

Channeling in Bent Crystallites: A New Method to Enhance the Radiation Shielding Efficiency*

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Abstract

A new method is proposed here aiming at designing a shielding wall with the efficiency significantly higher than that of traditional designs. This new design arises from the idea of using channeling in multilayered shielding wall structure, each layer composed of bent crystallites distributed in a way that each layer covers a small section of 2π angular range of which wall is exposed. Part of the incident charged particles will get channeled in bent crystallites in each layer. Bending of channeled particles in bent crystallites will change their directions in the wall increasing their path lengths in the wall which would enhance its shielding efficiency for charged particle radiations. Proposed design is useful for radiation shielding in fission power plants, future fusion reactors and air travel.

Keywords

Radiation Shielding, Bent Crystals, Channeling, Nuclear and Thermonuclear Reactors, Cosmic Rays

1. Introduction

Radiation shielding is a great concern in environments of nuclear technology and air travel [1] [2]. These environments include various radiation fields with a considerable component of charged particle rays. Charged particle rays include fission fragments, heavy and light ions and nuclei, and electrons. A major fraction of these particles from nuclear/thermonuclear reactors and cosmic rays has high energy loss rate in tissue and other materials. Shielding of human beings and material devices against their radiation is highly desirable. There are several radiation shielding designs using numerous materials of special characteristics,

*A new method for radiation shielding.

but none of them have made use of the concept presented here with the theme as “bending charged particle radiations in the shields to increase their path lengths in them”. Bending of charged particle rays would be achieved by employing a multilayered shield with each layer composed of pieces of bent crystals. Strong fields of bent crystalline planes and axes have an ability of bending charged particles entering planar and axial channels under certain conditions [3] [4] [5] [6]. Details of the method and its implementation are given below. Section 2 describes channeling condition in bent crystals whereas proposed method for enhancement of shielding efficiency is given in Section 3. Section 4 includes conclusion of the study.

2. Channeling in Bent Crystals

Ion channeling is the passage of a particle beam (particles travelling in parallel) through open spaces in materials, e.g., crystal planar and axial channels or possibly nanotubes. Traditionally, this process is studied in single crystals where a variety of channels, both with similar and very different geometric and electronic structures, are available. The channeled beam in a crystal travels on a very specific path with a statistical variation. Ion channeling was discovered in early 1960s and it continued developing due to a number of its present [7] [8] and potential uses including channeling in bent crystals [3] [9] [10] and defect measurement in crystals [11] [12] [13] [14] [15].

Steering of channelled particles in a crystal continues even if the crystal is slightly bent deviating from their original direction as in strong magnetic fields of strength several thousand tesla. This fact provides us with the possibility of designing a “crystalline kicker” (Uggerhøj, 2005) [3]. This crystalline kicker for charged particles is shown in **Figure 1**.

Lindhard [16] has shown that incident angle (θ_i) of the particle trapped in transverse field of the crystalline channel must not exceed the limiting angle, called Lindhard angle (θ_L), as given below,

$$\theta_i \leq \theta_L = \sqrt{\frac{2U_T}{\varepsilon_{\parallel}}}, \quad (1)$$

where U_T is the transverse potential of the channel and ε_{\parallel} is longitudinal kinetic energy of the particle in the channel and is given by,

$$\varepsilon_{\parallel} = m_0 c^2 \gamma \quad (2)$$

where γ is the well known Lorentz factor. Under the condition given in Equation (1), transverse kinetic energy of the channeled particle will remain below the transverse potential U_T . Let θ_{SO} is the angle of the curvature in the bent crystal subtended on length of one transverse oscillation of the planar channeled particle (L_{SO}) so that $L_{SO} = r\theta_{SO}$, where r is radius of curvature of the bent crystal. Channeling in the bent crystal will persist if,

$$\theta_{SO} \leq \theta_L. \quad (3)$$

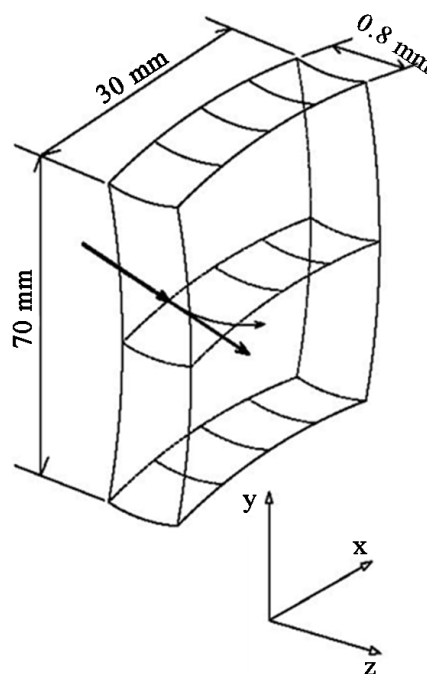


Figure 1. A schematic drawing showing bending of the channeled particles in the bent crystal. Typical dimensions are shown.

Maximum bending angle of the channeled particle (θ_{\max}) in the bent crystal is given by the following condition [17],

$$\theta_{\max} \leq \theta_L N_{Osc} \quad (4)$$

where N_{Osc} is the number of transverse oscillations made by the channeled particle in the bent channel of the crystal. Above Equations (1)-(4) describe completely the condition of channeling in the bent crystal for the purpose being served in this paper.

3. Proposed Method for Enhancement of Shielding Efficiency

It is shown in Section 2 that charged particles entering channels of a bent crystal under certain conditions would bend by an angle up to θ_{\max} (Equation (4)) which depends on Lindhard angle θ_L and number of transverse oscillations made by the channeled particle N_{Osc} . Value of θ_L is determined by properties of the crystalline material and used channel along with characteristics of the channeled particle like atomic and mass numbers, charge state and energy. The number of oscillations N_{Osc} can be controlled by length of the bent crystal. Let us now consider a test piece of a bent crystal (like Ge) with length L_T and Lindhard critical angle θ_T^L for a certain radiation (say proton, alpha particle or a fission fragment). The new scientific idea being presented here is that a multi-layered radiation shield with each layer composed of bent crystalline pieces arranged in a certain manner will serve as a kicker for charged particle rays changing direction of the radiations and hence increasing their path lengths in the shield giving rise to the enhanced shielding efficiency. The maximum bend-

ing angle (θ_T^{\max}) of a charged particle in the above mentioned bent crystal piece is given by,

$$\theta_T^{\max} \leq \theta_T^L \cdot \frac{L_T}{L_T^{SO}}, \quad (5)$$

where labels “T” and “SO” refer to test crystal piece and single transverse oscillation of the channeled particle, respectively.

Figure 2 shows the detail of the design pictorially. Left section shows a straight crystal whereas right section two layers of the proposed shield. This scheme can be employed for the cases when radiation field falling on the shield wall has at least a local directionality which means charged particles falling on a small surface area of the shield wall will incident in a an angular range as shown in **Figure 3**. In **Figure 3**, a 2D shielding box of a radiation source is shown. A wall of infinite dimensions will have 2π directions in which radiation can reach it. For a wall of limited dimensions, angular range will be much narrower than 2π . Angular range of radiations reaching each wall from the source may be divided into several sections, as divided into four sections in **Figure 3**. Particles falling in each such a section will have a limited angular range. In such cases above mentioned design will widen incident angular range of radiations falling on the wall increasing path lengths of radiations in the wall, hence enhancing shielding efficiency of the wall. In this scheme, bent crystalline pieces will be arranged in each layer in each section (I to IV) covering a section of the entire particle incidence range. Bent channels in bent crystals will offer entry into them to a part of radiations bending them in the shield. If a number of such layers, covering all the incidence range in a section, are employed in a structure, major fraction of incident charged rays will bend in the shield increasing path lengths of radiations in the shield. Two layers covering two small angular segments in the incidence range are shown in right column of **Figure 2**. In real case with 2D

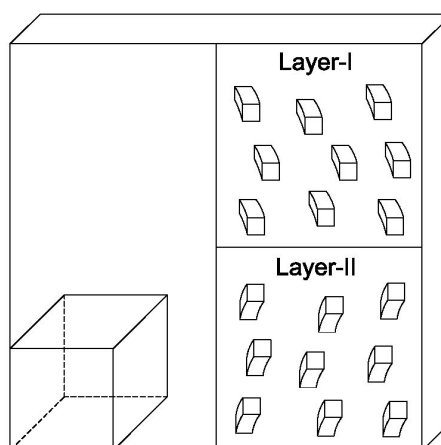


Figure 2. Design of the shielding wall of the charged particle radiations. Left part shows straight crystal structure whereas right part two layers of a multilayered shielding design with each layer composed of bent crystal pieces to bend a part of falling radiations.

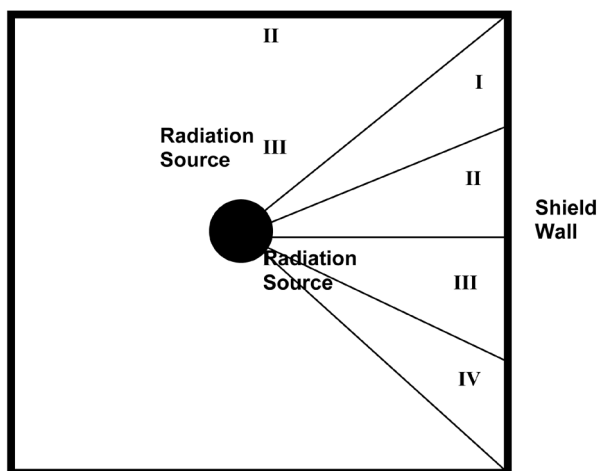


Figure 3. A charged particle radiation source enclosed by a shielding box (2D case for simplicity). Radiations falling on right wall are classified into four angular sections, each of them with a limited range of incidence angle of radiations falling on it.

shielding wall, wall surface will be divided in 2D grid with each grid element having a multilayered bent crystal structures. Alignment of crystal pieces will be arranged according to the range of incidence angles of charged particle rays. These bent crystal pieces will have length from fraction of a millimeter to tens of a millimeter depending upon charge and energy of radiations. Cross-sectional dimension of these elements will have inverse relationship with bending efficiency. This shield design will show efficiency better than the traditional shield wall. High efficiency amorphous material layers can also be joined behind this new multilayered structure for better shielding.

4. Conclusion

A new charged particle radiation shield design is proposed here. This design will have a higher shielding efficiency than the tradition designs. In the new design, multilayered wall structure with each wall composed of bent crystal pieces is proposed. Each layer will bent a part of charged particle rays entering in bent crystals under channeling condition increasing path lengths of radiations in the shield. If a sufficient number of layers are used, major fraction of charged particles will be bent in the shield travelling longer distance in the shield compared with the traditional design, hence enhancing shielding efficiency. This shielding design can be employed in a number of radiation environments with situations comparable to that described in **Figure 3**. It may be noticed that the present design is different but has some similarity with a proposal by Breese [18]. This design will consume shielding materials in a smaller quantity compared to the traditional design.

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