Abstract

The safe and secure transport of nuclear and radiological materials is critical due to the inherent risks associated with these hazardous substances. This paper explores innovative fabrication solutions that are enhancing safety protocols during transit. Advances in materials science, modular container design, and additive manufacturing (3D printing) have led to the development of stronger, lighter, and more adaptive containment systems. High-performance alloys, radiation-shielding composites, and nanostructured coatings are improving the durability and resilience of transport vessels, while smart technologies like IoT sensors, blockchain tracking, and AI-driven predictive maintenance enhance real-time monitoring and security. Together, these innovations signi f cantly reduce the risks of accidental releases and malicious interference during the transportation of nuclear and radiological materials. This paper highlights the need for continued industry collaboration and regulatory oversight to ensure that these advanced fabrication solutions meet stringent safety standards and address evolving threats.

Ke ords: N c ea a e a a ; Rad ca a e a a e ; Ad a ced ab ca ; C a e e ; Rad a e d ; S a ec e

Introduction

e a a c ea a d ad ca a e a c ca a a e ec , c d e e d c , ed ca d a c a d ea e , e ea c , a d d a a ca [1,2]. e e e a e e e a e a , e e , e e b a e c e e acc de a e ea e a c e e e ce. I a ab ca d e b ad a ce e a e a c e ce, a ac ce e , a d e e ec e a e c ea a a ce a e b e e a e c ea a d ad ca a e a d a [3,4].

e importance of securing nuclear and radiological materials in transit

e a c ea a d ad ca a e a e e e d e e a a d a e. e e a e a a e a a a ca b ca e e e e ea , e e a , a d ec a d ed, e ec ed, a e ed b bad ac [5]. D a , c a e a a e a c a e ab e, a e ea e ec e ac e a d e e b ade a c e e . ece a e b a e e , c b acc de e e a d a ca e e e e c e [6,7].

T ad a a e ea e a e e a ced ac a , ec a ed c a e e e , a d ea e a ed e . W e e e e d a e e e ec e, e e a e e a ea e e acc de a de be a e e e c a e ec e a ec e e a e a d a [8].

Innovative fabrication solutions for enhanced safet

Rece ad a ce e ab ca a e a ca e e e ec a d a e a c ea a d ad ca a e a . e e a e ce e ed a d e a e a , de a , a d d c ce e a ca e a ce e d ab , e , a d e c e c

e e e a e e a . e e e ca be ad ed acc da e d e e e a e a a d a a c d , d e a ed c ea a d ad ca a a .

Modular container s stems: E ee a e de e ed d a c a e e a ca be c ada ed acc da e a de a e ad ac e a e a , e c ea e d ed ca e . e e c a e a e de ed be ea a e b ed a d d a e b ed, a e c e a d a d ec a de e d e ec c a e a be a ed. e a e ed ce b e c a d c e a c a ed e e a c a e .

Adaptive shock absorption technologies: T ec a a acc de d a , c a e a e be e ed ada e c ab e a ad ba ed e ce e e ed d e e . e e e ca ac e a e da a e ca ed b ac , ed c e a b eac e c a e e e . I a a a e a , c a a e e a a d e e ec c e , a e e e e d d a ca e c d ea e.

Design for decommissioning and reuse: e c ce c ad e--c ad e de a be a ed e ab ca c a e e , e a e ca be a e dec ed e ed a e e d e e ce e. e e e a a e a d e e a c a e e a a e e e e e a e a c c ded.

Additive manufacturing (3d printing) and customi ation

Add e a ac , c a 3D , a a c ea a e e ab ca c ed a e c ea a d ad ca a e a a . e ec a d e b e ed b 3D a a ed c a e de a ca acc da e e a e a d a e a .

Custom- t containment vessels: Add e a ac a e ee c ea e be e c a e e e de ed ec ca e a e a e a e e ded d. e e c a e a e b e a , ed c e e d e e e c a e d a . C c a e e e ca a be de ed b - c ab be , ad a e d , a d ea e e e .

Rapid protot ping and testing: 3D a a d a d e a e e , acce e a e de e e e c a e e . a d ca ab e ab e e ee c e e de a d e e e e , e a e a e e ed be e de e .

On-demand manufacturing: Add e a ac a a -de a d d c c a e e e a d c e , ed c ead e a de a a c a e a ea a abe e eeded. e b a c a a abe a a dea a e e ad ac e a e a , c a e e ec a ed c a e .

Smart technologies and digitali ation for real-time monitoring

A de ad a ce ca ab ca , d a ec e a e c ea be e a ed c ea a d ad ca a e e a ce a e ea - e , da a a a , a d ed c e a e a ce.

Smart sensors and iot connectivit : C a e e e a e be e ed a e a a a e e e a ac , c a e e a e, ad a e e , a d ca c . e e e a ec ec ed e I e e (I T),0.062 9 e 0.078 ,

6. Velasquez MT, Ramezani A, Raj DS (2015) Urea and protein carbamylation in ESRD: surrogate markers or partners in crime?. Kidney Int 87: 1092-1094.

7. Horowitz M, Wilder S, Horowitz Z, Reiner O, Gelbart T, et al. (1989) The human