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Simulation of gamma irradiation system for a ballast water treatment

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Background: Invasion by different kinds of ballast water microorganisms is one of the most important marine environment problems around the world; therefore preventing the invasion of these unwanted and harmful stowaways is one of the main strategies of responsible agencies. Some of these methods such as ocean exchange, heating, filtration, hydro cyclones, UV irradiation and chemical treatment, have various problems such as technical deficiency, high costs, lack of safety and environmental side effects. ***Materials and Methods:*** A novel system of treatment by Gamma irradiation is designed to irradiate the blast water uniformly and effectively. To determine the dose distribution as a function of distance from the irradiation source, the MNCP code was used. The systems used for source implant in this simulation were Paterson-Parker, Paris and Network systems. In each system, Sivert-integral and inverse square law were used in MATLAB program to determine the dose distribution. ***Results:*** Results of initial laboratory tests on offshore water samples of Siri Island indicated that the appropriate dose for deactivation of organisms of water samples is approximately one kGy. It has been demonstrated that the dose can be provided by twenty five 100,000 Ci line sources of ^{60}Co in a triangle implant arranged in a 1×1×1 m^3 cubic shape water pipe. In order to increase efficiency and radiation safety, water passed from two other coaxial and bigger cubes, after passing from the first cube. A one meter thick wall of concrete around the cubes was adequate to shield the system completely. ***Conclusion:*** The main advantages of this system such as high efficiency, safety, reliability, minimum environmental adverse effects, proves that this novel method not only can be used for ballast water treatment, but is also effective for drinking water purification. **Iran. J. Radiat. Res., 2006; 4 (2): 93-97**

Keywords: *Gamma rays, triangle implant, ballast water, MCNP code, hydro cyclones.*

INTRODUCTION

Ballast water carried in ships to maintain safety and stability at sea is now recognized as one of the major vectors for the translocation of nonindigenous marine organisms around the world (1). As a result of these biological invasioAt the present time, a range of different treatment options have been proposed, or are being developed. However, it will take sometime before the necessary information is available, and to fully assess their effectiveness. Safety is always paramount in the adoption of any treatment procedure, and any option must only be used at the decision of the ship's master, if it affects the safety of the ship or crew.

One of these methods, that is the exchange of ballast water at sea, is a primary treatment method identified by all countries that have some form of control in place. Exchange of ballast water at sea in its various forms can approximately replace 95% to 100% of the original water. The efficiency of removal of organisms (as distinct from replacement of water) is a complex issue and has been shown to vary for particular ships, type of exchange option and types of organisms (3).

It is important to note that even if it is assumed that the efficiency of removal of organisms is the same as the water replacement efficiency in ocean exchange, large numbers of harmful organisms may still be present in the water discharged into the receiving port, and pose a significant residual threat even though the risk has been significantly minimized. This is especially true when ballasting occurs during an algal bloom in the ballast uptake port (4).

Another method is heating. The use of waste heat from the ship's main engine

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jacket coolers to heat ballast water can provide a very effective and environmentally attractive treatment option, and it is specifically suitable for treatment on international voyages involving voyage durations of about 10 days or longer, or to heat up small quantities of ballast water by circulation prior to discharge (such as passengers or container ships). However, if this option is to be used, heating needs to take place during transit, as the ship's main engine is not usually in operation during ballasting or deballasting [5].

Continuous self cleaning filters to separate various sized organisms are another method that have attracted a great deal of attention. Filtration can remove organisms from the water during ballasting or deballasting based on their size. However, as with most physical size separation technologies, there is always a compromise between size (and size distribution) and efficiency based on various operational parameters. The most likely candidates for large scale ballast water filtration include self-cleaning screen filters or possibly rapid sand filters. Other filters typically used in waste water or drinking water treatment such as precoat filters and membrane filters are not likely to be appropriate for use in ballast water treatment other than possibly in very specialized cases where small quantities of water are involved, or a particular problem exists where cost is not a major consideration [6].

Hydro cyclones have been proposed as an alternative to filtration, although initial tests in small prototype cyclones have given limited and inconclusive data [7].

Treating water with ultraviolet energy at various doses to inactivate bacteria and other organisms is a well established technology for fresh water. However, only a limited investigation has been carried out in the marine environment or in demonstrating the applicability of this technique for ballast water treatment so far. Water turbidity and presence of sediments in ballast water present one of the biggest challenges to the effectiveness of this technology. Pre-treatment of the water using filtration or hydro cyclones prior to UV treatment is likely to be necessary in most cases to improve clarity of the water, and the overall efficiency and effectiveness consequently [8].

A number of biocides/chemicals (including hydrogen peroxide, chlorine dioxide, ozone, glutaraldehyde, copper/silver ion systems) have been tested for effectiveness. Test work with some of the organisms on the Marine Target Species List (MTSL), although effective in some cases, requires high impractical concentrations or poses significant safety, environmental or operational problems [9].

In this paper a novel system is suggested for ballast water treatment by using gamma irradiation. Initial laboratory tests demonstrated that gamma irradiation that has been used for food disinfection during the recent years can be effective for deactivation of organisms of marine environments.

MATERIALS AND METHODS

In order to design a system in which we could irradiate the ballast water uniformly and effectively, we need to know: 1) the minimum dose required to be delivered, 2) the number of sources and their activity needed to provide a uniform and effective dose, 3) the dose distribution around each source and the source implant geometry and 4) the shielding required to ensure proper radiation protection.

To determine the dose distribution as a function of distance from the radiation source, the MCNP code was used. For programming this problem we assumed a cylindrical source of ^{60}Co of one meter length around which 51 coaxial cylinders were placed as detectors. The radius of detectors increased in 1 cm steps from 2 to 30 cm, 10 cm steps from 30 to 100 cm and 20 cm steps from 100 to 400 cm. Since the dose can not be calculated by MCNP code directly, we had to calculate the energy per history of the photon in each cell.

In this simulation the activity of the linear source was assumed to be 100,000 Ci (each cm = 1000 Ci), and the running time of the

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program was 3000 min. After changing the results from energy (MeV/gr) to dose (Gy), it became possible to find a relationship between the dose and distance from the radiation source figure 1.

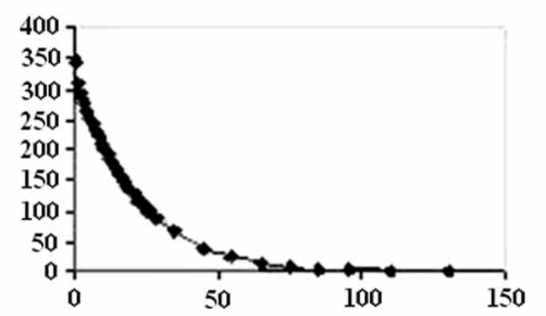

Figure 1. Dose-distance graph of a 100,000 Ci ^{60}Co linear source.

The conformed equation for the graph is obtained from a software called Table Curve (TC). The equation is as follows:

$$\ln y = a + b \cdot x + c \cdot \exp(-x) \qquad (1)$$

Where y is the dose, x is the distance, a = 5.780685168, b = -0.04543050, c = 0.135607292. The regulation coefficient of the equation is 0.999709724.

The systems of source implant in this simulation are extracted from the systems of implant in brachytherapy [10]. The appropriate systems for this purpose were Paterson-Parker system (planer and volume implants), Paris system (single plane, triangles and squares implants) and network system.

To determine the dose distribution in each system Sievert integral and inverse square law [11] were used in the program that was written in MATLAB for this reason. The comparison of the dose distribution in each system for nine 3000 Ci linear sources of ^{60}Co showed that the minimum dose in a point between two adjacent sources at the same distance from each of them was as follows: in the single plane implant it was 3293.5 (cGy/sec), in the squares implant was 4378.1 (cGy/sec), in the triangles implant 7360.2 (cGy/sec) and in the network system 5948.6 (cGy/sec). Therefore, the results showed that the triangles implants is the best system to provide a complete dose distribution in a specified irradiated volume.

After determination of dose distribution and system of source implant, the most recent work was to determine the number of sources needed to obtain the specified dose (1 kGy) in a defined volume.

A program was written in MATLAB by using the equation (1) and the superposition law for 113 linear sources with one meter length and activity of 100000 Ci. The distance between the sources was assumed to be 12 cm and the volume of treatment was set as 1 m^3. Minimum dose in this plan in the centre of volume was 9685.2 Gy and at the edges was 2966.2 Gy.

The simulation was repeated with the same condition for 85 and 25 sources with distances of 15 cm and 30 cm. Minimum dose in the centre and edges of the volume for 85 sources were 6637.4 and 2387.2 Gy and 1783.3 and 779.56 Gy for 25 sources (figure 2).

RESULTS

As the results defined, the final appropriate design of the system for obtaining 1 kGy in 1 m^3 volume is the triangle implant of 25 linear sources of ^{60}Co at distances of 30 cm from each other. In this

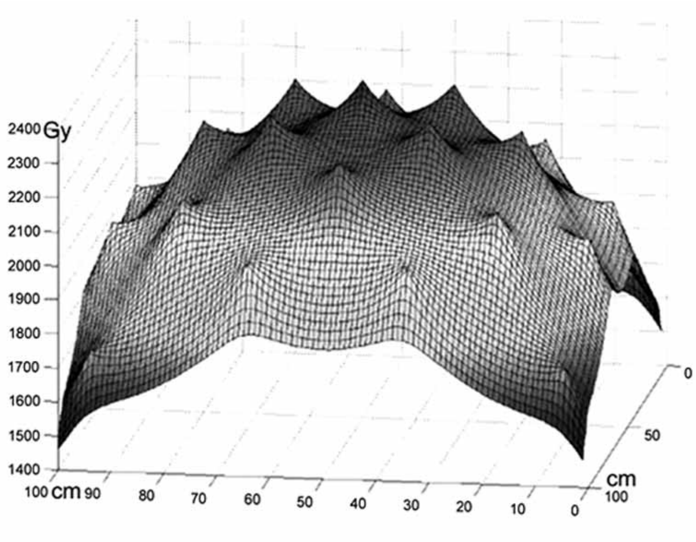

Figure 2. Dose distribution graph of 25 linear sources in 1 m^2 area.

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design, the minimum dose at the edges of the simulated volume is 779.56 Gy. Since this dose is wasted, it decreases the efficiency and safety of the system and increases the costs. To eliminate this problem two other coaxial cubes of dimensions 2×2×1.5 and 3×3×2.5 m^3 were sketched. After passing from the arranged sources in the main cube, water was turned and passed from the second and third cubes. The duration for water to pass from each cube was 1sec, 4.5 sec, and 12.5 sec respectively. The walls of the cubes were simulated to be form iron of 2 mm thickness. After the omission of the absorbed dose in the walls of the cubes, each 1 m^3 of water at the end of the treatment, absorbed 3204.55 Gy dose in total (figure 3). The shielding of the system was completed by a wall of concrete of one meter thickness around the third cube.

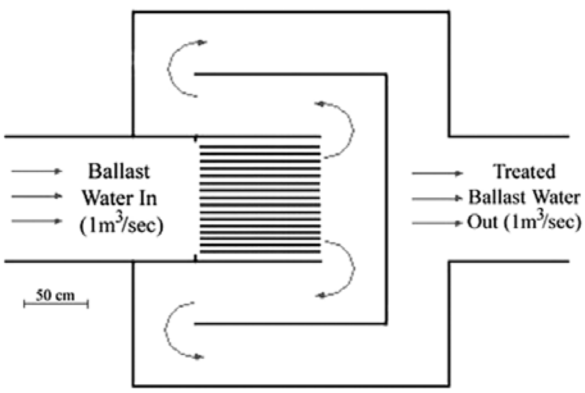

Figure 3. Up plan of the system and water direction.

DISCUSSION

The optimum dose for deactivation of marine organisms is found to be close and the output of the system is almost 3 kGy; therefore, by decreasing the activity of the sources to 35000 Ci (each cm = 350 Ci instead of 1000 Ci) the total dose absorption of each m^3 of water will decrease to nearly one kGy, so the construction costs of system will be 1/3 of the initial designed system.

Another way is to keep the total activity of the system constant and increase the number of sources, and to decrease the activity of each source. For example, consider a similar system with 113 similar linear sources in a 1×1×1 m^3 cube at distances of 12 cm and total activity of 105 Ci. The activity of each source will be approximately 23,000 Ci (each cm = 230 Ci). The minimum dose in this new design in the middle of the cube and at its edges will be 2120.1 Gy and 595.24 Gy (figure 4). Comparison of figure 2 and figure 4 shows that the dose distribution in the second design with 113 sources is more uniform than the system with 25 sources.

The third way of decreasing the total dose absorption and increasing efficiency is to double the speed of entering water or increase the distance between sources and radiation volume this involves new designs and calculations.

In conclusion the main advantages of this system, such as high efficiency; safety, reliability, minimum environmental side effects, proves that this novel method not only can be used for ballast water treatment, but is also effective for drinking water purification. Besides its other advantages, the cost of this system could be much lower and more economical than other systems used for this purpose.

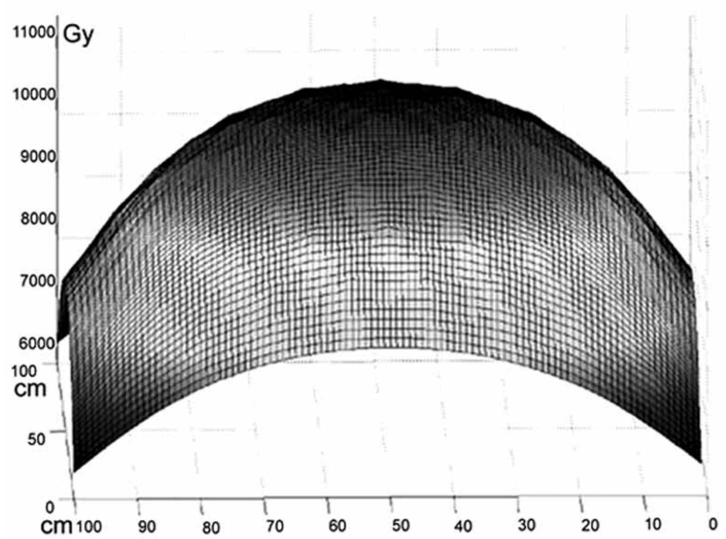

Figure 4. Dose distribution graph of 113 linear sources of ^{60}Co in 1 m^2 area.

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