Fission fragments and energy spectra of primary electrons in a fissioning plasma

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Abstract. Some isotopes like $^3$He, $^{235}$UF₆ gases irradiated by thermal neutron flux may produce partially ionized plasma with the presence of fast particles like protons, tritium or heavy fission fragments. If a sample with $^3$He gas sets in thermal neutron flux, the helium atoms may born highly energetic particles: protons and tritium nuclei, which create in their own turn primary electrons and their other successive generations.

In the present paper Boltzmann kinetic equation for plasma, created by volume source of ionization is developed and solved for special cases, like presence of external electric field, strong enough to cause Townsend ionization. The ways of possible existing of highly energetic electrons accelerated by strong electric field energy also thoroughly discussed. Statistical approach based on the Monte Carlo technique including definition of self-consistent electric field formed by boundary conditions and nuclear induced plasma internal properties coupled with direct Boltzmann formalism also was developed and discussed. Thus the outbreak or the time explosion of the energy distributions of all fast particle including primary and secondary electrons are calculated in the programming complex as a function of time from 10 ps to 10 ns and for different neutron flux pulses and neutrons homogeneous spatial distribution. Non-linear problems such as an electron–ion recombination and successive generation of secondary electrons and electron queues are solved by Monte Carlo technique and comprehensively described. Detailed calculations show that so called runaway electrons are not appearing in nuclear induced plasma and whatever strong external electric field applied, there is no way to supply them relativistic energy and create so called runaway electrons. The appearance of electrons with an energy around MeV is possible when electrons (beta electrons) are born within nucleus due to internuclear transformations of up and down quarks affected by neutrinos oscillations. It takes place in nuclear fission process provoked by neutrinos and antineutrinos Reines et al (1960 Phys. Rev. 117 159). Time dependent spectra of primary electrons as well as their successive generations are calculated and compared with existing experimental data and developed for nuclear induced Boltzmann kinetic equation solutions. It is also should be noted that the bremsstrahlung radiation or braking radiation can not be treated as a type of force (friction force). It is clear that the transformation of kinetic energy into electromagnetic energy is a unique phenomenon and if it exists while fast electron is stopping in the medium, then there should be the reversed process, when electron gains its kinetic energy from surrounding electric field.
1. Introduction

Any particle released out of nucleus with energy around of MeV’s order (as it was theoretically and experimentally shown [1–3]) is bearing enormous kinetic energy due to the internal binding energy transformation caused by transition of quarks under the influence of neutrino and antineutrino. Radioactive decay, nuclear fission are resulting fast particle, among them $\beta^-$-electrons and their immanent satellite antineutrino. It is also evident that such type of energy transformation may cause not only release fast electrons but also fast protons or probably more compound nuclei.

The pronounced experimental study of the antineutrino absorption reaction

$$p + \bar{\nu} \rightarrow \beta^+ + n$$

was demonstrated in the experimental set placed near 1000 MW Savanna River uranium fission reactor in South Carolina [3].

The flux of antineutrinos, coming from nuclear reactor, was equal to $10^{13}$ cm$^{-2}$s$^{-1}$. The authors did not discuss the way how the antineutrons were created, but it is evident that were passing by and responsible for quarks transitions from up and down states, which cause transformation strong interactions maintained by gluons under the antineutrinos guidance to destruction of nuclei and to the appearance of fast electrons or positrons. More over such type of strong interactions transition maintained by gluons into kinetic energy of fission fragments products cannot take place without neutrino or antineutrino participation. As it was experimentally shown, weak interactions neutrinos have three flavours changed and so what these are somehow unexpectedly destroying strong interactions by weak interactions, creating beta electrons or positrons as well as muons and tau leptons. Such a great transformations are taking place due to very small and insignificant reasons that neutrinos did. So the phenomenon of neutrino ability to be in three eigenstate is known as neutrinos oscillations. To these eigenstates sterile and heavy neutrinos also should be added. Particle accelerators and nuclear reactors are the best experimental tools to observe neutrino oscillations. In case of absence neutrino oscillation atmospheric neutrino anomaly in zenith-angle distribution are expected to be observed in ratio $\nu_\mu/\nu_\e = 2/1$. But experimental indications of atmospheric neutrinos measurement show the ratio $\nu_\mu/\nu_\e$ is about 60% [1–3]. In nuclear reactors neutrino measurements each isotope produces a unique neutrino spectrum. Plutonium breeding also might be revealed due to small, but noticeable change in the emitted neutrino spectrum, which is highly important for nonproliferation objectives.

So the strong connection of antineutrino spectrum associated with fission of the nuclear fuels $^{235}$U, $^{239}$Pu, $^{241}$Pu and $^{238}$U should exist and the confirmation of the fact is presented by P. Vogel [2]. Patrick Huber and Thomas Schertz determined the coefficients of antineutrino flux parametrization by the accurate analysis of experimentally measured beta spectra in nuclear reactors [4]. It was shown that the flux shape uncertainties play a minor role in the KamLand experiment and mixing angles $\theta_{13}$ are sensitive to that mentioned before details of the reactor neutrino spectra (KamLAND–Kamioka Liquid Scintillator Anti-Neutrino Detector, [5]).

If the initial reactor fuel composition is known, the number of each isotope fission rate might be calculated with a great accuracy. If neutrino oscillations exist, then the measured antineutrino flux ($\bar{\nu}_e$) beside nuclear reactor and faraway from it measurement should differ. And really, at least, the number of positrons should be changed and this was accurately confirmed by a parametrization procedure made by Patrick Huber and Thomas Schertz [4].

Considering the transition of neutron to proton, $\beta$-electron and antineutrino, the following might be assumed:

$$n \rightarrow p^+ + e^- + \nu,$$

$$\begin{bmatrix} u \\ d \\ d \end{bmatrix} \rightarrow \begin{bmatrix} u \\ u \\ d \end{bmatrix} + e^- + \nu,$$
and one more reaction

\[ ^3\text{H} \rightarrow ^3\text{He} + e^- + \nu. \] (4)

In this reaction, quarks transitions are possibly interacting as follows:

\[ \begin{pmatrix} u \\ d \\ u \\ d \end{pmatrix} \rightarrow \begin{pmatrix} u \\ u \\ u \\ d \end{pmatrix} + e^- + \nu. \] (5)

According to the quarks transitions, the reaction \(^3\text{He} + n \rightarrow p + T + 0.76\text{ MeV}\) might be presented with antineutrino participation:

\[ \begin{pmatrix} u \\ u \\ u \\ d \end{pmatrix} + \begin{pmatrix} d \\ u \\ d \end{pmatrix} \rightarrow \begin{pmatrix} u \\ u \\ u \\ d \end{pmatrix} + \begin{pmatrix} u \\ d \\ d \end{pmatrix} + e^- + \nu. \] (6)

2. Boltzmann kinetic equation for nuclear induced plasma

In nuclear induced plasma, three functions of energy distribution, namely, for protons, tritium nucleuses and electrons are defined. Let’s denote three fast particles (protons, tritium nucleuses, primary electrons) energy distribution functions as \(f_p(t, r, v)\), \(f_T(t, r, v)\), \(f_{pe}(t, r, v)\).

The system of governing equations for these fast particles looks as follows:

\[
\frac{\partial f_p}{\partial t} + \mathbf{v}_p \cdot \frac{\partial f_p}{\partial \mathbf{r}} + \frac{F}{m_p} \cdot \frac{\partial f_p}{\partial \mathbf{v}} = I_{sp} + I_{pi} + \sum_{i=1}^{N} I_{pexc,i} + I_{pelastic} + I_{prrec},
\] (7)

\[
\frac{\partial f_T}{\partial t} + \mathbf{v}_T \cdot \frac{\partial f_T}{\partial \mathbf{r}} + \frac{F}{m_T} \cdot \frac{\partial f_T}{\partial \mathbf{v}} = I_{sT} + I_{T_i} + \sum_{i=1}^{N} I_{Texc,i} + I_{Telastic} + I_{Trecc},
\] (8)

\[
\frac{\partial f_{pe}}{\partial t} + \mathbf{v}_{pe} \cdot \frac{\partial f_{pe}}{\partial \mathbf{r}} + \frac{F}{m_{pe}} \cdot \frac{\partial f_{pe}}{\partial \mathbf{v}} = I_{pi} + I_{T_i} + I_{pei} + \sum_{i=1}^{N} I_{peexc,i} + I_{peelastic} + I_{perec} + I_{peaff},
\] (9)

where

\[
I_{sp} = \int \int (f'_n f_p - f_n f_p) gbdV',
\] (10)

\[
I_{pi} = \int \int (f'_{3H_e} f_p - f_{3H_e} f_p) gbdV',
\] (11)

\[
I_{pexc} = \sum_{i=1}^{N} \int \int (f'_{3H_e} f_p - f_{3H_e} f_p) gbdV',
\] (12)

\[
I_{Texc} = \sum_{i=1}^{N} \int \int (f'_{3H_e} f_T - f_{3H_e} f_T) gbdV',
\] (13)

\[
I_{prec} = \int \int (f'_{pe} f_p - f_{pe} f_p) gbdV',
\] (14)

\[
I_{Trec} = \int \int (f'_{pe} f_T - f_{pe} f_T) gbdV',
\] (15)

\[
I_{peexc} = \int \int (f'_{pe} f_{3H_e} - f_{pe} f_{3H_e}) gbdV',
\] (16)

\[
I_{pelastic} = \int \int (f'_{p} f'_{3H_e} - f_{p} f_{3H_e}) gbdV',
\] (17)
\[ I_{\text{elastic}} = \int \int (f_T f^3_{He} - f_T f^3_{He}) gbdvd', \]  
(18)

\[ I_{pe_{\text{elastic}}} = \int \int (f_{pe} f^3_{He} - f_{pe} f^3_{He}) gbdvd', \]  
(19)

\[ I_{pe_{\text{aff}}} = \int \int (f_{pe} f^3_{UF} - f_{pe} f^3_{UF}) gbdvd', \]  
(20)

\[ I_{pe_{\text{rec}}} = \int \int (f_p f^3_{He} - f_p f^3_{He}) gbdvd'. \]  
(21)

It is evident that each integral needs special detailed explanation and long term treatment, connected with elementary processes and interaction potential of the colliding particles. Heavy particles immediately come to thermal equilibria with Maxwellian distribution functions, temperature and pressure are defined by the type of nuclear reactor. For Helium atoms the energy distribution is equal to:

\[ f^3_{He}(v) = n^3_{He} \left( \frac{m^3_{He}}{2\pi kT^3_{He}} \right)^{3/2} e^{-\left( \frac{mv^2}{2kT} \right)}. \]  
(22)

The first order corrections to the functions \( f_p(t, r, v) \), \( f_T(t, r, v) \), \( f_{pe}(t, r, v) \) corresponds to [6], and are expanded by Sonin’s polynomials, which might be used to define these corrections and transport coefficients:

\[(1 - s)^{-m-1}e^{-\frac{sx}{1-s}} = \sum_{p} (-x)^{p}(1 - s)^{-p-m-1} \frac{1}{p!} = \sum_{p} \sum_{q} (-x)^{p} s^{q} \frac{(m + p + q)q}{(n - p)!}, \]  
(23)

\[ S^{(0)} m(x) = 1, S^{(1)} m = m + 1 - x. \]  
(24)

In general case:

\[ S^{(n)} m(x) = \sum_{p=0}^{n} (-x)^{p} s^{(m + n)_{n-p}} \frac{(m + p + q)q}{p!(n - p)!}, \]  
(25)

\[ 0, (p \neq q), \]  
(26)

\[ S^{(p)} m(x) S^{(q)} m(x) dx = \frac{\Gamma(m + p + 1)}{p!}, (p = q). \]  
(27)

Each special case of mentioned above mutual interactions depend on scattering angle \( \chi \), relative velocity \( g \) and the impact parameter \( b \):

\[ \phi_{l}^{12} = \int_{0}^{\infty} (1 - \cos \chi) gbdvb, \]  
(28)

\[ \Omega_{l}^{12} = \pi^{1/2} \int_{0}^{\infty} e^{-g^2} g^{2r+2} \phi_{l}^{12} dg. \]  
(29)

The presence of electric field will shift the stationary energy distribution in thermal region and distribution of primary electron born from ionization, caused by protons and tritium will be distributed around energy of neutrals ionization potential [7]:

\[ f_{pe}(\varepsilon) = \frac{J}{(J + \varepsilon)^2}. \]  
(30)

The present detailed calculation of primary electrons energy function will present some different type of energy distribution. The exact expressions of the primary electrons energy distribution function are equal to [8]:
Conclusion

The expression for primary electrons born from tritium nucleuses might be written in the same way. The primary electrons in their own turn may also cause ionization processes and energy distribution for the primary electrons, created by fast electrons born from protons and tritium nucleuses are as follows [8]:

\[
f_{pe}(t, r, v) = \int_{E_{p0}}^{E_p} f_p(t, r, \mathbf{V}_p) \cdot \Omega_{pe}^\text{ion}(v, \mathbf{V}_p, E_{p0}) d\mathbf{V}_p,\]

(31)

\[
\Omega_{pe}^\text{ion} \left( \frac{E}{\Delta E}; \frac{V_p}{\mathbf{V}_e} \right) = A \left[ \frac{V_p^2}{V_p^2 + \mathbf{V}_e^2} \frac{\Delta E}{E} + \frac{4}{3} \ln \left( \frac{2.7 + V_p}{\mathbf{V}_e} \right) \right],
\]

(32)

\[
A = \frac{\mathbf{V}_e^2}{V_p^2} \left( \frac{V_{pe}^2}{V_p^2 + \mathbf{V}_e^2} \right)^{3/2} \left[ 1 - \left( \frac{\Delta E}{\Delta E_{\text{max}}} \right)^{1 + \frac{\mathbf{V}_p^2}{\mathbf{V}_e^2}} \right],
\]

(33)

\[
\Delta E_{\text{max}} = 4E_p \left( \frac{V_{pe}^2}{V_p^2 + \mathbf{V}_e^2} \right) \left( 1 + \frac{\mathbf{V}_e^2}{V_{pe}^2} \right),
\]

(34)

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