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Feasibility Study on a New Aggregate Concrete for Shielding High Energy X-ray Beams

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1. Introduction

The most common material for shielding X-ray is the concrete which can be adopted in almost any configuration and supply with radiation shielding and structural strength. However, it is widely known that the thickness of a concrete barrier for 1 MV X-ray beam is required about 1 meter which are about 6 times thicker than an equivalent lead shield [1]. Therefore, research and development of shielding material are needed to efficiently protect against the leakage radiations.

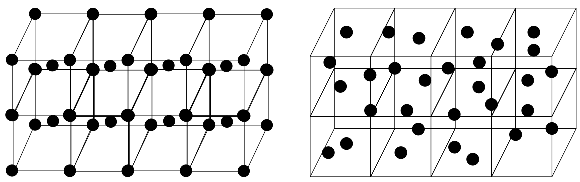
In this study, a new shielding material (i.e., aggregate concrete) was first designed to complement the concrete weakness of the high energy X-ray beam. The optimized condition of this shielding material was derived from the analysis of effective dose for various radiation beams, by using MCNP5 code [2]. Consequently, the capability of this shielding material was evaluated by the comparison of some other shield materials.

2. Methods and Materials

The ordinary concrete is a compound material composed of about 90 % by weight of oxygen and silicon with the rest of other ones (aluminum, calcium, sodium, etc.) [3]. These weight fractions of ordinary concrete can be easily changed by using various materials of different densities. Therefore, a new aggregate concrete was designed by the supplement of small-sized lead-balls within ordinary concrete. Especially, 1.5 mm diameter lead-ball, which is the smallest size in manufactured products, was used to prevent the spread of toxic lead in atmosphere and to increase the internal stress of concrete.

The optimized packing fraction of these lead-balls was calculated to reduce the amount of unnecessary lead as possible, and to maximize the economic profit. The calculation method was divided into two cases depending on the packing structure of these lead-balls, as shown in Figure 1. First, many lead-balls were arranged on a Body Centered Cubic (BCC) structure, whereas second, stochastic geometry (using URAN card) in MCNP5 code was used to randomly pack those within the cubical cells [4]. The radiation sources were also assumed from 4 MV to 15 MV X-rays (i.e., 4, 6, and 15 MV) to be produced from Varian 2100C accelerator which is widely used to treat the patients in hospitals [5]. These radiation beams were confined to a forward cone whose half-angle is 2.86 degrees about the x-axis.

The specific simulation configuration to compare shielding capability of some materials was presented in Figure 2. The shielding block was located at a distance of 100 cm away from the radiation source, and dose calculation at the end surface of this block was performed by using flux-to-dose rate conversion factors of American National Standards Institute (ANSI) [6]. On the basis of effective dose by penetrating radiations, the shielding capability of various materials (only concrete, lead sheet and concrete, and only heavy concrete) was evaluated to estimate the realistic possibility of a new shielding material.



(a) BCC Structure (b) Stochastic Geometry

FIG. 1. The Calculation Method for Packing the Lead-balls in the Cubic Cells

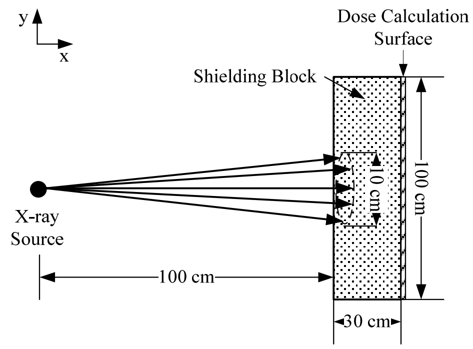


FIG. 2. Detailed Calculation Configuration to Evaluate the Shielding Capability of Various Materials

3. Results and Discussions

In order to determine the optimized packing fraction of 1.5 mm diameter lead-balls in ordinary concrete, the effective dose distribution as a function of packing fraction of those was calculated by using various radiation beams (4, 6, and 15 MV X-rays). In addition, a comparison of two calculation methods was also performed, as shown in Figure 3. It was found that the effective dose by penetrating radiations was exponentially decreased along with increasing packing fraction of the lead-balls, and the calculated results considering packing structure were almost equal in the whole range. Particularly, it is shown that the effective dose does not significantly reduce over packing fraction of 30 %; this fraction was selected as an optimized condition for a new shielding material.

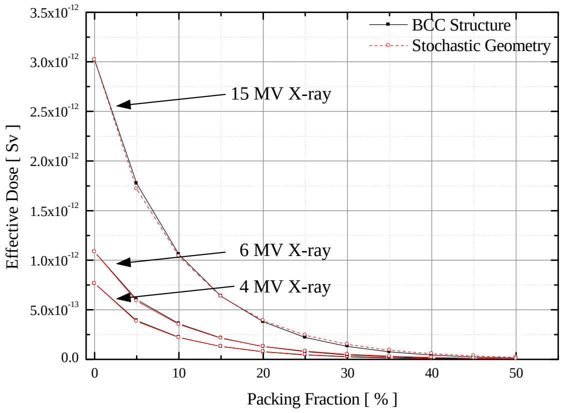


FIG. 3. The Effective Dose Distribution as a Function of Packing Fraction of the Lead-balls, for the Various X-ray Beams

Table 1. A Comparison of Effective Dose for Various X-ray Beams [Unit: Sv]

	4 MV X-ray	6 MV X-ray	15 MV X-ray
This Study	2.90e-14	5.21e-14	1.51e-13
Ordinary Concrete	7.65e-13	1.08e-12	3.02e-12
Lead Sheet + Concrete [a)]			
Case (1)	2.55e-14	4.22e-14	1.02e-13
Case (2)	2.36e-14	4.12e-14	1.13e-13
Case (3)	1.88e-14	3.66e-14	1.15e-13
Heavy Concrete [b)]	2.29e-13	3.61e-13	1.01e-12

[a)] *The calculation is divided into three cases: (1) Lead Sheet + Concrete, (2) Concrete + Lead Sheet + Concrete, (3) Concrete + Lead Sheet*
[b)] *This material is composed of 93 % by weight of iron with the rest of other ones*

The shielding capabilities of various materials were evaluated under the same simulation conditions, and the calculated results were presented in Table 1. It is recognized that a shielding barrier filled with the optimized lead-ball concrete can reduce the effective dose about 20 times more effective than an equivalent concrete barrier. Also, the shielding capability of this material is almost same with a combination of lead sheet (30 % volume of shielding block) and concrete (70 % volume of shielding block), and is about 7 times more effective than a heavy concrete.

4. Conclusions

In order to complement shielding capability of ordinary concrete for high energy radiations, a new aggregate concrete was designed by randomly mixing 1.5 mm diameter lead-balls and ordinary concrete. It is confirmed that the optimized packing fraction of these lead-balls is a 30 % of shielding block, and this shielding block can reduce the effective dose about 20 and 7 times more efficient than an equivalent ordinary and heavy concrete, respectively. Also, this lead-ball concrete has same shielding capability with a case of lead sheet use, and is more economic than lead sheet because lead sheet is always necessary to cover oneself with some additional form of wallboard, tile of plaster [1]. Consequently, this concrete is expected to be well applied to hospitals and institutes using high energy X-ray beams.

ACKNOWLEDGEMENT

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