3.4. Toxicity assessment

The toxicity of materials implication in buildings roofs was assessed by radioactivity and metal leaching experiments with rain water. For the proposed application, the risk from the use of fly ash is associated with three main reasons: a) outdoor exposure from the radioactive isotopes in the ash, b) internal exposure from the radioactive isotopes and toxic elements after inhalation of particulates and c) leaching of radioactive isotopes and toxic elements and contamination of water bodies. Regarding the direct exposure, the risk was estimated by the calculation of the radium equivalent activity (REA), the annual equivalent dose (AED) and the index of radiation protection (IRP) [8, 11]. Prior to the calculation, the concentration of minor elements, toxics and radioisotopes was determined by the methods described in Ref [8]. According to the results shown in Table 3, the AED and IRP can be higher than the existing limits and therefore the fly ash sample should be mixed with an inert material in order to minimize the risk. The second way of inhalation can be eliminated by material aggregation with a binder, reducing in this way any possible wind resuspension. Regarding the third reason, leaching experiments in a w orst case scenario of heavy rainfall, indicated the availability of some of the metals even at the high pH of the Class C fly ash [12]. Therefore and in order to minimize the environmental impact of the use of ashes for solar cooling purposes, mixing of the fly ash with either an inert material like soil or a green roof material or multifunctional nanocomposites with high water vapor adsorption [13] is proposed.

Table 3. Concentration of minor elements and radioisotopes in the ash samples and radiotoxicity indices.

Element (mg/kg)	**ADFA**	**ADBA**	**Element (mg/kg)**	**ADFA**	**ADBA**
V	41.4	BDL	Rb	26.8	68.0
Cr	169. 9	138.5	Sr	292. 6	255.1
Mn	299.2	396.2	Y	7.9	16.7
Ni	299.0	1824.2	Zr	129.2	171.8
Cu	13.9	42.1	Nb	11.2	20.4
Zn	38.9	31.5	Mo	3.2	2.4
Isotopes (Bq/kg)			**Isotopes (Bq/kg)**		
^{226}Ra	645±20	390±12	^{235}U	30±3	16±2
^{232}Th	43±2	38±2	^{40}K	222±12	224±13
REA (Limit 370 Bg/kg)	722	460	AED (Limit 1 mSv/y)	0.41	0.26
IRP (Limit <1 or 6 and 1 mSv/y)	2.44	1.56			

4. Conclusions

The extended use of air-conditioning and electricity to compensate the increased temperatures during the summer time has raised the need for the development and application of passive and efficient ways to cool down urban surfaces. In this work, fly and bottom ashes were tested as alternative applicators of the evaporative cooling principle. Cycle experiments with controllable laboratory conditions and under simulated solar irradiation, showed maximum differences between fly ash and concrete of 3.8, 4.1 and 6.4 °C for the surface, middle and bottom temperature increase, respectively. The substantial temperature reductions with the use of the fly ash material indicate their significant potential for cooling applications. Since, the environmental assessment revealed non negligible impact due to the high concentration of radioisotopes, further research on the treatment of fly ash for the removal of toxic elements and the increase of water vapor adsorption are in progress.

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References

[1] Q. Meng and W. Hu, Roof cooling effect with humid porous medium, Energy and Buildings 37, 2005, pp. 1-9.

[2] S. Wanphen and K. Nagano, Experimental study of the performance of porous materials to moderate the roof surface temperature by its evaporative cooling effect, Building and Environment 44, 2009, pp. 338–351.

[3] J. Alvarado, W. Terrell, M. Johnson, Passive cooling systems for cement-based roofs, Building and Environment 44 , 2009, pp. 1869-1875.

[4] Ecoba, Production and utilisation of CCPs in 2008 in Europe (EU 15), http://www.ecoba.com/ecobaccpprod.html, Accessed 8/10/2010.

[5] D. Karamanis, X. Aslanoglou, P.A. Assimakopoulos, N.H. Gangas, PIGE and XRF analysis of a nano-composite pillared layered clay material for nuclear waste applications, Nuclear Instruments Methods B 181, 2001, pp. 616–621.

[6] D. Karamanis and P.A. Assimakopoulos, Efficiency of aluminum pillared montmorillonite on the removal of cesium and copper from aqueous solutions, Water Research 41, 2007, pp. 1897-1906.

[7] E. Vardoulakis, D. Karamanis, G. Mihalakakou, M.N. Assimakopoulos, Moisture sorption properties of modified porous clays for roof evaporative cooling applications, Proceedings of 3rd International Conference PALENC, 2010, pp. 1-11.

[8] D. Karamanis, K. Ioannides, K. Stamoulis, Environmental assessment of natural radionuclides and heavy metals in waters discharged from a lignite-fired power plant, Fuel 88, 2009, pp. 2046-2052.

[9] O.K. Karakasi, A. Moutsatsou, Surface modification of high calcium fly ash for its application in oil spill clean up, Fuel 89, 2010, pp. 3966-3970.

[10] P. Hartmann, H. Fleige, R. Horn, Physical properties of forest soils along a fly-ash deposition gradient in Northeast Germany, Geoderma 150, 2009, 188-195.

[11] G. Skordas, P. Grammelis, E. Kakaras, D. Karangelos, M. Anagnostakis, E. Hinis, Quality characteristics of Greek fly ashes and potential uses, Fuel Processing Technology 88, 2007, 77-85.

[12] D. Karamanis, E. Vardoulakis, G. Antonopoulou, Ash as a Material of Passive Cooling of Buildings and Open-Air Areas, Final report of Project Funded by John S. Latsis Public Benefit Foundation, 2010 (In Greek).

[13] D. Karamanis, N. Okte, E. Vardoulakis, T. Vaimakis, Water vapor adsorption and photocatalytic pollutant degradation with TiO_2-sepiolite nanocomposites, Applied Clay Science (in press).