



OPEN The Rhisotope project: using radiation for conservation

Jordan A. Clark^{1✉}, James Larkin², Craig M. Marianno¹ & Thomas E. Johnson³

The illegal poaching of rhinoceros for their horns continues to threaten the survival of the species despite ongoing conservation efforts. As black-market demand grows, poaching and smuggling methods have become more advanced, outpacing the effectiveness of current strategies. In response, the Rhisotope Project proposes a novel deterrent: the implantation of low-activity radioactive sources into rhinoceros' horns to exploit the public fear of radiation and improve horn detection at borders. This research shows that radioactive horn implantation poses minimal risk to the animals' health and that the probability of radiation-induced harm is significantly lower than the likelihood of being poached. Measurements collected from 16 white rhinoceroses six months post-implantation revealed no adverse biological effects, and all recorded dose rates remained below deterministic thresholds. These findings support both the safety and feasibility of the approach. Radiation inclusion in the horns could decrease poaching risk, improve seizure rates, and support rhinoceros population survival. This method may also serve as a reference point for safe radiation application in the other four rhinoceros' species. Additionally, the concept could extend to other endangered fauna and flora. This innovative approach shows the ethical and practical utilization of radiation-based anti-poaching measures, contributing to conservation efforts.

Poaching crisis

There are international criminal networks entangling weapons, drugs, counterfeit goods, and rare animal commodities. These illegal operations extend to all parts of the globe harming not only human populations but also animals. The high market demand for rare and unique animal commodities targets specific animal species leading to their detriment caused by poaching. Specifically, the five rhinoceros species located in the eastern hemisphere have diminishing conservation statuses from "nearly threatened" to "critically endangered" due to consumer interest in their horns fuelling the poaching enterprise¹. With less than 30,000 rhinoceros left globally, this poaching crisis increases the probability of extinction from the wild within the coming decades without effective preventive action².

Campaign endeavor

To combat the declining rhinoceros' population, a physical and psychological deterrent to diminish the supply and demand of rhinoceros horns is paramount. A resource resistant to climate, cost-effective psychology of radiation deceiving, and increasing criminal penalties would provide a novel innovation for counteracting the poaching crisis. A solution is proposed using radioactive sources. Radiation offers advantages due to its physical properties, enabling long-lasting applications that can be tailored to specific scenarios for both animal species and detection purposes. The act of inserting a radioactive source into the horn of rhinoceros is expected to dissuade end user interest where practices include displaying the horn as a status symbol or consuming them as part of a decoction at gatherings³. On the supplier side, the radioactive implants will increase the physical detection capabilities during transport regardless of the means of transportation. Note that importation, possession, and use of rhinoceros horn materials is considered illegal in every country in the world. It is possible that persons importing rhinoceros horn could be injured by ingestion, or injection of rhinoceros horns from the Rhisotope project, however, the focus was only in the area of detection of rhinoceros horns.

Health of the animal

The health and safety of the rhinoceros has been the primary focus of this project's feasibility. Radiation dose calculations to ensure the health and well-being of the rhinoceros from the presence of a radiation source in its

¹Department of Nuclear Engineering, Texas A&M University, 423 Spence St, College Station, TX 77843, USA.

²Radiation and Health Physics Unit, Witwatersrand University, Johannesburg, South Africa. ³Environmental and Radiological Health Sciences, Colorado State University, Fort Collins, CO, USA. ✉email: jordanhillis98@gmail.com

horn were prioritized from the start of the project. With the horn composition consisting of keratin, melanin, and octocalcium sulphates, the horn is comparable to a fingernail⁴. Due to cell keratinization, the absence of live cells within the horn material makes the exposure from radiation an external dose. The composition of the horn provides a solid, non-porous structure for the implanted radiation source to stay set without movement. Since limited information is available regarding the effects of radiation on rhinoceros, human limits were applied to the animal for this project. Historically, the International Commission on Radiological Protection (ICRP) does not apply human dose limits to Reference Animals and Plants (RAPs). Instead, RAPs are assessed using species-specific absorbed dose rates that reflect population-level impacts like reduced reproduction or survival, rather than individual cancer risk. These thresholds are based on experimental and observational data from non-human species, not extrapolated from human health standards. However, for this research, individual effects are the primary focus to prevent damage to each specimen's skin and horn development.

Furthermore, limited resources on rhinoceros skin resulted in the use of human skin dose limits, where the human basal layer is located 70 μm within the skin⁵. Although rhinoceros skin is thought to be denser and thicker than human skin, worst case estimates were used in this study due to limited species-specific data. The white rhinoceros was selected as the model species because it has the most extensive biological and anatomical data available among all rhinoceros species. All calculations demonstrated that radiation doses to the rhinoceros were within human standardized dose limits. The focus of the calculations was to predict deterministic effects (tissue reactions) to the animal, the most at-risk tissue being the epithelial basal stem cell layer producing the keratinized horn⁵. Therefore, the skin dose limit used for all rhinoceros safety calculations to prevent unacceptable deterministic effects were based on the human limit of 0.5 Gy year⁻¹¹⁶. Stochastic effects were a secondary focus due to the perceived low probability of occurrence. The more rapid occurrence of deterministic effects results in tissue reactions that will affect the overall health of the animal, which would lead to stochastic outcomes.

Methods

Theoretical modelling

Prior to the implantation, theoretical modelling provided assurances that the proposed quantity and type of radioactive materials would be safe for the animals, as well as provide an effective deterrent. Two independent computational models provided theoretical results through simulations to estimate dose rates to the rhinoceros. One model utilized a simplified geometry simulating the maximum radiation dose rate from the implanted source to the tissue of interest using the Monte Carlo N-Particle (MCNP) version 6.2⁷.

The second model was based on a detailed computer tomography scan carried out by Ohio State University that allowed the construction of a detailed segmented model of the head of a rhinoceros. Using a Geant-4 based software (RayXpert) it was then possible to model differing activity concentrations, and source placement within the horn of the rhinoceros and the resultant dose to differing parts of the head (Fig. 1). Data comparisons between the independent simulations verified dose rates estimated below the annual skin dose limit with both in agreement of the safety for real-life applications.

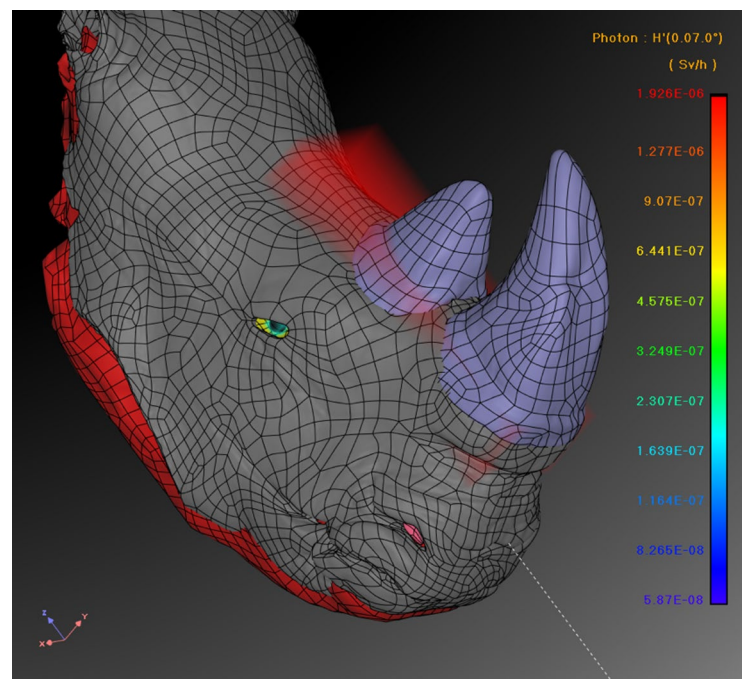


Fig. 1. Dose distribution calculated by RayXpert along with a dose concentration gradient.

Computational models

Independent theoretical models were developed to evaluate the viability of the field measurement campaign. Conducting computational modelling first enabled rapid, cost-effective evaluations to assess potential risks, optimize source strengths, and minimize unnecessary field costs, all of which informed adjustments to the design. The first model was an MCNP

radiation transport code simulating the photon source implantation into a homogeneous keratin right truncated cone⁷. Dose rates were tallied at the human basal stem cell depth at 70 μm within a soft tissue cylinder. Analysing source distances of 10 and 20 cm above the basal stem cells, 40 million particles were simulated to estimate the maximum dose rates reached to the rhinoceros. The second model used RayXpert to simulate a three-dimensional horn composed of keratin, with a human tissue values representing the plane for additional dose assessments at the depth of the epithelial basal stem cells. Validations were conducted between the empirical field measurements and theoretical computational estimates to assess model accuracy.

Field measurements

White rhinoceros (*Ceratotherium simum*) were the focus of this project due to the larger amount of existing data available. In June 2024, a total of 18 white rhinoceros and two black rhinoceros (*Diceros bicornis*) were implanted with radioactive sources by the Rhisotope and veterinarian teams. The order of source implantation for each rhinoceros was randomized based on the sequence in which animals were located, ensuring blinding of implant allocation. All experimental protocols were approved by the University of the Witwatersrand, Johannesburg Animal Research Ethics Committee (AREC) and the Rhino Orphanage, with all necessary institutional permissions and ethical approvals obtained prior to the study. All methods were carried out in accordance with the relevant guidelines and regulations of these institutions and are reported in accordance with the ARRIVE guidelines. The rhinoceroses were sourced from The Rhino Orphanage in Limpopo, South Africa, and all activities were conducted under the oversight of the reserve and collaborating institutions to ensure compliance with ethical and legal standards.

During the January 2025 measurement campaign, the Texas A&M University team evaluated 16 white rhinoceroses without knowledge of the source strengths implanted in each animal, maintaining blinding. The remaining four implanted rhinoceroses were not assessed due to terrain-related safety constraints. Additionally, five control white rhinoceroses, which did not have source implants, were also measured. The rhinoceros, familiar with their local veterinary team, were provided with hay and sedated using a mixture of etorphine, medetomidine, and azaperone. Naltrexone was used as the reversal agent. After approximately 7 to 10 min, signs of sedation were observed, and the veterinary team would cover their eyes with a mask and use earplugs to limit sensory input, and the animals were placed in a recumbent position, allowing the measurements to be taken.

For source implantation a drill was used to create a 4 mm diameter hole in each horn, at an appropriate distance from the skin to optimize the use of the radioactive source without increasing radiological risk to the at-risk tissue. A pure cobalt pellet containing ^{60}Co was inserted with source strengths consistent with positive detection capabilities for radiation portal monitors. The sources were cemented into the horn to ensure permanent placement.

During the measurement campaign, the same sedation process was applied, and approximately ten measurements were taken from various locations on each rhinoceros, including four points at the perimeter of the horn base, four at the perimeter of the mid-horn height, the forehead, and the eye socket. Two calibrated Mirion Accurad Personal Radiation Detectors (PRDs) were used to collect dose and count rate data. The Accurad PRDs report dose rates as personal dose equivalents, $\text{Hp}(10)$, for whole-body dose. The device has an accuracy of $\pm 10\%$ for ^{137}Cs and is energy-compensated, ensuring accuracy across different energies, especially for ^{137}Cs and ^{60}Co . For the source strengths used in the field, the Accurad can accurately measure the doses starting from as low as $0.1 \mu\text{Sv h}^{-1}$ using its energy-compensated CsI(Tl) detector⁸. Dose rate measurements were then evaluated against the respective dose limits to assess the radiation absorbed by the rhinoceros' skin and evaluate the potential risks, including the likelihood of DNA damage or cancer. The empirical field dose rates were compared to reference values for deterministic and stochastic skin effects, and risk probabilities were calculated to ensure the safety of each rhinoceros. Further analysis considered the risk of individual rhinoceroses to poaching within South Africa.

Results

Measurement campaign

After the analysis of safe applications through theoretical modelling, the first radiation source implantations into rhinoceros' horns were completed in June of 2024. In January of 2025, a measurement campaign was conducted to analyse empirical radiation data from 21 white rhinoceroses, which included 16 with implanted radiation sources and five controls. The measurements included radiation dose and count rates recorded at four key locations: the horn base, mid-horn, forehead, and eye socket region for each rhinoceros (Fig. 2). The terrain, wildlife, and climate create challenging conditions for prolonged measurements. The limiting conditions lead to restrictions for some individual measurements in specific cases, which can be seen within Tables 1 and 2.

Since the skin area directly beneath the horn could not be accessed due to anatomical constraints, ten measurement locations were selected to approximate the dose received by the most at-risk tissue. Field measurement dose rates to the most sensitive regions (specifically the horn base, forehead, and eyes) did not exceed the annual skin dose limit. The forehead and eye dose rates were below 85.4% of the annual human skin dose limit (Table 1). Additionally, due to the anatomical positioning of the rhinoceros' eyes (located laterally on the head and at a greater distance from the horn) the dose rates to the eyes remained below the human occupational eye dose limit of $150 \text{ mSv year}^{-1}$ ¹⁵. This positioning provides natural attenuation from the radioactive source, helping to reduce radiation exposure. Rhinoceros are known to have poor eyesight and



Fig. 2. Measurement locations and directionality for rhinoceros field measurements. The forehead, eye, base, and mid-height locations are identified along with the directional orientation of the measurements, where the back and front of the horn are oriented with respect to the rhinoceros’ field of view.

Sample #	Name	Gender	Control/Source	Forehead (Gy year ⁻¹)	Eyeball (Gy year ⁻¹)
1	Impi	Female	Control	X	X
2	Kei	Male	Source	0.01	0.01
3	Kabira	Female	Source	0.01	0.01
4	Kabelo	Male	Source	0.01	0.01
5	Annie	Female	Source	0.03	0.02
6	Mapimpi	Male	Source	0.01	0.01
7	Amelia	Female	Source	0.01	0.01
8	Jessie	Female	Source	0.02	0.01
9	Amalie	Female	Control	0.00	0.00
10	Shamara	Female	Control	0.00	0.00
11	Kraaitjie	Female	Control	0.00	0.00
13	Beckham	Male	Source	0.01	0.01
12	Ray	Male	Source	0.01	0.02
14	Charolette	Female	Control	0.00	0.00
15	Davie Day	Male	Source	0.01	0.01
16	Alexa	Female	Source	0.01	0.01
17	Eve	Female	Source	0.01	0.02
18	Three quarters	Male	Source	0.01	0.01
19	Nenkani	Male	Source	0.01	0.01
20	Duane	Male (passed)	Source	X	X
21	Lacy	Female (passed)	Source	X	X

Table 1. Dose rate measurements for individual rhinoceros’ foreheads and eyeballs. An X marker indicates no measurement was taken.

a high prevalence of cataracts⁹. While this does not indicate greater intrinsic sensitivity, how easily a tissue or organ is damaged specifically by radiation, it may reflect a reduced tolerance to additional exposure. Given that the human eye dose limit is designed to prevent lense of the eye damage (the most radiosensitive ocular effect) it was considered an appropriate threshold to avoid deterministic outcomes in rhinoceros. Applying this worst-case limit serves as a precautionary measure, recognizing the potential vulnerability of the species’ ocular health.

Of the four perimeter base measurements taken around the horn, all recorded dose rates were under 64% of the human annual limit, except for one left-base measurement, which reached 0.4 ± 0.04 Gy year⁻¹ (Table 2).

Sample #	Name	Gender	Control/source	Base left (Gy year ⁻¹)	Base right (Gy year ⁻¹)	Base front (Gy year ⁻¹)	Base back (Gy year ⁻¹)
1	Impi	Female	Control	0.00	0.00	0.00	0.00
2	Kei	Male	Source	0.03	0.06	0.04	0.09
3	Kabira	Female	Source	0.00	0.00	0.00	0.00
4	Kabelo	Male	Source	0.06	0.06	0.03	0.08
5	Annie	Female	Source	0.05	0.13	0.03	0.14
6	Mapimpi	Male	Source	0.11	0.05	0.04	0.11
7	Amelia	Female	Source	0.05	0.05	0.04	0.13
8	Jessie	Female	Source	0.09	0.09	0.04	0.13
9	Amalie	Female	Control	0.00	Laying on side	0.00	0.00
10	Shamara	Female	Control	0.00	0.00	0.00	0.00
11	Kraaitjie	Female	Control	On side	0.00	0.00	0.00
13	Beckham	Male	Source	0.09	0.14	0.08	0.18
12	Ray	Male	Source	0.06	0.04	0.04	0.12
14	Charolette	Female	Control	0.00	0.00	0.00	0.00
15	Davie Day	Male	Source	0.08	0.08	On ground	0.12
16	Alexa	Female	Source	0.13	0.09	0.10	0.08
17	Eve	Female	Source	0.40	In bush	In bush	0.13
18	Three quarters	Male	Source	0.03	0.04	0.01	0.08
19	Nenkani	Male	Source	0.01	0.03	0.01	0.07
20	Duane	Male (passed)	Source	0.04	0.05	0.07	0.07
21	Lacy	Female (passed)	Source	0.01	0.01	0.01	0.02

Table 2. Dose rate measurements for individual rhinoceros’ base locations.

However, 0.04 Gy year⁻¹ is below the 0.5 Gy year⁻¹ threshold for deterministic human skin effects. The highest dose rates were observed at the centre mid-height and base of the horn, corresponding to the area where the source was implanted from the backside of the horn. The measurement results align with modelling expectations even with changes in shielding attenuation, where the natural keratin of the horn was replaced by the adhesive and wooden plugs used to seal the drill hole where the radioactive source was inserted. Two measurements at the left base recorded higher dose rates than the back base, likely due to inconsistencies in the hole placement among individuals. These deviations were influenced by environmental stressors, drilling limitations, and restricted quality control. Similar inconsistencies were observed in count rate data, where in 7 of the 21 measurements, other base positions recorded higher counts than the rear placement.

Unfortunately, two rhinoceroses with implanted sources expired during the study period. Duane, a male, expired in December 2024, succumbing to injuries from a fight with another male. Lacey, a female, expired from a *Clostridium Novyi* type D infection, that can be fatal within five hours of exposure. By law, deceased rhinoceros must have their horns removed and placed into safe keeping. In this case, removal of the horn with the source still inserted allowed for a unique measurement at the exact centre of the horn base, directly beneath the radiation source, which was not feasible in the live animal. This location holds importance as the epithelial basal stem cells producing the horn are hypothesized to be the most radiosensitive area. Measuring the dose rate at the horn base therefore provides the most accurate estimate of radiation exposure to the most sensitive tissue. In contrast, dose measurements in live specimens could only be taken around the outer circumference of the horn, limiting direct assessment of stem cell exposure. The maximum dose rates recorded at the horn base for Duane and Lacey were 0.04 ± 0.004 Gy year⁻¹ and 0.007 ± 0.0007 Gy year⁻¹ respectively. Duane reported a higher dose rate due to receiving a higher activity source and potentially having the source closer to the skin compared to Lacey’s source placement. Regardless, both values remain well below the human skin dose limit.

The computationally derived theoretical dose rates were validated with the empirical field measurements. Using a personal radiation detector with a stated accuracy of ± 10% to collect the empirical dose data, all measured values fell within the bounds of the theoretical dose rates corresponding to the source height. This agreement was consistent across both theoretical modelling approaches, supporting the independent validity of each method.

Risk of skin deterministic and stochastic effects

As previously stated, this project focuses on deterministic effects (tissue reactions that are generally predictable based on the physical exposure conditions and the specific area of skin irradiated). In contrast, stochastic effects are probabilistic in nature and are primarily associated with cancer risk. The human absorbed dose limit of 0.5 Gy year⁻¹ serves as a deterministic threshold intended to prevent unacceptable damage to epithelial basal cells. In comparison, the dose rates observed during this measurement campaign align with findings from ICRP publication 124, which reported no observable effects in reference deer and rats at dose rates between 0.004 and 0.04 Gy year⁻¹.

The limit for beta particle exposure was also evaluated, as ⁶⁰Co emits a 0.31 MeV beta particle. Due to the shallow penetration depth of beta radiation, the beta particle emission threshold is set at 10¹⁰ particles per

second (10 GBq) for a small area of skin, assuming one beta particle is released per disintegration¹⁰. Exceeding this threshold could create a localized acute ulceration, representing the deterministic effect threshold for beta exposure. However, all source strengths used in this campaign were less than half of this beta dose limit, and contained only in the horn, providing complete shielding of the beta particles, providing a large safety margin.

Stochastic effects (particularly the risk of radiation-induced skin cancer) were addressed as a secondary concern. The estimated risk of developing non-melanoma skin cancer in humans from exposure to a 'hot particle' (highly radioactive beta emitting source of radiation) is approximately 7×10^{-7} per Gy, assuming a localized exposure area of 2 mm^2 ¹¹. The corresponding human mortality risk from such exposure is even lower, at 1×10^{-9} per Gy¹¹. This means that for every 1 Gy of absorbed dose to a small patch of skin, there is a 7 in 10 million chance of developing skin cancer, and only a 1 in a billion chance of the cancer being fatal. Given that the average lifespan of a rhinoceros is approximately 40 years, the extended time typically associated with radiation-induced cancers further reduces the likelihood that such effects would develop within the animal's natural lifetime¹².

Applying these human risk factors to the highest dose rates recorded at the base of the horn during the January 2025 measurement campaign, the estimated probability of inducing non-melanoma skin cancer is approximately 2.8×10^{-7} (or 2.8 in 10 million), and the estimated probability of fatality is 4×10^{-10} (or 4 in a billion) (Eqs. 1 and 2). These risk levels remain well below thresholds of concern and align with regulatory safety expectations.

$$0.4 \text{ Gy year}^{-1} \cdot 7 \times 10^{-7} \text{ Gy}^{-1} = 2.8 \times 10^{-7} \quad (1)$$

$$0.4 \text{ Gy year}^{-1} \cdot 1 \times 10^{-9} \text{ Gy}^{-1} = 4 \times 10^{-10} \quad (2)$$

Stochastic effects such as cancer induction are considered to have no threshold, meaning the probability increases with dose, but severity does not. However, the ICRP emphasizes that the human risk per unit dose is significantly reduced when the exposure is superficial, as with low-energy beta particles. In ICRP Publication 103, the nominal probability coefficient for human cancer induction from low linear energy transfer (LET) radiation exposure is approximately 5.5×10^{-2} per Sv for the whole population, which is substantially higher than localized skin exposure scenarios, reflecting the reduced risk for shallow, small-area exposures like those from embedded sources¹³.

Furthermore, both National Council on Radiological Protection (NCRP) and ICRP agree that when the absorbed dose remains below the deterministic threshold (0.5 Gy yr^{-1} to the skin), the risk of clinically significant effects is minimal, and any stochastic risk (particularly for localized hot particle exposures) is negligible¹⁴.

Activity|dose|risk

The current radiation source activities implanted into the rhinoceros horns resulted in dose rates well below the human annual skin dose limit for deterministic effects. Even if the source activity was doubled, the estimated dose rate would reach approximately 0.3 Gy year^{-1} , still below the human deterministic threshold of 0.5 Gy year^{-1} . If tripled, the dose rate measured 10 cm from the rhinoceros' skin would be approximately 0.4 Gy year^{-1} . While this remains below the human deterministic threshold, some outlier dose rates may occur due to variability in source placement and quality control during implantation.

Ultimately, decisions regarding source strength rest with key stakeholders (government agencies, private reserve managers, and national park authorities), who must weigh detection benefits against biological risk. Higher activity sources offer increased potential for detection during smuggling or border transport, enhancing the deterrent effect of the Rhisotope strategy. However, increasing the source strength will directly increase the biological risk to the animal.

Discussion

All five rhinoceros' species worldwide face a serious threat of population decline due to poaching. Most of the global rhinoceros' population is in South Africa, where the combined number of black and white rhinoceros was estimated to be approximately 16,056 at the end of 2023². During the same year, 499 rhinoceroses were illegally killed, resulting in a poaching incidence rate of 3.1% for an individual rhinoceros¹⁵.

This annual risk of poaching (3.1%) is orders of magnitude higher than the probability of a rhinoceros experiencing negative health effects from the controlled placement of a radioactive source in its horn. For example, the estimated risk of developing non-melanoma skin cancer from the highest recorded dose is approximately 0.000028%, and the risk of a fatal cancer outcome is only 0.00000004%. When compared directly, a rhinoceros is over 100,000 times more likely to be killed by poaching than to develop a non-fatal cancer from this intervention, and over 77 million times more likely to be poached than to die from a radiation-induced cancer. These probabilities represent that the risk of harm from inaction against poaching overwhelmingly exceeds the minimal and controlled radiological risk posed by this protective measure.

As supported throughout this report, the radiological risk to individual rhinoceroses is minimal, especially when compared to the far more immediate and devastating threat posed by poaching. From both a conservation and radiological safety standpoint, the greater detriment lies in inaction against poaching, not in the controlled and limited use of radioactive sources for protection. South African government officials estimate that if poaching rates reach 3.5% annually, there will be a collapse in the wild populations of rhinoceros¹⁵. In response to this escalating risk, a targeted public relations campaign accompanies the conservation work and is conducted through visible on-site signage, controlled demonstrations for local staff, and targeted information sharing designed to spread credible deterrence messaging through community networks. This is reinforced by coordinated international media engagement, ensuring both local and global audiences understand the enhanced protection, traceability, and enforcement measures in place.

The strategic inclusion of radioactive sources enhances the likelihood of detecting poached horns during transit, especially at border crossings. Based on known activity levels and typical detection thresholds of radiation monitoring systems, the probability of interception can be increased significantly. Future work will focus on refining detection models to account for various real-world scenarios, including different transit routes, concealment methods, and environmental conditions. Additional shielding assessments are needed to better understand the limitations and performance of radiation monitoring systems under diverse configurations. Expanding the analysis to include international border crossings, airport screenings, and other high-risk trafficking routes will provide a more comprehensive evaluation of detection capabilities. These continued efforts will strengthen the strategic use of radioactive sources, supporting the Rhisotope Project's mission to protect rhinoceroses through both enhanced biological safety and increased likelihood of interception during illegal transport.

Conclusion

The rhinoceros population faces an imminent threat, and without immediate, innovative action, there is a risk of losing the last remaining individuals. To alter the course of the rhinoceros' future, rapid and creative solutions must be implemented. Radioactive sources and nuclear science present a unique opportunity to disrupt the illegal poaching industry. By reducing consumer demand, making the horn undesirable with the inserted radioactive source, turning it into a hazardous commodity, increasing penalties for poachers from unauthorized possession of both the horn and radiation sources, and boosting the likelihood of border seizures, radiation offers a promising approach. Prioritizing rhinoceros safety while ensuring that radiation doses remain below the human deterministic threshold levels was successful for all 16 measured rhinoceroses. The stochastic effects on the animals were also reported to be several orders of magnitude below the concerns for radiation-induced cancer. This project demonstrates that radiation as a solution is feasible, as the conservative source strengths used in the study stay within safe limits and do not increase the risk of adverse effects. These findings allow for increasing the source strength to further improve detection probabilities at borders. The Rhisotope initiative has the potential not only to protect rhinoceros but also to safeguard other endangered species by setting a powerful precedent.

Data availability

Data is provided within the manuscript file.

Code availability

The authors declare that the data supporting the findings of this study are available within the paper. Materials and correspondence will be communicated through Jordan Clark.

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Author contributions

J.L. initiated the concept of the study. J.L., J.C., and C.M. developed the methodology. J.C. and C.M. conducted data processing and modelling with the support from J.L. and T.J. All authors discussed the results and improved the writing of the paper.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to J.A.C.

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