Radioactive Waste Materials in Construction: Fusing Safety, Sustainability, and Ingenuity

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1. Introduction

Integration of safety, sustainability, and innovation has become a critical imperative in today's world; this ideology is closely linked to the responsible utilisation of radioactive waste, decommissioning, and environmental protection. Responsible management of radioactive waste includes waste not only from the decommissioning of nuclear power plants but also various by-products generated from contaminated coal and biomass combustion.

This poster highlights the potential benefits of sustainable utilization of various radioactive waste by using it as a construction material, emphasises how this approach aligns with sustainability goals and the circular economy concept, as well as addresses concerns related to such practice.

2. Radioactive Waste Utilization and Sustainability

2.1. Background

Safety, sustainability, and innovation are crucial in many sectors, including that of radioactive waste management; these principles contribute to the safety and protection of people and the environment, advancement in sustainable practices and fostering breakthrough solutions. The integration of the three can transform the multidisciplinary cost-demanding and high-in-waste decommissioning into a cheaper, safer and quicker process. This would ensure more efficient waste utilization and cross-disciplinary collaboration while working towards a new era of responsible resource management beyond the nuclear energy industry.

Naturally, radioactive waste is mainly associated with the nuclear energy sector, however, it is crucial to recognise that waste is not bound to a singular source, instead, it represents the interconnectedness of many energy systems and the necessity for cross-sectional collaboration to create innovative solutions beyond traditional waste disposal. In the case study shown further, radioactive waste can also encompass waste from other energy sectors including coal and biofuel combustion and resulting by-products such as fly ash which can be contaminated with various radionuclides.

2.2. Benefits of The Approach

The most obvious benefit of this approach is the diverted waste stream from landfills and storage facilities. Naturally, not all materials can be recycled due to their individual properties and most importantly – activity levels. However, concrete and steel, which are classified as low-level waste, could be recycled and reused in the construction of high-level waste storage facilities or other civil engineering structures, with activity concentrations of radionuclides being kept under national limits.

Moreover, the circular economy approach would reduce the demand for virgin materials and in turn – environmental emissions. This is especially potent in the case of concrete since its demand keeps increasing and is expected to reach 20 bn m^3 in 2050 due to urbanisation and industrialisation. Considering that for every 1 kg of cement produced, 0,9 kg of CO_2 emissions are evolved, substituting virgin materials with recycled waste can help to minimise environmental impacts associated with resource extraction and production.

This sustainable approach also falls in line with Sustainable Development Goals (Fig. 1) addressing the three pillars of sustainability: environmental protection, social equity and economic viability.

United Nations Sustainable Development Goals associated with integration of safety, sustainability, and innovation in radioactive waste utilisation

The integration of safety, sustainability, and innovation can transform the multidisciplinary cost-demanding and high-in-waste decommissioning into a cheaper, safer and quicker process. The waste can be transformed into a valuable resource useful for nuclear facilities and various civil engineering disciplines. This would ensure more efficient waste utilization and cross-disciplinary collaboration while working towards a new era of responsible resource management beyond the nuclear energy industry.

3. Case Study: Radioactive Biomass Fly Ash Used as Partial Cement Replacement

3.1. Background

Biofuels have been gaining increasing importance worldwide as their use is a crucial part of the stride towards sustainability. However, the combustion process produces ~476 million tons of fly ash annually, which is often contaminated with ^{232}Th and ^{40}K, and anthropogenic radionuclide ^{137}C; the latter can pose a challenge in utilisation if activity concentration levels in fly ash are above certain national limits. Fortunately, due to its abundance, low cost and density, in recent years, fly ash has been used to partially replace Portland cement, however, this practice mostly involves fly ash generated from coal combustion. However, little research has been done on using radioactive biomass fly ash (BFA) as a partial cement replacement involves incorporating BFA leftover from the combustion of biofuels in power plants into cement or concrete mixtures.

The implementation of BFA can improve the strength and durability of the structures because fly ash is considered to have self-cementing properties, minimising the amount of contaminated by-products being disposed of in landfills while also reducing CO_2 emissions caused by the Portland cement industry.

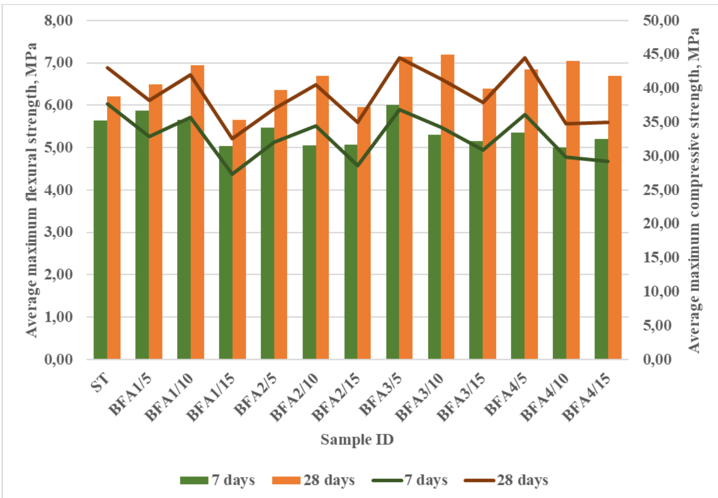
3.2. Mechanical Strength Analysis of Cement Mortars

Cement mortar is a workable paste composed of cement, sand, water, and in the case of this research - biomass fly ash. It is often used as a binding material of building blocks; however, it is important to note that mortar is not as durable as concrete, and thus should not be used as a main building material. It is however the initial step in analysing the effect BFA admixture has on cement; and if the mechanical strength of cement is not diminished, only then concrete structures are formed. The flexural and compressive strength tests were performed in accordance with LST EN 1015-11:2020 standard after the mortar blocks were cured for 7 and 28 days.

The cement mortar blocks were produced with 5%, 10% and 15% of cement replaced with BFA, standard blocks contained no BFA admixture:

BFA quantity, %	Cement, kg	Sand, kg	Water, kg	BFA, kg
0	658.2	1974.61	332.03	-
5	625	1974.61	332.03	24.74
10	592.45	1974.61	332.03	49.48
15	559.24	1974.61	332.03	74.22

All samples showed improved flexural and compressive strengths after longer curing time, proving that such a mean of utilisation results in improved strength and durability of structures. However, the most optimal amount of BFA to be used as cement replacement was determined to be ~ 10%; it is important to note that this experiment focused on cement mortars only and more research should be done on how BFA affects concrete structures.



Average maximum mechanical strengths of cement mortar after curing for 7 and 28 days. Bar charts representing compressive strength, line chart – flexural.

Despite this, the expanded concept of utilisation of by-products contaminated with radionuclides can be widely applied in various civil engineering projects such as immobilization of high-level radioactive waste, road and rail construction, and reinforced concrete manufacturing. Potential risks to human health and the environment should be mitigated by limiting the maximum quantity of radioactive waste used in specific areas of application depending on their activity levels.

4. Conclusions and Acknowledgements

The integration of safety, sustainability and innovation principles provides an opportunity to stride towards a future, where repurposing and reuse of radioactive waste is a conventional norm. This approach represents a shift from a linear waste disposal model to one where the life cycle of a product is expanded through reusing and recycling, which is in line with the circular economy concept. The example demonstrated is a small fraction of potential applications of radioactive waste and contaminated by-products from other industries, however, it demonstrates the interplay between the three pillars of sustainability and the stride towards innovation and collective commitment to progress and the planet.