# Numerical Investigation of Ignition in a Novel Positron-Catalyzed Fusion Propulsion Concept

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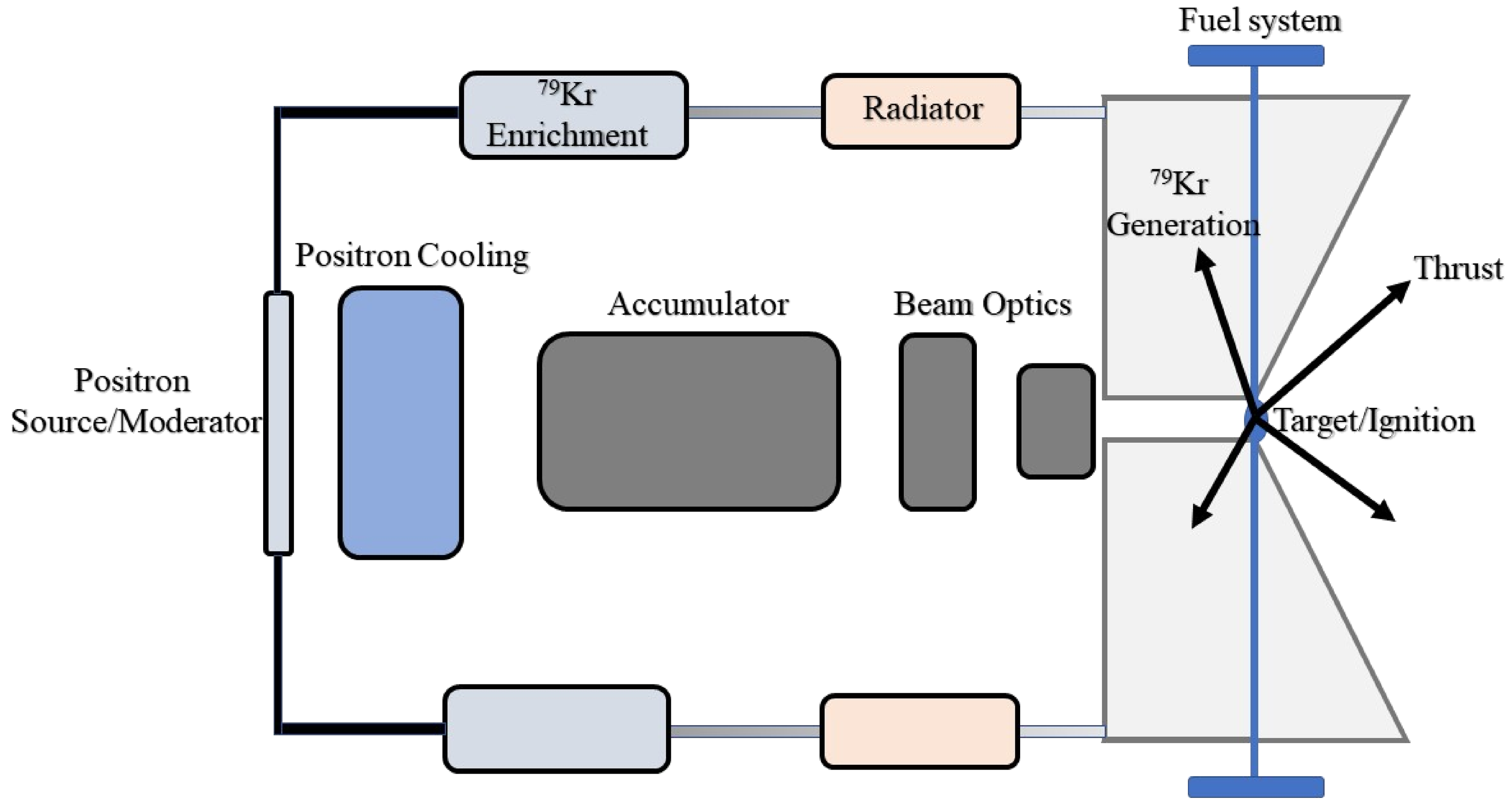



*Figure 1. Radioisotope Positron Propulsion (RPP) concept overview*

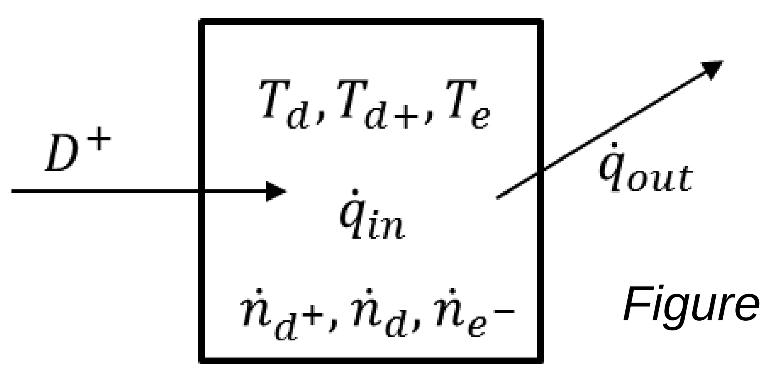
For the past several years, Positron Dynamics, Inc. has been developing a novel anti-matter based spacecraft propulsion technology [1]. The concept utilizes a radioisotope-generated beam of positrons to catalyze fusion in a dense Deuterium layer implanted on a Palladium tape. The underlying nuclear excitation process occurs when a virtual photon from positron-electron annihilation imparts a large amount of kinetic energy to a trapped deuteron [2]. Once this momentum transfer to the deuteron occurs, the fusion reaction probability is determined by the D-D fusion cross-section and surrounding Deuterium number density and geometry.

**The objective of this poster is to summarize a recent effort to investigate the ignition characteristics. Specifically, we were interested in estimating the minimum necessary positron flux and the minimum density of Deuterium required for ignition. The study followed two routes.**

First, a **zero-D model** was developed to study the energy balance. This model took into account energy gains and losses from annihilation, fusion, ionization, radiation, thermal diffusion, and so on. Typical output from the model is shown in Figure 3. This figure compares two sets of input positron fluxes and deuterium densities. The plot on left is the typical scenario in which the target fails to reach temperature high enough for a sustained fusion reaction. The second plot shows a case in which ignition is apparent.

Second, a **two-dimensional simulation** of the ignition burn was attempted using a hybrid fluid-particle approach with the code Starfish [3]. Due to the extreme densities encountered in the real system, the simulation had to employ artificial scaling of physical properties. The simulation models an infinitely long deuterium layer bounded on one side by the palladium tape and the ambient free space on the other. Annihilation-created Deuterons are injected from a small spot. Figure 4 shows the computational domain and a preliminary plot of ion densities and velocities warped by the local potential.

[1] Weed, R., *Radioisotope Positron Propulsion*, NASA Innovative Advanced Concepts, Phase I, 2018
[2] Morioka, S., "Nuclear Fusion Triggered by Positron Annihilation in Deuterated Metals", *Il N. Cimento*, 107a/N12, 1994
[3] Starfish, https://www.particleincel.com/codes/starfish
[4] Bosch, H.S., Hale, G.M., "Improved Formulas for Fusion Cross-Sections and Thermal Reactivities," *Nuclear Fusion*, 32, 4, 1992
[5] Hydrogen Radiated Power Loss Rates, https://www-amdis.iaea.org/FLYCHK/ZBAR/csd001.php




$$\frac{d}{dt}\left(\frac{3}{2}n_d k T_d\right) = S_a + S_f + S_e - S_{le} - S_i \qquad \frac{dn_j}{dt} = \dot{n}_j$$

*Figure 2. Control volume and energy and mass conservation equations used for the 0D model*

Energy sources were modeled with the following relationships:

**Annihilation:** $S_a = \dot{n}_a 1.02\text{MeV}$

**Fusion:** $S_f = \left(\frac{n_d n_d}{2}\right) < \sigma v >_f 3.268\ \text{MeV}$ with $< \sigma v >_f = 10^{-6} \cdot C_1 \cdot \theta \sqrt{\xi/(m_r c^2 T^3)} \exp(-3\xi)$ [4]

**Elastic Transfer:** $S_e = n_d \nu \frac{m_d}{m_{pd}} 3k(T_{pd} - T_d)$

**Line Emission:** $S_{le} = r(T_e) n_j \cdot 10^{-7}$ where $r$ is tabulated AMDIS radiated power loss rate in erg [5]

**Ionization:** $S_i = \dot{n}_e \epsilon_i$ with Saha equation used to obtain the ionization state at the current temperature

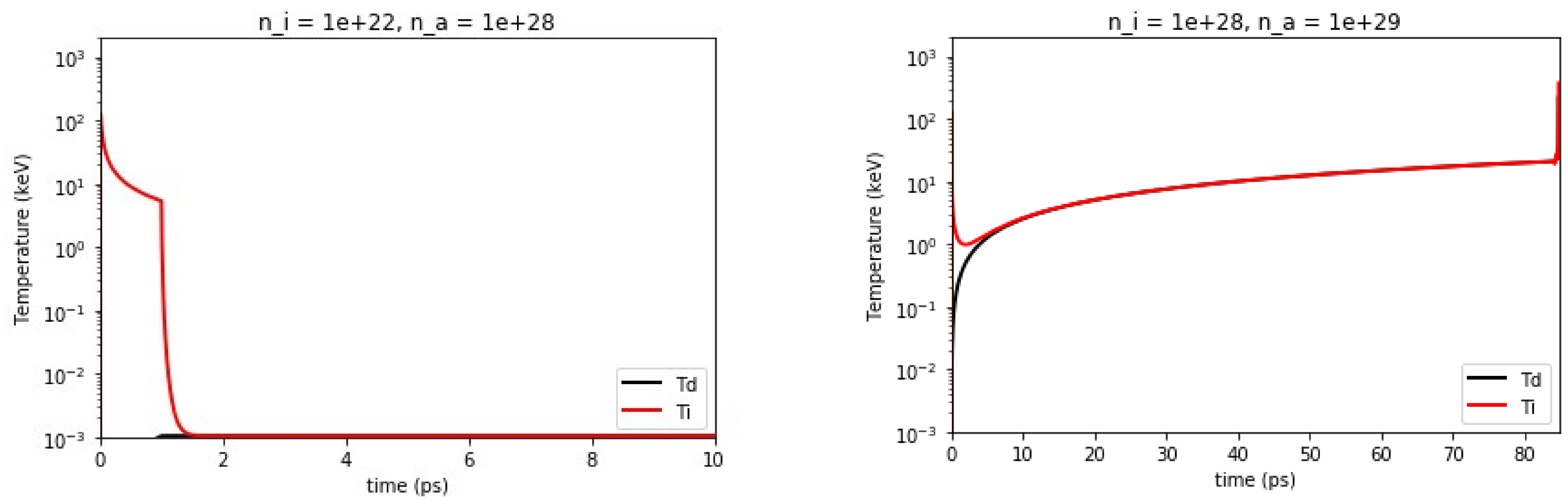



*Figure 3. Typical 0D results. The plot on left corresponds to a case in which ignition is not achieved.*

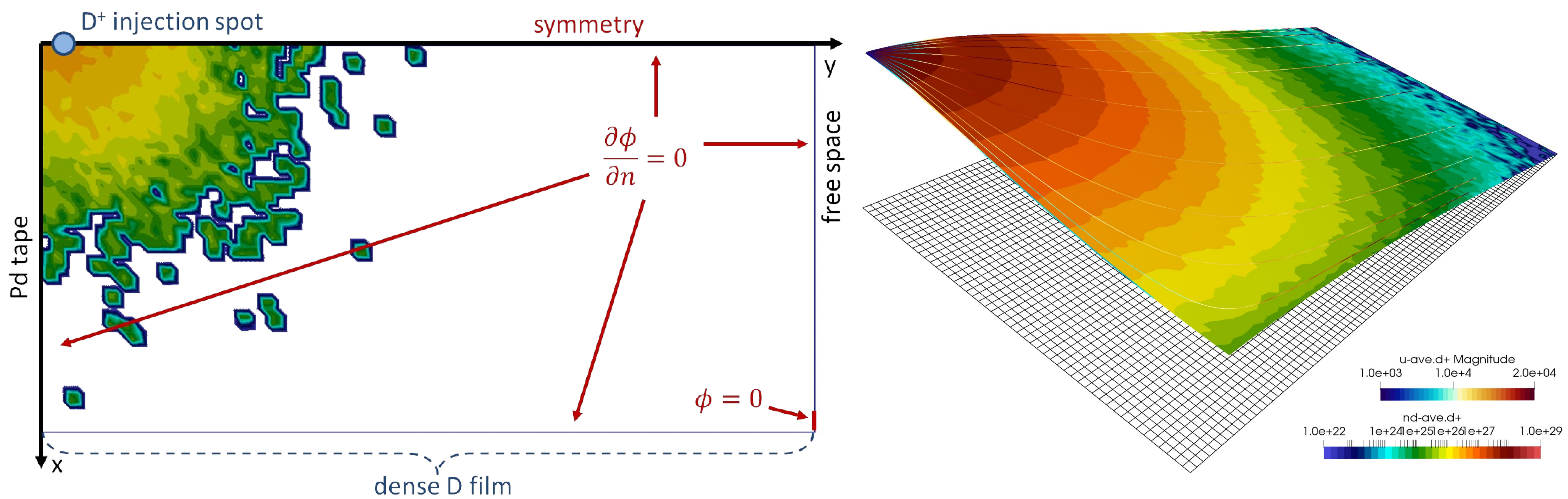



*Figure 4. Simulation setup and a proof-of-concept preliminary result from the two-dimensional hybrid PIC simulation*