Lead Free Radiation Protection Clothing Solution for Inspection Team

Yulai Xu1, Jing Yang2, Peng Li3

1. Innonano (Beijing) Special Materials Technology Co. Ltd； 2. HOPE Technology Development Co. Ltd； 3. China Arms Control and Disarmament Association

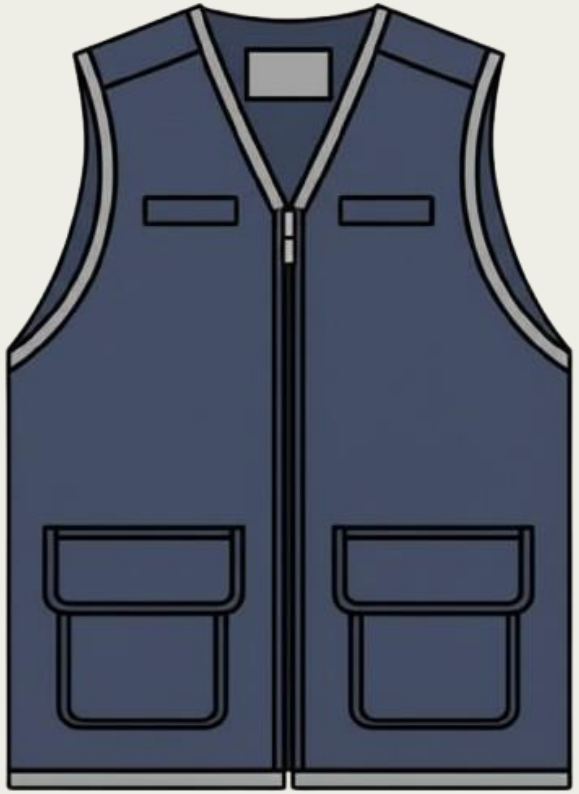
INTRODUCTION AND MAIN RESULTS

This work carried out a practical clothing solution to OSI inspection team based on different roles and functionalities of the inspectors, with theoretical analysis and test results being given for realistic challenging OSI scenarios.

Technology Research & Development · Innovative Solutions

OSI Protective Equipment

Research and Design Technical Solution



A Novel Integrated Personal Protective Equipment Solution for On-Site Inspection (OSI) Missions

Design and Analysis of Lead-Free, Modular, and Thermoregulated Protective Suits

- Lead-free and environmentally friendly
- Modular design
- Thermal control system

Project Background and Requirement Analysis

Challenges faced by OSI field inspections:

- Complex radiation environment (multiple threats from gamma rays, neutrons, beta radiation, etc.)
- Biological and chemical contamination risks (special pollutants such as aerosols, tritium, etc.)
- Long-duration operational requirements (4-8 hours of continuous work)
- Risk of heat stress due to high temperatures and strenuous activities

Necessity of developing new protective equipment

- Traditional lead shielding materials have issues such as heavy weight (>5kg), susceptibility to fatigue, and toxicity.
- Environmental requirements are increasing, necessitating the replacement of lead-containing materials and meeting sustainable development goals.
- Poor wearing comfort, making it difficult to meet the demands of prolonged continuous work.
- Traditional equipment is difficult to decontaminate and prone to accumulating radioactive dust.

OSI on-site inspection personnel require efficient and safe protective equipment.

Existing equipment shortcomings

- Weight
- Delead
- High thermal load
- Dust electrostatic adsorption

Core Innovative Technical Solution

Material Science Level

Lead-free composite shielding material system, combining:

- Bismuth oxide (Bi_2O_3): high atomic number (Z=83), high density (8.9 g/cm³)
- Rare earth materials: gadolinium oxide (Gd_2O_3) and lanthanide mixed oxides
- Flexible matrix: PVC/PU/TPU thermoplastic materials with filler content of 50-60 wt%, achieving a balance between flexibility and shielding effectiveness.

Surface Engineering Level

Antistatic coating design:

- Permanent antistatic performance, surface resistivity controlled between 10^5 and 10^8 Ω/sq
- Conductive fillers: conductive carbon black and graphene nanomaterials
- Matrix: cross-linked polyurethane or fluoropolymer
- Performance remains stable after 50 wash cycles, meeting ANSI/ESD standards.

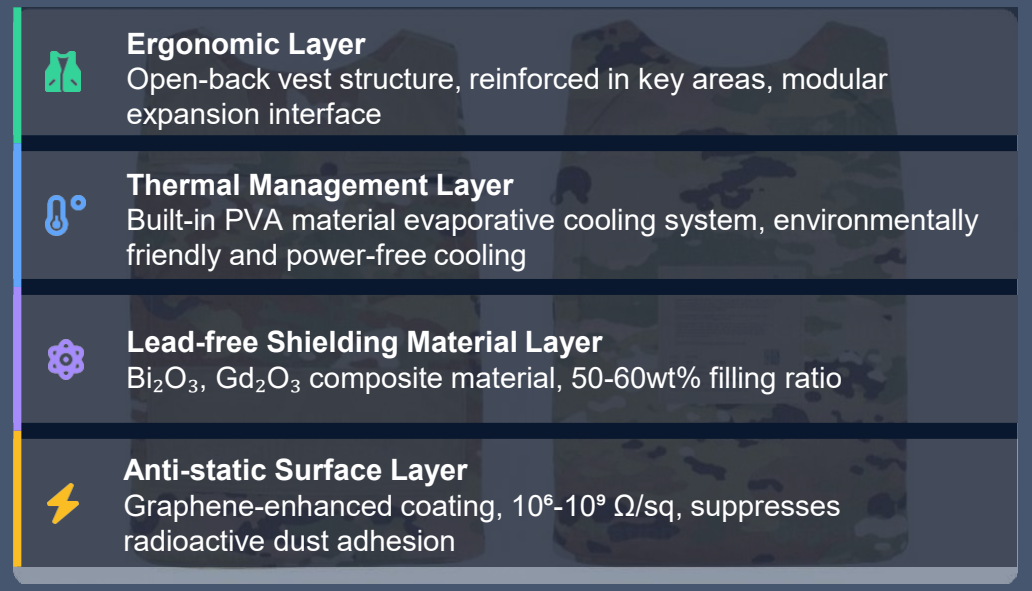
Ergonomics Level

- Open, lightweight vest structure weighing <1.5 kg
- Modular expandable design
- Key protection areas include the heart and spine

Thermal Management Level

- Passive evaporative cooling system weighing <0.5 kg
- Latent heat of vaporization: 2260 kJ/kg, continuous operation duration >90 minutes

Diagram of a four-layer structure



Materials
Weight reduction >60%

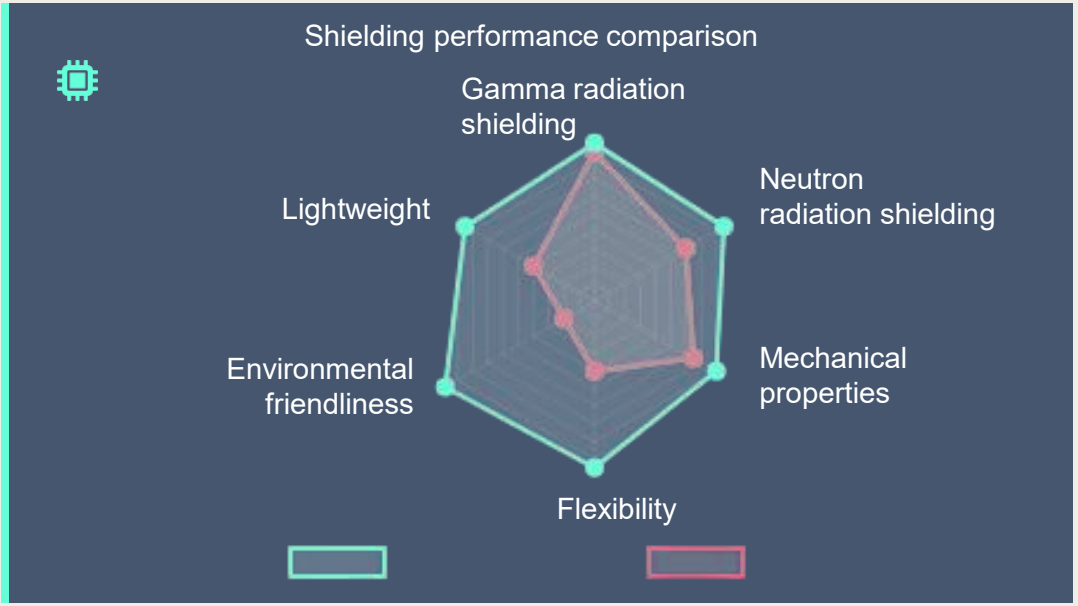
Modular expandable design
Mission adaptability >90%

Evaporative cooling system
Temperature difference 8-12°C

Anti-static coating
Decontamination efficiency increased by 75%

Photovoltaic Energy Storage System Solution to Inspection Team

Material	Atomic number	Density (g/cm³)	Shielding effectiveness	Environmental friendliness
Bismuth oxide	83	8.9	Excellent	Non-toxic
Gadolinium oxide (Gd_2O_3)	64	7.41	Outstanding	Non-toxic
Lanthanide mixture	57-71	6.5-8.2	Good	Non-toxic
Lead (reference)	82	11.34	Outstanding	Toxic



Key Performance Indicators

- Shielding and mechanical balance: Filler content 50-60 wt%, nano-scale dispersion improves interface bonding Aerosol protection: PM0.3 purification efficiency up to 99.99%
- Tritium protective layer: Butyl rubber with strong sealing, gas permeability coefficient $<10^{-10}$ cm³·cm/cm²·s·Pa
- Antistatic performance: Surface resistivity 10^5-10^8 Ω/sq, stable after 50 washes

Lightweight
Core protective component
<1.5kg

Flexibility
Bending angle
180°

Usage duration
High-temperature environment
>90 minutes

Breathability
Air permeability
≥95%

Photovoltaic Energy Storage System Solution to Inspection Team

Multi-layer Structure Analysis

Innermost Layer: Evaporative Cooling Vest

- Body-fitting PVA material, weight ≤ 0.5kg, efficient thermal management

Intermediate Layer: Core Protection Composite Material

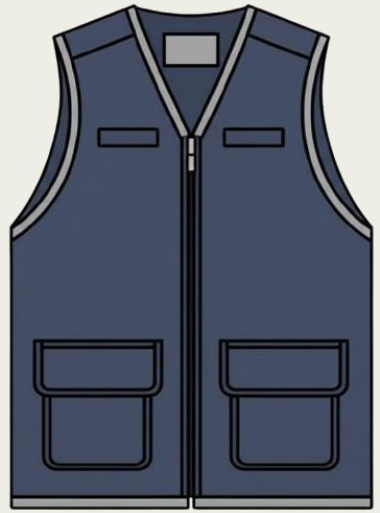
- Bismuth oxide/rare-earth filler composite, effective shielding against gamma rays and neutrons

Outer Layer: Anti-static Nanocoating

- Resistivity 10^5~10^8 Ω/sq, prevents radioactive dust adhesion

Optional Layer: Aerosol/Tritium Protection Layer

- Available as needed for specific tasks, PM0.3 filtration efficiency 99.99%



Key Features: Targeted Protection and Expandability

- Targeted protection for heart, lungs, chest, and abdomen;
- increased thickness of protective materials in the genital area to reduce genetic risks
- Open design compatible with standard protective suits at various mission levels
- Velcro and quick-connect interfaces support expansion with additional components such as protective arms and gloves

Core Protective Components

- Front and back protective panels, lightweight composite material covering vital areas of the torso

Cooling Liner System

- Passive evaporative cooling, directly adheres to the body, extends working time > 90 minutes

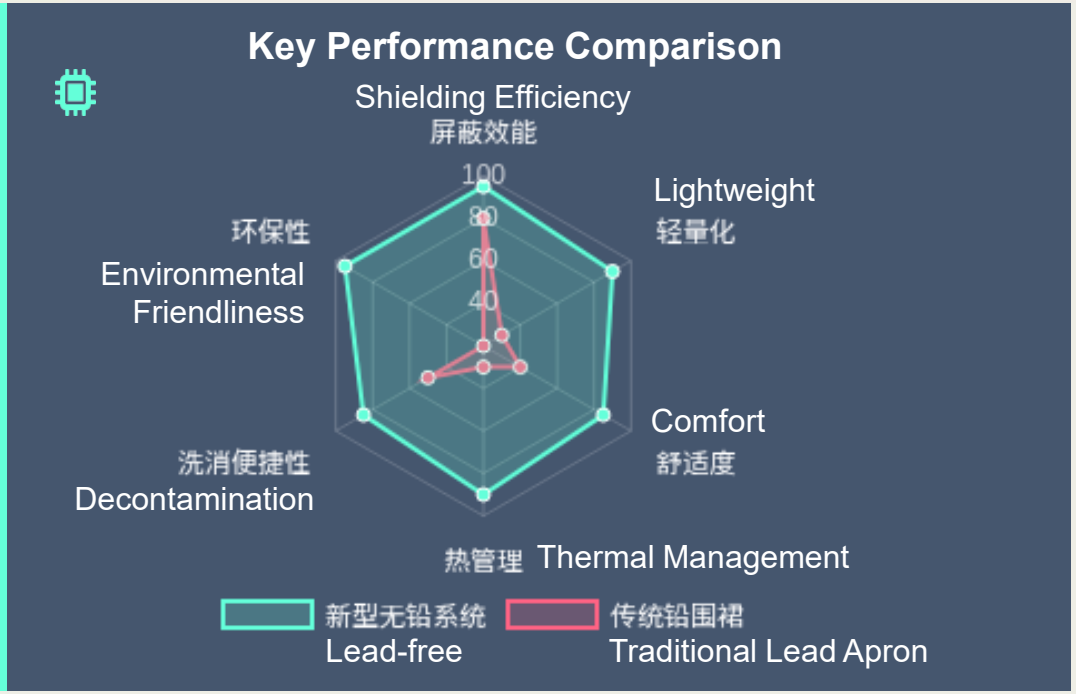
Optional Protective Gloves

- Flexible lead-free composite material, maintains dexterity and operational capability

Adjustable Belt System

- Ergonomic design with multi-point adjustment for balanced weight distribution

Photovoltaic Energy Storage System Solution to Inspection Team



Detailed technical parameter comparison

T4.2-48

Performance Indicators	Protective Vest	Lead Apron System
Shielding Performance	30keV>60%	0.5mmPb
Weight	< 1.5kg	5-8kg
Thermal Environment	> 90min	< 30min
Material Toxicity	Non-toxic	Lead toxicity
Electrostatic Adsorption	low adsorption	prone to electrostatic adsorption
Decontamination Difficulty	Low, stable washing performance	High
Aerosol Protection	PM0.3 99.99%	None
Comfort	High, open-back design	Low, hot and stuffy

Technological Synergistic Advantage

Environmentally Friendly and Lead-Free

- Avoids lead pollution, and ensures long-term user health.

Multi-dimensional Protection

- Gamma ray/neutron/aerosol/tritium combined protection.

Thermal Management System

- Extends working time by 3 times, significantly enhancing task sustainability.

Modular Design

- Flexible configuration to adapt to diverse mission scenarios.

Comprehensive Benefit Evaluation

- Adapting to the needs of diverse task scenarios

Comprehensive Benefit Evaluation

- All-dimensional performance enhancement, significantly improving user experience and task efficiency
- Weight reduced by 70%, working time extended by 200%.
- Meets environmental standards, sustainable use, easy cleaning and maintenance.
- Synergy between modular design and thermal management maximizes mission adaptability.