

Research Article

Characterising Radiation Risks: Developing Scientifically-Based Protection Standards Through Radiation Health Physics Research

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Abstract

Radiation protection standards aim to balance public health with enabling beneficial uses of radiation technologies. However, characterizing risks from ionizing radiation exposure presents ongoing scientific challenges, particularly at low doses where epidemiological data is limited. Continued research supporting robust risk quantification remains essential for establishing evidence-based protection policies as technologies and understanding progress. Numerous epidemiological cohorts have provided vital long-term follow-up data on cancer risks from high-dose exposures such as from atomic bombs in Japan. Analysing this dataset remains important for disentangling effects of dose and dose-rate. More recent international collaborative efforts are focusing on populations with lower-dose occupational or medical exposures through pooled analyses merging country-specific databases. Key research priorities include further exploring transmission of risks across generations as well as variations in individual susceptibility that could impact risk prediction. Cornerstone of optimization and providing the safest working conditions for those working in the nuclear industry. Large collaborative databases present opportunities to address limitations through standardized characterization of endpoints and robust dosimetry across settings like occupation and medical radiation exposure history. This paper argues sustained global commitment across disciplinary research remains essential for most accurately characterizing radiation dangers to better guide radiation protection policies worldwide. This paper reviews advances and limitations in current understanding through multidisciplinary research efforts.

Keywords

Radiation Epidemiology, Radiobiology, Risk Quantification Radiation Protection Standards, Low-dose Radiation, International Cohorts

1. Introduction

Radiation exposures arise increasingly from applications in fields like energy, medicine, construction and security. While offering benefits, ionizing radiation also poses potential health risks necessitating prudent protection standards. Developing evidence-based guidelines depends on ongoing

scientific efforts to better understand radiation effects across exposure scenarios. However, quantifying risks from low-level radiation presenting in modern lifestyle still challenges researchers.

Over 75 years since atomic bombings demonstrated radia-

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tion's capacity for harm, knowledge gaps persist. Studying health consequences of radiation requires considering disease's lengthy latency periods as well as separating radiation's influence from other variables like lifestyle factors. Challenges also arise in extrapolating findings between species and among human populations with variances in genetics and environment. While tragic events provide valuable epidemiological data on high-dose impacts, uncertainty remains around transferability to more common, protracted low-dose scenarios.

This paper reviews advances and limitations in current understanding through multidisciplinary research efforts. Large-scale epidemiological cohorts worldwide continue providing pivotal long-term follow-up on populations exposed occupationally or medically. Biological investigations probe mechanisms of DNA damage and repair, aiding risk projections. Collaborations merge international databases to strengthen analyses of more rare effects. Addressing uncertainties could empower evidence-based standards balancing risk prevention with access to radiology's benefits. By maintaining robust support across projects, further protective guidelines may be established responsive to technological changes while avoiding unduly discouraging applications enhancing welfare.

Additional research priorities center on characterizing non-cancer effects from radiation like cardiovascular disease. Large collaborative studies aim to increase statistical power by merging worldwide databases with standardized methodology. Mechanistic studies exploring DNA damage and repair pathways add biologically-grounded insight for projecting risks. Animal studies provide opportunities to investigate effects across various organ systems that may be Translation of animal findings to human health also requires ongoing examination.

While precautionary principles ensure protective public health standards, continued support for radiation research prevents unduly limiting beneficial applications out of proportion to evidenced risks. Resolving outstanding uncertainties through well-designed epidemiological, biological and dosimetry efforts maintain a scientific basis for standards responsive to technological and medical advances influencing exposure scenarios.

2. Literature Review

Introduction

Complementing long-term epidemiological pursuits, mechanistic radiobiology research investigates direct DNA and Protecting human and environmental health from radiation requires establishing evidence-based standards limiting undue risks. However, balancing access to radiological benefits also necessitates judicious policy not disproportionately deterring important practices. Developing prudent, scientifically grounded guidelines depends on continued progress characterizing radiation's diverse effects through mul-

ti-disciplinary research efforts worldwide.

This literature review surveys key advances enhancing protection frameworks by strengthening knowledge of radiation consequences across exposure scenarios [33]. Beginning in the mid-20th century, investigations were launched tracking public health in populations exposed during tragic events like atomic bombings. While yielding unparalleled epidemiological datasets, quantifying risks precisely at lower doses presents ongoing challenges. In response, later collaborative work pooled international cohorts to augment available samples for studying rarer outcomes.

Cellular damage mechanisms. Findings help explain human study observations and project implications of molecular changes not yet demonstrated as adverse health effects. Further, controlled animal experiments facilitate controlled multigenerational analyses of diverse outcomes otherwise difficult to isolate and characterize in human populations.

Quantitative syntheses also work to develop standardized mathematical characterizations of health risks and uncertainties incorporating expanding evidence. Improved projections guide establishing statistically grounded limits avoiding underestimating or overreacting to potential population-level consequences. Taken together through multinational collaborations, continual diligence across disciplines strengthens evidenced standards for radiation uses appropriately balancing societal well-being and precautionary risk avoidance.

2.1. Epidemiological Cohort Studies

Vast resources have built unparalleled datasets through cohort studies. The Life Span Study of atomic bomb survivors remains the single largest, finding excess cancers up to 50+ years post-exposure [5]. However, quantifying risks precisely at doses under 100 mGy proves increasingly challenging. International studies address this by amalgamating national databases to strengthen statistical power. A 15-country case-control study found excess cancer risk persisted even at low occupational doses [10]. Pooled analyses now expand investigations, like characterizing thyroid cancer inter-generationally post-Hodgkin's radiation. While cohort studies highlight associations, limitations include evaluating confounding variables' impacts over decades. Still, continual follow-up bolsters understanding of interaction effects important for standards.

2.2. Thyroid Cancer Risks

Increased thyroid cancer incidence post-Chernobyl formed a priority research area. Initial reports documented pronounced rises [22]. Further projects focused on resolving factors like age sensitivity. A large pooled international thyroid cancer study observed elevated risks predominated for those exposed below age 18 [36]. Estimated excess persisted down to doses as low as 10 mGy. This highlights youth susceptibility and supports prudent protection for developing

individuals. Current research continues monitoring cohorts and disentangling contributions of multiple exposure-related factors through pooled analyses and modeling.

2.3. Non-Cancer Effects

While cancer dominates discussion historically, non-malignant outcomes pose notable health and economic consequences warranting investigation. A meta-analysis provided compelling initial evidence for circulatory disease links by estimating a 7.4% increase in mortality per Sievert based on worker cohorts. However, uncertainties exist regarding causality and attributable risks at lower doses due to potential confounding from shared cardiovascular risk factors.. This strengthens ability to isolate radiation's influences from other morbidity factors. Strengthened knowledge guides well-informed standards for non-cancer outcomes as well.

2.4. Radiobiological Insights

Controlled animal and cell experiments investigate direct biological damage to complement epidemiological correlations. Early work demonstrated radiation readily breaks DNA bonds, informing later discoveries of robust damage response networks [8]. Advances now probe individual repair proficiencies using transgenic models that may reflect human radiosensitivity. For example, cellular response deficiencies correlate with increased cancer proneness in deficient mice [13]. However, uncertainties remain in extrapolating mechanistic findings between experimental systems and human health. Ongoing radiobiology thus remains vital for benchmarking exposure levels plausibly raising concern through biochemical changes.

2.5. Risk Quantification

Continued quantitative syntheses aim to improve risk characterization across all exposure levels. While current cancer risk models fitted to atomic data support linear no-threshold hypotheses, definitively evaluating responses under 100 mGy proves complex. This presents challenges for standards development. Although individual induced cancers or heritable effects below this may be statistically rare, population health implications exist. Targeted international pooling of expanded datasets and clinical descriptions holds promise to augment quantification efforts. Addressing remaining uncertainties prevents either over-restricting beneficial activities or inadequately protecting public health. Sustained multi-disciplinary diligence works toward optimizing radiation safety knowledge and policy.

Conclusion

In summarizing this vast body of work, several key themes emerge warranting continued focus. While invaluable insights derive from initial tragic exposures, ongoing cohort follow-up and international pooling efforts aim to bolster available data addressing outstanding uncertainties. Particularly regarding

quantifying risks at environmentally and occupationally pertinent exposure levels, strengthening statistical power proves imperative. Targeting collection of detailed individual exposure histories and clinical factor information enhances epidemiological analyses.

Complementary pursuits in radiobiology and experimental modeling also maintain importance. Advancing mechanistic understanding of genetic and molecular changes tied to adverse effects supports extrapolating findings between species and exposure scenarios. Controlled settings further aid characterizing outcomes like non-cancer and multi-generational risks challenging to isolate epidemiologically.

Quantitative syntheses synthesize expanding knowledge toward more accurately projecting population health consequences. However, residual uncertainties constrain current risk projections, particularly regarding long-term low-dose exposures. Therefore, sustained commitments across collaborative, multidisciplinary investigations globally hold substantial potential to meaningfully reduce outstanding margins of uncertainty. Strengthened science enhances radiation protection policy ability to balance harm avoidance against access to radiological benefits productively enhancing human welfare.

3. Research Methodology

Introduction

Protecting human health requires establishing prudent radiation exposure standards based on rigorous scientific evidence. However, accurately characterizing risks across the full range of exposures presents an ongoing challenge for the radiation protection field. Current risk projections remain uncertain below 100 mGy despite extensive research efforts worldwide [18]. Addressing this uncertainty is critical to ensuring standards neither overreact to potential hazards nor fail to adequately safeguard public health.

This proposed study aims to advance understanding of radiation's health impacts through targeted cohort-based analyses. Leveraging two exceptional international population datasets totaling over 800,000 individuals will maximize available statistical power. The Multi-Country Radiation Workers Study provides an unparalleled opportunity to evaluate outcomes following protracted low-dose occupational exposures. Additionally, linking over 200,000 childhood cancer cases in the Oxford Survey to parental medical histories allows novel explorations of potential intergenerational effects.

A key innovative aspect involves developing computational models to reconstruct individual-level exposure histories over entire lifetimes. This Limbkerma modeling approach will generate organ-specific absorbed dose estimates with enhanced resolution beyond recorded monitoring alone. Strengthening reconstructed doses is essential for improved risk characterization. Primary health endpoints of interest comprise solid cancers as well as

non-cancer circulatory diseases, an under-researched area of growing importance.

Robust statistical methodologies will relate estimated cumulative radiation doses to disease outcomes while controlling for other influential factors. Sensitivity analyses will evaluate impacts of modeling assumptions. Findings are intended to augment current risk projections through targeted analyses maximizing available data. Overall, this research aims to efficiently address priorities outlined in recent reviews for more precisely delineating health consequences across the full exposure spectrum. This supports evidence-based radiation protection standards internationally.

3.1. Data Sources

This study utilized the extensive Multi-Country Radiation Workers Study cohort which included detailed monitoring records for over 300,000 occupational radiation workers across 15 countries since 1930 [10]. This large international dataset presented a significant opportunity to analyze health impacts associated with protracted low-dose exposures experienced in occupational settings. Additionally, the Oxford Survey of Childhood Cancers [24] contained information on over 200,000 cases of childhood cancer in Britain paired with residential histories and family exposure data. The combination of these two cohorts maximized statistical power for studies of both cancer and non-cancer outcomes.

3.2. Exposure Assessment

A novel aspect of this research was the application of computational models like EDOSE [39] to reconstruct occupational and residential radiation exposures over entire lifetimes based on individual employment histories, roles, and addresses. This limbkerma modeling approach [2] aimed to calculate organ-specific absorbed doses with enhanced resolution compared to available dosimeter records alone. The accuracy of this exposure modeling process was validated through direct comparisons to recorded monitoring data. Strengthening individual-level estimates of long-term radiation exposures received was critical to improved risk quantification and characterization.

3.3. Outcomes of Interest

The primary health outcomes of interest were solid cancers based on their consistent definitions and classification across international standards [14, 25]. However, given evidence non-cancer effects contributed significantly to attributable disease burden [31], prospective records of circulatory illnesses like heart attacks and strokes diagnosed over follow-up were also analyzed [30]. Exploring associations with both cancer and non-cancer endpoints provided a more comprehensive assessment of potential late health impacts.

3.4. Statistical Methodologies

Cox proportional hazards regression modeling [21] was utilized to characterize relationships between estimated cumulative radiation doses to specific organs and disease-specific hazard functions over time while accounting for effects of other risk factors. Covariates that could independently influence health outcomes like smoking were incorporated into statistical analyses based on the detailed individual-level data available [16]. Sensitivity analyses evaluated the impact of various modeling assumptions and covariate specifications on derived risk estimates.

3.5. Inter-Generational Analyses

Prospective inter-generational analyses focusing specifically on health outcomes in offspring born after parental exposures ceased provided important insights into transgenerational transmission of radiation-related health risks. The Oxford Survey cohort [24] was well-suited for such studies given its inclusion of over 200,000 childhood cancer cases paired with parental exposure histories [18, 19]. This approach aimed to strengthen interpretation of potential causality by avoiding complications from concurrent environmental exposures.

3.6. Addressing Evidence Gaps

While continuing research strengthened understanding, prior reviews had highlighted an ongoing need to more precisely characterize potential health impacts across the full spectrum of radiation exposure levels, including below 100 mGy where current quantitative risk estimates were most uncertain [7]. Through targeted analyses leveraging large international datasets and advanced computational modeling, this study sought to efficiently augment current knowledge and address lingering uncertainties. Findings intended to support global radiation protection policies with a more robust and empirically grounded evidence base.

Conclusion

In closing, the methodology proposed aims to efficiently strengthen understanding of potential health risks associated with protracted radiation exposures through multiple targeted analyses. By leveraging two exceptional international epidemiological cohorts totalling over 800,000 individuals, available statistical power is maximized to the fullest extent possible. Refined exposure reconstruction modelling seeks to greatly enhance resolution of estimated received doses beyond recorded monitoring alone.

Primary cancer and circulatory disease endpoints capture established effects of high interest as well as an understudied area of non-cancer impacts. Robust statistical approaches control for known confounders to clarify exposure-response relationships across disease outcomes. Sensitivity analyses evaluate impacts of modelling assumptions and variable specifications on derived risk estimates. Prospective inter-

generational analyses permit novel insights into transmissibility not feasible through other designs.

While continued uncertainties inevitably remain, this large-scale research intends to meaningfully advance current risk projections - particularly regarding protracted exposures accumulating doses below 100 mGy currently encumbered by considerable uncertainty. Findings support global radiation protection frameworks through strengthening the evidence base. The methodological innovations, suite of targeted analyses, and exceptional datasets maximize potential to efficiently characterize health consequences across the entire continuum of radiation exposure scenarios.

Of course, subject to funding approval, the research plan may require refinements as the detailed implementation proceeds. Continued engagement with radiation epidemiology experts will ensure optimal analytic approaches and interpretation of results. But this proposed methodology offers a comprehensive, rigorous means to systematically address persisting priorities and knowledge gaps through judiciously leveraging internationally collaborative cohort resources. Overall, it presents an impactful strategy to advance radiation protection science.

4. Advantages of Radiation Technology Protection Under the Effective Exposure Control

- 1) Personal dosimeters use radiation-sensitive materials like optically stimulated luminescent dosimeters to precisely record external exposures. Microchip dosimeters also provide continuous, real-time monitoring of doses received within a person's breathing zone for even better accuracy.
- 2) Sophisticated bioassay methods like urinalysis and fecal sampling coupled with sensitive assays like mass spectrometry and whole-body counting enable identifying tiny amounts of internal radioactive contamination. This allows administering chelating agents or other treatments promptly to reduce further radiation exposures and risks to health.
- 3) New technologies like remote-operated inspection robots equipped with radiation detectors allow investigating hazardous environments or materials contaminated with radioactive substances without exposing personnel directly. This significantly lowers risks to worker safety.
- 4) Microchip dosimeters embedded in identification badges, smart dosimetry rings, or other items provide around-the-clock monitoring of external gamma and beta radiation exposures. In contrast, film or optically stimulated luminescent dosimeters only record cumulative doses over specific time periods. Continuous tracking better supports rapid response if action levels are exceeded.

- 5) Computational modeling platforms utilizing 3D scene simulations and developing knowledge of radiation transport replicate past and hypothetical exposure scenarios. This provides a quantitative means to evaluate radiation dose distributions within the body and resultant health risks to help optimize safety practices...
- 6) Enhanced emergency preparedness - Networked radiation sensors and simulation programs assist emergency responders in developing contingency plans and training exercises for accidental exposure scenarios.
- 7) Evidence-based standards - Robust dosimetry datasets collected over decades through personal monitors support epidemiological analyses, validating and improving exposure guidance.
- 8) Cost reductions - Automation technologies like remote instrumentation and advanced robotics decrease cost of physical radiation inspections while raising safety.
- 9) Improved medical response - In the event of an unplanned uptake, bioassay and imaging tools help determine proper chelation therapies or health surveillance protocols.
- 10) Streamlined investigations - Integrating monitoring data from across facilities into centralized databases expedites analysis following exposure incidents for timely corrective actions.

With continuous progress, radiation protection methods will gain even greater effectiveness and worker acceptance. Technologies must consider human factors to complement natural skills and priorities. Overall, a proactive approach bolsters the safety of those devoted to the benefits of the nuclear profession. Since, radiation protection technologies play an invaluable role in effectively managing both individual and collective worker exposures. Through precise monitoring, continuous tracking of doses, early detection abilities, and opportunities for remote and automated handling, risks can be significantly reduced. When paired with modelling, dosimetry data improves risk assessments and regulatory frameworks. Both evacuation protocol and medical responses are augmented as well.

5. Future Plans

- 1) Expanding the scope and duration of exposure records will strengthen epidemiological associations by incorporating additional worker populations across various national dose limits and work practices over several decades.
- 2) Including mixed fission-fusion environments will help disentangle low linear energy transfer dose risks, while military databases provide unique long-term low-dose scenarios.
- 3) Follow-up health surveillance of current workers as they age allows continued correlation between emerging incidences and reported exposures over working lifetimes to refine disease models.

- 4) Computational models incorporating worker lifestyle factors may help assay interaction effects to better resolve attributability of adverse outcomes to radiation.
- 5) Tissue-based studies using planar cell arrays or organoids could reveal genomic instability and epigenetic impacts not easily detectable population-wide.
- 6) Animal research pairing molecular analysis with pathology readouts following low acute or chronic exposures aid mechanistic understanding of how biological responses become disease likelihoods.
- 7) Consolidating statistically significant epidemiological findings and mechanistic data into an international consensus review supports scientifically optimizing global guidance consistent with Tactical Radiation Protection.
- 8) Ensuring guidelines are regularly re-examined and updated as new health evidence emerges maintains credibility and identification of evolving strategies to reduce exposures ALARA.
- 9) Training students in allied fields like statistics, programming and risk analysis will enhance interdisciplinary research capacity for addressing complex health issues over the coming decades.
- 10) Collaborating globally facilitates mutually beneficial data sharing, leveraging resources for definitive resolution of outstanding scientific uncertainties to benefit worker wellbeing worldwide.

6. Discussion

We were excited to comprehensively review the proposed long-term radiation health research initiative presented at our last meeting. The collaborative program laid out an ambitious vision that, if fully realized, could profoundly transform our collective understanding of radiation risk.

By harmonizing how we historically gathered data internationally and followed worker cohorts for decades past, emerging exposure-response trends from diverse scenarios were methodically resolved over time through statistical analyses of the sprawling databases. Linking comprehensive records allowed evaluating patterns across different exposures while partitioning confounding interactions. Initiating biorepositories established necessary infrastructure enabling future mechanistic studies as required to fortify population findings.

Promoting multidisciplinary investigations through cooperative past work in laboratories and mathematical modeling additionally helped address remaining questions about causative mechanisms. These efforts synergistically refined projection models guiding radiation application standards.

Forethoughtfully coordinating through an expert advisory board and stably funding key infrastructure upfront appropriately supported the initiative. Partnerships ethically balanced transparency with informed consent necessities for information sharing going forward. Training initiatives sustainably spread expertise as insights modified curricula.

Periodically reviewing milestones tracked past achievements while allowing mid-course amendments aligning with evolving science. Workshops constructively involved stakeholders throughout, while comprehensive reports transparently evaluated implications openly discussed.

Potentially, with enduring multi-decade resourcing, these initiatives' vast data holdings may have resolved even very low chronic exposure uncertainties to a high statistical certainty. Outcomes would authoritatively bolster worldwide assurance movements through consensus alignment.

Our group concurred this program clearly outlined a strategy ultimately enabling science-based international protection standards. We looked forward to continued inclusive discussion furthering progress across generations. Sustained collaborative action held immense promise for radiological workforce wellness worldwide.

7. Conclusion

The research initiative discussed here presents a comprehensive long-term strategy for continually strengthening the scientific foundation underlying radiation protection standards. While excited by the rich possibilities, we must also acknowledge some challenges that come with such work.

Undertaking research on this scale will require sustained commitment from all involved partners over many years. Significant coordination will be needed to ethically gather, securely link and analyze the volumes of data to be obtained. Resource needs are not trivial but promise high returns through safer practices and reassured workforce morale.

Some questions understandably remain too complex to definitively answer soon. Low-dose risk projection will likely involve incremental progress piecing together evidence from different study angles, requiring patience as understanding grows. Adjusting entrenched views also takes time through respectful consensus-building.

Furthermore, preventing unjustified fears while maintaining public transparency is a delicate balance. Open communication of uncertainties as well as findings helps build trust that standards hold safety as the highest priority. Regulatory decisions equally depend on social as well as scientific factors. However, the networking developed through such cooperation opens many doors. National and industrial sponsorships will likely continue seeing the benefits of investments in worker health assurance and global consistency. Most importantly, conclusive risk knowledge makes possible further reducing exposures via optimized protocols.

Overall, this research vision presents an achievable and worthwhile long-term strategy. Staying dedicated to the scientific process, continual reevaluation and stakeholder engagement point toward eventually resolving present unknowns in a manner protecting radiological personnel worldwide well into the future. Progress happens gradually but steadfastly through true collaboration.

8. Recommendations

Here are 15 recommendations for continuing/advancing the research initiative,

- a) Form an international advisory board (IAB) of experts to provide guidance and review progress. The IAB would ensure the research stays aligned with global priorities.
- b) Designate long-term funding from governments and related agencies. Stable financing is critical for sustaining data collection and multi-decade analyses.
- c) Standardize data collection procedures through harmonized protocols to facilitate sharing and combining information worldwide. Common formats improve consistency.
- d) Continue pursuing approvals and partnerships to expand the exposure database with additional records over time. A larger, longer-term dataset strengthens underlying statistics.
- e) Implement regular follow-ups with current worker cohorts through health surveillance programs. This allows refining risk projections as low-dose evidence emerges.
- f) Establish biorepositories and tissue banks from past workers when possible to enable mechanistic studies as techniques advance. Frozen samples extend research options.
- g) Secure ethics approvals and informed consent for future worker and population studies involving epidemiology and biological sampling. Ongoing regulatory compliance is important.
- h) Promote research opportunities and student/postdoc exchange programs across participating institutions globally. Wider collaboration fosters skills and new insights.
- i) Publish review articles periodically synthesizing the evidence base to assist optimizing protocols between guideline revisions. Timely communication supports best practices.
- j) Compile findings at project milestones into comprehensive reports for international advisory boards and regulators to evaluate progress. Structured assessments keep the effort accountable.
- k) Develop training tools and curricula grounded in the research outcomes. Strengthening education sustains the next generation of health physicists.
- l) Host workshops bringing together stakeholders and discuss emerging results. Interactive discussion aids consensus-building around implications.
- m) Measure impacts through follow-back surveys with regulators and facilities. Tracking outcomes helps refine approaches and justifies continued support.
- n) Maintain up-to-date participant and institutional databases of those involved to facilitate future communications and record-sharing as needed over the life of the initiative.
- o) Capture lessons learned to guide future long-term re-

search projects efficiently advancing international health protection goals. Knowledge gained supports continued progress.

- p) In conclusion, implementing these recommendations will help ensure the continued success and lasting impacts of this vital radiation health research initiative. Addressing both scientific and social considerations through stakeholder engagement, education, and timely guidance will strengthen the program's effectiveness over the long term.
- q) Designing a model of international cooperation through transparent data-sharing, skill-building exchanges and consensus-driven assessments maintains stakeholder commitment. Regular re-evaluation of objectives based on emerging evidence further optimizes the research focus.
- r) With committed long-term funding and infrastructure support, the initiative is well-positioned to keep advancing knowledge of radiation risks through diverse interdisciplinary studies. Achieving definitive resolution of present uncertainties empowers the adoption of ever more scientifically-substantiated protection approaches, globally.
- s) Most importantly, the enhanced worker health and public trust outcomes promise to justify continued sponsorship well into the future. Sustaining this level of resource mobilization provides returns through increased safety assurances for all. With perseverance, even the most challenging issues can be resolved for enduring benefit.

Abbreviations

DNA	Deoxyribonucleic Acid
MGy	Milli-gray
IAB	International Advisory Board

Conflicts of Interest

The author declares that no conflicts of interest.

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