Stellarator-mirror fusion-fission hybrid – a fast route to clean and safe nuclear energy

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For about 70 years, nuclear energy uses mainly the uranium-235 isotope, the concentration of which in natural uranium is only 0.7%. The remaining is uranium-238. Only about half the uranium-235 enters the fuel after enrichment. The rest remains in depleted uranium. In addition, less than half of the uranium-235 burns out in the fuel. In aggregate, only 0.2% of the mined uranium is used, while the rest is turned into waste. The major part of the waste is depleted uranium. It is usually stored at the site of production of nuclear fuel in the form of the toxic hexafluoride. The rest of the waste is spent nuclear fuel which is buried in short and long-term storage facilities. Note here that the energy gain in fission reactions is almost the same for all fissile isotopes, and they can in principle be burned with similar energy output as uranium-235. We here consider a subcritical system for efficient burning of uranium-238 and all accompanying fissile isotopes produced by it in neutron reactions.

The present inefficient and costly use of uranium can be changed with fast reactors which are able to burn all fissile isotopes. As an example, in a traveling wave reactor, fuel combustion reaches tens of percent [1]. With reprocessing, it is possible to close the fuel cycle with a critical fast reactor. In [2] a fuel cycle is derived, in which after burning 10% of fuel, it is unloaded from the reactor, fission products are removed during processing, the same amount of depleted uranium is added, and finally new fuel is made from this mixture. In this scenario in [2], the new fuel have identical isotopic composition to the previous one. In such a fuel cycle, depleted uranium is consumed and the waste is fission products. As only uranium 238 is consumed, the fuel resources could serve a world-wide energy production for about 100,000 years. Most importantly, the fuel cycle scenario seems consistent with nuclear non-proliferation, since the fuel isotope mixture in all states has an insufficient fraction of plutonium 239.

Attempts to make a practical fast reactor have so far not been successful. One reason is that fast reactors have a dramatically reduced self-stabilization. In addition, the portion of delayed neutrons in a fast reactor is lower than in light water reactors. This means that a critical reactor is less controlled.

Subcritical systems could solve this problem. We propose the stellarator-mirror hybrid [3] as a practical subcritical fast reactor system. The device is comparatively compact and is designed for steady-state operation. In a subcritical system, neutron reactions are controlled by an external neutron source (in our case by a plasma neutron generator), which substantially increases the safety and also provides more flexibility in the control.

[1]. J. Gilleland, R. Petroski, & K.Weaver, (2016). *Engineering*, *2*(1), 88.
[2]. V. Moiseenko and S. Chernitskiy, (2019). *Nuclear and Radiation Safety*, no. 1(81) 30.
[3]. V.E. Moiseenko, et al., (2021). *VANT ser. Thermonuclear Fusion* 44 111.