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Title

Enhancing Radiation Protection in Radioisotope Shipping Through Nested Shielding Inserts

Abstract

Introduction

The Sylvia Fedoruk Canadian Centre for Nuclear Innovation operates a cyclotron facility in Saskatoon that produces medical and research radioisotopes for national and international distribution. One of the primary research isotopes produced is zirconium-89 (^{89}Zr), which emits high-energy gamma radiation and requires more shielding during transport than is required for an equivalent activity of the more common fluorine-18. ^{89}Zr is typically shipped in commercially available lead or tungsten transport containers called pigs designed to accommodate 30 mL vials. However, ^{89}Zr produced at the facility is contained in 2 mL vials, resulting in significant dead volume within the pig. Commercial plastic vial adaptors address geometric fit but provide no additional radiation shielding so do not assist with meeting Transport of Dangerous Goods (TDG) dose rate requirements or ALARA goals. This work describes the design, fabrication, and testing of a shielding inserts called piglets intended to both address geometric fit and enhance radiation attenuation.

Methods

An inner shielding pig called a piglet was designed to nest concentrically within a commercially available pig, allowing a 2 mL vial to be securely positioned inside a cavity originally designed for a 30 mL vial. The piglet geometry maximized shielding thickness while maintaining compatibility with existing pigs. Initial prototypes were fabricated from lead due to its favorable shielding characteristics. Following client concerns regarding potential lead contamination from contact with vial septa, the design was replicated in bismuth, selected for its comparable shielding properties and reduced toxicity.

Piglets were fabricated by melting lead or bismuth and casting the material into sand molds. The castings were then machined on a lathe to achieve tight tolerances required for proper fit within the

tungsten pig. Dose rate measurements were collected at the top, top diagonal, side, and bottom surfaces of the tungsten pig both with and without the inner piglet.

Results

For the lead piglet evaluation, measurements were performed using 227 MBq of ^{89}Zr. When the tungsten pig was used without an inner piglet, dose rates measured 312 µSv/h (top), 1030 µSv/h (top diagonal), 1080 µSv/h (side), and 725 µSv/h (bottom). With the lead piglet installed inside the tungsten pig, dose rates were reduced to 44.7 µSv/h (top), 190 µSv/h (top diagonal), 568 µSv/h (side), and 712 µSv/h (bottom). The most pronounced reductions were observed at the top and top diagonal measurement locations, corresponding to the axial direction of the vial.

For the bismuth piglet evaluation, measurements were performed using 17.8 MBq of ^{89}Zr . Without an inner piglet, dose rates from the tungsten pig measured 17.4 µSv/h (top), 52.1 µSv/h (top diagonal), 88 µSv/h (side), and 84.4 µSv/h (bottom). With the bismuth piglet installed, dose rates decreased to 4.66 µSv/h (top), 23.8 µSv/h (top diagonal), 47.5 µSv/h (side), and 60.2 µSv/h (bottom). These results demonstrate consistent dose rate reductions across all measured surfaces when the inner piglet was used.

Although absolute dose rates differed due to the differing activities used in testing, both lead and bismuth piglets provided substantial shielding improvements within the tungsten pig, with the greatest benefit observed along the vial axis where dead volume was previously unshielded.

Conclusion

The addition of a shielding inner piglet effectively converts dead volume within standard tungsten transport containers into functional radiation shielding. Both lead and bismuth designs demonstrated significant dose rate reductions when compared to tungsten pigs used alone. The use of piglets allows for a nearly 90% increase in the shipping activity of ^{89}Zr while maintaining the same transport index. The bismuth piglet addresses contamination concerns associated with lead while maintaining effective radiation attenuation. Although developed for zirconium-89 transport in a pig, this approach is broadly applicable to other radioisotopes and facilities facing similar vial size mismatches. The piglet design provides a practical, low-cost method to enhance radiation protection and support TDG compliance without replacing existing transport systems.