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Study on Shielding Effectiveness of a Conceptual Active Radiation Shield Constructed with Multi-Wall Carbon Nanotube Added YBCO-123 Superconducting Material

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Abstract

It is well known that the astronauts will be exposed to galactic cosmic rays (GCR) and solar particle events (SPE) during long-termed space missions. As a result of their exposure to space radiation, the crew members will undergo both immediate and delayed effects. So the effective shielding is necessary and there are two types of countermeasures namely active and passive shielding. Superconducting magnetic shield is considered a visionary and one of the most promising active shielding methods. After briefly discussing the active and passive methods, this paper presents a conceptual superconducting magnetic shield constructed with multi-wall carbon nanotube (MWCNT) added YBCO-123 (Yttrium barium copper oxide) superconducting material. Theoretically, the proposed toroidal shield can deflect the lighter particles of up to 2400 MeV/n while for higher Z particles this cut-off energy is about 873 MeV/n. Some distinct limitations of this study are also discussed.

Background

Cosmic radiation has been identified as a severe health risk to the astronauts on long-term interplanetary voyages. In free space, far away from the shielding of terrestrial magnetic field, Solar Particle Events (SPE) and Galactic Cosmic Rays (GCR) are the key sources of the dose received and these two vary significantly in rate (Hoffman et al., 2005). Passive shielding and active shielding are two methods that are available for astroparticle shielding. The concept of active shielding works by the principle of deflecting charged particles outside the protected volume using electromagnetic fields. It is an alluring option instead of carrying an additional bulk material for radiation shielding. For making active shields, superconducting systems are promising. In the case of superconducting systems, electric current flows without dissipation, the power requirement is comparatively little, and dominated by the cryogenic system that maintains the super-conductor at low temperature. (Spillantini, 2000; Spillantini, 2008; Spillantini, 2010, Zaman, 2021).

Deflection of HZE particles by the active shield (superconducting toroid):
For a charged particle moving radially, i.e. having zero angular velocity; the equation of motion in an infinite toroidal magnetic field can be solved analytically. It can also be shown that a particle with zero angular speed $\dot{\theta} = 0$ is the most penetrating one and therefore, the shielding power (Ξ) of the toroid can be written in the following form (Vuolo *et al.,* 2016).

$$\Xi = \int_{R_i}^{R_e} B_\theta dR = \frac{\mu_0 I}{2\pi} \ln\frac{R_e}{R_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, I signifies the total current flowing in the toroid; R_e is the outer radius and R_i is the inner radius. The shielding power can be expressed in terms of the particle properties:

$$\Xi = \frac{m_0 c}{q}\sqrt{\gamma^2 - 1}(1 - \sin\varphi) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Here where m_0, q, γ and c are the particle rest mass, charge, Lorentz factor and speed of light, respectively. φ is the angle of incidence. Using (2), it is possible to estimate the maximum kinetic energy K_η of the particle that can be deflected by the toroidal field according to the following equation (Vuolo *et al.,* 2016)

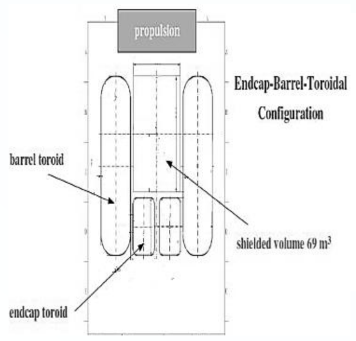
$$K_\eta = -\frac{m_0 c^2}{\eta}\left(1 - \sqrt{\left(\frac{q}{m_0 c}\frac{\Xi}{(1 - \sin\varphi)}\right)^2 + 1}\right) \ldots\ldots\ldots\ldots\ldots (3)$$

Where, η represents the number of nucleons. From equation (1) we can see that the total current (I) plays a vital role in generation of shielding power. So if we can utilize a conductor that constitutes greater current density, that may increase the bending power.

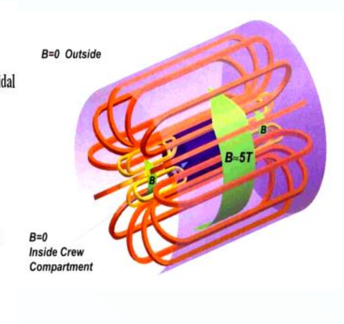
Objective

A study led by Ö. ÇİÇEK* and K. YAKINCI (2020) has found enhanced superconducting properties of multi-wall carbon nanotubes (MWCNT) added YBCO-123 Superconducting System. Utilizing the data (Current density) from their study we have proposed a toroidal superconducting magnetic shield and presented theoretical shielding power and maximum cut-off energies for lighter and heavier particles.

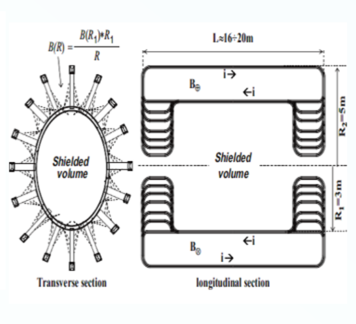
Previous works



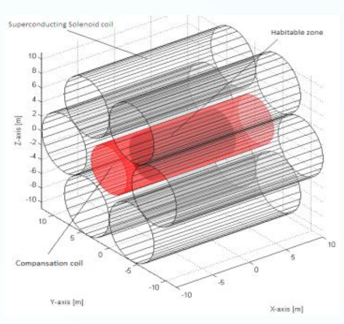
Choutko et al.(2004)
Single toroid endcap and toroid barrel



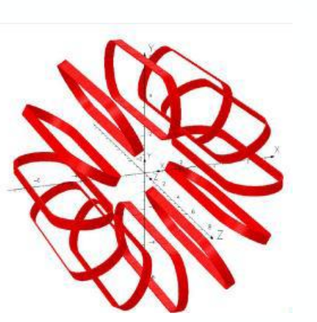
Hoffman et al.(2005)
dual-toroidal - solenoid

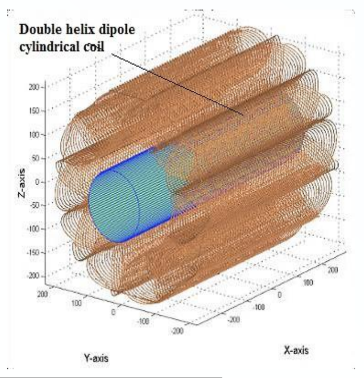


Spillantini et al.(2010)
Toroid barrel shield

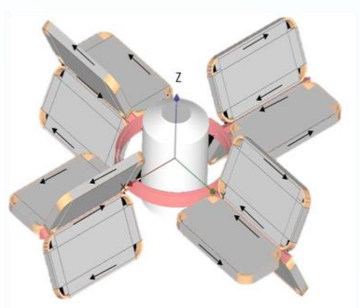


Westover et al. (2014)
6+1 expandable solenoid shield

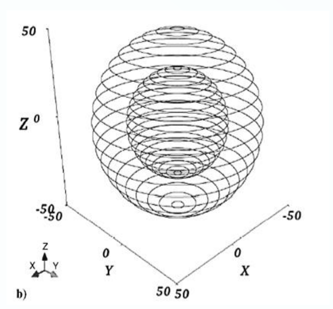




Battinson et al. (2014)
1.Racetrack toroid system
2. Double Helix Design



Calvelli et al. (2016)
pumpkin magnetic shield



Chesny et al. (2020)
field-reversed array of superconducting coils

Characterization of MWCNT added YBCO-123

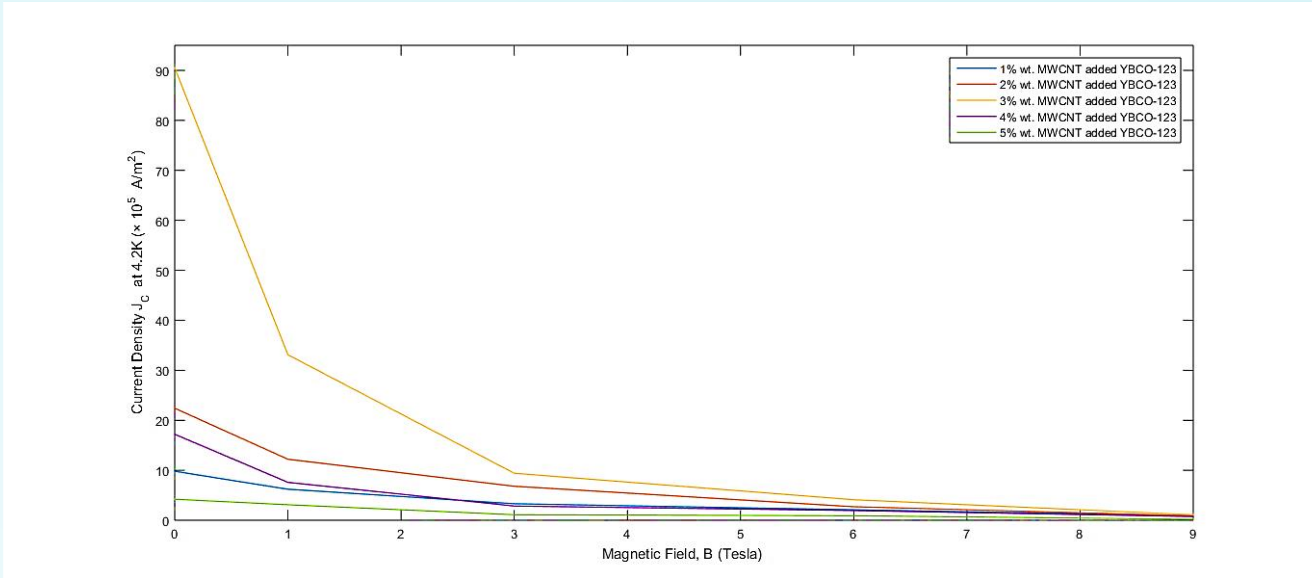


Figure 1: Variation of current density under magnetic field with different concentrations of MWCNT (1-5% wt.)

From figure 1 it is clear that at 3% wt. MWCNT addition, current density has the greater values (Ö. ÇİÇEK* , 2020).

Configuration of the proposed shield

Table 1: Toroid shaped radiation shield parameters

Winding cable material	**3% MWCNT added YBCO-123**
Former	**Aluminum**
height	**10 m**
Toroid inner radius, R_i	**3.70 m**
Toroid external/outer radius, R_e	**7.3 m**
Total current, I	**160.2 MA**
Current density, J	**4.1×10^5 A/m^2 (at 3% wt., 4.2K, 6T)**
Bending power, Ξ	**21.77 Tm**

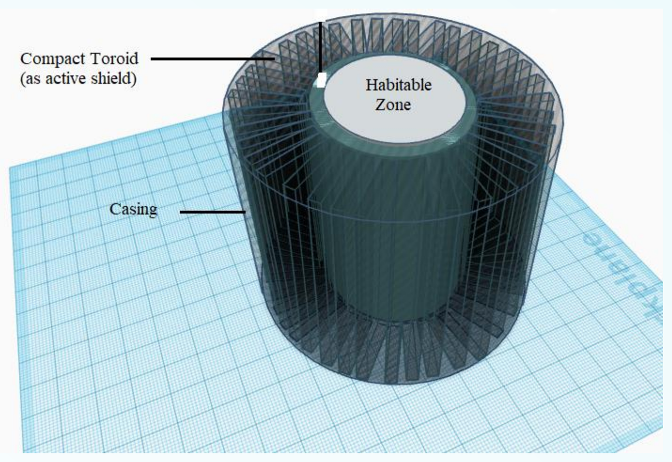


Figure 2(a) : Upper view

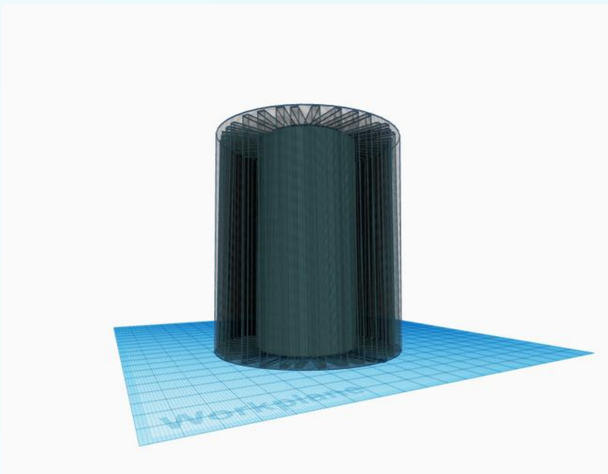


Figure 2(a) : Side view

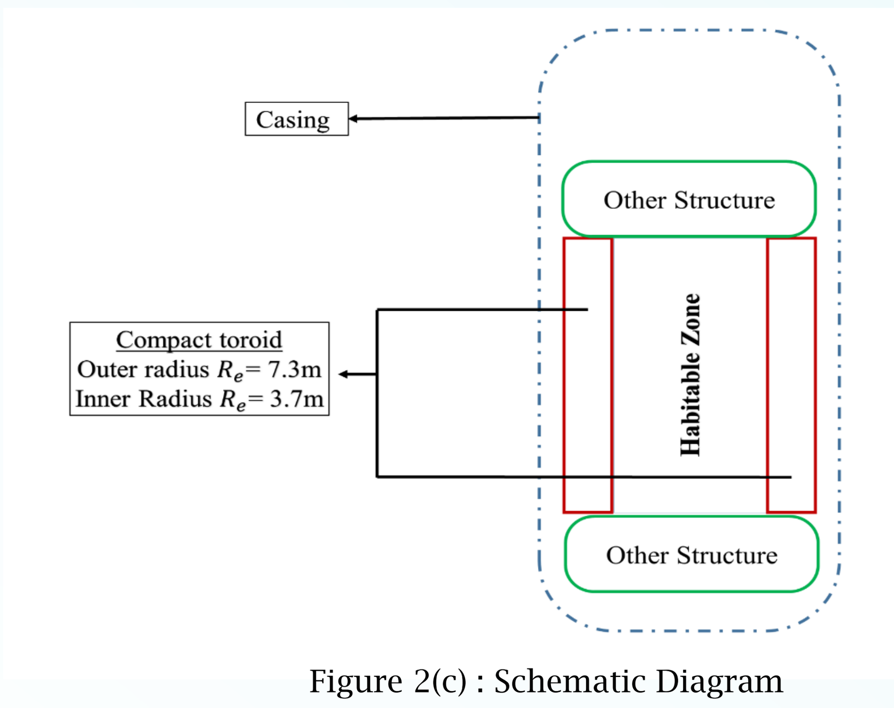


Figure 2(c) : Schematic Diagram

Figure 2 : a) shows the upper view, b) shows the side view and c) shows the schematic diagram of the proposed superconducting magnetic shield (Toroid)

Results

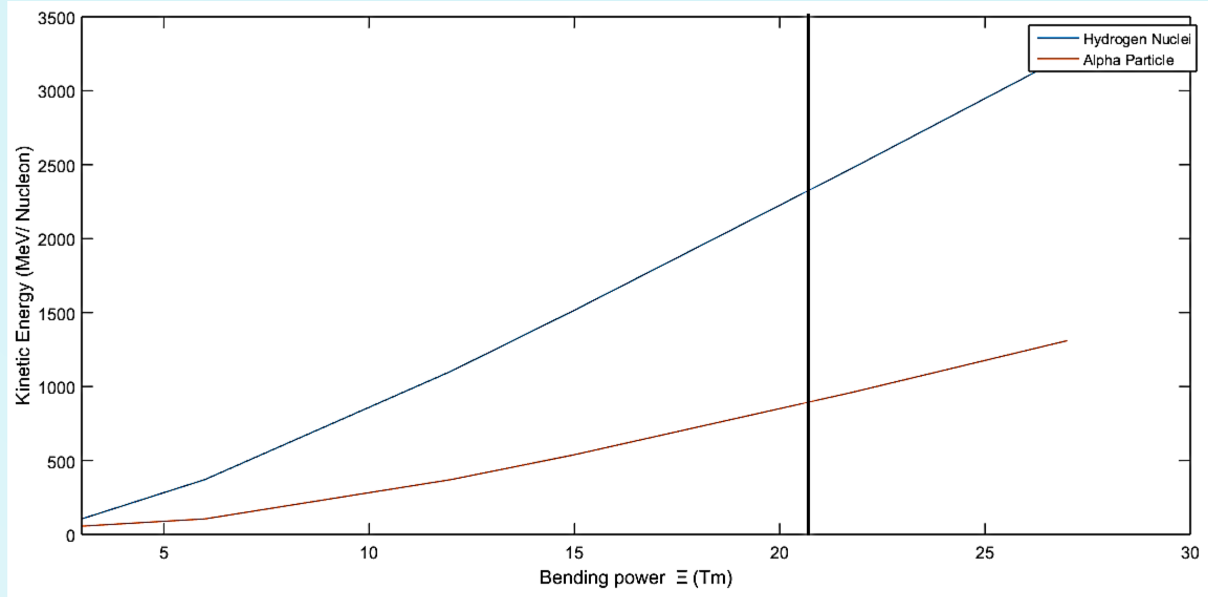


Figure 3: Ideal "cut off" kinetic energy (Black Straight line) given as a function of the bending power for lighter particles (Hydrogen nuclei, alpha particle)

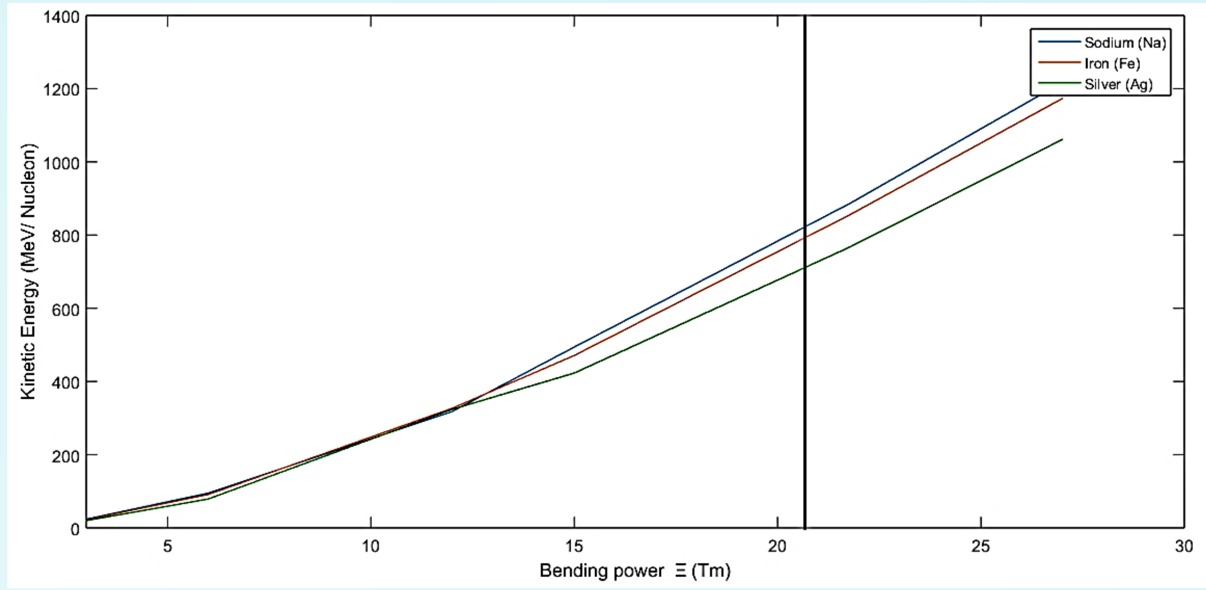


Figure 4: Ideal "cut off" kinetic energy (Black Straight line) given as a function of the bending power for heavier particles (Sodium, Iron and Silver)

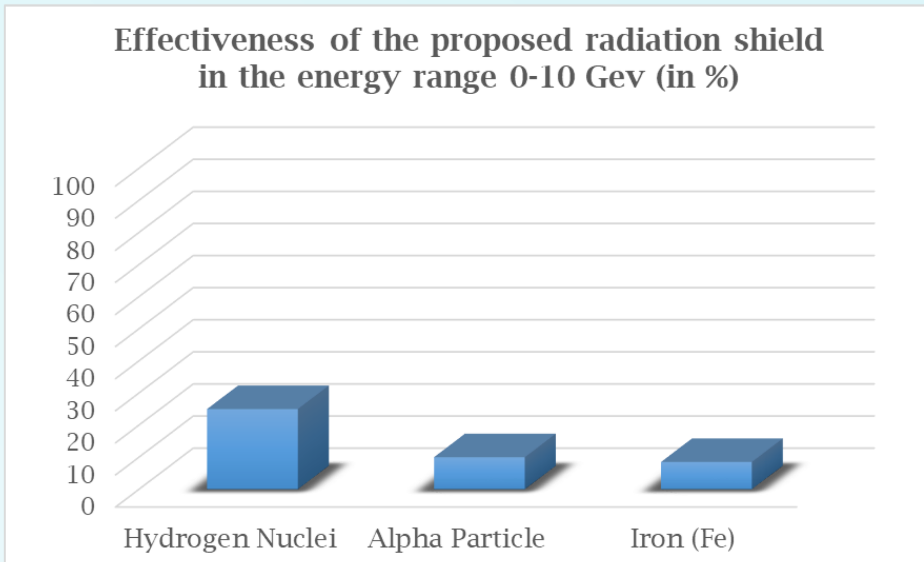


Figure 5: Effectiveness of the proposed shield in the energy range 0-10 Gev
(Example: This shield can deflect about 25% of the hydrogen nuclei in the range 0-10Gev)

Limitations of this study

When structural parameters change the current density also changes but in this study we have assumed that the current density will be the same as found by Ö. ÇİÇEK* and K. YAKINCI (2020). We have also omitted the secondary particle generation after collison with the shield.

References

1. Hoffman, J., Fisher, P., & Batishchev, O. (2005). Use of superconducting magnet technology for astronaut radiation protection. *Final Report for NIAC Phase I Contract CP*, 04-01.
2. Spillantini, P. (2000). Radiation shielding of spacecraft's in manned interplanetary flights. *Nuclear Physics B-Proceedings Supplements, 85*(1-3), 3-11.
3. Spillantini, P. (2008). Active shielding for long duration interplanetary manned missions. *cosp, 37*, 2998.
4. Spillantini, P. (2010). Active shielding for long duration interplanetary manned missions. *Advances in Space Research, 45*(7), 900-916.
5. Al Zaman, M. A., Maruf, H. M. A. R., Islam, M. R., & Panna, N. (2021). Study on superconducting magnetic shield for the manned long termed space voyages. *The Egyptian Journal of Remote Sensing and Space Science, 24*(2), 203-210.
6. Vuolo, M., Giraudo, M., Musenich, R., Calvelli, V., Ambroglini, F., Burger, W. J., & Battiston, R. (2016). Monte Carlo simulations for the space radiation superconducting shield project (SR2S). *Life sciences in space research, 8*, 22-29.
7. Çiçek, Ö., & Yakinci, K. (2020). Enhanced superconducting properties of multi-wall carbon nanotubes added YBCO-123 Superconducting System. *Journal of Molecular Structure, 1211*, 128089.