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Plane rectangular tritium target response to excitation by uniform distributed normal accelerated deuteron beam ☆

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Abstract

This work is a contribution to analytical study of the spatial dependency of the *d-T* mean neutron energy in the vicinity of a homogeneous tritium-occluded rectangular plane target. An accelerated deuteron beam excites the tritium target with normal incidence to the target plane. The transverse density of accelerated deuteron beam is assumed to be constant close to the target. Due consideration being paid to *d-T* collision kinetics, depending upon mass and kinetic energy of particles involved in the nuclear collision, nuclear reaction energy, etc, in particular circumstances, the elementary neutron energy emission in non-dispersive media can be considered to be omni-directional or very low anisotropical. Consequently, analytical expressions can be considerably simplified, taking into account the exothermic character of *d-T* fusion reaction. A number of expressions for energetic prediction of the fast neutron generated, in this case, by *d-T* reaction are proposed. Animated three-dimensional-graphics is suggested. Computationally tractable tools are of importance in the study of some situations such as induced reactions and activation analysis using 14 MeV neutrons, investigations in health-physics, radiation dose characterization, nuclear medicine, damage effects, and simulation studies.

Keywords: Rectangular source; Radiation field; Anisotropic emissivity; Fast neutrons generation; Iso-dose

1. Introduction

The spectacular widespread application of radiation processing and related technologies in many fundamental and practical domains has been enabled to a large extent by impressive efforts devoted to the development of suitable radiation sources. Extended sources represent an important class of irradiation facilities. Significant research efforts have been focused on the characterization of extended sources and their associated radiation fields, particularly to analytical characterization of these radiation fields. Among the popular radiation sources are those characterized as

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plane rectangular emitters. Following the extensive theoretical investigations initiated at National Institute of Standards & Technology, USA by Hubbell and coworkers, the case of plane rectangular source radiation field has been studied by many authors, useful new mathematical relationships being provided. One of the valuable results of those investigations is the series expression of the flux behavior starting with the assumption that the source emissivity law can be approximated by a Legendre polynomial expansion. A particular class of sources is represented by fast neutron emitters (Bahal et al., 1986; Csikai, 1989; Kenna and Conrad, 1966; Kim, 1989; Kishikawa and Shinomiya, 1970, 1971; Nargolwalla and Przybylowich, 1973; Oldham and Bibby, 1968; Pavlik and Winkler, 1986; Teodorescu, 1969; Timus, 1967; Tustanovski, 1980; Van Grieken et al., 1972).

Moreover increasing interest is being shown in obtaining accurate predictions of fast neutron fields produced by fusion-reaction-type extended sources. In this context an important source of radiation fields is the charged particle accelerator. In this study we develop analytical expressions for the characterization of the fast neutron field distribution produced around a homogeneous plane tritium target bombarded by a laminated deuteron beam having a rectangular-shape in transverse direction. The cross-section density of the accelerated beam considered here is uniform (zero gradient) distributed.

The analytical expression for the emitted neutron energy in an individual nuclear event is given as a series expansion, similar to those used in (Timus and Popescu, 1997; Timus and Srivastava, 1997; Timus et al., 1997, 2000b) for the general case of nuclear reactions at nonrelativistic energies. We use this expression to describe the spatial dependence of the neutron field, especially at high deuteron energy levels where the assumption of isotropic neutron emission is no longer valid. This is used to compute the neutron field behavior in an arbitrary point in space, both in forward and backward direction.

Furthermore, we show how the series' terms and its convergence rate depend on the characteristics of the nuclear reaction. By considering a finite number of terms in the series we obtain a handy analytical expression which can predict the neutron energy field with arbitrary precision. We use the obtained analytical expression in easy tractable mathematical computations needed for characterizing different aspects of the neutron field, in particular for a rectangular and a rectangular band source.

The results obtained in Section 4 are extended to the case of a rectangular band in Section 5. As an application, iso-dose curves are shown in Section 6. Energetic spectrum analysis of the neutron field generated by a rectangular source is presented in Section 7. The conclusions of the paper are summarized in Section 8.

2. Short survey of plane source radiation field literature

The knowledge of radiation field behavior around plane sources is of interest in many theoretical and applicative domains of research and development areas: radiation protection and shielding, characterization of induced reactions (implicitly activation analysis) with isotopic or accelerator-type neutron and/or gamma emitting sources, technologic irradiations and radiation processing, health physics, nuclear medicine, radiation dose measurements and prediction, sterilization, damage induced effects, special (civilian or non-civilian) simulations and other coming studies.

Taking into attention the general case of plane sources emitting in a dispersive medium, Hubbell and coworkers deduced useful and valuable expressions for characterization of the produced radiation field. Power and/or Legendre polynomials series expansions of approximating functions specific to interaction processes between radiation field and surrounding medium as well as to emission process itself have been introduced and used successfully to study and to elaborate analytical expressions destined to radiation field characterization. By mentioned series expansions, analytic expressions elaborated in Hubbell's works take into account both parameters of the dispersive or nondispersive medium pierced by the radiation field emitted by these plane sources and local emission characteristics (isotropic or anisotropic) of the sources. Both cases of ***disk-shaped* sources** (Hubbell et al., 1961; Hubbell, 1963a, b; Epstein and Hubbell, 1963) and ***rectangular sources*** (Hubbell et al., 1960; Hubbell, 1963a, b) have been systematically studied. Many authors, most of them relying on Hubbell's basic treatment, developed particular aspects of ***disk sources*** (Alaerts, 1975; Al-Zamel et al., 2000; Bromberg, 1992; Croitoru, 1969; Evans et al., 1993; Ezure, 2004; Gotoh and Yagi, 1972; Gusev et al., 1961; Janczyszyn and Loska, 1970; Janczyszyn and Taczanowski, 1972; Kalla and Al-Saqabi, 1991; Kalla et al.,1986, 1987b; Moens et al., 1981; Mohler, 1958; Op de Beeck, 1968; Ruby, 1994; Sievert, 1921–1922; H.M. Srivastava, 1995; Srivastava and Bromberg, 1995; Srivastava and Siddiqi, 1995; R. Srivastava, 1995; Timus, 1983, 1994a, b, 1995a, b; Timus and Evans, 1995; Timus and Popescu, 1997; Timus and Srivastava, 1997; Timus et al., 1994, 2000a; Todorov and Hubbell, 1994; Weiss, 1964), ***ring-shaped* sources** (Alaerts et al., 1975; Timus and Galatanu, 1989; Timus and Timus, 1972; Timus et al., 1997, 2000b) or ***rectangular sources*** (Abbas, 2001; Besenghi and Gabutti, 1991; Ezure, 2004; Gabutti et al., 1991; Galue and Kiryakova, 1994; Galue et al., 1994; Ghose et al., 1988; Glasser, 1984; Gotoh and Yagi, 1971;