

Neutron Flux-Irrated Hydrodynamics and Transport Coefficients of Fissioning $^{235}\text{UF}_6$ Plasma Laminar Flow

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ABSTRACT

For weakly ionized dense plasma exposed to fission fragment radiation, coupled self-consistent Boltzmann equations for fission fragments and generated primary electrons are defined. The kinetics of rapid particle energy generation in a plasma are researched based on these equations. For the helium-3 plasma exposed to neutron flux, steady-state analytical solutions for fission fragments and the functions of energy distribution of the primary electrons were identified and examined. We compare the outcomes with calculations of energy spectra from Monte Carlo methods.

Keywords- Fissioning plasma, Boltzmann equation and helium-3.

I. INTRODUCTION

For weakly ionized dense plasma exposed to fission fragment radiation, coupled self-consistent Boltzmann equations for fission fragments and generated primary electrons are defined. The kinetics of rapid particle energy generation in a plasma are researched based on these equations. For the helium-3 plasma exposed to neutron flux, steady-state analytical solutions for fission fragments and the functions of energy distribution of the primary electrons were identified and examined. We compare the outcomes with calculations of energy spectra from Monte Carlo methods. and merges with the thermal neutron flux, transforming the resultant plasma into a distinct physical entity. It is feasible to actually achieve the direct conversion of nuclear energy into excited atom electromagnetic radiation under these physical conditions. The energy distribution of fission fragments of primary electrons is one of the biggest internal unresolved issues with this difficult technology. Compared to an electric discharge, the evolution of these

energy spectra to their stationary state is entirely different. From the description of a discharge in external electric fields to the pumping of gas mixtures by electron beams, the study of kinetic processes based on the solution of the Boltzmann equation is concentrated and applied to a wide range of physical phenomena in many contemporary publications. The Boltzmann equation may also be used to describe plasma created by fission fragments; however, it must be modified to account for the physical parameters of gaseous mixtures including fissioning elements.

II. METHODS

We have been created for the thorough examination and resolution of the inhomogeneous gas Boltzmann equation.

[3] Developed full extent analysis and solution methods for the Boltzmann equation [4] applied to non-uniform gases. The Boltzmann equation was first applied to a weakly ionized plasma in a periodic electric field in one of the earliest works. The high frequency gas

discharge for a slightly ionized plasma was studied in this study under the following limiting conditions. Elastic collisions outnumbered inelastic ones, with electrons, ions, and excited molecules expected to have densities smaller than those of buffer gas [BG] molecules. Test gas is assumed to be at densities where the hydrodynamic approach makes sense, and the external electric field frequency is assumed to be greater than the plasma frequency. The main portion consists of the Boltzmann equation adjustment for a plasma electron distribution affected by a high-frequency external electric field. Thus, enough constraints were created for additional applications under the presumption that the initial and final velocities are near to one another. It should be noted that the Boltzmann kinetic equation was applied to fissioning plasma using the same assumptions; however, the crucial issue raised earlier—namely, the appearance of the primary electron spectra—was not even addressed. Given the existence of an electron density gradient, self-consistency of the external field is implied. Townsend ionization processes, which are related to secondary electron spectra, ought to be incorporated into the Boltzmann kinetic equation. The impact of an electron beam used as an ionization source was examined in [5], and the Boltzmann equation was also applied in [6] without any modifications. A sufficiently strong electric field can cause runaway electrons to appear in a fully ionized plasma, as was examined in. According to [8], the majority of electrons on their mean free path are continually accelerated because they gain more energy from the electric field than they do from inelastic collisions. The external force, treated as bremsstrahlung, was presented with the steady state Boltzmann equation. If we know the energy band in which this braking force appears and disappears, we can definitely take this case

into consideration as well. There was no discussion or presentation of the identification of fast electrons with energy around MeV, or "runaway electrons," and a statistical approach may be used to solve this issue [9]. It should be noted that the Boltzmann equation includes the energy band of the electron degradation spectra that is associated with its radiation, or bremsstrahlung, even though it was not defined. .. It was discovered that because of their Broglie wavelength and the experimentally significant resolution of runaway electrons' appearance, X-rays might be regarded as electrons. This remains an open issue. Consequently, we treat the interactions between the test or incident particle and atoms as though they were interactions between an incident particle and a complex dynamical system of charged particles moving in a state of dynamical equilibrium, rather than as two rigid spheres. result.

III. BOLTZMANN KINETIC EQUATIONS FOR PRIMARY ELECTRONS AND FISSION FRAGMENTS

Let's assume that the concentration of electrons and fission fragment species is significantly lower than that of neutrals or buffer gas and denote them as species by and by, respectively. We disregard the interactions between electrons and fission fragments as a result of this assumption. We also indicate the following functions of electron and fission fragment energy distribution. The Boltzmann equation then provides the following description of the j-type of fission fragments function of energy distribution:

$$\partial_{\mu} F_j(t, \vec{r}, \vec{\xi}) = \Omega_j^{fission}(t, \vec{r}, \vec{\xi}_0) + \Omega_j^{ion}(\vec{\xi}_j \rightarrow \vec{\xi}_j, F_j) + \sum_{k=1}^m S_{j,k}^{exc}(\vec{\xi}_j \rightarrow \vec{\xi}_j, F_j) \quad (1)$$

$$S^{el}(\vec{\xi}_j \rightarrow \vec{\xi}_j, F_j) - L_j^{rec}(\vec{\xi}_j \rightarrow \vec{\xi}_j, F_j * F_e)$$

We emphasize that, with the exception of the recombination term, which presents the nonlinear term $f_j(t, r, \xi)$ and includes the function of electron distribution, all terms in a weakly ionized plasma are linear with respect to the function $F_j * F_e$.

In this case, nuclear fission of any fissioning component density $\{n + F_{c \rightarrow ^3He}, UF_6, Be, ^{10}B\}$ in neutron flux is the source of j-type fission fragments, and the fission $\Omega_j^{fission}$ equals the following:

$$\Omega_j^{fission} \left(n + FC \rightarrow \sum_k F^k(\xi_0) \right) = n_{FC} * \Phi(t, \vec{r}) \sigma^{fission}(\epsilon_n) * (\vec{\xi}_j \rightarrow \vec{\xi}_j^0) \quad (2)$$

$$^3He + n \rightarrow P + T + 0.76MeV$$

$$^{235}UF_6, f f_l + f f_h + 165MeV$$

$\delta(\vec{\xi}_j - \vec{\xi}_j^0)$ Energy distribution of j-type fission fragment at the delta function-presented initial energy point. The subsequent term is equivalent to

$$S_j^{ion}(\xi_j) = n_{FC} \int_{\xi_j}^{\xi_0} \delta(\xi_j + I - G^{ion}(\xi_j, \xi_j)) \int_I^{E_j^0} (J_j(\xi_j) - F(\xi_j)) \xi_j \Omega_j^{ion}(\xi_j, \Delta E_j) P_j^{ion}(\xi) d(\Delta E_j) d\xi_j \quad (3)$$

In this equation, ΔE_j -fragment's energy loss is equal to the sum of the ionization potential and the energy gained by released electrons; n_{FC} is the buffer gas concentration (in our case, the concentration of the fissioning component). The probability of ionization and the differential cross section are

$$\Omega_j^{ion}(\xi_j, I) = \frac{6.5610 \cdot 10^{-14} Z_j^2}{(I)^2 E_j} \left(\frac{\xi_j^{av}}{\xi_j} \right)^2 \left[\frac{\xi_j^2}{\xi_j^2 + (\xi_j^{av})^2} \right]^3 \cdot \left[\frac{\xi_j^2}{\xi_j^2 + (\xi_j^{av})^2} + \frac{4}{3} \ln \left(2.7 + \frac{\xi_j}{\xi_j^{av}} \right) \right] \cdot \left(1 - \frac{I}{\Delta E_{max}} \right)^{1 + \frac{\xi_j^2}{(\xi_j^{av})^2}} \quad (4)$$

$$\Delta E_{max} = 4 E_e^{av} \left(\frac{\xi_j}{\xi_j^{av}} \right)^2 \left(1 + \frac{\xi_j^{av}}{\xi_j} \right)$$

And $P_j^{ion}(\xi) =$

$$\frac{\Omega_j^{ion}(\xi)}{\sum_{k=1}^m \Omega_j^k(\xi)} \quad (5)$$

Next, we define the delta- function $\delta(\xi_j - G(\xi_j - \xi_j))$ as a function that, while accounting for a specific interaction potential, returns the value of a j-type fragment from a different phase volume $\xi_j \rightarrow \xi_j$. The collision integral of the following kind is $G(\xi_j, \xi_j)$.

$$\Omega^{ion} = 2\pi(\chi) \left(\frac{db(\chi)}{d\chi} \right) d\chi \quad (6)$$

$$\Phi = \int_{b_{min}}^{\infty} (1 - \cos\chi) g b db$$

Here the deflection angle is χ . The term for correspondent leakage is displayed as

$$L_j^{ion}(\xi_j) = n_{FC} \int_w J_j(\xi_j) \xi_j \Omega_j^{ion}(\xi_j) d\omega \quad (7)$$

The probability and the differential cross section of the k-level excitation are equal:

$$\Omega_{jk}^{exc}(\xi_j, I_k) = \frac{6.5610 \cdot 10^{-14} Z_j^2}{(I(k))^2 E_j} \left(\frac{\xi_e}{\xi_j} \right)^2 \left[\frac{\xi_j^2}{\xi_j^2 + (\xi_e^{av})^2} \right]^3 \cdot \left[\frac{\xi_j^2}{\xi_j^2 + (\xi_e^{av})^2} + \frac{4}{3} \ln \left(2.7 + \frac{\xi_j}{\xi_e^{av}} \right) \right] \cdot \left(1 - \frac{I_k}{\Delta E_{max}} \right)^{1 + \frac{\xi_j^2}{(\xi_e^{av})^2}} \quad (8)$$

It should be noted that the following method could be used to assess the energy loss in elastic collisions:

$$\Delta E^{el} = 2 \frac{m_j}{M} E_j (1 - \cos\chi) \quad (9)$$

The following equation defines the electron energy distribution function.

$$\partial_\mu F_e(t, \vec{r}, \vec{\xi}_e) = \sum_j [S_{pe}^{ion}(F_j \rightarrow F_e)] + S_e^{ion}(\xi_e \rightarrow \xi_e, F_e) - T_e^{ion}(\xi_e \rightarrow \xi_e, F_e) + \sum_k^m S_e^{exc}(\xi_e \rightarrow \xi_e, F_e) - T_e^{exc}(\xi_e \rightarrow \xi_e, F_e) + S_e^{el}(\xi_e \rightarrow \xi_e, F_e) - T_e^{el}(\xi_e \rightarrow \xi_e, F_e) \quad (10)$$

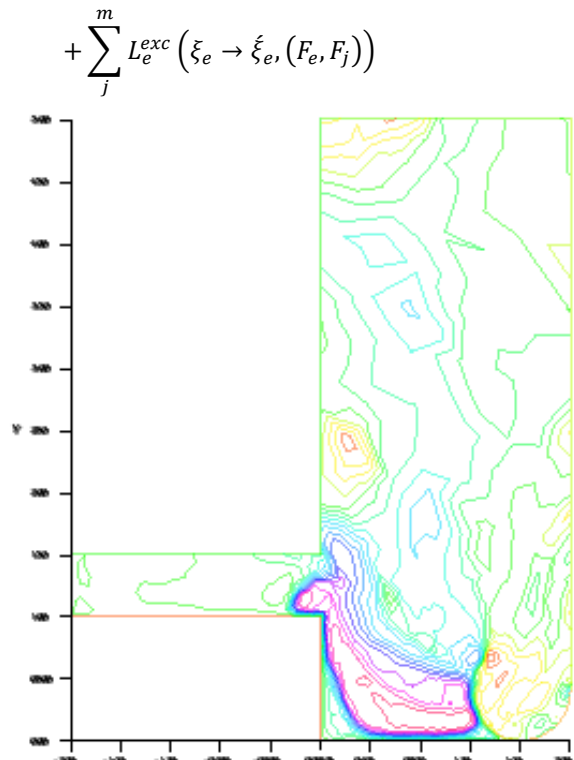


Figure 1: UF_6 laminar flow in fuel cycling loop

```
border a0(t=1.5,1){ x=-2; y=t; label=1; } // inlet ..
border a1 (t=-2,0){ x=t; y=1; label=2; }
border a2 (t=1,0) { x=0; y=t; label=2; }
border a3 (t=0,1) { x=1.6*t^1.2; y=0; label=2; }
border a4(t=3*pi/4,2*pi){ x=0.4*cos(t)+1.6; y=0.4*sin(t)+0.4; label=3; } // outlet
border a5(t=0,4,5){ x=2; y=t; label=5; }
border a6(t=2,0){ x=t; y=5; label=6; }
border a7(t=5,1.5){ x=0; y=t; label=7; }
border a8(t=0,-2){ x=t; y=1.5; label=7; }
```

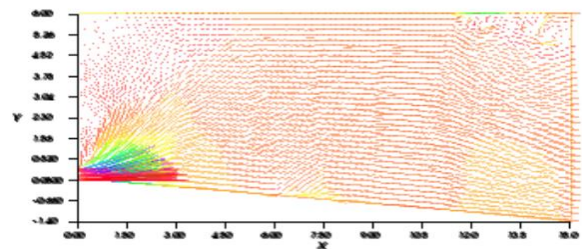


Figure 2: Triangularization and boundary conditions

IV. CONCLUSION

As a coupled system of fission fragments, the Boltzmann kinetic equations governing the energy spectra of fast particles in nuclear-induced plasma are defined. And electrons, which ought to be handled as self-consistent systems and offer a reasonable method for comprehensive explanation of fissionable plasma engaging in neutron interaction. This particular Boltzmann application and discussion of the kinetic

equations system for plasma of helium-3. The majority of primary electrons analytical expressions for spectra obtained on the presumption that fission products of helium-3 have energy spectra that are monochromatic.

According to a very thorough analysis done in [26, 27], the formation of runaway electrons in weakly ionized plasma appears to be practically impossible. The authors [19, 21] assert, however, that for arbitrarily small values of the electric field strength, the majority of electrons may be accelerated to a level of energy that can ionize neutrals, forming secondary electrons, and that the number of ionization events will rise exponentially, with their average velocity and energy being independent of the distance from the cathode [19]. For some specific reasons, the mean energy electron balance equation is insufficient to draw such firm conclusions regarding the formation of runaway electrons. Another important factor in the formation of runaway electrons was thought to be the force of friction [19, 21]. It provides an ambiguous response due to the subsequent explanations.

Not mentioned or presented were the identification of fast electrons with energy in the MeV region (runaway electrons), the beginning and ending points of radiation (bremsstrahlung), and how the kinetic equation should account for the creation of X-rays. [19]. The next question is whether or not the absorption of X-rays by electrons causes them to rise in kinetic energy, lifting them to the MeV level, where typically neutrino oscillations connected with the presence of beta electrons are present [24, 26]. The X-rays [21, 22] can also be treated like electrons (the de Broglie wave length).

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