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Original Article

The application of waste brass cartridges for gamma radiation shields and bullet proofing

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ABSTRACT

This report shows the results of the investigations into the possible use of waste brass cartridges for gamma-ray shields and bullet proofing. The increasing usage of bullets and the almost inert nature of the resulting waste cartridges is an environmental concern that is pushing a rethink. Waste brass cartridges were collected from different military institutions and washed. Some of the cartridges were cut to required sizes and prepared for elemental composition, surface morphology and crystallographic analyses. The results showed that the waste cartridges contained appreciable amount of brass and therefore adequate for intended use. The waste brass cartridges were then processed into different sizes and thickness (5 mm, 10 mm, 20 mm) for the gamma radiation tests using both Thermal Neutron Spectroscope and NaI(Tl) Gamma Spectroscope. Ballistic tests were also conducted for different material thickness and shooting range up to 100 m. The results showed that the 5–20 mm thick processed waste brass plates successfully shielded gamma-rays of up to 150 keV as applicable in general practice. At increased radiation energy, the transmitted intensity was found to decrease with increased material thickness for all energy levels. Models for relating the energy transmittance and material thickness were developed for different energy source and intensity up to 1500 keV. The mixture of lead and reprocessed brass had excellent shielding properties too, however holes resulting from improper mixing were observed. The optimal processing procedure and mixing ratio of the brass with lead to reduce the usage of lead in radiation shielding in currently being investigated. In addition, the projectile penetrated the sample materials at investigated thicknesses and shooting range. Effort is currently on to enhance the processing and make it suitable as a material for bullet proof purposes.

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1. Introduction

A cartridge also known as a round is an ammunition that contains projectile, an ignition and a propellant substance. These are encapsulated within a case that may be metallic, plastic or even paper that can fit into the barrel chamber of a gun for easy transport before and during shooting [1]. It is popularly called a bullet. Cartridges are classified by the type of 'small charge of an impact' that they contain. A blank is a cartridge that has no projectile, while a dummy is one that has no propellant and ignition substance contained in it. When it fails to ignite and shoot off, it is called a dud, while an ignited cartridge that fails to be transported out of the barrel is called a squib [1].

Most firearm cartridges contain brass as the casing, although several designs using ceramics and similar materials are also available but are not common. Brass is limber and strong, and it stretches rather than crack when it is fired. Brass cartridges have the advantage of being reusable hence it is more popular than those from aluminium casings. Brass cartridges do not corrode and will not scar or cause physical deformation to the rifle/gun as is possible with steel cartridges [2]. The type of brass used for cartridges is called cartridge brass and it contains about 70% copper and 30% zinc. Among many of the properties of this alloy are strength and hardness: essential requirements for resistance of materials to bullet penetrations [3].

Firearms are an accepted part of modern warfare and military operations, but after the job is done, the environment suffers. Not only do spent shells and casings litter the landscape, but they can also prove to be a hazard to local wildlife – not to mention the impact that chemical residues, such as bullet metals and rust, can have on future plant growth and sustainability [4]. Efforts are been made toward the use of biodegradable bullets which is an innovative area yet untapped. Waste cartridge are mostly used for Jewries which are scientifically of less importance. Exploring more scientifically relevant applications for waste cartridge is a step in the right direction (Schoolscience.co.uk).

Disposal of cartridges can have negative impact on the environment [4]. Although the gunpowder can be used in fertilizer, the rest of a cartridge is not beneficial to the environment. The lead found in many bullets should not be allowed to get stuck in the ground where it can leach into the local water supply. The need to reduce the environmental pollution resulting from disposal of spent materials is driving a rethink in the use of spent brass cartridge casings.

The application of materials to minimize gamma radiation intensity is termed shielding. The availability of brass coupled with its density (8.54 g/cm^3) makes it an attractive material for radiation shielding alongside other tested materials such as iron, clay materials, water and concrete [5,6]. Spent or depleted Uranium has also been reported to be used. Lead (Pb) is the most widely used shielding material due to its high atomic number (82), corrosion-resistant nature and density (11.34 g/cm^3) that makes it highly compact [7]. Some recent works have shown the potential of other common and synthetized materials that can serve as radiation shields for different energy levels. Such materials include high alloyed stainless steel [8], tellurite glasses [9,10], doped bioactive glasses [11], and Cerrobend alloys [12] among others.

There are however different energy levels of gamma radiation intensities that are in common use in most health facilities. They range from the common X-rays for diagnostic purposes to advanced nuclear medicine application including in the treatment of cancers as well as for material probing in manufacturing and investigative technologies (nrc.gov). However, the process of obtaining lead from mines has resulted in environmental pollution with human casualties because of the toxic quantities of other heavy metals that are released to the environment [13,14]. The possibility of using brass from waste cartridges as in a lead-brass alloy system to reduce the amount of lead in use is currently being suggested and investigated.

Besides the possibility of using brass (waste cartridges) for radiation shielding, its density can be an attraction for use as a bullet proof material. Among many of the properties of this alloy are strength and hardness: essential requirements for resistance of materials to bullet penetrations [3]. Some of the common bullet proof materials include ceramics, steel, fiberglass, reinforced wood, Kevlar, polyethylene among others (rrds.com). Bullets proof doors are bullet resistant barriers that support the rest of a secured environment. They are designed to block ballistic assaults within a certain range for a certain category of arms, and depending on the proofing qualities, they are ranked or categorized by manufacturers (tssbulletproof.com). Since the door is part of an entire system of building, architects usually are in search of a door solutions that combines many qualities such as having a good aesthetic look, offering sound barriers (if needed). It should also be able to allow minimum sound communication between spaces (if required) and in some cases offer transparency across spaces. Bullet proof door panels can be made up of several materials such as steel, (using appropriate gauge), fibre glass (as a core or as a lining) wood core with laminates and aluminium. Frames are usually of steel, aluminium or could be of steel with concrete poured into it. Brass has the potential of serving as a lining to the core of a panel possibly of wood or in combination with scrap metal that could easily be picked from the environment.

Hence, the aim of this work is to establish the potentials of waste spent cartridges either singly or in combination with other metals (lead) for radiation shielding and bulletproof material. It is also aimed at developing a predictive model for radiation shielding and material thickness. The objectives include investigation of the changes that occur to the thermomechanical properties of spent brass cartridge. It is also to establish the use of the spent cartridges in the making of bulletproof doors and for use as barriers for X-rays in nuclear medicine and related activities. It is hoped that the results of this work will provide some data on spent and reprocessed brass cartridge casings. The results will also highlight the reusability of waste brass casings from deadly bullets for peaceful purposes. The usefulness of the brass casing will also lead to reduction in environmental pollution from dumps. The observations from this study will also provide data for policy makers in determining how much of reprocessed brass can be used as replacement for lead as the major component in radiation shields for medical applications. This will enhance environmental cleanliness and reduction in the dependence on lead (Pb) for radiation shielding materials, hence reduction in the pollution associated with its mining.

The research is however limited to the use of spend/waste brass cartridge casings from the Nigerian Defence Academy and other related military institutions.

2. Materials and methods

2.1. Materials

The main material needed for these investigations are spent brass cartridges obtained from some military institutions in Nigeria. These institutions include the Defence Industry Corporation of Nigeria (DICON) Kaduna, the Nigeria Army School of Artillery (NASA) Kachia, and the Nigerian Defence Academy (NDA) Kaduna. The major part of this research was the analysis and characterization of the waste brass casings before and after processing it.

2.2. Methodology

The spent cartridges were collected from the Nigeria Defence Academy (NDA) and other sister military institutions in Nigeria. Some freshly spent cartridges were also collected and tested for changes to the mechanical properties and morphology as a result of the firing process.

The spent cartridges were washed in a rotary mixer with detergents or any other available soap and thereafter properly rinsed in clean water. They were then allowed to dry at atmospheric condition and oven dried. The dried cartridges were then melted in an electric furnace at temperatures over 1000 °C for five (5) hours. Five (5) stainless steel moulds (25cm × 25cm) of various thicknesses were made and the melted brass poured into them. Personal protective clothing was always worn. After cooling, the brass samples were collected and annealed in a furnace at temperatures less than 450 °C. They were then subjected to several tests.

Fresh brass was also obtained from identified sources and melted in moulds like the above to act as a control. Lead was melted to form a composite with the brass to predetermined thicknesses. The analysis of this sample was to give an insight into the level of replacement of lead in radiation shielding materials. The surface morphology using Scanning Electron Microscope (SEM), elemental composition using X-Ray Flourescence (XRF, Rigaku NEX-CG) and diffractogram using X-Ray Diffraction (XRD, Shimadzu XRD-5000) of the different spent cartridge samples were determined. This was to give an insight into the changes that have taken place as a result of the firing process when compared with fresh unused brass. It was also meant to give information into the different material/elemental constitution of some of the different cartridge casings available.

The results of the tests will help make decision on the optimum thickness to be used for the door and the radioactive shield. The chosen door design will determine the number of brass bullet casing that will be required for each since it is dependent on weight measurements. Moulds with desired design and sizes will be made and the brass melts poured in them. After cooling, the solidified brass was cleaned and subjected to further impact and ballistic tests to determine its performance in bullet proofing. Proper finishing processes such as smoothening of the edges, filings, painting and mounting of fittings for use as doors was done.

The Laboratories used for the different tests and analyses were chosen because of the availability of reliable facilities and technical know-how. As a matter of national security, the ballistic test could only be carried out in a military facility such as the Defence Industry Corporation in Kaduna. Further investigation will be carried out when the end use is for radioactive shields. Strict adherence to safety procedures for radioactive tests was observed.

2.3. Testing

2.3.1. Gamma radiation shields

The samples after removal from the moulds were cut to 5cm × 5cm and were taken into X-Ray radiography machine for test in a standard laboratory including the Radiology Department of the Ahmadu Bello University Teaching Hospital (ABUTH), Shika, Zaria, Nigeria. Thicknesses of 5 mm, 10 mm and 20 mm were tested under varying radiation intensities (see Table 7 for results). The transmission intensity for the different brass samples were under conducted using the Thermal Neutron Spectroscope at the Centre for Energy Research and Training (CERT) ABU Zaria and NaI(Tl) Gamma Spectroscope at Nuclear Physics Lab, NDA Kaduna. The results obtained are shown in Figs. 3 and 4.

2.3.2. Ballistic shielding

The samples were prepared to be squares of size 30cm × 30cm and of 5, 10 and 20 mm thicknesses. They were then subjected to ballistic impacts using the LAR and AK-47 standard test rifles and 7.62/39 mm calibre cartridges at the shooting range of the Defence Industry Corporation (DICON), Kaduna. Results are presented in Table 8

2.3.3. Fire proofing

The fire-proofing test was not concluded as at the time of concluding this report. It was discussed that doors with various thicknesses of spent brass be designed and tested for their ability to withstand fires. A control fire-proof door is to be procured from the open market and then tested too. Varying degrees of fire with properties of conventional fires will be used for the test. The fire service of the Nigerian Defence Academy will be contacted, at the appropriate time, for the test.

3. Results and discussion

Table 1 shows the elemental composition of the different cartridge samples sourced obtained from the X-ray fluorescence analyses [15–17]. It can be observed that the samples have varying compositions and particularly with respect to the copper component. Only samples 6 and 7 have same copper component. It is interesting to note that samples 1–3 have iron (Fe) content higher that 90% while copper is almost absent. The compositions observed are at variance with the literature value for brass cartridges [1]. Samples 1–3 appear to be steel cartridges which are also reported in literature but are not common (azom.com). The amount of zinc (Zn) in sam-

Table 1 – Elemental composition of some spent cartridges.

Elements	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
Ca	0.30	0.065	0.16	0.04	0,07	0.29	0.10
Mn	0.81	0.38	0.48	0.3	0.05	0.04	0.02
Fe	**92.10**	**95.40**	**94.90**	**1.3**	1.8	7.58	0.61
Zn	**2.70**	**0.805**	**3.93**	**8.5**	7.6	24.52	33.25
Sb	0.60	1.00	0.1	0.8	0.6	ND	0.03
La	0.70	ND	0.02	ND	ND	0.02	0.02
Hf	1.30	ND	ND	ND	ND	ND	ND
Re	0.19	ND	ND	ND	ND	ND	ND
Pb	1.00	0.64	ND	0.9	0.3	ND	ND
P	ND	0.19	ND	ND	ND	ND	ND
Cu	**ND**	**0.14**	**0.16**	**85.4**	90.5	59.06	59.12
Eu	ND	0.50	0.2	ND	ND	0.06	0.06
Ag	ND	ND	ND	ND	ND	3.70	2.9
Cr	0.30	0.065	0.038	0.08	0.09	ND	ND
Si	ND	ND	ND	ND	ND	4.0	4.0

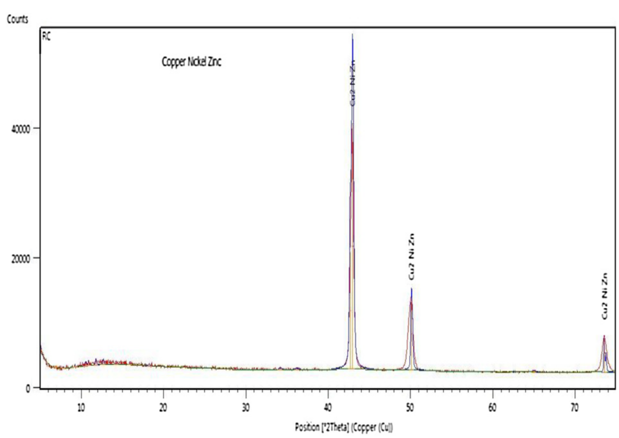

Fig. 1 – X-ray diffractogram of a sample of waste brass cartridge.

ples 6 and 7 are within the limits reported for cartridge brass although the copper content falls below reported values. They also contain significant amount of silver (3% Ag) which may influence their cost to the higher band. It is possible that the Nigerian Military may have developed an alternative to the common type of cartridges that best suits their purposes. It evident that samples 1–3 will not be suitable for this investigation since they do not contain copper and zinc in enough amounts to represent the presence of brass. They were therefore discarded.

Fig. 1 shows the diffractogram of one of the samples used for this investigation obtained from the X-ray diffractogram analysis [18,19]. The diffractogram was necessary to confirm the crystal nature of the sample apart from the information obtained from the elemental composition. It is evident that the sample contains copper and zinc in high proportions and the diffractogram agrees with literature particularly at theta (θ) between 40° and 80° [20]. These samples were further processed for the investigation. Fig. 2 shows the micrograph of the waste brass cartridge. The firing process has resulted in stress and the marked lines on the material. These lines are absent from the fresh brass material (image not shown). The presence of these fault lines implies that they can't be used anymore for firearm purposes because of the danger they pose. Hence their disposal status.

3.1. *Gamma shielding*

It was discussed that several thicknesses of the different materials should be tested for their radiation shielding properties at different energy levels of the incident rays. An optimal thickness will be evident for further development. In addition, certain tests were to be carried out that could help predict the radiation shielding ability of spent brass samples. The results* (Table 2) showed that both the fresh brass and spent brass had excellent radiation shielding ability for the tested energy levels. However, tests with energy levels as applied for oncological purposes could not be carried out due to breakdown of the equipment at the Teaching hospital (ABUTH) in Shika. It was also observed that the material that had a mixture of spent brass and lead though shielded the rays but had pocket of holes. This may be due to improper mixing of the lead-brass solution, a complication resulting from the large difference between the melting point of brass and lead. Efforts are currently on to find an optimal mixing condition to obtain a good alloy. It was observed that the 5 mm thick lead sample shielded the rays at all energy levels [21] (see also Table 2). Hence, other thicknesses were not tested because they are already known to exhibit excellent shielding characteristics but owing to the environmental and health hazard associated with their production, their use is being discouraged.

Figs. 3 and 4 shows the results of the transmittance tests using the Thermal Neutron Spectroscope and the NaI(Tl) Gamma Spectroscope respectively.

The relationship between sample thickness and transmitted intensities (averaged and normal) at different energy levels is observed to be perfectly polynomial in nature and hence does not follow a linear description within acceptable limits as can be seen in the models in Figs. 3 and 4. This in effect implies that as the sample size increases, the amount of gamma rays that was transmitted reduced but not in the same ratio. The model presented in the figures is deterministic such that the response of a sample thickness to gamma rays can be predicted for an energy intensity [6]. Models are usually necessary for predicting the relationships of different

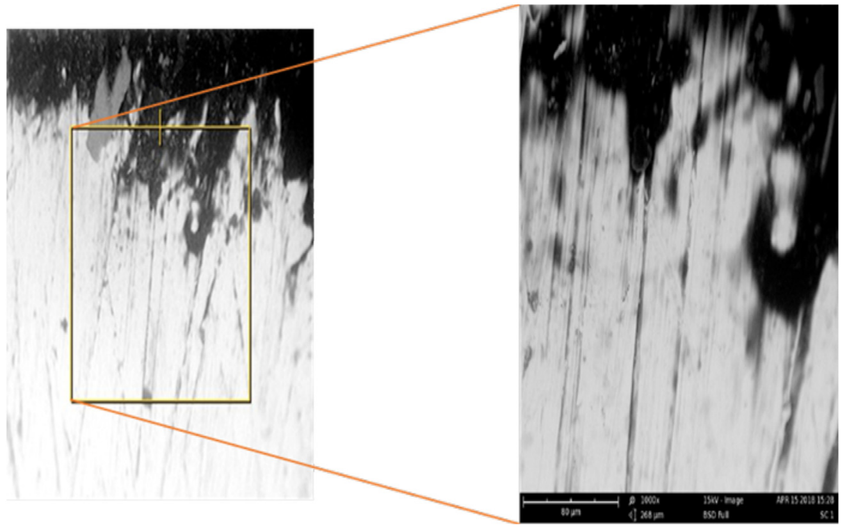

Fig. 2 – SEM image of waste cartridge brass.

Table 2 – Results of radiation impact on samples.

Materials	Thickness	Radiation exposure	Remarks
Brass	5 mm	50 keV	Rays shielded
		70 keV	Rays shielded
		120/150 keV	Rays shielded
	10 mm	50 keV	Rays shielded
		70 keV	Rays shielded
		120/150 keV	Rays shielded
	20 mm	50 keV	Rays shielded
		70 keV	Rays shielded
		120/150 keV	Rays shielded
Spent brass	5 mm	50 keV	Rays shielded
		70 keV	Rays shielded
		120/150 keV	Rays shielded
	10 mm	50 keV	Rays shielded
		70 keV	Rays shielded
		120/150 keV	Rays shielded
	20 mm	50 keV	Rays shielded
		70 keV	Rays shielded
		120/150 keV	Rays shielded
Spent brass-lead system	5 mm	50 keV	Rays shielded with holes
		70 keV	Rays shielded with holes
		120/150 keV	Rays shielded with holes
	10 mm	50 keV	Rays shielded with holes
		70 keV	Rays shielded with holes
		120/150 keV	Rays shielded with holes
	20 mm	50 keV	Rays shielded with holes
		70 keV	Rays shielded with holes
		120/150 keV	Rays shielded with holes
Lead	5 mm	50 keV	Rays shielded
		70 keV	Rays shielded
		120/150 keV	Rays shielded

parameters to a determined output as applicable in other scientific fields of endeavour including catalyst design, fluid flows among others [22–24]. The detailed investigation (underway) that will involve more thicknesses at both end of the spectrum should give a more robust relationship for describing this dependence. Nevertheless, it is instructive to know that the samples prepared from the waste brass casings can be used as an effective shielding material for low energy radiation as applicable in the hospitals and other related primary health facilities. This will provide a cheaper and more environmentally friendly alternative to the traditional lead that is in use.

3.2. *Ballistic shielding*

The different sample thickness of the brass samples was tested for their ballistic properties at different ranges. This was to help determine the extent of their applications particularly

Table 3 – Controlled Ballistic impact test on brass samples.

Materials	Thickness	Ballistic exposure	Remarks
Brass	5 mm	50 m	Sample perforated with 7.9 mm impact diameter and 12.6 mm exit diameter
		75 m	Sample perforated with 8.2 mm impact diameter and 12.3 mm exit diameter
		100 m	Sample perforated with 8.5 mm impact diameter and 12 mm exit diameter
	10 mm	50 m	
		75 m	
		100 m	
	20 mm	50 m	
		75 m	
		100 m	
Spent brass	5 mm	50 m	Sample perforated with 8.0 mm impact diameter and 12.8 mm exit diameter
		75 m	Sample perforated with 8.4 mm impact diameter and 12.4 mm exit diameter
		100 m	Sample perforated with 8.7 mm impact diameter and 12 mm exit diameter
	10 mm	50 m	
		75 m	
		100 m	
	20 mm	50 m	
		75 m	
		100 m	

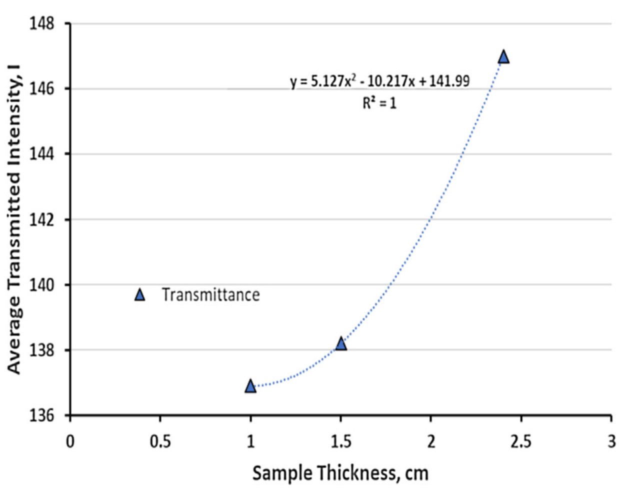

Fig. 3 – Averaged transmitted intensity measurement using Thermal Neutron Spectroscopy.

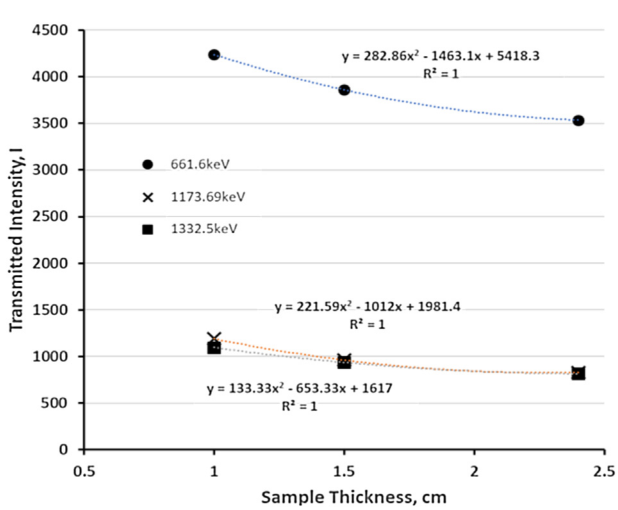

Fig. 4 – Transmitted intensity measurement using NaI(Tl) Gamma Spectroscopy at different energy levels.

for bullet proofing purposes. It was observed from the results (Table 3) that the bullets perforated the 5 mm thick samples at all distance of exposure with varying impact and exit bores as shown. Shorter distances were not tested since it has been proven that impact is directly proportional to shooting range. Samples of higher thicknesses could not be tested because of the weight implications if used for bullet proofing. The reason why the sample was perforated at the tested range with the chosen calibres is the subject of an ongoing investigation. One plausible explanation is the fact that the bullets could be made of steel, from the physical observation of the waste cartridges from the test. This has however not been proven but could provide a clue. The results obtained from the elemental composition analysis of some spent cartridges (Table 3) showed that some were of iron with as high as 94% content. This obviously is not in agreement with known global standards. Nevertheless, the different improvements to enhance the ballistic shielding properties of the spent brass samples are being investigated.

3.3. *Fire proofing*

It was discussed that doors with various thicknesses of spent brass be designed and tested for their ability to withstand fires. A control fire-proof door is to be procured from the open market and then tested too. Varying degrees of fire with properties of conventional fires will be used for the test. The fire service of the Nigerian Defence Academy will be contacted, at the appropriate time, for the test.

4. Conclusions

A preliminary investigation of the application of spent brass cartridges in radiation shields and bullet proof has been conducted. It can be concluded that;

1 Waste brass cartridge can serve other useful purposes besides materials for jewellery and plumbing

2 Brass from waste cartridge can serve as radiation shields for low to medium intensity radiations of up to 200 keV.
3 Optimal combination of brass with lead can result in reduction of lead quantity needed for radiation shielding
4 Model for predicting gamma ray shielding ability of brass plates from waste cartridges at different radiation intensity has been proposed
5 The application of waste brass cartridges in radiation shielding can significantly improve its worth and reduce environmental pollution arising from disposal.
6 Brass from waste cartridges can serve bullet-proof purposes when enhanced.

Conflict of interest

The authors declare no conflicts of interest.

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