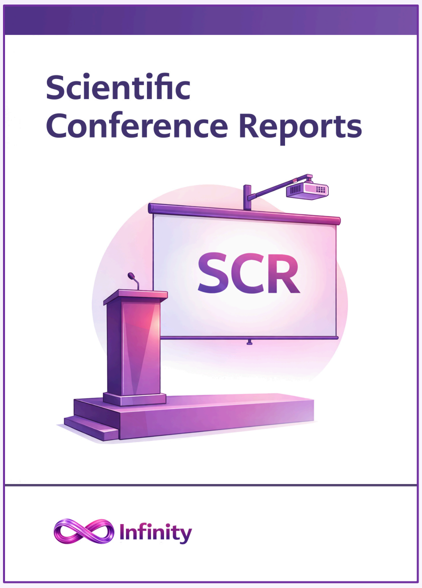
Workshop summary



From zero spore expectations to risk-based decision making: Lessons from the Cambridge workshop

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Workshop summary

From zero-spore expectations to risk-based decision-making: Lessons from the Cambridge workshop

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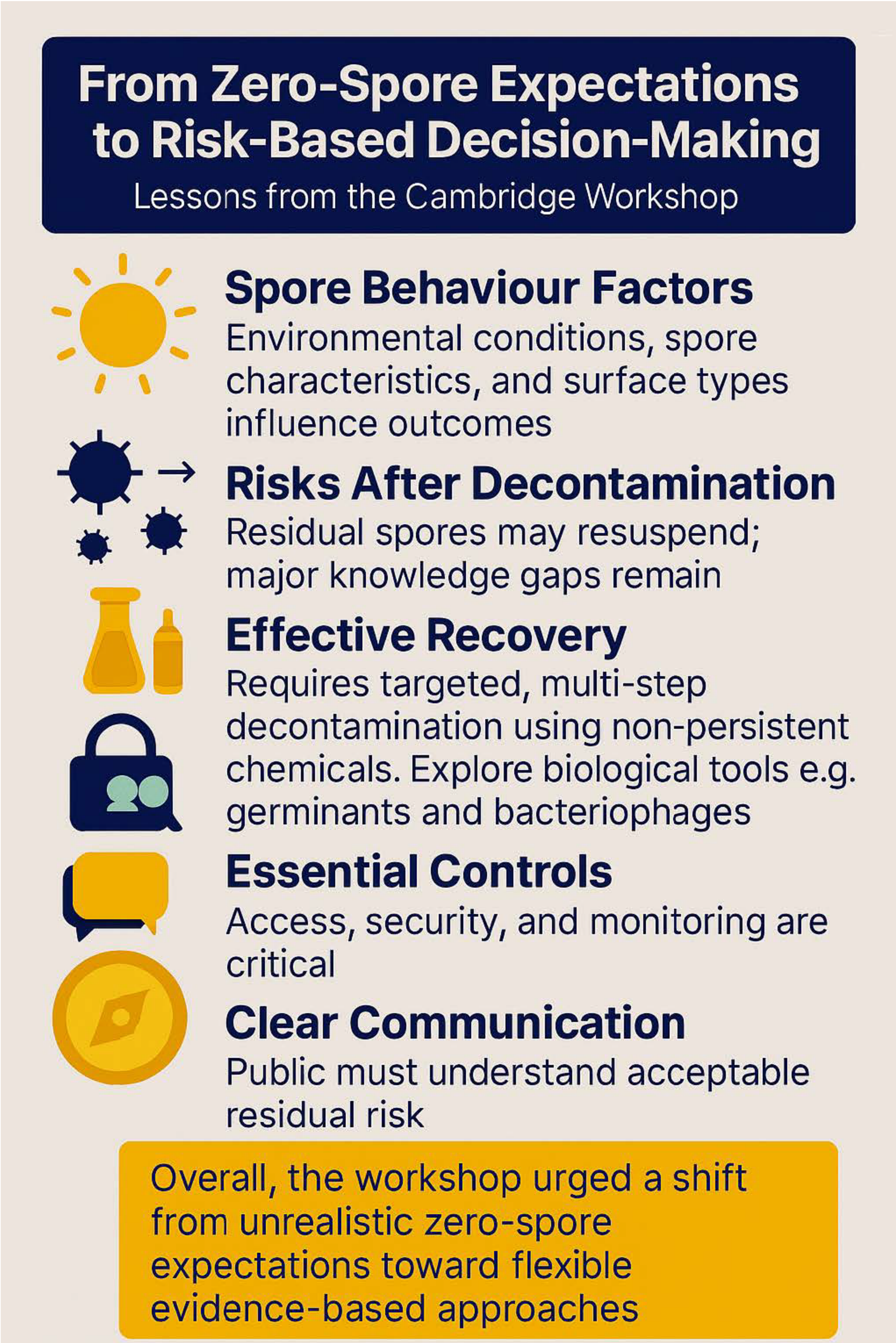
Abstract

The workshop concluded that environmental conditions, spore characteristics, and surface types all influence how *Bacillus anthracis* behaves after decontamination. Factors such as UV exposure, humidity, pH, weathering, and soil type affect spore survival and adhesion, while particle size and attachment to dust or fibres shape inhalation risk. Porous materials, carpets, and busy environments increase the chance of resuspension. Although engineering controls can reduce the movement of residual spores, major knowledge gaps remain, especially regarding the infectious dose, post-decontamination aerosol formation, and how exposure varies with height and population vulnerability.

Effective recovery requires targeted, multi-step decontamination using non-persistent chemicals, with potential support from biological tools such as germinants or bacteriophages. Agricultural areas may need long-term land-use planning where complete removal is unrealistic. Access control, proportionate security, and reliable monitoring, particularly methods that distinguish viable spores from DNA, are essential. Clear, consistent communication is critical: The public must understand that zero spores cannot be guaranteed, and acceptable residual risk depends on context, land use, and operational practicality. Policies must balance scientific uncertainty, resource limits, population needs, and coordinated messaging while managing misinformation risks.

Overall, the workshop urged a shift from unrealistic zero-spore expectations toward flexible, evidence-based approaches that balance science, practicality, and public expectations.


From Zero-Spore Expectations to Risk-Based Decision-Making
Lessons from the Cambridge Workshop
Spore Behaviour Factors
Environmental conditions, spore characteristics, and surface types influence outcomes
Risks After Decontamination
Residual spores may resuspend; major knowledge gaps remain
Effective Recovery
Requires targeted, multi-step decontamination using non-persistent chemicals. Explore biological tools e.g. germinants and bacteriophages
Essential Controls
Access, security, and monitoring are critical
Clear Communication
Public must understand acceptable residual risk
Overall, the workshop urged a shift from unrealistic zero-spore expectations toward flexible evidence-based approaches

1. Background: *Bacillus anthracis*, the causative agent of anthrax, most commonly affects livestock and wild animals but can also infect humans, with an estimated 1.83 billion people living in areas of anthrax risk. The assumption that inhalation of a single *B. anthracis* spore is fatal for all humans is based on incomplete evidence derived from the 2001 anthrax attacks in the US. This lack of knowledge led to the adoption of a remediation strategy requiring decontamination to achieve environmental levels of no detectable viable spores i.e., standards not required in healthcare facilities except in operating theatres. This raised the question of whether such expectations were reasonable, given that healthy animals and humans have lived and worked in environments naturally contaminated with spores without obvious harm.

The financial implications of achieving this level of cleanliness also needs to be considered. Decontaminating spore-laden buildings in the US is estimated to have cost approximately $300 million, and indirect costs from building closures and service disruption added further burden. For example, consider the economic impact of closing a major transport hub such as Waterloo for a year.

The aim of an unclassified workshop held at Downing College, Cambridge, on 8 December 2025 was to challenge existing assumptions about human and animal susceptibility to anthrax and to identify areas where further research was needed to support risk-based decision-making. The workshop also sought to determine how best to decontaminate affected sites in a timely and proportionate manner, balancing real and perceived risks.

1.2. Research questions addressed during the workshop

1.2.1. Risk and Reliability

- How confident can we be in the estimated inhaled lethal dose for humans (2,500–50,000 spores), given that this is based on animal studies and limited data?

1.2.2. Routes of Exposure

- If cutaneous anthrax is treatable, should inhalational anthrax remain the primary concern after environmental contamination?

1.2.3. Policy and Resource Allocation

- Does our zero-spore policy reflect prudent caution or unnecessary resource use, considering natural exposure rarely causes harm?

1.2.4. Environmental and Technical Challenges

- Under what conditions could an infectious spore aerosol form and reach respirable height after site decontamination?
- Could environmental factors like UV exposure reduce the pathogenicity of *B. anthracis* spores for humans, similar to effects seen in insects?

1.2.5. Communication and Public Perception

- What lessons from the pandemic can help us communicate infection risk effectively to non-scientific decision-makers?

1.2.6. Biosecurity and Decontamination

- What strategies would best prevent access and manage large-scale anthrax contamination on agricultural land or in public spaces such as railway stations?
- How do we balance effectiveness, safety, cost, and logistics when decontaminating without harming the environment?

1.2.7. The process

The workshop took place at Downing College, Cambridge, on the 8th December 2025. Participants included representatives from government, academia, and industry, attending in person or online, with input from the US EPA. To provide a fresh perspective, PhD students from a Veterinary health doctoral training programme based at Cardiff University also participated. Working in small groups, attendees discussed the research questions described. Comments were recorded on Post-it notes, collected by the facilitation team, and subsequently transcribed and collated for analysis using AI.

2. The responses provided by all workshop participants were grouped into the following themes:

2.1. Environmental Behaviour of Spores

- UV, humidity, pH, temperature, and natural weathering influence spore viability, adhesion, germination, and pathogenicity.
- Weathering, germination attempts, and decontamination may reduce virulence or cause loss of plasmids.
- Soil type and exosporium properties affect spore adherence and behaviour.

2.2. Spore Properties, Particle Dynamics, and Aerosolization

- Weaponization, encapsulation, and preparation methods alter spore behaviour compared with natural or environmental spores.
- Particle size, aggregation, and attachment to dust or fibres shape deposition in the respiratory tract and inhalational risk.
- Resuspension depends on energy from vibration, airflow, foot-traffic, and surface characteristics.
- Porous materials can trap or shield spores, affecting both decontamination and later aerosolization.
- Evidence gaps remain around aerosol formation after decontamination and the conditions required for infectious aerosols to form.

2.3. Surface Types, Flooring, and Engineering Controls

- Carpets, porous materials, and dirt-mat systems increase resuspension risk.
- Sticky mats have short lifespans; wet mats may perform better.
- Engineering controls such as additional doors and airflow management can reduce particle movement.
- Blue-light systems may help maintain lower background contamination levels.

2.4. Infectious Dose, Viability, and Human Susceptibility

- Infectious-dose estimates are highly uncertain and based largely on limited animal studies.
- Human susceptibility varies with age, health status, immunity, and environmental co-exposures.
- Viability does not always equal infectivity, especially for weathered or super-dormant spores.
- Exposure height (child/adult/animals) affects inhalation risk.

2.5. Post-Decontamination Risk and Exposure Pathways

- Risk arises from residual spores that are resistant, shielded, or re-suspended.
- Exposure pathways include inhalation, cutaneous contact, GI exposure, and eye exposure.
- Inhalational anthrax remains the primary concern due to delayed diagnosis and higher severity.
- Cutaneous anthrax poses a lower risk and is easier to recognise and treat.

2.6. Decontamination Strategies and Methods

- Use non-persistent liquid agents such as peroxides; peracetic acid is a possible alternative.
- Multi-step decontamination may be required, moving obstructing objects between steps.
- Biological approaches (germinants, bacteriophages) and 'germinate-to-eradicate' strategies may improve effectiveness.
- Natural weathering and biological predation may contribute but remain uncertain.
- Buildings may require tenting and gas for small structures or liquid spraying for larger ones.
- Agricultural land may not reach full decontamination; fallowing and long-term land-use planning are needed.

2.7. Access Control, Security, and Operational Decisions

- Access should remain restricted until acceptable post-decontamination spore levels are ensured.
- Urban versus rural contexts require different approaches (security presence versus signage).
- Cost–benefit considerations influence acceptable residual risk, especially in transport hubs.

- Key operational decisions include defining 'how clean is clean,' selecting areas for targeted decontamination, and deciding when items should be disposed of rather than cleaned.

2.8. Monitoring, Sampling, and Waste Management

- Monitoring must distinguish viable spores from DNA.
- Natural collectors (spider webs, insects, small animals) may support environmental surveillance.
- Wastewater and runoff disposal require careful planning.
- Some materials are better discarded than decontaminated.

2.9. Communication, Public Understanding, and Misinformation

- Clear, simple, consistent communication is essential; avoid jargon and use relatable analogies.
- Transparency about uncertainty builds trust; people must understand that zero risk is unattainable.
- Public behaviour is influenced by trust, non-compliance tendencies, and fatigue.
- Early engagement with local leaders and minority groups supports trust.
- Misinformation—potentially amplified by media or AI deepfakes—must be actively managed.
- Internal communication roles and responsibilities must be clearly defined.

2.10. Policy, Residual Risk, and Acceptability

- A zero-spore policy is unachievable due to detection limits and can create unrealistic expectations.
- Acceptable residual risk depends on land use, population vulnerability, and public tolerance.
- A clear explanation of non-zero risk to decision-makers is required.
- Policy must reflect evidence gaps, operational constraints, and the differing risks across environments.
- Insurance perspectives, cost–benefit analysis, and reinfection risks affect policy choices.

2.11. Population Differences and Context-Specific Considerations

- Farms are controlled environments; train stations have transient populations, increasing complexity.
- Immunocompromised individuals require particular attention in risk assessments.
- Health systems must avoid both under-diagnosis and over-diagnosis of anthrax following an incident.

2.12. Responses to individual research questions can be seen in Appendix A.

3. Prioritised research needs identified by workshop participants

Based on these responses, we have identified the following research needs:

3.1. Infectious Dose & Human Susceptibility

- Reduce uncertainty around infectious-dose estimates (currently based on limited animal data).
- Determine how age, health, immunity, and co-exposures affect susceptibility.
- Understand how viability differs from infectivity, especially for weathered or super-dormant spores.
- Assess how exposure height (children vs adults vs animals) influences risk.

3.2. Aerosol Formation & Resuspension After Decontamination

- Identify conditions under which infectious aerosols can form post-decontamination.
- Quantify resuspension forces (vibration, airflow, foot-traffic) across surfaces.
- Determine how particle size, aggregation, and attachment to dust/fibres affect inhalation risk.

3.3. Effectiveness of Decontamination Methods

- Evaluate performance of non-persistent liquid agents and alternatives like peracetic acid.
- Determine when multi-step decontamination is required and how to handle obstructing objects.
- Assess the feasibility and performance of biological approaches (germinants, bacteriophages).

- Establish realistic expectations for agricultural sites and long-term land-use planning.

3.4. Monitoring & Detection of Viable Spores

- Develop methods that distinguish viable spores from DNA fragments.
- Improve environmental sampling for post-decontamination decision-making.
- Assess the value of natural collectors (spider webs, insects, small animals).

3.5. Environmental Influences on Spore Behaviour

- Understand how UV, humidity, pH, temperature, and weathering affect viability and pathogenicity.
- Clarify impacts of soil type and exosporium properties on adherence and persistence.
- Investigate how decontamination or weathering might reduce virulence (e.g., plasmid loss).

3.6. Surface Types, Flooring & Engineering Controls

- Compare resuspension risk across carpets, porous materials, PVC, and dirt-mat systems.
- Evaluate the performance of sticky vs wet mats.
- Assess engineering options (airflow management, extra doors, blue-light systems).

3.7. Post-Decontamination Exposure Pathways

- Characterise contributions of inhalational, cutaneous, GI, and ocular exposure routes.
- Identify which residual spores (resistant, shielded, trapped in porous materials) pose a realistic risk.

3.8. Operational Thresholds & Decision Criteria

- Define practical criteria for 'how clean is clean.'
- Determine when disposal is preferable to decontamination.

3.9. Access Control & Context-Specific Risk

- Identify differences in access and risk management between rural and urban settings.
- Assess cost–benefit trade-offs for high-traffic sites like transport hubs.

3.10. Communication, Public Understanding & Misinformation

- Improve messaging strategies on non-zero risk and uncertainty.
- Understand how trust, fatigue, and misinformation shape public behaviour.

3.11. Health-System Readiness

- Avoid over- and under-diagnosis following an incident.
- Address vulnerability of immunocompromised populations.

4. Discussion

The workshop concluded that expecting a site to be completely free of anthrax spores is not realistic. Spores naturally exist in many environments, and very small numbers do not usually cause illness. Instead of aiming for total removal, decisions should focus on what level of residual risk is acceptable in different settings.

Participants highlighted that we still lack a clear understanding of how spores behave once they are in the environment. Sunlight, humidity, temperature, pH, and weathering all influence how long spores survive and whether they can still cause infection. Surfaces like carpets, porous materials, and soil can trap spores and later release them when disturbed, which makes it difficult to predict risk after decontamination.

A continuing concern is the possibility of spores becoming airborne again. Even after a site is cleaned, small numbers of spores may remain in dust or protected spaces and be stirred up by walking, airflow, or vibration. Engineering solutions can help reduce the movement of spores but cannot eliminate the risk entirely.

Another major uncertainty is how many spores it takes to make someone ill. Estimates vary widely, and an individual's susceptibility differs depending on age, health, and breathing patterns. A spore being viable does not always mean it can infect someone, especially if it has been damaged by the environment or by cleaning.

The group agreed that inhalation remains the main concern after decontamination, as early symptoms can be mistaken for flu, and illness can become severe. Cutaneous anthrax is easier to detect and treat and therefore poses less concern in most situations.

Practical decontamination approaches must be proportionate. Non-persistent chemicals can work well but may require repeated applications. Biological methods such as germinants or bacteriophages show promise but need further research. On farmland, complete removal of spores may be unrealistic, so long-term land-use planning may be needed instead.

Monitoring methods must improve, especially to distinguish viable spores from harmless DNA fragments. Natural collectors such as insects or spider webs may help in large outdoor areas. Safe disposal of contaminated materials also remains an operational challenge.

Clear communication is essential. The public needs to understand that 'clean' does not mean zero spores and that some very low-level risk will always remain. Messages must be simple, consistent, and open about uncertainties, while also addressing misinformation risks.

Policy decisions should account for scientific uncertainty, practical limitations, and differing expectations between settings such as farms, workplaces, and major transport hubs. Acceptable residual risk will vary based on who uses the space, the potential consequences of illness, and the costs of long-term management.

Overall, the workshop emphasised moving away from unrealistic zero-spore goals and adopting flexible, evidence-based approaches that balance science, practicality, and public expectations.

Appendix A - Group responses to individual research questions

A.1.1. Environmental and technical challenges

- Under what conditions could an infectious spore aerosol form and reach respirable height after site decontamination?
- Could environmental factors like UV exposure reduce pathogenicity of *Bacillus anthracis* spores for humans, like effects seen in insects?

Responses grouped as themes:

A.1.2. UV Effects, Weathering, and Environmental Factors

- UV inactivation may reduce pathogenicity under the right conditions.
- UV effectiveness depends online-of-sight, and indoor UV is screened by windows.
- Environmental factors such as humidity, pH, and natural weathering influence adhesion, germination, viability, and pathogenicity.
- Weathering or decontamination may cause loss of virulence factors such as plasmids.
- Environmental UV may reduce pathogenicity if spores enter germination

A.1.3. Spore Properties, Weaponization, and Surface Interactions

- Weaponization, including possible encapsulation, can alter spore behaviour.
- Soil type can change spore surface properties.
- Exosporium characteristics affect adhesion and should be mimicked in simulants.
- High pH increases particle adhesion to surfaces.
- Occlusion within porous materials can shield spores from decontamination

A.1.4. Adhesion, Resuspension, and Aerosolization Dynamics

- Re-aerosolization depends on the energy needed to detach individual spores or clumps.
- Vibrational energy, surface type, and attachment strength all influence resuspension.
- Spores adhere strongly to porous surfaces after decontamination; air or vacuum sampling is needed to measure free, respirable spores.
- Larger particles require less energy to resuspend but deposit higher in the respiratory tract.
- Spores attached to dust, soil, or fibres may resuspend differently and require more or less force.

- Foot-traffic causes more resuspension from carpets than from PVC flooring.
- Additional station doors may reduce the piston effect that resuspends particles.
- A major evidence gap remains in understanding aerosolization processes.

A.1.5. Surface Types, Flooring, and Engineering Controls

- Dirt-mat carpets may trap and re-release spores; alternative systems are needed.
- Sticky mats degrade quickly; wet mats may offer better performance.
- Flooring material influences resuspension risk (carpet > PVC).
- Blue-light systems may help reduce background contamination levels.

A.1.6. Infectivity, Viability, and Exposure Considerations

- Viability does not always equal infectivity; super-dormant spores' complicate assessment.
- Determining the effective infectious dose remains a key gap.
- Exposure height matters—risks differ for animals, adults, and children.
- Whether infectious aerosols can form after decontamination depends largely on the success of the decontamination process and the remaining contamination perimeter

A.1.7. Summary: Environmental factors such as UV, humidity and pH can reduce spore viability and influence adhesion and germination. Spore behaviour also varies with factors like weaponization, soil type, and exosporium properties, which affect how strongly spores attach to surfaces. Resuspension risk depends on surface type, particle size, and vibrational forces, with carpets and porous materials presenting greater challenges. Engineering measures such as improved flooring, alternative entry mats, and airflow controls can reduce re-aerosolization. Determining infectious dose, accounting for exposure height and spore state, remains a key evidence gap. Overall, the likelihood of infectious aerosol formation after decontamination depends on environmental conditions, surface interactions, and the effectiveness of the decontamination process.

A.2. Biosecurity and Decontamination

- What strategies would best prevent access and manage large-scale anthrax contamination on agricultural land or in public spaces such as railway stations?
- How do we balance effectiveness, safety, cost, and logistics when decontaminating without harming the environment?

<u>Responses grouped as themes:</u>

A.2.1. Access Control and Security

- Control access until acceptable post-decontamination spore levels are reached.
- Preventing access requires police or local-authority security rather than recovery teams.
- Security presence may draw unwanted attention on agricultural land; signage may be more appropriate.
- Consider how long police presence is needed to deter theft.
- Higher risk levels may be tolerated in train stations due to cost–benefit considerations.
- Cost is a major factor influencing risk appetite and decisions about restricting access.
- Public awareness of a deliberate release would likely be immediate.

A.2.2. Liquid Decontamination and Chemical Approaches

- Use non-persistent agents (e.g., peroxides) rather than chlorine bleach.
- Multiple decontamination steps may be needed; move objects that block surfaces between steps.
- Understand dose–response to avoid overdosing and minimise wastewater contamination.
- Use low volumes of decontamination agents to limit spores entering wastewater.
- Consider alternative agents such as peracetic acid and the logistics required (e.g., tanks).
- Use less persistent chemicals where possible, balancing availability and effectiveness.

A.2.3. Biological and Alternative Decontamination Methods

- Consider germinants or bacteriophages for decontamination.
- Approach may involve germinating spores before introducing phage.
- Explore 'germinate to eradicate' strategies using cheap, safe inorganic germinants like salts.
- Consider natural weathering, recognising uncertainty in duration and effectiveness.
- Account for biological predation (e.g., nematodes, protozoans).

A.2.4. Environmental Behaviour and Residual Risk

- Agricultural land may never be fully decontaminated; focus on future land-use provisions.
- Consider environmental factors such as diffusion kinetics, humidity, and temperature.
- Evaluate whether spaces can be segmented or sealed.
- Residual risk varies across hotspots or areas with high footfall.
- Animal grazing needs to be factored into risk and decontamination planning.

A.2.5. Monitoring, Sampling, and Waste Management

- Regularly monitor agricultural land for dead animals, especially around watercourses.
- Consider sampling protocols that distinguish viable spores from DNA.
- Plan wastewater disposal for decontamination runoff.
- Some items may be better disposed of than decontaminated.

A.2.6. Decontamination Strategies and Operational Choices

- Consider phased approaches, including incinerating materials that cannot be effectively decontaminated.
- Target decontamination where spores are likely to accumulate or in areas of greatest footfall.
- For small buildings: tent and gas.
- For large buildings: spraying.
- For agricultural land: leaving land fallow may be necessary.
- Availability of decontaminants may require mixed or staged approaches.
- Decide what constitutes "clean enough" to determine methods and disposal needs.

A.2.7. Stakeholder, Land-Use, and Practical Considerations

- Consider pressure to return land to owners promptly.
- Farmers and local enforcement support may be required for ongoing management.
- Evaluate people-, animal-, and environment-related factors holistically.

A.2.8. Summary: Post-decontamination management should focus on controlling access, using non-persistent and targeted decontamination methods, and considering alternatives like germinants and weathering. Residual risk depends on the environment and land use, especially on agricultural sites. Effective monitoring, waste handling, and clear thresholds for 'clean enough' are essential, alongside coordination with landowners and authorities.

A.3. Communication and Public Perception

- What lessons from the pandemic can help us communicate infection risk effectively to non-scientific decision-makers?

Responses grouped as themes:

A.3.1. Clear, Effective Communication

- Communicate likelihoods and disease progression clearly, even without precise spore numbers—use relatable analogies where needed.
- Use clear, consistent messaging delivered by trusted, well-pitched communicators (e.g., Hannah Fry, Alice Roberts).
- Avoid jargon, tailor messages to the public's level of understanding.

- Emphasize clear, repeated messaging to reinforce key points.
- Adopt an open communication style post-COVID (e.g., "We are unsure, but we recommend…").

A.3.2. Managing Uncertainty and Public Understanding

- Be transparent about uncertainty and maintain honesty to build trust.
- Present what is known, what is unknown, and what is being investigated.
- Communicating uncertainty—especially long-term—remains challenging; help the public understand that some level of risk is unavoidable.
- Assess what level of risk the public is likely to tolerate.
- Provide realistic timescales.

A.3.3: Public Engagement, Trust, and Behaviour

- Engage local figures and minority groups early to build trust and address misinformation.
- Consider that the public may resist being told what to do; anticipate non-compliance.
- Use simple, familiar examples (e.g., cold/flu) and test comprehension through scenarios or walkthroughs.
- Introduce health advice at appropriate times, offering reassurance when symptoms appear.

A.3.4: Countering Misinformation and Narrative Management

- Monitor threats such as AI-generated deepfakes and ensure trusted spokespeople communicate consistently across channels.
- Factor in the risk of misinformation or disinformation from media and social platforms.
- The narrative established during the initial response phase will shape later communications.
- Adjust the speed of communications to stem the spread of misinformation.

A.3.5: Information Load and Message Delivery

- Avoid information overload and fatigue.
- Differentiate between acute (immediate) and long-term communication needs.
- Use visuals and comparisons to clarify risk.

A.3.6: Internal Coordination

- Ensure internal communication lines are clear, including who is responsible at each stage.

A.3.7. Summary: Effective communication after a biological contamination event requires clear, consistent messaging tailored to the public's understanding, avoiding jargon and using relatable analogies. Communicators must be transparent about uncertainties, explain what is known and unknown, and provide realistic timescales to maintain trust. Engaging trusted local figures and diverse communities' helps build confidence, while anticipating non-compliance and using simple examples supports public understanding. Misinformation must be actively managed through coordinated, consistent messaging and monitoring of emerging threats such as deepfakes. To avoid fatigue, information should be paced appropriately, with distinct strategies for acute and long-term communication, supported by visuals were helpful. Strong internal coordination and clarity on roles ensure messages remain coherent and credible.

A.4. Policy and resource allocation

- Does a zero-spore policy reflect prudent caution or unnecessary resource use, considering natural exposure rarely causes harm?

<u>**Responses grouped as themes:**</u>

A.4.1. Feasibility and Meaning of a Zero-Spore Policy

- Zero spores are not achievable and depend on detection limits.
- Zero is only as good as what can be measured; background levels must be understood.
- The challenge is detecting zero spores; we cannot actually detect down to zero.
- Zero spore is a measurable threshold, but often unnecessarily stringent and risk-averse.

- What "zero spores" means is unclear to the public and policymakers.
- Zero-spore policies can increase perceived risk and the perceived need for absolute cleanliness.

A.4.2. Defining Acceptable Residual Risk

- Need to determine what residual spore concentration is acceptable to the public and decision-makers.
- Consider workplace risk thresholds and infection-rate scaling.
- Land use influences acceptable risk (e.g., farmland vs. major train stations).
- Spatial distribution scenarios must be considered in risk assessment.
- Public may tolerate natural low-level exposure in rural settings but not in crowded urban environments.
- Consider differences between natural exposure and incident-related exposure.

A.4.3. Communicating Risk and Managing Perception

- Communicate non-zero residual risk in clear, acceptable terms for decision-makers.
- Use analogous narrative approaches to explain actual risk.
- Public understanding of "zero spores" is limited; framing and explanation are essential.
- Technical decontamination differs from social and political decontamination—perception matters.
- Broader public risk in a high-profile urban incident differs from a natural occurrence.

A.4.4. Evidence Requirements and Detection Capabilities

- Examine contamination characteristics to determine tolerable residual hazard.
- Develop scalable tests detecting spores above meaningful thresholds.
- Need an evidence base for background levels and natural exposure.
- Understand evidence gaps around immunity from low-level exposure (e.g., Turkish farming communities).
- Assess evidence for natural infection vs. incident exposure.
- Need cost-benefit analysis to identify practical remediation levels.

A.4.5. Mitigation Options and Countermeasures

- Consider stockpiling, vaccine availability, and medical countermeasures.
- Vaccination, prophylaxis, or antibiotics could raise tolerable residual hazard.
- Assurance sampling may be more realistic than trying to reach zero detection.
- In some scenarios, managing occasional infections may be more practical than full decontamination.
- Evaluate whether full removal of viable spores is feasible across a whole area.

A.4.6. Policy, Governance, and Stakeholder Management

- Identify and collaborate with sceptics early to build buy-in.
- Current policy reflects scientific uncertainty and limited evidence.
- Capability must reflect policy and operational reality.
- Insurance sector perspectives may influence acceptable risk levels.
- Consider how to handle re-introduction of contamination after reopening.
- Decision-makers need a clear articulation of actual, rather than perceived, risk.

A.4.7. Population Differences and Operational Context

- Land-use context matters:
  - Farms = controlled environments with defined populations.
  - Stations = transient populations, more challenging.
- Farmers and similar groups may be more accepting due to familiarity with biohazards.
- Immunocompromised individuals present unique challenges.
- Health system must detect, diagnose, and treat cases without over-diagnosing anthrax post-incident.

A.4.8. Summary: A zero-spore policy is unattainable due to detection limits and may create unrealistic expectations. Instead, acceptable residual risk should be defined based on land use, public tolerance, and evidence on exposure and contamination. Clear communication about non-zero risk, supported by relatable explanations, is essential. Practical mitigation may rely on scalable testing, vaccination or prophylaxis, and assurance sampling rather than attempting full eradication. Policies must reflect scientific uncertainty, operational constraints, and differing risks across settings and populations.

A.5. Risk and Reliability

- How confident can we be in the estimated inhaled dose for humans (2,500-50,000 spores), given that this is based on animal studies and limited data?

Responses grouped as themes:

A.5.1. Differences Between Spore Types and Preparations

- Why assume weaponized, environmental, and natural spores have the same infectious dose?
- Differences between strains, environmental vs weaponized spores, and preparation methods may alter infectious dose.
- Weaponized spores likely behave differently from crude preparations.
- Studies often use healthy, non-weathered spores; weathered spores may behave differently and have reduced viability.
- The infectious dose may vary depending on exposure to decontaminants.

A.5.2. Evidence Limitations and Need for Better Data

- Limited confidence in current inhaled dose estimates; existing values reflect primary events, not post-decontamination scenarios.
- More evidence is needed on endemic areas, natural immunity, and immune response.
- Need clearer understanding of what the 2.5k–50k spore range represents (single spores vs agglomerates).
- Figures used in risk assessments are highly uncertain; the range is large and not well supported.
- Questions remain about whether comparative studies between fresh and weathered spores have been performed.
- Determining the dose received in human cases is extremely difficult.

A.5.3. Human Health Variability and Susceptibility

- Infectious dose likely varies with age, lung health, respiration rate, BMI, immunosuppression, and genetic factors.
- Additional influences include pollution, chronic respiratory insult, and co-infections.
- Intraspecies variability means extrapolating from healthy lab animals to diverse human populations is unreliable.
- Need to identify factors that make individuals more susceptible.

A.5.4. Challenges with Animal Data and Cross-Species Extrapolation

- Animal studies use healthy models and direct high-dose nasal exposures, unlike real-world or post-decontamination scenarios.
- Cross-species extrapolation is limited; primates show large variation and cannot be reliably compared to humans.
- Some work exists on repeated low-dose exposures, but data remain sparse.
- Responses differ widely between species, making extrapolation to humans uncertain.

A.5.5. Exposure Dynamics and Dose Characteristics

- Need better modelling based on realistic human exposure.
- Consider repeated vs single inhalation events (e.g., drummers).

- Spore dose and particle/matrix form determine deposition in different parts of the respiratory tract.
- Understanding the nature of the contaminant (dry powder vs liquid aerosol) is key.
- Matrix characteristics are often more important than the spores themselves.

A.5.6. Measurement and Detection Constraints

- Limits of detection constrain confidence in estimating infectious doses.
- What we can measure—not actual zero—determines practical thresholds.
- Time available and sampling reliability affect interpretation of results.

A.5.7. Summary: Estimates of the infectious dose for inhalational anthrax are highly uncertain due to differences in spore types, changes caused by weathering or decontamination, and major gaps in human exposure data. Animal studies are poor analogues for real-world conditions, and human susceptibility varies widely. Particle size, aggregation, and the surrounding matrix further complicate dose prediction. Detection limits also restrict confidence in measurements. Overall, much better evidence is needed to assess realistic risks after decontamination.

A.6. Routes of exposure

- If cutaneous anthrax is treatable, should inhalational anthrax remain the primary concern after environmental decontamination?

Responses grouped as themes:

A.6.1. Relative Risk: Cutaneous vs Inhalational Anthrax

- Cutaneous anthrax poses a lower risk because several conditions must align for infection.
- Following decontamination, the cutaneous risk is low.
- Cutaneous cases are easier to identify, and there is time to provide medical countermeasures.
- Cutaneous infection can progress to more severe disease in a minority of cases (~10%).
- Cutaneous infection may be more problematic in immunocompromised individuals.
- Questions remain about whether cutaneous anthrax is treatable with current antibiotics.
- There is no established model for cutaneous anthrax.
- Long-term understanding of residual cutaneous risk is needed.

A.6.2. Challenges of Inhalational Anthrax

- Inhalational anthrax is harder to diagnose because early symptoms resemble common flu.
- Once spores reach the bloodstream, treatment becomes much more difficult.
- Morbidity risk is higher for inhalational anthrax, making it the primary concern.
- Resource burden for inhalational cases is significantly higher than for cutaneous cases.
- Infection risk is influenced by spore size, aggregation, and whether spores are attached to dust or particles.
- Different particle sizes determine deposition in the lungs, upper airways, or GI tract.
- Consideration is needed for single vs repeated inhalation events.

A.6.3. Post-Decontamination Exposure Pathways

- Post-decontamination inhalational hazard arises from resuspension of resistant spores or spores shielded during decontamination.
- Spores must reach inhalational height to pose a risk.
- Humidity or environmental changes may alter spore attachment and resuspension behaviour.
- Entry through the eyes should also be considered.
- Reopening a train station while keeping food retailers closed may reduce GI exposure risk.

3.6.4. Environmental and Land-Use Considerations

- Risk levels depend on land use.
- Particle size changes require balancing hazards accordingly.

- Different environments (e.g., train stations vs agricultural areas) may influence exposure pathways and mitigation needs.

A.6.5. Monitoring and Detection Approaches

- Monitoring should remain simple and could use natural systems such as spider webs, rodents, insects, and other environmental collectors.

A.6.6. Summary: Cutaneous anthrax poses low post-decontamination risk and is easily detected and treated. Inhalational anthrax remains the main concern due to harder diagnosis, higher severity, and risks from resuspended spores. Exposure varies by environment, particle behaviour, and vulnerability of individuals, and simple environmental monitoring can help track residual hazards.