1. **Background and Goal of the present work**

In a resolution at the International Atomic Energy Agency (IAEA) 2002 General Conference, the IAEA adopted an integrated approach that includes physical protection and material accounting for transport of radioactive material and nuclear material and recommends that security system designers consult with safety experts. Herein we present examples of integrating safety and security by design for two transportation packagings of nuclear and other radioactive material: “smart drum” technology and a new, compact Type B packaging design for end-of-life management of disused radiological sources. Packaging safety functions, regulatory safety standards and security requirements, and fundamental design principles, illustrated by these two examples, are applicable to other transportation packagings of high-risk materials.

1. **Packaging Safety by Design**

Containment of radioactivity, shielding for radiation protection, and sub-criticality are the three primary safety requirements for Type B and fissile material transportation packagings under normal conditions of transport (NCT) and hypothetical accident conditions (HAC), as specified in U.S. Title 10 of the Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, and the IAEA Safety Standards Regulations for the Safe Transport of Radioactive Material, 2018 Edition, *Specific Safety Requirements, No. SSR-6 (Rev. 1)*. Packaging design, therefore, must demonstrate that the transporttion packaging meets all of the regulatory safety standards, either by testing or analysis. The following Type B and Type A fissile material transportation packagings show several important-to-safety structures, systems, and components (SSCs), such as bolted and split-ring closures, polyurethane foam impact absorber, ceramic and fiber thermal insulation, and stainless-steel containment vessel with cone seals of double VITON O-rings (not shown). For the Type B transportation packaging, containment of radioactivity is demonstrated by measurement of leakage rate across the containment boundary, whereas a pressure relief device   
(with filters) is often used for the Type A fissile transportation packaging.

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| *Type B transportation packaging* | *Type A fissile transportation packaging* |

The new compact Type B packaging design for end-of-life management of disused radiological sources, shown below, is another example of transportation packaging that meets all regulatory safety standards specified in 10 CFR 71 and SSR-6 (Rev. 1) during NCT and HAC. Furthermore, the stainless-steel structure components of the packaging also provide excellent long-term (>50 years) performance against general corrosion and stress corrosion cracking during extended dry storage, thus enabling subsequent transportation (without repackaging of the disused CsCl sources) to a geological repository or deep borehole for final disposal. Results of structural and thermal analyses showed that the compact Type B packaging design could accommodate up to seven disused CsCl sources, with a total heat dissipation capability of up to 1,000 W. Results of the MCNP shielding analyses showed that the calculated radiation dose rates satisfy the regulatory requirements for exclusive-use shipment of the package for direct disposal. For interim on-site or off-site storage after transport, the radiation dose rates at the external package surface will only decrease over time because of the decay of radioisotopes.

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| *(a) Compact Type B packaging design; (b) cask and containment vessel, and  (c) depleted uranium (DU) basket accommodating up to 7 CsCl capsules for a total heat load of 1,000 W (an ARG-US device is attached to the personnel shield)* |

**3. Packaging Security by Design**

The “smart drum” technology (<https://rampac.energy.gov/docs/default-source/rfid/rfid-wm2018.pdf>) is based on a robust drum-type transportation packaging that meets all regulatory safety standards for nuclear and other radioactive material and the ARG‑US radio frequency identification (RFID) surveillance tags (shown below attached to three Type B packagings [from left] and one Type A packaging [far right]), each with multiple sensors (temperature, radiation [gamma, neutron], shock, and seal integrity) that enable remote tracking and monitoring of packages in real time, with automatic alarm capabilities, to penhance security during transportation and in-transit storage. The ARG-US—meaning “watchful guardian”—RFID system consists of RFID surveillance tags, readers (not shown), and software for local and web application user interfaces that can continuously monitor and track tagged packages during their life cycles in storage, transportation, and disposal.

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| 4 tags on drums | | | |  |
| *Type B packagings (photos 1–3); Type A packaging (photo 4)* | | | |  |
|  | Type A Sensor Photo 2 | Type A Sensor Photo 1 | P1010477 |  |
| *RFID surveillance tag Tactile seal (shown between plates) Electronic loop seal* | | | |  |

Demonstrations and field-testing of the ARG-US RFID systems for drum-type packages during storage and transportation have been conducted over the last 10 years at selected U.S. DOE sites, including Argonne National Laboratory, Savannah River National Laboratory, and the Nevada National Security Site. Below are screen shots of a tactile seal alarm (red drum) sent by an RFID tag (top left); the satellite view of the time stamp and geographical location (latitude and longitude) of the vehicle/alarm in a highway truck stop (bottom); and after the tactile seal alarm was cleared (green drum) at 1:51:17 pm GMT, August 19, 2016 (top right).

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| *ARG-US RFID tactile seal alarm (red drum) in a “staged” incident at a truck stop* | |

The ARG-US device shown attached to the personnel shield of the compact Type B packaging design is based on the ARG-US Remote Area Modular Monitoring (RAMM)/ TRAVELER, which has been described in <https://rampac.energy.gov/docs/default-source/tracking/CN269-319_Liu_101418.pdf>. The design and performance of TRAVELER in real-time monitoring of nuclear cargo conveyance is also covered in an Interactive Content Presentation (ICP) at this confernece and will not be repeated here. The IAEA General Conference Resolution on nuclear security (GC[61]/RES/9) calls upon all Member States, within their responsibility, “to achieve and maintain highly effective nuclear security, including physical protection, of nuclear and other radioactive material during use, storage and transport and of the associated facilities at all stages in their life cycle.” Resolution GC(61)/RES/9 also calls upon all States “to improve and sustain, based on national security threat assessments, their national capabilities to **prevent, detect, deter and respond** to illicit trafficking and other unauthorized activities and events involving nuclear and other radioactive material.” Integrating safety and security by design for transportation packagings of nuclear and other radioactive material represents a positive step to achieve the goals enumerated above in IAEA GC(61)/RES/9.

1. **Future Work**

Development, testing, and integrating specialty sensors, small form-factor readers (fixed and mobile), power supplies (battery, energy harvesting), communication media (cellular, satellite, smart mesh), secured servers, and web application user interfaces will continue for the ARG-US remote monitoring systems technology. The patented ARG-US RFID surveillance tag was licensed to Evigia Systems, Inc., a U.S. company; the RFID system is commercially available and meets U.S. export control requirements. Technology transfer and commercialization of patented RAMM/TRAVELER to Embedded Planet, Inc., another U.S. company, is in progress.

1. **Conclusions and Acknowledgments**
   * Packaging safety functions, regulatory safety and security requirements, and fundamental design principles, illustrated by integrating safety and security by design of two transportation packagings of nuclear and other radioactive material, are applicable to other transportation packagings for risk-significant materials.
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