

This work describes the legal, radiological, logistics, and safety considerations involved in the transfer of decommissioned legacy ^{226}Ra sources totalling approximately 50 GBq (~ 1.4 Ci) of activity from Paraguay, to the United States, under the framework of the International Atomic Energy Agency's Global Radium-226 Management Initiative.

The Removal of legacy ^{226}Ra and ^{137}Cs Medical Sources from Paraguay to the United States Under the International Atomic Energy Agency's Global ^{226}Ra Management Initiative

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Abstract — Objective: To describe the transfer of six decommissioned legacy ^{226}Ra sources totaling $9.92 \pm 2.0\%$ GBq (268 mCi), and 116 decommissioned ^{137}Cs sources totaling $41.1 \pm 2.0\%$ GBq (1,110 mCi), from the Republic of Paraguay to the United States, within the framework of the International Atomic Energy Agency's Global Radium-226 Management Initiative.

Methods: The sources were removed from their original shielded packaging, a cement-filled 200-L steel drum. The sources were identified via spectroscopic analysis, assayed, and repackaged in six Type A containers; five containers contained ^{226}Ra sources, and one contained all the ^{137}Cs sources. The containers were wipe-tested, and dose rates on contact and at 1.0 m were measured.

Results: External wipe tests on the containers revealed counts slightly above natural background in one of the units (14% above background), well below the allowable surface contamination for a II-Yellow-coded (medium risk) Type

A container. Dose rates at 1.0 m for all containers (i.e., their transport indices) ranged between $1.1 \mu\text{Sv h}^{-1} \pm 10\%$ (0.11 mrem h^{-1}) and $4.4 \mu\text{Sv h}^{-1} \pm 10\%$ (0.44 mrem h^{-1}), also corresponding to a II-Yellow code. Thus all containers were II-Yellow-coded for air shipment to the United States. The transfer of the containers from hospital to airport, inspection, weighing at customs, and loading onto the aircraft proceeded without incident.

Conclusions: The safe transfer of decommissioned ^{226}Ra and ^{137}Cs medical sources from possessor to receptor countries is possible provided all national and international safety guidelines are adhered to. Based on our experience, we recommend that any country considering such a transfer avail itself of the safety and security standards associated with the International Atomic Energy Agency's Global Radium-226 Management Initiative.

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Keywords: ^{137}Cs brachytherapy sources; International Atomic Energy Agency Global 226 Ra Management Initiative; ^{226}Ra brachytherapy sources, decommissioned sources, legacy sources, Transport Index, Type A Containers, wipe testing

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INTRODUCTION

WITHIN A year of the discovery of radium in 1898 by Pierre and Marie Curie, the couple was using it to treat cancer in a modality called brachytherapy, consisting of the surgical insertion of radium sources directly into malignant tumors. The idea was to deliver a highly localized tumoricidal dose selectively to the malignant lesions, while sparing the surrounding healthy tissues. Radium-226 is the sixth member of the ^{238}U decay chain; it decays with a 1,600 y half-life to ^{222}Rn . In a brachytherapy radium source or “needle,” the ^{222}Rn is sealed in a stainless steel needle, allowing the radium decay series to build up internally. In particular, two members of the series — ^{214}Pb and ^{214}Bi — are gamma emitters with gamma energies between 241 keV and 2.2 MeV. A mean effective gamma energy comparable to that of ^{60}Co (1.25 MeV) was typically assigned to radium sources (Johns and Cunningham 1983). All alpha and beta emissions from the radium decay series were effectively stopped by the steel walls of the needles. However, the walls were essentially transparent to the MeV gamma rays, which were used to treat tumors. Radium was the only MeV radiation therapy available in the first half of the 20th century, until the introduction of ^{60}Co and linear accelerator units in the 1950s, which explains its widespread clinical use during that era. Because of its excessively long half-life, which presents significant long-term waste management challenges, and the introduction of short-lived isotopes with more favorable clinical characteristics such as ^{192}Ir and ^{125}I , most hospitals around the world had decommissioned their ^{226}Ra sources by the mid-1970s (Pirchio et al. 2007). The International Atomic Energy Agency launched the Global Radium-226 Management Initiative in 2021, with the purpose of collecting decommissioned ^{226}Ra sources from around the world and

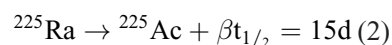
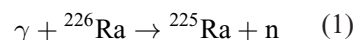
providing interested Member States appropriate assistance for their safe transfer to Member States interested in receiving them. At present, approximately 65 Member States possessing legacy, decommissioned ^{226}Ra sources are part of the program (IAEA 2025). Paraguay, as a possessor of such sources, has recently joined the program.

Receiving Member States have a vested interest in securing decommissioned ^{226}Ra sources, as feed material for the production of ^{225}Ac . As an alpha emitter, ^{225}Ac in the form of ^{225}Ac -DOTATATE is a promising radiopharmaceutical in theranostic (diagnostics + therapy = theranostic) applications. The use of an alpha emitter for cancer therapy has two advantages over standard-of-care beta emitters, such as ^{177}Lu , in the treatment of neuroendocrine tumors. First, alpha particles have a range of only a few cell diameters (0.1 mm), which selectively ablates cancer cells while sparing healthy tissues; beta particles by comparison have ranges of hundreds or thousands of cell diameters. In addition, the higher linear energy transfer (LET) of alpha vs. beta particles causes a higher proportion of irreparable double-strand breaks in DNA, resulting in better clinical efficacy. ^{225}Ac has the added advantage that its daughter ^{221}Fr decays by emission of a 218 keV gamma ray suitable for imaging with conventional nuclear medicine equipment, making ^{225}Ac a very attractive radioisotope for theranostic applications (Demirci et al. 2023).

MATERIALS AND METHODS

In 2025, within the framework of the International Atomic Energy Agency’s Global Radium-226 Management Initiative, Niowave, Inc. (Lansing, MI) and the Autoridad Reguladora Radiologica y Nuclear (ARRN) of Paraguay entered into a legally binding agreement (The Agreement) whereby Niowave would transfer decommissioned legacy

^{226}Ra and ^{137}Cs brachytherapy sources from the Republic of Paraguay to the United States of America. The ^{226}Ra sources were once used at the Instituto Nacional del Cancer (INCAN) of Paraguay between 1968 and 1972, primarily for the treatment of head and neck tumors. The ^{137}Cs sources were employed in the late 1980s and into the early 1990s for low dose-rate brachytherapy of cervical cancer. The transfer of the sources had two different purposes. The ^{226}Ra sources are to be used for the production of ^{225}Ac via the



reaction pathway (Maslov 2006). The ^{137}Cs sources, on the other hand, are to be permanently disposed of in a suitable repository. Niowave, Inc., had previously applied for and was granted the relevant US Nuclear Regulatory Commission (US NRC) permits necessary for importation of the sources into the United States. As part of the agreement, the ARRN had to certify based on original documentation that none of the sources were of Soviet or Russian origin. The ^{226}Ra sources were manufactured by Cisbio International (Gif-sur-Yvette, Essonne, France), and the ^{137}Cs sources were manufactured by Amersham plc (Buckinghamshire, UK).

Six ^{226}Ra sources and 116 ^{137}Cs sources had been in storage since 1998 at a specially designed vault at INCAN. The square vault is located approximately 150 m from the main hospital, in an unused former soccer field. The vault’s external dimensions are 5.52 m × 5.52 m. It has a cement floor, a system of motion-activated alarms, and three independent locks. All the sources were stored inside the vault in a 200-L steel drum with a diameter of 59 cm and a height of

89 cm. Located inside the drum was a hollow cylindrical concrete structure of approximately 80 cm in height, 57 cm in outer diameter, and 30 cm in inner diameter. All the sources were located in a smaller steel cylindrical container with a diameter of 27 cm and a height of 25 cm, itself located inside the hollow concrete cylinder, in a tight fit at the bottom of the 200-L steel drum. Because of friction and weight, removing the smaller steel cylinder containing the sources required tipping the 200-L steel drum on its side, as seen in Fig. 1. The six ^{226}Ra sources with manufacturer-certified activities of 2.04, 1.96, 1.85, 1.70, 1.55, and 0.81 GBq totaling $9.92 \pm 2.0\%$ GBq (268 mCi), and 116 ^{137}Cs sources totaling $41.1 \pm 2.0\%$ GBq (1,110.0 mCi decay-corrected to 1 April 2026), were inside the smaller steel cylinder. Each ^{226}Ra source was itself contained in a sealed cylindrical 3.0 mm thick, 2.0 cm diameter, and 11.0 cm long steel “cigarette”-type individual capsule. The ^{137}Cs sources were all contained in a single sealed cylindrical 3.0 mm thick, 5.2 cm diameter, and 7.4 cm long steel capsule, as seen in Fig. 2. Once appropriate identification of each specific source was done, the process of loading them into six Type A containers for international air shipment was undertaken (model SC1921G-3X6, Hopewell Designs, Inc., Alpharetta, GA). The sources were loaded as follows: all 116 ^{137}Cs sources were loaded into container #5256115, the 2.04 GBq (55.0 mCi) ^{226}Ra source into container #5256114, the 0.81 GBq and 1.55 GBq (22.0 mCi and 42.0 mCi) sources into container #3256052, the 1.70 GBq (46.0 mCi) source into container #5256110, the 1.96 GBq (53.0 mCi) source into container #3256051, and the 1.85 GBq (50.0 mCi) source into container #5256111. These containers meet or exceed IAEA Series SSR-6 (Rev. 2) safety standards (IAEA 2018). The Model SC1921G-3X6 Type A container is a



Fig. 1. Tipped over 200-L steel drum with smaller steel cylinder containing the sources removed. Note the hollow concrete cylinder inside the drum.



Fig. 2. The six ^{226}Ra sources (in outer circle) and 116 ^{137}Cs sources (in center circle) inside the smaller steel cylinder.

20-gallon drum, incorporating a reusable foam packaging and lead shield to hold the source(s) in the approximate center. The lead shield inside is 23 cm in diameter by 30.5 cm in height, surrounded by foam to center it in the drum. The outer dimensions of the drums are 46.35 cm in diameter and 54.61 cm in height, as seen in the drawing in Fig. 3. After torquing the lids of the six Type A containers with the sources inside, internationally required (IATA 2026) external wipe tests were performed (Bertin Environics RadEye B20-ER survey meter, Daytona Beach, FL; Ludlum Model 3001 Multi-Detector Survey Meter, Sweetwater, TX). The wipe tests were performed on both the lids and the bodies of each container, and the procedure took two days. Also as required for the determination of the transport index (TI), dose-rate measurements on contact and at 1.0 m were taken (Teledyne FLIR IdentiFINDER R225 Spectroscopic Personal Radiation Detector, Portland, OR). Finally, the six containers were labeled, strapped, and placed on pallets for transfer from INCAN to Silvio Pettrossi International Airport at Asuncion, ready for air shipment (Fig. 4).

RESULTS AND DISCUSSION

All numerical data are presented as mean $\pm$ standard deviation. In cases of single measurements, the manufacturer's quoted instrument precision is used. Statistical analysis was carried out using GraphPad Prism (version 8.0) and groups were compared using one-way analysis of variance (ANOVA) and a post hoc Mann–Whitney U test. P values < 0.05 were considered significant, consistent with generally accepted standards in biomedical applications (Bevington and Robinson 2003; Galiano and Lapointe 2019). Upon initially entering the vault and before manipulating the 200-L drum, the exposure rates on contact and at 1.0 m were $10.0 \pm 2.0 \text{ mR h}^{-1}$,

Model SC1921G-3X6

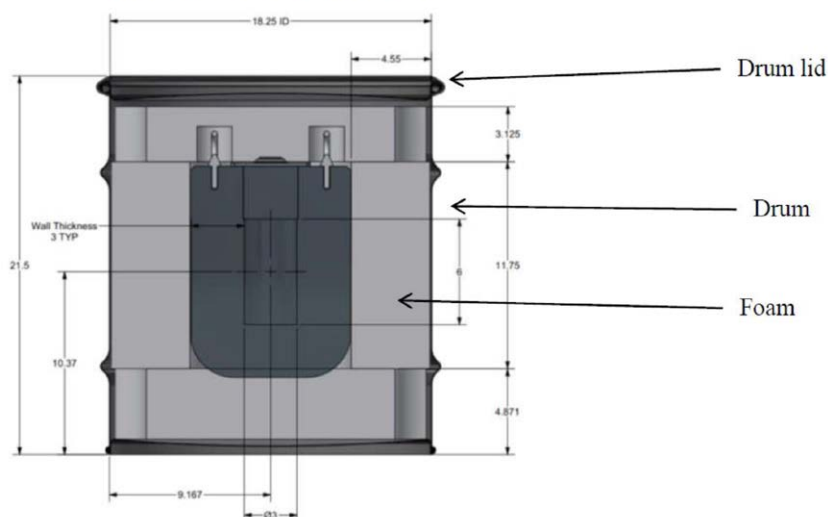


Fig. 3. Cross section of Type A shipping containers used for shipment of all the sources. All dimensions in inches.



Fig. 4. The six Type A shipping containers, covered, torqued, labeled, strapped, and placed on pallets, ready for transfer to the airport.

Table 1. Results of external wipe tests on the first four containers (Day 1, Bertin Environics RadEye B20-ER survey meter). Background was 1.0 cps cm⁻², all measurements $\pm$ 5%.

Date	Container ID	Container lid	Container body
		alpha/beta/gamma (cps cm ⁻²)	alpha/beta/gamma (cps cm ⁻²)
01/27/2026	05256115	0.58	0.23
01/27/2026	05256114	0.46	0.48
01/27/2026	03256052	0.50	0.35
01/27/2026	05256110	0.40	0.39

and 0.15 ± 0.03 mR h⁻¹, respectively (Victoreen model 493 detector, model 493-50 gamma/beta probe, Cleveland Heights, OH). Upon removal of the lid of the drum, the exposure rate at 1.0 m increased to 0.70 ± 0.15 mR h⁻¹ — a fivefold increase. External wipe tests on the drum's surface proved negative for removable contamination. After removal from the main drum, the following exposure rates were measured for the smaller steel (inner) cylinder containing all the sources (Figs. 1 and 2): 33.0 ± 5.7 mR h⁻¹ on contact with the lid on and 88.0 ± 9.03 R h⁻¹ at 5.0 cm with the lid removed. Note that this uncovered exposure rate is equivalent to 88,000 mR h⁻¹! No attempt was made to take a measurement on contact with the uncovered inner cylinder due to the expected excessive dose the operator would receive, and the risk of paralyzing the detector (Hall and Giaccia 2006). For obvious reasons, paralysis under such extreme working conditions cannot be tolerated (Martin 2006; NCRP 1997; Rossi 1956; Zinke-Allmang et al. 2017).

The results of external wipe tests on the six containers are presented in Tables 1 and 2. In all cases, the external counts were well below natural background levels, with the only exception being the beta and gamma counts on the body of container

#03256051, which exceeded background by approximately 14%. However, the International Air Transport Association (IATA) alpha/beta/gamma surface contamination limit for the international civilian air transport of a Type A container is specified as 240 cpm/cm² (4 cps/cm²) net of background (IATA 2026). In the case of container #03256051, this limiting condition was satisfied by a comfortable margin, since the background-subtracted counts amounted to only 47 cpm/cm², well below the 240 cpm/cm² IATA limit (see Table 3).

In compliance with national and international air shipment requirements, in order to determine the transport index (TI), dose-rate measurements on contact and at 1.0 m were taken for each of the six Type A containers. For a Type A container, the maximum permitted dose rate on contact with any external surface cannot exceed 2.0 mSv h⁻¹ (200 mrem h⁻¹). The transport index is defined as the numerical value of the maximum dose rate in mrem h⁻¹ at 1.0 m from any external surface of the container. The transport index in turn determines the classification, coding, and labeling of the container (IAEA 2018; IATA 2026). Results of dose-rate measurements on contact and at a distance of 1.0 m for all containers are presented

in Table 3. Note that the maximum dose rates at 1.0 m for all containers (i.e., their transport indices) ranged between 0.11 and 0.44. Transport indices of 0–1.0 correspond to a II-Yellow code (medium risk); thus, all six containers were coded and labeled II-Yellow in preparation for shipment. The containers were covered, torqued, labeled, strapped, and placed on pallets for transfer from INCAN to Silvio Pettrossi International Airport at Asuncion for air shipment to the United States (Fig. 4). Under heavy police escort and tight ARRNs oversight, the sources were moved by convoy over a distance of approximately 30 km to the airport. Once at the airport and after filling out relevant paperwork, the palletized containers went through the x-ray scanner as required by local customs regulations, as shown in Fig. 5 (Galiano 2002). There was some initial concern about possible damage to the x-ray detectors from the strong gamma emissions of the sources. However, no adverse effects were observed; in fact, the resulting radiographs were determined to be of satisfactory inspection quality. Next, the palletized containers were weighed (Fig. 6); the total declared shipping weight of the six containers plus the base pallets was 1,068 kg. Approximately two days later, the palletized containers were loaded onto a commercial cargo aircraft for a flight to the United States. At the request of ARRNs personnel present during the loading process, the containers were loaded in the aft cargo hold of the aircraft to minimize the in-flight dose to the crew in the flight deck, which the loadmaster understood and agreed to (Fig. 7). Cargo aircraft carry no passengers or cabin crew; rather, all

Table 2. Results of external wipe tests on the last two containers (Day 2, Ludlum Model 3001 Multi-Detector Survey Meter). Backgrounds were alpha 1.0 cpm cm⁻², beta/gamma 325 cpm cm⁻², all measurements $\pm$ 5%. The only measurement above background (14%) was that of beta/gamma of body of container #03256051.

Date	Container ID	Container lid		Container body	
		alpha (cpm cm ⁻²)	beta/gamma (cpm cm ⁻²)	alpha (cpm cm ⁻²)	beta/gamma (cpm cm ⁻²)
01/28/2026	03256051	1.0	261	0.0	372
01/28/2026	05256111	1.0	227	1.0	301

Table 3. Dose rate measurements in SI (and legacy units) on contact and at a 1.0 m distance, for all containers (Teledyne FLIR IdentiFINDER R225 meter). The maximum dose rates in mrem/h at 1.0 m for all containers — i.e. their Transport Indices — ranged between 0.11 and 0.44, corresponding to a II-Yellow code (medium risk). All measurements ± 10%.

Date	Container ID	Contents	Max surface dose rate in $\mu\text{Sv h}^{-1}$ (mrem h ⁻¹)	Max dose rate at 1.0 m in $\mu\text{Sv h}^{-1}$ (mrem h ⁻¹)
01/27/2026	05256115	Cs-137: 41.1 GBq (1110 mCi)	6.0 (0.6)	1.1 (0.11)
01/27/2026	05256114	Ra-226: 2.04 GBq (55 mCi)	80 (8.0)	3.7 (0.37)
01/27/2026	03256052	Ra-226: 2.36 GBq (64 mCi)	93 (9.3)	4.4 (0.44)
01/27/2026	05256110	Ra-226: 1.70 GBq (46 mCi)	57 (5.7)	3.5 (0.35)
01/27/2026	03256051	Ra-226: 1.96 GBq (53 mCi)	78 (7.8)	3.5 (0.35)
01/27/2026	05256111	Ra-226: 1.85 GBq (50 mCi)	61 (6.1)	3.4 (0.34)

crew members are in the flight deck. ARRN also requested that, if possible, the containers be loaded with no other cargo in the aft cargo hold to minimize dose to ground handlers at the departure and arrival airports. This can be understood considering that if there is no additional cargo to load into or unload from the aft cargo hold, the time needed by ground handlers

in proximity to the containers is minimized. The loadmaster also accommodated this request. The key idea here was the ALARA concept, i.e. to reduce the risk of any stochastic effects on crew and/or ground personnel.

CONCLUSION

The dose rates at 1.0 m for all containers (their transport indices)

ranged between 0.11 and 0.44, corresponding to a II-Yellow (medium risk) code. Therefore, all six containers were coded and labeled II-Yellow. External wipe tests revealed no contamination above natural background, with the slight exception of one unit (14% above background). In any case, this was well below the maximum allowable surface contamination for an air-shipped II-Yellow-coded Type A container. There was concern about possible damage to the airport x-ray detectors from the gamma emissions of the sources. However, no such adverse effects were observed. At ARRN’s request, the containers were loaded in the aft cargo hold of the cargo aircraft, without any other cargo. The purpose was twofold: to minimize the dose to the flight deck crew during flight and to ground handlers during the loading and unloading of the containers. In summary, it is possible to safely transfer decommissioned legacy ²²⁶Ra and ¹³⁷Cs medical sources from willing possessor countries to willing recipient countries, provided all national and international safety standards are strictly followed. Based on our experience, we recommend that any country considering such a transfer give serious consideration to availing itself of the safety and security standards associated with the International Atomic Energy Agency’s Global Radium-226 Management Initiative.



Fig. 5. The palletized containers ready to slide through the x-ray machine at the airport, under the author’s supervision.



Fig. 6. The six containers and base pallets being weighed. Total declared shipping weight was 1,068 kg.



Fig. 7. Loading the containers in the rear cargo hold of the aircraft to minimize dose to the crew, under the author's supervision.

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REFERENCES

- Bevington PR, Robinson DK. Confidence intervals. In: Data reduction and error analysis for the physical sciences. 3rd ed. New York: McGraw Hill; 2003: 208–210.
- Demirci E, Selcuk NA, Beydagi B, Ocak M, Toklu T, Akcay K, Kabasakal L. Initial findings on the use of [225Ac]Ac-DOTATATE therapy as a theranostic application in patients with neuroendocrine tumors. *Mol Imaging Radionucl Ther* 32:226-232; 2023.
- Galiano E. The digital radiographic and computed tomography imaging of two types of explosive devices. *Appl Radiat Isot* 57:861-865; 2002.
- Galiano E, Lapointe M. Mechanical, chemical, structural, and radiological changes in pigeon bone, associated with the dietary intake of nickel recovery slag. *J Environ Sci Pollution Res* 5:348-351; 2019.
- Hall E, Giaccia A. Radiobiology for the radiologist. Philadelphia, PA: Lippincott Williams & Wilkins; 2006.
- International Atomic Energy Agency. Regulations for the safe transport of radioactive material. IAEA Safety Standards Series No. SSR-6 (Rev. 2). Vienna: IAEA; 2018: 107–110.
- International Atomic Energy Agency. Recycling radioactive sources to support cancer treatments [online]. 2025. Available at <https://www.iaea.org/newscenter/news/recycling-radioactive-sources-to-support-cancer-treatments>. Accessed
- International Air Transport Association. Dangerous Goods Regulations. 67th ed. Montreal: IATA; 2026.
- Johns HE, Cunningham RC. Brachytherapy: intercalary and interstitial sources. In: The physics of radiology. Illinois: Thomas Publisher; 1983: 453–455.
- Martin JE. Physics for radiation protection: a handbook. Germany: Wiley GmbH; 2006:650.
- Maslov OD, Sabelnikov AV, Dmitriev SN. Preparation of 225Ac by the

- ^{226}Ra (gamma,n) photonuclear reaction on an electron accelerator, MT-25 microtron. Radiochem 48:195-197; 2006.
- NCRP. Calibration of survey instruments used in radiation protection for the assessment of ionizing radiation fields and radioactive surface contamination. NCRP Report No. 112. Bethesda, MD: National Council on Radiation Protection and Measurements; 1997.
- Pirchio R, Galiano E, Saravi M, Banchik D, Munoz C. On the physical, spectral, and dosimetric characteristics of a new brachytherapy source. Med Phys 34:2801-2806; 2007.
- Rossi HH. Radiation dosimetry. In: Hine GJ, Brownell GL, eds. Radiation dosimetry. New York: Academic Press; 1956:667–691.
- Zinke-Allmang M, Nejat R, Galiano-Riveros E, Bayer J, Chen M. Applied clinical physics. In: Physics for the life sciences. Nelson Education Ltd; 2017: 658–659.
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