India Commercialises Globally Marketable Lead-free X-ray Shielding Tiles from Industrial Waste

X-RAY, gamma ray, and neutron shielding materials are an essential part of civil construction in X-ray diagnostic, Computerised Tomography (CT) scanners, cath labs, dental X-rays, Bone Mineral Densitometer (BMD), sterilisation plants, cancer treatment bunkers, brachytherapy, nuclear power plants, radioactive nuclide storage, particle accelerators, hot cells, etc., to protect public, patients and environment from the radiation hazard. As per the Atomic Energy Regulatory Board (AERB) India, an adult can be exposed to up to 20mSv (millisieverts) per year (average over 5 consecutive years) of radiation. Unwanted radiation exposure can cause skin burns, nausea, organ failures, genetic disorders, cancer, cardiac arrest, and cataracts. Therefore, the thickness of the radiation shielding wall is kept different depending on the energy of incoming radiation, type of radiation, and its attenuation characteristics to keep the leakage radiation below the permissible limit. For example, 2mm and 450mm thick lead are recommended by the National Commission of Radiological Protection (NCRP) and AERB to build an X-ray diagnostic room and 10 MV cancer treatment bunkers, respectively. Apart from lead, concrete is also widely used for radiation shielding applications. The AERB and NCRP recommend to use of a 2300 mm (2.3m) thick concrete wall of density 2.35 g/cc for building $\geq$10 MV radiotherapy bunkers. The brick and concrete walls tend to crack and develop structural defects and pores during manufacturing/construction, which leads to radiation leakage. The quality and density of bricks vary from place to place and no standard mortar is available to apply between the joints to avoid radiation leakage.

The atomic number and density of the shield play a prominent role in attenuating high-energy radiations. Therefore, iron ore, chrome ore, tungsten ore, barite, lead shot, and steel/iron shots are used with the concrete matrix to prepare high-density concrete for radiation shielding applications. Iron and its ores are widely used due to its moderate atomic number, cost-effectiveness, and availability. In this context, the CSIR-Advanced Materials and Processes Research Institute (CSIR-AMPRI), based in Bhopal, Madhya Pradesh has converted the iron-rich red mud into X-ray, gamma ray, and neutron shielding materials.

Red mud is an alumina industry waste. Globally, 170 million tons of red mud are generated annually and left unused in the disposal ponds due to inadequate technologies for its large-scale utilisation. Heavy metals like Arsenic, Cadmium, Lead, Chromium, Mercury, etc., leach out from the accumulated red mud and pollute soil and water bodies. Moreover, fugitive emissions from the dry stacked red mud pond pollute the atmosphere and cause burning effects, and skin & eye irritation. Although $\approx$700 various applications of red mud have been patented, till now only 3-4% of red mud is used mainly by the cement industries for making cement clinkers, which serves as the backbone of the cement manufacturing process as a binding agent. The red mud ponds were reported to have breached in various countries like India, China, Brazil, and Hungary and spread the caustic (pH > 11) red mud over wide areas, spoiling the public and wildlife through its hazards and making the land infertile.

CSIR-AMPRI came out with a solution. It has converted red mud into X-ray shielding tiles in a green and economically viable manner through a ceramic route, capable of shielding until 140 kV X-rays. The tiles were fabricated through the conventional ceramic route by mixing red mud with a certain wt% (percentage by weight) of high dense and high atomic number additives and clay binder to increase their X-ray attenuation coefficient and mechanical strength, respectively. X-ray attenuation means the reduction in intensity of X-rays when it passes through the shield/medium. The radiation shielding tiles developed in the lab scale at CSIR-AMPRI possess a flexural strength of 23 N/mm^2 and a breaking strength of 2000N. The 12mm thick tile possesses attenuation equivalent to 2mm lead at 100 kV. Noteworthy, none of the heavy elements were found to leach out from the tiles above the permissible limit recommended by the Central Pollution Control Board (CPCB) and the World Health Organization (WHO). The radiation shielding material developed by CSIR-AMPRI is recommended by AERB, India (https://aerb.gov.in/images/PDF/layout_guidelines.pdf) to build radiation shielding structures in radiography and fluoroscopy, CT scanner room, cath labs, bone mineral densitometry, dental X- rays, mammography and C-arm as an alternative to toxic lead. CSIR-AMPRI