INVESTIGATION OF PROTON AND ALPHA RADIATION EFFECTS ON POLYMER CONCRETE BY USING GEANT4

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In this study, the effects of proton and alpha radiation on polymer concrete material have been investigated by using GEANT4 which is a freely distributed code with a very wide range of use. The polymer's selection is due to its preferable regarding its physical and chemical properties such as low cost of production, ease of synthesizing and light weight etc. The radiation effects of different induced particles and also stopping power and penetrating distance investigations have been done to examine the possibility of using the polymer concrete as shielding material. To reach our aim as simulating the different situations, GEANT4's PhysListEmStandard and G4EmStandardPhysics libraries have been employed for two types of polymer concrete samples where one has 0 % natural standard CEN sand while other has 75 % of natural standard CEN sand. The rest of the studied materials consists of polyester resin. Obtained results such as the penetrating distance and the stopping power have been discussed for both studied materials.

Introduction

Scientific developments in many fields are oriented to make human life more easy and comfortable. To reach the mentioned aim, scientific researches help to the technological developments and vice versa within a loop. Those two sides of new era always keep their improvement and shape the human life. Among all science branches, natural and engineering sciences have almost the most important place in the determination of mankind's destiny. From the first known scientific explores to our present time and in the planning of future investigations, human beings always questioned to the nature they are living in. Even philosophical and other social sciences have asked and still asking the questions which could only be answered with natural sciences and engineering skills. Due to that, there has been always a tendency to the natural sciences such as physics, chemistry, mathematics etc. and engineering sciences. The most former engineering branch is civil engineering which emerged with the transition of settled life and continuously improving and developing ever since. One sub branch of civil engineering investigates the properties and characteristics of construction materials to produce more effective, environmental friendly and convenient materials. Those kind of materials are generally used in new style eco buildings, low cost mass housing and also scientific research and application buildings such as particle accelerator facilities and nuclear reactors. Nuclear reactors are one of the piece of scientific art and have a many purpose wide range use. The most known reason of the nuclear reactor's usage is to produce electricity energy which is an indispensable request of our daily lives. Operating a nuclear reactor employs the nuclear fission principle to generate heat and transform that energy into electricity. As a result of fission principle, energetic neutrons and other particles occur during the fission process and some of them with unexpectedly high energy, flux or intensity may cause unpredicted injuries or consequences. To avoid from the harm of the secondary particles and other heavy ions that may be produced during fission and also to keep the environment nuclear clean and safe, many precautionary steps have been developed and applied. One of them is the shielding which has a vital importance on operating a nuclear reactor. To be able to construct the shielding as much as possible to protect the environment around the sophisticated research facilities such as nuclear power plants and accelerator complexes, different materials also different composites have been investigated and studied so far. One of the new focus point of the scientists is now the use of an old known material which is polymer. Polymer concrete (PC) has been in use since the third quarter of the 20th century and the attention to the studies increasing rapidly for the use of PC's in different areas [1]. The reason of wide range use of polymer based materials is due to their ease of synthesis and their chemical/physical properties such as light weight, convenient, durable and low production cost [2]. The wide used polymer concrete has been developed by combining the different type of aggregates according to the PC's use of purpose and the polymers as binders instead of cement and water [3]. In many cases, where the primary concern is the time and cost efficiency, scientists refer to the computer based simulation techniques. With one other improved engineering branch, computational sciences, it is possible to simulate a situation and investigate the processes about the specific one. There exists enormous number of simulation programs and techniques to study the requested situation. One of the most known and preferred program is called GEANT4 [4] which is the abbreviation of "Geometry and Tracking For". The name of software remains continues after itself due to the very wide usage area of it such as medical applications, particle accelerator design and investigation, particle-material interactions investigation, space science applications and investigations, nuclear reaction investigations and military purposes. In this study, the simulation ability of GEANT4 has been used to investigate the particle-material interaction of the PC under proton and alpha induced particles which aimed to be used as shielding material for fission nuclear reactors. To simulate the effects of induced particles and see the interactions involving penetrating distance of the particles and the stopping

power of PC for each particle, PhysListEmStandard and G4EmStandardPhysics libraries have been selected among many exists inside GEANT4 and the materials have been identified one by one inside the created environment that has the studied sample and geometry inside it.

Experimental

The shielding from unexpected radiation to avoid from its harm and danger has vital importance. To be protected from the harms of radiation, shielding is one of the most possible and common way. In this study, one of the possible shielding material which is polymer concrete has been investigated by using two different combination of its ingredients. In the first sample, named as “Material 1”, the mixture contains 0 % of natural standard CEN sand while the second sample, named as “Material 2” contains 75 % of the mentioned material. For the first studied materials, the mixture contains 100 % polymer while the second studied material has 25 % polymer in this situation. The first sample contains 98,4 % polyester, 1,2 % Methyl Ethyl Ketone Peroxide (MEKP) and 0,4 % liquid cobalt solution for some cases as set accelerator. On the other hand, second sample contains 75 % natural standard CEN sand, 24 % polyester, 0,8 % MEKP and 0,2 % liquid cobalt solution for given purpose within the previous material. Both materials with 100 cm x 100 cm dimensions generated inside GEANT4, have been exposed to alpha and proton induced radiation in the energy interval of 1-250 MeV by using GEANT4 to see the effects and results of mentioned particles on the studied sample materials.

Results and Discussion

Obtained results for different induced particles by using GEANT4 have been given in the following figures and in the tables as Table 1 for the alpha induced situation where Table 2 represents the for the proton induced situation.

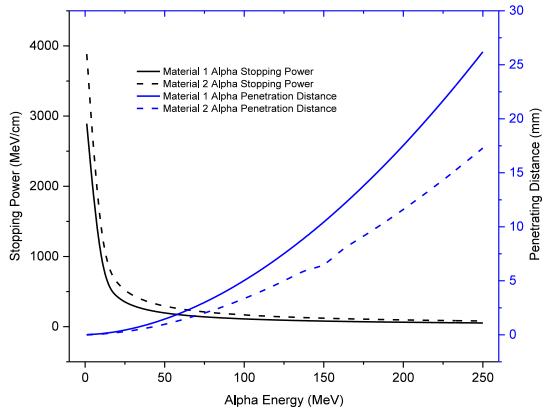

Fig. 1. Stopping power and penetrating distance results on both materials for alpha induced situation

The results for alpha induced situations on both sample materials are given in Fig. 1 as graphics and as numeric results on Table 1. As it can be seen from the graph easily, with the increase of incoming particles energy the penetrating distance of alphas

Table 1. Stopping power and penetrating distance results on Material 1 for alpha induced situation

Alpha Energy (MeV)	Material 1 Stopping Power (MeV/cm)	Material 1 Penetrating Distance (mm)	Material 2 Stopping Power (MeV/cm)	Material 2 Penetra-ting Distance (mm)
1	2893.43	0.003828	3883.58	0.002375
10	685.099	0.0856658	991.362	0.06048
20	403.561	0.284907	593.686	0.197014
30	292.752	0.581669	434.471	0.397833
40	232.405	0.969439	346.587	0.658538
50	194.122	1.44339	290.257	0.957806
60	167.475	2.00053	250.952	1.34793
70	147.789	2.63844	221.807	1.77332
80	132.605	3.35482	199.462	2.25008
90	120.512	4.14768	181.594	2.77663
100	110.637	5.01547	166.992	3.35196
110	102.411	5.95665	153.764	3.97507
120	95.4455	6.96985	144.39	4.64506
130	89.467	8.05382	135.47	5.36113
140	84.2759	9.20736	127.729	6.12249
150	79.7238	10.4293	120.917	6.2834
160	75.6973	11.718	114.885	7.77797
170	72.1093	13.0739	109.504	8.67072
180	68.8904	14.4947	104.673	9.60601
190	65.9857	15.98	100.31	10.5832
200	63.3504	17.5289	96.3488	11.6018
210	60.9483	19.1405	92.7425	12.6611
220	58.7492	20.8139	89.4327	13.7606
230	56.728	22.5485	86.3889	14.8988
240	54.8637	24.3435	83.5798	16.0782
250	53.1384	26.1981	80.9788	17.2955

on both samples increases too yet the rates of the increases are different and the gap between the differences gets greater on the higher energies. From there, it could be said that, by using natural standard CEN sand will make the material more suitable for shielding. On the other hand, stopping power rates decreases with the increase of energy contrast to the penetrating distance and the rate of Material 2 bends on early energies respect to Material 1 which does not contain natural standard CEN sand. The result shows us that the use of CEN sand as an additive makes the material more convenient to be used as shielding material. The consequences which could be seen from Fig. 1 are detailed for further purposes and more mathematical calculations as given in Table 1.

In this study, the same calculations have been completed for proton induced situation like completed for alpha particle before. Fig. 2 represents the obtained results in graphical form for the proton induced situation. The obtained results from GEANT4 simulation, which also used for plotting the graphs, have been given in Table 2 for each studied sample materials with the obtained stopping power and penetrating distance values for each of them. For proton particle induced situation, results have been shaped similar to the alpha induced particle

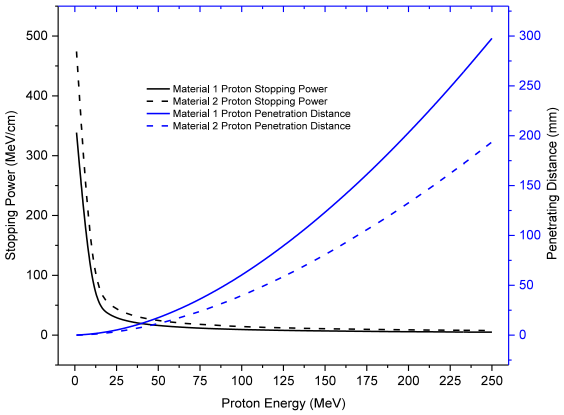

Fig. 2. Stopping power and penetrating distance results on both materials for proton induced situation

Table 2. Stopping power and penetrating distance results on Material 1 for proton induced situation

Proton Energy (MeV)	Material 1 Stopping Power (MeV/cm)	Material 1 Penetrating Distance (mm)	Material 2 Stopping Power (MeV/cm)	Material 2 Penetrating Distance (mm)
1	338.7	0.0189312	474.197	0.0138497
10	59.059	0.99485	87.6763	0.646885
20	33.5291	3.29612	50.3205	2.2205
30	24.0838	6.87205	36.3802	4.59385
40	19.0796	11.5757	28.9246	7.7014
50	15.9561	17.336	24.2457	11.4961
60	13.8115	24.0952	21.0246	15.9399
70	12.2437	31.8046	18.6631	21.008
80	11.0455	40.4202	17.4645	26.6496
90	10.0985	49.9034	15.4243	32.8608
100	9.3312	60.2102	14.243	39.6117
110	8.696	71.3299	13.3009	46.8799
120	8.1614	83.2095	12.4906	54.6456
130	7.70513	95.8294	11.7985	62.8209
140	7.31107	109.162	11.2004	71.5948
150	6.96727	123.182	10.6782	80.7414
160	6.66468	137.873	10.2185	90.3171
170	6.3963	153.218	9.8105	100.803
180	6.14709	169.202	9.44607	110.7
190	5.91762	185.807	9.11856	121.481
200	5.71084	203.019	8.82267	132.637
210	5.52357	220.823	8.55406	144.158
220	5.35318	239.206	8.30915	156.037
230	5.19752	258.152	8.08288	168.266
240	5.05477	277.65	7.8624	180.836
250	4.9234	297.684	7.65954	193.739

situation however, the numeric values on the penetrating distance axis almost multiplied by a factor of ten. The shape of the penetrating distance on both materials shows that the increase of the incoming particles energy results as the increase of penetrating distance. Even the penetrating distance value increases with the increase of energy, the Material 2 has more acceptance for the possible use of a promising shielding material, rather than Material 1. In the perspective of stopping power values, the declining decrease with the increasing energy, has the some shape with alpha particle induces situation yet the numerical values on the axis has one-tenth obtained for alpha particles.

Conclusion

In this study, we aimed to investigate the effects of alpha and proton radiations on the PC material. To understand the effects of mentioned radiations on two different PC samples, where one contains natural standard CEN sand while other sample does not, both samples have been exposed to alpha and proton radiations within the energy interval of 1-250 MeV via the GEANT4 simulation program. To create as much as realistic situations inside the GEANT4 simulation, the materials have been generated with the dimensions of 100 cm to 100 cm.

Due to the nature of the selected radiation particles, as expected the penetrating of alpha resulted lower than the penetrating of proton. All simulation results show that, the sample produced by adding the natural standard CEN sand, has more acceptable values in the manners of stopping power and penetrating distance to be used as a shielding material between 1-250 MeV energetic alpha and proton radiations.

References

1. *Young R.J.* // Introduction to Polymers, Chapman & Hall, London. 1981. 331 p.
2. *Hollaway L.* // Polymer and Polymer Composites for Civil and Structural, Engineering. Netherlands: Springer, 2012. 259 p.
3. *Kumar R.* // A Review on Epoxy and Polyester Based Polymer Concrete and Exploration of Polyfurfuryl Alcohol as Polymer Concrete. Journal of Polymers. 2016. 13.p.
4. *Agostinelli S., et al.* // Nuclear Instruments and Methods in Physics Research A. 2003. V. 506. P. 250-303.