Collection and collimation of fission fragments using electromagnetic fields

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Use of electromagnetic fields to collect and collimate energetic fission fragments into a charged particle beam has been proposed to either direct conversion to electrical power or, after neutralization, as a source of thrust for rocket propulsion systems[1-3]. Highest efficiency for collection of the fragments produced in a fuel matrix is a very important requirement in this proposal. As Chapline and Matsuda of LLNL[2] noted, the extraction of fission fragment power above way permits isotopic separation of fission fragments, leading to a convenient separation of more active radioisotopes from less active ones. However, it is also noted that there is no such thing as a quick trip to these high goals as this area of work is facing several inadequate methods and technologies. One of the major concerns is the stopping or energy degradation of fragments within the fuel matrix before they are collected.

In RIB facilities where 'drivers' are fission fragment sources, collection and collimation of the fragments is a core issue. In order to have the RIBs for experiments as early as possible, available technologies have been put in use for beam production, however time interval between production and extraction of the fragments remained high, at around tens of seconds for most species, thus making isotopes that have shorter half-lives unavailable as RIBs. Here, the release time of fragments, produced and stopped inside the fuel matrix, is governed[4] by diffusion, adsorption-desorption, and effusion processes.

Present work is a model study on fission-fragment collection and collimation using electromagnetic fields, wherein fission events take place in 'inverse kinematics'. As discussed in [5], it is possible that slow-neutron fission reactions including the discrete-resonances can be induced in inverse-kinematics, when an ion-beam of reactant-nuclei of right kinetic energy is made to pass through a column of thermal-neutrons. In such fission events, there is only bare minimum loss of fragment kinetic energy due to ionizations in the fuel matrix since 'fuel' is in the form of an ion beam passing through a high vacuum chamber. A modification required for the present study is that a neutral beam of reactant nuclei is to be used in place of the ion beam.

Simulations have been carried out using an application program developed using the GEANT4 Toolkit[6]. A simple geometry of an evacuated cubical volume of side length 20 cm that sustains uniform electric field in z-direction is assumed in the program. It is assumed that neutron induced fissions of Pu239 nuclei occur within this volume in 'inverse kinematics'. The asymmetric mass split in the fission would release approximately 170 MeV as fragment total kinetic energy. From the known characteristics, the average light fragment mass, primary charge and kinetic energy have been determined as 97 amu, 38 units, and 100 MeV, respectively. Similarly for the average heavy fragment, the above quantities are 139 amu, 54 units and 70 MeV, respectively. Ion pairs of above characteristic numbers were generated using the *G4ParticleGun* class. This can shoot any heavy ions with */gun/ions* command after "ions" is selected by */gun/particle* command. A macro file was used to set momentum directions and starting positions of the ions to random values in a suitably selected range. While simulating for fission events, one can also chose similar random values for A, Z, Q(charge of ion) and fragment kinetic energies as well.

Representative plots from the simulation are given in Figs. 1 and 2 for two randomly selected 'fission axis' directions. In a fission event, the complimentary fragments fly away at opposite directions that are aligned with the fission axis (cm and lab motion of the fragments nearly coincide in the inverse kinematic fission reaction also). In simulation given in Fig.1, the light fragment initially is in –x direction and heavy fragment is in +x direction with (Px, Py, Pz) = (-1., 0., 0.) and (+1., 0., 0.), respectively. These initial directions were changed to (0., -0.2, -0.7) and (0., +0.2, +0.7) for simulation given in Fig.2. The electric field was set at a value of 10^9 V/m in both simulations. The positions at which the fission event occurs have been selected as the origin in both cases. The fission fragment trajectories are shown in magenta color. In

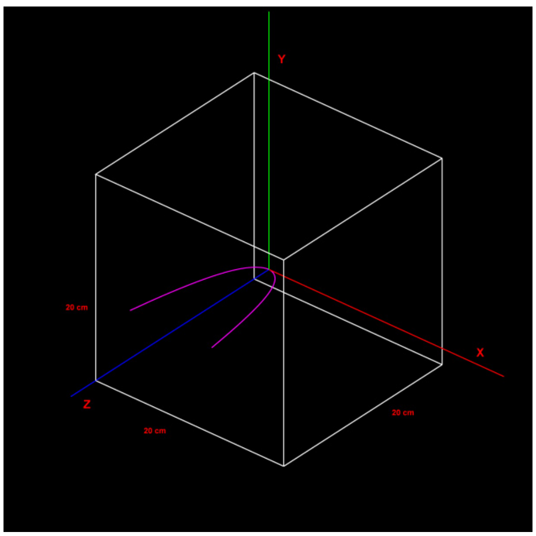

Fig. 1 Trajectories of complimentary fission fragments(magenta) produced at origin with initial directions as –x and +x.

Fig.1, the trajectories are parabolas in xz-plane. Whereas in Fig.2, the trajectories are slightly more complicated and one can observe characteristics such as turning back of the fragment(deceleration and re-acceleration) that is set initially with a dominant –z component. When the fragments emerge from the electric field region, they will travel in straight lines, tangent to the curves at the exit-points.

This initial study of fission fragment collection and collimation is to check for insurmountable obstacles to the development of the concept in physical grounds. This work will also be extended to include magnetic field . The electric field strength required is extremely high for the level of collimation seen in the presented figures. In literature, there are reports on fission-fragment direct-energy-conversion where such high fields are studied[7], wherein the nuclear fuel is in the form of micron thin films. There are also proposals to use magnetic field to collect and collimate the fission fragments into a charged particle beam[3] wherein the field strength required is less than 1 Tesla-meters. These avenues of work at present suffer from some technology non-readiness factors, however, the promises they hold for future are tremendously high and therefore worth pursuing.

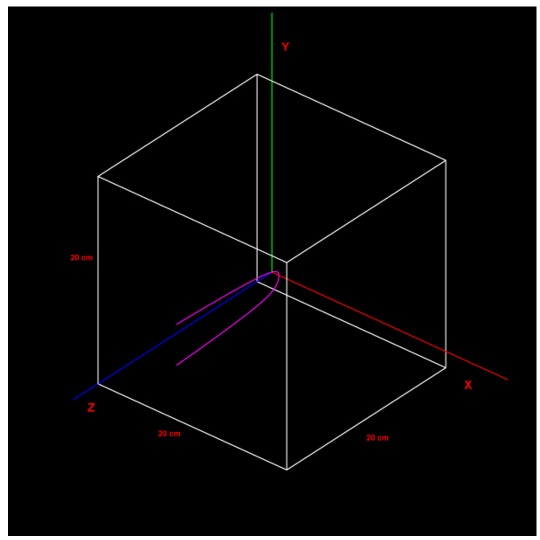

Fig. 2 Same as Fig.1 except that the initial directions changed to (0.,-0.2,-0.7) and (0., 0.2,0.7)

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