not necessary, because even in the physically impossible situation of $\eta \to 1$, Y would be acceptable and the ratio $Y/\langle Y \rangle$ would be less than ten.

According to the projects of such power plants, the average value $\langle \eta \rangle$ of η will be of the order of 0.1 (see, e.g., Refs. [8, 10, 17] where it is assumed that all of the microexplosions have the same yield and, therefore, for all of them $\eta = \langle \eta \rangle$). For example, W.R. Meier et al. [10] described a project of a power plant with $\eta = \langle \eta \rangle = 0.2 - 0.3$ and $Y = \langle Y \rangle = 132$ MJ. In the situation when m_{tot} in the targets of a power plant is fixed, $Y(\eta \to 1) \approx \langle Y \rangle / \langle \eta \rangle$. Thus, $\langle \eta \rangle$ and $\langle Y \rangle$ from Ref. [10] correspond to $Y(\eta \to 1) \approx \langle Y \rangle/(0.2 - 0.3) \approx 440 - 660$ MJ. Creation of a reactor chamber able to withstand a microexplosion with such and even much higher yield is quite possible (see, e.g., Refs. [6–8, 14, 18] and bibliography in Ref. [18]).

Usually, it is assumed that in the power plants utilizing only the DT microexplosions, the atomic fraction x_D of deuterium and the atomic fraction x_T of tritium in the fuel should be equal to 0.5. For example, in Ref. [19] the term "the conventional 50–50 DT mixture" was used. Note, however, that for such power plants, the fuel with $x_T = 0.3 - 0.4$ and $x_D = 1 - x_T = 0.6 - 0.7$ was also proposed [20] (see also Ref. [18] and bibliography therein). The target with $x_D = x_T = 0.5$ for ignition of the microexplosion described in Ref. [10] should contain about $(1.56 - 2.34) \times 10^{20}$ deuterons and the same number of tritons. This number can be presented as approximately $(2.59 - 3.89) \times 10^{-4} N_A[\text{mol}^{-1}]$, where $N_A \approx 6.02214 \times 10^{23}$ mol^{-1} is the Avogadro number. The numbers of moles of D_2, T_2 and DT in the target before its use will depend on the target technology, but it is evident that the sum of these numbers will be in the order of 10^{-4}. Thus, the acceptability of $Y(\eta \to 1)$ in the considered situation is not related to "picomol quantities of the fuel" mentioned in Ref. [1].

The Section "Fusion processes" of Ref. [1] contains the statement that for magnetic confinement fusion and ICF, "D + D fusion cannot be used". For ICF, this statement is mistaken. First of all, the tritium-poor fuel with an x_T of, for example, 0.005–0.01 [8, 21] (see also Ref. [19] where higher x_T are considered), in which physically important D + D fusion reactions are possible, can be compressed by or with the use of thermal radiation from one or several DT microexplosions ignited by the driver(s) with the parameters acceptable for energy production (see, e.g., Refs. [18, 22–24]). Note that in such scenarios, $\langle\eta\rangle$ of the tritium-poor fuel can be of several percent (see, e.g., Refs. [21, 24]) and an occasional increase in η of this fuel can result not only from the absence or relatively weak growth of instabilities at its implosion, but also from its compression to a higher density due to an occasional increase in Y of the DT microexplosion(s). Therefore, the ratio of the maximum possible value $Y^*_{\max}$ of the total yield Y^* of the group of microexplosions that occurs due to one operation of the driver(s) to the average value of Y^* will probably be higher than the maximum possible ratios of $Y/\langle Y\rangle$ in the power plants utilizing DT microexplosions. In any case, $Y^*_{\max}$ can be calculated and the undesirable consequences of the occasional increases in Y^* can be prevented by means of the proper choice of the safety factors (see also Refs. [13–15, 18] and bibliography in Ref. [18]). We repeat that the realization of the values $\eta \to 1$ is physically impossible (see also Refs. [6, 8, 16, 19]).

Statement about supposed annihilation of antiproton with proton in ultra-dense hydrogen

L. Holmlid describes the supposed annihilation of antiproton with proton in ultra-dense hydrogen as

$$\mathrm{p} + \overline{\mathrm{p}} \to 2\mathrm{K}^{\pm}(96\ \mathrm{MeV}) + 2\pi^{\pm}(69\ \mathrm{MeV}) + 2\pi^{\pm}(0\ \mathrm{MeV}), \tag{1}$$

where in parentheses the kinetic energies of the particles are presented [1]. This description corresponds to the situation when the kinetic energies of proton and antiproton can be considered negligibly small and differs strongly from the description of annihilation of antiproton with proton on the basis of the experimental data obtained in other laboratories [25, 26]. For example, G. Vulpetti described the mean result of annihilation of antiproton with proton at rest in liquid hydrogen as

$$\begin{aligned} \mathrm{p} + \overline{\mathrm{p}} \to\ & (1.527 \pm 0.019)\pi^{+} + (1.527 \pm 0.019)\pi^{-} \\ & + (1.96 \pm 0.23)\pi^{0} + 0.012\mathrm{K}^{+} + 0.012\mathrm{K}^{-} \\ & + 0.013\mathrm{K}^{0} + 0.013\overline{K^{0}} \end{aligned} \tag{2}$$

and presented the following average total energies of the annihilation products: $E(\pi^{+}) = E(\pi^{-}) = 374$ MeV, $E(\pi^{0}) = 358.5$ MeV, $E(\mathrm{K}^{+}) = E(\mathrm{K}^{-}) = E(\mathrm{K}^{0}) = E(\overline{K^{0}}) = 633$ MeV [25]. These values of E correspond to the average kinetic energies $\langle E_k\rangle(\pi^{+}) = \langle E_k\rangle(\pi^{-}) \approx 234.4$ MeV, $\langle E_k\rangle(\pi^{0}) \approx 223.5$ MeV, $\langle E_k\rangle(\mathrm{K}^{+}) = \langle E_k\rangle(\mathrm{K}^{-}) \approx 139.3$ MeV, $\langle E_k\rangle(\mathrm{K}^{0}) \approx \langle E_k\rangle(\overline{K^{0}}) = 135.3$ MeV. G. Vulpetti used the experimental data obtained at CERN and Columbia University [25]. Even if in the experiments of L. Holmlid the ultra-dense hydrogen and antiprotons really arose (the convincing arguments against this assumption are presented in Ref. [5]; see also bibliography in Refs. [4, 5]), the strong difference between the products of annihilation of antiproton in ultra-dense and liquid hydrogen, in particular, the absence of a significant number of neutral pions in the former case, would probably be impossible. Note that neutral pion mainly decays into two gamma quanta [25]. It is also worth noting that when describing the annihilation of stopped antiprotons with nucleons of the nuclei of elements heavier than hydrogen, D. Polster et al. [[26] (page 1168, left column)] wrote the following: "The total available energy of 1880 MeV of the annihilation of an antiproton with a nucleon at nearly zero kinetic energy produces an average of five pions ($3\pi^{\pm} + 2\pi^{0}$) with mean kinetic energies of 210 MeV." The distances between nucleons in nuclei are less than the supposed distance between protons in ultra-dense hydrogen. Thus, the strong difference between (1) and (2) cannot be attributed to the high density of the ultra-dense hydrogen.

Stopping of negative pions in matter is accompanied by their strong interaction with nuclei and emission of neutrons and charged particles [26, 27]. L. Holmlid does not discuss the possibility of manifestation of this mechanism of the generation of neutrons in his experiments, although he declares that "The instruments detect neutrons from fusion in D_2 and also possibly neutrons from muon-capture process, for example in surrounding materials" [3]. Fusion in D_2 is supposed to be catalyzed by muons arising due to decay of negative pions [1–4].

Conclusions

The results presented in this paper demonstrate that the statement of L. Holmlid about breeding of tritium in IFE power plants is ungrounded, his other considered statements about thermonuclear fusion are mistaken and the strong difference between the products of the supposed reaction (1) and the products of annihilation of antiprotons with protons in liquid hydrogen and with nucleons of the nuclei of elements heavier than hydrogen is an additional argument against the assumption about generation and subsequent annihilation of antiprotons in his experiments. These results also demonstrate, in combination with those presented by K. Hansen and J. Engelen in Ref. [5], that the statement "The use of all resources for fusion research on non-sustainable D + T fusion instead of sustainable muon-induced fusion may be a fatal mistake for humanity", made by L. Holmlid in Ref. [4], is mistaken.

Author contributions
M. Sh. wrote the manuscript text.

Funding
No funding.

Availability of data and materials
All data used are published previously.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The author declares no competing interests.

Received: 12 December 2023 Accepted: 27 June 2024

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