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Enhancing Transparency for Bioscience Research and Development

SUMMARY

Advanced technologies now give researchers powerful new tools to drive breakthroughs in the life sciences. However, these advances are also accompanied by risks of deliberate misuse. The present moment offers an important political opportunity to enhance transparency in the context of the Biological Weapons Convention. The Ninth Review Conference in 2022 renewed an opening to advance long-stalled discussions on confidence-building, transparency, compliance, and verification. This report presents a comprehensive compendium of options for enhancing transparency in three categories: (1) collection and analysis of data through scientific, technical, and other means; (2) procedures to support data collection and analysis; and (3) institutions to house these processes. Together, these three focus areas provide a structured way to consider the suite of measures needed to distinguish peaceful bioscience and biotechnology research and development from potentially hostile applications of the tools and capabilities associated with these fields.

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Executive Summary

Rapid advances in modern bioscience and biotechnology are providing researchers with powerful new tools to drive breakthroughs in human health, climate resilience, and economic growth. However, these advances are also accompanied by risks of deliberate misuse. The Biological Weapons Convention (BWC)—now in its 50th year—embodies the global norm against biological weapons development and use and is the main international treaty that guards against these risks. While vital, the BWC is constrained by a lack of robust mechanisms for assessing compliance. Now is the time to address this gap by taking action to enhance transparency in life science research. Transparency can build trust between nations, increase the opportunity cost of developing biological weapons, strengthen capabilities to detect covert biological weapons programs, and mitigate the deliberate misinformation campaigns that plague the current geopolitical landscape.

This moment is marked by both the breakneck speed of life science advances and a political opening within the BWC to reopen decades-long stalled discussions on confidence-building, transparency, compliance, and verification. Governments, private industry, nongovernmental organizations (NGOs), and academia should work together to enhance transparency in life science research, fostering innovation and its societal benefits while also protecting against deliberate or accidental misuse.

A Comprehensive Compendium of Options for Enhancing Transparency in Life Science Research

The last major global effort to identify methods and approaches to enhance transparency, VEREX, took place more than 20 years ago. Since then, major advances in bioscience, biotechnology, artificial intelligence (AI), and related fields have created a variety of powerful new tools and capabilities that can be applied to collect and analyze data to enhance transparency. To take advantage of the opportunity presented by these developments, NTI | bio has developed a comprehensive compendium of options for enhancing transparency, which spans (1) the collection and analysis of data through scientific, technical, and other means; (2) the procedures to support the data collection and analysis; and (3) the institutions to house these processes. This report presents a compendium of options which have varying degrees of feasibility and effectiveness.

The compendium of options presented in this report is intended to support formal and informal processes aimed at increasing compliance with the BWC and strengthening the norm against biological weapons. NTI | bio is hopeful that the BWC States Parties may undertake a review, a VEREX 2.0, to formally present options for strengthening transparency measures for the Convention. Outside of formal channels, NGOs, industry, and academia are encouraged to join NTI | bio in advancing approaches that do not necessitate United Nations endorsement or implementation.

To develop this compendium of options, NTI | bio conducted research, held several expert interviews, and convened an in-person workshop that included an international group of more than 30 participants with expertise in the BWC, bioscience and biotechnology research and development, biosecurity, and international security.

Recommendations

BWC States Parties have a critical window of opportunity to take concrete steps toward enhancing transparency and building confidence in compliance with the norm against biological weapons development. Drawing from the comprehensive compendium of options explored in this study, the report authors recommend a set of six actions that are likely to be practical and effective.

1. **Define a clear threat model to inform BWC enhanced transparency measures:** Design a threat model, which can evolve with ongoing advances in bioscience and biotechnology, that defines the scope of key threat scenarios associated with biological weapons development programs.
2. **Explore open-source data collection and AI analysis:** Evaluate the potential of publicly available information collection and AI analysis to detect meaningful signals of high-risk or illicit activities related to biological weapons development.
3. **Conduct a pilot project to explore integration of sample and data collection during site visits:** Experiment with site visit procedures that incorporate standardized sample and data collection while balancing intellectual property protection with transparency.
4. **Strengthen BWC confidence-building measures:** Strengthen and modernize the confidence-building measures process to make it a more effective transparency tool.
5. **Develop a joint assessment process to assess BWC compliance:** Enable States Parties to demonstrate and assess compliance through a structured, standardized, and internationally recognized process.
6. **Strengthen the BWC Implementation Support Unit to lay the groundwork for establishing a Biological Weapons Convention Implementation Organization:** States Parties should take a series of intermediate steps to strengthen the BWC Implementation Support Unit and other BWC-linked structures.

It is unacceptable and avoidable for a state to pursue a biological weapons program. The benefits of modern bioscience research are innumerable. Developing robust measures to enhance transparency can reduce the risks of biological weapons development while safeguarding critical bioscience research. Governments, NGOs, industry, and academia must work together to advance these goals and foster a safer and more secure future.

Introduction

In 2020, the world shut down because of a microscopic biological threat, the SARS-CoV-2 virus. Over the next year, the virus found its way across the globe, killing millions of people and causing trillions of dollars in global economic losses. Furthermore, the crisis contributed to the deterioration of trust in institutions. While there were many lessons learned from the COVID-19 response, the world still remains vulnerable to another potentially more devastating biological event. The next catastrophe could be caused by a laboratory accident or the deliberate misuse of modern biology.

Rapid advances in modern bioscience and biotechnology are providing researchers with more powerful tools to make scientific breakthroughs that can have tremendous positive impacts on human health, economic development, and efforts to fight the effects of climate change. However, these advances are also accompanied by risks of deliberate misuse. The same technologies that allowed scientists to design an effective vaccine to combat COVID-19 in less than one year could present significant risks if put in the hands of a nefarious actor.

Reducing biological risks requires technical safeguards against misuse of biological tools, and to address state bioweapons risks, it is particularly important to deploy strategies to make pursuit of those weapons unattractive. A central pillar of this effort is to strengthen the global norm against the development and use of biological weapons, as embodied in the Biological Weapons Convention (BWC).

However, the norm alone is not enough. The BWC lacks a formal verification regime and has limited mechanisms to promote transparency or assess compliance. In a world of increasingly sophisticated and accessible biotechnologies, this institutional gap poses a growing risk. Without credible means to evaluate whether countries are abiding by their obligations, mistrust and uncertainty can deepen, and covert biological weapons development becomes even more difficult to detect and deter.

Effective transparency for state-led or -supported bioscience research and development is a critical element of broader efforts to safeguard the tools of modern bioscience and biotechnology against accidental and deliberate misuse. In this context, "state-led or -supported" refers to any biological research and development that is conducted directly by, is officially sanctioned by, or materially contributes to a government's research program, including covert or unsanctioned work performed on behalf of or in support of the government.

A Historic Opportunity to Revisit BWC Verification and Transparency

Now, for the first time in more than two decades, a political opportunity has opened to reexplore meaningful transparency measures for the BWC, an issue that has long stalled amid political disagreement. This opportunity invites renewed attention to earlier efforts to address BWC compliance and verification, particularly the work of the VEREX ad hoc group.

In 1991, VEREX was established to identify measures that could determine "whether a State Party is developing, producing, stockpiling, acquiring or retaining microbial or other biological agents or toxins, of types and in quantities that have no justification for prophylactic, protective or other peaceful purposes."[1]

The group identified 21 potential verification measures, ranging from surveillance of publications and information sharing to on-site visual inspections. These proposals were carried forward into negotiations over a legally binding verification mechanism.[2] However, after a decade of talks, the draft protocol became increasingly contentious, ultimately leading to the collapse of the VEREX process in 2001. A key argument behind the breakdown was the claim that the proposed verification measures were not feasible and would not meaningfully enhance compliance with the BWC. As a result, the BWC still has no formal compliance or verification mechanism.

The Ninth BWC Review Conference in 2022 marked a new turning point. States Parties agreed to establish a Working Group on strengthening the Convention, signaling renewed political will to engage with long-standing challenges.[3] The group's mandate includes exploring concrete measures for key issue areas such as transparency, confidence-building, compliance, and verification—as well as developments in science and technology relevant to the Convention.

Defining Enhanced Transparency

Today, a range of existing tools and mechanisms can support enhanced transparency in bioscience and biotechnology research and development. These tools span a broad spectrum of activities for assessing compliance with the BWC. One end of the spectrum is the status quo defined by the BWC confidence-building measures (CBMs), which are in place to help increase transparency regarding life science research. CBMs are necessary but insufficient for providing confidence that States Parties are complying with the BWC prohibition on development or use of biological weapons. The other end of the spectrum is a full verification regime, which is what the Ad Hoc Group was working to create, following the 1994 VEREX process.[4]

Previous efforts to create a verification regime have failed, and there is still no consensus within the biosecurity community that verification, as traditionally understood, is practical or feasible. The debate about the feasibility of verification within the context of biological weapons goes back decades.[5] Verification is challenging because bioscience and biotechnology are broadly embedded within the economy, and they are more deeply dual use (i.e., they have the potential for both beneficial and harmful uses) than technologies covered by other arms control agreements. These are the main reasons why this report does not necessarily argue for a full verification regime.

Between the two ends of this spectrum, there is a wide range of options for more robust transparency measures that are more ambitious than CBMs, as currently implemented, and more practically feasible than full verification. **The authors define "enhanced transparency" as the tools, measures, and structures that fall in the space between status quo CBMs and full verification.**

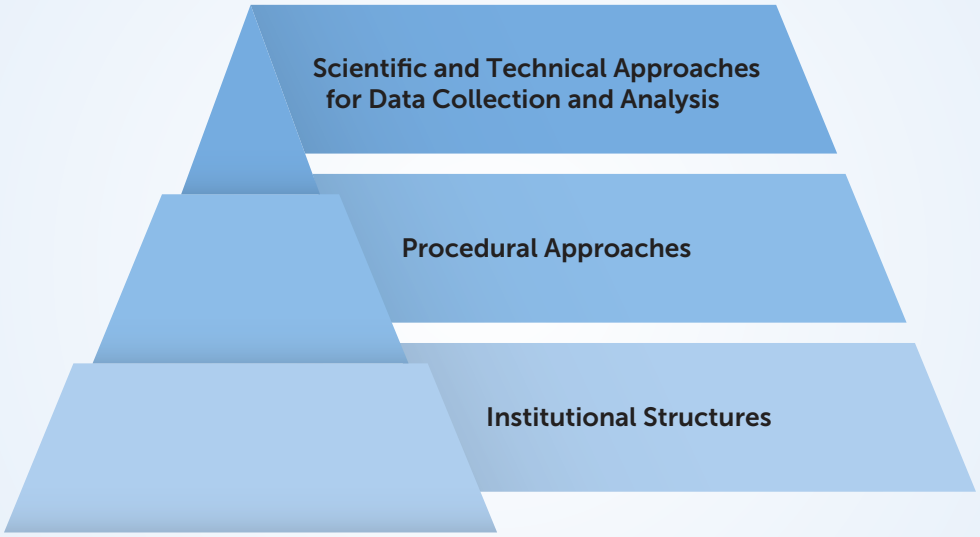
Enhanced transparency measures can reduce the risk of misperceptions regarding bioscience and biotechnology research and development by providing data and evidence analyzed in an unbiased fashion. For enhanced transparency measures to be successful, they need to be adaptable to technological advances and implementable by BWC States Parties. With technology continuously advancing, enhanced transparency measures can form the basis of a modern treaty compliance system that is rooted in validated data and objective evidence. An effective enhanced transparency regime can increase the cost of hiding covert biological weapons development activities and open opportunities to detect BWC violations. A comprehensive enhanced transparency regime can be implemented in a way that sheds light across all stages of research and development, including the earliest stages in which discerning intent is the most difficult.

This report organizes the options for enhancing transparency into three pillars (Figure 1):

1. **The collection and analysis of data through scientific, technical, and other means.** This pillar entails the deployment of modern scientific methods and technologies to collect and analyze data that can offer meaningful insights to help differentiate between legitimate bioscience research and offensive uses of bioscience and biotechnology.
2. **Procedures used to gather and analyze data and evidence.** Approaches span from on-site mechanisms to off-site procedures. Beyond data collection, collaborative activities like scientific exchanges can contribute to transparency even when direct monitoring is limited.

3. **The institutions that support these processes.** This pillar includes augmenting current institutional structures or developing new ones—either within the BWC or adjacent to it—to support needed scientific, technical, and procedural approaches.

Figure 1: Relationship between Key Elements of an Effective Approach to Enhancing Transparency in Bioscience Research and Development



Note: Enhanced transparency measures can reduce the risk of misperceptions in bioscience research and development through the gathering and analysis of data using scientific and technical means, the procedures and processes that are used to gather the data, and the institutions that serve as a home for these efforts.

The next three sections in this report explore a comprehensive compendium of options for enhancing transparency and consider respective benefits and challenges. The compendium includes commonly cited options as well as newer ideas that are particularly promising, but it does not represent an exhaustive list of all possible approaches, and inclusion does not necessarily imply endorsement.

A Framework for Assessing Biological Weapons Programs: Capacity, Capability, and Intent

The concept and public imagination of what a typical biological weapons program looks like are still deeply rooted in historical context. While there is always potential for a program to look like the United States Biological Warfare Laboratory Building 470 at Fort Detrick or the Soviet Union's Zagorsk-6 facility, it could also look quite different as evidenced by the Iraqi biological weapons program in the 1980s. The tools of modern bioscience and biotechnology allow for a much broader array of possible agents, delivery systems, and laboratory footprints. Nefarious actors now have the potential to design a novel deadly agent on their home computer, a feat unthinkable two decades ago. Although the contours of a modern biological weapons program may have evolved, three critical factors remain: *capacity, capability,* and *intent*.

Capacity

Capacity refers to the resources that a state possesses to support a biological weapons program, such as plans, facilities, tools, technologies, personnel, and financial resources. It is often the easiest indicator to observe with basic transparency efforts, such as CBMs, publication databases, and publicly available satellite images. However, capacity alone does not indicate the presence of a biological weapons program. For example, while Fort Detrick's capacity has greatly expanded since the era of Building 470, it is now dedicated to peaceful research. Identifying an actor's capacity is necessary but not sufficient to determine the existence of a biological weapons program.

Capability

Capability refers to the knowledge and abilities required to develop or support a biological weapons program. Without the necessary knowledge, there is no amount of state capacity that can lead to a biological warfare program. For example, while not a state supported endeavor, reports indicated that when al-Qaeda was interested in building a robust biological warfare program, the organization had capacity but no capability and needed to pursue people with the necessary knowledge and ability, such as Aafia Siddiqui.

Intent

Intent refers to a state's motivation behind its actions to develop and maintain a biological weapons program. Intent may be the most critical factor to determine and is also the most difficult. Efforts to enhance transparency can lead to a better understanding of intent by uncovering patterns of activities. For instance, a state may attempt to mask illicit research by publicly stating a legitimate objective, but enhanced transparency approaches may reveal indicators of research activities that do not match declared goals. This type of disconnect between stated objectives and observed activities can, over time, reveal patterns of behavior that can allow inference of intent.

Addressing Challenges to Implementing Effective Transparency Measures

Implementing enhanced transparency measures faces several political, financial, technical, legal, and operational hurdles. These challenges can be addressed through strategic and tailored approaches designed to navigate the complex landscape of international governance while fostering collaboration and minimizing friction generated by competing national interests.

- **Political and Institutional Challenges:** Concerns regarding sovereignty and national security often impede international initiatives. Viable enhanced transparency approaches should promote voluntary participation and pilot programs that foster collaboration and build trust over time in new approaches—to lay the groundwork for subsequent adoption on a wider international scale. To help reduce geopolitical friction, such frameworks should offer options that respect national interests and accommodate varying levels of engagement.
- **Financial and Technical Barriers:** Securing adequate and sustained funding for biosecurity initiatives is a persistent challenge, particularly amid competing global priorities. An effective approach should incorporate financing strategies and partnerships among a diverse range of governments, international organizations, and the private sector. On the technical front, an effective enhanced transparency framework should include capacity-building components and mechanisms to leverage expertise from diverse sectors to address the pace of technological change and the complexity of data integration.
- **Legal and Regulatory Issues:** Addressing legal challenges, especially those involving inspections and data sharing, requires a careful balance between national sovereignty and international agreements. Any new binding measures under the BWC will face major challenges to adoption. An effective strategy for enhancing transparency should explore the near-term development of nonbinding measures under the BWC and the promotion and adoption of individual updated national frameworks and cooperative agreements that facilitate compliance with international norms while preserving national sovereignty.
- **Cultural and Operational Resistance:** Resistance from scientific research communities, especially within industry, may arise if transparency measures are seen as risking exposure to sensitive intellectual property or creating reputational risk. An effective approach must incorporate safeguards for intellectual property and privacy to build trust among stakeholders. A credible model should also emphasize stakeholder engagement across the scientific community and design safeguards that preserve academic freedom and innovation.

Understanding these challenges—and identifying viable strategies to address them—has informed the development of the recommendations in this report. To ensure proposed solutions take into account technical feasibility and policy relevance, the report integrates expert perspectives and interdisciplinary research about the history of efforts to strengthen the BWC.

Methodology

This report draws on research conducted by NTI | bio and insights from subject matter experts in areas including the BWC, bioscience and biotechnology research and development, biosecurity, and international security. From September 30 to October 2, 2024, NTI | bio convened more than 30 experts for a workshop in Amsterdam, the Netherlands. The workshop was informed by NTI | bio research and several semistructured interviews with individuals specializing in the history and limitations of the BWC, bioscience research, biosecurity, nonproliferation regimes, and biological policy—several of whom also participated in the workshop. This report synthesizes key findings from these engagements and proposes a path forward for exploring, testing, and potentially institutionalizing enhanced transparency measures to strengthen confidence in BWC compliance.

The approaches and recommendations presented in this report are informed by expert discussions at the project workshop and several interviews with subject matter experts, but they do not necessarily reflect the views of all project participants.

Data Collection and Analysis Through Scientific and Technical Means

Transparency hinges on analyzing reliable data and evidence to gain insights that help distinguish legitimate research activities from potentially harmful activities. The technical and scientific means to collect and analyze data are essential to any effort to enhance transparency in life science research. The last official review of such approaches is in the 1993 VEREX report. The subsequent three decades have ushered in significant advances in bioscience, biotechnology, data science, artificial intelligence (AI), and satellite imaging, creating new opportunities to collect and analyze relevant data. These advances now allow more rapid and easier access to data sources, have led to improvements in detection sensitivity, and have sharpened analytical capabilities.

The primary goal of data collection and analysis is to define what typical life science research looks like across different data streams, allowing analysts to more readily identify anomalies that may signal malicious activities. However, not all types of data will be equally useful. Therefore, observers must first identify the most relevant evidence to help spot signs of potentially harmful bioscience research amid a broad range of peaceful research happening around the world. The choice of analytical method depends both on the available data and on practical limitations.

This section covers means for data collection both on- and off-site. After discussing scientific, technical, and other means, the section presents analytical methods to turn raw data into relevant insights, including a variety of analytical techniques for biological samples and computational methods for data analysis. This section and subsequent sections explore a broad range of ideas recommended by experts consulted for this project, some of which are likely to be more feasible and effective than others. While it is valuable to consider this range of options, this report does not necessarily endorse all of them.

On-Site Data Collection

The goal of on-site data collection and analysis is to acquire the information, including samples and documentation, necessary to assess laboratory activities. Once collected, this information can be used to determine whether the observed activities align with the declared research activities at the facility. Any discrepancy between stated research activities and findings from analysis of collected samples and data may signal a cause for concern.

Sampling Within and Around Laboratories

Biological sampling lies at the heart of on-site data collection, as these samples can only be gathered in person—unlike other data types, such as archival records, which can be accessed both on- and off-site.

- **Sampling of laboratory equipment and surfaces:** Comprehensive sampling from a variety of locations within laboratory facilities—including test tubes, centrifuges, incubators, biosafety cabinets, refrigerators, freezers, storage areas, and frequently touched surfaces such as door handles

or computer keyboards—could offer valuable information about ongoing research activities. Additionally, used gloves, masks, or other personal protective equipment may carry residues of handled materials. Inspection teams should pay special attention to sampling areas likely to harbor residues not easily cleaned or disinfected, such as corners, cracks, equipment ventilation grates, or difficult-to-access internal components of laboratory instruments.

- **Sampling biological research materials:** An additional source of information about ongoing research activities is the existing library of biological material samples within a laboratory. This could include cultures, frozen microbial stocks, and nutrient broths as well as samples from research animals where applicable.
- **Sampling of laboratory wastewater and solid waste:** On-site data collection and analysis also can include sampling from laboratory wastewater and solid waste. Analyzing wastewater, effluent, and solid waste samples can yield data and evidence that can be analyzed and compared to stated research objectives to enhance confidence that a laboratory is, in fact, carrying out the stated research activities. Additionally, this sampling approach can help make hiding illicit activities more costly, since any covert program would need to address the fact that even traces of past work could be detected.
- **Sampling of air and dust:** Air and dust samples from laboratories can capture biological agents that may not be easily identified through other sampling methods. Air sampling should ideally target areas with higher aerosol generation, such as near centrifuges, biosafety cabinets, incubators, animal housing areas, and ventilation or heating, ventilation, and air conditioning (HVAC) systems.
- **Medical testing of personnel:** On-site visits could include collection of biological samples from laboratory personnel. Potential sample types range from less invasive techniques, such as swabbing hands, to more invasive and potentially more revealing techniques, such as collection of saliva or blood samples. While analysis of hand samples could provide similar information to sampling of laboratory surfaces and waste, blood or saliva samples tested for antibodies to known pathogens could reveal information about prior exposure to disease. Antibody results from personnel could be compared to stated ongoing and past research activities, scanning for any previous infections of significant or important diseases. For such testing to yield relevant insights, inspection and analysis teams need to be able to compare testing results to the medical history of tested personnel, particularly records of laboratory-acquired infections.

Archival and Observational Data

On-site visits are an opportunity to access further data streams beyond physical samples. Paper and digital records of research activities as well as the critical inputs to bioscience research like electrical energy are valuable testimonies of ongoing activity.

- **Interviews and laboratory notebooks:** Analyzing laboratory notebooks can provide information about experimental procedures, as well as the timing and personnel involved in specific research activities. Complementary interviews with laboratory personnel can further clarify notebook entries, explain anomalies, and offer context on day-to-day laboratory practices. Together, these

methods can confirm whether recorded laboratory activities align with declared research objectives or reveal discrepancies that may warrant further investigation.

- **Financial and procurement records:** Analysis of financial documents and procurement records from a laboratory can provide valuable insights into ongoing research activities. Observers can use procurement data to analyze whether the types and quantities of materials acquired—such as growth media, reagents, or specialized equipment—align with declared research objectives. Unusual procurement patterns, such as unexplained high-cost acquisitions, can indicate activities inconsistent with stated peaceful purposes. Similarly, reviewing financial transactions may reveal relationships with undeclared partners or suppliers, potentially signaling concealed collaborations or illicit research efforts.

- **Energy consumption:** High-containment laboratories require significant energy for HVAC systems, laboratory equipment, and other systems. Varying energy usage may elucidate activity patterns over time. For example, a variable rate of air changes per hour depending on occupancy of the laboratory could give indications about periods of high and low levels of activity.[6] These data would reveal any after-hours activity or atypical fluctuations in activity levels. Similarly, laboratories with higher safety standards use more energy.[7] Energy consumption could therefore indicate which level of safety standards are being maintained, with higher energy usage being a possible indicator of work with dangerous pathogens that require higher safety standards.

- **Surveillance camera footage:** With appropriately placed surveillance cameras, footage can provide additional information about experiments conducted in a biological laboratory, as well as overall activity on the premises. While some footage may be accessible off-site, surveillance camera footage is likely to be housed and accessed on-site, especially in older and less technologically advanced laboratories.

- **Digital forensics:** As biology moves from the bench into computational approaches, the digital records of research offer an important audit trail of laboratory activities. Starting in the 1990s, biologists began to heavily rely on rule-based computer simulations and data analysis pipelines. These methods produce digital footprints, including dataset versions, log files, and simulation metadata that inspectors can archive and inspect to verify a facility's stated research scope. More recently, machine learning and generative AI models have transformed in silico research, including tasks such as protein structure prediction and generative protein and genome design. Because these approaches often run on shared servers or third-party platforms, additional traces, such as records of every request that a facility's computers have made to cloud-based AI platforms, become valuable data points for transparency.[8]

Off-Site Data Collection

Off-site data collection and analysis is a potentially valuable approach that can provide insights into research facilities both to complement on-site collection and to use when on-site access is not available. Off-site monitoring also can be used on a continuous basis to provide information about ongoing activities between site visits. This monitoring can inform subsequent on-site data collection or could even point to additional facilities to include in routine or challenge inspections.

While off-site collection cannot provide the depth of evidence possible to collect on-site, it avoids the challenges that come with inspection agreements and circumvents challenges over inspectors' physical access to the facilities in question and the modalities of such site visits. Many methods of off-site data collection can be conducted without consent or involvement of the actors responsible for a laboratory facility.

Remote Sensing and Imaging

Facility-level operations can be tracked remotely to reveal construction work, daily activity patterns, or unexpected events. Advances in remote sensing and imaging have greatly expanded the range of off-the-shelf tools—and, with sufficient investment, custom systems could be developed to support more precise, real-time facility monitoring.

- **Satellite imaging:** Significant advancements in satellite technology over the past 30 years have drastically improved the spatial and temporal resolution of satellite imagery as well as geographic coverage, and the technology is expected to continue to improve. Specifically, satellite imagery could provide information on the design of and gating to a laboratory facility, deliveries, and other types of (human) movement. For example, satellite imagery of a facility's construction design can give indications about its biosafety level and by extension the research activities that a laboratory is equipped for.[9]

- **Infrared imaging:** Passive infrared sensors detect heat signatures in the form of electromagnetic radiation, enabling monitoring of heat generation associated with energy-intensive activities or bioreactor operation. Infrared imaging can identify on-site human activity and heat signatures of facilities and laboratories; the latter data allow observers to identify resistive heating locales, find building envelope leaks, and compare relative equipment loading.

- **Radar and lidar imaging:** Radio detection and ranging (radar) and light detection ranging (lidar) technologies, which are types of active remote sensing, offer valuable tools for penetrating visual obstructions and generating imagery of research facilities. Radar systems transmit electromagnetic waves that reflect off the objects and return to the receiver, giving information about the measured objects' locations and speeds.[10] Lidar, in contrast, uses pulsed lasers to measure distances.[11] Radar imaging remains unaffected by weather and lighting conditions and can therefore be used to regularly track construction activity, facility expansion, or alterations in building structure indicative of bioscience-related activities. Lidar enables precise external 3D structural mapping of a structure with higher resolution but is vulnerable to adverse weather conditions.[12]

Research Outputs

In the life sciences, the culture of openly sharing scientific results and strong career incentives to produce high-profile publications drives scientists to disseminate results frequently. Likewise, the patent system rewards researchers and firms for disclosing novel methods, targets, and compositions in exchange for time-limited exclusivity. Because both publications and patents must publicly detail experimental findings, methodologies, and claimed inventions, they offer valuable insights into who is working on what, making them a rich source of information for any effort aimed at increasing transparency in ongoing research.

- **Publications:** Scientific literature provides a practical source for tracking research activities at government, academic, and private institutions. Studying publication and citation patterns can reveal institutional collaboration networks. Bibliometric analysis may reveal unusual affiliations, collaborations, or emerging dual-use research trends not clearly aligned with an institution's stated objectives.[13]
- **Patents:** Patent databases offer critical transparency opportunities by providing early indications of emerging technologies and research priorities. Analysis of patent archives can help find trends in technological innovation, bridging the gap between early scientific discovery and concrete applications, and thereby identify emerging dual-use capabilities and technologies.

Research Inputs and Trade Flows

Analyzing international trade data for necessary inputs to bioscience research, such as laboratory equipment, can provide early indicators of undeclared or illicit bioscience activities. In fact, international trade records helped shed light on Iraq's illicit biological weapons program. In 1995, United Nations (UN) inspectors confronted Iraqi officials with documents proving the importation of biological growth media at quantities that exceed civilian use cases. The production of biological weapons would be one possible explanation for these imports. While the documents alone were not sufficient to provide proof, Iraqi officials felt some pressure and ultimately admitted to their biological weapons program, which led to its subsequent dismantlement.[14] Closely monitoring the flow of goods for bioscience research or production of biological materials could contribute to similar insights and results today.

- **Harmonized System code tracking:** Administered by the World Customs Organization, Harmonized System (HS) codes offer a uniform numerical classification system for the tracking of import and export processes. HS codes could be used to track the many technologies that allow countries to pursue life science research or development, such as HS code 3821, culture media for microorganisms.[15] The UN COMTRADE database, administered by the UN Statistics Division, offers access to comprehensive international trade data based on official national statistics.[16] One limitation of this approach is that HS codes do not provide information on the end user or the end use of specific imports, only aggregate data at a country level. Additionally, relevant HS categories, such as for biotechnology equipment, are broad and might not allow for item-specific analysis.
- **Export licensing data:** The export of specific dual-use items—including those relevant to biotechnology and life science research such as high-parameter flow cytometers—can be covered by national or multilateral export controls. If such items are not categorically prohibited, exporters might require a license for specific items. While export control license applications and their rejections are typically not publicly available, there are some exceptions or indirect ways to gather insights. For example, governments periodically publish aggregated statistics on export control license applications and decisions, such as the U.S. Bureau of Industry and Security's Annual Report to Congress.[17] Disclosures resulting from freedom-of-information requests, court actions, or public testimonies and hearings might also provide insight into the international trade of goods required for life science research and development activities.

Data Collection from Industry

Biological research facilities rarely work in isolation; they often collaborate with external providers of synthesized DNA or specialized AI model developers to advance their research. Requesting data from these external partners within the biotechnology industry can contribute to enhanced transparency in the life sciences. Applying these ideas would need to balance security concerns with protecting intellectual property.

- **DNA synthesis (screening) requests:** DNA synthesis is a service widely used in bioscience research in laboratories worldwide. Using synthesis screening data to enhance transparency would face significant feasibility challenges, including the need to draw on private industry data, which is typically not publicly shared. However, if shared, DNA synthesis screening data could provide granularity about the type of research being conducted in a lab that purchases DNA from external vendors. Continuous automated analysis may be able to help validate the authenticity of a stated research agenda.
- **Digital logs from AI model providers:** Research labs often access off-site AI services via application programing interfaces instead of hosting models locally. Consequently, the request logs that AI providers maintain can provide valuable insights about in silico research activities and may help clarify researchers' objectives. As models grow more powerful, these logs are likely to become more valuable. Moreover, by examining not just the specific inputs—DNA sequences, protein-structure predictions, or other biology-focused queries—but also their accompanying metadata such as time stamps or usage patterns, one can gain deeper insight into research activities.[18,19]

Outbreak Data

Keeping the possibility of accidental laboratory leaks in mind, unusual disease outbreaks in geographical proximity to known or suspected life science research facilities could indicate which pathogens the facility works with. A growing number of established centers for data collection and routine monitoring of disease outbreaks could enhance efforts to quickly detect outbreaks of unknown origin. Organizations like the World Health Organization (WHO) Global Hub for Pandemic and Epidemic Intelligence in Berlin, Germany, and national institutes for disease control already conduct disease surveillance, but identification of potential lab leaks may add new functions that build on these systems, which traditionally serve public health goals. For example, genomic surveillance programs should be threat-agnostic instead of focusing on a set of predefined pathogens to take into account the possibility of engineered biological weapons.

Addressing Challenges in Data Management and Analysis

As technology advances, the capacity to collect vast amounts of data from numerous sources and facilities has grown exponentially, particularly through remote monitoring technologies like satellites and biosensors and through analysis of publicly available information. However, it is vital to also consider how these data are stored and analyzed and how access to these data are managed. Discussions regarding the governance of data—where it will be housed, who can access it, and under what conditions—will be critical moving forward, particularly to ensure transparency, neutrality, and trust among States Parties in enhanced transparency processes.

Data Storage and Managing Access

Storing enhanced transparency-related data in an accessible, neutral repository—ideally managed by an international organization—would prevent control by a single state and facilitate equitable access. States would need to create data-sharing agreements to address potential concerns over security, privacy, and sovereignty, particularly when sensitive national security or proprietary information is involved.

Third-party access raises critical questions: Who beyond States Parties should access sensitive data and under what conditions, and how can neutrality and security be ensured? Vetted international or civil society organizations can serve as impartial arbiters, free from national bias. However, allowing such access presents challenges, including concerns over proprietary or security-sensitive information. Clear protocols are needed to define access rights while safeguarding classified data. Moreover, the integrity and security of the data repository are essential to prevent breaches that could compromise national security and erode trust in the system.

Data Analysis to Help Discern Intent of Dual-Use Research

Determining intent is a major challenge when analyzing data related to bioscience research and development.[20] Much of biological research is dual use, meaning it can be used for peaceful purposes (e.g., medical research or vaccine development) or for malicious intent (e.g., biological weapon development). The goals of biological research are especially difficult to evaluate because of its profound dual-use nature and its deep integration into a wide range of civilian and military activities.[21]

Data Analysis

Advances in science and technology have created powerful new methods for analyzing and interpreting diverse data streams.

Analysis of Biological Samples

Researchers can choose from a spectrum of sample analysis methods—from rapid, targeted polymerase chain reaction (PCR) assays to comprehensive mass-spectrometry analyses—each offering different trade-offs in sensitivity, specificity, and throughput. The optimal choice hinges on the question at hand (e.g., detection of single microbial species versus profiling a community of different species), the nature of the samples, the available equipment, and financial resources.

- **PCR diagnostics:** PCR is a widely used method to make large numbers of copies of a specific DNA sample rapidly, allowing scientists to quickly detect a previously defined small sample of DNA (or a part of it).[22] The technique can be used to quickly screen for specific pathogens (e.g., *Bacillus anthracis, Yersinia pestis*), known engineered genetic elements (e.g., synthetic genes, resistance markers), or other previously identified DNA fragments of interest.
- **Metagenomic sequencing:** Metagenomic sequencing techniques are used to explore all genetic material present in each sample, whether stemming from viruses, viroids, or free DNA. Unlike PCR diagnostics, metagenomic sequencing does not require a target to be predefined. These techniques are therefore best used to identify unknown or unexpected pathogens, engineered organisms, and unusual biological agents, as well as for discovering entirely novel or undeclared genetic constructs. In the context of enhancing transparency, metagenomic sequencing uncovers the presence of non-declared or novel organisms.
- **Mass spectrometry:** Mass spectrometry (MS) uses the charge-to-mass ratio to identify proteins and their posttranslational modifications—that is, chemical changes that occur after a protein has been produced in a cell. Detecting proteins and their posttranslational forms via MS confirms that the corresponding genes are present and actively expressed and translated into proteins. The presence of proteins that do not match declared research objectives might indicate undeclared genetic manipulations, pathogen production, toxin expression, or other prohibited or undisclosed research activities.
- **16S rRNA sequencing:** 16S rRNA sequencing is a targeted genetic sequencing approach used specifically to identify and classify bacterial species present in a sample by analyzing the highly conserved 16S ribosomal RNA gene found universally in bacteria. It provides a rapid, cost-effective snapshot of bacterial diversity and composition. 16S rRNA sequencing provides specific insight into research activities involving bacteria, characterizing microbial community composition and detecting the presence of unexpected bacteria. If declared research activities focus on nonbacterial organisms but bacteria are found prominently, this could be another cause for concern.

Computational Approaches and Machine Learning

Using computational approaches, including machine learning (ML), analysts can process and analyze large amounts of data that humans alone cannot parse. These methods help identify patterns in the input data and detect signals that stand out from the baseline patterns. Computational approaches can therefore enhance transparency by detecting potential deviations from declared research objectives or unusual activity patterns indicative of potentially undeclared or dual-use research.

- **Machine learning–based anomaly detection:** ML-enabled anomaly detection systems apply algorithms that independently establish baseline patterns from voluminous, high-dimensional data, then use these baselines to flag significant deviations. Anomaly detection models could flag unusual patterns across various datasets, including biological data, procurement records (such as excessive orders of sensitive materials), or satellite imagery.
- **Natural language processing for publication analysis:** As one type of ML algorithm, natural language processing (NLP) provides computers with the ability to process data encoded in human language. NLP-based techniques such as topic modeling can detect dual-use research patterns, inconsistencies, or shifts in research focus when analyzing published literature or other natural language–based records of research activity.[23]
- **Genetic engineering attribution algorithms:** Genetic engineering attribution (GEA) algorithms are trained specifically to recognize engineered genetic sequences or signatures characteristic of genetic manipulation technologies and infer the likely lab of origin from the genetic signature.[24] GEA reverses the process of analyzing samples from a specific laboratory, instead linking genetic material found outside of the laboratory to its likely origin. GEA algorithms can enhance transparency, for example, by facilitating analysis of environmental samples close to labs to assess whether microbes are engineered or natural.

Procedural Approaches

The previous section described the types of data and evidence that can enhance transparency in laboratory research activities. This section will focus on the procedures for collecting and analyzing such data and evidence.

The approaches in this section span from on-site mechanisms, such as routine and challenge inspections, to off-site and indirect methods, such as standardized declarations and satellite imagery. Beyond data collection, procedural activities like capacity building, scientific collaboration, and regular engagement between States Parties can deepen cooperation and enhance the overall effectiveness of the Convention, even when direct monitoring is limited.

Defining the Threat Model

To ensure a transparency regime is both effective and manageable, the problem it is designed to address must be clearly defined. This begins with articulating the primary threat—or set of key scenarios—that the regime aims to detect. A well-defined threat model enables policymakers and technical experts to determine which types of information should be prioritized for collection and analysis. Prioritization increases the likelihood that the transparency regime will be able to detect early indicators of concern and respond in a timely and coordinated manner. Without such clarity, transparency efforts risk becoming overly broad, inconsistent, or misaligned with the actual threats they are meant to mitigate.

A unified threat model that all BWC States Parties can agree on and use to design enhanced transparency approaches would be ideal but is likely to be very challenging to develop. While many BWC States Parties currently have their own biological weapons threat models, many of them are classified and cannot be shared to inform development of a unified threat model. Additionally, some experts are concerned that putting together a unified threat model, which details what a modern biological weapons program may look like, could pose an information hazard—either as a playbook for how to develop a biological weapons program or as an outline for what to avoid when putting together a clandestine bioweapons program.

Some indicators for a threat model likely could serve as triggers for action and could be agreed to by all BWC States Parties, such as a massive buildup of ammunition filled with a biological agent. However, another approach to a threat assessment could be to develop and continually analyze an index of baseline signals. Basic and beneficial research should have common signals (inputs, outputs, sampling results, laboratory staffing, etc.). Therefore, if a baseline signal were established, deviations from the baseline (i.e., anomalies) could be more readily identified. Detection of an anomaly would not necessarily indicate the presence of a biological weapons program, but it may help identify when further investigation is warranted. AI could be used for analysis to help develop the baseline signal, running on a continuous basis to update and refresh over time.

On-Site Monitoring Approaches

On-site monitoring approaches represent some of the most effective tools available for enhancing transparency in life science research activities. These procedures involve direct physical access to facilities and hands-on assessment of ongoing work. While such procedures can be challenging to implement due to concerns related to national security, sovereignty, proprietary information, or operational disruption, they also can enable the collection of high-fidelity, context-rich data that are often unattainable through other means. By allowing experts to observe operations, review records, and gather material evidence, on-site monitoring—through ad hoc, routine, or challenge inspections—can help reduce ambiguity regarding research intent.

Routine Inspections

Routine on-site inspections rely on independent and trusted experts to observe facilities, review records, interview personnel, and collect samples firsthand. Such inspections create an unbiased record of activities that can help reduce misperceptions about BWC compliance. The effectiveness of routine inspections depends on overcoming logistical, political, and confidentiality challenges and will require clear protocols, sample collection and analysis approaches using modern technologies, and incentives for sustained participation. This method has long been a cornerstone of arms control verification regimes and was a key verification element proposed in VEREX.[25]

Historical examples demonstrate the power of on-site inspections as a tool to directly verify compliance and deter noncompliance, as evidenced by the United Nations Special Commission inspections (UNSCOM) in Iraq during the 1990s following the Gulf War.[26] UNSCOM inspections aimed to dismantle Iraq's biological weapons program and were crucial in verifying compliance with the BWC. Lessons can also be drawn from retrospective analyses of analogous on-site inspections under the Chemical Weapons Convention (CWC), including work by the Stockholm International Peace Research Institute.[27]

While on-site inspections can be effective, they present significant challenges. Inspections are intrusive, often leading to concerns about national security and confidentiality of intellectual property. This is particularly concerning when proprietary or sensitive information might be observed and recorded. Organizing routine inspections is logistically complex and expensive, requiring cooperation between states and international bodies. Resistance from inspected states and actors can further complicate the process.

To address these challenges and improve inspection efficiency, inspections can be augmented by integrating modern technologies such as portable biosensors for real-time detection of biological agents, body cameras for transparency, and drones to complement physical inspections. Such methods will still need to account both for the potential unwillingness of the observed party and for collecting data when the observed party attempts to withhold or manipulate the data and inspected spaces.

Further refinement of inspection data collection objectives and requirements will be necessary to move forward. Identifying and prioritizing the most useful and relevant data streams will be essential to ensure inspections are achieving their goals. A set of criteria for identifying *where* and *when* the inspections should take place needs to be established, to determine which laboratories qualify for inspections. To ensure rigor of inspections, replicability of inspection results, and comparability across different facilities, standardized procedures are needed to guide *how* inspections are operationalized. Having a clear, defensible evidence-

based schedule lends credibility to the inspection process and limits the potential for a state party to claim that inspections are politically biased. Who the inspectors are is also a critical aspect of the inspection process, as their expertise, independence, and neutrality are essential for the credibility and effectiveness of inspections.

Challenge Inspections

Challenge inspections, in addition to routine inspections, can uncover concerning biological research developments before evidence is lost or hidden. Challenge inspections have been used in a range of arms control contexts, though primarily in response to chemical weapons use. For example, the UN conducted investigations in Syria in 2013 following allegations of chemical weapons use during the civil war.[28] Although these inspections have not been extensively used in the biological context, the principle remains similar: by responding rapidly to emerging suspicions or reports, challenge inspections provide an opportunity for transparency.

Challenge inspections may be hindered by delays due to diplomatic negotiations, allowing the identified facility time to conceal evidence before the inspection takes place. There is also the risk of escalating tensions among states, based on false or inaccurate reports.

A successful process for challenge inspections will require agreements by States Parties that specify the triggers and tripwires that lead to the initiation of a challenge inspection. There should also be an established cadre of agreed-upon third-party inspectors from which a selection can be made. Some of the politicization of a challenge inspection can be mitigated by implementing neutral, standardized procedures with previously established triggers, tripwires, and inspectors.

Voluntary Peer Review

Voluntary peer review differs from an inspection because the country being observed voluntarily initiates an extra measure of transparency. To improve the effectiveness of the peer review process, it will be important to establish a standardized methodology that incorporates collection and analysis of data and samples.

First proposed by France at the Seventh Review Conference,[29] voluntary BWC peer review exercises (PREs) offer a flexible approach that can include document reviews of biological research and safety protocols, facility visits to laboratories and research centers, and scientific exchanges that facilitate dialogue and collaboration among scientists.[30] To date, these efforts have been voluntarily agreed to either bilaterally or multilaterally between the interested States Parties. The voluntary nature of these processes has led to uneven participation. To date, 43 States Parties have participated in six exercises, with the first pilot program conducted by France in 2013.[31]

Conducting thorough reviews often requires significant resources, which can be a limiting factor for many states. Moreover, political sensitivities surrounding information and facility access may hinder participation. PREs have been called largely illusory in the past,[32] since the organizing States Parties retain control over the exercise objectives, focus, stakeholder involvement, process, and access to results. PREs currently lack standardization, posing challenges for comparison among the various exercises.

Standardization could enhance PRE reliability and effectiveness; this effort could include setting the focus, process, objectives, and criteria for the information to be collected.[33] Furthermore, introducing and testing data and sample collection procedures during on-site visits could lay the groundwork for a more comprehensive and standardized data collection process as part of PREs. By starting with a modest, small-scale approach, select data and samples could be collected and analyzed on-site, and the effectiveness of these approaches can be evaluated over time.

BWC State Party Declarations

Declarations are among the most accessible tools for enhancing transparency under the BWC. By documenting biological research activities, defense-related programs, and relevant national infrastructure, declarations allow States Parties to share information in a low-cost, politically feasible way that does not require physical access or inspections. While currently voluntary under the BWC through CBMs, these submissions offer a valuable starting point for trust building and transparency, helping reduce ambiguities and suspicions among states. [34] Declarations also can serve as a foundation for audits, using on-site inspections or remote monitoring, enabling cross-checking of reported information against observed activities, and identifying discrepancies or potential noncompliance.

Confidence-Building Measures

Since they were established in 1987, CBMs have remained the only formal tool under the BWC for promoting transparency and building confidence among States Parties. While this approach has had some success in building trust, participation remains inconsistent and the quality of submitted data varies. Some states may submit incomplete or outdated information, reducing the overall effectiveness of CBMs as a transparency tool. Furthermore, because participation is voluntary, there are no consequences for failing to comply or for submitting inaccurate data. Since 1987, only nine States Parties have submitted CBM reports every year: Canada, Finland, Germany, the Netherlands, Norway, the Russian Federation, Spain, United Kingdom, and the United States.[35]

The primary advantage of CBMs is that they are voluntary, nonintrusive, and low cost. The reliance on voluntary participation is a major limitation, leaving gaps in the data and providing the opportunity for masking noncompliance. While not a dramatic step forward, enhancing CBMs and their associated processes could help advance transparency goals.

- **Improving CBM forms:** Since the Ninth BWC Review Conference, States Parties, international organizations, and civil society have made recommendations on how to improve CBMs, including updating the CBM forms to capture additional information such as (1) biomedical activity carried out by research units controlled by ministries of defense of States Parties deployed outside of the national territory and (2) information on human and animal vaccine production facilities.[36] Experts have also noted the importance of modernizing CBMs to ensure they capture information relevant to 21st-century bioscience and biotechnology research and development. Others have suggested improving the design of the CBM forms to make them more user-friendly. Instead of requiring respondents to fill in all information in open-text fields, some questions could be reformatted into

checkboxes. This adjustment could streamline the process, particularly for routine data, making it easier for States Parties to complete their CBMs accurately and on time.

- **Supporting CBM analysis:** CBM data have limited value if they are not analyzed effectively. Even if participation, completeness, and accuracy were improved, the BWC Implementation Support Unit's (ISU) limited analytical capacity hampers the effectiveness of CBMs to promote transparency and build trust. Analysis could take various forms, such as summarizing the content of submitted forms, identifying trends and changes over time, or assessing the validity and accuracy of CBM content.

  To enhance the effectiveness of CBMs, the BWC could be amended to expand the scope of the ISU mandate. The ISU could analyze the data and present the results in an annual report to States Parties. This report would provide an impartial, collective assessment of CBM submissions, creating a valuable resource for all States Parties. Alternatively, there has been a continued call to make CBM submission available to the public, which would enable third-party entities to assist with this review.

- **Expanding CBM submission training:** To increase CBM participation, it will be important to provide both funding and technical support to help States Parties compile and submit their CBMs. This is especially true for the initial submission, which is often the most difficult due to the lack of established procedures, connections, and a comprehensive understanding of the national biosecurity landscape. Providing dedicated support at this stage could help States Parties overcome these challenges, setting them on a path to more consistent, long-term participation. Furthermore, expanding training opportunities can enhance the quality and accuracy of CBM submissions. Offering targeted training for officials in relevant ministries and providing clear guidelines or blueprints on how to prepare and submit a CBM would support this goal.

Mandatory Declarations

As a step beyond voluntary CBMs, mandatory declarations could enable states to demonstrate compliance without on-site inspections or intrusive monitoring. Mandatory declarations would provide strong positive incentives for compliance and impose political costs for noncompliance. The lack of systematic independent assessment of declarations may leave room for states to withhold or omit sensitive information, but despite these challenges, the system would be improved by incorporating real-time digital reporting platforms for more dynamic transparency.

Currently, the BWC has no mandatory reporting requirements. Both the CWC verification system and the International Atomic Energy Agency (IAEA) safeguards system rely on formal declarations, establishing baselines for monitoring.[37] In the context of the CWC, these declarations enable the Secretariat of the CWC to track the global movement of scheduled chemicals and detect any suspicious transfers or trends.[38]

Determining standardized formats and criteria for the content of mandatory declarations would be crucial. A standardized system with clear guidelines on what information needs to be included would enhance comparability and reduce ambiguity by ensuring that all States Parties provide consistent and relevant data. Introducing processes such as audits, third-party inspections, or the use of open-source intelligence would help ensure that the information provided in declarations is accurate and complete. Striking the right balance between transparency and protecting sensitive information will be crucial to ensuring states' willingness to fully participate.

Remote Monitoring

Remote monitoring approaches leverage rapidly advancing tools, such as satellite imagery, biosensor networks, and open-source data, to continuously observe facilities or regions for signs of suspicious activity. These tools can support early warning, complement on-site inspections, and provide additional layers of transparency beyond self-reported data. Their ability to gather information without physical access to sensitive sites or proprietary information makes them a more politically feasible and scalable path to oversight.

Independent Network of Satellites

The establishment of an independent network of satellites dedicated to tracking biological weapons–related activities would allow for continuous remote monitoring under the BWC. This network could consist of high-resolution imaging satellites that could be made accessible to all BWC States Parties through a negotiated agreement. A key advantage of a satellite network is its ability to provide continuous coverage across vast geographical areas, allowing for monitoring of suspected facilities. It could enable the detection of suspicious activities, such as unusual construction, transport movements, or environmental changes, offering prompt warnings that might otherwise go unnoticed. The shared data streams could also act as a deterrent, as states would be aware that their activities are being observed by an impartial system. This continuous remote monitoring could also reduce reliance on sporadic on-site inspections.

Several aspects of a satellite-based system require further development, particularly the ownership of the satellite network and the legal and technical frameworks for sharing and managing the collected data. Issues such as data privacy, access control, and the interpretation of findings will need to be carefully negotiated, as will the procedures for responding to potential violations. The integration of AI and machine learning to process and analyze large volumes of satellite data could enhance the system's effectiveness by automatically identifying patterns and anomalies that warrant further investigation.

Global Biosensor Networks

Global biosensor networks could deploy automated sensors in strategic locations to detect biological agents in real time. These sensors could be placed near high-security laboratories or in regions where illicit biological activities might occur, providing nonintrusive, 24/7 detection of pathogens or toxins. While biosensors offer timely detection, distinguishing between natural and weaponized agents can be challenging, and the high cost of deploying and maintaining such networks globally remains a significant barrier. Privacy concerns may also arise along with questions related to the authority to place sensors within sovereign territory.

Integration of Open-Source Intelligence

The use of open-source intelligence (OSINT) leverages commercially and publicly available information such as satellite images, social media posts, and scientific publications to detect early signs of biological weapons development. OSINT platforms, combined with AI-based data analysis, can identify suspicious activities or patterns that might indicate misuse of biological research. This method is relatively low cost and widely accessible, making it a potentially valuable tool for BWC States Parties. However, OSINT's reliance on commercially or publicly available data sources means it may lack reliability or conclusive evidence, and that it may need to be corroborated with other transparency methods.

Hybrid Monitoring Systems

A hybrid monitoring system would combine multiple technologies, such as satellites, drones, biosensors, and AI analytics, into an integrated framework for continuous remote monitoring. This approach offers a comprehensive and multilayered view of global biological activities. For example, satellites could provide broad surveillance, drones could gather closer visual data, and AI could analyze public health trends. While a hybrid system would offer more robust monitoring, the complexity and cost of integrating these platforms are significant challenges. Additionally, states may be hesitant to agree to such extensive surveillance. The development and implementation of continuous remote monitoring systems would require international cooperation, legal frameworks, and technical standards.

Scientific Exchanges

A significant influence on the misperceptions surrounding bioscience research and development can be attributed to the insular nature of some research laboratories. Scientific exchange programs can significantly reduce misperceptions and build trust in bioscience research. Embedding visiting scientists directly into research environments, host institutions can provide firsthand insight into their scientific aims, operational practices, and safety and security norms. Over time, networks of scientists forged through exchanges can contribute to rapid information sharing, collective problem-solving, and early warning of emerging biological threats.

Historical examples demonstrate the power of these exchanges. During the late and post–Cold War periods, U.S.–Soviet, and later U.S.–Russian, laboratory-to-laboratory cooperation helped reorient former Soviet biological weapons scientists toward peaceful research and allowed American scientists to witness dismantlement and redirection efforts firsthand.[39] These exchanges not only built mutual trust but also laid the groundwork for ongoing scientific collaboration.

Incident Reporting and Whistleblower Disclosures

Two critical and complementary tools that support transparency under the BWC are incident reporting and whistleblower disclosures. These mechanisms can help detect potential violations of the BWC and deter the misuse of biological science. They are nonintrusive methods that rely on secure, voluntary disclosures.

To enhance the effectiveness of incident reporting and whistleblower disclosures, secure digital platforms can be developed to allow anonymous, encrypted submissions. Such platforms would act as neutral, international channels protecting the safety and anonymity of the reporter. AI tools could help analyze reports to assess their credibility, detect patterns, and prioritize the most urgent cases for investigation.

Incident Reporting

Incident reporting is a formal process, usually led by governments or institutions, for reporting unusual events that may suggest a potential violation of the BWC. These reports are often based on external observations, such as unexplained disease outbreaks or the suspicious transfer of dual-use biological materials, and are submitted through official diplomatic or institutional channels. Currently, the concept of incident reporting under the BWC is covered primarily in Article V and Article VI.[40] These articles provide a framework for states to raise concerns and request investigations when there are suspicions of noncompliance. More standardized reporting requirements along with creating neutral or anonymous reporting channels might help mitigate the political sensitivities that often arise when one state reports potential violations by another.

Whistleblower Disclosures and Protections

Whistleblower disclosures come from individuals inside laboratories, research programs, or government facilities who possess firsthand knowledge of illicit or dangerous activities. These individuals can help uncover violations that might otherwise go undetected. Whistleblowers played a key role in revealing Iraq's secret biological weapons program in the 1990s.[41] However, whistleblowers often face significant risks, such as retaliation from their employers or governments. To address this issue, whistleblower protections should be established at the international level rather than the national level, ensuring that individuals have a secure, impartial mechanism for reporting misconduct.

Implementing Transparency Efforts

Improving transparency in bioscience research and development is essential for building trust among nations and enhancing collective efforts to prevent the misuse of biological agents. During the third session of the Working Group on the Strengthening of the BWC, experts discussed how transparency and verification efforts should move beyond a binary between having and not having a legally binding mechanism.[42, 43] Incremental steps and approaches can be taken toward enhancing transparency. The previous section outlined several scientific, technical, and procedural approaches for states to engage in transparency measures, each with varying degrees of commitment, enforceability, and levels of confidence in their assurance.

- **Voluntary measures** allow states to disclose information at their discretion; states often implement such measures on their own accord to foster trust and confidence in the international community. For example, some States Parties partake in voluntary transparency initiatives such as PREs.
- **Politically binding measures** represent a commitment by states to uphold certain practices without the legal enforceability of a treaty. For instance, countries may voluntarily submit CBMs to the BWC, detailing their biological research activities, capabilities, and measures to prevent the misuse of biological agents. Although not legally binding, the development and approval of the forms were done by consensus and reflect a collective political will to enhance transparency in treaty compliance.
- **Legally binding measures** impose formal obligations on member states. While the BWC itself lacks strong legally binding enforcement mechanisms, there are frameworks related to biological security that have legally binding aspects. One example of legally binding enforcement exists in the CWC, which has established obligations for member states to declare and eliminate their chemical weapon stockpiles.
- **Coercive measures** are those that are imposed on a state. Coercive measures involve strategies that compel states to disclose information or adhere to certain standards, often in response to concerns about noncompliance.[44] This approach may include diplomatic pressure, economic sanctions, or public exposure of a state's activities through media or international advocacy. An example of this is when the UNSCOM uncovered Iraq's biological weapons program through a series of inspections after the 1991 Gulf War.
- **Non-voluntary measures** include information that is generated without the consent of the state.[45] There is a wide and growing range of open-source information that could constitute nonvoluntary transparency materials.

Institutional Structures

Institutional structures provide a lasting foundation and serve as a home for the procedures associated with the collection and analysis of scientific, technical, and other data. While the BWC provides a clear, widely supported institutional framework to house these activities, other institutional structures and settings should not be discounted. Existing institutional structures may need to be modified, or new ones may need to be developed. In this section, we examine a range of options for institutional structures that can advance international efforts to enhance transparency.

Structures Outside the UN System

While structures within the UN would provide legitimacy, reaching political agreement to establish or modify such structures is likely to be challenging. Outside the formal mechanisms and structures of the BWC, more nimble groups and organizations that are outside the BWC and UN system can begin to make progress promoting and tracking compliance, developing and demonstrating best practices, and piloting novel ideas and approaches.[46] The goal of external structures is to move forward on new ideas, demonstrating their utility, and to lay the groundwork for adoption into formal UN institutional settings in the future.

Voluntary Coalition

The establishment of a formal compliance mechanism within the BWC faces significant political challenges due to the requirement that adoption of new protocols be by consensus. A parallel path could be through the formation of small groups of motivated like-minded countries, voluntary coalitions, and formal minilateralist groups. These types of efforts are well established in the nonproliferation field, including the Australia Group, an informal forum of 42 countries that protect against chemical and biological weapons program development using national export control procedures.[47] Additionally, there are examples of global biosecurity-oriented groups including the Global Health Security Agenda, the Global Partnership Against the Spread of Weapons of Mass Destruction, the International Experts Group of Biosafety and Biosecurity Regulators, and the Biosafety Level 4 Zoonotic Laboratory Network.[48] Going forward, voluntary coalitions should take a more inclusive approach, striving for diverse membership that includes members from the Global South.

A smaller group of motivated parties could develop a coalition to engage in a more formalized voluntary transparency agreement. Such a group could focus on voluntary peer review exercises among participating nations. Countries could share with BWC States Parties insights from their reviews, contributing to a broader understanding of the best practices for these transparency exercises. For the initiative to succeed, it would require a strong foundation of government technical expertise, financial resources, and sustained political will. Over time, it could prove its effectiveness and either encourage more countries to join or its practices could be adopted into the formal UN system.

Open-Source Community Effort

A global, independent biosecurity watchdog organization, modeled after groups like Amnesty International or Human Rights Watch and building on existing civil society efforts,[49] could monitor biological research through open-source intelligence to track activities that could signal noncompliance with the BWC. By functioning outside formal governmental structures, this organization could maintain greater flexibility in monitoring and analysis, acting as a neutral party to raise alarms about illicit or potentially dangerous research. Its reports could be shared with the BWC and the public.

Multistakeholder Partnerships

Collaboration between States Parties and civil society organizations, similar to the International Partnership for Nuclear Disarmament Verification (IPNDV), could also be explored. The IPNDV is an initiative that includes more than 25 countries and civil society working to identify and develop practical solutions to the technical and procedural challenges associated with effectively verifying nuclear disarmament.[50] A similar organization could be set up to address technical and procedural approaches to enhance transparency and strengthen the BWC.

Industry-Led Initiatives

The biotechnology industry could contribute to enhancing transparency by forming a self-regulating body dedicated to setting and enforcing ethical guidelines for dual-use research. An international organization, such as the International Biosecurity and Biosafety Initiative for Science, whose mission is to work collaboratively with global partners to strengthen biosecurity norms,[51] could establish a biotechnology industry standards board. This board could serve as an intermediary between the private sector and international regulators, promoting PREs and incident reporting, thus fostering trust and compliance with biosecurity standards.

This could also lead to the creation of a "transparency certification" program for biotech companies and research institutions. This voluntary program would recognize organizations that comply with strict transparency and biosecurity standards, providing them with reputational benefits and encouraging them to adopt best practices.[52] By offering a certification that highlights responsible research, industry could incentivize greater openness and accountability in dual-use research, helping to reduce biosecurity risks.

Regional Activity Networks

Establishing regional activity networks under the BWC could enhance accessibility, inclusivity, and sustained engagement, particularly for low- and middle-income countries. Regional networks could enable more frequent regional meetings, easing the burden of travel to Geneva and allowing broader participation in biosecurity discussions and capacity building. Regional networks could focus on regional PREs, scientific exchanges, assistance with CBMs, and incident reporting.

Reference Lab Network

A trusted reference laboratory network is critical to validating incoming samples acquired through on-site inspections or other means. The international system already has many laboratory networks, including those found within the UN Secretary General's Mechanism for Investigation of Alleged Use of Chemical and Biological Weapons (UNSGM), WHO, Food and Agriculture Organization, and World Organization for Animal Health, all of which focus on related areas of health and biosecurity. Establishing a BWC-specific lab network would enhance transparency by providing standardized, reliable analytical results that can be shared among States Parties.

Establishing a reference lab network for the BWC could centralize expertise, promote standardized testing procedures, and increase the speed and accuracy of biological sample analysis. However, challenges such as ensuring international participation, securing sufficient resources, and addressing concerns over sensitive data and national security would need to be carefully managed. Clear, internationally accepted recognition criteria for labs would be crucial for maintaining the network's credibility.

Structures Within the UN System

While housing institutional structures outside the formal UN system may offer greater agility and adaptability, official mechanisms within the UN provide several advantages, such as broad international legitimacy, access to established infrastructure, and proven conflict resolution mechanisms. This section outlines options for expanding existing structures and creating new ones within the UN system to strengthen global efforts to enhance transparency.

Strengthening the Biological Weapons Convention

The BWC can serve as a home for new institutional mechanisms to strengthen transparency, cooperation, and accountability, though political and logistical challenges must be overcome to achieve this goal.

- **Establishing the Biological Weapons Convention Implementation Organization:** The Organization for the Prohibition of Chemical Weapons (OPCW) oversees the CWC and is more than 100 times larger than the current BWC ISU. To effectively implement and oversee an effective enhanced transparency regime, a larger structure, similar to the OPCW, will be necessary. The Biological Weapons Implementation Organization (BIO) could take the place of the existing BWC ISU, be formally mandated and sustainably financially resourced, and provide structured management and oversight of enhanced transparency procedures. Establishing BIO would require overcoming the political, logistical, and financial challenges of creating and maintaining a new large-scale multilateral institution.

  Since the Ninth Review Conference, States Parties have made a variety of recommendations regarding possible structures and functions for a BWC implementing organization that aims to strengthen BWC enforcement and enhance global efforts to prevent the use of biological weapons.[53] BIO activities could include sharing information and monitoring compliance with the BWC, organizing and conducting visits to high-security biological research facilities, providing technical

assistance to states in need of capacity building for biosecurity and BWC implementation, and collaborating with other organizations to strengthen global biosecurity. These activities within BIO should be managed and supported by a technical secretariat.

- **Expanding the mandate of the BWC ISU:** The ISU coordinates BWC meetings, facilitates the CBM process, and assists States Parties with implementation of the BWC. Expanding the mandate and financial resources of the BWC ISU would significantly enhance transparency and compliance efforts and could be advanced incrementally through decisions at upcoming BWC Review Conferences. This could serve as an intermediate step on the pathway to establishing a full BIO, and it would allow for immediate improvements to the current system without the immense political, financial, and operational hurdles to creating a large new multilateral organization.

  Currently, the ISU employs just four individuals, with an annual budget of approximately $2.1 million. This small team has been consistently underfunded and lacks the resources necessary to manage any substantial initiatives aimed at expanding BWC-related compliance activities or implementing approaches to enhance transparency. Importantly, the mandate and budget of the ISU must be renewed every five years at the Review Conference.

  A permanent and better resourced ISU with an expanded mandate could play a crucial role in overseeing a broader range of activities aimed at fostering transparency. This would involve managing existing programs and facilitating new initiatives designed to promote information sharing and collaboration among States Parties. An adequately funded ISU could ensure that transparency efforts are systematic, consistent, and sustainable. One key benefit would be the ISU's ability to conduct basic analyses of CBMs and other relevant materials. An expanded ISU could also coordinate a greater number of workshops and training sessions to educate states on best practices for reporting and sharing information through the CBM process.

- **Establishing mechanisms within the BWC for incident reporting:** The BWC currently relies on Articles V and VI to discuss any concerns that States Parties have regarding treaty implementation or to discuss accusations of breaches of treaty obligations. What the treaty lacks is a formalized incident reporting mechanism. (See page 26 of this report for additional details on incident reporting.) BWC States Parties have previously proposed establishing a more formalized reporting mechanism to improve transparency and accountability in handling biosecurity incidents. However, major obstacles still exist, including political reluctance to formally acknowledge violations, concerns over national sovereignty, and delays in addressing incidents.

- **Establishing a science and technology advisory mechanism:** For decades, proposals have called for establishing a science and technology mechanism for the BWC to assess scientific and technological developments relevant to the Convention and advise States Parties. Drawing on the model of the OPCW's Scientific Advisory Board, this mechanism could provide States Parties with regular assessments, helping them stay ahead of emerging threats. It could also foster international collaboration among scientists, enhancing transparency and building confidence in the BWC. Since the Ninth Review Conference, States Parties have made progress toward this goal, particularly with the initial development of a science and technology advisory mechanism proposal. The current draft outlines key elements such as the board's role and functions, structure and composition, meeting schedules, and relationship with the ISU.[54]

Securing political buy-in for this approach from all BWC States Parties may be difficult, particularly as the details still need to be ironed out and some States Parties may resist external advisory influence on sensitive national matters. Coordinating with existing bodies and ensuring the mechanism reflects the global community could further complicate its implementation.

Expanding the Mandate of the UN Secretary General's Mechanism

The BWC has no internal institutional mechanism, procedures, or resources to investigate either the alleged use of biological weapons or the alleged development and production of biological weapons. There are two external related mechanisms. The UNSGM is the only international mechanism for investigating the alleged use of biological weapons. However, even with efforts in recent years to strengthen the readiness of the UNSGM for biological weapons investigations, many gaps remain.[55] One major gap that needs to be addressed is a mechanism to investigate alleged biological weapons development and production, not use.

Additionally, the WHO established the Scientific Advisory Group for the Origins of Novel Pathogens (SAGO). The SAGO advises the WHO Secretariat on technical and scientific considerations regarding emerging and reemerging pathogens. The SAGO can provide technical and scientific findings to the Secretariat related to the origins of a pathogen that has emerged, but it has no mandate to cover research if there has been no outbreak.

The BWC has mechanisms to discuss alleged breaches of the Convention, such as Article V and VI provisions, but not to implement a formal investigation for allegations of biological weapons development and production. If the UNSGM were expanded to include investigations of alleged malicious development and production, this could, for the first time, provide an institutional investigative mechanism for potential Article V and VI consultations.

Recommendations

NTI | bio has initiated an effort to identify scientific, technical, procedural, and institutional tools and mechanisms that can enhance transparency. The objective is to reduce the risk of misperceptions among BWC States Parties about other nations' bioscience research and development capabilities and intentions. This report explores a wide range of options informed by discussions with international experts at the project workshop in Amsterdam and through several expert interviews. The following recommendations reflect the views of the report authors on priority concrete actions that are likely to be effective and practical for enhancing transparency regarding States Parties' compliance with the BWC. Some of these recommendations build on concepts that have been under discussion for years among the BWC community, and some of the recommendations present newer ideas.

With strong interest among States Parties in promoting transparency and confidence building and in strengthening the BWC, a political window of opportunity creates an imperative for taking these concrete steps now. While informed by expert discussions and key findings from this project, these recommendations do not necessarily reflect the views of all project participants.

1 Define a clear threat model to inform BWC enhanced transparency measures.

Design a threat model, which can evolve with ongoing advances in bioscience and biotechnology, that defines the scope of key threat scenarios associated with biological weapons development. Developing a clearly defined threat model is crucial for building an effective enhanced transparency regime. It defines the scope of the problem the regime is meant to address and allows for more focused, clearly scoped information collection and analysis activities.

- Governments and other key stakeholders should develop a shared understanding of the types of threat scenarios for biological weapons development of greatest concern, to include black swan events, along with the types of signals most likely to indicate nefarious biological weapons–related research and development.
- Governments should collaborate with private industry and academia to develop baseline, "status quo" signals usually associated with legitimate bioscience research. Determining a baseline can facilitate more effective identification of anomalies from this baseline.
- Governments, with support from technical experts, should design a process for continuously updating the biological weapons development threat model, baseline signals associated with legitimate bioscience research, and anomaly identification, to include exploring the use of AI to support continuous updates where feasible.

2 Explore open-source data collection and AI analysis.

Evaluate the potential of publicly available information collection and AI analysis to detect meaningful signals of high-risk or illicit activities related to biological weapons development. While such an approach would need to be tested and validated, if shown to be effective, it could unlock vital information and provide indicators that would otherwise be lost in the noise.

- Communities of experts in the private sector and within NGOs should explore approaches for collecting and analyzing publicly available data streams—such as research publications, trade data, and satellite imagery—to determine which data sources could be most effective for detecting activities associated with the development of biological weapons.
- If and when effective publicly available data sources are identified, experts in the private sector and NGOs should test machine learning and other AI methods for analyzing those data. Such a pilot project could explore the feasibility of using this approach to establish a baseline of normal activities associated with legitimate bioscience research and detect signals of concerning activities potentially associated with biological weapons development.

3 Conduct a pilot project to explore integration of sample and data collection during site visits.

Experiment with site visit procedures that incorporate standardized sample and data collection. A key consideration of effective site-visit procedures is balancing the protection of intellectual property with providing sufficient transparency regarding the bioscience research being conducted.

- NGOs, in partnership with industry, academic institutions, or both, should test, refine, and validate site visit information collection procedures. The site-visit pilots should focus on determining what data and information are necessary and sufficient to obtain a clear understanding of the work going on within the lab while balancing protection of intellectual property and other sensitive information.
- This pilot project should also consider and evaluate ways to incentivize participation and disincentivize nonparticipation for site visits. Including these considerations will allow for a more operational transition if a site-visit pilot proves effective.
- Governments should experiment with incorporating procedures for collection and analysis of samples and other data into existing peer review processes.

4 Strengthen BWC Confidence-Building Measures.

Strengthen and modernize the CBM process to make it a more effective transparency tool. An ambitious strategic effort to strengthen CBMs offers an opportunity for enhancing transparency within an existing, internationally agreed-upon framework.

- Governments should work with the BWC ISU to update CBM forms to bring reporting in line with ongoing advances in modern bioscience and biotechnology and their convergence with AI and other computational approaches.
  - » Governments should perform a holistic review process to make the forms simpler to both fill out and analyze for all States Parties, including the inclusion of check boxes and drop-down lists where appropriate.
- The ISU's mandate should be expanded to conduct annual analyses of CBM submissions. The analysis should be optimized to identify trends, inconsistencies, and areas for further engagement to build trust and incentivize participation.
- Governments should provide capacity-building resources—as a core activity of a new mandate for the ISU and funded through assessed contributions—for training countries on how to make initial CBM submissions, as well as how to improve the quality of submitted information over time.
  - » Governments should support lower- and middle-income countries with technical assistance to develop national CBM preparation procedures, build connections, and grow awareness of national bioscience frameworks.

5 Develop a joint assessment process to assess BWC compliance.

- Enable States Parties to demonstrate and assess compliance through a structured, standardized, and internationally recognized process. Joint assessment processes help countries identify the most critical gaps in their implementation and compliance frameworks, fostering prioritized action for closing those gaps.

  Governments should develop a process to assess the ability of each state party to fulfill its Article IV obligation to "take any necessary measures to prohibit and prevent the development, production, stockpiling, acquisition, or retention of the agents, toxins, weapons, equipment and means of delivery."
- This process should include both external evaluation and self-assessment, and it should be modeled after other successful examination processes such as WHO's Joint External Evaluation and the International Health Regulation States Parties Self-Assessment Annual Reporting. If implementing an assessment process proves successful, it should be a core mandate and not reliant on ad hoc voluntary funding.

- The joint assessment processes should analyze BWC treaty obligations at an operational level, through the review and analysis of related national action plans and national frameworks. States Parties can use the joint process to demonstrate compliance progress over time as well as identify gaps in national action plans and frameworks that could be prioritized for updating.
- To ensure the effectiveness of the external evaluation elements of this process, it is important to develop standardized approaches that support consistency across countries.

6 Take intermediate steps to strengthen the BWC Implementation Support Unit to lay the groundwork to establish the Biological Weapons Convention Implementation Organization.

The establishment of the BIO will allow for more oversight and analysis, comparable to the organizational constructs for the CWC and the IAEA. The establishment of a full BIO will require significant resources and a multilateral agreement. To lay the groundwork for this longer-term goal, States Parties should take a series of intermediate steps to strengthen the BWC Implementation Support Unit and other BWC-linked structures.

Leading up to and at the 10th Review Conference, BWC States Parties should take multiple concrete steps to strengthen the BWC Implementation Support Unit and expand its mandate and resource base.

- As a first step, States Parties should establish an indefinite ISU mandate through a memorandum of understanding or other document so it does not need to be reestablished every five years at the BWC Review Conference. States Parties should also increase the annual BWC ISU budget to $10 million (from $2.1 million) to support an increased staff that can lead a broader set of activities and form specialized teams. The expanded scope of ISU activities should include oversight and management of an updated CBM regime as well as other enhanced transparency measures, management of a science and technology advisory function, expanded training and capacity-building efforts, and other expert advisory functions. This expanded ISU could then be folded into the larger BIO, once established.
- BWC States Parties should finalize negotiations and establish the Science and Technology Advisory Mechanism. While this mechanism could eventually be incorporated into a BIO, there is political momentum to establish it sooner and an urgent need to provide advice that keeps pace with rapid scientific and technological advances and addresses emerging biological risks.
- BWC States Parties should establish regional networks to support deeper engagement on BWC implementation activities. Informal regional networks can foster enhanced regional development of national capacities and frameworks. These arrangements can involve regional meetings, augment national implementation, and more directly address capacity-building challenges that countries face.

Conclusion

In 1975, the first international arms control convention that banned an entire class of weapons of mass destruction was born in BWC. Over the past 50 years, the BWC has gained 189 States Parties and four signatories and led to the dismantlement of biological weapons programs. The past 50 years have also seen growing suspicions and mistrust among states regarding compliance with the BWC, growing mistrust in multilateralism, and rapid advances in bioscience and biotechnology that pose increasing dual-use challenges.

With renewed international energy to strengthen the BWC and develop stronger confidence-building and transparency measures for bioscience research and development, this report offers practical recommendations. These are concrete actions that governments, the private sector, and nongovernmental organizations can take to help achieve these goals. If some or all of these recommendations are implemented, the international community can lower the risk of misperceptions related to BWC compliance, increase opportunities to detect covert biological weapons development activities, and rebuild trust among governments.

BWC States Parties should undertake a review, such as VEREX 2.0, to formally present options for strengthening transparency measures for the Convention. This report is designed to offer information and recommendations that can inform such an endeavor. Additionally, NGOs, industry, and academia are encouraged to join NTI | bio in advancing the approaches and recommendations outlined in this report that do not necessitate UN endorsement or operationalization.

The BWC faces numerous challenges, but it also provides important opportunities. The risk of a state pursuing a biological weapons program is unacceptable and avoidable. The benefits of modern bioscience research are innumerable. Implementing enhanced transparency can protect the world from the risks of nefarious biological weapons development while safeguarding critical bioscience research. Governments, NGOs, industry, and academia must work together to foster a safer and more secure future.

Abbreviation List

AI	artificial intelligence
BIO	Biological Weapons Implementation Organization
BWC	Biological Weapons Convention
CBMs	confidence-building measures
CWC	Chemical Weapons Convention
GEA	genetic engineering attribution
HS	Harmonized System
HVAC	heating, ventilation, and air conditioning
IAEA	International Atomic Energy Agency
IPNDV	International Partnership for Nuclear Disarmament Verification
ISU	Implementation Support Unit
ML	machine learning
NGO	nongovernmental organization
NLP	natural language processing
NTI	Nuclear Threat Initiative
NTI | bio	NTI Global Biological Policy and Programs Team
OSINT	open-source intelligence
OPCW	Organization for the Prohibition of Chemical Weapons
PCR	polymerase chain reaction
PREs	peer review exercises
SAGO	Scientific Advisory Group for the Origins on Novel Pathogens
UN	United Nations
UNSGM	United Nations Secretary General's Mechanism for Investigation of Alleged Use of Chemical and Biological Weapons
UNSCOM	United Nations Special Commission
WHO	World Health Organization

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About NTI

The Nuclear Threat Initiative (NTI) is a nonprofit, nonpartisan global security organization focused on reducing nuclear, biological, and emerging technology threats imperiling humanity. The biosecurity mission is conducted by NTI's Global Biological Policy and Programs (NTI | bio).

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