ORIGINAL ARTICLE

Monte Carlo Simulation and N-XCOM Software Calculation of the Neutron Shielding Parameters for the NCRP Report 144 Recommended Conventional Concretes

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Abstract

Purpose: Radiation shielding requires deep knowledge about the shielding materials properties. Additionally, the interaction between the radiation and materials should be well understood.

Materials and Methods: Monte Carlo (MC) simulation, NXCOM, and WinXCOM computational programs were utilized for the concrete shielding properties against 1.5 MeV neutron beam and ^{137}Cs emitted γ-ray. In a simulated "good geometry" using MCNP5 MC code, NXCOM and WinXCOM, radiation attenuation factor (μ), microscopic neutron removal cross-section ($\sum R$), Half and Tenth Value Layers (HVL and TVL) of the studied concretes were derived. Obtained results by the methods were compared and discussed.

Results: For ^{137}Cs emitted γ-ray, mass attenuation factor (μ/ρ) obtained as 0.026 cm^2/g, 0.025 cm^2/g, and 0.025 cm^2/g for the Serpentine concrete as the minimum factors by MCNP5 code, WinXCOM and NXCOM software, respectively. Good agreement was seen in the results derived by the use of the applied calculation methods. Maximum values for the μ/ρ were calculated as 0.03 cm^2/g, 0.029 cm^2/g and 0.029 cm^2/g by MCNP5 code, WinXCOM and NXCOM, respectively. For the neutron attenuation factor, calculations were conducted for the concretes and the highest and lowest Σ_R/ρ were derived for Serpentine and Ordinary concretes. MCNP5 MC code was calculated Σ_R/ρ for the Serpentine and Ordinary concretes as 0.039 cm^2/g and 0.030 cm^2/g, respectively. Σ_R/ρ for the Serpentine and Ordinary concretes as 0.039 cm^2/g and 0.030 cm^2/g, respectively.

Conclusion: It was concluded that the calculated results showed N-XCOM program can be applied for the shielding calculations for the conventional concretes studied in this work.

Keywords: Neutron; Monte Carlo; Shielding; Tenth Value Layers; Half Value Layers.

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1. Introduction

Deep knowledge about shielding properties of the concretes as a shielding material in diagnostic and therapeutic radiation facilities such as γ-ray attenuation factor (μ) and neutron removal cross-section (ΣR), Half Value Layer (HVL), and Tenth Value Layer (TVL) is one of the main requirements. National Council on Radiation Protection and Measurements (NCRP no.144) [1] has recommended some concrete types for shielding against radiation. Ordinary concrete (2.35 g/cm^3), Magnetite concrete (3.53 g/cm^3), Barytes concrete (3.35 g/cm^3), Magnetite and steel concrete (4.64 g/cm^3), Limonite and steel concrete (4.54 g/cm^3), and Serpentine concrete (2.10 g/cm^3) have been recommended by NCRP 144 as shielding materials in the radiology facilities designing. Concrete is a common shielding material in radiation facilities. Although, recently smart concretes have been developed by adding some nanoparticles or microparticles in the radiation shielding and the conventional concretes with nano or micro scale particles showed excellent shielding properties, to know about the base material (conventional concretes) is important [2-9]. Shielding properties of ordinary concrete loaded with micro- and nano-particles against neutron and gamma radiations have been investigated by Mesbahi and Ghiasi [10]. They simulated ordinary concrete dopped with PbO_2, Fe_2O_3, WO_3 and H_4B micro-scale and nano-scale particles by Monte Carlo (MC) MCNP code and reported that the concrete with nanoparticles showed higher neutron and photon attenuation property relative to microparticles. They reported that the concrete with nanoparticles showed higher neutron and photon attenuation property relative to microparticles and they recommended the application of nanoparticles in the fabrication of new concretes. The base material in their study was ordinary concrete with a density of 2.35 g/cm^3 which was recommended by NCRP 144. Ghasemi Jangjoo and Ghiasi [11] studied shielding aspects of ordinary concrete dopped with some percentage of nanoparticles and designed a safe 18MV radiotherapy room with primary barriers made of the nanoparticle included ordinary concrete and reported that required concrete thickness in primary and secondary barriers was reduced by around 0.8% compared to pure concrete application. Additionally, required lead and Borated Polyethylene for door designing decreased by 25% and 15%, respectively, due to primary barriers nanoparticles compared to the same room with ordinary concrete primary barriers. Nowadays, different smart concretes have been developed by researchers and the shielding properties against neutron and photon beams have been presented in the literature [2-9, 12-16]. Pure concretes recommended by NCRP 144 are being widely used in radiation facilities as shielding materials due to the concretes easy accessibility and cost-effective compared to the recently developed smart concretes. The mentioned traditional pure concretes shielding properties have not been studied comprehensively and the concretes attenuation factors against neutron and γ-ray study is useful in the safe bunker designing for diagnostic or radiotherapy treatment room designing. Al-Kayatt [17] introduced a computational program, NXCOM, which could calculate concretes and concrete aggregate with different material shielding properties with acceptable accuracy and applied for different materials neutron and γ-ray shielding properties compared to MC simulation-derived data. For γ-ray attenuation of the materials, the program predictions were tested by comparing to the MCNP code of the MC simulation and well-known WinXCOM program results, and an excellent agreement was noticed [17]. Performance of newly developed concretes incorporating WO_3 and barite as radiation shielding material was the subject of Al-Ghadimi et al. [18] and they concluded that the increase in the amount of WO_3 caused a reduction in the HVL and an increase in the radiation protection efficiency for the prepared concretes.

Variation of photon or γ-ray intensity vs. shielding or absorber material is given by "Beer and Lambert" presented low as below (Equation 1):

$$I(x) = I_0\, e^{-\mu x} \tag{1}$$

Where I_0 is the initial photon or γ-ray intensity, $I(x)$ is the penetrated photons in distance x in the absorber material or absorber and μ refers to the total attenuation factor. The total mass attenuation factor can be derived using a total density of the absorber material (ρ) and the logarithm of both sides of Equation 2.

$$\frac{\mu}{\rho} = \frac{1}{\rho x} \ln\left(\frac{I_0}{I}\right) \tag{2}$$

The mass attenuation factor of a compound or mixture is determined by μ/ρ or the mass attenuation factor of the absorber or shielding material compound elements (Equation 3).

$$\mu/\rho = \sum W_i(\mu/\rho)_i \quad (3)$$

In the above Equation, ρ_i and $(\mu/\rho)_i$ are partial density and mass attenuation factor of the ith constituent, respectively (as appeared in the compound), and W_i is the weight fraction. For the estimation of the microscopic neutron removal cross-section, analytical formulation has been presented below (Equation 4) [9, 19].

$$\sum R = \frac{0.602\rho}{A}\delta_t \quad (4)$$

And, microscopic mass removal cross-section is obtained by $\Sigma R/\rho$.

In Equation 4, A is atomic mass, ρ is density and δ_t refers to the total cross-section (barn) for each atom in a unit of volume of the absorber or applied shielding material. Chilton *et al.* [20] reported an equation for the neutron mass removal cross-section as follows (Equation 5).

$$\Sigma R/\rho = 0.206A^{\frac{-1}{3}}Z^{-0.294}\ (cm^2g^{-1}) \quad (5)$$

In the current study, the authors aimed to calculate shielding properties of the NCRP 144 recommended concretes such as γ-ray and neutron attenuation factors (μ (cm^{-1}) and μ/ρ (cm^2/g)) using ^{137}Cs γ-ray, and microscopic neutron removal cross-section (Σ_R (cm^{-1}) and Σ_R/ρ (cm^2/g)), HVL (cm) and TVL (cm) using simulated narrow 1.5 MeV neutron beam in the "good geometry". MC simulation method, NXCOM, and WinXCOM computational software performance preciseness also was evaluated by comparing the results derived by the methods and with the others' works. It may be true to state that there is no publication on all traditional concrete shielding properties while the concretes are being used widely for their easy accessibility and cost-effectiveness.

2. Materials and Methods

MCNP5/1.60 MC simulation code, NXCOM software, and WinXCOM computational programs were employed for the calculations and simulations in the current study. Capabilities of the MC simulation MCNP5 code in the complex geometries simulations and complicated radiation physics 3D problem solving were used. The used MCNP5 MC simulation code F1 tally was used in the simulation for the photons and neutrons number scoring. Using the code, a "good geometry" was set up for scoring the photons and neutrons those not scattered by the simulated concrete slab and the scattered radiation in "good geometry" was not scored. Due to the presence of low-energy radiation in the problem, both elastic and non-elastic scattering options were enabled. Figure 1 shows the simulated "good geometry" for precise calculation of the 1cm concrete slab attenuation factors against ^{137}Cs γ-ray and narrow 1.5 MeV neutron fields.

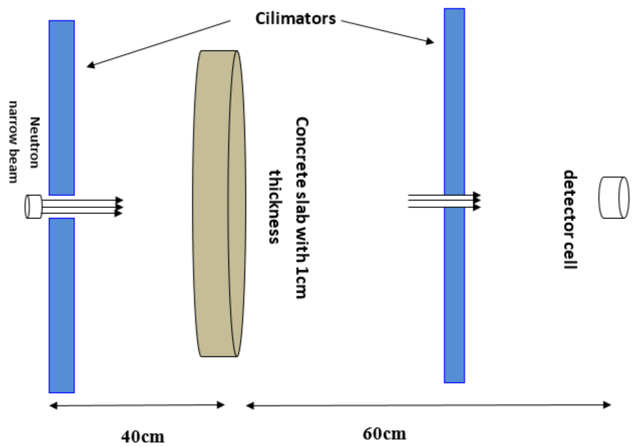

Figure 1. MCNP5 MC simulation code set up of a "good geometry" for the concrete attenuation estimation

Additionally, the MC code's rich cross-sections and physics libraries were also used for the calculations. NXCOM and WinXCOM computational software also were utilized for the calculations. The atomic composition of the recommended conventional concretes were presented in Table 1. Additionally, μ (cm^{-1}), μ/ρ (cm^2/g), and TVL (cm) for the ^{137}Cs quality were derived by MCNP5, WinXCOM and NXCOM, and the results are presented in Table 2. ΣR (cm^{-1}) and ΣR/ρ (cm^2/g) were estimated by NXCOM, MC simulation, and WinXCOM for the applied radiation sources of energy. ΣR (cm^{-1}) and ΣR/ρ (cm^2/g) for the

Table 1. Typical compositions of some conventional concretes recommended by NCRP 144 [23]

Concrete Type	Ordinary	Magnetite	Barytes	Magnetite and Steel	Limonite and Steel	Serpentine
Density (g cm^3)	2.35	3.53	3.35	4.64	4.54	2.1
Hydrogen	0.013	0.011	0.012	0.011	0.031	0.035
Oxygen	1.165	1.168	1.043	0.638	0.708	1.126
Silicon	0.737	0.091	0.035	0.073	0.067	0.460
Calcium	0.194	0.091	0.168	0.258	0.261	0.15
Carbon	-	-	-	-	-	0.002
Sodium	0.04	-	-	-	-	0.009
Magnesium	0.006	0.033	0.004	0.017	0.007	0.297
Aluminum	0.107	0.083	0.014	0.048	0.029	0.042
Sulfur	0.003	0.005	0.361	-	-	-
Potassium	0.045	-	0.159	-	0.004	0.009
Iron	0.029	1.676	-	3.512	3.421	0.068
Titanium	-	0.192	-	0.074	-	-
Chromium	-	0.006	-	-	-	0.002
Manganese	-	0.007	-	-	-	-
Vanadium	-	0.011	-	0.003	0.004	-
Barium	-	-	1.551	-	-	-

Table 2. Attenuation factor calculated in energy range up to ^{137}Cs γ-ray using the MC MCNP5 code calculation, WinXCOM and N-XCOM software methods for the Ordinary concrete

Gamma ray attenuation coefficient (cm^{2}g^{-1}) and concretes TVL (*1)						
Concrete type	**MCNP5**	**WinXCOM**	**N-XCOM**	**MCNP5 estimated TVL (cm)**	**WinXCOM calculated TVL (cm)**	**N-XCOM calculated TVL (cm)**
Ordinary	0.027	0.026	0.026	85.28093	88.5607	88.56097
Magnetite	0.029	0.027	0.027	79.39949	85.2803	85.28093
Barytes	0.027	0.027	0.028	85.28093	85.293	85.28093
Magnetite and steel	0.030	0.028	0.028	76.75284	82.235	82.23518
Limonite and steel	0.031	0.029	0.029	74.27694	79.399	79.39949
Serpentine	0.026	0.025	0.025	88.56097	92.1034	92.1034

1.5 MeV neutron source were calculated and TVL, and HVL were estimated and the obtained results by the used methods tabulated in Table 3 for the studied concretes. For more study, shielding parameters for the atoms in the studied concretes were derived by MCNP5 and NXCOM, and Tables 4 and 5 show the results of the calculations. Equations 1 and 2 show the method of the γ-ray linear and mass attenuation factors. Equations 4 and 5 also describe the neutron linear and mass removal cross-sections. In the current study, NCRP 144 recommended that pure concretes (without any dopping material) be calculated by the MC simulation and XCOM calculation. MCNP5 MC simulation code calculation was conducted under “good geometry” that allowed only not-scattered radiation to scoring by application of F1 tally that scores the number of photons or neutrons in the simulated scoring small volume filled by tissue-equivalent water.

The calculations were carried out for the studied concretes by changing the simulated 1cm in thickness absorber medium between the radiation source and scoring cell. Then, all of the studied concrete shielding factors were derived and the results are presented.

Finally, the obtained results by the use of MCNP5 MC code, WinXCOM, and NXCOM were compared. It should be mentioned that statistical error in MC the simulation-derived results was less than 0.01 in all calculations.

3. Results and Discussion

Our results showed the shielding characteristics of the NCRP 144 recommended concrete calculated by using the MC simulation, WinXCOM and NXCOM software. For ^{137}Cs emitted γ-ray, μ/ρ obtained as code, WinXCOM and NXCOM, respectively. The ratios of maximum/minimum for the calculated μ/ρ for

Table 3. MCNP5 MC code estimated and N-COM software calculated shielding parameters for NCRP report 144 recommended conventional concretes against medical linacs produced secondary photoneutron average energy reported by the NCRP publication report no. 144

Concrete type	Density (g/cm^3)	MCNP5 estimated Σ_R/ρ (cm^2/g)	N-XCOM calculated Σ_R/ρ (cm^2/g)	MCNP5/N-XCOM calculation	MCNP5 estimated Σ_R (cm^{-1})	N-XCOM estimated Σ_R (cm^{-1})	MCNP5 estimated TVL (cm)	N-XCOM estimated TVL (cm)
Ordinary	2.35	0.030	0.030	0.992	0.0701	0.0705	32.84715	32.66078
Magnetite	3.53	0.032	0.033	0.970	0.110	0.116	20.93259	19.84987
Barytes	3. 35	0.038	0.036	1.055	0.1273	0.1206	18.08786	19.09275
Magnetite and steel	4.64	0.033	0.034	0.958	0.150	0.157	15.35057	14.66615
Limonite and steel	4.54	0.033	0.033	0.974	0.145	0.149	15.8799	15.45359
Serpentine	2.10	0.039	0.037	1.054	0.089	0.077	28.1143	29.6343

Table 4. Neutron effective mass removal cross-section estimated by MC simulation for the concrete some elements for the neutron energy of 1.5 MeV (ΣR/ρ(cm^2/g))

Energy	H	O	K	Ca	Na	Si	Al	Ti
100 keV	0.03536	0.02486	0.03575	0.02851	0.02714	0.03457	0.03616	0.025601
200 keV	0.035219	0.024777	0.035591	0.028402	0.027041	0.03442	0.035999	0.025499
300 keV	0.035079	0.024695	0.035434	0.028294	0.026943	0.03427	0.035838	0.025398
400 keV	0.034939	0.024613	0.035278	0.028188	0.026846	0.034122	0.035679	0.025299
500 keV	0.0348	0.024532	0.035123	0.028082	0.026749	0.033975	0.035521	0.025200
600 keV	0.034661	0.024452	0.034968	0.027977	0.026654	0.033829	0.035364	0.024402
700 keV	0.034523	0.024372	0.034815	0.027872	0.026558	0.033684	0.035209	0.024105
800 keV	0.034386	0.024292	0.034663	0.027768	0.026464	0.03354	0.035054	0.023908
900 keV	0.034249	0.024213	0.034512	0.027665	0.02637	0.033396	0.0349	0.022812
1000 keV	0.034112	0.024135	0.034362	0.027563	0.026276	0.033254	0.034747	0.021716
1100 keV	0.033976	0.024057	0.034214	0.027461	0.026184	0.033113	0.034596	0.021622
1200 keV	0.033841	0.02398	0.034066	0.027361	0.026092	0.032973	0.034445	0.021528
1300 keV	0.033706	0.023903	0.033919	0.02726	0.026	0.032834	0.034296	0.021435
1400 keV	0.033572	0.023827	0.033773	0.027161	0.02591	0.032695	0.034148	0.021342
1500 keV	0.033438	0.023752	0.033628	0.027062	0.025819	0.032558	0.034	0.021250
1600 keV	0.033305	0.023677	0.033485	0.026964	0.02573	0.032422	0.033854	0.021158
1700 keV	0.033172	0.023602	0.033342	0.026866	0.025641	0.032286	0.033709	0.021068
1800 keV	0.03304	0.023528	0.0332	0.02677	0.025553	0.032152	0.033564	0.020977
1900 keV	0.032908	0.023454	0.033059	0.026674	0.025465	0.032019	0.033421	0.020888
2000 keV	0.032777	0.023381	0.03292	0.026578	0.025378	0.031886	0.033279	0.020799

0.026 cm^2/g, 0.025 cm^2/g, and 0.025cm^2/g for the Serpentine concrete as the minimum factors by MCNP5 code, WinXCOM and NXCOM software, respectively. Good agreement was seen in the results derived by the use of the applied calculation methods. Maximum values for the μ/ρ were calculated as 0.031cm^2/g, 0.029 cm^2/g, and 0.029cm^2/g by MCNP5 ^{137}Cs γ-ray were obtained as 1.19, 1.16, and 1.16, respectively for the Limonite and steel concrete. Differences may be attributed to the concretes composition so that the most contributed elements in the Serpentine concrete and Limonite and steel concrete are Oxygene (O) and Iron (Fe) with 1.126 and 3.421 partial density according to Table 1. In photon-

Table 5. Neutron effective mass removal cross-section calculated by NXCOM for the concrete some elements for the neutron energy of 1.5 MeV (ΣR/ρ (cm^2/ g))

Energy	H	O	K	Ca	Na	Si	Al	Ti
100 keV	0.0354	0.02486	0.03575	0.02851	0.02714	0.0345	0.0361	0.0256
200 keV	0.0353	0.0247	0.0356	0.0284	0.0270	0.0344	0.0359	0.0254
300 keV	0.0351	0.0246	0.0354	0.0282	0.0269	0.0342	0.0358	0.0253
400 keV	0.0349	0.0246	0.0352	0.0281	0.0268	0.0341	0.0356	0.0252
500 keV	0.0348	0.0245	0.0351	0.0280	0.0267	0.0339	0.0355	0.0252
600 keV	0.0346	0.0244	0.0349	0.0279	0.0266	0.0338	0.0353	0.0244
700 keV	0.0345	0.0243	0.0348	0.0278	0.0265	0.0336	0.0352	0.0241
800 keV	0.0344	0.0242	0.0346	0.0277	0.0264	0.0335	0.0350	0.0239
900 keV	0.0342	0.0242	0.0345	0.0276	0.0263	0.0333	0.0349	0.0228
1000 keV	0.0341	0.0241	0.0343	0.0275	0.0262	0.0332	0.0347	0.0217
1100 keV	0.0340	0.0240	0.0342	0.0274	0.0261	0.0331	0.0345	0.0216
1200 keV	0.0338	0.0239	0.0340	0.0273	0.0260	0.0329	0.0344	0.0215
1300 keV	0.0337	0.0239	0.0339	0.0272	0.0260	0.0328	0.0342	0.0214
1400 keV	0.0335	0.0238	0.0337	0.0271	0.0259	0.0326	0.0341	0.0213
1500 keV	0.0334	0.0237	0.0336	0.0270	0.0258	0.0325	0.034	0.0212
1600 keV	0.0333	0.0236	0.0334	0.0269	0.0257	0.0324	0.0338	0.0211
1700 keV	0.0331	0.0236	0.0333	0.0268	0.0256	0.0322	0.0337	0.0210
1800 keV	0.0330	0.0235	0.0332	0.0267	0.0255	0.0321	0.0335	0.0209
1900 keV	0.0329	0.0234	0.0331	0.0266	0.0254	0.0320	0.0334	0.0208
2000 keV	0.0328	0.0233	0.0329	0.0266	0.0253	0.0318	0.0332	0.0207

material interaction, Fe as a relatively heavy material removes more and higher energy photons comparing to O. Additionally, the contribution of the elements in the partial density of the concretes, Fe with 3.421 and O with 1.126 can be a cause of more attenuation factor of the Limonite and steel concrete. In the case of the concretes TVL, higher TVL for the 137Cs γ-ray was calculated for Serpentine concrete, and the lowest TVL was also estimated for the Limonite and steel concrete. For the Serpentine concrete, obtained TVL for the ^{137}Cs γ-ray obtained as 88.56097 cm, 92.1034 cm, and 92.1034 cm by the use of MCNP5 MC code, WinXCOM and NXCOM software, respectively. It can be expected higher TVL for low radiation attenuation so that the minimum attenuation of γ-ray and maximum TVL were calculated for the Serpentine concrete. Minimum TVL also was derived for the Limonite and steel concrete as 74.27694 cm, 79.399 cm, and 79.39949 cm obtained by MCNP5 MC code, WinXCOM and NXCOM software, respectively. For the neutron attenuation factor, calculations were conducted for the concretes and according to Table 3, the highest and lowest ΣR/ρ (cm^2/g) were derived for Serpentine and Ordinary concretes. MCNP5 MC code was calculated ΣR/ρ (cm^2/g) for the Serpentine and Ordinary concretes as 0.039 cm^2/g and 0.030cm^2/g, respectively. According to Table 3, the difference between the highest and lowest TVL was calculated as 53.26% and 52.28% by MCNP5 MC code and NXCOM for the 1.5 MeV mono-energy neutron point source. The difference between the highest and lowest TVLs also was derived as 13.33%, 13.79%, and 13.79% by the MC simulation method, WinXCOM, and NXCOM software, respectively for the 137 Cs isotope γ-ray that can be found in Table 3. Investigation of the conventional concrete attenuation factors such as TVL and other properties is important because of the wide use of them in radiology and radiotherapy facilities due to their easy accessibility and cost-effectiveness. In this study, the concretes shielding properties were studied by three different methods that can enhance the study results' presciseness. MCNP5 MC simulation code and NXCOM software calculated the highest microscopic neutron mass removal cross-section as 0.039 cm^2/g and 0.037cm^2/g, respectively, for the Serpentine concrete with 2.10 g/cm^3 density and TVLs calculated as 28.1143 cm and 29.6343 cm by MCNP5 MC code and NXCOM program, respectively. In the neutron attenuation calculation a good agreement was observed according to the results. Maximum TVL was calculated for the ordinary concrete while the minimum value wasestimated for the barytes concrete. According to Table 1, Barium is the maximum element contributed to the Barytes concrete composition. Our results revealed that high γ-ray attenuation is associated with low neutron attenuation. The attenuation factors may strongly depend on the concretes composition and elements in the concretes composition. Table 3 shows the MC simulation calculated ΣR/ρ (cm^2/g) in different neutron energies. The results tabulated in Table 3 show that with increasing in neutron beam energy, ΣR/ρis decreases. The calculated shielding parameters in our study have been enhanced recently by adding some percentage of nano- or micro-scale heavy metals. Mesbahi and Ghiasi [10] by adding microparticles and nanoparticles of some materials, reported that 8% and 7% enhancement in the ordinary concrete attenuation factor against the mono-energitic neutron (100-3000 KeV) and photon (142-1250 KeV) beams obtained. Our results in ΣR/ρ calculation against different energies of a neutron source in good geometry are in good agreement with Mesbahi and Ghiasi [10]. The trend of the concrete attenuation against neutron in both studies, i.e., our study and Mesbahi and Ghiasi [10] publication, is in good agreement. In Tables 4 and 5, in addition to the agreement on the methods of calculation, the atoms attenuation factor in both Tables decreases by increasing the neutron energy. In the current study, additionally, their study revealed that the presence of nanoparticles performs better than microparticles in the shielding parameters enhancement. The effect of dopped material size on the concrete and on the shielding factors enhancement was revealed in Mesbahi and Ghiasi publication [10] and other works [21, 22]. Ghasemi-Jangjoo and Ghiasi [11] reported an 8% decrease in the primary barriers required thickness by adding nanoparticles in ordinary concrete. Recently developed smart concretes show higher attenuation factor against photon and neutron, but, due to easy accessibility and cost-effectiveness, traditional concretes are being widely used for radiologic facilities shielding. On the other hand, our results showed that the MC simulation method and WinXCOM, and NXCOM software performance in the shielding properties deriving of different materials is in acceptable agreement. This observation was reported also by Al-Khayatt in the publication that calculated attenuation factors for different concretes by NXCOM and MCNP and compared the results to the experimental [17]. In Al-Khayatt's study, it was stated that the NXCOM program has been constructed, verified and used to calculate ΣR (cm^{-1}) and ΣR/ρ (cm^2/g) for the fast neutrons and γ-ray attenuation factors for different energies (μ (cm^{-1})) and (μ/ρ(cm^2/g)) through homogeneous mixtures. Additionally, in the publication, NXCOM is defined as a mix of the MERCSF-N and XCOM programs. It was concluded that the comparison between the results of the removal cross-sections method and based on the MCNP MC simulation method showed that the NXCOM program is extremely simple and gives reasonable results compared to the experimental and MC simulation method in neutron and γ-ray attenuation factors calculation. Good agreements were observed between MCNP and WinXCOM methods. The calculation results were reported and it was deduced that using the NXCOM program leads to facilitate testing different materials for shielding against neutrons and γ-rays [17]. Our calculated results were in good agreement with Al-Khayatt publication results and conclusion. Our study also approved a reasonable agreement between MCNP5 MC simulation code, NXCOM and WinXCOM computational software in the materials shielding properties estimation. Finally, we found that the NXCOM and WinXCOM can be used for the shielding characteristics of different materials with acceptable preciseness and fast estimation of the attenuation factors.

4. Conclusion

The MCNP5 MC simulation method, WinXCOM, and NXCOM computational programs were used to different concretes shielding properties against mono-energy 1.5 MeV neutron beam and 137Cs emitted γ-ray. We found good agreement in the attenuation factors of the studied concretes. Reasonable agreements were observed between the methods of calculated results. Additionally, NCRP 144 recommended that the concretes shielding properties be characterized using the MC simulation and computational WinXCOM and NXCOM programs. Attenuation factors of the concretes were comprehensibly characterized and good agreement was observed between the methods of calculated results. Finally, it was concluded that using the computational WinXCOM and NXCOM programs estimate attenuation factors of different materials with a reasonable agreement with MC simulation and fast calculation may be considered an advantage of the programs. The authors recommend the application of the programs as useful and acceptable preciseness tools. The calculated results showed N-XCOM program can be applied for the shielding calculations for the conventional concretes studied in this work.

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