**Investigation of the released p-11B fusion energy from proton beam interaction with 11B target**

Daponta C.[1], S. D. Moustaizis[1 and P. Lalousis[2]

*[1] Technical University of Crete, Lab of Matter Structure and Laser Physics, Chania, Crete, Greece*

[2] *Institute of Electronic Structure and Laser FORTH, Heraklion, Greece*

**Abstract**

Between the so-called “advanced fusion fuels”, *p-11B* nuclear fusion reaction is of interest, due to the production of three (3) iso-energetic charged alpha particles with *8.7 MeV* total energy, which can directly be converted into electricity [1, 2, 3]. In the present work, we examine the possibility of exploiting the energy of these three (3) fusion produced alpha particles, considering the interaction of a beam of accelerated protons with a solid *11B* target. During this kind of interaction, protons with a kinetic energy between 650 keV and 1MeV are of particular interest, as in this energy range, the exploitation of the *675keV* resonance is possible. As the protons move through the solid *11B* target, they lose gradually their initial kinetic energy *EK(0*), in the context of a *Continuous Slowing Down Approximation* (*CSDA*). *Stopping power* expresses the specific energy loss rate per unit path length of the protons inside the *11B* target and can be used for the determination of their range – penetration depth (*RCSDA*) in the solid *11B* material, through the integration of the *Bethe-Bloch* formula. Protons deposit the biggest part of their energy in the *Bragg peak*. However, until the end of their range in the *11B target,* where they have eventually lost all of their initial kinetic energy and stop, *p -11B* nuclear fusion reactions are induced. In a specific position *z* inside the *11B* target, the production of alphas depends on the number of protons, the solid *11B* target particle density and the cross section corresponding to the residual energy of protons. As it is observed through our numerical evaluations, when the protons initial kinetic energy is higher, the production of alpha particles increases significantly, while the maximum production of alpha particles occurs at a greater depth within the *11B* target. The alpha particles produced from *p-11B* nuclear fusion reactions inside the 11B target, can either exit its two sides (in a straight line or at an angle *θ*)*,* or remain inside it, if the distance to be travelled is greater than their range in solid *11B.* The use of the *Bragg-Kleeman* rule enables us to determine the alpha range in the *11B* target. Determining a suitable *11B* target thickness and considering a uniform alpha particle energy loss across their path, we calculate the energy spectrum and the angular distribution of the alphas exiting the *11B* target. This evaluation could be useful for the determination and the development of a potential experimental diagnostics configuration, concerning the alpha particles production detection. The study of two schemes, one electrical and one thermal, for the conversion of alpha energy into electrical energy, shows that the configuration of the proton beam interaction with the *11B* target is not effective for energy production. The number of protons in the beam remains relatively small, regardless of whether it is produced using a high-intensity laser beam [4, 5, 6] or high current pulsed power technology [7]. As an example, it is noteworthy to mention that a compact pulsed power device, operating at *800 kV-1MV*, with a pulse duration between *100ns -  1 μs*, produces a proton beam current of *15 kA* [7], that is able to deliver  ~ *1017* protons to the Boron target. Considering a repetition rate of a *10Hz*, a *100%* conversion efficiency of the proton beam to three (3) *2.9 MeV* fusion born alphas and no input power losses for the operation of the pulsed power device, the output *p-11B* fusion power would be of the order of *1.5 MW*. However, in a more realistic case, the alpha production efficiency is *10-3–10-4*, the input electric power losses are *~20%* for the proton beam generation and the remaining alphas in the Boron target reduce the useful electric output power to the range of *kWatt*, which is much lower than the input power of the proton beam. Thus, in the context of more efficient schemes, recent efforts concern a hybrid configuration, in which a proton beam interacts with a plasma [8] or with a relatively low temperature *11B* medium (~< *100 eV*) [9]. These two schemes allow the determination of the stopping power and the fusion probability (as a function of the electron density), as well as of the contribution of potential related processes, such as the chain reaction and the avalanche effect [9, 10].

**References**

[1] H. Hora, S. Eliezer, G. J. Kirchhoff, N. Nissim, J. X. Wang, Y. X. Xu, G. H. Miley, J. M. Martinez-Val, W. McKenzie, and J. Kirchhoff, “Road map to clean energy using laser beam ignition of boron-proton fusion,” *Laser and Particle Beams,* vol. 35, no. 4, p. 730–740, 2017.

[2] H. Hora, “Clean boron fusion using extreme laser pulses: A laser-driven technique to ignite proton-boron fuel offers the possibility of nuclear fusion for clean, Sustainable energy generation”, SPIE, The international society for optics and photonics, httpt://spie.org/, 14 July 2015.

[3] [https://hb11.energy](https://hb11.energy/)

[4] A. Picciotto, D. Margarone, A. Velyhan, P. Bellini, J. Krasa, A. Szydlowski, G. Bertuccio, Y. Shi, A. Margarone, J. Prokupek, A. Malinowska, E. Krouski, J. Ullschmied, L. Laska, M. Kucharik, and G. Korn, “Boron-Proton Nuclear-Fusion Enhancement Induced in Boron-Doped Silicon Targets by Low-Contrast Pulsed Laser”, *Phys. Rev.*, vol. X 4, p. 031030, 2014.

[5] D. Margarone, A. Picciotto, A. Velyhan, J. Krasa, M. Kucharik, A. Mangione, A. Szydlowsky, A. Malinowska, G. Bertuccio, Y. Shi, M. Crivellari, J. Ullschmied, P. Bellutti, and G. Korn, “Advanced scheme for high-yield laser driven nuclear reactions”, *Plasma Physics Controlled Fusion*, vol. 57, p. 014030, 2015.

[6] D. Margarone, J. Bonvalet, L. Giuffrida, A. Morace, V. Kantarelou, M. Tosca, D. Raffestin, P. Nicolai, A. Piccioto, Y. Abe, Y. Arikawa, S. Fujioka, Y. Fukuda, Y. Kuramitsu, H. Habara, and D. Batani, “In-Target Proton-Boron Nuclear Fusion Using a PW-Class Laser”, *Applied Sciences*, vol. 12, p. 1444, 2022.

[7] K. Perrakis, S. D. Moustaizis and P. Lalousis, “Numerical investigations on high flux neutron production from a high-current pulsed ion device”, *Proceedings of the 47th Conference on Plasma Physics,* 2021.

[8]Thomas. A. Mehlhorn, L. Labun, B. M. Hegelich, et al., "Path to Increasing p-B11 Reactivity via ps and ns Lasers", LPB, 2022, 2355629, 16 p, (2022).

[9] N. Nissim, Z. Henis, C. Daponta, S. Eliezer, S.D Moustaizis, P. Lalousis and, Y. Schweitzer, “Parametric scan of plasma parameters for optimization of the avalanche process in p11B fusion”, *Presentation in the 2nd International Workshop on proton-Boron fusion*, Catania, Sicily, 5-8 September 2022.

[10] S. Moustaizis, C. Daponta, S. Eliezer, Z. Henis, P. Lalousis, N. Nissim and, Y. Schweitzer, “Alpha heating and avalanche effect simulations for low density proton-boron fusion plasma”, *Presentation in the 2nd International Workshop on proton-Boron fusion*, Catania, Sicily, 5-8 September 2022.