Benchmarking Facilities to Establish Sustainable Laboratory Programming, Design, Construction and Operations in Low and Middle Income Countries

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BACKGROUND:

Global Affairs Canada
Affaires mondiales Canada

The tasks of this assessment focused on **Problem Identification** across organizational, operational, technological, and environmental domains. The ultimate goal from the information gained from this initiative is to transition from a conceptual initiative to full-scale implementation of sustainable laboratories.

Multiple facilities at fifteen institutions were benchmarked across five countries in Africa and Southeast Asia through surveys and site visits. The assessment, while primarily technical in nature that focused on systems, components, and concepts for biocontainment laboratory risk mitigation, found that the primary challenges to sustainability are a combination of **budget/funding and human-factor related gaps** in knowledge, communication, and maintenance capacity rather than purely technical.

This presentation presents the background, the approaches and methodologies of data gathering, and benchmark findings. Additionally, the presentation includes the team's analysis, conclusions and recommendations.

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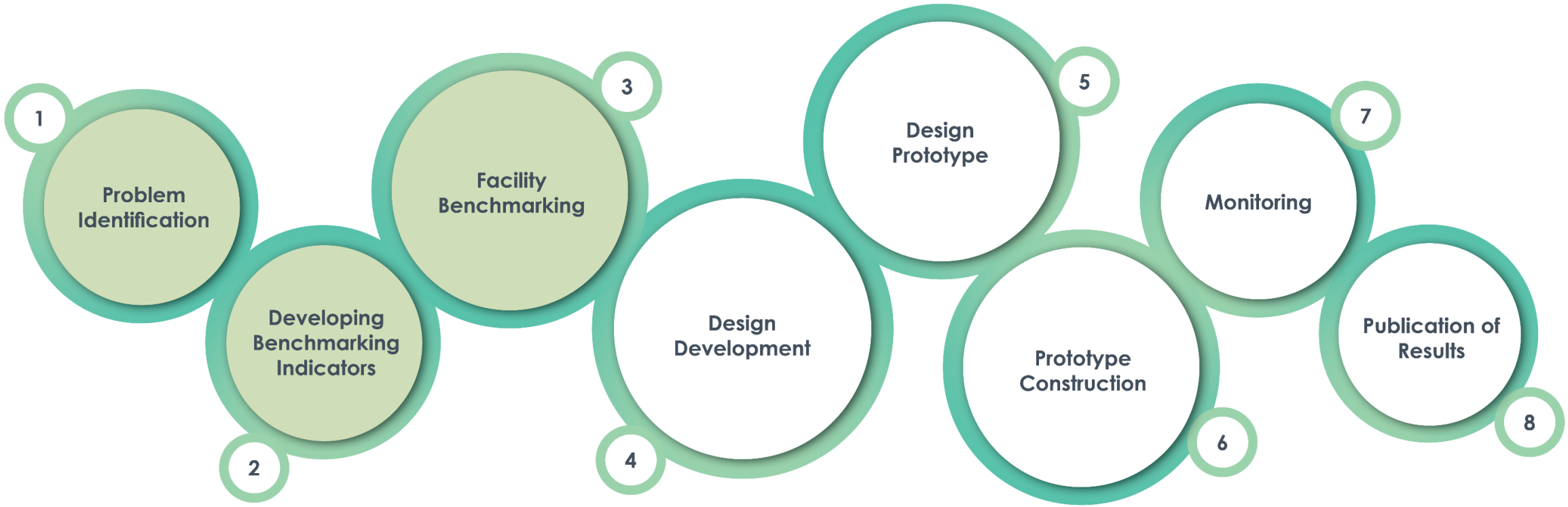
PROJECT DESCRIPTION:

Critical stakeholder objectives included the developing sustainable infrastructure, training, and expertise to reduce biological risks arising from both accidental and deliberate misuse, in alignment with the **G7 Global Partnership's priorities**.

Moving beyond the "one-size-fits-all" model for biocontainment laboratories by identifying and implementing innovative, context-specific solutions that enable safe, effective, and sustainable laboratory operations across diverse environments, including lower-resource settings under the **BioPREVAIL** framework.

This Concept Project was initially structured as an 8-Task program:



APPROACHES AND METHODOLOGIES : TECHNICAL ASSESSMENT

The technical assessment at the different facilities included systems, components, and concepts for biocontainment laboratory risk mitigation. These elements must be aligned and interoperable with the SOPs established for each individual laboratory.

Given that risk profiles vary significantly between facilities based on their unique designs, operations, and institutional risk assessments the hazards present, it is essential that any framework or mechanism implemented considers these contextual factors.

A critical aspect of this evaluation was the requirement that all systems, components, and conceptual **implementations be testable**. This implies that each element must be capable of validation either through commissioning, qualification, or performance testing in order to demonstrate that it meets the intended objectives of the risk assessment or any applicable biosafety, biosecurity, and biorisk management guidelines.

Validation of any biocontainment solution provides the necessary evidence that the implemented measures are functioning as designed and that they continue to deliver the expected level of risk mitigation.

Integration into laboratory operations was evaluated for sustainability, acknowledging that **risk mitigation is dynamic and requires ongoing verification**. Mechanisms for periodic review, re-validation, and performance monitoring are essential to maintain effective safety and security systems as conditions, technologies, or operational **requirements evolve**.

This technical assessment establishes a foundation for long-term operational integrity, sustainability, and effective risk management within biocontainment laboratories, ensuring that safety and security, and **containment objectives are achieved through harmonized and validated practices.**

APPROACHES AND METHODOLOGIES : INITIAL STEPS - FACILITY SELECTION

Southeast Asia

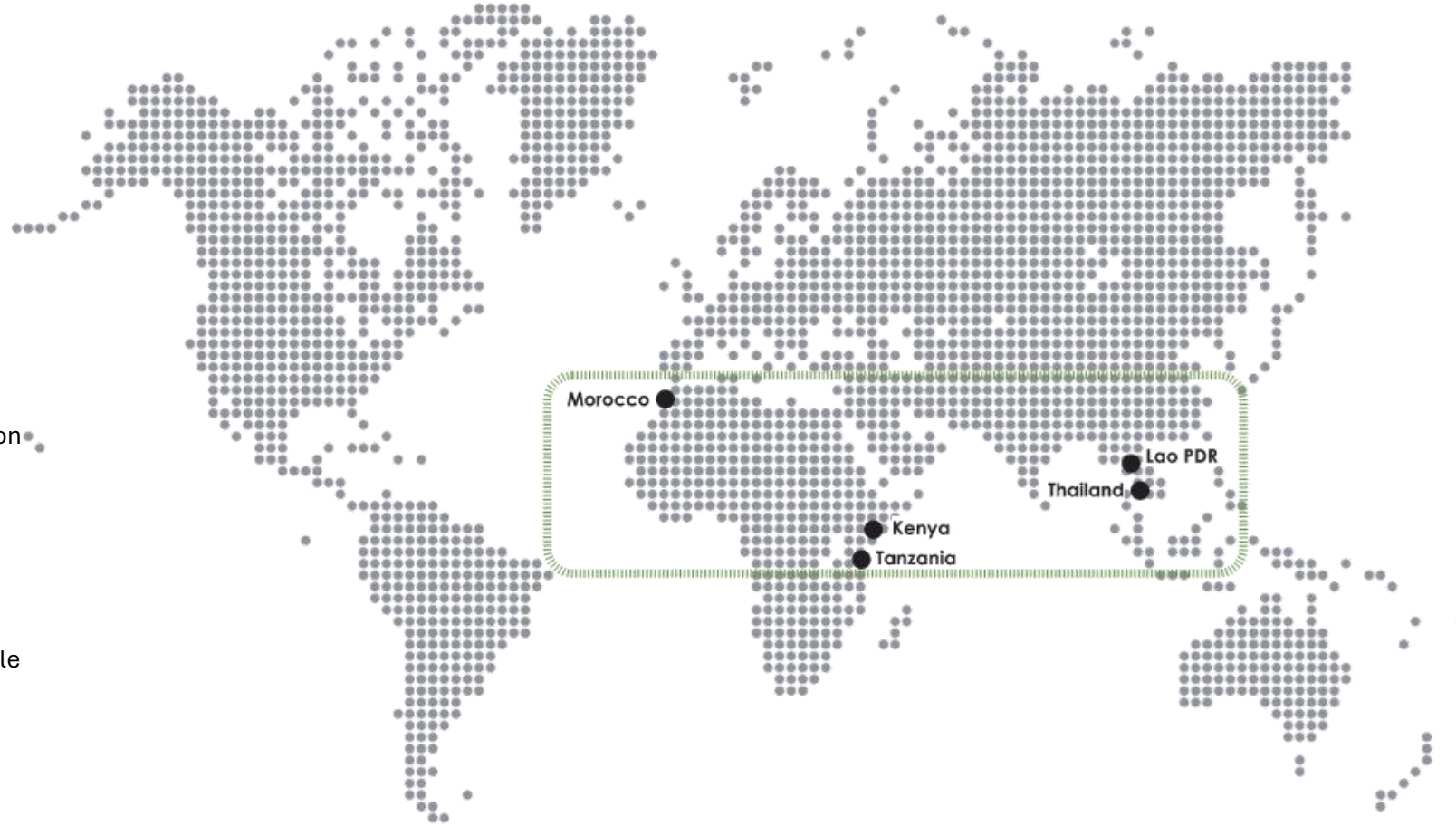
- National Institute of Health, Department of Medical Sciences, Bangkok, Thailand
- Bamrasnaradura Infectious Disease Institute, Bangkok, Thailand
- Monitoring and Surveillance Center for Zoonotic Diseases in Wildlife and Exotic Animals (MoZWE), Mahidol University, Bangkok, Thailand
- Regional Reference Laboratory for FMD in SE Asia, Pakchong, Thailand
- Lao Oxford Mahosot Hospital Wellcome Trust Research Unit (LOMWRU), Microbiology
- Laboratory, Infectious Diseases Building, Mahosot Hospital, Vientiane National Center for Laboratory and Epidemiology, Vientiane, Lao PDR
- Institut Pasteur du Laos, Vientiane, Lao PDR

East Africa

- Kenya Central Veterinary Laboratories, Kabete, Kenya (multiple facilities on campus)
- Kenya National Veterinary Reference Laboratory, Embakasi
- National Public Health Laboratories, Nairobi, Kenya
- International Livestock Research Institute (multiple facilities on campus), Nairobi, Kenya
- Tanzania National Public Health Laboratories (multiple facilities on campus), Dar es Salaam
- Tanzania Veterinary Laboratory Authority (multiple facilities on campus), Dar es Salaam

North Africa

- Clinvet, (multiple facilities on campus), Mohammedia, Morocco
- Pasteur Institute du Maroc, Rodolphe Mérieux Laboratory (multiple facilities on campus), Casablanca, Morocco



APPROACHES AND METHODOLOGIES : INITIAL STEPS – CONTACT AND SURVEY

- Developed survey through an **iterative process**
  - Create a baseline for what a sustainable laboratory would entail
  - Categorizing topics came after analysis of responses

- Once contact was made the team **sent the ZOHO survey** and instructions.

- Developed a **schedule to visit** the facilities to interview the facility staff and managers

- Team **visited the laboratory facilities** for benchmarking
  - Reviewed Zoho Survey responses to provide any clarity of survey questions
  - Toured the laboratories to better understand, assess and identify problem areas that have systematically proven to be a challenge in the areas of facility maintenance and operations.










APPROACHES AND METHODOLOGIES : ZOHO SURVEY

1. **General Information** (Questions 1–18), covers basic details:
   - Facility name, location, and year of construction.
   - Type of laboratory (BSL levels, CL3, PC3, etc.).
   - Design standards used (national/international).
   - Facility size, renovation history, and laboratory missions.
2. **Operations and Maintenance** (Questions 19–50), focuses on:
   - Staffing levels and working schedules.
   - Maintenance practices and budgets.
   - Operational downtime, spare parts, and external service contracts.
   - Major operational risks and diagnostics throughput.
3. **Certification** (Questions 51–57), asks about:
   - Certification details (certifying body, year, scope).
   - Standards used and recertification processes.
4. **Risk Assessment** (Questions 58–59) Inquires about biosafety manuals, risk documentation, and laboratory hazards.
5. **Architecture & Adaptability** (Questions 60–64), examines:
   - Structural design (building and laboratory interiors).
   - Access to natural light.
   - Laboratory adaptability to changing scientific missions.
6. **Security** (Questions 65–68), documents:
   - Physical and electronic security measures.
   - Past security incidents.
7. **Waste Management** (Questions 69–72), explores:
   - Types of waste generated.
   - Decontamination and biological waste handling procedures.
8. **HVAC** (Questions 73–86), collects data on:
   - Airflow control systems.
   - Filtration, isolation, exhaust systems, and hazard management.
9. **Building Management System** (Questions 87–90),
   - Integration of HVAC and BMS systems.
   - Staff training and use of diagnostic tools.
10. **Electrical Systems** (Questions 91–116), includes:
    - Energy consumption, power reliability, and backup systems (generators, solar, UPS).
    - Telecommunication and security integration.
11. **Plumbing** (Questions 117–136), details:
    - Sinks, eyewash stations, and backflow prevention systems.
    - Effluent treatment, gas systems, and water supply reliability.

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APPROACHES AND METHODOLOGIES : **FACILITY VISITS**

The team looked at all aspects of the laboratories, including:

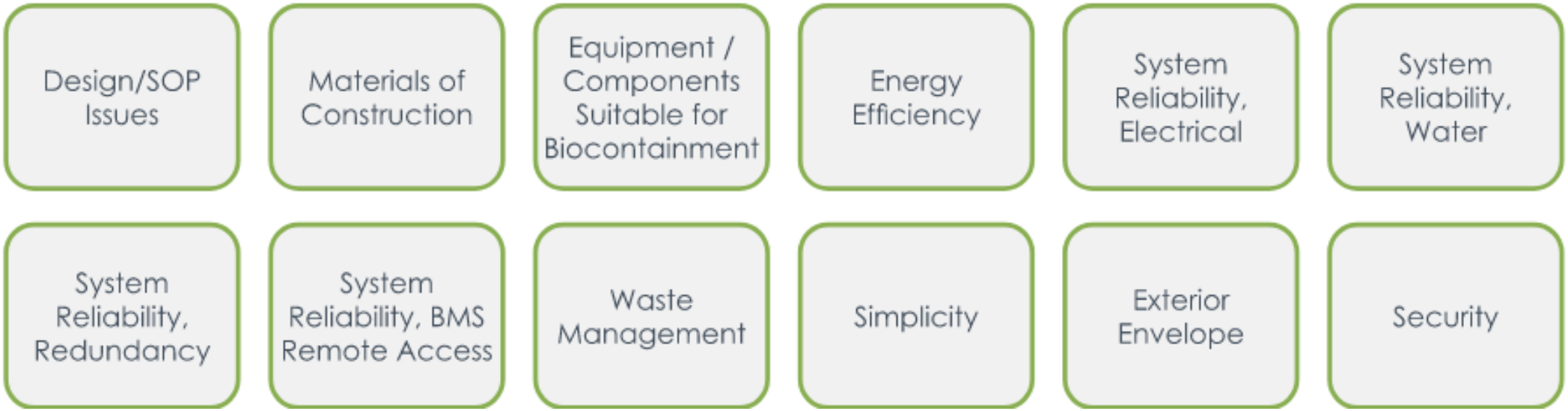
- Site and civil related issues - security, waste management, and sewerage.
- Utility related issues - source, distribution, reliability and redundancy.
- Architectural related issues - exterior envelopes, durability, cleanability, and ability to decontaminate.
- Mechanical system related issues - airflows, filtration, hazard management, material compatibility, and system isolation.
- Plumbing system related issues - water, specialty gases, liquid effluent management, and system isolation.
- Electrical system related issues - lighting, power, backup systems, and security systems.
- Equipment related issues - primary containment devices and waste management systems and equipment.

While our focus was on the Building Systems, the team also engaged with the stakeholders on administrative management, budgets, in house or external contractor support and control systems as well as personal protective equipment (PPE) management.

The fundamental goals of the survey and facility tours were hoping to ask…

“Why is this important for Sustainability?
…and what is the root cause(s)/issue(s) that makes the topic a sustainability problem?”

DETAILED FINDINGS : CHALLENGE THEMES



In addition to the more tangible challenges, all of the benchmarked facilities that we have commented on include several *intangible aspects* related to the cause of laboratory sustainability challenges:

- Their **budgets** for laboratory operations and maintenance were never enough. This was particularly consistent for laboratories that were under national authority, such as a Ministry.

- There is a **lack of basic maintenance skills** and training for the specialized components and systems in a biocontainment laboratory of both internal and external maintenance personnel. Hence, expertise in laboratory maintenance had to be "imported" and therefore created a budgetary strain.

- **Retention in staff** seemed to be an issue, where on many occasions staff had been trained for basic maintenance (at a potential high cost). However these staff members changed jobs for more lucrative salaries.

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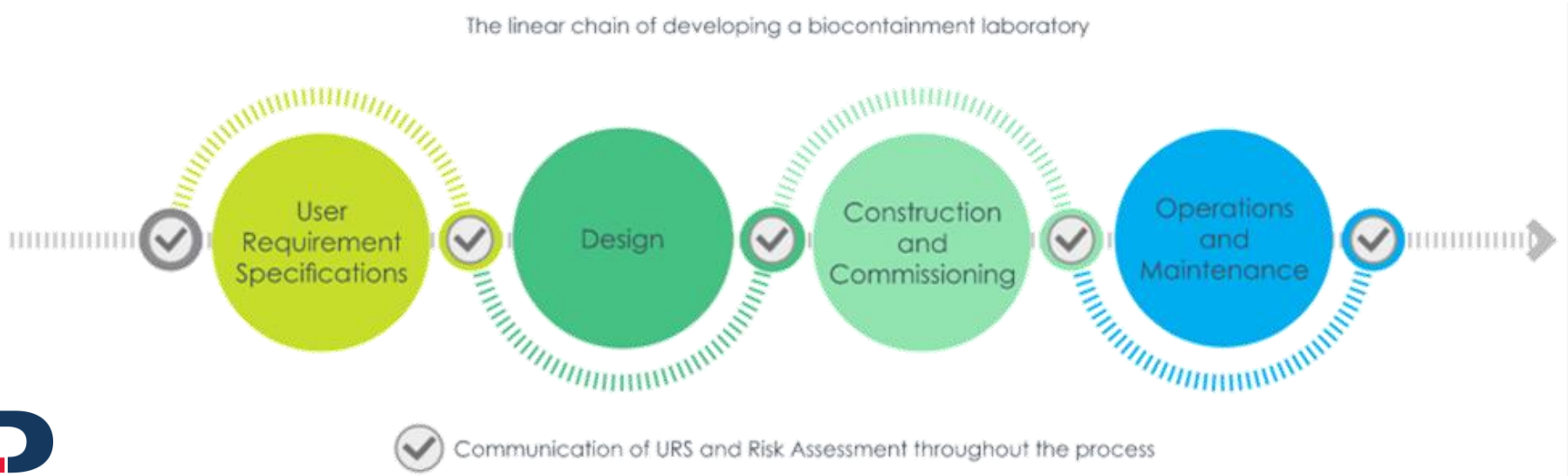
DETAILED FINDINGS : ....THE HUMAN FACTOR

The linear process of developing a biocontainment laboratory should start with a well-defined User Requirements Specifications (URS) which includes a risk assessment (RA). The next step is the communication of the URS and RA to Architects and Engineers that are knowledgeable about biocontainment laboratories and the interpretations required to implement the URS into a comprehensive tender set. The third step is the construction of the laboratories, and our team has found that various tendering processes between the design and Building Contractors have been used where majority of these processes were quite inefficient. There is evidence that most of the designs did not go through a peer review process (by suitably qualified biosafety experts, engineers and architects) whereby all stakeholders agreed with the design. We found in some instances that a clean room design was applied as opposed to a containment design.

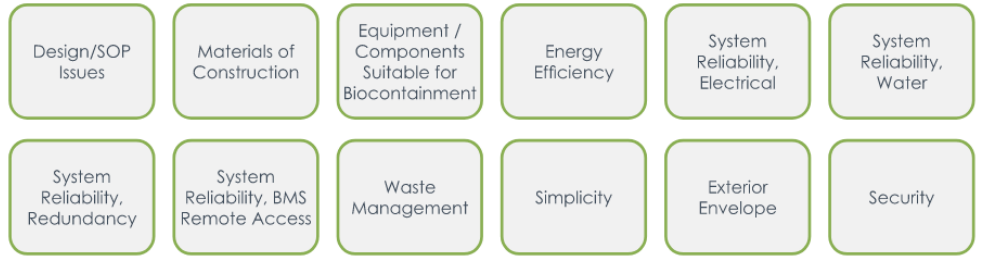
Additionally, building contractors lacked previous experience building laboratories and did not understand various finishing or mechanical requirements for a biocontainment laboratory. Some of these tendering processes involved a Project Management group which is also a critical connection in the human-factor challenge, on the provision they have the required experience.

Building contractors and the construction process need to include important communication with the knowledgeable designers and the End Users' URS. Building construction documents should also include the ability to test and/or verify the intention of the risk assessment, or guidelines if and when used, have been met and are continually providing the intended risk mitigation as long as the laboratory is operational. This testing should be conducted by Commissioning Agents that are qualified and knowledgeable of biocontainment systems, components and the SOPs that will be used.

The last step is the operations and maintenance of the laboratories that need to be conducted by the Laboratory Staff who are also knowledgeable on all aspects of the biocontainment laboratory. The laboratory staff includes the administration, the biosafety team, the researchers and diagnosticians, and the maintenance team. The maintenance team plays a crucial role, and it was observed in this project that maintenance of the laboratories was dealt with both internally and externally or a combination thereof.



DETAILED FINDINGS : THEME – ENERGY EFFICIENCY



The Reality ⚡
- Low cost → low priority
- Unreliable power

Where Energy Goes
- Air movement (fans)
- Cooling / reheating air

What's Working ✅
- Air recirculation
- Night setbacks
- Split AC systems

Gaps ⚠️
- No turndown during low use
- Complex airflow control

Opportunities ♻️
- Energy recovery systems
- HEPA recirculation

CONCLUSIONS:

The mission results demonstrate that sustainable laboratory operations in LMIC contexts depend far more on **simplicity, maintainability, and human-capacity alignment** than on advanced technological interventions

- The first and foremost challenge to sustainability was an overwhelming **influence of human factors** compared to purely technical deficiencies.
- Cross-regional patterns exist that **construction and equipment procurement is based on price** rather than performance which leads to maintenance problems quickly in the life of the facility.
- Donor funding that provides facility construction and equipment is **not accounting for maintenance** for a prolonged period (after warranty) and the maintenance and associated level of training was never properly understood and budgeted by the recipient organization.
- Donor funding ideally should flow through a contractor and **not through the Ministry**.
- Private/commercial institutions versus government-funded institutions indicated fewer operational challenges due to their **funding and procurement models**.
- A careful balance must be achieved between the objective of reducing utility consumption such as power and water use, and the potential increase in system complexity associated with implementing conservation technologies.

RECOMMENDATIONS:

The recommendations as derived from the findings and analysis are structured in three groups to match the different levels of responsibility, influence, and implementation capacity within the BioPREVAIL initiative and its partners. This tiered approach ensures that each recommendation is actionable by the appropriate stakeholder and that the effort moves logically from policy to practice

GROUP 1 – STRATEGIC / PROGRAMMATIC

Who it's for: Global Affairs Canada (GAC), BioPREVAIL steering group, donors, and policy-level decision-makers.

Why it matters: Addresses governance, funding, and program-design issues that determine long-term sustainability. Ensures high-level alignment with G7 initiatives, Signature Initiative to Mitigate Biological Threats in Africa (SIMBA), and global health-security frameworks. Establishes the "enabling environment" policies, oversight, peer review, and accountability within which technical solutions can succeed.

- Require a biocontainment peer-review at each step of a laboratory project, including user-definition, planning, design, construction, and operation.
- Adopt a "Simplicity First" principle for all laboratory systems.
- Mandate User Requirement Statements + Risk Assessment alignment checks.
- Require biocontainment and biosafety experience within the design, construction and commissioning teams which should be supported by biosafety and biosecurity professionals.
- Prioritize training, capacity-building, and retention strategies of administrative, science and maintenance staff responsible for the biocontainment laboratory infrastructure.

GROUP 2 – TECHNICAL / DESIGN & ENGINEERING

Who it's for: Designers, engineers, architects, and implementing partners.

Why it matters: Translates strategic intent into concrete design and construction practices. Ensures that sustainability principles (simplicity, maintainability, testability) are embedded in the physical and mechanical systems. Promotes standardization and risk-based decision-making across prototype and future facilities. In short: These are the choices that make the laboratory itself reliable, serviceable, and safe.

- Early engagement of the facility operations team to influence design decisions that may affect O&M budgets and complexity.
- Implement biocontainment training for designers and engineers that are responsible for laboratory design.
- Standardize designs with locally maintainable materials and components.
- When required by the risk assessment, only select HEPA filter solutions that are fully scan testable and capable of decontamination according to an industry acceptable standard, such as ASME.
- Minimize use of complex automation where local support is limited.
- Avoid through-barrier autoclaves unless essential.
- More sustainable and maintainable filters for outside air intakes at AHUs and/or building louvers.

GROUP 3 – OPERATIONAL / IMPLEMENTATION & CAPACITY

Who it's for: Laboratory operators, managers, biosafety officers, and maintenance teams.

Why it matters: Focuses on the day-to-day operational behaviors that ultimately determine whether sustainability goals are achieved. Encourages institutional ownership, continuous training, and performance verification. Provides practical steps that can be implemented immediately within existing facilities.

- Implement preventive maintenance and operational transition programs as part of the donor countries' responsibility for the first 3-5 years, inclusive of budgets.
- Implement biocontainment training programs for facility maintenance staff.
- Introduce proper piping and material installation standards.
- Validate laboratory waste decontamination and disposal is appropriately conducted internally or by external vendors.
- Strengthen certification quality control for BSCs.

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