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Detection of Cs-137 in Electronic Waste and Its Concealment in Concretes: Challenges for Safe Controlled Market Transition

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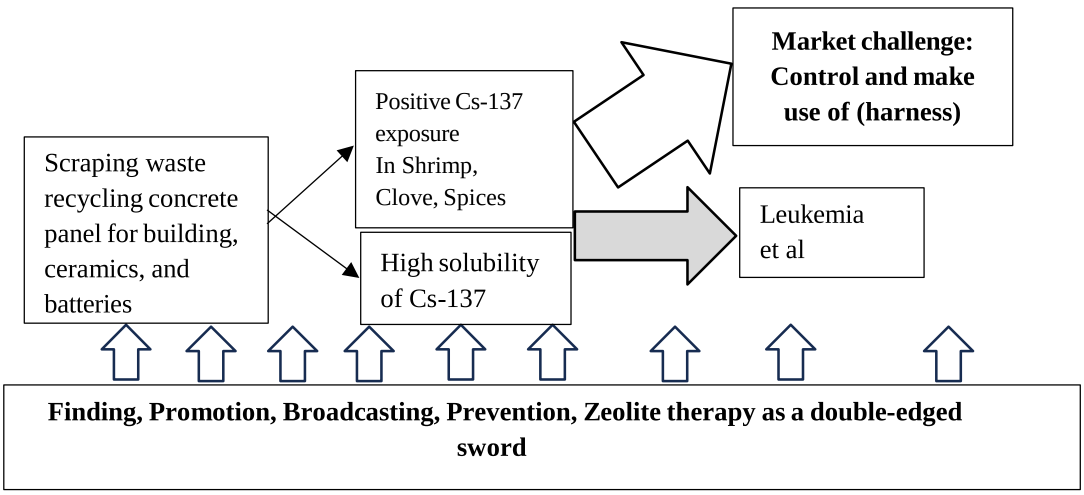
Graphical Abstract



***Abstract*—** *Environmental cases related to recycling slag-concrete, ceramic, and electronic waste have been reported periodically. The practice of improperly discarding electronic waste in developing countries should be eliminated. Not only concrete but also solid-state battery (SSB) waste is becoming a future source for recycling processes. The problem is that Cs-137, a radioactive alkali metal with high solubility, can be present in fly ash used for alkali-activated materials (AAM). Mixing AAM with water and cellulose forms new solid materials for applications ranging from small electronic components to large building materials.*

This review utilized Science Direct and PubMed-based search engines with keywords: Cs-137 and Cs-137 doping. Identification and screening were performed on electronic waste and concrete using Bayesian network and Bayesian analytic approaches to find supporting references on radioactive Cs-137 exposure in groundwater, aquifers, and seawater. The focus was on electronic waste and slag-concrete; nuclear hazard disaster scenarios were excluded.

The results yielded 16 supporting references on Cs-137 in electronic waste, 13 references on Cs-137 hidden in slag-concrete, and 7 references on recycling Cs-137 from fly ash as alkali-activated materials (AAMs), plus one figure showing a mat display made from waste cable at an exhibition. Radioactive Cs-137 in groundwater, hidden Cs-137 in concrete, Cs-137 in electronic devices, gamma-ray generators, waste furnace byproducts from steel production for SSB factories, perovskite solar cells (PSCs), and AAMs are discussed. The conclusion emphasizes that radioactive Cs-137 exposure in groundwater should be widely known, and monitoring should be conducted by people everywhere.

Keywords*—*Alkali-Activated Materials (AAMs), Cs-137, Fly ash, Groundwater, Leukemia, Market challenge.

I. INTRODUCTION

The problem of waste furnace byproducts from steel production becoming new mechanical materials, associated with Cs-137, has been reported [1]. Ceramic concrete, formerly used as cement, is now being recorded [2], and alkali-activated fly ashes (AAFA) cement is being developed for the future [3]. The aim is to necessitate effective strategies for safe global management with proper recycling standard operating procedures (SOPs).

Cesium-137 has been used in perovskites [4], perovskite solar cells (PSCs) [5,6,7], immobilization of Cs-137 in concealed hazardous radioactive pollutants [8], and prioritizing low-cost alternatives and local waste materials [9]. Positioning these materials as essential for sustainable construction and climate change mitigation should also be recognized [9]. AAM is made from fly ash, water, and cellulose with a highly alkaline solution. Alkali-activated fly ash-slag concrete has fresh mechanical durability properties and provides innovative infrastructure solutions at low economic cost without commercial activators [10]. The market challenges must be paralleled with recycling processes for scrap slag-concrete, which should follow strictly high-level SOPs to prevent Cs-137 exposure in groundwater. The market challenge requires control and harnessing of resources, working closely with relevant stakeholders to achieve sustainability goals.

II. METHODS

This review was conducted using Science Direct and other search engines based on PubMed, with keywords: Cs-137 and Cs-137 doping. Identification and screening were performed on electronic waste and concrete using Bayesian network and Bayesian analytic approaches to find supporting references on radioactive Cs-137 exposure in groundwater and seawater. The focus was on electronic waste and slag-concrete; nuclear hazard disaster scenarios were excluded.

III. RESULTS

Three tables and one figure (Fig. 1) are presented:

1) Table 1: Sixteen references on electronic waste-Cs-137 pollution
2) Table 2: Thirteen references on recycled waste (old and new slag-concrete) before 30 years of successful concealment
3) Table 3: Seven references on Cs-137 recycling from fly ash as alkali-activated materials (AAMs)

TABLE 1
SIXTEEN REFERENCES SUPPORTING ELECTRONIC WASTE-CS-137 POLLUTANT

Author, Year	Topic/Aims Variables of Interest	Adjustment for Other Variables	Comparative Risk	Clarification
Pinajian 1967 [11]	Cs-137	Ba-137	Long and short time gamma-ray	Generator gamma-ray
Hirohata A 2020 [12]	Cs-137	Spintronic	Magnetism and Magnetic Materials	Principles and device application
Felser 2007 [13]	Cs-137	Spintronic	Solid State Chemistry	Challenge for Materials Science
Shicholin OO 2024 [14]	Cs-137	Zeolite	Prussian Blue	Mitigate Cs-137
Zheng Z 2023 [15]	Zeolite-Rich	Cs-137/RA nuclides	From Fly Ash	Effective immobilize RA
Pandey PC 2023 [16]	Cs-137	Prussian blue Nanoparticles (PBNPs)	Sensing and removal Cs-137	PBNPs display superparamagnetic
Liu H 2023 [17]	Cs-137	Removal	Radioactive (RA)	Wastewater
Skvara F 2007 [18]	AAM	Or Geopolymer?	Silikaty	Ceramics
Skvara F 2000 [19]	AAFA	Blast-furnace slag or fly ash	Proceeding 14th IBAUSIL	Geopolymery.eu
Proust V 2024 [20]	Cs-137 waste	Cs entrapment	Adsorption efficiency	To microstructure
Milyutin V 2023 [21]	Cs-137	Removal	By Sorbents of Various Classes	From Liquid Alkaline High-Level RA waste
Pang M 2025 [22]	Cs-137	Zn-doped Mn Hexacyanoferrate electrode	Excellent Cs-electrosorption capacity and stability	RA wastewater and salt lakes
He P 2019 [23]	Cs-137	By geopolymer precursor technique	Safe trapping	RA nuclear waste such as Cs-137
Wu Y 2024 [10]	AAM/AAFA	Escalating environmental	Entirely from waste materials, low-carbon	Source of alkaline waste
Qin Y 2022 [24]	AAM	Geopolymer to limit CO_2 emissions	Industrial by-products	Precursor
Franca S 2023 [25]	AAM	Precursors	In high pH solution	Building materials

Cs-137 in CNT-reinforced polymer is used in the present prosthetic industry for advanced materials and devices [26], slag-alkaline cement [10], Cs-137 in activated fly ash (AFA) as a potential landfill barrier [27], and the use of alkali-activated materials (AAM)/alkali-activated cement (AAC) based on blast furnace slag [28]. AAM future perspectives for structural applications have been reported [29].

TABLE 2
THIRTEEN REFERENCES OF RECYCLED WASTE (OLD AND NEW SLAG CONCRETE) BEFORE 30 YEARS OF SUCCESSFUL CONCEALMENT

Author, Year	Topic/Aims Variables of Interest	Adjustment for Other Variables	Comparative Risk	Explanation
Yubonmhat K 2024 [1]	Cs-137 contaminated Solidification	PSCs/Perovskite	Ordinary Portland Cements (OPC)	Electric arc furnace dust (EAFD)
He P 2019 [23]	Cs-137 waste trapping	Precursor technique	Good chemical and thermal stability	Low leaching rate
Kriven WM 2024 [9]	Cs-137-AAM	Essential for sustainable construction	Good for climate change mitigation	To harness the benefits of these Geopolymers
Alhassan 2023 [8]	Cs-137	AA Binders	High temperature and acid resistance	Cs in geopolymer
Zhang C 2025 [27]	Cs-137	Activated Fly Ash (AFA)	Decrease pore density	Potential as landfill barriers
Abubakre OK 2023 [26]	Cs-137	CNT-reinforced polymer nanocomposites	The present prosthetic industry	Advanced Materials and Devices
Zhou J 2025 [4]	Cs-137	Cs doping strategy boost Perovskite	Toward efficient and long-lasting rechargeable Zn-air batteries	Bifunctional electrocatalyst
Wu Y 2024 [10]	AAM	Escalating environmental notice	By utilizing low-carbon industrial waste	AAM large-scale construction project
Marvilla MT 2021 [28]	AAM/AAC	Has superior properties compared to OPC	AAM/geopolymers also minimized environmental risk	Mechanical, physical and durability properties AAC based on blast furnace slag
Rossi L 2022 [29]	AAM	Future perspectives	From existing standards	To structural applications
Qin Y 2022 [24]	AAM-Polymers	Geopolymer to limit CO_2 emissions	Vs. Ordinary Portland Cement (OPC)	Industrial by-products/precursor
Ge K 2025 [30]	Fly Ash	Preparation of low-carbon cementitious materials	Hydration process	Sustainability assessment
Franca S 2023 [25]	AAM	Dissolution process	Polycondensation of precursors	Of precursors in high pH solution for buildings

TABLE 3
SEVEN REFERENCES RECYCLING CS-137 FROM FLY ASH AS ALKALI-ACTIVATED MATERIALS (AAMS)

Author, Year	Topic/Aims Variables of Interest	Adjustment for Other Variables	Comparative Risk	Information
Tian Y 2022 [31]	Fly Ash → Perovskites	$AgNbO_3$-based ceramics	The lead-free perovskite family	Silver niobate perovskites
Wu Y 2024 [10]	AAM	Escalating environmental concern	By utilizing low-carbon industrial waste	AAM large-scale construction project
Abhishek HS 2022 [32]	AAFA → Slag Concrete	Fresh mechanical and durability properties of AAFA	Innovative Infrastructure Solutions	From waste materials
Palomo A 1999 [3]	AAFA → A cement for the future	Cement and Concrete Research	From waste materials	No other solid material was used
Puertas F 2000 [33]	AFA → Slag cement	Strength behavior	Cement and concrete research	Alkali-activated fly ash/slag cements
Zhang C 2025 [27]	AFA	Engineering Properties and Soil Structure	In a Compacted Natural Soil Liner	Environmental Engineering to landfill old computers
Alhasan M 2023 [8]	AA Binders	High temperature and acid resistance	Sustainability, Life Cycle Assessment	Cesium in geopolymer

FIGURE 1: Electronic waste (cable) creatively made as a mat on display in Jakarta, 2020

IV. DISCUSSION

The association of Cs-137 with electronic waste is shown in Table 1. Recycling Cs-137 from old and new slag-concrete (Table 2) and from fly ash as alkali-activated materials (Table 3) are discussed. Cs doping is also used in BOLEDs [34], LEDs [35], perovskite phases [36], and dielectric ceramics [37,38], as well as for improvement of near-infrared (NIR) properties [39]. Nanostructured niobium-doped nickel-rich multiphase positive electrode active material for high-power lithium batteries has been reported [40]. Electronic materials are associated with dielectric properties through electrical and ferroelectric characterization of $BaTiO_3$ ceramics [41,42], and studies on the structure, morphology, dielectric, and piezoelectric properties of large-grain $(Ba_{0.85}Sr_{0.15})_{1-x}Pb_xTiO_3$ ceramic systems [43]. Preparation and characterization of ceramic materials with low thermal conductivity and high strength using high-calcium fly ash were reported in the International Journal of Minerals, Metallurgy and Materials [44].

Silver niobate perovskites—structure, properties, and multifunctional applications including dielectric, piezoelectric, high-power energy storage/conversion, photocatalytic, and photovoltaic devices—have been reviewed [32]. Alkali-activated material (AAM), also known as geopolymer, is a precursor material for high-performance construction materials with a lower carbon footprint and superior properties compared to ordinary Portland cement (OPC), using waste glass to produce alternative alkaline solutions [45]. Graphene and carbon nanotubes (CNTs) are carbon allotropes that possess high specific surface areas for Cs-137 water treatment, and their possible hybrid applications can be expected [46]. The year 2023 marked the 70th anniversary of carbon nanotube discovery, focusing on real-world solutions [47]. The reinforcement effects of CNTs for polymer-based nanocomposites have been reported [48]. Cesium and bromine doping into hexagonal boron nitride represents an early effort to dope CNTs with Cs [49]. Solid-state lithium batteries (SSLB): advances, challenges, and future perspectives underscore the need for renewable, efficient, and reliable energy storage systems [50].

To improve the range of performance of low-cost batteries, electronics, and building concrete materials, recycling Cs-137 from fly ash is creative for entrepreneurs. The reasons are as follows.

4.1 Radioactive Cs-137 in Groundwater and Seawater: Highest Solubility

Group 1 elements in the periodic table are alkali metals that are highly soluble. Their high solubility in water gives them strong fluidity. The name "alkali metal" for Group 1 elements comes from their ability to reduce water to form alkalis (soluble bases) and hydrogen gas. The higher the period number in Group 1, the more vigorous the reaction with water, and the solubility increases with increasing atomic number (Z). Cesium has a higher atomic number than sodium, potassium, and lithium. The higher atomic weight of Cs-137 compared to Cs-133 results in higher pH and greater solubility. This study explains why recycling slag-concrete containing Cs-137 is more challenging.

4.2 Hidden Cs-137 in Ceramic and Concrete

The mystery of hardness lies in pH [28], and Cs-137 has been successfully hidden in concrete, awaiting its 30-year half-life, but this is not broadly known. Recycling to extract the high pH is not transparent, and laypeople may unknowingly use these materials. Middle entrepreneurs may not realize the source of the high pH and may neglect the hazardous exposure. This enhanced pollucite structure by geopolymer precursor technique safely traps cesium through doping [23]. The state of the art and perspective of geopolymer precursors have been reported by Qin [24]. Preliminary reactivity tests for precursors of AAM for building concrete have been reported [25]. Low-carbon cementitious materials preparation based on fly ash from biomass power plants by alkali-salt solid waste stimulation, bringing sustainability, was recorded in Process Safety and Environmental Protection [30].

4.3 Cs-137 in Conductors, Insulators, Capacitors, Inductors, Resistors, and OLEDs

Electronic waste is rich in Cs-137 and should be disposed of in deep geological repositories or adsorbed and hidden in concrete, but the latter approach acts as a double-edged sword. On one side, it serves as an economic source of fly ash without commercial activators, becoming a market challenge in infrastructure building concrete and electronics. On the other side, slag-concrete made from fly ash acts as a source of Cs-137 radioactive exposure to groundwater and air. Despite the fact that trace Cs-137 removal from wastewater is successful using polymer metal oxide composites versus bone powder chitosan [51], its existence and hazardous nature remain a concern.

4.4 Cs-137 Long-Lived to Ba-137 Short-Lived and Application: Gamma-Ray Generator

In gamma-ray generators, Cs-137 is placed in a specialized chromatography column, waiting to decay to Ba-137 (which is used for diagnosis and therapy in medical applications [56]). Ba-137m is a Group 2 (IIa) element in the periodic table. The atomic number increases by one due to the conversion of a neutron into a proton. Gamma emission occurs when the excited Ba-137 nucleus quickly transitions to its ground state by emitting a high-energy gamma ray (662 keV). Gamma rays are highly penetrating and dangerous to humans because they cause cellular damage. Gamma rays are used to induce mutations in genetic experiments and can sterilize medical equipment and foods, as reported since the year 2000. Boumous et al. reported the electrical and ferroelectric characterization of $BaTiO_3$ ceramics [41], and its dielectric properties have been revealed since 2019 [42].

4.5 Waste Furnace Byproducts from Steel Production as Sources for Battery Factories and Recycled Concrete/Ceramics, and Immobilization of Cs as Environmental Case

The concept is similar to lanthanum (La) doping (e.g., 1%) aiming to enhance ferroelectricity and ferromagnetism by tuning the dielectric response to create better materials for applications like data storage [38]. A unique advantage of lead-free metal halide $Cs_2ZnCl_4{:}Sb^{3+}$ is its use as a near-infrared (NIR) light source. The NIR light-emitting diode device based on $Cs_2ZnCl_4{:}Sb^{3+}$ demonstrates potential as a non-visible light source in night vision. The high-efficiency NIR emissive materials also serve as an effective strategy for designing novel eco-friendly materials [39]. The effect of Cs doping and antisolvent on the linear and nonlinear characteristics of $CH_3NH_3PbI_3$ perovskite thin films has been reported [52]. The optical bandgap of the films depends on the amount of Cs doping [52].

Nanostructured niobium-doped nickel-rich multiphase positive electrode active material for high-power lithium-based batteries involves an initial lithiation of the hydroxide precursor at an intermediate temperature, followed by cooling, dopant mixing, and high-temperature calcination [40]. Slag cement and the process of making it have been patented since 1908 [53], and AAM is driving commercial adoption in the context of climate change, as reported in Waste Biomass Valorization since 2010 [54]. Li et al. [55] and Jose et al. [50] reveal the secret of fly ash and high pH in solid-state batteries as challenges, progress, and prospects. They are Sustainable Materials and Technologies.

<u>Limitations</u>

AAM and AAFA contain hidden Cs-137 and serve as hidden financial sources for many entrepreneurs. The products are also promoted as environmentally friendly due to CO_2 adsorption, oxygen production, and the fact that fly ash does not emit CO_2 [30], so they are considered beneficial for fighting climate change. On the other hand, like mining, people on the street also want to recycle waste old and new slag concrete without realizing the strict SOP required for handling the highly soluble Cs-137 with its 30-year half-life. The Bayesian interpretation of AAM, AAFA, precursors, fly ash, etc. with high pH sources is not transparent regarding their content. Cs-137 in these materials also has no age limit, so it should be fixed before use. Cs-137 from hazardous nuclear sources could support the aims of this study for safe trapping as a high-pH solution [29]. Dielectric properties [38] and spintronics [12,13] should be included in these electronics, in parallel with capacitors, isolators, conductors, resistors, inductors, sensors, LEDs, piezoelectric devices, and photovoltaics. In parallel with Cs-137, Cs, Ba, and lanthanum (La) should also be included in association with concretes and ceramics [38,41,42].

Apart from AAM, AAFA, precursors, and slag-concrete, many references do not explicitly describe Cs-137 but refer to high-pH sources that firmly clarify the existence of Cs-137. Electronic waste Cs-137 with a 30-year half-life hidden in slag-concrete could become a source of modern mining fortunes to overcome the climate crisis (US), obligation crisis (Japan), canola crisis (Canada), economic crisis in developing countries, tariff wars, and contribute to peace efforts alongside the prevention and therapy of leukemia. This global public health enthusiasm should soon be supported by the executive, judiciary, and legislative branches. It requires political will.

V. CONCLUSION

The mishap of Cs-137 contamination can be turned into a benefit for all people globally through proper management, and promotion to everybody on guarding of safe recycling practices, and awareness of Cs-137 in alkali-activated materials (concrete geopolymers and waste electronics).

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CONFLICT OF INTEREST

The author declares no conflict of interest but demands proper SOP in recycling waste old and new slag concrete and SSB rubbish. We are One Earth.

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