Institut Pasteur du Cambodge

PASTEUR NETWORK

Annual Report 2025

PHNOM PENH

INSTITUT PASTEUR DU CAMBODGE

PASTEUR NETWORK

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1 The IPC in 2025 at a Glance: The Director's Remarks

The Institut Pasteur du Cambodge (IPC), created in December 1953, is a non-profit research institution operating under the high patronage of the Cambodian Ministry of Health (MoH). Our mission is to contribute to the prevention and treatment of infectious diseases through research, public health activities, and training. This report presents the Institute's activities in 2025.

As of 31 December 2025, the Institute employed 315 personnel (including 51 civil servants attached to the Ministry of Health) representing 17 nationalities. Scientific activities are carried out by more than 60 scientists, each holding at least a PhD or a doctorate degree in medicine, veterinary medicine or pharmacy and another PhD or master's degree.

The IPC's activities encompass four main categories: (i) biomedical research with a specialization in infectious diseases, (ii) support and capacity building for public health in Cambodia and the Greater Mekong Sub-region, (iii) the provision of health services (laboratory, vaccination), and (iv) training and education. The IPC focuses on infectious diseases and on public health challenges and issues, which include illnesses related to arboviruses, respiratory viruses, rabies, malaria, antimicrobial resistance in microorganisms, and zoonosis, among others.
These complex scientific matters, particularly those that involve pathogens with complex life cycles that can involve humans, mammals, and arthropods — studied with a One Health approach — could not be effectively addressed without complementarity between the Institute's units and specialists (entomologists, doctors, veterinary scientists, immunologists, epidemiologists…).
Scientists can rely on high-level technical platforms to carry out their research and public health activities including a Biosafety Level3 (BSL3) laboratory, sequencing platform, single-cells analysis, biobank and an animal research facility.

Research activities done in 2025 were featured in 67 articles published by scientists affiliated to IPC, appearing in peer-reviewed international journals. Among them are 35 (52%) as first or last author and 32 (48%) with an IF greater than or equal to 4.
In 2025, several large-scale projects were implemented in the field by different IPC units, in close collaboration with their partners, following a One Health approach. These notably included PREZODE-AFRICAM, ECOMORE, and RACSMEI.

Post-exposure rabies management activities increased slightly in 2025, by 3.4% compared to 2024, with the management of 60,206 patients in our 3 rabies prevention centres (58,203 in 2024). The risks related to rabies indeed remain high in Cambodia: 56 % of the 203 animals tested for rabies virus at the Virology Unit were positive.

The IPC plays a major role in the training of university students. Its scientists participate in curricula offered by local universities, including the University of Health Sciences (UHS) in Phnom Penh. Additionally, the IPC itself welcomes many students for internships and practical experiences. During 2025, 138 students interned at the IPC. (154 in 2024). Among these138 students, 105 (76%) were Cambodian nationals, while the others were from France, Marocco, French, Morocco, Pakistani, Cameroon, Bangladesh, Guinean.

An ambitious capacity-strengthening policy for young Cambodians was put in place in 2022 (young talents at the IPC), allowing them to carry out their doctorate studies at the IPC (scholarships for non-IPC students and continued salaries for IPC personnel). This policy continued throughout 2025. As a

result, 2 Cambodian defend their PhD (Immunology and Epidemiology and Public Health Unit) and IPC hosted 15 PhD student on 31st December 2024 (9 Cambodian and 6 foreigners)

Our Health Service activities in 2025 showed an overall favorable trend compared with 2024: (i) activity at the Medical Biology Laboratory declined by 9.4% (5.1 vs. 5.9 million "B"), despite a 2.3% increase in the number of analyses performed (167,627); (ii) the Laboratory of Environment and Food Safety recorded a 1.54% increase in the total number of tests performed (36,312 vs. 35,768); and (iii) the International Vaccination Centre registered a 30% increase in the total number of injections administered, including vaccinations and immunoglobulins (68,530 vs. 53,017).

2025 Highlights

Human Resources

New staff members and promotion

The Institute welcomed several new staff members, including to key management positions.

- Mr Nicolas RESTANO, succeeded Mr Christophe MOUSSET as Chief Financial Officer in July 2025.
- Professor Blandine RAMAERT, succeeded to Nathalie DE REKENEIRE as head of the Clinical Research Group of the Epidemiology and Public Health Unit joined IPC in December 2025

Several of our staff members were promoted or entrusted with new responsibilities.

- Dr Jean Popovici, Head of the Malaria Research Unit, was appointed Research Director of the Institut Pasteur;
- Dr IV Sophea from the Epidemiology Unit and Dr LAY Sokchea from the Immunology Unit joined the body of International Network Scientists (PSRL) as Research Assistants.
- Dr EAKRY Chanthina was appointed Deputy Head of the Vaccination Service in December.

IPC's action on diversity, equity and inclusion

In 2025, IPC has undertaken a structured initiative to strengthen diversity, equity and inclusion within the institution, with a particular focus on gender equality, the prevention of inappropriate conduct, and the promotion of a safe and respectful working environment. This approach is rooted in Pasteurian values of integrity, respect and equality, and reflects IPC's commitment to improving its internal practices in a sustainable and institutional manner.

A major component of this initiative is the development and implementation of a Gender Equity Plan. This work is being carried out with the support of specialized partners, including Shiftbalance, a consultancy firm specializing in diversity and inclusion, and Gender and Development for Cambodia, a Cambodian organization committed to promoting gender equality. The initiative has been launched under the framework of the ECOMORE network, funded by the Agence Française de Développement.

To establish a diagnosis and identify potential gaps, IPC launched an anonymous staff survey and conducted individual interviews with selected team members. This participatory approach helps better understand gender dynamics within the institution and identify areas for improvement that are adapted to the local context. Following this assessment and the establishment of IPC's Gender Equity Plan, several actions have been implemented.

As April 2025, 58 staff members, representing approximately 20% of IPC personnel, have taken part in the three training sessions on this topic organized by ShiftBalance. Each session lasted six hours; two sessions were conducted in Khmer and one in English.

IPC has formalized a set of institutional documents designed to guide professional conduct and reporting procedures. These include the Code of Conduct, the anti-corruption and anti-fraud policy, the procedure for collecting and managing misconduct reports through a dedicated reporting platform, the sexual harassment policy, and the investigation procedure for reported cases. IPC has also defined the composition of the Listening Team and of the coordination committee responsible for investigations in sexual harassment cases. These documents, adapted to IPC's context and inspired by those of the Institut Pasteur in Paris, provide a common reference framework for all staff.

In parallel, IPC has strengthened its framework for preventing and responding to sexual harassment. A dedicated training session was organized by Shiftbalance on 17 September 2025 for 12 colleagues, including members of the Listening Team. This team serves as the first point of contact and support in the event of a report. The training covered how to receive disclosures, ensure safe referral, document cases appropriately, and maintain strict confidentiality. This measure helps build trust and ensures that reports are handled in a respectful, appropriate and professional manner.

A "Women@IPC" Committee has been established at IPC to support the needs and well-being of female staff. The objective of this group is to propose measures to Management to improve work-life balance, particularly during pregnancy, maternity leave, and return to work. The committee also promotes women's health and safety by identifying workplace risks and recommending preventive actions. It may support awareness initiatives on topics such as breast cancer prevention and stress management. Finally, it provides an official forum for female staff to raise concerns, share ideas, and contribute to positive organizational change.

Finally, the institution has planned a major effort to disseminate and ensure ownership of these tools. Heads of units and services have been asked to present and explain the documents to their teams, posters with a QR code linking to the reporting platform has been displayed, and information sessions are scheduled in Khmer and English, with monthly sessions planned from February 2026 onward.

Important visits at IPC

Visit of H.E. Prof. Prof. Yasmine BELKAID, President of Institut Pasteur (October 19th-20th)

Accompanied by Ms Odette Tomescu-Hatto (Vice-President for International Affairs) and Professor David Fidock (Scientific Advisor to the President), Professor Yasmine Belkaid, President of the Institut

Pasteur (Paris), visited IPC to learn more about the activities of the Institut Pasteur du Cambodge (IPC) and to meet our scientists.
During this brief visit, Professor Belkaid met with key partners: H.E. Youk Sambath (Secretary of State of Ministry of Health), H.E. Olivier Richard (Ambassador of France), and Professor Vonthanak Saphonn (Rector of University of Health Sciences). She also held discussions with IPC researchers, who presented their ongoing work, and made a short tour of the institute.
This visit provided an opportunity to deepen mutual understanding and to explore ways to strengthen collaborations between IPC and the Institut Pasteur, as exemplified by existing research projects such as RACSMEI, ECOMORE, and SEA-ROADS.

Research: research activities, support for research

7th Scientific Advisory Board Meeting (March 26th-28th)

The 7th meeting of the Scientific Advisory Board of the Institut Pasteur du Cambodge (IPC) took place from March 26 to 28, 2025. This committee brings together nine high-level scientific experts from various countries: Cambodia (3), Australia (2), France (2), Singapore, and Japan (1). This council reviewed the activities of the Institute's various entities and met with scientific staff from various categories (unit heads, scientists, students, etc.). The recommendations made at the end of these three days of intensive work are particularly valuable and useful in guiding the development of our Institute's organization and activities (see details in §2.5, page 17).

Two IPC Students defended their PhD thesis in 2025

Two Cambodian IPC students defended their PhD in 2025: Mrs. OU Teyputita, Virology Unit; (University of Montpellier, France), and Mrs. YEAN Sony, in Medical and Veterinary Entomology Unit (University of Paris-Saclay, France).

Implementation of structuring projects on zoonoses and emerging diseases using a One Health approach

Several major projects were implemented in the field this year, including AfriCam-PREZODE (*Preventing Zoonotic Diseases Emergence*), the ECOMORE project (*Strengthening Health Security in the Indo-Pacific Region*), RACSMEI (*Risk Assessment of Multiple Endemic Infectious Pathogens in a One Health Perspective*), VIRAGE (*Generating Strategic Evidence to Strengthen Rabies Prevention and PEP Access*) and SEA-ROADS *(One Health Regional Approach for Integrated and Interconnected Urban Dengue Surveillance Southeast Asia (SEA-ROADS).* More detailed information on these projects is provided later in this report,

Training and knowledge dissemination

Course "Immune responses to arbovirus infections from a One Health perspective", 24th-29th November 2025, Sea

35 students attended the course, from 19 different countries, including 12 students from the Pasteur Network. 14 teachers, including 6 from the Pasteur Network have joined the course organized in Siem Reap. Most arboviral diseases cause a disturbance in the host immune response which leads to immunopathology. Therefore, knowledge on immune mechanisms induced by arboviruses and how these mechanisms are disturbed is very important to advance vaccine development. Hence, a course that expands and re-enforces knowledge in aspiring scientists in Asia on the immune responses to arboviruses, host-pathogen interactions, the animal models and human challenge models available is

of crucial importance. This 6-day course has provided an in-depth exploration of the interactions between arboviruses, their vectors (mosquitoes, ticks), and vertebrate hosts.

Cell Culture, Virus Isolation and HA/HI in Seasonal Influenza, June 23rd- July 19th

This training was conducted by the Cambodian National Influenza Center (NIC) and WHO H5 Reference Laboratory at IPC for the National Institute of Public Health, with the aim of providing hands-on experience in cell culture, virus isolation, and HA/HAI testing. The training, fund by WHO and IPC, strengthened practical knowledge of biosafety protocols and laboratory procedures while familiarizing participants with IPC-recommended workflows, technical standards, and best practices for influenza diagnostics and virological testing.

Study Visit at the IPC's Medical Biology Laboratory from public hospitals, July 31st - August 1st

On 31 July and 1 August 2025, the Medical Biology Laboratory (MBL) of the Institut Pasteur du Cambodge (IPC) welcomed 20 laboratory professionals from 10 public hospitals in Phnom Penh for a study visit, in alignment with the directives of His Excellency the Minister of Health. Accredited to the ISO 15189 international standard by Cofrac since 2018, the MBL shared its experience in implementing a robust quality management system. The visit focused on key areas such as(i) Laboratory quality management, (ii) technical operations, (iii) biosafety and biosecurity practices. This initiative, coordinated by the National Institute of Public Health (NIPH), aimed to strengthen collaboration and promote quality practices across Cambodia's public health laboratory network.

Strengthening outbreak investigation and animal disease surveillance in Cambodia, July 1st - 3rd

The Virology Unit provided technical support to the Food and Agriculture Organization of the United Nations (FAO) in delivering a three-day training from July 1–3, 2025, in Kep province for the General Directorate of Animal Health and Production (GDAHP) on the use of Kobo Toolbox for animal disease surveillance and outbreak investigation. The training brought together 33 participants from GDAHP.

UHS–IPC Scientific Seminars

In 2023, the University of Health Sciences (UHS) and the IPC launched an initiative to maintain a series of scientific seminars involving researchers from both institutions to promote information sharing, interactions, collaborations. In 2025, one session (the 9th session) was organized covering the gap analysis results of the research study entitled "Developing and piloting infections prevention and control intervention to reduce the incidence of the hospital-acquired infection in Cambodia and Laos PDR.

Insects: the art of detail: A photo exhibition, Institut Français du Cambodge, Phnom Penh, September 12th – November 1st, 2025

After organizing the 1st conference on ticks and tick-borne diseases in Southeast Asia in 2023, the 6th international conference on the tiger mosquito, *Aedes albopictus* in 2024 and publishing a book on "the insects in Cambodia" in three languages (Khmer, English, French) in 2024, Dr Sébastien BOYER and the Medical and Veterinary Entomology Unit, we organized a photo exhibition related to the biodiversity and medical entomology. The exhibition "Insects: The Art of Detail" reveals unknown abundant and beautiful biodiversity through a series of photographs. Trained in groundbreaking photographic techniques developed by French inventor Nathanaël Maury, we capture extremely small subjects in very high resolution. These remarkably sharp images reveal details, essential for identifying species and understanding their interactions with their environment. They also reveal unexpected elements, thus opening new perspectives in entomology—the study of insects.

Certification of the IPC BSL-3 Laboratory to ISO 35001:2019

A structured audit pathway supported the laboratory's certification process. A Stage 1 external audit conducted in April 2025 identified six non-conformities, all of which were addressed through corrective actions. Internal audits in June 2025 identified twelve additional non-conformities, primarily related to climate change considerations, monitoring of risk mitigation plans, document control, and equipment maintenance. All findings were resolved prior to the certification audit. In December 2025, the IPC BSL-3 laboratory was officially certified to ISO 35001:2019, confirming full compliance with international biosafety, biosecurity, and biorisk management standards.

Improvement of Service Activities

Extension of Opening Hours for the Medical Biology Laboratory and the International Vaccination Center

To improve service delivery and facilitate public access, the Medical Biology Laboratory (MBL) extended its opening hours from Monday to Friday, from 5:00 p.m. to 6:00 p.m. until 8th September. In addition, as of 10th January, Saturday afternoon opening hours were also extended for both the MBL and the International Vaccination Center (IVC), with services available until 5:00 p.m. for the MBL and until 3:00 p.m. for the IVC.

Extension of the certification of the Laboratory for environment and Food Safety (LEFS)

In 2025, with financial support of CAPRED, LEFS broadened its accreditation scope by adding 2 more parameters of heavy metal on water along with 8 additional parameters of pesticide residue in rice and pepper, as detailed below.

This extension represents an important step forward in supporting the export of Cambodian agricultural products, particularly rice and pepper, as part of IPC's contribution supported by the CAPRED project.

Providing expertise for Ministry of Health

Emerging Diseases

The IPC's three WHO reference centres carried out public health activities alongside and in support of MoH teams, including in 2025: (i) monitoring human influenza viruses (the dominant circulated influenza virus in 2025 was A/H1N1pdm (43%) flowed by A/H3N2 (39%) and influenza B/Victoria (17.5%) and the virological confirmation of 18 cases of highly pathogenic avian influenza virus H5N1.

Other expertise

Beyond its contribution to public health through these reference centers, its participation in technical working groups, and the training activities it organizes for various MoH institutions, IPC also brings its expertise to the implementation of major MoH projects, including the BSL-3 laboratory and the cyclotron. Support was provided for the construction and operational readiness of the BSL-3 facility at the National Institute of Public Health (NIPH), scheduled for inauguration in January 2026. IPC also contributed to the upgrading of laboratory protocols for specialized projects at Calmette Hospital including Cyclotron and Bone Marrow Transplant facilities.

Management

IPC 2030: a major campus restructuring project

IPC has launched IPC 2030, an ambitious project to restructure and modernize its campus, including the construction of a new building to support future growth. The first phase of the study (initial

programming) has been completed, defining the key organizational and structural aspects of the project. At the end of this phase, the total investment was estimated at approximately $20 million.
Several discussions have been initiated with various funding agencies, in coordination with Institut Pasteur in Paris, to explore possible financing options and ensure the successful implementation of the project. However, the contacts established in 2025 have not, at this stage, led to the identification of concrete funding prospects. This situation raises the broader issue of IPC's development and the need to adapt its infrastructure to the evolution of its activities. In the short term, the second floor of the Direction-Administration building will need to be fitted out. In parallel, the possibility of constructing a new building on the campus should be explored.

Pursued the modernization of financial and human resources functions

Throughout 2025, particular attention was given to consolidating the major organizational and system changes initiated in 2024, including the implementation of the new accounting system developed on Dynamics 365, changes in accounting standards and currency management, as well as the introduction of a revised job mapping structure. Actions were also initiated to enhance visibility on the performance of service activities and support a more proactive management of resources.
These various initiatives constitute important foundations to support the future development of the Institute and further strengthen the overall efficiency of the organization.

In Conclusion

In 2025, the Institut Pasteur du Cambodge confirmed its scientific dynamism, as highlighted by the Scientific Advisory Board, its strong commitment to public health, and its growing role within Cambodia's research landscape. Major structuring projects, particularly in the One Health field, such as RACSMEI, AfriCam, and ECOMORE, were launched or further advanced, while the Institute continued to invest in the next generation of scientists, with a high number of 14 PhD students and further progress in the development of Cambodian scientific leadership.
At the same time, the year also brought to light several important challenges, including the situation in the Virology Unit, which still lacks sufficient senior virologists, the difficulty in securing funding for the IPC 2030 project and, more broadly, the need for the Institute to expand, as well as the continued fragility of IPC's economic model, which remains heavily dependent on external funding and service revenues.
Throughout the year, IPC continued to provide high-level support to the Ministry of Health through its contributions to public health, scientific expertise, and training. These achievements were made possible by the commitment of a dynamic and dedicated community of scientists, physicians, and staff.
I would like to warmly thank all IPC staff for their remarkable efforts and dedication, as well as the members of the Scientific Advisory Board and the Liaison Council, in particular its President, H.E. Prof. CHHEANG Ra, Minister of Health, for their guidance and continued support.

Dr André SPIEGEL
Professeur agrégé du Val-de-Grâce
Director of the *Institut Pasteur du Cambodge*

2 Institut Pasteur du Cambodge in 2025

2.1 Overview of the Institute

Statutes and Operational Systems

The IPC, created in December 1953, is a non-profit research institution operating under the high patronage of the Cambodian Ministry of Health (MoH). The IPC's statutes and operational systems are codified in the agreement signed between the Royal Government of Cambodia and the Institut Pasteur in Paris in 1992 and were since modified through two amendments. The IPC's laboratories are at the full disposal of the Ministry of Health of Cambodia for any studies or research relevant to the prevention of illness and the protection of public health. The institute's guidance also falls within the purview of the Institut Pasteur in Paris, France, as regards its scientific and technical approaches and plans. The institute is part of the Pasteur Network (PN), which is a worldwide network of more than thirty member institutes united by Pasteurian values, which contribute to the improvement of global health.

Governance

The IPC is led by a director and is monitored by the Liaison Council. The IPC's director is appointed by the President of the Institut Pasteur in Paris, France, in consultation with the Kingdom of Cambodia's MoH. The IPC's deputy director is nominated by the director, in consultation with the MoH, from within the pool of Cambodian scientists serving in the national public service and who have doctorates in biology or public health.

The Institute's activities are reviewed on an annual basis by the Liaison Council presided by His Excellency the Minister of Health of Cambodia. The council is composed of ten high-ranking members from the Cambodian government or from its universities. The director general of the Institut Pasteur in Paris, the ambassador of France to Cambodia, and representatives of key international organizations in the health sector (WHO, UNICEF) round out the membership.

The IPC's scientific activities are also reviewed every two or three years by the Scientific Advisory Board, whose last session was held in 26-28 March 2025 (cf. point 2.5, page 17). Our scientific strategy is then adapted, based on the recommendations from both the Liaison Council and the Scientific Advisory Board.

In addition, on the administrative and financial side, at the beginning of each year, the Chief Financial Officer (CFO) sends the consolidated financial statements of the previous year to the Institut Pasteur (Department of International Affairs). An external financial audit is also performed in April of each year.

2.2 Structure

The organizational chart appears at the end of this report, in Annex 1.

The Institute is composed of:

- A management unit comprising the director, the deputy director, and the chief financial officer;
- Administrative, financial and logistical services;
- Six research units: Malaria, Epidemiology and Public Health, Immunology, Medical and Veterinary Entomology, Virology, Bioinformatics and AI Applications;
- Health services, including a Medical Biology Laboratory (MBL), a Laboratory of Environment and Food Safety (LEFS), and an International Vaccination Centre;

- Public health laboratories, comprising 3 WHO reference centres hosted by the Virology Unit (the National Influenza Centre in Cambodia, the WHO's regional H5 reference laboratory, and the WHO's Coronavirus Network (CoViNet) Reference Laboratory.
- A Voluntary Confidential Counselling and Testing for HIV (VCCT) service, and three rabies prevention centres that provide pre- and post-exposure prophylaxis at a fee.
- Four technical platforms: (i) a BSL-3 Laboratory, (ii) a biobank, (iii) a sequencing platform, and (iv) a single-cell analysis platform.

2.3 Human Resources

2.3.1 Workforce Overview

In 2025, the Institute continued to strengthen its human capital through strategic recruitment, workforce development, diversity promotion, and employee engagement initiatives.

As of 31 December 2025, the Institute employed **315** personnel (including **51** civil servants attached to the Ministry of Health) representing **17** nationalities, supporting scientific research, public health, laboratory services, and operational functions.

The workforce included:

- 11 Cambodian scientists: (1 research director, 7 research fellows, and 3 research assistants (2 nominated on January 1st 2026);
- 9 Cambodian PhD students;
- 35 expatriate staff, including:
    - **9** staff were on institutional contracts, including **8** from Institut Pasteur Paris (IPP) and **1** from Expertise France.
    - **26** staff on IPC contracts, including **2** Research Scientist, **10** postdoctoral researchers, **1** IT engineer, **5** PhD students, **2** Research Engineers and **6** other professionals such as project managers.

Workforce Profile	2025	2024
Total Employees	315	298
Cambodian Nationals	89%	88%
Expatriate Staff	35	37
Nationalities represented	17	17
Women Employees	58%	58%
Median Age	33 years old	32 years old

The workforce remained highly diverse and multidisciplinary, with strong national representation and continued international scientific collaboration.

2.3.2 Diversity and Leadership

The Institute prioritizes gender balance and equity; 58% of staff members are women. The professional development of scientific leaders and other national professionals is a matter of great importance to the IPC. Of the **24** management positions (3 directors, 14 research or service unit heads and deputy heads and 7 service support managers), **12** (50%) are occupied by Cambodian nationals and **7** (29 %) by women.

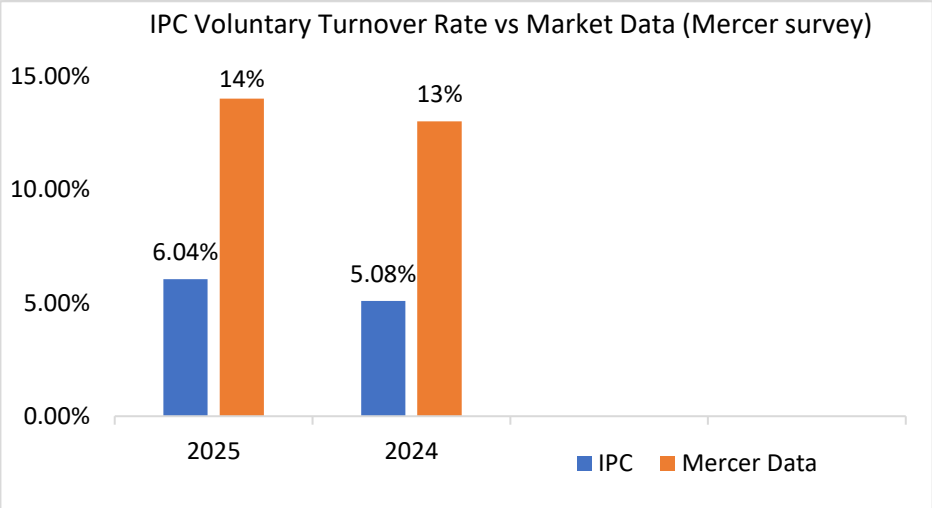
2.3.3 Workforce Mobility and Retention

Recruitment

During 2025, the Institute recruited **55** new employees across research, health, and administrative functions to support operational and scientific priorities. Of these, **15** positions represented replacement hires following staff departures, while **40** positions supported organizational growth and project expansion.

Turnover Rate

The Institute recorded an overall turnover rate of **11%** in 2025, including a voluntary turnover rate of **6%**, corresponding to **18** employees who voluntarily left the Institute during the year.



The Institute's voluntary turnover rate remained stable compared with Mercer benchmark data for both 2024 and 2025, indicating relatively strong workforce retention in a competitive labor market.

2.3.4 Employee Engagement

HR Satisfaction Survey

An HR Satisfaction Survey was conducted from **24 August to 15 September 2025**, aiming to evaluate HR services in terms of responsiveness, effectiveness, and inclusiveness, and to inform future strategic priorities. The survey received **106** responses, representing participation across all units of the Institute. The results were presented and shared with all staff during dissemination sessions held on 17–18 November 2025, ensuring transparency and open communication of results across the organization. The results provide valuable insights into staff perceptions of HR support services and are being used to guide the development of the HR 2026–2027 strategic priorities, particularly in strengthening service delivery and improving the overall employee experience.

Staff Representative Election

On 14 November 2025, the Institute organized the election of staff representatives to strengthen employee participation and internal governance. The election resulted in the selection of **8** staff representatives for a two-year term, serving as a formal channel between staff and management to support dialogue on workplace issues, organizational initiatives, and employee concerns. The process recorded a strong voter participation rate of **80%**, reflecting high levels of staff engagement and interest in institutional governance. This mechanism ensures transparency, inclusiveness, and effective communication within the Institute.

2.3.5 Learning and Development

In 2025, Institut Pasteur du Cambodge strengthened staff capacity through digital learning using the **Coursera** platform. A total of **69** staff members were invited, of whom **28** completed at least one course, resulting in the completion of **52** courses across various learning areas. Overall, the initiative contributed to promoting continuous learning and supporting staff professional development through flexible online training opportunities.

2.4 Finances and investments

2.4.1 Finances

Most of the IPC's revenue comes from binding research contracts funded by donors (43% vs 29% in 2024) and from services offered by IPC (41% vs 57% in 2024). The year 2025 showed a strong increase in our research contract fundings, rebalancing the share of dedicated research funds closer to pre-COVID levels.

The Royal Government of Cambodia does not directly fund IPC, but it makes a significant contribution through tax and customs exemptions. Table 1 provides details on the different revenue streams, while Figures 1 and 2 below illustrate the breakdown of funding by country and by donor in 2025.

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Research contracts	60%	58%	59%	55%	56%	54%	40%	22%	28%	34%	29%	**43%**
Health services	21%	23%	25%	29%	31%	34%	52%	71%	47%	48%	57%	**41%**
MESRI grant	14%	12%	11%	11%	11%	10%	6%	3%	5%	4%	5%	**1%**
Other revenues	5%	7%	5%	5%	2%	2%	2%	4%	20%	14%	9%	**15%**
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	**100%**

Table 1: *Revenue breakdown by source type (2014–2025)*

The share of income attributable to service activities primarily comes from our International Vaccination Unit, Medical Biology Laboratory, and Consulting/Expertise in Public Health. Other revenues mainly stem from financial investments and exceptional revenue.

The bad debt related to COVID-19 invoices was settled at the beginning of 2025 with the support of the Ministry of Health and the Ministry of Economy and Finance.

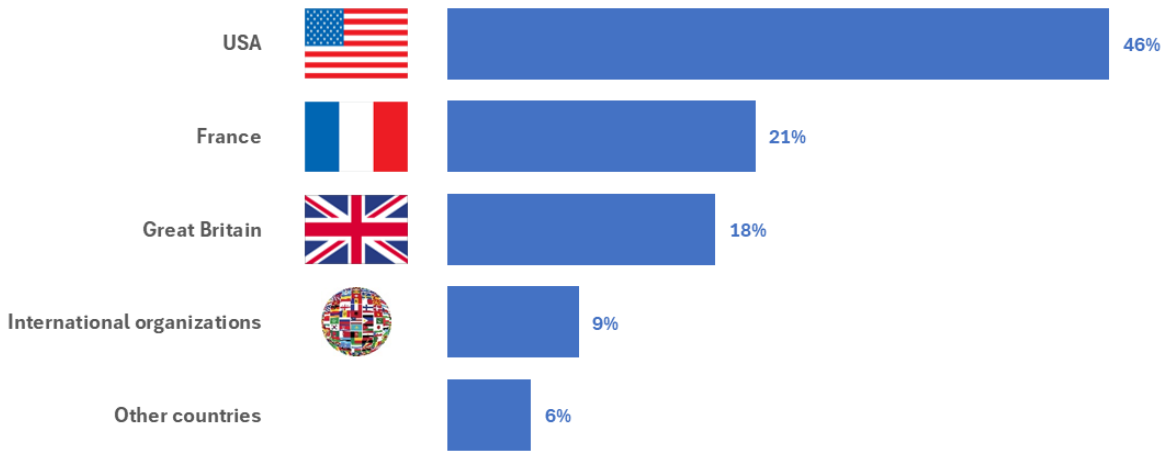


Figure 1: *Breakdown of the research funds received by country*

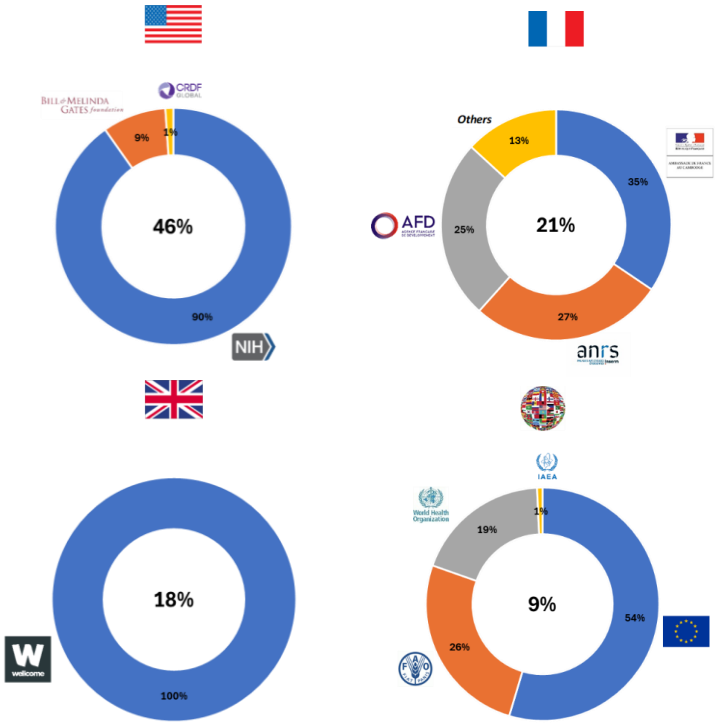


***Figure 2**: Breakdown of the research funds received by donor*

2.4.2 Investments in Fixed assets

Following a year 2024 marked by significant investments, notably financed through IPC's own funds, 2025 reflected a more consolidated approach to fixed assets acquisition.

During the year, IPC also revised the capitalization threshold for fixed assets to USD 5,000, in alignment with international accounting practices and the guidelines applied by most donors. Despite this transition phase, total additions to fixed assets amounted to USD 280,043 in 2025, of which 56% were financed through IPC's own resources.

Key investments completed during the year included:

- Acquisition of a new digital PCR system (QIAcuity One 5plex) for the Malaria Unit through project funding;
- Purchase of a new CFX Opus 96 Real-Time PCR System for the Virology Laboratory using IPC own funds;
- Acquisition of a new microbalance for the Metrology Laboratory to support compliance with the latest ISO requirements;
- Renewal of two field mission vehicles financed on IPC own funds;
- Purchase of two new biosafety cabinets;
- Acquisition of a refrigerated centrifuge and several -86°C freezers through project funding;
- Completion of minor renovation works across the campus.

2.4.3 2025: A Year of Consolidation and Transformation

Throughout 2025, particular attention was given to consolidating the major organizational and system changes initiated in 2024, including the implementation of the new accounting system developed on Dynamics 365, changes in accounting standards and currency management, as well as the introduction of a revised job mapping structure.

Efforts during the year focused on process optimization, corrective adjustments and the strengthening of internal procedures, notably through improvements in banking processes and updates to the Delegation of Authority framework.

From a financial management perspective, the work carried out during the year contributed to strengthening the security of financial flows, optimizing treasury management practices and progressively improving budgetary and accounting monitoring. Actions were also initiated to enhance visibility on the performance of service activities and support a more proactive management of resources.

These various initiatives constitute important foundations to support the future development of the Institute and further strengthen the overall efficiency of the organization.

2.4.4 IPC 2030: A Major Campus Restructuring Campus

IPC has launched IPC 2030, an ambitious project to restructure and modernize its campus, including the construction of a new building to support future growth. The first phase of the study (initial programming) has been completed, defining the key organizational and structural aspects of the project. At the end of this phase, the total investment was estimated at approximately $20 million.

Several discussions have been initiated with various funding agencies, in coordination with Institut Pasteur in Paris, to explore possible financing options and ensure the successful implementation of the project. However, the contacts established in 2025 have not, at this stage, led to the identification of concrete funding prospects.

This situation raises the broader issue of IPC's development and the need to adapt its infrastructure to the evolution of its activities. In the short term, the second floor of the Direction-Administration building will need to be fitted out. In parallel, the possibility of constructing a new building on the campus should be explored.

2.5 7th Scientific Advisory Board Meeting (March 26th-28th 2025)

From 26 to 28 March 2025, the Institut Pasteur du Cambodge (IPC) convened its fifth Scientific Advisory Board (SAB) meeting, gathering distinguished experts to discuss major global public health challenges and the Institute's most recent research advances.

The SAB, composed of eight eminent scientists, provided key recommendations to support IPC's mission:

- Prof. Sharon Lewin – Doherty Institute for Infection and Immunity, University of Melbourne, Australia
- Prof. Anavaj Sakuntabhai – Director, Institut Pasteur of Japan
- Prof. Linfa Wang – Duke-NUS, National University of Singapore
- Prof. Ivo Mueller – Walter and Eliza Hall Institute (WEHI), Melbourne, Australia; Institut Pasteur, Paris, France
- Prof. Sylvain Brisse – Institut Pasteur, Paris, France
- Prof. Arnaud Fontanet – Institut Pasteur, Paris, France
- Prof. Saphonn Vonthanak – Rector, University of Health Sciences, Phnom Penh, Cambodia
- Prof. Chhea Chhorvann – Director, National Institute of Public Health, Phnom Penh, Cambodia
- Dr Ly Sovann (2025), Director of Cambodian Communicable Disease Control Department, Phnom Penh, Cambodia

The last meeting was held in 2021, and it had not been possible to organize another one since then, owing to the end of the Covid-19 epidemic, changes among some of IPC's scientific staff, and the difficulty of identifying a time slot compatible with the schedules of the SAB members.

Throughout the three-day meeting, IPC's research teams—spanning Epidemiology, Virology, Malaria and Molecular Epidemiology, Immunology, and Medical & Veterinary Entomology—presented their latest findings. Additionally, key research groups working on clinical research, one-health, and antimicrobial resistance shared their insights. IPC's public health services, including the Medical Biology Laboratory, Vaccination Center, and Laboratory for Environment and Food Safety, also showcased their recent achievements and future directions.

The SAB commended Institut Pasteur du Cambodge (IPC) for its remarkable achievements over the past three years, as well as for its careful follow-up on most of the recommendations made at the previous SAB meeting in 2021. It particularly highlights the success of several structuring initiatives, including the creation of the Grants Office and the development of cross-cutting programmes such as antimicrobial resistance, One Health, and bioinformatics.

Please find below a summary of the general comments included in the SAB'sreport.

IPC has undergone significant staff and scientific leadership changes. In several units, these leadership transitions have been viewed positively. However, the departure of the only Cambodian research unit head in virology is considered regrettable, although it resulted from personal circumstances. IPC's scientific output is regarded as very impressive, covering a broad range of fields, from fundamental immunology, virology, epidemiology and public health to bioinformatics and entomology. IPC also continues to play an essential public service role in Cambodia, particularly through diagnostic microbiology, reference functions in virology and malaria, general vaccination services, and rabies prevention. Major grants have been secured from key funding agencies, including Wellcome, NIH, the Gates Foundation, ANRS/MIE, and Expertise France. However, the SAB identifies the changing global health landscape, particularly in relation to the current US administration, as a major risk for the Institute.

The SAB makes several structuring recommendations for the next three years. First, it recommends strengthening strategic relationships with Cambodian institutions, particularly the CDC, NIPH, and UHS. While the Director and Deputy Director maintain regular and positive interactions with these institutions, relationships at other levels appear to remain more operational than strategic. The SAB therefore recommends establishing formal mechanisms for regular strategic dialogue involving unit heads, in order to strengthen collaboration in research, education, service delivery, and capacity building. It also encourages IPC to actively contribute to the development of future PhD programs at UHS and NIPH, including by hosting students, providing teaching and mentoring, and considering joint appointments.

Capacity building and training of Cambodian staff are identified as a central priority. The SAB supports IPC's objective that, within five to ten years, 75% of scientific staff should be Cambodian and more than 50% of units should be headed by Cambodians. To achieve this goal, it recommends developing a structured plan for training and capacity building at all levels of the organization, including administration and leadership positions

The SAB also recommends strengthening scientific cohesion and institutional culture. This could include regular participation of senior leadership in scientific seminars, the establishment of a visiting scientist program, and the creation of a competitive travel fund for PhD students and postdoctoral researchers. It also stresses the need to develop professional development opportunities at all levels, including for PhD students, postdoctoral researchers, PSRLs, deputy unit heads, and unit heads. Formal leadership training, executive coaching for new unit heads, conflict resolution training, presentation skills training, and mentoring programs are recommended. It also recommends paying particular attention to PhD students, who are currently enrolled in a wide range of universities and

may lack the support normally provided within structured doctoral programs. For postdoctoral researchers and PSRLs, the SAB recommends reviewing the PSRL model through broad consultation with Cambodian staff, better communicating its value, and establishing mentoring arrangements outside their unit of affiliation.

2.6 Publications in 2025

The IPC's research and public health activities are detailed in later sections (section 7, page 170). A summary of these is presented in figures 4 and 5 below.

Research activities done in 2025 were featured in 67 articles published by scientists affiliated to IPC, appearing in peer-reviewed international journals. Among them are 35 (52%) as first or last author and 32 (48%) with an IF greater than or equal to 4 (figures 3 & 4).

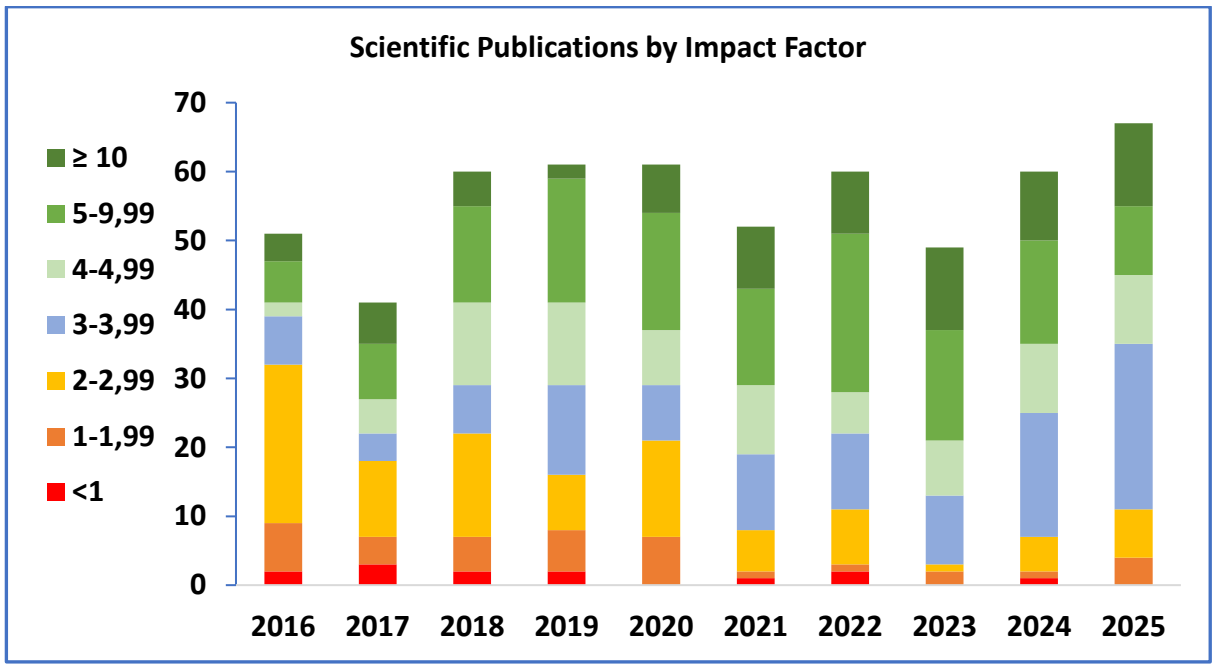


Figure 3: *Scientific publications, sorted by impact factor of the journal (2016-2025)*

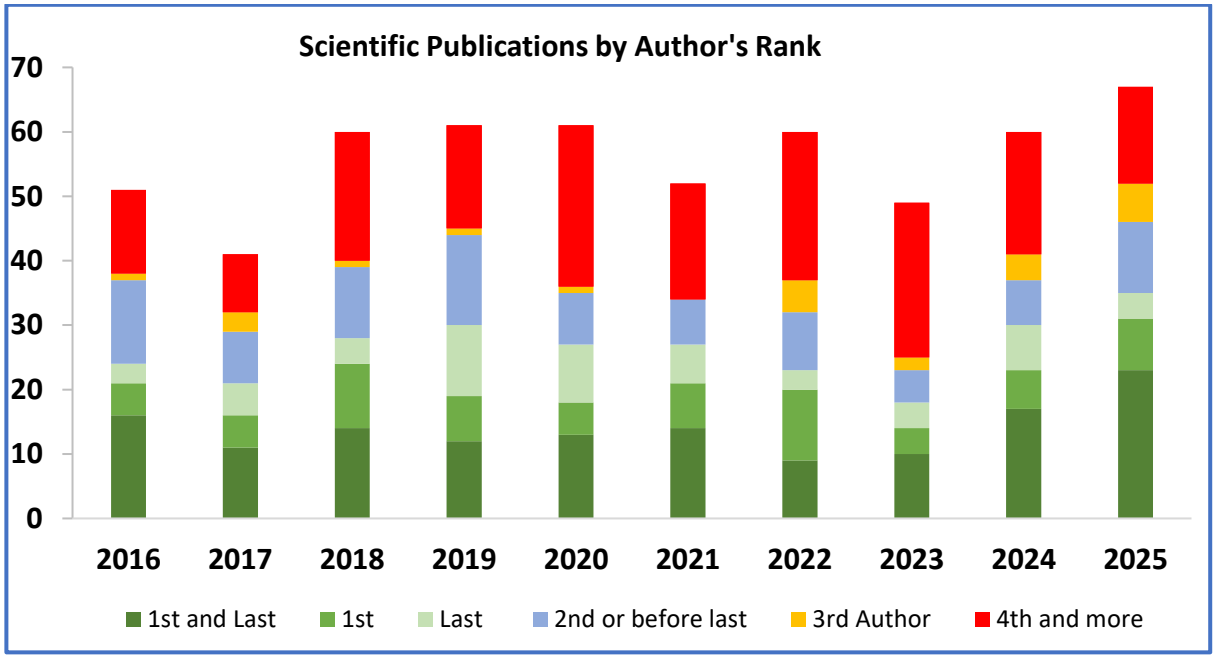


Figure 4: *Scientific publications by author's rank (2016-2025)*

2.7 Training and Internships in 2025

The IPC plays a major role in the training of university students. Its scientists participate in teaching offered by local universities, including the University of Health Science (UHS) in Phnom Penh, and welcomes many students for internships and practical experiences.

Student Internships

In 2025, the Institute continued to play an active role in academic capacity building by hosting a total of **141** students and trainees from both Cambodian and international institutions. These training placements contributed to strengthening research capacity, laboratory skills, and scientific collaboration across multiple disciplines.

Academic Level	Local	Expat
PhD	12	8
Master Degree	19	14
Bachelor Degree	68	0
Associate Degree	5	0
Others	4	11
Total	***108***	***33***

Among the **33** expatriate interns and trainees hosted in 2025 were participants from France, Morocco, Pakistan, Cameroon, Bangladesh, and Guinea, reflecting the Institute's diverse international academic collaboration network.

Trainees were hosted through partnerships with several national and international academic institutions, including:

- University of Health Sciences – **60** trainees
- University of Puthisastra – **15** trainees
- Royal University of Phnom Penh – **10** trainees
- Institute of Technology of Cambodia – **3** trainees
- Local and other partner universities – **20** trainees
- Foreign universities – **33** trainees

These collaborations demonstrate the Institute's continued role in supporting scientific training, research exchange, and regional academic cooperation.

International Master's in Infectious Disease

Since 2019, the IPC provides important and substantive support to the International Master's Program in Infectious Diseases, a two-year program jointly offered by the University of Health Sciences (UHS - Cambodia) and the Université Paris-Saclay (UPS - France).

Throughout the year, IPC is involved in the curriculum's delivery through lectures, practical teaching, and internship supervision. Each year, IPC scientists contribute more than 200 hours of training in total. The IPC appointed a senior scientist, Dr. Jean Popovici (head of the Malaria Research Unit) and a project manager, Emilie Carlot, as focal points to facilitate the coordination of this program with the UHS and UPS. Moreover, the IPC also supports this program by granting IPC scholarships to cover university fees and provide stipends for Cambodian students enrolled in this master's program. Two scholarships are awarded per program year to promising candidates. The IPC also accommodates students within its premises for a moderate fee, when vacancy allows it.

The 2025-2026 academic year welcomes 14 students (7 men and 7 women) of 8 nationalities, including 3 Cambodians.

In 2025, for various reasons, including a student enrollment considered too low, UPS decided to discontinue this program. During the 2025–2026 academic year, only M2 students were admitted; this therefore marked the final year of this high-level program, which trained 78 students from 17 different nationalities between 2019 and 2026.

	M1	***M2***
2019-2020	***P1:** 9 students (4 Cambodians)*	
2020-2021	***P2**: 9 students (4 Cambodians)*	***P1**: 9 students (4 Cambodians)*
2021-2022	***P3**: 7 students (2 Cambodians)*	***P2:** 9 students (4 Cambodians) + 4 new students*
2022-2023	***P4**: 14 students (5 Cambodians)*	***P3**: 5 students (1 Cambodian) + 4 new students*
2023-2024	*Class was not open due to insufficient students' registrations*	***P4:** 12 students (4 Cambodians) + 7 new students (2 Cambodians)*
2024-2025	***P5**: 8 students (3 Cambodians)*	***P6**: 8 new students (1 Cambodian)*
2025-2026		***P5:** 6 students (3 Cambodians) + 8 new students*

***Table 2:** Number of students enrolled in the International Master's Program since its creation (P = promotion)*

2.8 Scientific Seminars

In 2025, the organization of the IPC's scientific seminars every other week was coordinated by three scientists: Ms. KHIM Nimol (Malaria Research Unit), Mr. DIM Bunnet (Epidemiology and Public Health Unit) and Ms. Anna S. FOMSGAARD (Virology Unit).

23 seminars were held in 2025 (table 3).

Date	Name	Grade	Organisation/Unit	Title
8-Jan	OU Teyputita	PhD Student	Virology Unit	Diversity and characterization of coronaviruses circulating in bats in Cambodia
9-Jan	Sungmin SON	Associate Professor	Korea Advanced Institute of Science & Technology	CRISPR diagnostics for rapid multiplexed detection of flavivirus
14-Jan	Tamara GILES-VERNICK	Research Director	IP Paris	(Not knowing) TBE: The social emergence of tickborne encephalitis
22-Jan	SORN Sopheak	PhD Student	Epidemiology and Public Health Unit	Study of dengue-like illness in Kampong Thom Province, Cambodia (DENTHOM)
5-Feb	Anna Signe FOMSGAARD	Post-Doc	Virology Unit	Field-Deployable Genomic Surveillance for Viruses and Animal Hosts
6-Feb	Gérald SPAETH	Professor	IP Paris	Going nuclear: Leishmania epigenetic subversion of macrophage immuno-metabolic functions
19-Feb	Praveen RAHI	Researcher	Medical Biology Laboratory	Tracing Prokaryotic Fingerprints: Identifying and Tracking Pathogens through Systematics
5-Mar	SOUR Kimhoung	Master's graduate student	Virology Unit	Deciphering virus diversity in European bats: an integrative approach to identify putative zoonotic emergences

19-Mar	HEANG Vireak	Research Engineer	Sequencing Platform	Detection of Elephantid betaherpesvirus 1 in a Fatal Female Young Asian Elephant and Two Other Young Elephants in Cambodia Using Sequence-Independent, Single-Primer Amplification (SISPA) and Realtime Polymerase Chain Reaction (qPCR)
23-Apr	Giorgio GONNELLA	Head of Unit	BAIA	Single-cell insights and beyond: research of the BAIA Unit at IPC.
23-Apr	Simon CAUCHEMEZ	Director	IP Paris	Analysing household studies to decipher the drivers of infectious disease transmission, susceptibility and infectivity.
21-May	Bastien MALINGE	PhD Student	Virology Unit	Cross sectional study of the Cambodian poultry trade network to identify risk factors for Avian Influenza evolution events - Preliminary results
11-Jun	Brice FEUFACK DONFACK	Post-Doc	Malaria Research Unit	Sustained efficacy of artemether-lumefantrine in Laos: genomic and phenotypic evidence of potential lumefantrine resistance.
17-Jun	Lien DE CALUWÉ	Post-Doc	Immunology Unit	IgG glycosylation during DENV infection
2-Jul	Juliana AIZAWA PORTO DE ABREU and Sahina SIDHIK	Post-Doc	Medical and Veterinary Entomology Unit	The intersecting trajectories of two scientists advancing health through research
3-Sep	Jurre SIEGERS	Post-Doc	Virology Unit	Emergence of a Novel Reassortant Clade 2.3.2.1e Avian Influenza A/H5N1 Virus Associated with Human Cases in Cambodia
17-Sep	LY Sowath	Research Director	Epidemiology and Public Health Unit	VIRAGE SURVEY: UNDERSTANDING KNOWLEDGE, ATTITUDES AND PRACTICES (KAP) TOWARDS RABIES IN CAMBODIA
1-Oct	Barbara HAN	Research Scientist	Cary Institute of Ecosystem Studies	Predicting unknown unknowns in disease ecology
1-Oct	OU Teyputita	PhD Student	Virology Unit	Characterization and control of emerging viral diseases in Cambodia: insights from bat coronaviruses and chikungunya virus
8-Oct	Lea BALDOR	PhD student	Malaria Research Unit	PvDBP gene amplification: extent and implications of infection by multi-copy parasites from two endemic countries, Ethiopia and Cambodia.
22-Oct	LAY Sokchea	PhD Student	Immunology Unit	Specificity and functionality of antibody responses shape dengue disease outcomes

26-Nov	Timothée VERGNE	Associate Professor	National Veterinary School of Toulouse	Highly pathogenic avian influenza vaccination strategy in France: from research to policy
3-Dec	Johanna BOUCKAERT	Researcher	Institute of Tropical Medicine in Antwerp	Leveraging epitope insights to improve current dengue serodiagnostics

Table 3: *List of the 23 seminars held in 2025*

2.9 Visiting Scientists

In 2025, the Institute hosted **33** visiting scientists from a wide range of international research institutions, reflecting its strong global scientific collaboration network. Visitors came from leading partner organizations and academic institutions including CIRAD, INRAE, Institut Pasteur Paris, IRD, KAIST, the University of South Florida, Université de Liège, Mahidol University, and Duke-NUS Medical School.

2.10 Visits and missions at IPC in 2025

Table 4 provides an overview of the main visits and missions of delegations received by IPC, along with the major events that took place in 2025.

Date	Type	Description
9-Jan	Visit	Mr. Christophe SOLA, Teacher for M1 (Master of Infectiology), Université Paris Saclay
14-Jan	Visit	Dr. Tamara Giles-Vernick, Director of Research and Head of the Anthropology and Ecology of Disease Emergence Unit at the Institut Pasteur, Paris
15-Jan	Visit	Mrs. Aurélie SALAIRE - Director of Shift Balance
6-Feb	Visit	Mr. Luis SAGAON TEYSSIER, Research Director of the Institut de recherche pour le développement (IRD)
11-Feb	Visit	Mr. Yannick CARON, Independent Researcher, Animal health, Doctor of Veterinary Medicine
19-Feb	Visit	Mr. Julien CAPPELLE, Health Ecologist of CIRAD
19-Feb	Visit	Mr. Christian MERIAU, Director of GIP CYROI
19-Feb	Visit	Prof. Roch GIORGI, Directeur de l'UMR SESSTIM
20-Feb	Visit	Delegation from Phnom Pen Accueil
7-Mar	Event	The 3rd PhD's Day at IPC celebrates the research, dedication, and achievements of IPC's PhD students, and to recognize the essential role they play in IPC's scientific community and future
26-28 -Mar	Event	Scientific Advisory Board meeting, to review the activities of the Institute's various entities and met with scientific staff from various categories
1-Apr	Visit	Delegation of British Embassy, led by Mr. Sam BECKWITH, FCDO Regional Director for Health (SE Asia) and Health Advisor
21-Apr	Visit	Prof. Simon CAUCHEMEZ, Director of the Mathematical Modelling of Infectious Diseases Unit at Institut Pasteur in Paris
15-21-May	Training	Regional workshop on "Metagenomic Sequencing of Respiratory Viruses" at Duke-NUS Medical School in Singapore, Co-led by Erik Karlsson, Head of Virology Unit in collaboration with Dr. Giorgio Gonnella, Head of the Bioinformatics and Artificial Intelligence Applications (BAIA) Unit
19-21-May	Training	Introduction to Statistical Data Analysis with R, led by Ms. Andréa ANTONIOLLI and Dr. Cécile SOMMEN
20-May	Visit	National Health Products Quality Control Center (NHQC), led by Mr. TEP Keila, Director of NHQC
22-May	Visit	Dr. TRANH THI Anh-Dao, Attaché for scientific and higher education cooperation of the Embassy of France in Cambodia to the Rabies Prevention Center in Battambang

28-May	Visit	H.E. Jacques PELLET, the French Ambassador to Cambodia, to the Rabies Prevention Center in Kampong Cham
04-06-Jun	Training	Environmental Surveillance and Monitoring of Pathogens at High-Risk Interfaces, hosted by the Virology unit
04-06-Jun	Visit	Ms. Odette TOMESCU-HATTA, Executive Vice-President of the International Affairs Department at Institut Pasteur in Paris (IPP) and delegation
04-05-Jun	Event	ECOMORE Entomology & Climate Workshop, aimed at finalizing the regional entomology protocol of the project, funded by the Agence Française de Développement (AFD)
6-Jun	Event	Annual Liaison Counsil, chaired by His Excellency Professor Chheang Ra, Minister of Health
12-Jun	Event	Kick-off event for research studies VIRAGE (Integrated Vision of Rabies Surveillance and Control in Cambodia) and RACSMEI (Risk Assessment of Community Spread of Multiple Endemic Infectious Diseases in a One Health Perspective)
20-Jun	Visit	Students from University of Puthisastra, led by Mrs. UNG Huykhim, Assistant Dean
23-24-Jun	Training	Food Safety – Good Hygiene Practice and HACCP, hosted by the Laboratory of Food and Enviroment Safety
25-26-Jun	Training	First Aid Training (Session1), hosted by HSeQM Servise
4-Jul	Visit	Delegation of the Académie de Médecine, led by Pr Christian BOITARD, Pr Patrice Debré, Pr Jacques BAULIEUX
11-Jul	Training	First aid for laboratory (Session2), hosted by HSeQM Service
17-Jul	Training	First aid training for field mission, hosted by HSeQM Service
25-Jul	Visit	Delegation of the Open Medical Institute, Prof. Wolfgang Aulitzky and Mrs. Stephanie Faschang
31-Jul	Visit	Japanese delegation led by Dr. Naomi Seki (Fujishima), Director of the Department of Preparedness and Response
31-Jul - 01 Aug	Visit	Study tour for laboratory staff from public hospitals, hosted by Medical Biology Laboratory
14-Aug	Training	Intermediate Linux Command Line for IPC staff for a basic knowledge gathered on the basic course (or on self-study) and understand how to do more advanced skillshosted by BAIA
2-Sep	Visit	Delegation of the Médecins Sans Frontières (MSF) Switzerland, led by Jessa Pontevedra, MedOps Support South East Asia/Flying Medical Coordinator
5-Sep	Visit	Dr. Anne Goldfeld, Professor of Medicine at Harvard Medical School (Boston, USA)
12-Sep	Exhibition	Conference by Nathanaël Maury and Dr. Sébastien Boyer and Exhibition of insect in detail at Institut Français du Cambodge
15-Sep	Visit	Dr. Philippe BUCHY, Director of Institut Pasteur du Laos
15-Sep	Visit	Delegation of the Australian Parliament, DFAT and CAPRED, led by Ms Fiona Phillips MP to IPC and the Laboratory of Environment and Food Safety
16-Sep	Visit	Rodolphe Mérieux Laboratory, led by Gabriel Pedone, Deputy Director of Laboratory
19-Sep	Event	Certificate handover ceremony for completion of a three-week joint training program for NIPH Staff, on Cell Culture, Virus Isolation, and HA/HAI for Seasonal Influenza, held at IPC's Virology Unit
28-Sep	Event	World Rabies Day (IPC's flagship PEP & outreach activity)
Oct	Event	Pink October, Breast Cancer Awareness Month at IPC with the four sessions led by Dr. Ramouy from IPC, focused on prevention, early detection, and support, with 135 female IPC staff participating
15-17-Oct	Visit	Mrs. Emilie CARTIER, Head of the Geographical Division, International Affairs Department at the Institut Pasteur
20-Oct	Visit	Prof. Yasmine BELKAID, President of Institut Pasteur, Mrs. Odette TOMESCU-HATTO, Executive Vice-President of International Affairs Department, Institut Pasteur and Prof. David FIDOCK, Scientific Advisor to the President, Institut Pasteur

21-23 Oct	Event	2025 Pasteur Network Annual Meeting (PNAM) at Ho Chi Minh, Vietnam
7-Nov	Visit	Mme. Marie BUSCAIL, First Advisor at the French Embassy, official visit to the Battambang Rabies Prevention Center
12-Nov	Visit	Benjamin BECHAZ, French Global Health Regional Counsellor for South-East Asia, French Embassy in Bangkok
13-Nov	Visit	Assoc. Prof. Vratislav Fabián, Co-founder of Medicton Group, Czech Republic to Metrology Laboratory of IPC
17-Nov	Visit	Dr. Sabine Walter, German Regional Doctor of Embassy of the Federal Republic of Germany to the Medical Biology Laboratory and International Vaccination center
17-18 Nov	Visit	The Sarawak Infectious Disease Centre (SIDC)'s delegation, led by Prof. Ivan K. S. Yap, CEO of the SIDC
24-28 Nov	Event	IUIS-Pasteur Network Immuno-Cambodia 2025, orgainze by the Immunology Unit of IPC at Siem Reap
26-Nov	Visit	H.E. Dr. LY Sovann, Director of CDC and delegation to the BSL3 laboratory
19-Dec	Visit	Dr. Marc JOUAN, Director of Institut Pasteur New Caledonia (IPNC)

Table 4: *Visits and missions of delegations received by IPC, along with the major events in 2025*

2.11 Institutional Issues, Objectives and Outlook (2026–2030)

The general objectives remain the same as those of previous years, in line with recommendations made at the last Liaison Councils and the last SAB.

2.11.1 Defining our Scientific Strategy

Finalizing a 5-year Strategic Plan

The last two SAB meetings recommended the development of a 5-year strategic plan. However, it did not seem possible to the new Management to begin such work without first having a thorough knowledge of the IPC and of the context in which it evolves.

This plan should be developed together with all IPC scientists as well as with key partners. The plan should also be coordinated with the MoH (hospitals, specialized Cambodian centres), the Ministry of Agriculture, Forestry and Fisheries, the Ministry of Environment, and the main universities in Cambodia.

Discussions and exchanges with IPC scientists on this topic began in November 2024. Meetings were scheduled with our main partners at the MoH and MAFF during the first quarter of 2025 to gather their views on (i) the IPC's place in Cambodia's health and research systems, and (ii) the nature of our future partnerships.

The plan should be finalized in 2026 and should demonstrate how the IPC can build local scientific capacity and skills transfer to local health authorities and actors. This would allow the IPC to concentrate on highly specialized public health issues as well as on research.

2.11.2 Continuing the Development of Quality Standards

The IPC currently has 4 accredited laboratories (MBL, LEFS, and the Metrology Laboratory, BSL-3).

The Virology Unit, due to its size and to the critical activities it carries out (diagnoses critical for public health), has begun developing a quality approach in 2023.

2.11.3 Promoting our Staff's Career Development and Making the IPC a More Attractive Workplace

Within 5 to 10 years, Cambodian scientists should make up at least 75% of the scientific staff and more than 50% of the units should be headed by Cambodians. This will involve identifying young talent,

training them and, for the most promising, building career paths that are attractive enough to motivate them to stay at the Institute. The criteria for identifying these future elites among the young talents must include an assessment of managerial potential in the same way as 'intellectual and technical' potential.

Supporting PhD Students
The IPC shall continue to support the training of young Cambodian scientists by covering the costs related to their PhD. In 2024, 9 PhD Students were supported, for a total of around €100,000.

Strengthening Management Skills
Current efforts to build up professionalism and skills in management, including supervision, mentorship, and structure-wide orientation, should be maintained.

Professional Development and Career Attractiveness
In order to identify "young talents" with high potential within the Institute and to plan career paths, the IPC organizes meetings with each head of unit, together with the Human Resources department and management (director, deputy director, CFO). These "Young Talents" meetings began in 2022 and will continue ever since. The process makes it possible to identify young talents (promising laboratory technicians, young PhD students, etc.) and to determine paths allowing their personal development in line with the Institute's strategy).

2.11.4 Fine-tuning the IPC's Economic Model

The IPC is a not-for-profit organization. Its economic model relies on the successful pursuit of research and institutional grants, and on the earning of revenue through services such as vaccinations and laboratory analyses.

The activities of the Medical Biology Laboratory need to be further expanded to generate additional revenue. This appears achievable, given the Laboratory's recognized technical excellence and strong reputation. However, the Laboratory is operating in an increasingly competitive environment, notably because of competition from non-accredited laboratories, and it also faces accessibility constraints linked to the lack of parking space for patients.
Several operational measures have already been implemented to support this effort. Opening hours were extended in December 2025, with services available until 6:00 p.m. from Monday to Friday, and further expanded in January 2026 through Saturday afternoon opening. In addition, the possibility of extending opening hours to evenings and weekends, as well as the creation of an external sampling center, is currently under consideration.

For LEFS, significant investment was made in 2023 and 2024, with the support of **CAPRED** (the Cambodia–Australia Partnership for Resilient Economic Development), to strengthen the Laboratory's capacity for the analysis of heavy metals, pesticide residues, and antibiotic residues.
Part of this new analytical panel was accredited in 2025, enabling LEFS to perform the analyses required for the export certification of food products subject to these requirements. This new capacity is expected to support the economic development of the relevant sectors in Cambodia while also contributing to IPC's financial autonomy.
At the same time, the Laboratory faces strong competition from laboratories located outside Cambodia, whose higher testing volumes enable them to offer analyses at lower cost.

In 2026, a position dedicated to the promotion and development of our service activities should be created in order to support the growth of this area.

3 Research and Public Health Activities

3.1 Malaria Research Unit

3.1.1 Functional Structure

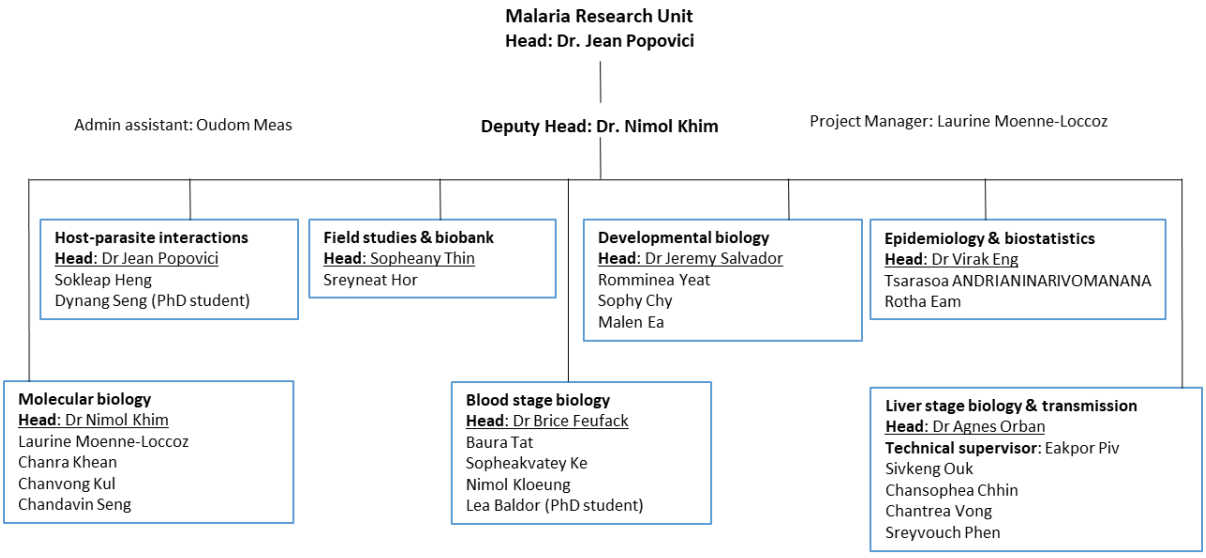
The Malaria Research Unit (MRU) is led by Jean POPOVICI since September 2022. The Unit encompasses six thematic areas, each led by one of the unit members: epidemiology & biostatistics, molecular biology, liver-stage biology & transmission, blood-stage biology, developmental biology and host-parasite interactions.

As of January 2026, The Unit is composed of one Head of Unit (J. POPOVICI–IP permanent researcher), one Deputy Head (KHIM Nimol–IPC permanent researcher), four postdoc researchers (Brice FEUFACK, Agnes ORBAN, Jeremy SALVADOR and Tsarasoa ANDRIANINARIVOMANANA), one junior research assistant (ENG Virak), two PhD students (SENG Dynang and Lea Baldor), one field studies and biobank supervisor (THIN Sopheany), five research engineers (HENG Sokleap, Laurine Moenne-Loccoz, TAT Baura, OUK Sivkeng and YEAT Romminea), one project manager (Laurine Moenne-Loccoz) and twenty technical & administrative staff.

The MRU is the WHO's main Southeast Asian laboratory for molecular surveillance of malaria diagnostic and drug resistance.

In 2023, a Pasteur International Unit (PIU) has been created associating the MRU at IPC with the Plasmodium Genetic Unit at Institut Pasteur de Madagascar (Benoit Witkowski) and the Infectious Disease Epidemiology and Analytics G5 group at Institut Pasteur Paris (Michael White). This PIU will enable to further understand the challenges revolving around elimination of *P. vivax*.

The MRU is also member of the Asia-Pacific International Center of Excellence in Malaria Research (ICEMR) aiming at understanding the epidemiology of malaria in Cambodia and in Papua-New Guinea and of the VISPA consortium aiming at advancing serological diagnostic to provide radical cure treatment.



3.1.2 Research Programs – Major Achievements in 2025

Our unit's research activities are designed to provide insights useful for malaria elimination. These projects are mainly focused on Cambodia's key public health challenges but have implications beyond the country. Our activities are divided into four main axes: anti-malarial chemotherapy, pre-clinical vaccine development for *Plasmodium vivax*, host–parasite interactions and operational research for malaria elimination through improved diagnostics and innovative approaches. In the past years, our research has shifted from a main focus on *P. falciparum* (now on the verge of eradication in Cambodia) to an emphasis on *P. vivax*, a parasite far less studied and resilient to current elimination strategies.

Axis 1: Chemotherapy of Malaria Parasites

***P. falciparum* drug resistance surveillance.**

The surveillance of drug resistance in the Greater Mekong Subregion (GMS) used to be a major activity of the unit. In the past years this has been reduced in terms of commitment and now mainly concerns support to other countries. This program is supported by the WHO.

In the past years, samples of *P. falciparum* were collected during therapeutic efficacy studies (TES) performed by Malaria Control Programs in each country of the region. However, with the numbers of cases decreasing, Cambodia has replaced traditional TES by integrated drug efficacy surveillance (iDES) where follow-up of infected patients is done continuously.

We are the main laboratory for characterizing resistance profiles of *P. falciparum* collected in these TES or iDES. The main result obtained from 2024 is the characterization of lumefantrine resistant parasites from Laos (**Feufack et al, in press Lancet Microbe**). Our work also has investigated how triple combination therapies could select for drug resistance P. falciparum (**Roesch et al. 2025. Nature Communications**).

Research Project Name	MalaWHO
Funding	WHO
Project duration	2024 (annual contract)
External collaborator	National Malaria Control Programs (NMCPs): Cambodia, Vietnam, Laos, and WHO (Pascal Ringwald)

Therapeutic options against *P. vivax* liver stages.

P. vivax is characterized by the formation of dormant stages called hypnozoites responsible for the chronic nature of this infection. Because of this feature, *P. vivax* will be extremely difficult to eradicate. We have developed a method capable of medium throughput screening for drugs targeting this stage, making our unit one of the few laboratories able to perform this research at a global level.

To date, more than 10,000 molecules have been screened using our platform with the identification of promising hits. This activity is financed by MMV. In parallel, we have developed a research program—financed by the National Institute of Health (NIH)—with the University of Georgia to guide structure-activity relationships. This effort enables as well to better apprehend the biology of this elusive parasite stage (**Maher et al. eLife, 2024**). We also contributed to characterize new antimalarials (**Bouzón-Arnáiz et al. 2025. Scientific Reports**)

Name	PIVLA-HYPNOLEAD
Funding	Medicine for Malaria Venture (MMV, Switzerland)/National Institutes of Health (NIH, USA)
Project duration	2019-2024 (NIH); 2021-2024 (MMV)
External collaborator	University of Georgia USA (UGA, Dennis Kyle, Steven Maher, Anthony Ruberto)

Optimal drug regimen for *P. vivax* radical cure.

Primaquine (PQ) represents the gold-standard molecule used for the *P. vivax* radical cure. Beside the hepatotoxicity of this drug in G6PD-subjects, there is no consensus on the posology to adopt. Moreover, the individual drug efficacy is poorly characterized, notably because of the difficulty in proposing a suitable follow-up design. Understanding these aspects is critical for the elimination of *P. vivax*. To address these different points, we have developed a collaborative project with the University of Maryland (UMD) which aims to determine the most effective PQ regimen. To avoid bias due to reinfection, we relocate enrolled patients in a no-transmission area during their entire follow-up. The first patients were recruited in November 2021, and 164 patients have been enrolled. The study is now completed and we have shown that high dose primaquine is needed in Cambodia leading to changes in the National Treatment Guidelines (**Eng et al, Lancet Infect Dis. 2025**). Besides, our work has also shown that some P. vivax isolates responded differently to artesunate raising the concern of possible drug resistance emergence in this species (**Tebben et al. 2025. Lancet Microbe**)

Name	PRICURE
Funding	NIH
Project duration	2020-2025
External collaborator	University of Maryland USA (UMB, David Serre), National Center for Parasitology, Entomology, and Malaria Control Cambodia (CNM, Dysoley Lek)

Axis 2: Pre-clinical Vaccine Development for Plasmodium vivax

Blood-stage vaccine development.

Thanks to the development of in vitro short-term cultures in the MRU in the past years, we are now able to evaluate blood-stage vaccine candidates to determine how they block parasite invasions in erythrocytes. We are currently focusing on PvDBP, PvRBP2b and PvRBP2a.

Name	PvMABS
Funding	NIH
Project duration	2020-2025
External collaborator	Case Western Reserve University USA (CWRU, Chris L. King), Walter and Eliza Hall Institute Australia (WEHI, Wai-Hong Tham), Burnet Institute (James Beeson), Mahidol University Thailand (Jetsumon Sattabongkot Prachumsri), CNM Cambodia (Dysoley Lek)

Name	Evaluation of PvRBP2a
Funding	A*STAR Singapore (Agency for Science, Technology and Research) and NTU Singapore (Nanyang Technological University)
Project duration	2023-2025
External collaborator	A*STAR Singapore (Laurent Renia)

Transmission-blocking vaccine development

We have partnered with the University of Oxford to evaluate transmission-blocking candidates against *P. vivax* using our standard membrane feeing assay. Analyses are completed and results are being prepared for dissemination.

Name	TBV
Funding	Oxford University UK
Project duration	2023-2024
External collaborator	University of Oxford UK (Sumi Biswas), IRD France (Anna Cohuet), CNM Cambodia (Dysoley Lek)

Pre-erythrocytic vaccine development.

We have established a collaboration with the University of South Florida to evaluate pre-erythrocytic vaccine candidates to block sporozoites infection of hepatocytes. Analyses are completed and results are being prepared for dissemination.

Name	MULTIVAX
Funding	NIH
Project duration	2023-2025
External collaborator	University of South Florida USA (USF, John Adams)

Axis 3: Host-Parasite Interactions

Factors involved in *P. vivax* growth within its host

We know very little about the factors influencing the growth of *P. vivax* in its human hosts. We started a project that aims at deciphering the contribution of human factors (specifically G6PD deficiency and HbE hemoglobinopathy) and of parasite genotypes on erythrocyte invasion and on the development of *P. vivax.* Using a combination of scRNA-seq, genotyping, and in vitro phenotype, we aim at better understanding how the parasite develops in its host. The first scRNA-seq libraries were sequenced in 2023 showing that the pipeline is fully functional, and the project will continue in the coming years.

Name	INVAVAX
Funding	NIH
Project duration	2022-2027
External collaborator	UMB USA (David Serre), CNM Cambodia (Dysoley Lek)

Receptor-Ligand Interactions Involved in Duffy-Negative Red Blood Cell Invasion

The molecular mechanisms involved in the invasion of *P. vivax* into Duffy-negative erythrocytes are still unknown. Thanks to our ability to perform in-vitro short-term cultures of *P. vivax*, in collaboration with colleagues from Drexel University and Jimma University, we are aiming to identify the mechanisms that enable *P. vivax* to invade Duffy-negative red blood cells, an erythrocyte phenotype common in Africa, where increasing evidence of P. vivax infections is reported. Collection of parasites have been conducted in Ethiopia and samples have recently been shipped to IPC to perform in vitro analyses. Epidemiological analyses of parasites infecting Duffy negative and positive individuals are also a primary objective of this project as well as understanding molecular mechanisms underlying P. vivax growth in these red blood cells.

Name	VIDUNAF
Funding	NIH
Project duration	2022-2027
External collaborator	Drexel University USA (Eugenia Lo), Jimma University Ethiopia (Delenesaw Yewhalaw)

Mechanisms of Parasite Dormancy and Biology of Relapses

The mechanisms driving the biology of hypnozoites are completely unknown. We are combining analyses of finely characterized in-vivo relapses with in-vitro analyses of liver-stage infections to decipher the biology of these elusive parasites. Our first libraries for scRNA-seq were prepared and results are being analysed to make sure the pipeline is optimal for these studies.

Name	HYPNOMICS
Funding	NIH
Project duration	2023-2028
External collaborator	UMB USA (David Serre), CNM Cambodia (Dysoley Lek)

Clinical protection against *P. vivax*

We and others have shown that some individuals can display clinical protection against *P. vivax* enabling them to be asymptomatic upon infection. We have started a project to determine the factors involved in this protection. Led by Jean Popovici and Tineke Cantaert at IPC, this project will study the genetic and immunologic determinants involved in this protection. Project is ongoing and results will be presented in future reports.

Name	IMUVIVAX
Funding	NIH
Project duration	2023-2028
External collaborator	UMB USA (David Serre), CNM Cambodia (Dysoley Lek)

Immune evasion of *P. vivax*

Following the identification of an in vitro immune evasion mechanism of *P. vivax* through a gene amplification (*pvdbp*), we have established a project started in 2023 to further understand the extent, dynamics and mechanisms associated to this phenotype. This project led by Jean Popovici and Eugenia Lo (Drexel University) will rely on two field sites, Cambodia and Ethiopia. Project is ongoing and results will be presented in future reports.

Name	PvEVAS
Funding	NIH
Project duration	2023-2028
External collaborator	Drexel University USA (Eugenia Lo), Ethiopian Public Health Institute Ethiopia (EPHI, Sindew Feleke & Abnet Assefa), CWRU USA (Chris L. King), UMB USA (David Serre), London School of Hygiene and Tropical Medicine UK (LSHTM, Rob Moon)

Axis 4: Operational Research for Malaria elimination (fuelling basic biology research)

Efforts in the past years, including those conducted by IPC (Epidemiology Unit in collaboration with ours) have led to a massive reduction in P. falciparum malaria in the country *P. vivax* is now the main species encountered in GMS. In Cambodia, it represents 90% of registered symptomatic cases. This parasite will be inherently more difficult to eradicate, not only because of its specific biology that causes chronic infections, but also because of the limitations in the methods developed so far.

The overall aim of this axis is to fill this gap to help identify the most relevant future eradication strategies.

Deciphering malaria epidemiology in Cambodia. Our unit is part of the NIH Asia-Pacific ICEMR (Program Director: I. Mueller/ L. Robinson), which aims to address the key challenges to malaria elimination in the Asia-Pacific. We have applied serological investigations to evaluate the transmission of *P. vivax* in Eastern Cambodia and our results show that this tool provides great opportunity to understand fine-scale epidemiology (**Tacoli et al, in preparation**).

We have performed a final cross-sectional survey in 2023 to determine how much epidemiology has changed over time since the start of this study. In 2024, our ICEMR was renewed for an additional 5 years, and in 2025, NIH renewed ICEMR for the next annual period despite a potential ending of the grant.

Name	ICEMR Asia-Pacific
Funding	NIH
Project duration	2017-2029
External collaborator	WEHI Australia (Ivo Mueller), Burnett Institute Australia (Leanne Robinson), IPP France (Michael White), CNM Cambodia (Dysoley Lek)

Targeting asymptomatic reservoirs of *P. vivax.*

The results of epidemiology analyses performed in the past years have shown that, while *P. falciparum* is on the verge of elimination, a reservoir of *P. vivax* remains. This reservoir consists of populations at risk of exposure, who are immune, and who rarely present a sufficient parasite density to show a positive result on a rapid diagnostic test (RDT).

Therefore, a rational approach is to propose a test and a treatment strategy focused on the populations most at risk of having been recently in contact with the parasite. Because of its inconstant presence in the blood, the methods aiming at a direct detection (PCR) of the parasite are not sufficiently conclusive. Instead, we propose a serology-based methodology aiming at the characterization of recently exposed individuals, followed by a radical cure treatment (seroTAT). Our objective is to provide evidence about the feasibility and the acceptability of this strategy in rural Cambodia. We have implemented a pilot seroTAT study to evaluate the feasibility and acceptability of such approach in communities. Our data show very promising results and suggest that these should be scaled-up for evaluation of impact on *P. vivax* prevalence (**Tacoli et al. The Lancet Regional Health, Western Pacific, 2025)**. Following this seminal feasibility study, we have been approached by the WHO to implement seroTAT in the Greater Mekong Region (see below)

Name	WHO Laos
Funding	The Global Fund
Project duration	2025-2026
External collaborator	WEHI Australia (Ivo Mueller)

Developing a minIon approach for G6PD sequencing

As G6PD deficiency is a major host polymorphism involved in primaquine safety, understanding the epidemiology of this human polymorphism and better associating response to primaquine with human genotypes requires having a field-compatible tool for generating sequences of this gene. We have developped a MinIon pipeline to perform this sequencing in malaria-endemic areas. Our data show very good genotyping obtained (Tacoli et al, 2026).

Surveillance of malaria infections among febrile illness in endemic areas

We have conducted in 2023 a surveillance study to determine the true burden of malaria infections among febrile treatment seeking individuals.

The rationale of this work is that a significant number of infections might not be detected by current diagnostic tools (RDTs). We have enrolled nearly 1000 individuals from 6 Cambodian provinces, and the main results are (i) current diagnostic tools detect only 40% of malaria cases and (ii) there seem to be an increasing number of non-falciparum non-vivax malaria cases compared to previous years (**Khim, Orban et al, in preparation**)

Long-term culture of *Plasmodium vivax*

P. vivax cannot be cultured in vitro continuously. We recently obtained funding to pursue innovative efforts to establish long-term culture for this parasite (PI Jean Popovici, co-PI Jeremy Salvador). Our approach relies on (i) access to a range of isolates from infected patients and (ii) mimicking in vitro bone marrow and splenic conditions that we believe are critical for parasite maintenance.

Name	PvCULT
Funding	NIH
Project duration	2025-2028
External collaborator	CNM Cambodia (Dysoley Lek)

Drug resistance in Papua New Guinea

Through a collaboration with Alyssa Barry (Deakin University) and Moses Laman (PNGIMR), we will investigate and characterize Plasmodium falciparum circulating in PNG in order to precisely determine antimalarial drug susceptibility and in case of resistance, the molecular determinants associated to it.

Name	PREEMPT
Funding	NHMRC
Project duration	2025-2028
External collaborator	Deakin (Alyssa Barry), PNGIMR (Moses Laman)

3.1.3 Research Programs – Outlooks for 2026

Are listed below projects that just started, however most projects indicated above are still ongoing.

Targeting malaria asymptomatic reservoirs

Cambodia is close to malaria elimination, but residual transmission linked to asymptomatic reservoirs remains a risk in last-mile areas. Understanding the extent of asymptomatic malaria reservoirs in these communities, particularly where transmission persists, is essential for an effective elimination strategy. Detecting asymptomatic carriers, is crucial, as these infections often go undetected by standard diagnostic tools such as rapid diagnostic tests (RDTs) and microscopy. We aim to conduct a cross-sectional study in areas where malaria transmission persists to identify asymptomatic malaria reservoirs and factors associated with residual transmission.

Name	SILENT-Pf
Funding	WHO Western Pacific Region/TDR
Project duration	2026-2027
External collaborator	CNM Cambodia (Dysoley Lek)

Development of strategies for detecting and eliminating hidden parasite reservoirs

This project aims to elucidate the biological and epidemiological characteristics of malaria across contrasting transmission settings, focusing on high-transmission areas in Cameroon and low-transmission, elimination-phase settings in Cambodia. By working in these two distinct contexts, we aim to identify Plasmodium tissue reservoirs, assess parasite persistence, and discover biomarkers of infection. Investigating asymptomatic Plasmodium carriers and associated risk factors is critical, as these silent infections sustain transmission while evading routine detection, posing a major threat to malaria elimination efforts, particularly in countries nearing elimination such as Cambodia. The findings will inform the development of targeted strategies to detect and eliminate hidden parasite reservoirs, addressing urgent scientific and public health priorities for achieving sustainable malaria elimination.

Name	MAP-RES
Funding	SPARK (Seeded Partnerships for Advancing Research & Knowledge)
Project duration	2026-2028
External collaborators	IP Cameroon (Noella Efange), IP Paris (Michael White), CNM Cambodia (Dysoley Lek)

Unraveling the human, ecological, and environmental drivers of *Plasmodium knowlesi* malaria emergence in Cambodia.

Plasmodium knowlesi was first reported in 2011. A previous study conducted in 2023 identified a substantial number of *Plasmodium knowlesi* cases among patients seeking treatment at health centers in western Cambodia, highlighting ongoing transmission and the zoonotic malaria burden in the

country. To assess the circulation of the simian *Plasmodium* species in human populations living in the forest and peri-forest villages, epidemiological, behavioral, and entomological data will be integrated to identify key human and ecological drivers of zoonotic *Plasmodium* emergence and to generate evidence to inform adaptive malaria surveillance and targeted control strategies.

Name	DEKLIC
Funding	French Foundation via IRD
Project duration	2025-2028
External collaborator	IRD (Anne Poinsignon), Entomology and Veterinary Unit (Sebastien Boyer), Epidemiology and Public Health Unit (Claude Flamand), CNM Cambodia (Dysoley Lek)

3.1.4 Support to National Authorities

Public Health Support for diagnostic of malaria

Through a contract with the WHO, we are the main laboratory in the Greater Mekong Sub-region (GMS) that provides support to national programs for characterizing drug resistance markers and phenotypes of *Plasmodium falciparum*. We are now expanding this support to also leverage our molecular diagnostic capacity to support national authorities in their diagnostics, especially of low-density parasite infections encountered in asymptomatic individuals screened during active surveillance surveys.

We are endorsed as a WHO UKNEQAS referee lab to evaluate performance of diagnostic capacity in endemic settings as well as drug resistance molecular marker genotyping.

PvSeroTAT

Following our seminal study evaluating feasibility of PvSeroTAT in endemic area of Cambodia (**Tacoli et al, The Lancet Regional Health Western Pacific, 2025**), we have been approached and endorsed by the WHO to provide serological testing on samples collected by malaria control programs in the GMS in order to treat potential P. vivax hypnozoite carriers and contribute to malaria elimination in the region. By being member of the VISPA consortium, with support from WEHI colleagues, we are now the first ones to perform these analyses in real-life programmatic settings.

3.1.5 Training and Teaching

PhD students

SENG Dynang: University Paris-Saclay. Study of the biology of hypnozoites and relapses in Plasmodium vivax (Oct 2022-Oct 2026).

BALDOR Lea: University Paris-Saclay. Extent, dynamics and mechanisms of Plasmodium vivax immune evasion caused by PvDBP gene amplification (Oct 2023-Oct 2027)

Master & Engineer students:

	Name	Dates	Current position
Master 2	Zeinab Ouaid	2025	Research Engineer
	Lucas Guseli	2025	Applying to PhD
	Tariqur Rehman	2025	Applying to PhD
Master 1	Julie Cathala	2025	Master 2 Student
	Shairin Shoheli	2025	Master 2 Student
	Boubacar Barry	2025	Research technician

Teaching

Jean Popovici coordinated the TU Host-Pathogen Interactions of the Joint Master's offered by the UHS and the *Université de Paris-Saclay*. He provided 3 hours on antigenic variation in Plasmodium parasites and 3h on multipartite interactions for second-year master's students. He provided 3h lectures to first year Master students on Plasmodium parasites. He is jury member and one of the coordinator for IPC of this Master degree.

Brice Feufack, Dynang Seng, Nimol Khim and Agnes Orban: supervised a 4*4h practical class on the techniques used to study malaria parasites.

Lea Baldor provided 1h30 lectures to second year Master students on PvDBP gene duplication: Strategy for Plasmodium vivax immune evasion.

Brice Feufack provided 1h30 lectures to second year Master students on Malaria Parasite-Host interaction: Receptor-ligand biology and RBC polymorphisms.

3.1.6 Outlook for upcoming 3 – 5 years

A number of ongoing projects listed above will continue for the next 3 to 5 years.

Our research will keep focusing on the challenges related to malaria in the GMS with a specific attention on *P. vivax*. These will keep combining basic laboratory research with applied, operational questions for elimination.

We are expanding our network of collaborators to leverage our knowledge and expertise (ie. in vitro culture of *P. vivax*) and use it at the service of other epidemiological contexts where malaria elimination is far from being achieved (i.e.. Ethiopia, Papua New Guinea).

In addition, we have to anticipate the complete elimination of *P. falciparum* in the region for the very near future and, though less likely, of *P. vivax*. In that regard, we expect to expand our research to other pathogens than strictly *Plasmodium* parasites.

Our immediate attention for this matter is to identify public health needs in Cambodia (and the region) with significant research gaps currently unaddressed at IPC to determine the most strategic decisions to be made for future research to be done in our unit. This could obviously include other parasitic infections, but also perhaps fungal infections or even bacterial pathogens.

3.1.7 Scientific Publications 2025

Note: *The name of authors from the Institut Pasteur du Cambodge are underlined*

1. **14 days of high-dose versus low-dose primaquine treatment in patients with Plasmodium vivax infection in Cambodia: a randomised, single-centre, open-label efficacy study.**
   Eng V, Lek D, Sin S, Feufack-Donfack LB, Orban A, Salvador J, Seng D, Heng S, Khim N, Tebben K, Flamand C, Sommen C, van der Pluijm RW, White M, Witkowski B, Serre D, Popovici J.
   Lancet Infect Dis. 2025 Mar 17:S1473-3099(25)00033-7. doi: 10.1016/S1473-3099(25)00033-7.

2. **Anopheles mosquitoes in Mondulkiri forest, Cambodia: abundance, distribution, seasonal patterns and Plasmodium prevalence**
   S. Boyer, B. Doeurk, A.Rakotonirina, S. Chy, C. Vong, E. Piv, B.Tat, M. Ea, C. Chhin, S.Phen, N. Kloeung, S. Ke, J. Popovici, P. Piola, B. Witkowski, P.O Maquart, A.Vantaux
   Malar J. 2025 Jan 10 doi:10.1186/s12936-024-05166-9

3. **Assessment of the in vitro activity and selectivity of Artemisia afra and Artemisia annua aqueous extracts against artemisinin-resistant Plasmodium falciparum.**
Roesch C, Ashraf K, Vantaux A, Marin AA, Maher SP, Franetich JF, Kloeung N, Ke S, Vo HTM, Mazier D, Witkowski B.
Malar J. 2025 May 11;24(1):150. doi: 10.1186/s12936-025-05375-w.

4. **Evaluating the technical feasibility of serological testing and treatment for Plasmodium vivax in mobile at-risk of malaria Cambodian populations**
Costanza Tacoli, Sopheany Thin, Malen Ea, Nimol Khim, Agnes Orban, Dysoley Lek, Rhea J. Longley, Michael White, Leanne J. Robinson, Benoit Witkowski, Ivo Mueller and Jean Popovici.
The Lancet Regional Health, Western Pacific, March 14, 2025.
Doi: https://doi.org/10.1016/j.lanwpc.2025.101518

5. **Genetic polymorphism of Plasmodium falciparum using merozoite surface proteins 1 and 2 (msp-1 and msp-2) genes in Oveng and Mintom, South region of Cameroon.**
Nanssong-Vomo CT, Feufack-Donfack LB, Bouopda-Tuedom AG, Ibrahima-Ibrahima, Kiam CB, Youmsi Fotso GJ, Kemeni MN, Fotso BT, Abate L, Eboumbou C, Ayong L, Mbida-Mbida JA, Nsango SE.
BMC Infect Dis. 2025 Nov 19;25(1):1613. doi: 10.1186/s12879-025-11923-1

6. **MK-7602: a potent multi-stage dual-targeting antimalarial.**
Favuzza P, Palandri J, de Lera Ruiz M, Bailey W, Boyce CW, Danziger A, Fawaz MV, Kelly M, Murgolo N, Robbins JA, Vavrek M, Zhao L, Lei Z, Guo Z, Reaksudsan K, Steel RWJ, Hodder AN, Ngo A, Dziekan JM, Thompson JK, Triglia T, Birkinshaw RW, Penington JS, Scally SW, Dans MG, Coyle R, Sevilleno N, Orban A, Feufack-Donfack LB, Popovici J, Lee MCS, Papenfuss A, Lowes KN, Sleebs BE, McCarthy JS, McCauley JA, Boddey JA, Olsen DB, Cowman AF.
EBioMedicine. 2025 Dec 6;123:106061. doi: 10.1016/j.ebiom.2025.106061.

7. **YAT2150 is irresistible in Plasmodium falciparum and active against Plasmodium vivax and Leishmania clinical isolates.**
Bouzón-Arnáiz I, Rawat M, Coyle R, Feufack-Donfack LB, Ea M, Orban A, Popovici J, Román-Álamo L, Fallica AN, Domínguez-Asenjo B, Moreno J, Arce EM, Mallo-Abreu A, Muñoz-Torrero D, Lee MCS, Fernàndez-Busquets X.
Sci Rep. 2025 Jan 23;15(1):2941. doi: 10.1038/s41598-025-85346-y.

8. **Emoquine-1: A Hybrid Molecule Efficient against Multidrug-Resistant Plasmodium Parasites, Including the Artemisinin-Resistant Quiescent Stage, and Also Active In Vivo.**
Li Y, Nguyen M, Laurent M, Wein S, Paloque L, Kessavdjee-Djouma S, Witkowski B, Musset L, Augereau JM, Cerdan R, Robert A, Liu Y, Meunier B, Benoit-Vical F.
J Med Chem. 2025 Jan 24. doi: 10.1021/acs.jmedchem.4c02702.

9. **Tolerance of Plasmodium falciparum mefloquine-resistant clinical isolates to mefloquine-piperaquine with implications for triple artemisinin-based combination therapies**
Roesch C, Cosson A, Mairet Khedim M, Khim N, Kloeung N, Ke S, Srun S, Eam R, Khean C, Kul C, Adoux L, Popovici J, Leang R, Ringwald P, Ariey F, Coppée R, Witkowski B.
Nat Commun.2025 Nov 27;16(1):10634.doi: 10.1038/s41467-025-65629-8.

10. **Artemether-lumefantrine for the treatment of *Plasmodium falciparum* malaria in Laos: a therapeutic efficacy study coupled to genomic and in vitro phenotypic analyses. 2025. The Lancet Microbe. In press**
Feufack-Donfack LB, Khim N, Tat B, Banouvong V, Khamlome B, Chindavongsa K, Chanthavisouk C, Reyburn R, MS, Kloeung N, Ke S, Khean C, Seng C, Kul C, Eam R, Orban A, Salvador J, Vezain V, Dorgebray P-E, Coppée R, Ariey F, Witkowski B, Ringwald P, Popovici J.
DOI: 10.1016/j.lanmic.2025.101324

11. **Parasite clearance in patients with Plasmodium vivax monoinfection treated with artesunate in Cambodia: an observational secondary analysis of trial data. The Lancet Microbe. 2025**
Tebben K, Eng V, Seng D, Tat B, Feufack-Donfack LB, Orban A, Yeat R, Salvador J, Sin S, Ko K, Khim K, Flamand C, Sommen C, Lek D, Serre D, Popovici J.
DOI: 10.1016/j.lanmic.2025.101256

Pre-Publications

1. **High prevalence of mixed Plasmodium falciparum and Plasmodium vivax co-infections in Duffy negative individuals in Ethiopia.**
Tat B, Feufack-Donfack LB, Neneyoh Yengo B, Eng V, Tefera Shenkutie T, Abebe A, Tsigie M, Tacoli C, Khim N, Feleke SM, Lo E, Popovici J.
medRxiv . 2025 Sep 18:2025.09.16.25335845. doi: 10.1101/2025.09.16.25335845.

2. **PvDBP Gene Amplification Is Associated with Functional Immune Evasion by Plasmodium vivax in Vivo. Available at SSRN:**
Baldor L, Seng D, Heng S, Khim N, Hor S, Thin D, Salinas N, Tolia N, Chitnis C, Mueller I, Foroughi S, Christopher L.K, Lo E, Witkowski B, Flamand C, Feufack-Donfack LB, Popovici J. https://ssrn.com/abstract=6134918 or http://dx.doi.org/10.2139/ssrn.6134918

3. **Temporal trends in Plasmodium vivax diversity in eastern Cambodia evidence declining transmission.**
Eam R, Hoon KS, Sutanto E, Rai A, Trimarsanto H, Rumase A, Thin S, Hor S, Chhorvann C, Tol B, Price R, Popovici J*, Auburn S*.
Available at https://www.medrxiv.org/content/10.64898/2026.03.03.26346840v1

4. **Challenges in Plasmodium diagnostics in countries nearing malaria elimination: a cross-sectional survey among treatment-seeking patients in health facilities in malaria endemic provinces of Cambodia with contrasted transmission intensity.**
Khim N, Orban A, Thin S, Sin S, Guepin S, Feufack-Donfack LB, Eng V, Ea M, Chy S, Seng C, Eam R, Khean C, Kul C, Kloeung N, Ke S, Flamand C, White M, Lek D, Popovici J.
Available at https://www.medrxiv.org/content/10.64898/2026.03.03.26347480v1

5. **A study protocol for an Observational Feasibility Study on Mass Drug Administration and Serology Integrated with Reactive Case Detection for Vivax Malaria Elimination in Cambodia.**
Kheang ST, Siv S, Shrestha M, Popovici J, Mueller I, Robinson L, Huynh T, Do T, Jambert E, Lynch C.
Available at DOI: 10.64898/2026.02.11.26346129

3.2 Epidemiology & Public Health Unit

3.2.1 Functional Structure

The Epidemiology and Public Health Unit (EPHU) conducts operational and translational research addressing major public health challenges in Cambodia. The unit focuses on cross-disciplinary epidemiological and clinical studies designed to inform prevention strategies, strengthen health systems, and support evidence-based policy decisions at national and international levels. Its mission is to improve the understanding, prevention, diagnosis, and management of endemic and emerging infectious diseases in the general population, with a particular focus on vulnerable and hard-to-reach populations.

EPHU research activities integrate multiple disciplines, including infectious disease epidemiology, environmental and climate-related health, clinical research, biostatistics, mathematical and spatial modelling, and social sciences. A strong emphasis is placed on One Health approaches, explicitly linking human, animal, and environmental health dimensions. Recent and ongoing research addresses a broad range of priority public health issues in Cambodia, including rabies, arboviral diseases, HIV, tuberculosis, viral hepatitis, malaria, antimicrobial resistance, leptospirosis and other multiple priority pathogens for Cambodia and South-east Asia. Through these activities, the unit has generated substantial scientific and public health contributions, including evidence that has informed national and international guidelines and recommendations.

The unit benefits from a coherent functional structure, built around complementary expertise and led by senior scientists with strong experience in epidemiology, clinical research, and methodological development. In 2025, EPHU comprised 46 members, including a young, dynamic, and highly motivated team of researchers, technical staff, and students. This combination of senior leadership and early-career researchers, together with a deep understanding of the local context and strong partnerships with national authorities, represents a major asset for the unit's scientific productivity, innovation capacity, and long-term sustainability.

In 2025, EPHU consolidated its organization around **three complementary research groups**, ensuring scientific coherence across projects while fostering interdisciplinary collaboration:

- **Community Epidemiology Group,** led by Dr. Ly Sowath, functions as the unit's core platform for field-based data collection and community-level operations, contributing to numerous collaborative research projects led by EPHU, other units and external partners. The group coordinates and implements population-based surveys, longitudinal follow-up, and rapid field investigations across projects, ensuring standardized data collection procedures, quality control, and operational consistency. It plays a central role in epidemiological data collection and community engagement activities, and serves as a key interface between research, surveillance systems, and public health action.
- **Clinical Research Group**, led by Dr. Nathalie de Rekeneire and Dr. Dim Bunnet, serves as the unit's platform for clinical and patient-based research, conducting clinical trials as well as observational and operational research studies. The group contributes to the generation of evidence informing national and international strategies for the prevention, diagnosis, and treatment of diseases affecting vulnerable populations, while strengthening the interface between clinical care, epidemiology and public health decision-making. In November 2025, the leadership of the group transitioned with the appointment of Prof. Blandine Rammaert as Head of the Clinical Research Group, marking a new phase aimed at strengthening scientific

leadership and the development of locally initiated clinical research aligned with national priorities.

- **Methodology and Data Analysis Group**, coordinated by Dr. Claude Flamand, serves as the unit's transversal methodological and analytical platform, supporting epidemiological and clinical research activities within EPHU and in support of other IPC units. The group develops and implements tools for study design, sampling strategies, data management, statistical analysis, and modelling, ensuring methodological rigor, data quality, and comparability across projects conducted within the unit and beyond. It provides analytical leadership for mixed methods approaches and contributes to translating complex data into evidence directly usable for public health policy and intervention planning.

The year 2025 marked a structural turning point for the unit with the operational launch of three major multi-year projects coordinated by EPHU: **VIRAGE, RACSMEI, and AFRICAM**. These projects significantly reinforced the unit's **leadership in epidemiological research and population-based studies** within IPC and at national level. They exemplify EPHU's strategic positioning at the interface of One Health, health systems research, and population-based epidemiology and provide a strong framework for strengthening interdisciplinary collaboration, integrating social sciences into large-scale research programs and developing more ambitious and integrated epidemiological projects. In parallel, the clinical research group reached a key milestone in 2025 by successfully executing the closing phase of projects, consolidating datasets, and moving from field data collection to scientific achievements and valorization.

In 2025, EPHU strengthened its governance and transversal support functions in response to the growing scale and complexity of its research portfolio. A Project Management Office (PMO) was established to support project coordination, monitoring, reporting and compliance with funder requirements, improving operational efficiency and allowing scientific staff to focus on research leadership. In parallel, communication and data management capacities were reinforced through the recruitment of a dedicated Communication Officer and efforts to strengthen data governance, quality control, and interoperability across studies, enhancing the visibility, robustness, and long-term valorization of the unit's work.

EPHU research activities rely on close collaborations with IPC laboratory units and strong partnerships with national authorities, including the **Ministry of Health (MoH)** and its component entities (NCHADS, CENAT, CNM, NMCHC, CDC–MoH, National Immunization Program, National Viral Hepatitis Program, hospitals), the **Ministry of Agriculture, Forestry and fisheries (MAFF)** particularly with the General Directorate of Animal Health and Production - GDAHP) and the **Ministry of Environment (MoE)**. Academic partnerships include the University of Health Sciences (UHS), Royal University of Agriculture (RUA) and the Cambodia Academy of Digital Technology (CADT). At the international level, EPHU collaborates with a broad network of scientific partners, including Institut Pasteur of Paris, the Pasteur Network, INSERM, ANRS-MIE, CIRAD, IRD, and the World Health Organization.

EPHU activities are supported by major national and international funders, including the Wellcome Trust Foundation, NIH, ANRS-MIE, the European Union, L'Initiative (Expertise France), the Agence Française de Développement (AFD), the French Embassy in Cambodia, and the French Ministry for Europe and Foreign Affairs. Securing substantial multi-year funding has enabled the unit to strengthen scientific supervision, project management, and capacity building.

The unit remains attentive to challenges related to the **retention of trained Cambodian talents**, in a context of increasing competition between institutions. Continued investment in mentorship, career development pathways, and sustainable funding is therefore essential to ensure the continuity, resilience, and long-term impact of EPHU's activities.

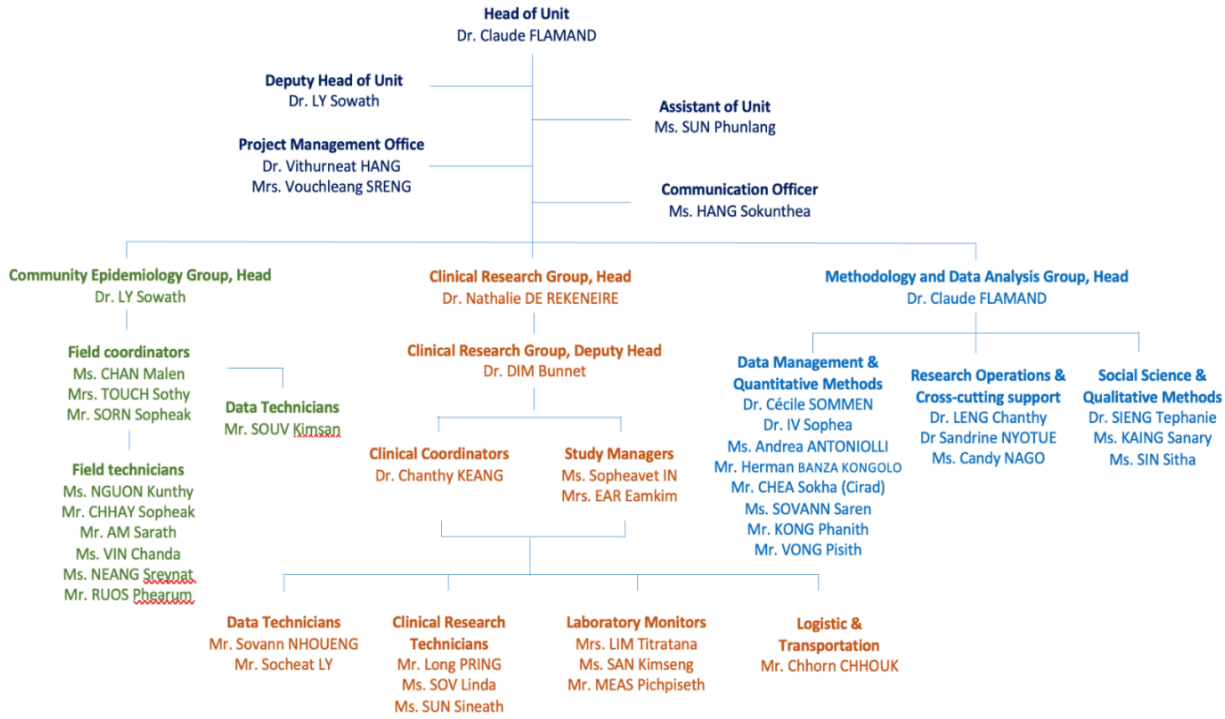


Figure 5: *Epidemiology and Public Health Unit organigram, 2025*

3.2.2 Research Programs - Major Achievements In 2025

Rabies

Follow-up of Patients Receiving the WHO 2018 - Recommended Rabies PEP Using Intradermal Vaccination Protocol

This study aims to evaluate the duration of the protective antibody response against rabies by following a cohort of approximately 170 patients at 14 days, 6 months, 1 year, and 3 years after receiving the first dose of the vaccine schedule. The cohort consists of patients who were bitten by dogs with a known rabies infection status and who received a 3-session intradermal rabies post-exposure prophylaxis (PEP) at the Institut Pasteur du Cambodge (IPC).

As of September 2025, follow-up and blood sampling have been completed for years 1, 2, and 3 in 153, 110, and 134 participants, respectively. No PEP failures were encountered, and a protective level of immunity against rabies was observed among participants at one year (published). With additional funding from FEF, this study becomes one component of the VIRAGE project allowing to extend the follow up of the cohort till 5th and 6th years after the PEP.

Collaborations	Epidemiology and Public Health Unit (Touch Sothy, Ly Sowath, Claude Flamand), Immunology Unit (Tineke Cantaert), Virology Unit (Erik Karlsson), IPC Vaccination Center (Thai Pisey, Peng Yiksing)
Funding	- Institut Pasteur du Cambodge: 2019-2025 - French Ministry of Europe and Foreign Affairs through the Solidarity Funds for Innovative Projects (FEF) :2025-2027 as part of the VIRAGE project

VIRAGE – Generating Strategic Evidence to Strengthen Rabies Prevention and PEP Access

The VIRAGE project supports Cambodia's commitment to the global "Zero by 30" strategy by addressing gaps in rabies awareness, post-exposure prophylaxis (PEP) access, and risk management through a One Health approach. Building on CAP-RAGE findings, VIRAGE conducted a nationwide population-based survey including more than 15,000 Cambodian residents from 104 villages, allowing the update of key epidemiological indicators for rabies burden estimation. Preliminary results estimate a national dog population of approximately 5.7 million, corresponding to a human-to-dog ratio of 2.7. The annual bite incidence was estimated at 1.5%, representing around 255,943 bite events per year nationwide. Among individuals bitten in the past 12 months, 69% reported accessing PEP.

In parallel, VIRAGE also builds on the analysis of 25 years of PEP surveillance data at IPC, providing a unique long-term perspective on trends in rabies exposure, access to care, and the role of specialized PEP services in Cambodia. Additional analyses are being conducted to assess PEP regimen completion, identify factors associated with incomplete vaccination, and generate operational evidence to improve patient follow-up and service delivery. Together, these findings provide robust, policy-relevant data to refine burden estimates, identify gaps in equitable PEP access, and inform evidence-based rabies control strategies at national level.

Collaborations	Team Leaders: C. Flamand, S. Ly, T. Sieng, H. Guis (CIRAD). In coll. with Yi CDC MoH and GDAHP MAFF, RUA
Funding	French Ministry of Europe and Foreign Affairs through the Solidarity Funds for Innovative Projects (FEF): 2025-2027

HIV and/or Tuberculosis

DATURA-ANRS 12424 Clinical Trial: Determination of the Adequate Tuberculosis Regimen in Adults and Adolescents Hospitalized with HIV-Associated Severe Immune Suppression (CD4 ≤ 100 cells/µL)

Mortality in people entering into HIV care late and who have tuberculosis (TB) co-infection is high. The objective of the DATURA clinical trial is to estimate the impact of an intensified initial phase of tuberculosis (TB) treatment on mortality at 48 weeks among HIV-infected adults and hospitalized adolescents for TB with CD4 ≤ 100 cells/µL in comparison with the standard TB regimen.

At the end of December 2025, among 209 patients who were pre-enrolled, 160 participants were included in this study. The recruitment of study participants was stopped on 17 December 2025 for futility following the DSMB recommendation. The follow-up of the last participant finished on 07 November 2025. Data cleaning plan to finish by the end of February 2026, and dissemination of results plan in mid 2026.

Collaborations	Team leaders: Epidemiology and Public Health Unit: Nathalie de Rekeneire, Dim Bunnet (Clinical Research Group), Partners: NCHADS, Cambodia-China Friendship Preah Kossamak Hospital, Khmer-Soviet Friendship Hospital, Calmette Hospital, AID Health Care Foundation, NCHADS Clinic and Laboratory
Funding	ANRS-MIE (2021-2026)

Hepatitis

HEPEDIAC – ANRS 12420 Clinical Trial: Pilot Therapeutic Study of DAA Treatment for Children and Adolescents with Active HCV Infection in Cambodia

Transmission from mother to child is the primary route of acquisition for both Hepatitis C (HCV) mono-infection and HCV/HIV co-infection in children. Cirrhosis occurs in less than 5% of children, but the proportion of patients with bridging fibrosis/cirrhosis has been reported to increase from 11% to 20% over a median period of 5.8 years. The objective of this study is to evaluate the effectiveness of the

sofosbuvir/daclatasvir combination for children aged at least 6 years and for adolescents with active HCV infection. Recruitment started in August 2023. By the end of 2025, 23,647 children had been screened, and among them, 23 children were included in the therapeutic phase. The recruitment of the last study participant finished on 31 July 2025 and follow-up of last study participant plan to finish in January 2026. Data analysis will be conducted in 2026.

Collaborations	Team Leaders: Nathalie de Rekeneire, Dim Bunnet (Clinical Research Group, IPC). Olivier SÉGÉRAL (University of Geneva) Partners: NCHADS and OI/ART sites, Jayavarman VII Hospital, Kantha Bopha 1 and 2 Hospitals, National Pediatric Hospital, Battambang Provincial hospital, CDC national viral hepatitis program
Funding	ANRS-MIE (2022-2026)

Fungal infections

FUNGICAM - ANRS 0465. Prevalence of invasive fungal infection - Histoplasma spp., Talaromyces marneffei, Cryptococcus spp. - in severe immunocompromised HIV-infected patients in Cambodia

Histoplasmosis, talaromycosis, and cryptococcosis are serious invasive fungal diseases (IFDs) in patients with advanced HIV disease, but little data is available on histoplasmosis and talaromycosis in Cambodia. Lack of awareness and insufficient availability of reliable diagnostic methods lead to delayed diagnosis. Antigenic and molecular methods emerged for the rapid diagnosis of IFDs. The objectives of this study are to assess the prevalence of these IFDs in patients with advanced HIV disease in Cambodia and raise awareness and train local actors on these infections and new and simple diagnosis tools. Biobank samples were used from the STATIS study (ANRS 12290), a study on the diagnostic management of tuberculosis in severely immunocompromised HIV-positive patients in Cambodia. Laboratory capacity building training was conducted from 14 – 18 October 2024 and clinical training was conducted in three sections from 1st – 3rd April 2025. All the laboratory testing of these 3 IFDs has been completed since October 2025. Dissemination of the primary result plan on 19 March 2026.

Collaborations	Team leaders: Nathalie de Rekeneire, Dim Bunnet (Clinical Research Group, IPC) Partners: Dr Sokleaph Cheng (PI Sud, IPC), Aude Sturny-Leclère (PI Nord, IPP), Dr Emilie Mosnier (UHS), Pr Antoine Adenis (CIC1424 Inserm of the Cayenne hospital center)
Funding	ANRS-MIE (2024-2025)

One Health

RACSMEI - Risk Assessment of Multiple Endemic Infectious Pathogens in a One Health Perspective

The RACSMEI project aims to strengthen Precision Public Health in Cambodia, a country facing a high burden of infectious and zoonotic diseases. Grounded in a One Health framework, the project integrates human, animal, vector, and environmental data to generate a comprehensive and nationally representative assessment of infection risks across ecological and social contexts. Following a national kick-off meeting held on 12 June 2025, the project entered its implementation phase with the inclusion of 104 villages selected through a structured sampling design. Field data collection formally started on 18 December 2025, marking the launch of one of the largest integrated One Health population-based surveys conducted in Cambodia. RACSMEI implements a large-scale survey covering approximately 15,000 individuals, alongside parallel investigations in animals, vectors, and environmental compartments. The study combines advanced laboratory and analytical approaches,

including multiplex serology, environmental sampling, metagenomics, and mathematical modelling, to characterize exposure patterns and transmission dynamics. The project focuses on a range of priority endemic and emerging pathogens of public health relevance, including dengue, chikungunya, Zika, Japanese encephalitis, avian influenza, Nipah virus, hantaviruses, leptospirosis, *Burkholderia pseudomallei*, arenaviruses, tick-borne encephalitis virus (TBEV), and severe fever with thrombocytopenia syndrome virus (SFTSV), among others.

Collaborations	Team leaders: Epidemiology and Public Health Unit (S. Ly, T. Sieng, C. Flamand, M. Chan, S. Sorn, A. Antoniolli, S. Sovann), IP Paris (S. Cauchmez, J. Paireau, M. White); CIRAD (H. Guis), Virology Unit (Erik Karlsson), LBM (S. Cheng), Medical and Veterinary Entomology Unit (S. Boyer), Malaria Consortium, MoH (K. Sidonn), MaFF (T. Sothyra), MoE (C. Monidarin)
Funding	Wellcome Trust Discovery Award

ECOMORE 3 – Regional Arbovirus Surveillance and Transmission Risk Assessment

ECOMORE 3 is a regional project aiming to study the circulation of priority arboviruses in Cambodia, Laos, Vietnam, and the Philippines, including dengue, chikungunya, Zika, Japanese encephalitis virus, and West Nile virus. The project seeks to better characterize the determinants of arbovirus transmission by integrating epidemiological, serological, environmental, entomological, and socio-demographic data across contrasted ecological and population settings. In Cambodia, ECOMORE 3 will build on the RACSMEI platform, leveraging its nationwide One Health population-based survey to generate robust evidence on arbovirus exposure patterns and infection risks.

The Epidemiology and Public Health Unit will play a central scientific coordination role in the implementation of population-based serological surveys, ensuring harmonized study design, field procedures, data collection, and analytical approaches across participating countries.

These activities will contribute to strengthening regional capacities for arbovirus risk assessment, surveillance, and evidence-based prevention strategies in Southeast Asia.

Collaborations	Team leaders: Epidemiology and Public Health Unit (C. Flamand, S. Ly, T. Sieng, M. Chan, S. Sorn, A. Antoniolli, S. Sovann), IP Paris (S. Cauchemez, J. Paireau, M. White); CIRAD (H. Guis), Virology Unit (Erik Karlsson), LBM (S. Cheng), Medical and Veterinary Entomology Unit (S. Boyer), Malaria Consortium, MoH (K. Sidonn), MaFF (T. Sothyra), MoE (C. Monidarin)
Funding	AFD-Ecomore 3 : (2025-2028)

AFRICAM-PREACTS- PREZODE

AFRICAM is a One Health research study developed under the framework of the Preventing Zoonotic Disease Emergence (PREZODE) initiative, coordinated by CIRAD and IRD and implemented across four African countries and Cambodia. The project seeks to improve understanding of zoonotic disease risks by examining interactions at the human–animal–environment interface across diverse ecological and socio-economic settings. In Cambodia, the epidemiological component of AFRICAM consists of a two-year longitudinal serological follow-up conducted in three villages in Battambang Province. The study includes 390 households, representing 1,263 individuals tested every 6 months on average.

The study integrates human serology with parallel investigations in domestic animals, wildlife reservoirs, and environmental compartments, alongside detailed data on socio-economic conditions, behaviors, and exposure patterns.

Analyses will focus on estimating seroprevalence and seroconversion dynamics for selected zoonotic and vector-borne pathogens, and on identifying individual, household, environmental, and ecological factors associated with infection risk.

Collaborations	Epidemiological Survey - Team Leaders: S. Ly, A. Antoniolli, K. Nguon, C. Flamand; PREZODE - AFRICAM - Team leaders: Anne-Laure Banuls (IRD), V. Herbreteau (IRD), Flavie Goutard (Cirad), and H. Guis (CIRAD) . Partners in Cambodia: IRD, CIRAD, IPC, *Agronomes et Vétérinaires sans Frontières* (AVSF), International Development Enterprises (IDE), ITC, Wildlife Conservation Society (WCS), Battambang Hospital.
Funding	AFD, Foundation Simone Del Duca: 2025-2028

ZOPRAC Study: Zoonotic paramyxovirus risk along an anthropogenic gradient in Cambodia

Tropical regions with high biodiversity are recognized as hotspots for zoonotic pathogen spillover, where human-induced environmental changes further amplify the risk of paramyxovirus emergence. Understanding how biodiversity influences the risk of zoonotic paramyxovirus emergence remains challenging due to the complex and multifactorial nature of these relationships. This underscores the importance of integrated health approaches that encompass human, animal, and environmental health.This study aims to understand and prevent the risk of emergence of paramyxoviruses in Cambodia, to Improve our knowledge of the influence of biodiversity and other factors on microbiomes structures and zoonotic risks, and to improve capacities to detect emergences and create new solutions for early rapid pathogen detection and characterization. Quantitative, qualitative, and participatory methodologies were used. The Epidemiology and Public Health Unit conducted cross-sectional surveys in Battambang and Steung Treng provinces during June-July 2025 and in Phnom Penh capital city in February 2026 covering a round 700 individuals aged ≥12 years old.

Collaborations	Epidemiology and Public Health Unit: K. Nguon, M. Chan, S. Ly, C. Flamand. Virology Unit: T. Hem, V. Hul, J. Guillebeau, E. Karlsson CIRAD: Julien Cappelle
Funding	European Union, grant No. 101059483: 2024-2025

3.2.3 Research Programs - Outlook for 2026

IDTB4Child (Innovative Diagnosis of TB for Children) 2026 - 2028: Evaluation near-point-of-care tongue-swab molecular test for TB diagnosis and treatment monitoring in children under 10 years in Burkina Faso and Cambodia.

Tuberculosis (TB) remains one of the leading infectious causes of disease and death in children worldwide (~11% of the global TB burden), yet diagnosing TB in young children is notoriously difficult. Many cannot produce sputum (the standard sample for most TB tests) while current clinical decision-making tools often miss true cases or lead to overtreatment. As a result, an estimated half of pediatric TB cases go undetected globally. United Nations High-Level Meeting on TB (UNHLM), countries committed that by 2027 every person with presumptive pulmonary TB should be tested using a rapid molecular diagnostic. Near point-of-care (nPOC) tests (MiniDock MTB, pluselife) based on non-invasive samples such as tongue swabs can help achieve this goal. These tests are portable, rapid (~30 min), low-cost (~USD 4 per test, ~USD 400 per device), and can operate without electricity, enabling same-day treatment initiation and reducing loss to follow-up. Institut Pasteur du Cambodge is coordinating the study implementation in Cambodia and will work in collaboration with the TB national program (CENAT). The project plan to recruit 1300 children in four pediatric hospitals (2 in Cambodia and 2 in Burkina Faso). In Cambodia 800 children plan to recruit within 24 months from

National Pediatric Hospital in Phnom Penh and Angkor Hospital for Children in Siem Reap. Study duration 36 months.

Collaborations	Coordinating investigator: Jonathan Hoffmann, Fondation Mérieux and Bunnet DIM, Epidemiology and Public Health Unit, IPC. Scientific Advisor: Prof. Blandine RAMMAAERT, Epidemiology and Public Health Unit, IPC. Project coordinator: SOV Linda, Epidemiology and Public Health Unit, IPC. Burkina Faso Principal investigator: Abdoul-salam OUEDRAOGO (Centre Muraz, Bobo-diolasso, Burkina Faso) Cambodia Principal investigator: Huot Chan Yuda: National Center for Tuberculosis and Leprosy control (CENAT)
Funding	ANRS 00901-R-PR
Sponsor	Fondation Mérieux (FM)

VIRAGE - Strengthening One Health Capacities for Rabies Surveillance and Control

In 2026, activities conducted under the VIRAGE project will continue with the implementation of a quantitative survey among animal health professionals, carried out in collaboration with the GDAHP of the MAFF. This survey will aim to better document their knowledge, attitudes, and perceptions regarding health issues addressed through a One Health approach, as well as their professional practices, operational needs, and the main challenges they face in carrying out their duties. It will help identify the factors that facilitate or limit their involvement in surveillance, prevention, and response systems for zoonotic risks. This quantitative component will be complemented by focus group discussions conducted in collaboration with the Royal University of Agriculture, involving professionals from different sectors, including human health, animal health, and, where relevant, the environment. These qualitative discussions, conducted across Cambodia's 25 provinces, will provide a deeper understanding of perceptions, institutional and operational constraints, and intersectoral coordination needs. In addition, workshops will be organized in 2026 with the CDC-MOH, the MAFF, and other partners involved in rabies surveillance and management, in order to discuss findings, identify operational priorities, and strengthen intersectoral coordination. Together, these activities will contribute to a better characterization of existing capacities, gaps, and priority actions to strengthen integrated approaches to disease surveillance and control at the human-animal-environment interface.

Collaborations	Team Leaders: C. Flamand, S. Ly, T.Sieng, H. Guis (CIRAD). In coll. with Yiksing Peng (IPC Vaccination Center), Yi Sengdoeurn (CDC MoH) and Mam Somoni (GDAHP MAFF)
Funding	French Ministry of Europe and Foreign Affairs through the Solidarity Funds for Innovative Projects (FEF) :2025-2027

RACSMEI - Advancing Integrated One Health Surveillance and Precision Public Health in Cambodia

In 2026, RACSMEI will move forward with the completion of nationwide field data collection and the consolidation of the different human, animal, vector, and environmental components of the survey. Key activities will include data validation, sample processing, and the development and optimization of diagnostic tools and laboratory workflows required for the detection and characterization of priority pathogens. The project will also initiate the first stages of integrated data analysis, linking epidemiological, serological, environmental, entomological, and socio-behavioral information.

In addition, focus group discussions will be conducted with community health workers and other community representatives to discuss preliminary findings, explore local perceptions of infection risks and climate-sensitive diseases, and identify practical barriers and opportunities for prevention,

surveillance, and community engagement. These activities will support the transition from field implementation to analysis, interpretation, and stakeholder feedback, while strengthening the project's contribution to evidence -based One Health surveillance and Precision Public Health in Cambodia.

Collaborations	Team leaders: Epidemiology and Public Health Unit (C. Flamand, S. Ly, T. Sieng, M. Chan, S. Sorn, A. Antoniolli, S. Sovann), IP Paris (S. Cauchemez, J. Paireau, M. White); CIRAD (H. Guis), Virology Unit (Erik Karlsson), LBM (S. Cheng), Medical and Veterinary Entomology Unit (S. Boyer), Malaria Consortium, MoH (K. Sidonn), MaFF (T. Sothyra), MoE (C. Monidarin)
Funding	Wellcome Trust Discovery Award (2025-2030)

CHIK-IMM study, 2025-2028: Characterization of the immunological mechanisms that drive chronic chikungunya disease pathogenesis

Chikungunya Infection results in acute arthritis, which can develop in a chronic form. The chronic joint pain is caused by sustained inflammation and bears hallmarks of auto-immune rheumatoid arthritis. However, the relative contribution of T cells, antibodies and B cells in the disease pathogenesis is unknown. To investigate the association between the acute immune response to CHIKV and the development of chronic arthritic disease to identify biomarkers to predict the development of chronic disease. The Institut Pasteur du Cambodge (IPC) will collaborate with the National Center for Malariology, Parasitology and Entomology (CNM) and 13 referral and national hospitals across Cambodia to identify around 800 clinical cases for laboratory confirmation of chikungunya infection. Confirmed cases will be followed up at 7 days, 3 weeks, 6 months, and at 1 year among along with clinical examinations and blood samplings. This study will be conducted by the Immunology Unit and Epidemiology & Public Health Unit, IPC.

Collaborations	Team Leaders :-Dr. Tineke Cantaert, Immunology Unit, IPC Co-investigators: Dr. Sowath Ly and Dr. Claude Flamand, Epidemiology and Public Health Unit, IPC ; Dr. LEANG Rithea, National Dengue Control Program, CNM
Funding	Wellcome Trust: NOV 2025 – OCT 2028

3.2.4 Support to National Authorities

The following summarizes key support to Cambodian national authorities over the year 2025.

- N. de Rekeneire and Dim B. participate in the writing of the hepatitis elimination guidelines, coordinated by the national viral hepatitis program, CDC MoH. This National Guideline was published by the MoH in 2025.
- Ly S. worked with the Emergency Operations Center (EOC) coordinated by the Cambodian CDC-MoH.
- C. Flamand participated in Dengue and Influenza surveillance workshops organized by CDC-MoH and WHO and the consultative committee on One Health Strategy for Cambodia organized by MoH.
- T. Sieng participated in the AMR Technical Working Group (TWG-AMR) coordinated by MoH.

3.2.5 Teaching and Training

Teaching and Training

- Dim Bunnet, Teaching Clinical Research at the Master of Infectiology, University of Health Science & Paris-Saclay University

- Sovann Nheuong, Teaching Data management in clinical research at the Master of Infectiology, University of Health Science & Paris-Saclay University
- Socheat Ly, Teaching Data management in clinical research at the Master of Infectiology, University of Health Science & Paris-Saclay University
- Claude Flamand, Teaching in Biostatistics & Epidemiology at the Master I & II of Infectiology, University of Health Science & Paris-Saclay University
- Nathalie de Rekeneire, Teaching in Clinical Trials Methodology at the Master of Infectiology, University of Health Science & Paris-Saclay University
- Nathalie de Rekeneire, Teaching at the Master 2 Santé Globale dans les Suds- Santé mondiale of ISPED
- Cecile Sommen, Andrea Antoniolli, Training in Biostatistics with R, Institut Pasteur in Cambodia, November 2025
- Tephanie Sieng. "Equity, Diversity & Inclusion in Science and Immunology." IUIS Training Course, organized by the International Union of Immunological Societies (IUIS), Siem Reap, Cambodia, 24–29 November 2025.
- Tephanie Sieng. "Humanities French and Methodology." Manusastra Program, Royal University of Fine Arts (RUFA) & Institut National des Langues et Civilisations Orientales (INALCO), Phnom Penh, 2025. Undergraduate level.
- Tephanie Sieng. Qualitative Research Methodology. Manusastra Program, Royal University of Fine Arts (RUFA) & Institut National des Langues et Civilisations Orientales (INALCO), Phnom Penh, 2025.

PhD students

- Ms Andréa Antoniolli; Paris Cité University, ED 393, 2022 – 2026; Thesis title: Transmission of leptospirosis in Cambodia. (Director: C. Flamand)
- Mr Herman Banza Kongolo, Paris Cité University, ED 393, 2022 – 2026; Thesis title: Estimation of the rabies load burden in Cambodia (Director: C. Flamand, Co-supervisor: H. Guis)
- Mr Sopheak SORN, Paris Cité University, ED 393, 2023 – 2027; Thesis title: Transmission dynamics and determinants of arboviruses in Cambodia (Director: C. Flamand, Co-supervisor: Sowath Ly)
- Ms Malen CHAN, Paris Cité University, ED 393, 2024 -2027; Thesis title: Transmission dynamics and determinants of arboviruses in Cambodia (Director: C. Flamand, Co-supervisor: Sowath Ly)

Master's students

- Mr. Nheuong Sovann (UHS-Epidemiology, 2020–2025). Master thesis defended in 2025.
- Ms. In Sopheavet (Master in Epidemiology, National Institute of Public Health, 2022-2025). Master thesis will be defended in February 2026.
- Ms. Sun Sineath (Master of Health and Community Development, National Institute of Public Health, 2022–2026).
- Mr. Pring Long (Master in Epidemiology, National Institute of Public Health, 2022–2026).
- Mrs. Sreng Vouchleang (Master in Epidemiology, NIPH, 2023–2026).
- Ms. Elise Cendres (Mastère in Public Health, Pasteur CNAM, 2024-2025).
- Dr. Dim Bunnet (master's in clinical research, Jame Lind Institute, Switzerland 2025 – 2027).

Internship

- Ms. Guillemette de TREMIOLLES, Internship in Infectiology, University of Paris-Cité (2024_2025).

3.2.6 Outlook for upcoming 3 – 5 years

The research strategy of the EPHU for the upcoming years will focus, in the short term, on implementing integrated, multidisciplinary research programs aligned with national and regional identified public health priorities. The launch of key multidisciplinary and intersectoral projects represents both a major challenge and a strategic opportunity for the development of the unit's research agenda and the growth of the team's capabilities. These programs aim to deepen our understanding of priority infectious diseases and inform targeted strategies for disease surveillance, prevention, and management. Addressing the significant challenges of upcoming projects will require strengthening the team's capacity, particularly in statistical data analysis, data science, and environmental sciences, while continuing to foster the training of young talents within the methodology and data analysis group. Recruiting additional resources in Data Science will be crucial to this strategy, particularly to address future challenges related to the interactions between health, the environment, and climate. Hosting international post-doctoral researchers will also be essential for further strengthening the unit's capacity-building strategy.In the medium term, the promotion of collaborative, multi-scale One Health projects will position the unit at the forefront of field-based One Health approaches, an area that remains underdeveloped. These projects will strengthen the unit's research strategy and enhance its regional positioning, reputation, and impact. Integrating social sciences and community engagement will also be a key priority. A dedicated social sciences group will be created within the unit, specializing in the integration of qualitative and quantitative approaches.In clinical research, a key priority will be to revitalize the development of investigator-led projects within the clinical research group, particularly on diseases and health conditions affecting vulnerable populations. While the group is already recognized by ANRS-MIE as a leading study site for multicentric studies, the next step will be to strengthen its scientific leadership, increase its contribution to in-house research, and expand its capacity to design, coordinate, and implement clinically relevant studies aligned with national public health needs. The arrival of a new clinical research group leader represents an important opportunity to redefine priorities, stimulate new project development, reinforce capacity-building, and enhance the scientific output of the group in 2026 and beyond. This will be particularly important following Dr. Nathalie de Rekeneire's planned departure and will help ensure both continuity and renewed momentum for clinical research activities within the unit.

Beyond a three-year horizon, the results generated through these approaches should allow the evaluation of future intervention strategies and strengthen collaborations with health authorities to identify precision-based and culturally appropriate public health strategies aimed at reducing transmission risks in the most exposed populations. Finally, in the longer term, given Cambodia's evolving public health priorities, it will be important to explore opportunities to broaden the unit's research themes to include non-communicable diseases, such as respiratory diseases, cardiovascular diseases, and cancers.

3.2.7 Scientific Publications 2025

Note: *The name of authors from the Institut Pasteur du Cambodge are underlined*

1. **Anopheles mosquitoes in Mondulkiri forest, Cambodia: abundance, distribution, seasonal patterns and Plasmodium prevalence.** S. Boyer, B. Doeurk, A.Rakotonirina, S. Chy, C. Vong, E. Piv, B.Tat, M. Ea, C. Chhin, S.Phen, N. Kloeung, S. Ke, J. Popovici, P. Piola, B. Witkowski, P.O Maquart, A.Vantaux. Malar J. 2025 Jan 10 doi:10.1186/s12936-024-05166-9. IF: 2.4

2. **Accuracy of alternative PHQ-9 scoring algorithms to screen for depression in people living with HIV in Sub-Saharan Africa.** Bernard C, Font H, Zotova N, Wools-Kaloustian K, Goodrich S, Kwobah EK, Awoh AR, Nko'o Mbongo'o GC, Nsonde DM, Gandou P, Minga A, Tine JM, Ndiaye I, Dabis F, Seydi M, de Rekeneire N, Yotebieng M, Jaquet A; Ie DEA Cohort Collaboration. J Acquir Immune Defic Syndr. 2025 Feb 1. doi: 10.1097/QAI.0000000000003551. IF: 2.8

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Oral Communications and Posters

1. **AMR in One Health context — RAMSES study: Antimicrobial resistance and healthcare practices in Takeo communities: a study on usage and socio-cultural implications. Raising Awareness.** Sieng T. — AMR Workshop, organized by CDC, Ministry of Health of Cambodia, Kampong Chhnang, Cambodia, 23–25 July 2025. Oral presentation.

2. **Community practices, perceptions, and antibiotic use in three villages of Takeo Province, Cambodia: social insights into AMR from the RAMSES study."** Sieng T. National AMR Technical Working Group Meeting, organized by Ministry of Health of Cambodia, Phnom Penh, 25 July 2025. Oral presentation.

3. **RAMSES research study." Raising Awareness**. Sieng T. AMR Workshop, organized by CDC, Ministry of Health of Cambodia, Kampong Cham, Cambodia, 6–8 August 2025. Oral presentation.

4. **Postdoctoral research presentation.** Sieng T. LIMEEP-PS Annual Laboratory Meeting, Observatoire de Versailles Saint-Quentin-en-Yvelines (OVSQ), Université Paris-Saclay, Guyancourt, France, 10 July 2025. Oral presentation.

5. **Enhancing knowledge and skills to improve care.** Sieng T. Antibiotic Resistance Scientific Conference. University of Health Sciences, Cambodia & Académie Nationale de Médecine, France, Phnom Penh, 2–4 July 2025.

6. **Healthcare-seeking practices and antibiotic use in Cambodia: social science perspectives.** Sieng T. Center for Khmer Studies (CKS), Phnom Penh, 25 July 2025.

7. **Climate-Driven Models for Predicting Dengue Outbreaks and Aedes aegypti Risk: Insights from French Guiana.** C.Flamand. Symposium "The impact of climate change on emerging infectious diseases". INRS - Centre Armand-Frappier Santé Biotechnologie Laval, Quebec, Canada October 8-10, 2025

8. **Antimicrobial resistance and healthcare practices in Takeo communities**. Sieng T. Pasteur Network Annual Meeting, organized by the Pasteur Network, Ho Chi Minh City, Vietnam, 21–24 October 2025. Poster.

3.3 Immunology Unit

The Immunology Unit at IPC was founded in 2018 with a major emphasis to investigate host immune responses to pathogens of major public health importance in Cambodia. Our laboratory is focused on three major research axes:

- Investigation of immunopathological mechanisms of vector-borne infections,
- Identification of new immune-related biomarkers for infectious diseases, and
- Development of new vaccination strategies for neglected tropical diseases. Moreover, we are hosting a transversal single cell analysis platform.

3.3.1 Functional Structure

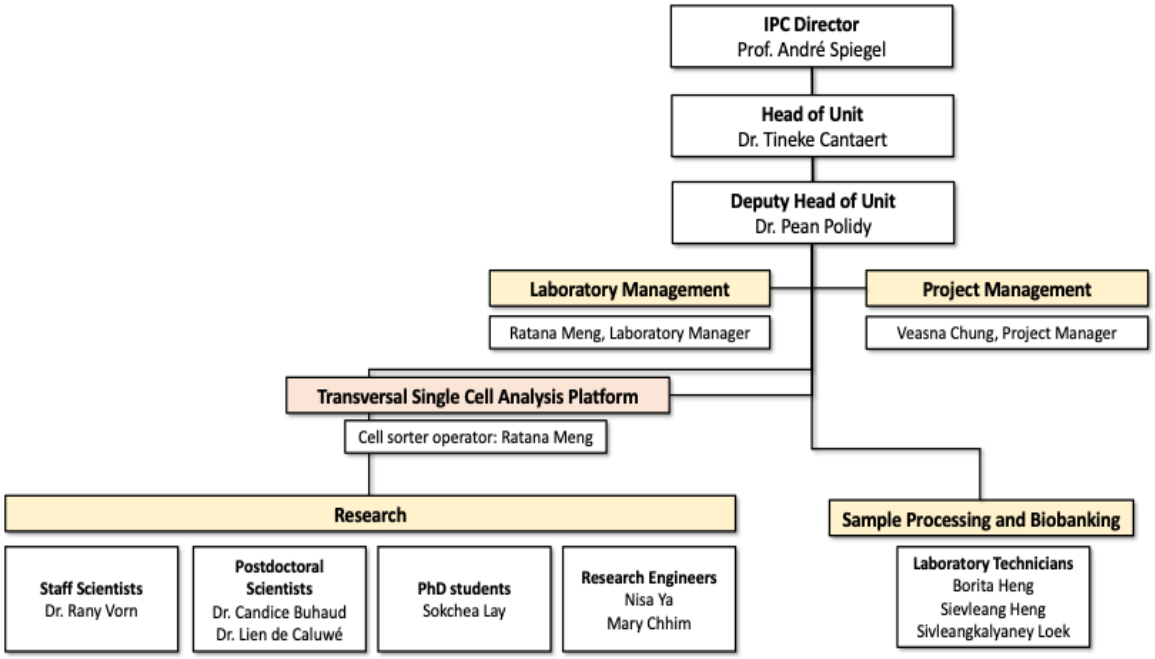

Figure 6: *Immunology Unit Organizational Chart*

3.3.2 Research Programs – Major Achievements in 2025

Axis 1: Investigation of immunopathological mechanisms of vector-borne infections.

1.1. Determining of disease mechanisms leading to severe dengue in secondary dengue-infected cases

Dengue viruses infect up to 390 million individuals each year, of which 500,000 cases require hospitalization. Since 2012, dengue has been the most important vector-borne viral disease of humans and likely more important than malaria globally in terms of morbidity and economic impact. The mosquito vectors, *Aedes aegypti* and *Aedes albopictus* both thrive well in populated urbanized areas, contributing to the spread of dengue. Disease outcome after infection varies greatly between individuals.

Centers for Research in Infectious Diseases (CREID) network of the Pasteur Institute (PICREID)

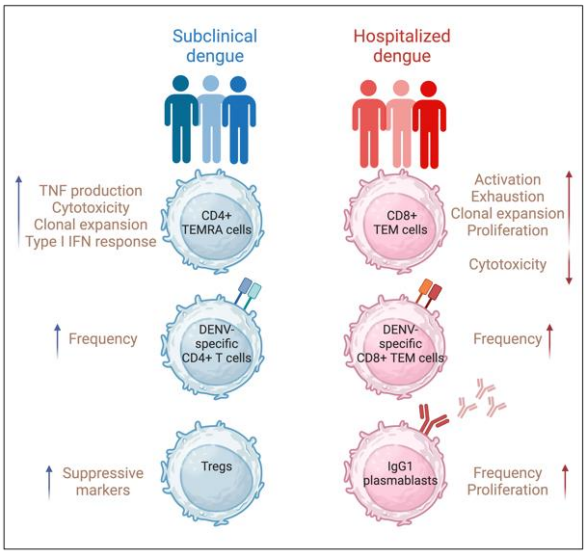

***Figure 7**: Single cell analysis of subclinical and hospitalized dengue cases reveals altered frequencies and functions of T and B cell subsets in severe dengue (Gonnella et al, Cell Host Microbe, 2025).*

IP Cambodia is part of the NIH funded consortium PI-CREID. Here, the Immunology Unit is involved in the study of host adaptive immune responses to emerging infectious diseases in South-East Asia. In this framework, we have established a single cell analysis and monoclonal antibody discovery platform at IP Cambodia to increase our insight into the adaptive immune response (both B and CD4 T cell responses) at a single cell level. This platform also allows the study of the sequence-function relationship of human antibodies generated during arbovirus infections by combining sequencing at a single cell level with antibody repertoire analysis.

Investigation of adaptive immune signatures associated to protection after DENV infection

To define adaptive immune signatures associated to protection from hospitalized dengue, we performed in depth immunoprofiling, single cell T cell receptor (TCR) and B cell receptor (BCR) analysis and quantified DENV-specific T cells in Cambodian children with subclinical infection or hospitalized dengue. We uncover that individuals with subclinical infection exhibit increased frequency and clonal expansions of CD4+ TEMRA cells and DENV-specific CD4+ T cells and demonstrate a gene expression signature showing increased Treg functionality. Across all T cell subsets, subclinical cases upregulated a type I IFN response gene signature. In contrast, expanding CD8+ EM cells from hospitalized patients show signs of exhaustion and are functionally impaired. In addition, hospitalized dengue is characterized by high frequencies and clonally expanded IgG1-expressing plasmablasts. These findings identify novel candidate correlates of protection and support a rationale for T cell directed interventions for dengue disease (Gonnella et al, Cell Host Microbe, 2025).

Start/End Year	2020-2025
Collaborations	Virology Unit, IP Cambodia (DUONG V), Epidemiology and Public Health Unit, IP Cambodia (LY S), Entomology Unit, IP Cambodia (BOYER S), Institut Pasteur Paris (SAKUNTABHAI A, SIMON-LORIERE E, HASAN M)
Funding	NIH PICREID (1U01AI151758 – 01): 2020-2025

Assessment of dengue E-protein epitope-specific antibodies and correlation with disease severity.

Our understanding of a protective humoral immune response to dengue virus (DENV) remains limited. The envelope (E) protein of the virus is the main target of the antibody (Ab) response, including neutralizing antibodies. While anti-fusion loop (FL) monoclonal Abs (mAbs) can induce antibody dependent enhancement (ADE) in vitro, some mAbs targeting quaternary epitopes can cross-neutralize different DENV serotypes. However, the specific contribution of each Ab subset to disease outcome remains poorly characterized. We aim to define the dynamics of the DENV E epitope-specific Abs and assess their association with disease outcome in a Cambodian cohort of hospitalized and subclinical dengue patients. We quantified and isolated anti-E epitope-specific Abs and tested the Ab subsets for their enhancing and neutralizing capacity. During the critical phase of disease, the

proportion of FL-targeting antibodies is increased in plasma from hospitalized patients compared to subclinical cases. Antibodies targeting quaternary epitopes on the E-dimer interface are reduced in severe dengue patients compared to patients with classical dengue fever, a finding that was replicated in an independent Columbian cohort of adult dengue patients. Functionally, isolated antibodies from plasma targeting quaternary epitopes showed stronger neutralization, while antibodies binding to the FL displayed a stronger enhancing potential in *in vitro* studies. Taken together, we show that the proportion of different anti-DENV E epitope-specific Abs in the critical phase of disease are correlated with protection from disease susceptibility and disease severity. These insights have important implications for the design of novel vaccine strategies.

Start/End Year	2020-2025
Collaborations	Virology Unit, IP Cambodia (DUONG V), Epidemiology and Public Health Unit, IP Cambodia (LY S), Entomology Unit, IP Cambodia (BOYER S), Institut Pasteur Paris (SAKUNTABHAI A, SIMON-LORIERE E, REY F), Institute of Tropical Medicine (ARIEN K)
Funding	NIH PICREID (1U01AI151758 – 01): 2020-2025

Characterization of E-dimer-Binding Memory B cells Response and Antibodies

Despite their central role in long-term immunity to dengue infection, the persistence, functional properties and maturation of dengue-binding memory B cells (MBCs) remain poorly defined. The envelope (E) protein of the virus is the major target of the humoral immune response. Here, we have characterized soluble E-dimer (sE-dimer)-binding MBCs in a well-defined cohort of patients with hospitalized dengue and their subclinical household contacts, up to one-year post-infection. Flow cytometry and single-cell transcriptomics revealed that hospitalized patients exhibited an enrichment of activated and proliferating sE-dimer-binding B cells at two months post infection compared to subclinical infected cases. By one-year post-infection, sE-dimer-binding MBCs had increased in frequency in both groups. Ex-vivo single-B cell cultures generated 102 monoclonal antibodies (mAbs), one-third of which bound preferentially to the sE-dimer rather than the sE-monomer, indicating selective targeting of conformational epitopes. The most potent DENV2-neutralizing antibodies were sE-dimer specific, DENV2 restricted and primarily derived from subclinical donors, while hospitalized donors showed a higher frequency of serotype cross-neutralizing mAbs, cross-binding sE-monomer/sE-dimer antigens. Secondary infection was associated with increased cross-reactivity and elevated somatic hypermutation rates, suggested germinal center re-entry and further affinity maturation. Together, these findings demonstrate that sE-dimer-binding MBCs are durable, occupy distinct B cell subsets, and give rise to antibodies whose breadth and

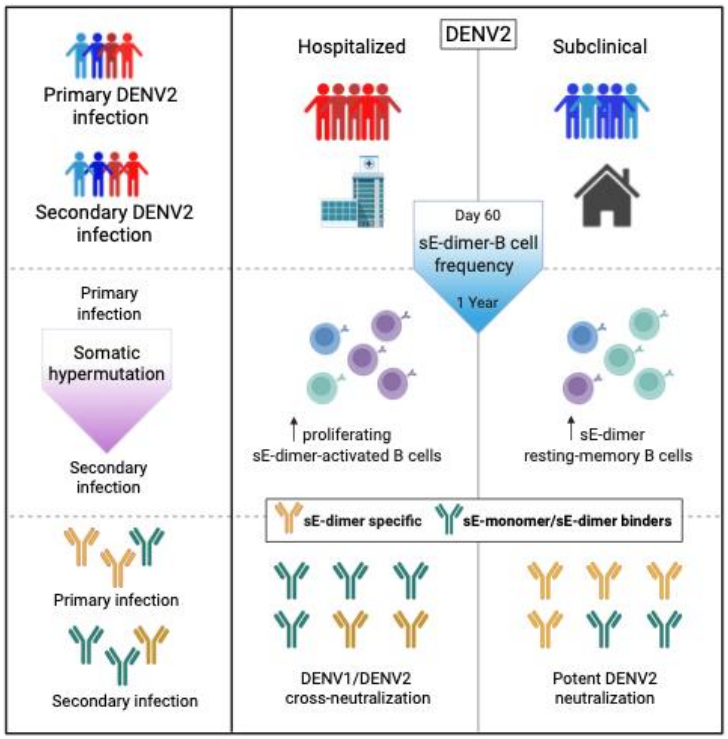

Figure 8: *Graphical abstract, Bohaud et al, submitted.*

potency are shaped by previous infection history and disease severity. This work provides insight into the dynamics of dengue-binding B cell immunity and informs rational design of E-dimer-based vaccines.

Start/End Year	2020-2025
Collaborations	Virology Unit, IP Cambodia (DUONG V), Epidemiology and Public Health Unit, IP Cambodia (LY S), Entomology Unit, IP Cambodia (BOYER S), Institut Pasteur Paris (SAKUNTABHAI A, SIMON-LORIERE E, REY F)
Funding	NIH PICREID (1U01AI151758 – 01): 2020-2025

1.2 Understanding of immune correlates of protection to *Plasmodium vivax* malaria

Plasmodium vivax (Pv) is the most widespread human malaria parasite and is particularly resilient to current elimination efforts. Naturally acquired immunity to Pv has been observed, where exposed subjects can develop partial immunity after multiple exposures to Pv enabling the control of parasite densities. However, life-long exposure rarely seems to confer sterile immunity and individuals can carry low-level parasitemia. Increased understanding of the immunological mechanisms, potential antigenic targets and parasite factors that confer protection to clinical Pv malaria is urgently needed for future vaccine development. Leveraging a longitudinal cohort we have constituted in endemic area of Cambodia in collaboration with the Malaria Molecular Epidemiology Unit, we have identified individuals displaying remarkable clinical protection against Pv.

The project encompasses 2 aims: The first specific aim (SA1) will be to understand the factors that drive the production of anti-PvDBP BIabs and therefore further clinical protection against Pv. By phenotyping and functionally characterizing DBP-specific CD4+ T cells and B cells in naturally infected participants with characterized amounts of BIabs, we will have a better understanding of the adaptive immune response of individuals leading to the production of naturally-acquired anti-PvDBP BIabs. The second aim is to decipher the immune factors leading to protection against Pv malaria for individuals not producing anti-PvDBP BIabs. We will identify host immune factors associated to protection from clinical Pv malaria. We will study ex vivo and in vitro the immune responses in Pv-infected patients. Using single cell cultures of antigen-specific B cells, we aim to identify novel humoral targets on the Pv merozoite or iRBC that could be involved in conferring protection from clinical Pv malaria trough blockade of invasion or alternative antibody effector functions.

Start/End Year	2023-2028
Collaborations	Malaria Molecular Epidemiology Unit, IP Cambodia (POPOVICI J) University of Maryland (SERRE G)
Funding	NIH – R01

1.3 Development of monoclonal antibodies to Crimean-Congo hemorrhagic fever virus (CCHFV)

The CCHFVACIM project is an ambitious collaborative effort aimed at developing both prophylactic and therapeutic effective countermeasures against Crimean Congo Haemorrhagic Fever Virus (CCHFV), one of the most threatening vector-borne pathogens, widely distributed. The project combines deep structural biology studies on viral glycoproteins and investigations of the immunogenicity of the viral antigens, alongside optimisation of an mRNA vaccine candidate and the characterisation of the resulting protective immunity, as well as with the development of immunotherapeutic monoclonal antibodies (mAbs) based on CCHFV's antigenic targets.

In using different Gn_Gc_GP38 viral antigens, we characterized the CCHFV-specific B cells responses longitudinally in patients with low versus intermediate disease severity. mAbs were generated from single-B cell cultures and evaluated for their cross-reactivity against diverse CCHFV strains, as well as

related viruses within the same family, and for their specificity toward conformational and quaternary epitopes. At the same time, the B cell receptor (BCR) repertoire of these antigen-specific B cells was analyzed to guide the recombinant production of selected monoclonal antibodies.

Start/End Year	2024-2028
Collaborations	Institut Pasteur (REY F) Karolinska Institute (MIRAZIMI A)
Funding	EU HORIZON-HLTH-2023-DISEASE-03 -CCHFVACIM

1.4 Pasteur International Unit

Understanding the detailed interactions between pathogens and the immune system and determining the correlates of protection versus pathology are critical for understanding and controlling infectious diseases and pave the way for the development of new diagnostics, vaccines, therapeutics, or innovative infection-reduction strategies. To address current public health challenges and anticipate those that may arise in the future (Disease X), the global objective of this proposal is to build a sustainable immunology research ecosystem in the African (Senegal and Madagascar) and South-East Asian (Cambodia) Pasteur Institutes around COVID-19 and dengue research projects. The creation of the PIU was approved in 2023 and the PIU agreement was signed in 2024.

In June 2025, the Immunology Unit of Institut Pasteur Madagascar organized an immunology training workshop. On this occasion, scientists from the Immunology Units of Pasteur Cambodia and Pasteur Senegal participated as instructors, reinforcing cross-site collaboration and promoting sustainable capacity building and knowledge transfer within the PIU network.

Start/End Year	2023-2029
Collaborations	Immunopathophysiology and infectious diseases dpt, Institut Pasteur de Dakar (VIGAN-WOMAS I) Immunology and Infectious Disease Unit, Institut Pasteur de Madagascar (SCHOENHALS M)
Funding	Institut Pasteur du Cambodge/Pasteur Network

Axis 2: Biomarkers of Infectious Diseases

2.1. Circulating miRNA as Predictive Tools for Immune Reconstitution Inflammatory Syndrome in HIV/TB Co-infected Individuals: A Proof-of-Concept Study

MicroRNAs (miRNAs) regulate post-translational gene expression and are potential biomarkers for infectious diseases. Immune reconstitution inflammatory syndrome (IRIS), a severe inflammatory response after antiretroviral therapy (ART) initiation, occurs as paradoxical IRIS (worsening of treated infections) or unmasking IRIS (response to undiagnosed infections). In the ANRS 12358 study (Pean et al. 2025; 10.3389/fimmu.2025.1603338), we identified hsa-miR-146a-5p, hsa-miR-29c-3p, and hsa-miR-29a-3p as predictive IRIS biomarkers using a flow cytometry-based approach (Patent No: NT/NG/IDM-22-0055). This study further validates circulating miRNAs (n=27 miRs) as IRIS biomarkers in HIV/TB co-infected individuals. Plasma samples (n=660) from the CAMELIA trial and CAPRI-NK study in Cambodia were analyzed using the FirePlex™ miRSelect assay. Statistical analyses identified four significantly differentially expressed miRNAs linked to inflammation, cytokine regulation, and NK cell activation, enhancing IRIS prediction. Combinatorial analysis improved accuracy, reducing false positives and negatives. However, technical challenges with a new version of FirePlex kit (e.g., buffer composition, probe concentration) led to over-saturation in miRNAs detection, preventing replication. Discontinuation of the original kit (e.g. the version of kit that we used in ANRS12358 study) further hindered validation. Despite these limitations, circulating miRNAs remain promising IRIS biomarkers,

emphasizing the need for standardized detection methods. Further research is essential for clinical translation. The study was published in Journal of Frontiers in Immunology (Pean et al. 2025; 10.3389/fimmu.2025.1603338

Start/End Year	2022-2023
Collaborations	IP Paris (SCOTT D), IP Cambodia (PEAN P), IP Cambodia (BORAND L)
Funding	DARRI, IP Paris, France: 2022-2023

Course "Immune responses to arbovirus infections from a One Health perspective"

Most arboviral diseases cause a disturbance in the host immune response which leads to immunopathology. Therefore, knowledge on immune mechanisms induced by arboviruses and how these mechanisms are disturbed is very important to advance vaccine development. Hence, a course that expands and re-enforces knowledge in aspiring scientists in Asia on the immune responses to arboviruses, host-pathogen interactions, the animal models and human challenge models available is of crucial importance. In addition, recent advances in our understanding of the vector susceptibility to arbovirus infection, vector competence and vector-virus interactions will provide additional insight into this complex topic from a One health Perspective. This 6-day course has provided an in-depth exploration of the interactions between arboviruses, their vectors (mosquitoes, ticks), and vertebrate hosts. We have delved into host-pathogen interactions and the innate and adaptive immune responses to arboviruses. Understanding the immune responses to arbovirus infections is crucial for developing effective preventive and therapeutic strategies. 35 students attended the course, from 19 different countries, including 12 students from the Pasteur Network. 14 teachers, including 6 from the Pasteur Network have joined. An Equity, diversity and inclusion session was held, a grant writing workshop and 2 poster sessions were held.

Start/End Year	2025 (Nov 24-29)
Collaborations	None
Funding	International Union of Immunological Societies – Pasteur Network

3.3.3 Research Programs – Outlook for 2026

Axis 1: Investigation of immunopathological mechanisms of vector-borne infections.

1.1. Determining of disease mechanisms leading to severe dengue in secondary dengue-infected cases

Assessment of the interaction between IgG Fc and FcgR during dengue infection.

Other than virus neutralization, many other functions are attributed to antigen-specific antibodies in protection against viral infections, which are critically dependent on the formation of immune complexes, the Fc portion of IgG and interaction with Fcγ receptors and downstream effector functions. We have recently shown that DENV infection causes a specific increase in afucosylated IgG

glycoforms, which correlates with disease severity and has prognostic potential (Bournazos et al, Science 2021). Hence, we identified a key role for the Fc glycan structure in dengue pathogenesis, but the mechanism underlying this observation remains to be determined. Different IgG Fc glycoforms have different affinities for Fc gamma receptors, which activate and initiate downstream effector functions. One of these mechanisms crucially dependent on IgG Fc-Fc gamma receptor interactions is antibody-dependent enhancement (ADE). Therefore, we seek to investigate how DENV infection modulates the glycosylation profile of IgG Fc and how IgG Fc-Fc gamma receptor interactions contribute to disease outcome after dengue infection. DENV could modulate the IgG1 glycosylation profile either by eliciting distinctive inflammatory cues to B cells or through direct infection of B cells. Dynamic changes in glycoenzyme expression over time will be assessed and in vitro conditions and pathways that lead to changes in glycoenzyme expression will be identified.
Four *in vitro* cell-based assays have been optimized in the immunology unit to evaluate antibody-effector functions of IgG generated during dengue infection: antibody-dependent enhancement assay, antibody dependent cytotoxicity assay, antibody dependent phagocytosis assays, and complement dependent cytotoxicity. All four assay results will be correlated to clinical outcome and other parameters such as viral load, DENV IgG titers, platelet count, haematocrit and duration and severity of symptomatic infection. Protection and risk signatures will be uncovered using multivariate analysis methods.

Start/End Year	2023-2028
Collaborations	Rockefeller University (RAVETCH J, BOURNAZOS S)
Funding	NIH R01

Investigation of the impact of lipid metabolism on dengue infection and pathogenesis
The geographic expansion of Aedes mosquitoes has led to an increase in Dengue worldwide. The only licensed vaccine has poor efficacy in dengue-naïve individuals and children. Efforts to combat this disease require a better understanding of the pathophysiological mechanisms involved in the transition to severe forms of dengue. METABODEN is a multidisciplinary project that will explore the interaction between disease severity and host lipid metabolism by studying the dengue virus (DENV)-induced lipid metabolism reprogramming and consequences in pathogenesis. METABODEN aims to (i) identify changes in lipid molecular species and key lipid metabolism enzymes in longitudinal pediatric samples in order to establish a link between DENV-induced blood lipid metabolic imprinting and disease severity and (ii) to decrypt and investigate on molecular mechanisms accounting for DENV-induced lipidome remodeling.
As part of these aims, CITE-seq was performed in 2025 on innate immune cells from 16 individuals stratified into four clinical groups: subclinical infection, dengue fever, dengue hemorrhagic fever, and dengue shock syndrome. Integrated transcriptomic and surface proteomic analyses was conducted to identify immune signatures associated with disease severity and to uncover molecular pathways contributing to dengue pathogenesis In 2026, CITE-seq data will be analyzed and correlated to disease outcome. In addition, metabolomic and lipidomic profiling was conducted in 2025, of a longitudinal cohort of dengue cases with differential disease outcome. In 2026, data will be further analyzed and finalized. Besides increasing fundamental knowledge on the role of lipid metabolism in DENV pathogenesis, METABODEN will also lead to the identification of biomarkers for dengue severity and potential targets for antiviral intervention.

Start/End Year	2024-4046
Collaborations	Dorothee MISSE (IRD), Laurence BRIANT (IRIM), Fabien Blanchet (IRIM)
Funding	ANR

1.2 Understanding of immune correlates of protection to *Plasmodium vivax* malaria

To have a better understanding of the immunological factors associated to protection from Pv, we have studied the single cell landscape of the immune response in individuals displaying various levels of protection against Pv malaria. In 2025, Single-cell RNA sequencing was performed on 20 PBMC samples obtained from chronically infected asymptomatic individuals and symptomatic malaria patients seeking treatment, with the goal of identifying transcriptomic signatures associated with symptomatology and clinical protection. In 2026, the candidate markers identified through transcriptomic analyses will be validated by multiparametric flow cytometry and Luminex-based cytokine profiling. In parallel, functional *in vitro* studies using sorted primary cell populations from these individuals will be employed to assess the function of monocytes, T and B cell subsets in Pv infection.

In addition, in 2026, we will finalize the phenotypic and functional analysis of DBP-specific CD4+ T cells and the longitudinal evaluation of anti-DBP antibody titers in the cohort, and associate those data with the presence of Blabs.

Start/End Year	2023-2028
Collaborations	Malaria Molecular Epidemiology Unit, IP Cambodia (POPOVICI J) University of Maryland (SERRE G)
Funding	NIH – R01

1.3 Development of monoclonal antibodies to Crimean-Congo hemorrhagic fever virus (CCHFV)

In 2026, the most interesting mAbs (either virus-cross reactive mAbs or mAbs targeting quaternary epitopes) will be recombinantly expressed for structural characterization (IP Paris) and in vitro neutralization assay (Karolinska Institut). At IPC, we will setup a competition assay in order to map more in details the epitopes of the newly produced mAbs. At the same time, we will screen additional single B cell supernatants for either cross-binding or binding to quaternary epitopes.

In 2026, we will perform scRNAseq analysis of CCHFV-specific B cells of convalescent patients, in order to understand in depth the generation, durability and gene expression profile of CCHFV-specific memory B cells.

Start/End Year	2024-2028
Collaborations	Institut Pasteur (REY F) Karolinska Institute (MIRAZIMI A)
Funding	EU HORIZON-HLTH-2023-DISEASE-03 -CCHFVACIM

1.4 Characterization of the immunological mechanisms that drive chronic chikungunya disease pathogenesis

Chikungunya virus (CHIKV) represents a widespread mosquito-transmitted, arthritogenic virus that causes chronic debilitating joint pain and arthritis in almost half of infected patients. Currently, no effective therapies or biomarkers predicting chronic disease exist, as the mechanisms driving chronic CHIKV symptoms remain elusive. The central hypothesis of our proposal is that dysregulated antibody responses modulate susceptibility to chronic chikungunya through impaired antiviral activity, as well as excessive and inappropriate activation of pro-inflammatory pathways. This hypothesis will be tested by the in-depth characterization of a unique cohort of chikungunya patients with resolved or

chronic disease. We will comprehensively analyze the immune responses during the acute phase of CHIKV infection, aiming to identify the immune determinants of susceptibility to chronic chikungunya disease. We will additionally characterize the heterogeneity of humoral immune responses from patients with differential disease outcomes. Lastly, using novel mouse models of chikungyunya disease, we will investigate the immunopathogenic mechanisms of CHIKV infection, as well as determine the mechanisms by which antibodies modulate disease pathogenesis. These studies are expected to lead to the identification of the immune pathways and biomarkers that are associated with disease chronicity, guiding the development of novel vaccination and therapeutic strategies to prevent or treat chikungunya disease.

Start/End Year	2024-2030
Collaborations	Rockefeller University (RAVETCH J, BOURNAZOS S)
Funding	Wellcome Trust Discovery Award

1.5 Development of Monoclonal Antibodies to Severe Fever with Thrombocytopenia Syndrome Virus (SFTSV)

SFTSV is an emerging tick-borne bunyavirus of the Phenuiviridae family. It causes acute febrile illness with thrombocytopenia and can lead to multi-organ failure with fatality rates up to 30%. Since its discovery in China in 2009, SFTSV has become endemic in Japan and South Korea, with evidence of circulation in Southeast Asia, including Vietnam and Thailand. Its main vector, *Haemaphysalis longicornis*, is rapidly expanding due to climate change, raising concern for global spread. No licensed vaccine or targeted antiviral treatment is available, and existing therapies show inconsistent efficacy. The viral envelope glycoproteins Gn and Gc, responsible for receptor binding and fusion, are the main antibody targets and represent key entry points for vaccine and therapeutic development.

The aim of this project is to contribute to the development of future vaccines and therapies against SFTSV. The engineering of stabilized prefusion Gn/Gc antigens exposing conserved quaternary epitopes will be developed by IP Paris (Pablo Guardado-Calvo). These antigens will enable the discovery of novel monoclonal antibodies (mAbs) from convalescent patients in Cambodia and in Laos (IP Laos, Chittaphone Vanhnollat). By isolating memory B cell-derived mAbs and mapping the conserved epitopes they target, this work will provide structural insight into mechanisms of SFTSV inhibition.

Start/End Year	2026-2028
Collaborations	IP Laos (VANHNOLLAT/WONG), IP Paris (GUARDADO-CALVO)
Funding	Pasteur Network SPARK grant

1.6 Pasteur International Unit

Understanding the detailed interactions between pathogens and the immune system and determining the correlates of protection versus pathology are critical for understanding and controlling infectious diseases and pave the way for the development of new diagnostics, vaccines, therapeutics, or innovative infection-reduction strategies.

To address current public health challenges and anticipate those that may arise in the future (Disease X), the global objective of this proposal is to build a sustainable immunology research ecosystem in the African (Senegal and Madagascar) and South-East Asian (Cambodia) Pasteur Institutes around COVID-19 and dengue research projects. The creation of the PIU was approved in 2023 and the PIU agreement was signed in 2024.

Start/End Year	2023-2029
Collaborations	Immunopathophysiology and infectious diseases dpt, Institut Pasteur de Dakar (VIGAN-WOMAS I) Immunology and Infectious Disease Unit, Institut Pasteur de Madagascar (SCHOENHALS M)
Funding	Institut Pasteur du Cambodge/Pasteur Network

Axis 2: Discovery and Characterization of Broadly Neutralizing Antibodies (bnAbs) Against HIV-1 CRF01_A/E Clade in Cambodia (CAM-NAB)

HIV remains a major global public health challenge despite widespread access to antiretroviral therapy (ART). In 2022, approximately 39 million people were living with HIV worldwide, with about 1.3 million new infections annually. Although ART effectively suppresses viral replication, it does not eradicate HIV, requiring lifelong treatment and posing challenges related to adherence, cost, and sustainability, particularly in resource-limited settings. Broadly neutralizing antibodies (bnAbs) represent a promising next-generation approach for HIV prevention and treatment. bnAbs target conserved regions of the HIV envelope glycoprotein and can neutralize diverse viral strains. Clinical studies have demonstrated partial protection against HIV acquisition, suppression of viremia, and delayed viral rebound following ART interruption.

Long-acting, half-life–extended bnAbs administered every 3–6 months offer potential advantages for improving adherence and feasibility in low-resource settings. Most bnAbs identified to date originate from individuals infected with HIV-1 clade B. Cambodia's HIV epidemic is dominated by HIV-1 CRF01_AE, and viral genetic diversity may influence bnAb breadth and potency. Evidence suggests reduced efficacy of some clade B–derived bnAbs against CRF01_AE, highlighting the need for region-specific bnAb discovery. The study protocol was submitted for approval to the National Ethics Committee for Health Research (NECHR) in February 2026.

Start/End Year	2026-2028
Collaborations	NCHAD; CHC; IPC; Program in Molecular and Cellular Medicine-Boston Children's Hospital; BIDMC; Rockefeller University.
Funding	Stavros Niarchos Foundation/Rockefeller University

Axis 3: Vaccine Responses to Rabies Virus Vaccination

We aim to continue our long-term follow up of individuals bitten by rabid suspected dogs receiving the IPC PEP regimen. Until 2026, individuals will reach a 5-year follow up after rabies PEP. Rabies virus neutralizing antibodies and rabies-specific T cells will be determined and compared at D0, Y2, Y3 and Y5. From these data, waning of immune-mediated protection (both humoral and cellular) will be determined.

Start/End Year	2024-2026
Collaborations	Virology Unit, IP Cambodia (KARLSSON E), Epidemiology and Public Health Unit, IP Cambodia (FLAMAND C, LY S), Vaccination center, IP Cambodia (PENG Y)
Funding	French ministry of foreign affairs and French embassy in Cambodia (FEF)

3.3.4 Support to National Authorities

Tineke CANTAERT, PhD and Polidy PEAN, MD, PhD are both coordinators of the immunology module used in master's degree year. The degree program is offered jointly by the (University of Health Sciences, Phnom Penh, Cambodia and *Universite Paris Saclay*, Paris, France).

3.3.5 Teaching and Training

PhD students

- LAY Sokchea: Antwerp University, Belgium (2023-2026)
- RAULT Loeiza (based in New Caledonia): University of New Caledonia, France (2024-2028)

Internship/Master students:

- Borita HENG: University of Health Sciences/University Paris Saclay. M1 Master thesis.

Teaching

- Tineke CANTAERT, PhD and Polidy Pean, MD, PhD: Master Infectious Diseases. University Paris-Saclay-University of Health Sciences, 10 hours (M1 and M2)
- Tineke CANTAERT, PhD and Polidy PEAN, PD, PhD: Member of the Steering Committee International Master Infectious Diseases and coordinator of the Immunology Module (M1)
- Tineke CANTAERT, PhD: Master Immunology-ImmunoPathology, Sorbonne University, 2 hours (M2)
- Tineke CANTAERT, PhD, Master Vaccinology, University de Lyon, 2 hours (M2)

3.3.6 Outlook for upcoming 3 – 5 years

The strengths of the immunology unit in infectious diseases research are dependent on the commitment and quality of our workforce, our resources (e.g., biobanking, state of the art technology-including maintenance contracts, biosafety level II laboratories), strong collaborations with most other IPC Units (Virology, Epidemiology and Public Health, Medical and Veterinary Entomology, BAIA, Malaria Molecular Epidemiology Unit) and longstanding collaborations with excellent research groups worldwide.

This is exemplified by our high-quality research output. We continue to emphasize collaborative work in an environment of cultural diversity. We aim to create an educational learning environment for students, PhD students and postdoctoral researchers with weekly lab meetings and monthly journal clubs.

Within the Pasteur network, we have formed a Pasteur International Unit with the Immunology Units of IP Madagascar and IP Dakar, respectively, to increase the visibility of Immunology in the Pasteur Network. In 2024, two innovative grant proposals have been awarded, a Wellcome Discovery Award (PI: Cantaert Tineke) aiming to understand the immunological mechanisms that drive chronic chikungunya disease pathogenesis, and a EU Horizon project (PI: Ali Mirazimi, Karolinska University) aiming to discover novel antibodies against Crimean Congo hemorrhagic fever surface glycoproteins. In addition, following research projects will be further conducted in the following years: 1/ R01 NIH (PI: Stylianos Bournazos, Rockefeller University), on the investigation of IgG Fc- FcgR interactions during DENV infection, 2/ R01 NIH (PI: Cantaert Tineke and Popovici Jean) on the evaluation of immune responses in asymptomatic Pv-infected individuals, 3/ an ANR project (PI: Dorothee Misse, IRD) on the assessment of lipid metabolic changes during DENV infection, 4/ A collaboration with NIH researchers on the evaluation of skin immunity to mosquito saliva (PI: Fabiano Oliveira, NIH), 5/ Continue the follow up of a longitudinal PEP cohort after rabies exposure (PI: Claude Flamand).

3.3.7 Scientific Publications 2025

Note: *The name of authors from the Institut Pasteur du Cambodge are underlined*

1. **FcγRIIIa is a noncanonical costimulatory molecule for CD8 T cells.**
   Kao KS, Pihlstrom NL, Niejadlik EG, Cantaert T, Ahmed R, Ravetch JV, Bournazos S.
   Proc Natl Acad Sci U S A. 2025 Jul 8;122(27):e2509016122. doi: 10.1073/pnas.2509016122. Epub 2025 Jul 1.
   PMID: 40591599 Free PMC article.

2. **Definition of clinical immunology around the globe.**
   Crispín JC, Cantaert T, Pinzon-Charry A, Mavilio D, Seri A, Miossec P.
   Front Immunol. 2025 Jan 28;16:1483391. doi: 10.3389/fimmu.2025.1483391. eCollection 2025.
   PMID: 39935477 Free PMC article.

3. **Immune profiling in subclinical secondary dengue-infected cases reveals adaptive immune signatures correlated to protection from severe dengue.**
   Gonnella G, Libri V, Gioacchino E, Mella S, Sann S, Sorn S, Ken S, Seffer V, Ya N, Heng L, Yay C, Sakuntabhai A, Ly S, Dussart P, Duong V, Hasan M, Cantaert T.
   Cell Host Microbe. 2025 Jul 9;33(7):1191-1207.e4. doi: 10.1016/j.chom.2025.06.006. Epub 2025 Jun 27.
   PMID: 40580952 Free PMC article.

4. **Asymmetrically glycosylated IgG1 antibodies are universal and drive human disease.**
   Azzam T, Bournazos S, Gunduz H, Adams T, Flowers MW, Niejadlik EG, Duong V, Brown TJ, Roberts AM, Sastre DE, Avci FY, Lam WA, Cantaert T, Roberts BR, Diamond B, Ravetch JV, Du JJ, Sundberg EJ.
   Nat Commun. 2025 Dec 12;17(1):383. doi: 10.1038/s41467-025-67070-3.
   PMID: 41387437 Free PMC article.

5. **Toward a deeper understanding of dengue: novel method for quantification and isolation of envelope protein epitope-specific antibodies.**
   Lay S, Bohaud C, Sorn S, Ken S, Rey FA, Ariën KK, Ly S, Duong V, Barba-Spaeth G, Auerswald H, Cantaert T.
   mSphere. 2025 May 27;10(5):e0096124. doi: 10.1128/msphere.00961-24. Epub 2025 Apr 11.
   PMID: 40214258 Free PMC article.

6. **A set of plasmatic microRNA related to innate immune response highly predicts the onset of immune reconstitution inflammatory syndrome in tuberculosis co-infected HIV individuals (ANRS-12358 study).**
   Pean P, Meng R, Benichou E, Srey P, Dim B, Borand L, Marcy O, Laureillard D, Blanc FX, Cantaert T, Madec Y, Weiss L, Scott-Algara D.
   Front Immunol. 2025 Jun 20;16:1603338. doi: 10.3389/fimmu.2025.1603338. eCollection 2025.
   PMID: 40625756 Free PMC article.

3.4 Virology Unit

3.4.1 Functional Structure

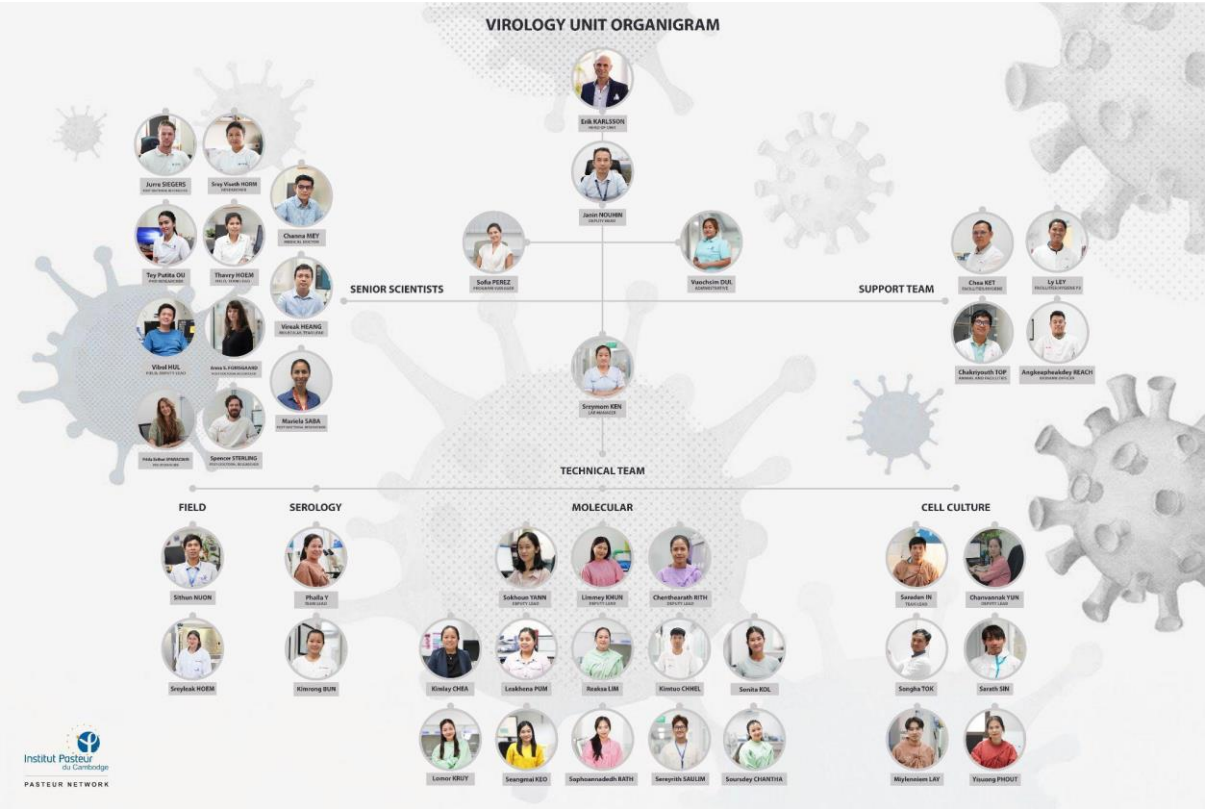

Figure 9: *Virology Unit organigram, 2025*

For 30 years, the Virology Unit (the Unit) is committed to conduct biomedical research and surveillance, and contributes to the prevention and control of infectious diseases in Cambodia, in Southeast Asia, and around the globe. These activities comprise four main components, i) arboviruses (e.g. dengue, Zika, chikungunya and Japanese encephalitis viruses), ii) respiratory syndromes (seasonal, avian influenza, COVID-19 and other respiratory viruses), iii) zoonotic and emerging pathogens (e.g. coronaviruses, hantavirus, Nipah virus and other emerging viruses), iv) Rabies and other viruses (enteroviruses, hepatitis viruses, etc.) The cross-cutting activities comprise of cell culture, virus isolation, sequencing, biosafety level 3 (BSL-3) laboratory, animal facility, quality, security and hygiene and administrative and stock management.

The Unit is structured in three components: i) Laboratory Management, ii) Technical Groups and iii). Research and Surveillance Teams *(Figure 9).*

In 2025, the unit comprises 44 staff including 4 Post-Doc, 4 PhDs, 2 PhD candidates, 7 Master's degree holders, 1 medical doctor, and 26 technical staff. The ratio of female/male was 1.44 and there are 7 nationalities including 37 Cambodian team members.

Within the research and surveillance groups, the Virology Unit has developed numerous research programs conducted in collaboration with other units at IPC including the Epidemiology and Public Health Unit (EPH), the Medical Veterinary Entomology Unit, and the Immunology Unit as well as with governmental partners from the Ministry of Health (Cambodian CDC-MoH, National Center for Parasitology, Entomology and Malaria Control, National Institute of Public Health), the Ministry of Agriculture, Forestry and Fisheries (National Animal Health and Production Research Institute, General Directorate of Animal Health, Production and Forestry Administration), the Ministry of Environment

(Department of Wildlife) and other collaborators across the globe. These programs focus on infectious diseases of concern to the Cambodian population.
The unit provides diagnosis of arboviruses and rabies support to the national control programs under the MoH and hosts 3 national and international reference laboratories, including the National Influenza Center, the WHO's H5 Reference Laboratory, and the WHO Coronavirus Network (CoViNet) Reference. Laboratory.

3.4.2 Research Programs – Major Achievements in 2025

Axis 1: Arboviral Diseases

DenThom: Study of dengue-like illnesses in Kampong Thom Province, Cambodia.

The primary objective of this NIH-funded project within the CREID network is to study the prevalence and incidence of dengue and dengue-like illnesses in Cambodia by implementing a novel study site in Kampong Thom, a province in the center of Cambodia that is a major transport axis, and where information on dengue transmission and circulation is lacking so far. The full description of this project is detailed in the Epidemiology and Public Health Unit, the Immunology Unit and Medical & Veterinary Entomology Unit sections (see page 54 & page 107). The Virology Unit is involved in the project's implementation in the field mission, in collaboration with the Epidemiology and Public Health Unit as well as in the diagnosis of arboviruses in humans and mosquitoes using serological and molecular assays. The inclusion started in April 2022. In 2025, the Virology Unit is involved in constituting a biobank of follow-up samples of DENV index cases. Follow-up samples from 16 index cases were collected, including 2 samples of Day 60 and 14 samples of Year 1 visits.

Research Project Name	DenThom
Funding	NIH collaborative agreement (1-IPC-NIH-U01-AS-2020)
Project duration	August 2020 to May 2025
Collaboration	Institut Pasteur du Cambodge: Virology unit (Duong Veasna, Ou Tey Putita, Ken Sreymom), Epidemiology and Public Health Unit (Ly Sowath), Immunology Unit (Tineke Cantaert), and Medical and Veterinary Entomology Unit (Sebastien Boyer) IP, Paris (Anavaj Sakuntabhai) Jayavarman VII hospital, Siem Reap, Cambodia Kampong Thom, Stoung and Baray-Santuk hospitals, Kampong Thom

Current knowledge of exposure to ticks and tick-borne diseases among rural population in Cambodia

Ticks transmit a wide range of pathogens affecting both human and animal health, yet their diversity and associated disease burden remain poorly characterized in Cambodia. Within the framework of the DENTHOM project, we assessed tick species diversity, presence of associated pathogens, and potential transmission risks in rural communities of Kampong Thom province located in the central part of Cambodia.

A total of 1,429 ticks were collected from animals and surrounding vegetation in 82 households, primarily from dogs (97.3%). Most ticks were adults (91%) and were dominated by Rhipicephalus sanguineus (97.3%), followed by R. microplus (2.4%) and R. haemaphysaloides (0.3%). PCR screening for major tick-born pathogens of public health concern including severe fever with thrombocytopenia syndrome virus (SFTSV), tick-borne encephalitis virus (TBEV), Crimean-Congo hemorrhagic fever virus (CCHFV), Rickettsia, Borrelia, Ehrlichia, and Coxiella yielded no positive results. To broaden the pathogen detection range, 91 tick pools (15 – 16 ticks/pool) were further analyzed by metagenomics sequencing, with analyses ongoing.

Human exposure was assessed in 200 serum samples from residents of households where ticks were collected using commercial ELISA kits for the detection of IgG antibodies. Serological evidence of past exposure was observed for TBEV (56%), SFTSV (6%), CCHFV (3%), scrub typhus (11%), Borrelia (5%), and Coxiella (1%). Neutralization assays confirmed past exposure to SFTSV in 6/11 ELISA-positive samples, whereas no confirmation was observed for CCHFV. Exposure to TBEV was confirmed by a seroneutralization assay in 3 out of 10 samples strongly positive with ELISA. A publication is expected by mid 2026. In parallel, in-house ELISA targeting IgG and IgM antibodies to tick bites are under development using twelve tick peptides candidates (IrCRT1a, IrSPI1a, IrLIP5a, DISC17, DISC17x3, LIP04x03, DISC17xLIP04, Lippocalin_04, SPI_01, SPI_11, Calreculin_25, and Calrecutin_39).
Overall, our study provided preliminary evidence of tick exposure and circulation of tick-borne pathogens, particularly SFTSV, in rural Cambodia. Larger One Health-oriented studies are needed to better define the medical, veterinary, and socio-economic impact of tick-borne diseases in the country. A manuscript is under preparation and is expected to be submitted by Q1-2026

Research Project Name	Current knowledge of exposure to ticks and tick-borne diseases among rural population in Cambodia
Funding	NIH (Award Number 3U01AI151758-03S1)
Project duration	August 2022 – October 2023
Collaboration	Institut Pasteur du Cambodge: Virology Unit (J. Nouhin, L. Khun, L. Heng, P. Y, S. Ken, and V. Duong); Medical and Veterinary Entomology Unit (P.-O. Maquart, S. Yean, K. Heng, S. Leng and S. Boyer); Epidemiology and Public Health Unit (S. Sorn and S. Ly) Institut Pasteur Paris (A. Dziedziech, S. Bonnet, R. Paul, S. Mohamed Ali, M. Eloit, N. Dheilly, S. Temmam, and A. Sakuntabhai) Hokkaido University (K. Matsuno)

Development and Clinical Validation of Multiplex CRISPR Diagnostics for Arboviral Diseases

In collaboration with the Korea Advanced Institute of Science and Technology (KAIST) and partners through the CISED initiative, the Virology Unit continued validation of next-generation CRISPR-based diagnostic platforms for arboviral diseases. This work focused on programmable Cas13a kinetic barcoding technology, enabling multiplex molecular detection of co-circulating arboviruses within a single reaction. Using clinical serum samples collected in Cambodia, the assay successfully differentiated dengue virus serotypes 1–4, chikungunya virus, and Zika virus with high concordance to RT-qPCR reference testing while maintaining compatibility with portable and field-deployable fluorescence detection systems. Beyond improving diagnostic sensitivity and multiplexing capacity, this collaboration contributes to the development of rapid, scalable, and decentralized molecular diagnostics for outbreak response and arbovirus surveillance in Cambodia and the broader region. Further validation and optimization of the platform will continue in 2026 through a prospective cohort study using paired saliva and serum samples from dengue patients to evaluate diagnostic performance across sample types and infection kinetics. A manuscript describing this work is currently in preparation.

Research Project Name	Development and Clinical Validation of Multiplex CRISPR Diagnostics for Arboviral Diseases
Funding	KAIST
Project duration	2025-2027
Collaboration	Institut Pasteur du Cambodge: Virology Unit (E.A. Karlsson, J. Nouhin and team) Korea Advanced Institute of Science and Technology (KAIST) (S. Son, Y. Han and collaborators)

Axis 2: Respiratory Viruses

Avian influenza surveillance in key Live Bird Markets (LBMs).

Longitudinal avian influenza virus (AIV) surveillance in Cambodian live bird markets continued in 2025 through collaboration between IPC, the Food and Agriculture Organization of the United Nations (FAO), and the National Animal Health and Production Research Institute (NAHPRI). These activities form part of ongoing efforts to monitor AIV circulation, characterize viral diversity, and support early warning for zoonotic and poultry health threats in Cambodia. The collection, analysis, and sequencing are complete for the 2017–2024 sessions, 2025 are ongoing, and several manuscripts are in preparation (see below). This collaboration is to continue for the 2026 season. A total of 589 AIV-positive samples with high viral loads were selected for virus isolation, while 164 viruses underwent sequencing prioritization. In total, 194 viral sequences were successfully generated, including 148 from samples collected in 2025 and 46 from samples collected in 2024. Sequenced viruses included H5, H6, H7, H9, H10, and H11 subtypes. Molecular characterization and phylogenetic analyses are ongoing, together with additional laboratory testing of poultry and environmental samples. These surveillance activities continue to provide one of the longest-running datasets on avian influenza circulation in Southeast Asia and support ongoing risk assessment, outbreak preparedness, and manuscript development. Surveillance and collaborative activities are planned to continue through 2026.

Sequencing of avian influenza samples to investigate outbreaks and the diversity of influenza viruses circulating in Cambodian poultry.

Genomic characterization of avian influenza viruses (AIVs) continued in 2025 to support outbreak investigations, molecular epidemiology, and risk assessment of influenza viruses circulating in Cambodian poultry systems. These activities build upon long-term surveillance conducted through Cambodian live bird markets and poultry interfaces and form a core component of IPC's influenza preparedness and early warning activities. Sequencing and phylogenetic analyses of viruses collected during 2025 are ongoing in collaboration with international partners including the WHO Collaborating Centre in Melbourne, the World Influenza Centre at the Francis Crick Institute (United Kingdom), the United States Centers for Disease Control and Prevention (US-CDC), the University of Hong Kong, and other collaborating laboratories. Since 2021, IPC has expanded in-house influenza genomic capacity through collaboration with the Johns Hopkins University Applied Physics Laboratory, implementing a novel multi-segment barcoded PCR sequencing pipeline using Oxford Nanopore Technologies. This platform is now fully operational at IPC and enables internal sequencing of approximately 24–48 influenza viruses per week from avian influenza surveillance activities. Genomic analyses focus on understanding viral evolution, reassortment, transmission dynamics, antigenic diversity, and molecular markers relevant to zoonotic and poultry health risk. Data generated through these activities support ongoing phylogenetic, antigenic, and molecular risk assessments and contribute to several manuscripts currently in preparation.

Emergence and Continued Detection of Reassortant A/H5 Viruses in Cambodian Poultry Systems

Highly pathogenic avian influenza (HPAI) A/H5 viruses continued to circulate in Cambodian live bird markets and poultry systems during 2025, with genomic analyses revealing the continued predominance of reassortant viral lineages involving both historically endemic and globally circulating influenza gene constellations.

Historically, HPAI A/H5N1 viruses detected in Cambodia primarily belonged to clade 2.3.2.1c, which remained regularly detected through national surveillance activities. However, increasing circulation of H5 viruses carrying genetic components related to globally distributed clade 2.3.4.4 viruses has altered the molecular landscape of A/H5 viruses circulating within Cambodia. Genomic characterization of poultry and human-associated viruses collected between late 2023 and 2025 demonstrated that currently circulating H5 viruses represent reassortant lineages containing hemagglutinin genes clustering with regional clade 2.3.2.1e viruses together with internal gene segments related to clade 2.3.4.4b viruses. Some viruses also carried the PB2-627K mutation associated with mammalian adaptation. These findings indicate that the presently circulating Cambodian H5 viruses represent more than persistence of previously endemic strains. Rather, they constitute a novel reassortant lineage with a unique genomic constellation whose implications for viral fitness, transmission, host adaptation, and zoonotic risk remain under active investigation. By 2025, this reassortant H5 lineage had become the dominant genotype in Cambodian live bird markets. Ongoing phylogenetic, molecular, and risk assessment studies are being conducted in collaboration with national and international partners to better understand the emergence, spread, and public health significance of these viruses.

Continued Circulation and Diversity of Non-H5 Avian Influenza Viruses

Multiple non-H5 avian influenza virus (AIV) subtypes continued to circulate in Cambodian live bird markets during 2025, reflecting the complex and dynamic ecology of influenza viruses within poultry systems. A/H7 viruses continued to be detected sporadically through longitudinal surveillance activities. These viruses, which have previously been associated with zoonotic infections globally, have circulated intermittently in Cambodia and the Greater Mekong region since their initial detections in poultry. Sequencing and molecular analyses of Cambodian A/H7 viruses collected between 2020 and 2025 are ongoing, with a detailed report on viral circulation and evolution currently in preparation.

Endemic circulation of A/H9 viruses also continued in Cambodian poultry. Molecular analyses confirm ongoing circulation of BJ94/Y280-like lineage viruses, which remain among the most commonly detected low pathogenic avian influenza viruses in Cambodian live bird markets and continue to warrant attention due to their known zoonotic potential and role in reassortment with other influenza viruses. A detailed analysis of A/H9 circulation and evolution is underway and expected to be reported in 2026. Surveillance activities additionally detected less frequently observed influenza subtypes including H6, H10, H11, and other rare viruses. These findings reinforce the value of sustained longitudinal surveillance and genomic characterization to better understand viral diversity, reassortment dynamics, and emerging risks at poultry–human interfaces.

Research Project Name	Avian influenza surveillance in key Live Bird Markets
Funding	Food and Agriculture Organization of the United Nations
Project duration	2023
Collaboration	Institut Pasteur du Cambodge: Virology Unit (E. Karlsson), EPH Unit (S. Ly, M. Chan) Ministry of Agriculture, Forestry and Fisheries: National Animal Health and Production Research Institute, Cambodia

Investigation of etiology and risks for morbidity and mortality from influenza-associated SARI in Cambodian children.

Severe acute respiratory infection (SARI) surveillance in Cambodian children continued in 2025 through long-standing collaboration between IPC and Kantha Bopha Hospital, serving both as an early warning platform for avian influenza and as a broader system for investigating severe respiratory

disease etiology. Respiratory viruses of interest, including respiratory syncytial virus (RSV), coronaviruses, influenza viruses, and paramyxoviruses, continued to undergo laboratory characterization and genomic investigation. Sequencing and phylogenetic analyses of respiratory virus samples collected between 2021 and 2025 are ongoing through collaborations with Duke-NUS and other international partners. These activities support improved understanding of the pathogens associated with severe pediatric respiratory disease in Cambodia while strengthening preparedness and laboratory response capacity for seasonal and emerging respiratory viruses.

Research Project Name	Investigation of etiology and risks for morbidity and mortality from influenza-associated SARI in Cambodian children
Funding	US-DHHS, USAID, FAO, WHO, Virology internal funding
Project Duration	2014-2025
Collaborations	Institut Pasteur du Cambodge : Virology unit (E. Karlsson) MoH/CCDC, WHO CC Melbourne/Peter Doherty Institute, Duke-NUS, WHO, US-CDC, NIPH; Kantha Bopha Hospital; NAMRU-2

Surveillance activities in Cambodia and using novel collection and sequencing techniques.

Environmental surveillance activities continued in Cambodia during 2025 as part of efforts to evaluate novel sampling and sequencing approaches for pathogen detection at high-risk animal–human interfaces. These activities complement traditional surveillance approaches based on individual animal sampling and aim to expand surveillance coverage while improving operational feasibility and biosafety. Environmental sampling included air, water, soil, feathers, carcass wash, feeding sources, and surface samples collected from high-risk poultry environments including cages, chopping boards, and defeathering equipment. By integrating environmental surveillance into existing monitoring systems, the project seeks to better characterize pathogen circulation while reducing the need for extensive direct animal handling.

Research Project Name	Surveillance activities in Cambodia and using novel collection and sequencing techniques
Funding	Food and Agriculture Organization of the United Nations
Project duration	2022-2025
Collaboration	Institut Pasteur du Cambodge : Virology unit (E. Karlsson) Ministry of Agriculture, Forestry and Fisheries: National Animal Health and Production Research Institute

TrackFlu - Tracking the spread of avian influenza viruses in live bird market networks

Initiated in 2024, the TrackFlu project investigates avian influenza virus (AIV) transmission dynamics within Cambodian live bird market (LBM) networks and poultry value chains. Given the high bird densities and complex trade connections linking farms, traders, and markets, these systems represent important interfaces for viral emergence, maintenance, and dissemination. Field activities initiated during late 2024 and continuing through 2025 focused on cross-sectional investigations during periods of increased poultry movement and trade. Surveillance and data collection were conducted in provinces with previous outbreaks and high poultry density, including Battambang, Kampong Thom, Takeo, Prey Veng, Svay Rieng, and Phnom Penh. Activities integrated biological sampling with structured collection of data related to poultry movement, trading networks, and biosecurity practices. Building upon these initial activities, a longitudinal component is planned to monitor selected high-risk market networks and poultry systems over time. Through combined virological and network-based analyses, TrackFlu aims to identify factors influencing AIV transmission and spread and to support development of more effective surveillance and control strategies in Cambodia.

Research Project Name	TrackFLu
Funding	European Research Council
Project duration	2024-2029
Collaboration	Institut Pasteur du Cambodge: Virology Unit (Erik Karlsson) INRAE (Claire Guinat)

ACIP: AVERT-Cam: An Early Warning System for AIV Transmission and Gene Flow in Cambodia

AVERT-Cam continued in 2025 as a collaborative initiative between Institut Pasteur Cambodia, Hong Kong, and Paris to develop an early warning framework for avian influenza virus (AIV) transmission, evolution, and control in Cambodia. The project integrates virological, epidemiological, and evolutionary approaches to better understand AIV maintenance, transmission pathways, and the effectiveness of current control measures. Initial activities focused on recent H5 influenza events occurring between 2023 and 2024 and included an extensive retrospective analysis of H5 viruses collected between 2006 and 2024. This work substantially improved understanding of the genetic evolution, transmission dynamics, and epidemiology of highly pathogenic avian influenza A(H5N1) viruses circulating in Cambodia and the wider region. Key findings from these analyses were published in 2025 in the *New England Journal of Medicine*, representing an important milestone for the consortium and contributing to ongoing efforts to strengthen influenza risk assessment and preparedness.

Research Project Name	ACIP: AVERT-Cam
Funding	IP Paris
Project duration	2024-2025
Collaboration	Institut Pasteur du Cambodge: Virology Unit (Erik Karlsson) Hong Kong University-Pasteur Research Centre (Dhanasekaran Sijaykrishna) Institut Pasteur Paris (Duchene Sébastian)

H5N1 Cross-Platform Readiness

This project, funded by Wellcome and led by researchers across Africa and Southeast Asia (SEA), aims to establish a multidisciplinary research platform for the rapid detection and characterization of H5N1 avian influenza infections. By leveraging molecular and immunological tools, the project will enhance local surveillance capacity, identify human H5N1 infections, and assess population immunity through antibody and T-cell assays. The research will be conducted in collaboration with leading institutions in Africa, SEA, and international partners, ensuring coordinated responses to potential pandemic threats. The project builds upon existing genomic surveillance and immunology research networks, integrating expertise in viral detection, immunological analysis, and public health strategy. Initial field activities are set to begin following the implementation of laboratory capacity-building efforts and regulatory approvals.

Research Project Name	H5N1 Cross-Platform Readiness
Funding	Wellcome
Project duration	2025–2027
Collaboration	Institut Pasteur du Cambodge (Erik Karlsson), Wellcome-funded MIPs and CIDRI-A, University of Oxford (Dong, Dunachie, Screaton), Mahidol University (Dejnirattisai, Chantima), National University of Singapore (Tan), La Jolla Institute for Immunology (Grifoni, Sette), Africa Health Research Institute (AHRI), Kenya Medical Research Institute-Wellcome Trust Research Programme (KWTRP), Mahidol Oxford Tropical Medicine Research Unit (MORU), Oxford University Clinical Research Unit (OUCRU), Malawi-Liverpool-Wellcome Trust Clinical Research Programme (MLW).

Pilot implementation of the SILAB LIMS system in Cambodia for use in AIV surveillance

The aim of this pilot program is to implement an ISO-accredited LIMS system in the AIV laboratory to investigate its utility, data sharing possibilities, and to facilitate accreditation. In 2025, a total of 55 human AIV cases were recorded by the Virology Unit, 50 of which were entered into the LIMS system under the Unit's surveillance program, along with 2 poultry AIV cases following outbreak response.

Research Project Name	Pilot implementation of the SILAB LIMS system in Cambodia for use in AIV surveillance.
Funding	FAO
Project duration	Started March 2022 through 2025, and to be continued in 2026
Collaboration	Institut Pasteur du Cambodge: Virology Unit (Erik Karlsson, Heidi Auerswald) Theramo

Aetiologic Agents of Community-Acquired Pneumonia in Cambodia - CAP study

The primary objectives of this study are to: (1) identify the causative agents of community-acquired pneumonia (CAP), and (2) detect novel viruses or pathogens responsible for CAP. The study was implemented from March 26 to December 31, 2025 at Kantha Bopha Hospital and Calmette Hospital, enrolling a combined total of 535 patients across pediatric and adult populations. A total of 5,336 respiratory samples were analyzed using molecular diagnostic methods, generating valuable data on the epidemiology of CAP in Cambodia. The study captured two distinct patient profiles: a predominantly pediatric cohort at Kantha Bopha Hospital (mean age 6 years) and an adult cohort at Calmette Hospital (mean age 56.3 years), providing important comparative insights across age groups and care settings. Across both sites, respiratory viruses and bacterial pathogens were frequently identified, underscoring the multifactorial etiology of CAP. Influenza A (including A-H1pdm09 and A-H3) and Human Rhinovirus were among the most commonly detected viral pathogens in both pediatric and adult populations. Among bacterial causes, *Haemophilus influenzae* and *Streptococcus pneumoniae* were consistently predominant. Notably, cases of Avian Influenza A/H5N1 were detected at both hospitals, reinforcing the importance of continued surveillance for emerging diseases. The higher positivity rate observed in the pediatric cohort further highlights the critical role of comprehensive viral diagnostics in childhood pneumonia management. A subset of RT-PCR negative samples will be further analyzed using metagenomic sequencing to identify potential novel pathogens. Additionally, serum samples will be tested for IgG antibodies against emerging pathogens using a multiplex serological assay developed by the Singaporean team at the National Centre for Infectious Diseases.

Research Project Name	CAP-Study
Funding	PREPARE Programme, National Centre for Infectious Diseases, Singapore
Project duration	2024-2026
Collaboration	Institut Pasteur du Cambodge: Virology Unit (Veasna Duong, Erik Karlsson, and Kang Sunheng) Calmette Hospital (Dr. Sotharith Bory) Kuntha Bopha Hospital (Dr. Nguon Yaneth), Cambodoa National Centre for Infectious Diseases, Singapore (Dr. Yeo Tsin Wen)

Axis 3: Zoonoses

Rodents as reservoirs for Hepatitis E virus (HEV), Arenavirus and other rodent-borne viruses and Risk Assessment of Infection in Human in Cambodia – HEPAR project

Rodent-borne viruses, including hantaviruses, arenaviruses, and rodent hepatitis virus (HEV-C), are poorly documented public health threats in Cambodia. From 2020 to 2022, we conducted the HEPAR

project aiming to assess viral circulation in rodents and evaluate human exposure across urban, semi-urban, and rural settings. Rodents and human samples were analyzed using molecular and serological assays. Overall, 9.7% of rodents were found to carry at least one virus, with the highest infection rates in urban area, where human exposure was also more frequent, highlighting ongoing zoonotic transmission risk. Scientific output: the findings of the HEPAR study has been accepted for publication in Microbiology Spectrum. Two additional manuscripts on characterization of Seoul orthohantavirus and HEV-C are under preparation and are expected to be submitted by mid-2026.

Research Project Name	Rodents as reservoirs for Hepatitis E virus (HEV), Arenavirus and other rodent-borne viruses and Risk Assessment of Infection in Human in Cambodia - HEPAR
Funding	IPC Internal Funding and CREID Pilot Program
Project duration	2020 – 2022
Collaboration	Institut Pasteur du Cambodge: Virology Unit (J Guillebaud, J Nouhin, V Hul, T Hoem, O Yanneth, M Sim, L Khun, P Y, L Heng, S Ken, L Pum, R Lim, K Chel, S Nuon, S Hoem, B Nalikka, K Mae Bienes, EA Karlsson, P Dussart, V Duong); Epidemiology and Public Health Unit (K Nguon, M Chan, and S Ly) Ministry of Agriculture, Forestry and Fisheries (C Meng) Institut Pasteur Paris (J-M Reynes and A Sakunthabhai)

Characterization of rodent associated Hepatitis E virus (HEV-C) in Phnm Penh (Cambodia) HEV-C:
HEV-C was detected in 14 of 750 rodents, all identified as Rattus norvegicus, collected from market in Phnom Penh. Analysis of Illumina-generated sequences is ongoing. Funding and collaboration: see the HEPAR project.

Pathogen discovery in rodents
Southeast Asia, a global hotspot for emerging infectious diseases, has a tropical climate supporting year-round ectoparasite activity. Economic growth and demand for meat products spur increases in agriculture and livestock. Deforestation brings wildlife populations into greater contact with livestock and people. Cambodia already has an enormously high burden of infectious diseases; however, little is known about hotspots of undetected rodent-borne pathogens. We aim to conduct an explorative study to detect the presence of emerging viruses including SFTSV and *Orthonairovirus* in rodents collected from various settings of Cambodia including urban, semi-urban, and rural area. This is a retrospective study utilizing samples available in the Virology biobank. Rodent samples will be tested for pathogen using molecular assays including PCR and next generation sequencing.
For SFTSV, none of the 750 small mammals were tested positive. Although no evidence of infection was detected in the sampled animals, the possibility of low-level prevalence or localized transmission outside the study population cannot be excluded. Continued surveillance vectors and potential reservoir host is recommended to improve understanding of SFTSV ecology and to inform assessment of potential zoonotic risk.
For *Orthonairovirus,* a novel virus (Cencurut virus, CENV) has been discovered in Asian house shrews in Singapore, with a high detection frequency of 91.9% (n=34/37), and high genetic diversity (1.4% to 5.0% nucleotide dissimilarity), suggesting co-circulating variants across the Singaporean shrew population. Asian house shrews are a peridomestic animal, common in Singapore, that live in close proximity to humans. In this study, we aim to investigate the prevalence of CENV and tissue tropism, and to explore *Orthonairovirus* diversity in small mammals from Singapore (n=113) and Cambodia (n=716). A bead-based serological assay is also being developed to assess exposure history of Cambodian small mammals and humans towards CENV and new orthonairoviruses discovered from this project.

In 2025, CENV was detected in small mammals from Singapore (n=5/113), belonging to the *Rattus* and *Mus* genus, but not in Cambodian small mammals (n=0/113). No other Orthonairoviruses were detected using a pan-Orthonairovirus family PCR assay. Further investigation using metagenomics sequencing are ongoing and is expected to provide valuable insights into the virome of Cambodian small mammals.

Research Project Name	Investigating *Orthonairovirus* diversity and their risk as a zoonotic pathogen
Funding	Khoo Postdoctoral Fellowship Award (KPFA) Duke-NUS Medical School, Singapore
Project duration	2024 – 2026
Collaboration	Institut Pasteur du Cambodge: Virology Unit: (L Khun, S Rath, V Heang, Erik Karlsson, J Nouhin) Duke-NUS Medical School: Dolyce Low Hong Wen, Gavin James Smith

Biodiversity conservation to mitigate the risks of emerging infectious diseases (BCOMING).

In 2025, the BCOMING project was implemented in three provinces in Cambodia with varying levels of anthropization and biodiversity protection measures: Phnom Penh, Battambang, and Stung Treng. Seven field missions were conducted in February, March, May, June, August, October, and December. A total of 1,552 bats from 13 genera and 36 species were captured. *Rhinolophus* species comprised 47.2% (732/1,552) of the sample, with *R. shameli* accounting for 80.9% (592/732) within this genus. This was followed by *Taphozous* species at 22.6% (350/1,552), of which *T. melanopogon* represented 98.9% (346/350).

Sarbecovirus screening on the bat rectal samples

Of the 1,458 rectal swabs tested by sarbecovirus RT-qPCR, 30 were positive across the following species: *H. larvatus* (n=1), *H. pomona* (n=2), *R. acuminatus* (n=2), *R. malayanus* (n=2), *R. microglobosus* (n=1), *R. pusillus* (n=1), *R. shameli* (n=19), and *T. melanopogon* (n=2). Twenty-eight positives originated from Stung Treng and three from Battambang (one *R. shameli* with low viral load, one *R. malayanus* with Ct ≈24, and one *T. melanopogon* with low viral load).

Among these 30 Sarbecovirus positives, **nine samples** were positive for sarbecovirus with **low viral load**: *R. shameli* (n=6), *R. microglobosus* (n=1), and *T. melanopogon* (n=2). The **remaining 21** positives underwent further RT-qPCR classification: 16 as group 1 (13 *R. shameli*, 2 *H. pomona*, 1 *H. larvatus*; all from Stung Treng), 1 as group 4 (*R. malayanus* from Stung Treng), and 4 as unclassified (1 *R. malayanus* from Battambang, 2 *R. acuminatus*, 1 *R. pusillus* from Stung Treng). Sequencing to obtain whole-genome sequences is ongoing for these 21 sarbecovirus positives.

Sarbecovirus and Pancoronavirus screening on Domestic animals and Rodents

A total of 298 rodents and 365 domestic animals were collected across three provinces: Phnom Penh (February 2025: 110 rodents, 120 domestic animals), Stung Treng (March 2025: 105 rodents, 145 domestic animals), and Battambang (May 2025: 83 rodents, 100 domestic animals).

Of these, All of (n=663) samples tested negative for sarbecoviruses by RT-qPCR.

14/298 rodent rectal swabs tested positive by pan-CoV Chu RT-PCR (3 from Stung Treng and 11 from Battambang), with their 14 RdRp sequences belonging to rodent coronavirus.

91/365 cloacal swabs from chickens and ducks tested positive by pan-CoV Chu RT-PCR. Of these, 50 RdRp sequences belonged to gammacoronavirus species (11 from Phnom Penh, 22 from Stung Treng, 17 from Battambang), while the remaining 41 were identified as infectious bronchitis virus (8 from Phnom Penh, 22 from Stung Treng, 11 from Battambang).

Research Project Name	BCOMING
Funding	European Union HORIZON-CL6-2021-BIODIV-01
Project duration	August 2022 - July 2026
Collaboration	Institut Pasteur du Cambodge: Virology Unit (Duong Veasna and Julia Guillebaud), Epidemiology and Public Health Unit (Ly Sowath, Medical and Veterinary Entomology Unit (Sébastien Boyer) CIRAD-ASTRE (Julien Cappelle) IRD-TransVIHMI (Martine Peeters and Ahidjo Ayouba) IRD-ISEM (Rodolphe Gozlan and Marine Combe) MERFI (Alex Smajgl) Université de Liège (Johan Michaux and Pauline Van Leeuwen) Avia-GIS (Guy Hendrickx and Cedric Marsboom) INRAE University of Antwerp (Vincent Sluydts) Helmoltz Centre for Infection Research (Sébastien Calvignac-Spencer and Lorenzo Lagostina) CERFIG (Alpha Kabinet Keita) iDE (Moung Vandy) Nature Metrics (Tiffany Jedrecka and Kate Denton) Flora and Fauna International (Pablo Sinovas and Thi Sothearen) Europa Media (Gabriella Lovasz and Zsuzsanna Selmeczyk)

Improving multiplex, pan-viral PCR and Nanopore sequencing for real-time, in-field detection of zoonotic pathogens

In 2025, this project transitioned from assay development to operational field deployment. A portable "lab-in-a-bag" platform was assembled and successfully deployed during four field missions in Cambodia, demonstrating that multiplex pan-viral sequencing can be conducted directly at high-risk human–animal interfaces. The PiiP assay performed successfully under field conditions, confirming its suitability for same-day pathogen detection outside centralized laboratory settings. Viral targets were expanded to include alphaviruses, orthopoxviruses, ebolaviruses, and the RES-MOR-HEN clade, broadening preparedness coverage to additional high-consequence pathogens. In parallel, the system was complemented by an expanded animal barcoding panel incorporating avian, vertebrate, and invertebrate markers, enabling simultaneous identification of both host and pathogen from a single sample. Methodologies and deployment approaches developed through this project were presented and taught during environmental surveillance and pathogen detection trainings at IPC and at the Joint FAO/IAEA Centre in Vienna, contributing to international capacity building in portable genomic surveillance. Beyond zoonotic pathogen detection, the portable field laboratory was deployed in northern Cambodia to support conservation activities through molecular sex determination of endangered Giant and White-shouldered Ibises. By bringing molecular diagnostics directly to rural field settings, this work contributed critical information supporting the first evidence-based breeding programs for both species and highlighted the broader applications of decentralized molecular technologies for conservation and biodiversity science.

Research Project Name	Improving multiplex, pan-viral PCR and Nanopore sequencing for real-time, in-field detection of zoonotic pathogens
Funding	International Atomic Energy Agency (IAEA) ZODIAC Project
Project duration	2023-2026
Collaboration	Institut Pasteur du Cambodge : Virology unit (E. Karlsson) John's Hopkins Applied Physics Laboratory International Atomic Energy Agency (IAEA) Food and Agriculture Organization of the United Nations (FAO)

Continuation of the CANARIES Network

The Consortium of Animal market Networks to Assess Risk of Emerging Infectious diseases through Enhanced Surveillance (CANARIES) first convened on 12–14 June 2019 in Phnom Penh, Cambodia.

CANARIES was established as a global One Health think tank and collaborative network linking formal and informal human and animal surveillance systems, with the goal of integrating programs, policy, legislation, and research to improve prevention and response to emerging infectious diseases at high-risk interfaces.

Following disruptions caused by the COVID-19 pandemic, CANARIES reactivated and expanded its activities in 2025 through regular Steering Committee engagement, virtual coordination, development of an official charter, website and social media presence, manuscript preparation, collaborative grant applications, and cross-network technical activities. The consortium maintained its guiding vision of "Healthy Markets, Healthy People", recognizing live animal markets not as problems to eliminate, but as complex systems requiring scientifically grounded, culturally appropriate, and economically sustainable approaches to risk reduction.

A major milestone in 2025 was the CANARIES II: FLIGHT technical meeting held in Bangkok, Thailand (1–3 December 2025), convened by CANARIES in collaboration with the Food and Agriculture Organization of the United Nations (FAO) and IPC, with support from DTRA and the UK National Academy of Sciences. The meeting brought together multidisciplinary experts from Asia, Africa, Europe, and international organizations to reconnect the network and co-develop a novel Market Mapping Tool (MMT) designed to characterize and assess live animal markets through integrated biological, behavioral, infrastructural, and governance dimensions. Participants reaffirmed CANARIES' role as a "canary in a coal mine" for emerging disease threats and agreed upon a forward-looking roadmap focused on coordination and communication, sustainability, governance, and collaborative research. Pilot implementation of the MMT was confirmed for 2026 in three countries in Asia and three in Africa, with additional voluntary uptake anticipated across partner institutions.

Research Project Name	Continuation of the CANARIES Network
Funding	DTRA–UKGCRF DTRA through FAO Network Strengthening Grant (UK Academy of Sciences)
Project duration	2019-2028
Collaboration	Institut Pasteur du Cambodge : Virology unit (E. Karlsson)

Axis 4: Rabies and other viruses

Rabies Virus Transmission from Golden Jackals to Humans in Battambang: Molecular and Serological Investigation

In October 2025, multiple human exposures to golden jackals were reported in Moung Reussey district, Battambang province. On October 6, 2025, a jackal attacked and injured three villagers in Phum Pou 1 village, Khum Kear commune. The implicated animal was killed immediately by villagers, along with three additional jackals from the same pack; however, none of these animals were available for laboratory testing. Two further villagers were reportedly attacked on October 5 and 8, 2025. A separate golden jackal from the same pack (not involved in human exposure) was killed on October 10, 2025, and rabies virus infection was confirmed by NAHPRI.

All five exposed individuals received timely rabies post-exposure prophylaxis (PEP) at the Battambang Rabies Prevention Center. One patient (female, 67 years) developed clinical signs compatible with rabies 20 days post-exposure, including rapid progression to acute neurological symptoms with hydrophobia. She was hospitalized on October 25, 2025 and died on October 28, 2025. Diagnostic

confirmation was not possible, as post-mortem sample collection was declined by the family. Based on exposure history and clinical presentation, the case was classified by CDC-MoH as a suspected human rabies case.

Molecular testing at IPC Virology Unit confirmed rabies virus infection in the golden jackal sample. Whole-genome sequencing and phylogenetic analysis demonstrated that the jackal-derived virus clustered within the Asian SEA3 minor clade, together with strains circulating in dogs and humans in Cambodia. This genetic similarity suggests epidemiological linkage between wildlife and domestic transmission cycles and supports the likelihood of cross-species spillover. A serological study of the four survivors showed adequate rabies virus neutralizing antibody titers, consistent with protective immune responses following PEP. These findings confirm effective vaccine-induced immunity in exposed individuals.

This investigation highlights the importance of integrating epidemiological assessment, molecular diagnostics, genomic surveillance, and serological evaluation to strengthen rabies outbreak investigations and risk assessment at the wildlife–domestic animal–human interface.

Improved monitoring of rabies activities with a Laboratory Information Management System (LIMS)

Starting from 2023, the Virology Unit's routine rabies diagnostic activities began to be documented in a FAO-supported veterinary public health Laboratory Information Management System (LIMS) known as SILAB. This system oversees all samples received for direct diagnosis by Direct Fluorescent Antibody test (DFAT), and for serological diagnosis by FAVNT, which is offered as a paid service. The implementation of SILAB facilitates faster result reporting to both customers and authorities. Following an assessment of the laboratory's needs for rabies diagnostic operations, two LIMS administrators were trained to manage rabies-related activities using SILAB. Additionally, four technicians were trained in sample and result entry. The adoption of the SILAB LIMS enhances sample tracking, testing, and reporting, and improves the overall management of the Virology Unit's diagnostic capabilities. The SILAB LIMS system has been in regular usage and expanded in 2024.

In 2025, a total of 226 cases of Rabies were recorded under the Virology Unit's Rabies Surveillance, 62% of which were positive, with the majority coming from dog samples (97%) and the rest coming from cats. Under the Pet Service, 88 cases were reported of which 87 were positive. The samples that tested positive were dog samples (68%) and cat samples (32%).

Research Project Name	SILAB-IPC
Funding	Food and Agriculture Organization of the United Nations (FAO)
Project duration	2023 – 2025
Collaboration	Institut Pasteur du Cambodge: Virology Unit (Erik Karlsson, Heidi Auerswald); Istituto Zooprofilattico Sperimentale dell'Abruzzo e del Molise (IZSAM, Ecole DEL NEGRO)

Confirmation and Sequencing of MPXV genomes from Monkeypox outbreak in Phnom Penh, Cambodia (2023 – 2024)

Following Cambodia's first documented mpox outbreak, IPC generated full MPXV genomes from all 20 confirmed local cases identified between December 2023 and May 2024 using Oxford Nanopore sequencing. Phylogenetic and phylodynamic analyses classified the outbreak as Clade IIb, lineage C.1, and supported a single introduction event into Phnom Penh, most likely linked to regional circulation, followed by sustained local human-to-human transmission. Genomic analyses identified a high frequency of APOBEC3-associated mutations, providing further insight into viral evolution during

transmission. IPC continues to support national mpox surveillance and response activities. Findings from this work were accepted for publication in *Emerging Microbes & Infections* in 2025.

Human papillomavirus E6 and E7 coding gene variations and their possible association with the occurrence of cervical intraepithelial neoplasia.

Human papillomaviruses (HPV) are the primary etiological agents of cervical cancer, with women living with HIV at increased risk of persistent infection and disease progression. In Cambodia, data on HPV molecular diversity remain limited. We conducted genomic characterization of HPV infections in 64 HIV/HPV co-infected women enrolled in the AIMA-CC study (2019–2021). Near-full HPV genomes were generated from cervical swabs using rolling-circle amplification and target enrichment metagenomics on the Illumina MiSeq platform.

From the initial sequencing round, 28 HPV genomes (≥30% coverage) were recovered from 24 samples, revealing high genotype diversity (14 genotypes), with HPV16 most frequent (n=5), followed by HPV18, HPV56, and HPV58 (n=3 each). HPV co-infections were identified in nine participants. A second round using Twist target enrichment improved genome recovery, yielding full genomes from 10 patients (HPV16 n=6; HPV18 n=4).

Phylogenetic analysis demonstrated substantial HPV16 heterogeneity, including sub-lineages A1, A3, A4, and C1, whereas all HPV18 genomes clustered within sub-lineage A1 (Figure X). Variant analysis showed E6/E7 variability in HPV16 but not in HPV18. The E6 D25E substitution (T178A/G) was observed in both CIN2+ and <CIN2 cases; however, associations with disease could not be assessed due to limited sample size.

This study provides the first systematic genomic insight into HPV diversity and oncogene variation in HIV-positive women in Cambodia. The observed HPV16 lineage diversity and frequency of co-infections highlight the need for larger studies to investigate variant evolution, recombination, and clinical impact. A manuscript describing these findings is under preparation and is expected to be submitted by mid-2026.

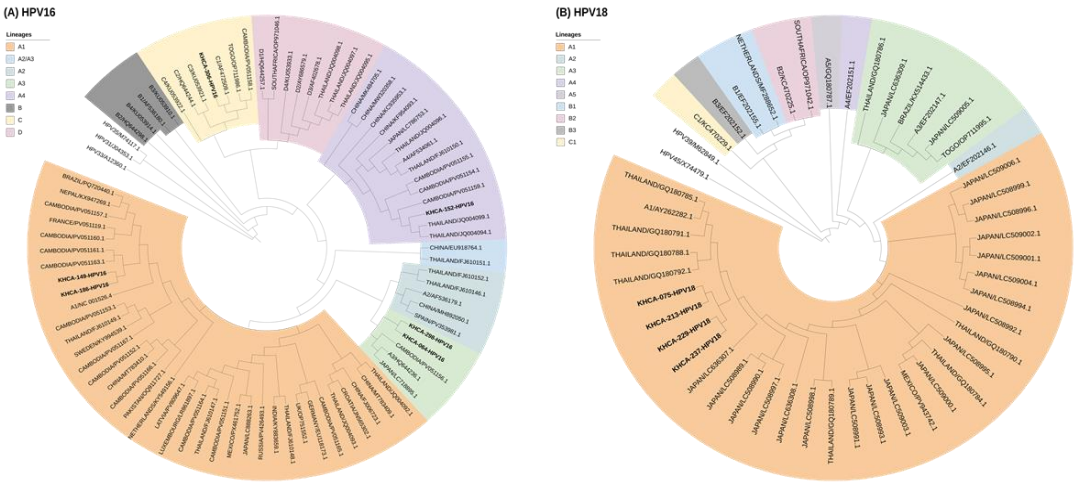

Figure 10: *Maximum likelihood full genome phylogenetic tree of HPV16 (A) and HPV18 (B) including our samples, all available Cambodian genomic sequences, as well as selected additional sequences from other countries. Cambodian strains included in the present study are labeled as follow: KHCA-306-HPV16 (HPV16-C1), KHCA-152-HPV16 (HPV16-A4), KHCA-298-HPV16 (HPV16-A3), KHCA-064-HPV16 (HPV16-A3), KHCA-075-HPV18, KHCA-213-HPV18, KHCA-229-HPV18, and KHCA-237-HPV18 (HPV18-A1).*

Research Project Name	Human papillomavirus E6 and E7 coding gene variations and their possible association with the occurrence of cervical intraepithelial neoplasia.
Funding	IPC Internal Funding
Project duration	2022 – 2023
Collaboration	Institut Pasteur du Cambodge: Virology Unit (L. Khun, N. Boukli, and J. Nouhin), Sequencing Mini-Platform (J. Nouhin, N. Khim and V. Heang), Bioinformatics and Artificial Intelligence Applications Unit (Giorgio Gonnella). Calmette Hospital (S. Limsreng, A. Korn). University of Health Sciences (S. Kim, S. Moeung). ANRS (O. Segeral). Institut de Recherche pour le Développement (P. De Beaudrap).

Molecular Characterization Hepatis C Virus (HCV) circulating in Cameroun

Understanding of HCV molecular epidemiology is essential for monitoring transmission dynamics and inform public health response. In the era of direct-acting antiviral (DAA) therapy, knowledge of HCV genetic diversity also supports patient management, particularly in case of virological failure. The majority of described HCV infection and treatment outcome is associated with HCV genotype 1, which is globally distributed and well conserved. In contrast, high diversity HCV lineages are observed in high endemic areas such as Africa. In collaboration with the Virology Unit at Centre Pasteur du Cameroon (CPC), we have conducted a study aiming to describe HCV genotypes, subtypes, pattern of recombinants, and potential co-infection circulating in Cameroon between 2013 and 2023. The study will be conducted in collaboration with Centre Pasteur du Cameroun (CPC). A total of 100 HCV positive samples was transferred to IPC.

Among 10 samples showing genotypic discordance in Core and NS5B gene by Sanger sequencing, whole genome ONT sequencing confirmed all as natural recombinants, predominantly genotype 2/1 with recurrent NS2/NS3 breakpoints, followed by genotype 4/1 recombinant with E2/p7 breakpoint and one complex genotype 4/2/1 recombinant. These findings revealed ongoing circulation of diverse HCV recombinants in Cameroon and underscore the limitation of partial genome genotyping for surveillance and patient management.

Near-complete human pegivirus 2 (HPgV-2) genomes were identified in six individuals, revealing co-infection dynamics, highlights viral diversity, and supports improved diagnostics. Analysis of HCV genomic data is ongoing. One manuscript of characterization of HPgV-2 is under revision at Microbiology Resource Announcement, and a second manuscript describing the characterization of HCV recombinant form is in preparation.

Research Project Name	Molecular Characterization Hepatis C Virus (HCV) circulating in Cameroun
Funding	IPC Internal Funding and Calmette & Yersin Internship Grant
Project duration	2025
Collaboration	Institut Pasteur du Cambodge: Virology Unit (L Pum, EA Karlsson, and J Nouhin); Sequencing Platform (V Heang and J Nouhin) Centre Pasteur du Cameroun (A Mounchili and R Njouom)

Veterinary Virus Diagnosis

Molecular Diagnosis of EEHV in Elephants

Elephant Endotheliotropic Herpesvirus (EEHV) is a major cause of fatal hemorrhagic disease in young Asian elephants under eight years old, with mortality rate up to 85%. In April 2024, the Virology Unit investigated the sudden death of a 2-year-old female baby Asian elephant in Mondulkiri, Cambodia. Clinical signs (Lethargy and anasarca) indicated suspicion of EEHV. Necropsy samples (Heart, lung, spleen, intestine, tongue, skin, liver, and stomach) were analyzed. SISPA metagenomics on heart and

spleen specimens using ONT sequencing detected Elephantid betaherpesvirus 1 (EEHV-1), predominantly in spleen, with 91.1% of genome coverage. Phylogenetic analysis of the terminase gene showed that our EEHV-1 sequence was clustered with EEHV-1A strain from India, Europe and North America *(Figure11).* qPCR targeted EEHV1 U41 gene (Major DNA-binding protein gene) confirmed EEHV-1 in all tissues, with Ct value ranging from 26 to 39.

Concurrently, Phnom Tamao Wildlife Rescue Centre (PTWRC) experienced a doubling of its elephant population due to rescues and international diplomatic transfers, with incoming 4 young elephant requiring intensive veterinary and husbandry care, including EEHV monitoring. On August 26, 2024, the EEHV diagnosis of two 4-year-old Asian elephants from PTWRC was conducted using qPCR, and both elephants tested positive for EEHV1. Test results were communicated to the veterinary team on the same day, enabling immediate initiation of antiviral treatment. This early detection of EEHV was critical for timely therapeutic decision-making and ultimately contributed to the survival of the affected elephants.

Following these cases, a longitudinal surveillance program for EEHV was established in collaboration with rescue center to monitor the eight elephants (4 adults and 4 juveniles) in the facility. Whole blood, conjunctival swab, oral swab, and trunk wash samples were collected periodically and screened by qPCR for the presence of EEHV DNA. As a result, EEHV1 DNA was detected in three of the juvenile elephants, confirming active viral circulation among elephants at the center. In 2025, we have provided 441 testings.

IPC Virology Unit continues to contribute to ongoing EEHV surveillance efforts at PTWRC into 2026. A manuscript describing molecular diagnosis and management of EEHV in Cambodian Asian Elephants is under preparation and expected are expected to be submitted by mid-2026.

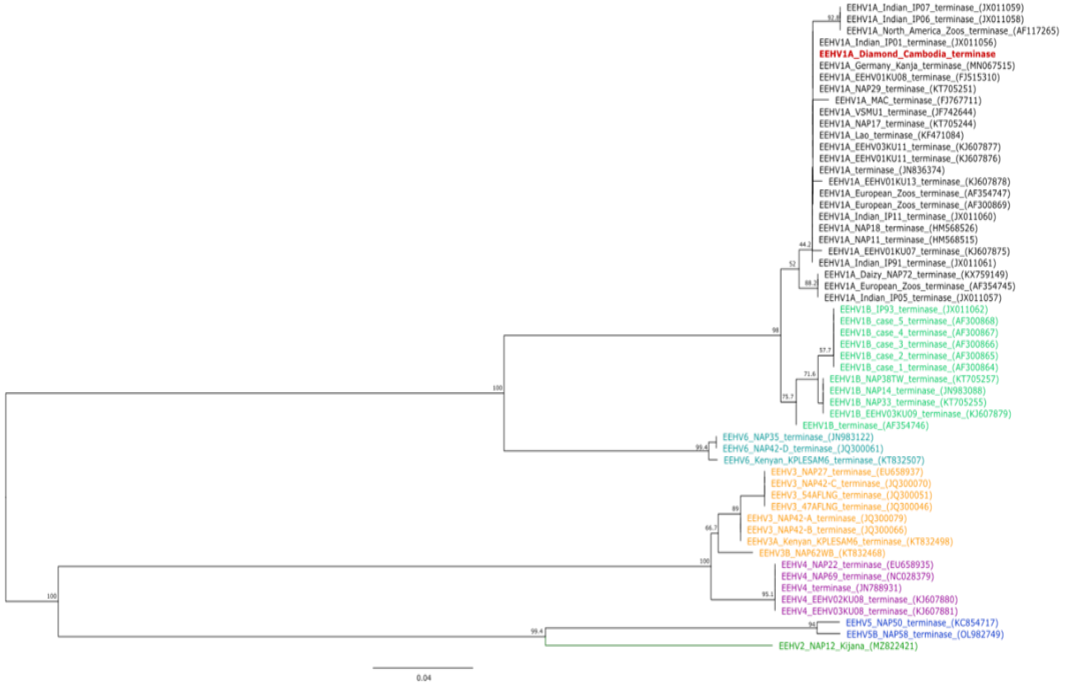

Figure 11: Phylogenetic tree of EEHV. Phylogenetic trees were inferred using the Maximum Likelihood with 1,000 bootstrap replicates, *based on GTR models of nucleotide substitution, as recommended by the PhyML software. Trees were visualized and annotated using FigTree v.1.4.4 and Inkscape 1.4. One sequences from the present study (indicated in red), and GenBank reference sequences (indicated in various colours: EEHV1A in black, EEHV1B in light green, EEHV6 in teal, EEHV2 in dark green, EEHV3 in orange, EEHV4 in purple, and EEHV5 in blue).*

Viral diagnostics in wildlife

In addition to the molecular diagnosis of EEHV in elephants, the Virology Unit provided support to PTWRC, Wildlife Alliance, and other stakeholders in testing of viral infection in wildlife including bear, deer, and golden jackal presenting clinical symptoms (Table 5).

Table 5: *Viral diagnosis in wildlife in 2025*

Animal species	Tested Number	Testing	Result
Bear	28	FMD	Negative
	22	Avian influenza	Positive (n=6)
	16	Herpes	Positive (n=1)
Deer	2	FMD	Negative
Douc Langur	16	Respiratory infection (FTD33)	Positive: Staphylococcus aureus (n=10) and Klebiella pneumonia (n=14)
Gibbon	2	Avian influenza	Negative
Irrawaddy Dolphin	3	Avian influenza and SISPA	Negative
Red-breasted parakeet	4	Avian influenza	Negative
Bat	1	Rabie	Negative

For Douc Langurs, testing of respiratory infections was conducted on 34 respiratory pathogens including Influenza A using Fast Track Diagnostic respiratory pathogens 33 multiplex assay (FTD33) and RT-qPCR. In 2025, we received 16 samples. Among these, 10 samples tested positive for *Staphylococcus aureus* and 14 samples tested positive for *Klebsiella pneumoniae*.

IPC Virology Unit continues to support viral diagnostic effort in wildlife into 2026.

Axis 5: Other major One Health Projects

RACSMEI

RACSMEI seeks to establish an integrated, cost-effective, and multidisciplinary research framework to strengthen Precision Public Health in Cambodia through a One Health approach to priority infectious diseases. The program brings together expertise across human, animal, vector, and environmental health to generate evidence needed for more targeted and effective public and animal health interventions. The consortium is implementing a nationally representative cross-sectional survey focused on zoonotic and endemic pathogens using multiplex detection approaches across the human–animal–environment interface.

The study will include approximately 10,000 randomly selected participants, alongside sampling of domestic and peri-domestic animals, vector species, and environmental reservoirs. By integrating innovations in multiplex serology, environmental sampling, metagenomics, and modelling, RACSMEI aims to provide an unprecedented understanding of pathogen circulation and exposure across Cambodia.

The program addresses key questions related to the epidemiology, ecology, and transmission dynamics of infectious diseases, including disease burden, spatial transmission risks, and the drivers of pathogen spread at the individual, household, community, and national levels. Field implementation and sampling activities commenced in November 2025.

Research Project Name	RACSMEI
Funding	Wellcome Trust
Project duration	2025 – 2030
Collaboration	IPC's Epidemiology Unit (Dr. Claude FLAMAND, Dr. Tephanie SIENG) Malaria Consortium (Ms Mousumi RAHMAN) Medical Biology IPC Laboratory (Dr. Sokhleap CHENG) IPC Virology Unit (Dr. Erik KARLSSON, serological testing, pathogen detection and metagenomic sequencing.) IPC Medical and Veterinary Entomology (Dr. Sebastien BOYER) Institute Pasteur France (Prof Simon CAUCHEMEZ, Dr. Michael WHITE)

ECOMORE 3

As part of efforts to strengthen health security in the Indo-Pacific region, the ECOMORE 3 project will focus on studying the circulation of priority zoonotic and vector-borne diseases in Southeast Asia. Using innovative laboratory diagnostic techniques, the project will integrate data on environmental and climatic factors, while also characterizing vectors and animal reservoirs. The ECOMORE consortium, coordinated by the Institut Pasteur, brings together five key partners across four countries: the Institut Pasteur du Cambodge (IPC) in Phnom Penh, the Institut Pasteur du Laos (IPL) in Vientiane, the National Institute of Hygiene and Epidemiology (NIHE) in Hanoi, and the Research Institute for Tropical Medicine (RITM) in Manila. These national institutes, affiliated with their respective Ministries of Health, play vital roles in their countries' public health systems. The French National Research Institute for Sustainable Development (IRD) will contribute expertise on the climate component of the program.

In Cambodia, a multidisciplinary team—comprising virologists, entomologists, epidemiologists, and climatologists—will adopt a One Health approach to conduct a nationally representative longitudinal survey on zoonotic and endemic diseases. The study will also explore how human activity, land use, and climate change influence the distribution of major vectors in the country. In parallel, novel diagnostic tools will be developed to support research activities and build sustainable capacity.

The project aims to: (1) strengthen integrated human, animal, and environmental health approaches, and (2) establish a collaborative framework for epidemic preparedness and response (PPR). These goals will be implemented across four key areas: Laboratory Capacity, Climate and Health, Surveillance, and Response.

Research Project Name	ECOMORE 3
Funding	AFD
Project duration	2024-2027
Collaboration	Institut Pasteur du Cambodge: Virology Unit (E Karlsson) Institut Pasteur du Cambodge: Epidemiology and Public Health Unit (Claude Flamand and Sowath Ly) Institut Pasteur du Cambodge : Entomology Unit (Sébastien Boyer) Institut Pasteur du Laos, Lao RDP National Institute of Hygiene and Epidemiology (NIHE), Vietnam Research Institute of Tropical Medicine (RITM), the Philippines

PREZODE-AFRICAM

Funded by the PREZODE initiative and led by IRD and CIRAD, this project investigates how hydrological, climatic, and environmental dynamics influence the risks of emergence of zoonotic diseases in diversified ecosystems representing key animal-human-environment interfaces. The project also aims to implement activities to reduce the emergence of zoonotic risks and strengthen, in coordination

with local and national partners, the existing surveillance systems towards an integrated One-Health surveillance.

The study protocol of seroprevalence survey has been approved by NECHR. This study is a longitudinal, prospective cohort conducted over 22 months in three rural villages in Ek Phnom district, Battambang province, Cambodia (Figure X). The three study villages are located along the 250 km-long Sangker River: Prek Norin is located 20 km from the provincial capital, Prek Trab is 30 km away, and Bak Prea is a floating village 50 km from the provincial capital with limited road access.

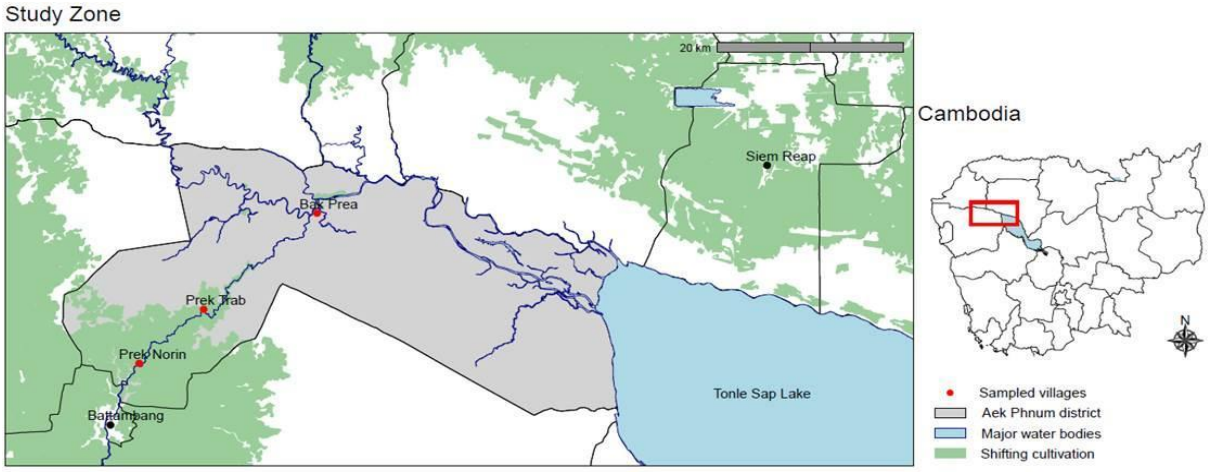

Figure 12: *Study area and the distribution of the three selected villages.*

Participants are enrolled during an initial recruitment campaign (M0) and followed every six months across four data collection rounds (M0, M6, M12, M18). The study adopts a fixed cohort design with no new enrolments after the baseline. Alongside the human cohort, concurrent sampling of domestic animals, wildlife (rodents), water and soil is conducted to support the integrated One Health surveillance approach.

Within the Virology Unit, we are investigating seven viruses: five arboviruses–dengue (DENV), zika (ZIKV), chikungunya (CHIKV), Japanese encephalitis (JEV), west Nile (WNV)–as well as orthohantaviruses and avian influenza. Table X details the pathogens investigated in humans by serology, in domestic and wild animals by RT-qPCR.

Table 6: *Overview of Investigated viruses*

	Pathogen	Human seroprevalence	Domestic animals PCR	Rodent PCR
Viruses	Arboviruses (DENV, ZIKV, CHIKV, JEV, WNV)	✓		
	Hantaviruses	✓		✓
	Avian flu	✓	✓	

In 2025, the first field mission was completed, covering human, domestic, and wild animal sampling. Table Y presents the species distribution by study sites. RT-qPCR screening detected H5N1 in 4/24 ducks and 1/74 chickens collected from Prek Trab village tested positive for H5N1. None of the rodents tested positive for orthohantavirus. Field and laboratory activities will continue in 2026.

Table 7: *Number of human participants and animal by species and study site*

	Bak Prea	Prek Norin	Prek Trab	Total
Human	396	433	433	1262
Female	203	249	218	470
Male	193	184	215	592
Domestic animal	32	123	114	169
Chicken	22	94	74	190
Duck	6	20	24	50
Swine	4	9	16	19
Rodent	43	42	15	100
Rattus exulans	34	37	12	83
R. norvegicus	3	2	2	7
R. rattus	6	3	0	9

Research Project Name	PREZODE-AFRICAM
Funding	French Development Agency (AFD)
Project duration	2024-2026
Collaboration	Institut Pasteur du Cambodge: Virology Unit (L Khun, S Ken, T Hoem, S Nuon, V Hul, EA Karlsson, and J Nouhin), Medical and Veterinary Entomology Unit (S Boyer); Epidemiology and Public Health Unit (S Sorn, C Flammand, and S Ly) IRD (V Herbreteau and A-L Banuls) CIRAD (H Guis)

ACIP: CLIMPATHIC – Strategy for Genomic Surveillance of Pathogens in Wastewater

The goal of this project is to develop tools for genomic surveillance of pathogens (endemic, (re)-emerging) in the context of climate change. The full strategy will be developed for dengue and Leptospira which are mentioned as important to follow in the context of climate change and can also be found in wastewater. However, this research proposal has to be considered as a pilot study using a pathogenic virus and bacteria to develop strategies applicable to global surveillance by monitoring pathogens in wastewater.

In this proposal three types of strategy will be developed for genomic surveillance with a global increase in complexity:

First, real-time PCR assays targeting these two pathogens will be adapted and implemented which will allow the monitoring of the circulation of a target pathogen and its presence and frequency in the population.

Secondly, targeted sequencing allows getting precious information on the type of strain, pathogenicity, and vaccine escape of the circulating strains, including an approach to evaluate those present at lower frequencies will be developed.

Third, metagenomics as an open approach that potentially allows the detection of any pathogens will be developed. These methods will be applied to wastewater samples, taking advantage of the national wastewater surveillance of SARS-CoV-2 already in place for each country of the consortium.

Research Project Name	CLIMPATHIC
Funding	ACIP - FUNDED 2024, IP Paris
Project duration	2024-2028
Collaboration	Institut Pasteur du Cambodge : Virology Unit (Erik Karlsson), Sciencano (Laura Van Poelvoorde) Institut Pasteur New Caledonia (IPNC)

WaSPP: Detection of pathogens with pandemic potential in urban wastewater as an early warning of human adaptation and transmission

This project aims to develop and implement a robust wastewater surveillance system to monitor viral families with pandemic potential in Southeast Asia.

Focusing on priority pathogen panels, the initiative will optimize protocols for sample concentration and next-generation sequencing, and validate these methods in local laboratories across the region. Pilot surveillance activities will be carried out in Malaysia, Indonesia, and Cambodia. The broader objective is to establish a model for wastewater-based surveillance tailored to pandemic-prone viruses, define a target product profile, and foster a regional network to support knowledge exchange and professional development in pathogen monitoring.

Research Project Name	WaSPP
Funding	Imperial College, HKJC Charities Trust (Institute of Philanthropy)
Project duration	2025 – 2027
Collaboration	Institut Pasteur du Cambodge: Virology Unit (EA Karlsson)

BioPrevail Built Environment Design Challenge - CoLab

CoLab is a circular plastic waste-to-resource system where decontaminated lab plastics are converted into cold-storage consumables using accessible locally adaptable technologies through a closed-loop process. A key innovation is the integration of heat-recovery from biobank -80C freezers, capturing and reusing waste heat to power stages of the recycling workflow or support ancillary operations. This improves energy efficiency while ensuring that all materials entering the recycling pathway meet strict biosafety requirements, eliminating residual biological hazards. At the same time, establishing a controlled, traceable recycling workflow improves biosecurity by ensuring that materials originating from the biobank environment are securely handled throughout the process.

During the Development Phase at the end of 2025, the team refined the cold-storage box design through structured user testing and successfully produced early prototypes using recycled filament in collaboration with our 3D-printing partners. In parallel, we conducted technical assessments and iterative system testing to identify solutions that are feasible and effective within the constraints of our existing equipment, technical capacity, and on-site resources.

By the time of the showcase in mid-December 2025, several foundational systems had been established. A campus-wide waste segregation process was implemented, exhaust ducting was installed to recover waste heat from −80 °C freezers, and significant progress was made in filament production.

A substantial portion of this phase focused on improving recycled feedstock quality through systematic experimentation with plastic blends and additives. While iterative and hands-on in nature, this work was critical to developing a reliable and scalable material refinement process.

To strengthen long-term implementation capacity, the team also completed a three-day 3D-printing training, building in-house technical expertise to support future production.

Research Project Name	CoLab
Funding	Global Health Security Fund through BioPrevail
Project duration	Sep 2025 - May 2026
Collaboration	Institut Pasteur du Cambodge: Virology Unit (S Perez, H Lim, J Nouhin, L Heng, S Kong, W Kuork, EA Karlsson)

3.4.3 Scientific Trainings, Workshop and Symposia

Workshops and Trainings

African Swine Fever Sequencing Training in collaboration with the National Center for Veterinary Diagnostics

In March 2025, the Virology Unit, in collaboration with FAO ECTAD and Vietnam's National Center for Veterinary Diagnosis (NCVD), conducted a technical training mission in Hanoi focused on sequencing and genomic analysis of African Swine Fever Virus (ASFV), with broader applications for avian influenza and veterinary pathogen surveillance. The training combined hands-on laboratory work and bioinformatics instruction, including nucleic acid extraction, Nanopore sequencing, genome mapping, phylogenetic analysis, and use of rapid analysis platforms such as CZID. Participants successfully generated and analyzed ASFV sequencing data from outbreak samples while also identifying critical challenges related to sample quality, metadata collection, laboratory infrastructure, and sequencing workflows. The mission strengthened NCVD's capacity for pathogen genomic surveillance and laid the foundation for continued technical exchange, advanced bioinformatics training, and regional collaboration between Vietnam, FAO, and IPC to support veterinary outbreak preparedness and response.

Organizers	Erik Karlsson, Janin Nouhin, Leakhena Phum
Funding	FAO ECTAD – Regional Office for Asia and the Pacific (RAP)
Dates	2 March 2025 – 6 March 2025
Collaboration	Institut Pasteur du Cambodge: Virology Uni Food and Agriculture Organization of the United Nations (FAO ECTAD-RAP) National Center for Veterinary Diagnosis (NCVD), VietnamDepartment of Animal Health, Vietnam

Metagenomic Sequencing of Respiratory Viruses

In May 2025, the Virology Unit partnered with PREPARE and the Asia Pathogen Genomics Initiative (Asia PGI) through Duke-NUS Medical School to deliver a regional training workshop on metagenomic sequencing of respiratory viruses in Singapore. The workshop brought together laboratory technicians and scientists from across the PREPARE CAP/RESPIRO network to strengthen regional capacity in pathogen genomics and respiratory virus surveillance. The training combined lectures, laboratory practicals, and bioinformatics sessions using both Oxford Nanopore Technologies (ONT) and Illumina sequencing platforms. Participants received hands-on experience in metagenomic workflows, sequencing approaches including SISPA and capture-based methods, genomic data analysis, and phylogenetics. The workshop also addressed ethical, legal, and governance considerations surrounding pathogen sample and data sharing, reinforcing regional collaboration and sustainable capacity building in respiratory virus genomics.

Organizers	Erik Karlsson, Janin Nouhin, Vireak Heang, Limmey Khun, Giorgio Gonnella
Funding	PREPARE: RESPIRO, AsiaPGI
Dates	May 15, 2025 - May 21, 2025
Collaboration	Institut Pasteur du Cambodge : Virology Unit with The Asia Pathogen Genomics Initiative (Asia PGI)

Cell Culture, Virus Isolation and HA/HI in Seasonal Influenza

This training was conducted by the Cambodian National Influenza Center (NIC) and WHO H5 Reference Laboratory at IPC for the National Institute of Public Health, with the aim of providing hands-on experience in cell culture, virus isolation, and HA/HAI testing. The training strengthened practical knowledge of biosafety protocols and laboratory procedures while familiarizing participants with IPC-

recommended workflows, technical standards, and best practices for influenza diagnostics and virological testing.

Organizers	Erik Karlsson, Janin Nouhin, IN Saraden, BUN Kimrong, HENG Leangyi, PHOUT Yisuong, YUN Chanvannak, Y Phalla, Miylenniem LAY, Sreymom Ken
Funding	IPC, WHO
Dates	June 23, 2025 - July 19, 2025
Collaboration	Institut Pasteur du Cambodge : Virology Unit

Training Program for technical staff under the General Directorate of Animal Health and Production on the Utilization of Tablets for Animal Diseases Surveillance and Outbreak Investigation

This training was conducted to equip GDAHP staff with the skills necessary to utilize tables effectively in surveillance and outbreak investigation efforts and control animal diseases in a timely manner to reduce its impact. The training also involved the development of specific outbreak investigation forms for critical diseases using KOBO Toolbox.

Presenter/Organizer	Frida Sparaciari/FAO
Funding	FAO
Dates	Jul 1, 2025 - Jul 3, 2025
Collaboration	Institut Pasteur du Cambodge : Virology Unit FAO

Training Course for Veterinary Diagnostic Laboratory Network Partners: Surveillance and Monitoring of Pathogens at High-Risk Interfaces

In June 2025, the Virology Unit, in collaboration with the International Atomic Energy Agency (IAEA) under the ZODIAC initiative, hosted a regional training course on surveillance and monitoring of pathogens at high-risk interfaces at IPC in Phnom Penh. The five-day program brought together veterinary laboratory partners and technical experts from across Asia, including participants from Indonesia, Lao PDR, Malaysia, Mongolia, Nepal, Sri Lanka, Thailand, and Vietnam. The training combined lectures, field exercises, and laboratory demonstrations focused on environmental and One Health surveillance, sampling at live animal markets, biosafety, field-forward diagnostics, PCR, Nanopore sequencing, metagenomics, and interpretation of environmental surveillance data. A notable component of the training was collaboration with the Asia Pathogen Genomics Initiative (Asia PGI) at Duke-NUS, which contributed expertise and strengthened discussions around the legal and ethical governance of environmental sampling and data sharing. This convergence of IPC, IAEA, Asia PGI, and national veterinary partners highlighted the growing regional momentum toward integrated surveillance, pathogen genomics, and practical One Health preparedness at high-risk human–animal–environment interfaces.

Organizers	Erik Karlsson, Janin Nouhin, Sreymom Ken, Anna S. Fomsgaard, Frida Sparaciari, Jurre Siegers, Sopheak Thet, Kim Lay Chea, Vibol Hul, Songha Tok, Victor Omondi, Sophoannadedh Rath, Sarath Sin, Miylenniem Lay, Sereyright Saulim, Limmey Khun, Sreyviseth Horm, Sofia Perez
Funding	Joint FAO/IAEA Centre and Asia Pathogen Genomics Initiative
Dates	Aug 4, 2025 - Aug 22, 2025
Collaboration	Institut Pasteur du Cambodge : Virology Unit Joint FAO/IAEA Centre and Asia Pathogen Genomics Initiative

Utilizing Metagenomic Data from Environmental Samples for Public Health Action

The workshop established a shared understanding of how Environmental Surveillance (ES) data, including metagenomics, can be used for pathogen detection and public health actions and response

in South Africa. It provided a platform to reflect on what ES could look like in a national context, drawing inspiration from ongoing international experiences. The workshop explored how ES data could be better communicated and interpreted between academia and different stakeholders. Through shared presentations, discussions and group exercises, participants exchanged ideas and reflections that can enable future applications of ES in the South African context, and begin building a professional network or working group to continue collaboration beyond the workshop. The objectives of the workshop was to build understanding and effective use of Environmental Surveillance (ES) by introducing its principles and applications for detecting and tracking pathogens in wastewater, exploring current knowledge gaps and practical challenges in South Africa, and strengthening the capacity to interpret and communicate sequencing data so it can inform meaningful public health action.

Organizers	Anna S. Fomsgaard, Frida Sparaciari, Erik Karlsson, Sofia Perez
Funding	Durban University of Technology
Dates	Nov 24, 2025 - Nov 26, 2025
Collaboration	Institut Pasteur du Cambodge : Virology Unit Durban University of Technology

Next Generation Sequencing and Nanopore Sequencing Applications for the Detection and Characterization of Pathogens

This training focused on virus detection using Nanopore sequencing and integrated indexed primers.

Presenter / Organizer	Anna S. Fomsgaard / IAEA
Funding	Joint IAEA/FAO Centre
Dates	Nov 10, 2025 - Nov 16, 2025
Collaboration	Institut Pasteur du Cambodge Joint IAEA/FAO Centre

Symposium

Framework for Live Animal Market Investigations and Guidelines Harmonization and Techniques in Africa and Asia

The CANARIES II: FLIGHT technical meeting was convened in Bangkok, Thailand (1–3 December 2025) by the CANARIES network in collaboration with FAO and IPC, bringing together multidisciplinary experts from Asia, Africa, Europe, and international organizations to advance One Health approaches for live animal market risk assessment and surveillance. Participants further developed the conceptual framework for a novel Market Mapping Tool (MMT) integrating biological, behavioral, infrastructural, and governance dimensions of live animal markets. Pilot implementation of the MMT was confirmed for 2026 across three countries in Asia and three in Africa, marking an important transition for CANARIES from network coordination toward practical implementation and market-focused risk reduction.

3.4.4 Teaching and Students

Visiting Scientists

- SON Sungmin, Korea Advanced Institute of Science and Technology (KAIST), South Korea, 7–10 Jan 2025, Collaborative research on Dengue Virus diagnostic development
- HEO Yunnyeong, Korea Advanced Institute of Science and Technology (KAIST), South Korea, 7–10 Jan 2025, Collaborative research on Dengue Virus diagnostic development

- Tritipchatsakun Chawapon, Korea Advanced Institute of Science and Technology (KAIST), Thailand, 7–10 Jan 2025, Collaborative research on Dengue Virus diagnostic development
- Claire GUINAT, National Research Institute for Agriculture, Food and the Environment, France, 13–22 Jan 2025, Collaborative research on Dengue Virus diagnostic development
- Pauline VAN LEEUWEN, Université de Liège, Belgium, 26 Jan–28 Mar 2025, Fieldwork and lab work support for the BCOMING project
- Claire GUINAT, National Research Institute for Agriculture, Food and the Environment, France, 12–23 May 2025, Collaborative research on Dengue Virus diagnostic development
- Cong XU (Charles), Wildlife Conservation Society, Hong Kong, 24 May–16 Aug 2025, Genetic viral screening and metagenomics on biobanked wildlife samples
- Dolyce LOW Hong, Duke-NUS Medical School, Singapore, 23–27 Jun 2025, Genetic and serological screening for Orthonairovirus diversity and zoonotic risk
- Claire GUINAT, National Research Institute for Agriculture, Food and the Environment, France, 8 Aug 2025–1 Mar 2026, Collaborative research on Dengue Virus diagnostic development
- Sara ZUFAN, National Research Institute for Agriculture, Food and the Environment, France, 1 Sep 2025–31 Dec 2026, Genetic and serological screening for Orthonairovirus diversity and zoonotic risk
- Brown BULLOCH, Laval University, Canada, 15 Sep–19 Dec 2025, Antigenic and phylogenetic analysis of avian influenza virus, fieldwork and in vitro assays
- Jane LUCAS, Cary Institute of Ecosystem Studies, USA, 28 Sep–7 Oct 2025, Collaborative work on disease ecology and soil science
- Barbara HAN, Cary Institute of Ecosystem Studies, USA, 28 Sep–7 Oct 2025, Talk on predicting unknowns in disease ecology and meetings with grant collaborators
- Béatrice CHATAIGNER, CIRAD/INRAE, France, 15–22 Dec 2025, Field site visit for BCOMING data collection sites

Student Interns

- UM Chanthou, Royal University of Phnom Penh, Cambodia, Feb–Jul 2025, Bachelor in Bio-Engineering
- HONG Sreynich, University of Puthisastra, Cambodia, Jun–Jul 2025, Master of Biology
- LIM Sokhany, University of Puthisastra, Cambodia, Jun–Jul 2025, Master of Biology
- PHY Chhoryt, Royal University of Phnom Penh, Cambodia, Jul–Aug 2025, Bachelor Student
- VAT Cheng, Royal University of Phnom Penh, Cambodia, Jul–Aug 2025, Bachelor Student
- TITH Sokteang, Royal University of Phnom Penh, Cambodia, Jul–Aug 2025, Bachelor Student
- SIENG Saychinh, University of Health Sciences, Cambodia, Mar–Sep 2025, Master of Medical Biology
- KHY Yanuth, University of Puthisastra, Cambodia, Sep–Dec 2025, Bachelor in Science Research
- SIM Nita, University of Puthisastra, Cambodia, Sep–Dec 2025, Bachelor in Science Research
- ANN Reaksa, University of Puthisastra, Cambodia, Sep–Dec 2025, Bachelor in Science Research
- THY Chanthoerun, University of Puthisastra, Cambodia, Sep–Dec 2025, Bachelor in Science Research
- Thomas MARTINEZ, University Paris Cité, France, Jan–Jul 2025, Master – 6th Year of Pharmacy
- Aristide MOUNCHILI NJIFON, University of Yaoundé, Cameroon, Mar–Jun 2025, PhD Student
- Celia MOURGUES, École Nationale Vétérinaire de Toulouse, France, Jul–Aug 2025, Master of Veterinary Medicine

- Julien MAIRE, École Nationale Vétérinaire de Toulouse, France, Jul–Aug 2025, Master of Veterinary Medicine

PhD students

- Ou Tey Putita, Université de Montpellier, France, 2021-2025, Diversity and characterization of coronaviruses circulating in bats in Cambodia
- Julia Guillebaud, University of Montpellier, France, 2022-2025, Assessment of the risk of emergence of coronaviruses in human population at the wildlife interface in Cambodia
- Frida Esther Sparaciari, James Cook University, Australia, 2023-2026, University, Development of a framework for determining zoonotic emerging infectious disease risk profiles at traditional food markets in Cambodia
- Thavry Hoem, University of Montpellier, France, 2024-2026, Population dynamic and spatial distribution of rhinolophus sp. Bat: Contribution to risk assessment of Coronaviruses Spilloever in Northern Cambodia

Master students

- Kimrong Bun, University of Health Sciences, 2025 - 2026
- Chanvannak Yun, University of Health Sciences, 2025 - 2026
- Phalla Y, University of Health Sciences, Medical Biology, 2025 - 2026

Bachelor students

- Heng Leangyi, University of Health Sciences, Cambodia, Medical Laboratory Technology, 2022 - 2025
- Chel Kimtuo, University of Health Sciences, Cambodia, Laboratory Technology, 2023-2026
- Chantha Soursdey, University of Puthisastra, Cambodia, Medicine, 2023-2025

Teaching

- HORM Sreyviseth, course “Infectious Disease agents” (13h) for Foundation Year – Infectious Disease at University of Health Sciences in Phnom Penh - Sep - Nov 2025
- HORM Sreyviseth, course “Respiratory Infection” (5h) for 5th Year Pharmacy – Clinical Biology at University of Health Sciences in Phnom Penh - Jan 2025

Received Training

Attendees	Topic	Training Name / Focus	Short Description and Purpose of Training	Location	Organizers and Trainers
Frida Sparaciari	Thematic Analysis Research Methods Masterclass	Data analysis	It covers the philosophical foundations of qualitative research, study design, data collection methods, and tools for both data collection and analysis.	Australia	JCU
Frida Sparaciari		Croucher Summer Course	Emerging viral infections	Hong Kong	HKU-Pasteur Research Pole
CHEA Kimlay	The Risk Awareness of HPAI in Cambodia	Revising & Updating Risk awareness communicatio n Materials	The workshop: Present and validate findings from the reviews of FAO/ GDAHP AIV communication materials, develop and seek agreement, discuss and prioritize effective communication methods,	Cambodia	FAO/ GDAHP

			define next steps for design, productions, finalization...		
HEANG Vireak	Next Generation Sequencing	Strengthening genomics informed surveillance, diagnosis, and control of infectious diseases across the Asia-Pacific	Whole genome sequencing and bioinformatic analysis of viral and bacterial pathogens	Australia	The University of Melbourne
Leangyi HENG	Dengue Prevention and Control	Ninth Singapore International Dengue Workshop	Equipping participants with knowledge and skills to strengthen the national integrated surveillance, control, and clinical management of dengue; Promoting close intersectoral collaboration, among laboratory, field, and clinical components	Singapore	NEA and WHO
Leangyi HENG	Implementation of the Biological Weapons Convention	Biological weapons convention	Focused on the history of biological warfare, modern synthetic biology risks, and the "Article X" mechanism for international cooperation	Virtual	UN office for Disarmament Affairs
Leangyi HENG	Project Management in Global Health	Project Management in Global Health Professional Development	The course trains professionals to plan, implement, manage, and evaluate global health projects effectively	Virtual	University of Washington
Leangyi HENG	Fundamentals of Laboratory Biosecurity	Laboratory Biosecurity	Biosafety and Biosecurity	Virtual	Integrated quality laboratory services
Leangyi HENG	Essentials of Laboratory Safety	Laboratory Biosafety	Biosafety and Biosecurity	Virtual	Integrated quality laboratory services
Vibol HUL	EMS Management on the 7-1-7 Assessment Tool for National level	EMS (Event Monitoring System) emergent response of outbreak	Rapid response tool especially: 7-1-7 assessment tool	Kampot	Cambodia CDC, MOH

Sophoannadedh RATH	Bioinformatics	Bioinformatics Training	Introduction to bioinformatics basic and learn how to choose the correct tools used when analysing data.	Laos	Institut Pasteur, Paris
Khun Limmey	Project Management in Global Health	Project Management in Global Health Professional Development	The course trains professionals to plan, implement, manage, and evaluate global health projects effectively	Virtual	University of Washington
Khun Limmey	Bioinformatics And Genomic Epidemiology	Genomic Epidemiology of Viral Pathogens	To implement genomic epidemiology during viral outbreak	Signapore	Asia PGI through the Duke-NUS Centre for Outbreak Preparedness (COP)
Keo Seangmai, Chantha Soursdey	RPA and LAMP	Recombinase polymerase amplification (RPA) and Loop-mediated isothermal amplification (LAMP)	Lectures and laboratory activities. - participants able to perform new molecular analyses(RPA and LAMP).	Laos	Institut Pasteur, Paris
Leakhena Pum, Sofia Perez	Project Management in Global Health	Project Management in Global Health Professional Development	The course trains professionals to plan, implement, manage, and evaluate global health projects effectively	Online	University of Washington
Leakhena Pum	Infectious disease	Emerging Pathogen	This course covered major infectious diseases and emerging pathogens, including transmission, diagnosis, prevention, and control.	France	Institut Pasteur, Paris
Janin Nouhin	Mpox Virus Genomic Sequencing	Genomic Sequencing of Emerging High Threat Pathogens	To enhance regional readiness and response to emerging public health threats, by developing a pool of trained personnel capable of conducting genomic sequencing and analysis for MPXV, and other public health priority pathogens, in their respective countries.	Australia	

3.4.5 Support to National Authorities

National Dengue Control Program (NDCP) in Cambodia

As part of a collaboration with WHO and NDCP, the Virology Unit receives samples of suspected dengue cases from six provincial hospitals, from the National Pediatric Hospital in Phnom Penh, and from IPC's Medial Biological Laboratory (LBM). Results from the virological monitoring of samples from patients with hemorrhagic syndromes are reported weekly or monthly to the various monitoring program participants (Director of the NDCP, hospital physicians, etc.). This long-term ongoing investigation shows that all four DENV serotypes are co-circulating in Cambodia with changing dominant serotypes. The surveillance data between 2000 and 2025 reveals that there were four big dengue outbreaks observed in 2007 by DENV-3, in 2012 by DENV-1, in 2019 by DENV-1 and in 2024 by DENV-2. DENV-4 circulates at background level. The genomic data showed that there was constant replacement of serotypes/genotypes/lineages and these replacements were often associated with big dengue outbreaks.

In 2025, the Virology Unit received 2246 samples from suspected dengue patients admitted to the sentinel hospitals and 1760 were confirmed positive by RT-PCR (78.4%). DENV-2 (n=1111; 49.5%) was the major serotype detected followed by DENV-1 (n=354; 15.8%), DENV-3 (n=150; 6.7%) and DENV-4 (n=145; 6.5%). Besides, DENV, Zika virus (ZIKV) is reported to be endemic in Cambodia but in low prevalence.

Cambodian National Influenza Center

Seasonal human respiratory virus surveillance (Influenza-like Illness and Severe Acute Respiratory Illness)

IPC's Virology Unit has been Cambodia's National Influenza Center (NIC) since 2006 and in the same year, the influenza-like illness (ILI) surveillance was established, in collaboration with the MoH and WHO, and allows for the collection of influenza strains and data on seasonality. In 2025, eight hospitals in these provinces contribute to ILI surveillance: Kampot, Battambang, Kampong Cham, Mondulkiri, Svay Rieng, Preah Vihear, Angkor Children's Hospital (Siem Reap) and the National Pediatric Hospital (Phnom Penh). Each hospital randomly collects clinical samples from a maximum of 5 ILI patients per week. Samples are first analyzed by NIPH and are then sent to IPC for confirmation.

IPC's Virology Unit conduct Severe Acute Respiratory Illness (SARI) surveillance by receiving SARI samples from the children hospitals (Kuntha Bopha in Phnom Penh and Jayavaraman 7 in Siem reap) and receiving SARI samples with detection positive H5N1 from NIPH for confirmation testing.

Human seasonal influenza

Cambodia has two distinct seasons, the dry season, which generally runs from November to April, and the rainy season, which starts in May/June and ends in October/November. In Cambodia, influenza cases usually increase during March–June, and peak between July and September, corresponding to influenza circulation in the temperate regions of the southern hemisphere, although low level year-round circulation of influenza occurs. The current global COVID-19 pandemic has significantly altered both the surveillance and landscape of respiratory diseases worldwide. Indeed, the introduction of control measures in early 2020 to reduce the transmission and disease burden of SARS-CoV-2 infection has shown a remarkable reduction in the infection rates of many respiratory diseases despite continued, or even increased, testing for influenza in some countries. In 2025 a total of 449 ILI samples were received from NIPH for influenza confirmation testing. 325 samples (72%) were tested positive for influenza virus. The dominant circulated influenza virus in 2025 was A/H1N1pdm (43%) flowed by

A/H3N2 (39%) and influenza B/Victoria (17.5%). No influenza B/Yamagata virus circulated in Cambodia in 2025.

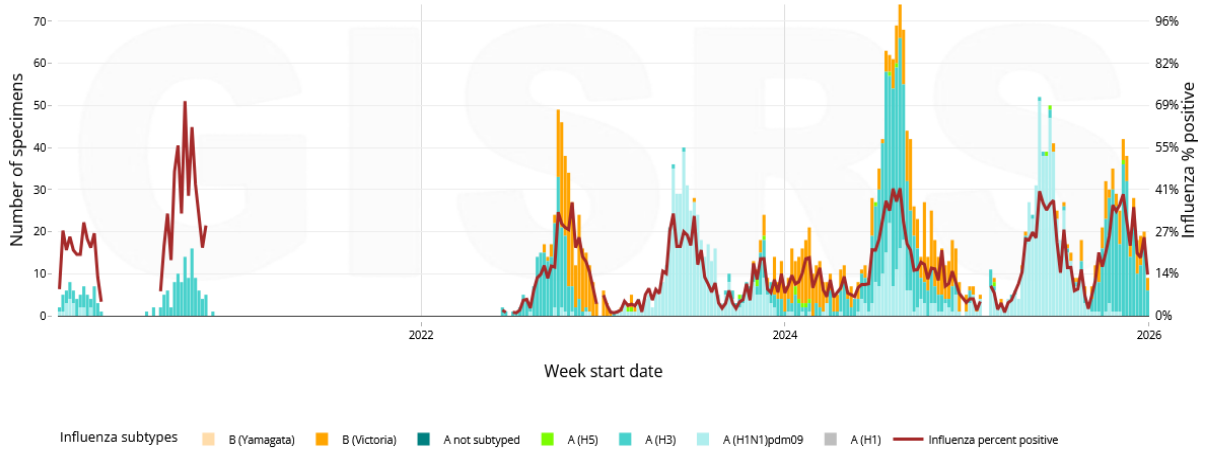

Figure 13: *Number of influenza cases detected in sentinel and outbreak samples 2020-2025. No influenza cases were detected in Cambodia in 2021. Influenza returned to Cambodia in 2022. Data source: FluNet (https://www.who.int/tools/flunet)*

Respiratory syncytial virus and parainfluenza virus

While the dangers of avian influenza and SARS-CoV-2 are well established, the prevalence and etiology of other respiratory pathogens such as parainfluenza virus (PIV), respiratory syncytial virus (RSV), adenovirus and rhinovirus have not been well studied. RSV is particularly important as it is the leading cause of respiratory infection-associated hospitalization of children aged <5 years in industrialized countries. New WHO guidelines are establishing an enhanced global influenza surveillance and response system (GISRS+) system which focuses on including RSV surveillance into existing sentinel systems.

As per surveillance decisions, IPC began prospectively screening all samples from symptomatic children <5 years of age in August 2021 for RSV and PIV. Unlike influenza, RSV and PIV were detected in Cambodian children, with a small outbreak of PIV-2 in October and RSV-A in late October, early November 2021. RSV-B and PIV-3 were also detected sporadically. RSV and PIV were continued to be monitored in 2025 with only a limited number of samples tested. Sequencing, analysis, and publication are underway to describe these viruses in Cambodian children expected mid- to late 2026.

In 2025 a total of 74 samples of 55 SARI cases were received and tested for RSV and PIV with only 1 sample detected positive for RSV B.

WHO H5 Reference Laboratory

Detection and response to A/H5N1 infections in humans in 2023 – 2025.

Highly pathogenic avian influenza (HPAI; subtype A/H5N1) has remained endemic in Cambodia since 2004 and continues to pose significant risks to both animal and human health.

By November 2025, Cambodia had reported a total of 90 confirmed human A/H5N1 cases with 52 deaths (overall case fatality rate [CFR] 57.8%). Following the last human case reported in 2014, Cambodia experienced nearly a decade without confirmed human infection before spillover re-emerged in 2023. Since re-emergence, 6 human cases were detected in 2023**,** followed by 10 confirmed cases in 2024**,** and 18 confirmed cases with 9 deaths in 2025 (2025 CFR 50.0%), representing the highest annual burden of human A/H5N1 infection reported in Cambodia since 2013. Human cases

during 2025 were detected across multiple provinces including Phnom Penh, Prey Veng, Siem Reap, Kratie, Kampot, Takeo, Svay Rieng, and others, highlighting the continued widespread circulation and spillover risk associated with poultry exposure and high-risk interfaces.

Historically, HPAI A/H5N1 viruses circulating in Cambodia following the 2013 outbreak period were primarily classified within clade 2.3.2.1 viruses.

Between 2014 and 2018, the dominant viruses detected in Cambodia belonged to clade 2.3.2.1c, while broader regional evolution of H5 viruses continued with the emergence and spread of clade 2.3.4.4 viruses globally. Through longitudinal surveillance conducted jointly by IPC and the National Animal Health and Production Research Institute (NAHPRI), HPAI viruses belonging to the 2.3.4.4 lineage, including H5N6 variants, were identified in Cambodian poultry and live bird markets beginning in 2018–2020, while clade 2.3.2.1 viruses continued circulating in poultry populations.

The Cambodian National Influenza Center (NIC) and WHO H5 Reference Laboratory at IPC maintained enhanced laboratory surveillance and rapid genomic characterization of all suspected human A/H5N1 cases throughout 2025. Samples were sequenced using iiMS-PCR and real-time Oxford Nanopore GridION workflows, allowing genomic characterization within 24 hours of sample receipt. Sequencing coverage of the HA gene routinely exceeded 100× and was integrated with contemporaneous poultry and live bird market surveillance data to support outbreak investigations and genomic epidemiology. Phylogenetic analyses consistently demonstrated close clustering between human infections and poultry or live bird market viruses from associated geographic areas, supporting epidemiologic evidence that infections resulted from repeated poultry-to-human spillover rather than sustained human-to-human transmission. Sequence data were rapidly shared through international databases including GISAID to support global situational awareness and risk assessment.

Deeper molecular and phylogenetic analyses of viruses obtained from human cases and associated poultry between late 2023 and 2025 demonstrated that the currently circulating Cambodian A/H5N1 viruses represent a reassortant genotype. While the hemagglutinin (HA) gene remains closely related to regional clade 2.3.2.1 viruses circulating in Cambodia and Southeast Asia, the internal gene constellation contains segments derived from clade 2.3.4.4b viruses, including the mammalian-adaptive PB2-627K mutation.

This reassortant genotype therefore represents more than a continuation of historical Cambodian H5N1 viruses and instead constitutes a distinct viral lineage requiring continued monitoring and formal risk assessment. Although no evidence currently suggests sustained human transmission, the emergence and continued circulation of this reassortant virus underscores the importance of coordinated human, animal, and environmental surveillance to rapidly identify evolutionary changes that may alter zoonotic or pandemic risk.

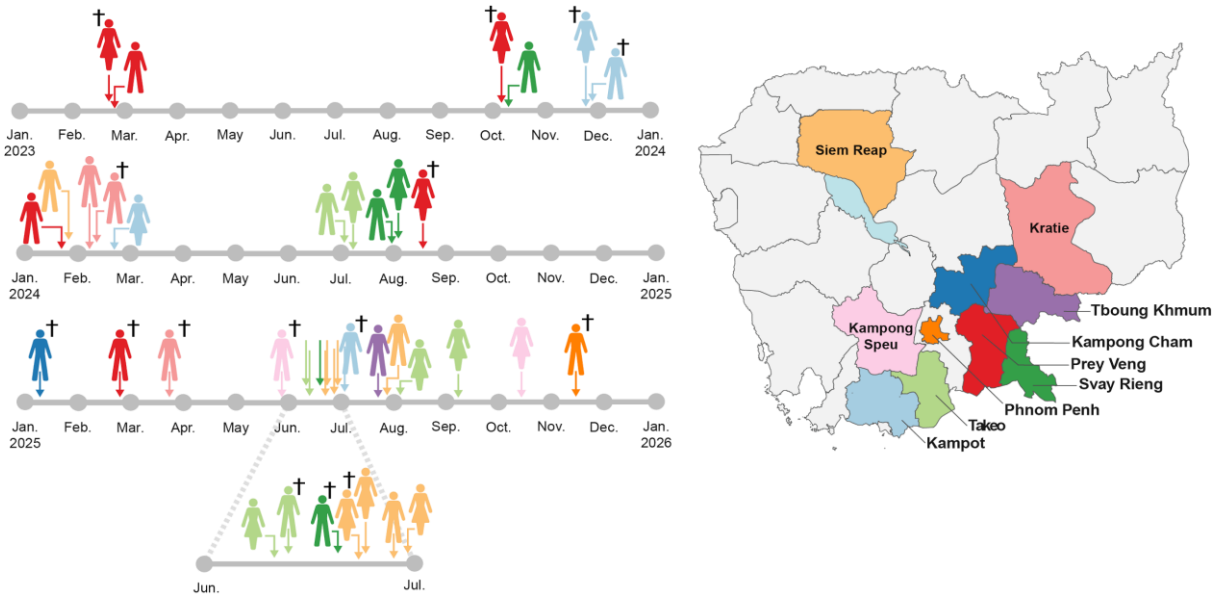

***Figure 14**: Case timeline of A/H5N1 infections in Cambodia between 2023 and 2025. The positive detection of this case represents the 18th case in 2025.*

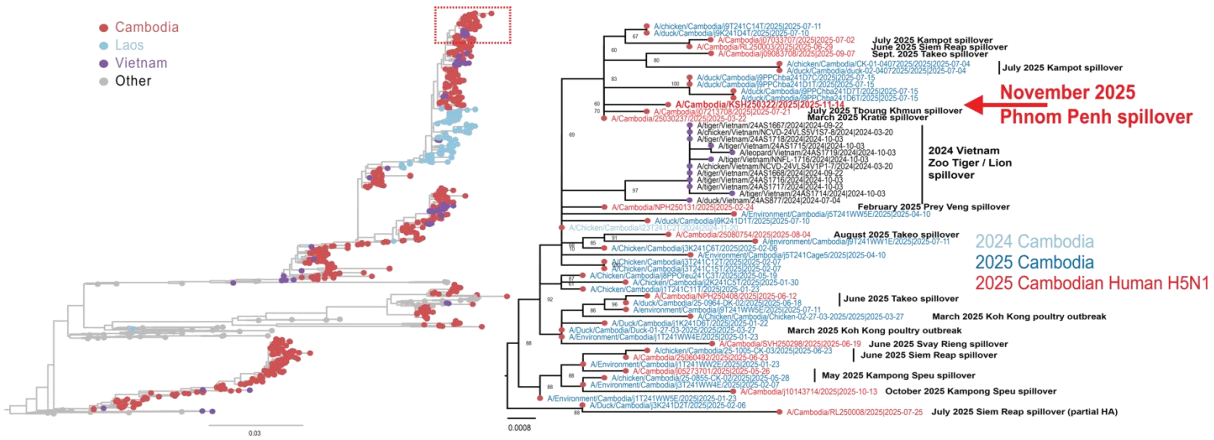

***Figure 15:** Phylogenetic tree of A/H5Nx hemagglutinin (HA) gene for sample from case from the Phnom Penh spillover in November 2025 and from human cases and associated poultry, poultry outbreaks, and Live Bird Market surveillance in 2023-2025. Sequences were aligned using MAFFT v.7.490 (PMID: 23329690), trimmed using trimAL (PMID: 19505945) and phylogenetic trees were constructed using IQ-TREE v.2.0.3 (PMID: 32011700) with the best-fit nucleotide substitution model (GTR+F+I+G4 chosen according to Bayesian Information Criterion (BIC)). Trees were visualized and annotated using FigTree v.1.4.4 (http://tree.bio.ed.ac.uk/software/figtree/) and Adobe Illustrator 27.3. Human A/H5N1 cases are highlighted in bold red. A/H5N1 sequences from case in this report and are indicated by red arrow and annotation. Other bird market and poultry samples available from Cambodia are indicated in light blue (2024), and dark blue (2025). Other spillovers are indicated by annotation.*

WHO Global COVID-19 Reference Laboratory (Now CoViNeT Laboratory)

Novel coronavirus disease 2019 (COVID-19)

Following the detection of a cluster of cases of pneumonia of unknown etiology in Wuhan, China in December, 2019, on 27 January, IPC confirmed the first COVID-19 case (a traveller from Wuhan) in Cambodia. In April 2020, the work done at IPC in response to the global COVID outbreak was recognized by designating the Virology Unit as a WHO COVID-19 global reference centre. In addition,

IPC continues working closely with the Cambodian CDC, which is the coordinating entity designated for notification of suspected cases, and the COVID-19 sampling system. While testing significantly decreased since 2022, by 31 December 2025, IPC had tested over 945,040 samples 472 samples in 2025) for SARS-CoV-2 by RT-PCR and identified (or confirmed when first identified by NPHL at NIPH or one of the regional laboratories) 11,953 of positive cases as part of surveillance and response, including the ongoing community transmission events.

SARS-CoV-2 Sequencing

IPC has been able to establish a highly multiplexed PCR amplicon approach using the ARTIC Network multiplex PCR primers set v3, v4, and MIDNIGHT protocols on Oxford Nanopore GridION/MinION technology, in part from collaboration with partners at IP-Paris. This technique has successfully been employed by IPC to sequence SARS-CoV-2 samples with low viral load (Ct = <30) and is used weekly to sequence a limited number of samples to help with the COVID-19 response efforts and for monitoring clusters and community spread. Between January 2020 and the end of December 31st 2025, IPC was able to sequence 3,405 samples (2.44 % of the total reported cases at that time) and submitted results to GISAID.

Viral Isolation Titration

Having a BSL-3 level facility and experience in isolating numerous types of viruses, IPC was quickly able establish viral isolation and tittering (both TCID50 and PFU) for COVID-19 in Cambodia. At the current time, 129 viral isolates (Wuhan-like, Alpha, and Omicron) are available from patients identified in Cambodia. We have as yet been unsuccessful in isolating the Delta VoC. This strain biobank is vital, not only for our continued validation and technical improvement work, but also for establishing serological assays for sero-epidemiological surveys and contact-tracing efforts. Further isolation attempts are made on all possibly viable samples available.

Diagnostic for rabies infection in animals

2025 Rabies Surveillance: Post-Mortem Diagnostic Outcomes at IPC Rabies Prevention Centers

To better understand rabies virus diversity in Cambodia, whole-genome sequencing was performed. One golden jackal, 58 dog brains, and 3 human samples collected in 2021–2025 with RT-PCR cycle threshold (Ct) values <20 were selected for sequencing using an amplicon-based approach adapted from the ARTIC Network rabies virus protocol. Multiplex PCR amplification was conducted with the rabvSEasia/V2 primer scheme, generating overlapping tiled amplicons across the viral genome. Sequencing libraries were prepared and run on the GridION platform with R10 flow cells. Raw reads were processed using the ARTIC bioinformatics pipeline (artic-rabv environment) to generate consensus sequences. Consensus genomes, together with representative regional and global reference sequences retrieved from GenBank, were aligned using MAFFT. Maximum-likelihood phylogenetic trees were inferred with IQ-TREE using automatic model selection, with branch support assessed by 1,000 bootstrap replicates. The phylogenetic analysis revealed that all viruses clustered within the Asian major clade, specifically the Asian SEA3 minor clade *(Figure 16).* This genetic homogeneity suggests sustained circulation of a dominant lineage in Cambodia.

The inclusion of a wildlife isolate highlights the importance of monitoring potential cross-species transmission at the animal–wildlife interface.

Tree visualization and annotation were performed using FigTree and Inkscape. All 59 sequences clustered within the Asian major clade, specifically the Asian SEA3 minor clade.

Figure 16: *Maximum likelihood full genome phylogenetic tree of rabies virus. Maximum-likelihood phylogenetic trees were inferred with IQ-TREE using automatic model selection, with branch support assessed by 1,000 bootstrap replicates. Tree visualization and annotation were performed using FigTree and Inkscape. Cambodian strains included in the present study are indicated in red.*

3.4.6 Outlook for 2026

Research Programs

Preventing Avian Influenza in the Pacific

The PACAI project, funded by the PREZODE initiative and led by the Institut Pasteur de Nouvelle-Calédonie, aims to prevent the emergence and spread of Highly Pathogenic Avian Influenza (HPAI) within Pacific Island Countries and Territories (PICTs).

The project will implement advanced surveillance techniques in domestic and wild bird populations and utilize innovative diagnostic tools to enhance detection capabilities. PACAI will also assess the economic and societal impacts of avian influenza, strengthening local preparedness and response strategies. Activities are conducted in close collaboration with regional and international partners, adopting a multidisciplinary One Health approach to safeguard both human and animal health.

The planning phase is underway, with initial fieldwork pending regulatory approvals from local authorities.

Research Project Name	PACAI (Preventing Avian Influenza in the Pacific)
Funding	PREZODE Initiative (France 2030)
Project duration	2025-2027
Collaboration	Institut Pasteur du Cambodge: Virology Unit (Erik Karlsson). Institut Pasteur de Nouvelle-Calédonie (M. Dupont-Rouzeyrol), Institut Pasteur Paris (J. Vanhomwegen), Institut de Recherche pour le Développement (IRD) (A. Ponchon, E. Vidal), Institut Agronomique Néo-Calédonien (IAC), Institut Pasteur du Cambodge, Université de la Nouvelle-Calédonie, Communauté du Pacifique, Direction des Affaires Vétérinaires Alimentaires et Rurales, Bird Conservation New Caledonia, Direction des Affaires Sanitaires et Sociales, Centre Hospitalier Territorial.

Development and Assessment of Novel, High-Throughput Immunological Assays for Viral Spillover Surveillance

This project, funded by the UKRI Funding Service and led by the University of Oxford, aims to develop and apply innovative, high-throughput immunological assays to enhance surveillance and early detection of zoonotic virus spillover events in Southeast Asia, a region of significant vulnerability for emerging infections. Immunological tools focusing on antibody and T-cell responses will be established to comprehensively map the immune landscape against critical viral families, including Coronaviridae, Orthomyxoviridae, and Paramyxoviridae, in high-risk populations in Cambodia and Vietnam. The project will assess how immunological surveillance strategies can detect spillover events earlier than traditional methods, thereby strengthening pandemic preparedness and response. Additionally, potent broadly neutralizing antibodies against zoonotic viruses will be identified from previously infected individuals.

The project fosters a strong collaborative network involving regional researchers and international experts, enhancing local research capacity and enabling regionally-led responses to future health crises. The planning phase is progressing, with fieldwork scheduled to commence in April 2025, following ethical and regulatory approvals.

Research Project Name	ImmunoSurveil-SEA (Development and Assessment of Novel, High-Throughput Immunological Assays for Viral Spillover Surveillance)
Funding	UK Research and Innovation (UKRI) Funding Service
Project duration	2025-2028
Collaboration	Institut Pasteur du Cambodge (Claude Flamand, Erik Karlsson, Sowath Ly, Tineke Cantaert, Veasna Duong), University of Oxford (Le Van Tan, Gavin Screaton, Nguyen To Anh, Peter Horby), Bioinformatics Institute Singapore (Sebastian Maurer-Stroh), Duke-NUS Medical School (Anthony Tan, Nina Le Bert), Imperial College London (Azra Ghani, Ruth McCabe), National Institute of Hygiene and Epidemiology Vietnam (Pham Quang Thai, Khang Pham Van, Le Hai Dang, Lê Thị Thanh, Nguyễn Phương Anh, Nguyễn Vũ Sơn), National University of Singapore (Chee Wah Tan, Hannah Clapham).

Scaling up early warning surveillance using novel collection and sequencing techniques.

The objective of this proposal is to expand air-based surveillance in live animal markets employing cutting-edge detection and sequencing methods and to further benchmark their performance and utility against standard surveillance techniques. Scale up focuses on using techniques piloted in Cambodia to expand to surveillance in Indonesia, Vietnam, Laos, and the Philippines.

Research Project Name	Scaling up early warning surveillance using novel collection and sequencing techniques.
Funding	Institute of Philosophy, In Discussion 2026
Project duration	2025-2027
Collaboration	Institut Pasteur du Cambodge: Virology Unit (Erik Karlsson) Food and Agriculture Organization of the United Nations (FAO) Hong Kong University Other ministries, stakeholders in partner countries

Workshops

In 2026, the Virology Unit will continue expanding its regional capacity-building activities through specialized workshops and technical training programs focused on pathogen surveillance, sequencing technologies, genomics, and environmental monitoring. These activities will support technology transfer, strengthen laboratory and analytical expertise, and reinforce collaborative networks with national, regional, and international partners.

Planned Workshops and Training Sessions for 2026:

- WaSPP Wastewater Surveillance Workshop – March 2026
- NAHPRI Environmental Surveillance Training – February 2026
- KAIST CRISPR and Diagnostic Development Training – Q2 2026
- Nepal Avian Influenza Sequencing and Genomics Training – TBD
- Additional workshops under PREPARE, environmental surveillance, and pathogen genomics initiatives as opportunities arise.

Together, these workshops will strengthen IPC's role as a regional center of excellence for infectious disease surveillance and laboratory capacity building, while fostering sustainable knowledge-sharing and collaborative preparedness efforts across Asia and beyond.

Other Points

The Virology Unit enters 2026 during a period of rapid scientific growth, expanding regional responsibility, and important institutional transition. Over the past three decades, the Unit has evolved from a traditional virology laboratory into an integrated platform for pathogen surveillance, outbreak response, genomics, environmental surveillance, and One Health innovation. This trajectory will continue in 2026 through strategic expansion of technical capacity, stronger regional engagement, and continued investment in people, partnerships, and emerging technologies.

A defining milestone for 2026 will be the celebration of the Virology Unit's 30th anniversary. This anniversary represents not only an opportunity to recognize the Unit's history and scientific contributions, but also to reflect on its evolution and future direction. Activities planned around the anniversary will highlight the Unit's scientific achievements, long-standing partnerships, and role in strengthening infectious disease surveillance and preparedness in Cambodia and beyond. Bringing together former staff, collaborators, government partners, and international networks will provide an opportunity to celebrate past accomplishments while shaping the next generation of virological research and public health impact.

The Unit will continue strengthening and refining its internal structure to support increasingly complex scientific and reference laboratory activities. While recent years have brought challenges, including staff turnover and evolving funding landscapes, they have also created opportunities to sharpen scientific priorities and strengthen institutional identity. Greater emphasis will be placed on

communication, visibility, and strategic outreach to better convey the Unit's impact to scientific, policy, and public health audiences.

Expansion of human resources remains essential. Increasing demands associated with outbreak response, environmental surveillance, pathogen genomics, and multidisciplinary One Health programs require additional scientific, bioinformatics, and technical expertise. Recruitment and mentorship of scientists, postdoctoral fellows, students, and technical staff will remain a central priority to ensure continuity, maintain innovation, and support the next generation of Cambodian and regional researchers.

Scientific dissemination and visibility will remain another major focus. Large datasets generated through avian influenza surveillance, environmental and wastewater monitoring, pathogen genomics, zoonotic disease ecology, and emerging virus research continue to provide important opportunities for publication, technical guidance, and policy-relevant outputs. Translating these data into high-quality scientific products will reinforce the Unit's role as a leader in regional infectious disease surveillance and research.

Core surveillance activities including live bird market surveillance, influenza monitoring, and investigations at wildlife and environmental interfaces will remain foundational to the Unit's mission. Particular emphasis in 2026 will be placed on expanding environmental surveillance approaches, including wastewater, air, and environmental sampling, as scalable tools capable of detecting pathogens and monitoring risk at human–animal–environment interfaces before recognized human disease occurs.

The Unit will also continue integrating emerging technologies into surveillance and research workflows. Advances in rapid sequencing, field-forward diagnostics, CRISPR-based detection systems, metagenomics, and computational approaches will strengthen outbreak detection and genomic response capabilities while supporting broader efforts in pandemic preparedness and predictive surveillance.

Several important institutional milestones are expected during 2026. Following successful technical review, the Unit has obtained approval for FAO Reference Center designation and is awaiting final administrative and legal formalization of the designation. This milestone reflects growing international recognition of IPC's expertise and its role as a regional hub for One Health surveillance, diagnostics, and innovation. Building on this momentum, the Unit will also begin formal preparations toward designation as a WHO Collaborating Center for One Health Innovation in Emerging and Endemic Virus Surveillance and Response, reflecting its expanding role in linking research, surveillance, and implementation across human, animal, and environmental health sectors.

Ultimately, 2026 will focus not only on growth, but on consolidation ensuring that scientific innovation, surveillance capacity, and institutional development advance together. Through strengthened partnerships, continued innovation, and sustained commitment to One Health principles, the Virology Unit aims to remain a leading platform for pathogen surveillance, preparedness, and translational virology research across Cambodia and the broader region.

3.4.7 Outlook for next 3 to 5 years

Looking ahead, the Virology Unit is entering a new phase of scientific maturity, international engagement, and institutional growth. Building upon three decades of experience in infectious disease surveillance, diagnostics, and research, the Unit aims over the next three to five years to evolve from a nationally recognized laboratory into a globally connected center for One Health innovation, pathogen intelligence, and emerging disease preparedness.

The infectious disease landscape continues to evolve rapidly, shaped by climate change, ecological disruption, urbanization, changing agricultural systems, and increasingly complex human–animal–environment interactions. In response, the Unit's future direction will extend beyond traditional laboratory diagnostics and outbreak response toward more integrated and anticipatory surveillance systems. Human, animal, and environmental health surveillance will increasingly be considered as interconnected components of a unified preparedness framework.

Environmental surveillance is expected to become a defining pillar of this next phase. Building upon work in live bird markets, clinical settings, wastewater systems, wildlife interfaces, and environmental genomics, the Unit aims to further develop surveillance systems capable of detecting and characterizing pathogens before recognized disease emergence. Air sampling, wastewater monitoring, and integrated environmental approaches will increasingly complement clinical and veterinary surveillance, helping move preparedness from reactive response toward earlier warning and risk intelligence.

Genomics and computational biology will continue driving this transformation. The Unit will further streamline real-time sequencing and metagenomic workflows to support both routine surveillance and emergency response activities. Miniaturized and field-forward sequencing systems, improved bioinformatics infrastructure, and increasingly automated analytical pipelines will strengthen genomic epidemiology, phylogenetics, evolutionary analysis, and visualization capabilities. Recruitment and development of dedicated bioinformatics expertise will remain central to ensuring that increasingly large and complex datasets can be translated into actionable public health intelligence.

Alongside surveillance expansion, the Unit seeks to strengthen its capacity for mechanistic and translational virology. Development of enhanced in vitro systems, expansion of biorepositories including immortalized and primary cell lines, and establishment of reverse genetics and pseudovirus platforms will support deeper investigations into viral evolution, host adaptation, pathogenesis, and immune responses. These approaches will allow stronger integration between field surveillance, laboratory experimentation, and translational public health research.

Diagnostic innovation will remain another strategic priority. Molecular and serological platforms will continue expanding through development of multiplex diagnostics, Luminex-based assays, CRISPR technologies, and novel field-deployable systems. Building on successful implementation of multiplex serology for coronaviruses and arboviruses, these platforms will be broadened to additional pathogens and One Health applications, strengthening surveillance while enabling more flexible and scalable responses to emerging infectious disease threats.

International collaboration will remain fundamental to the Unit's long-term trajectory. Partnerships across the Pasteur Network, WHO, FAO, OFFLU, Duke-NUS, and other regional and global institutions will continue to facilitate technology transfer, training, and collaborative research. Increasingly, the Unit seeks not only to participate in international initiatives but to convene and lead them positioning Cambodia as an active contributor to global preparedness, surveillance innovation, and One Health implementation.

Sustainable growth will also depend upon continued investment in people. Over the coming years, the Unit aims to strengthen opportunities for postgraduate education, postdoctoral mentorship, regional fellowships, and scientific exchange. Expansion of student and visiting scientist programs, including Cambodian students training abroad and international trainees conducting research at IPC, will help cultivate a diverse and internationally connected scientific workforce. Continued publication of the substantial datasets generated across surveillance and research programs will remain essential for

ensuring visibility, attracting collaboration, and translating science into policy and public health impact.

Institutionally, several major milestones are expected to define this next phase of development. Following successful technical review, FAO Reference Center designation has been achieved and awaits final administrative formalization, representing an important milestone in recognition of IPC's regional leadership and technical expertise. Building upon this foundation, the Unit intends to pursue formal designation as a WHO Collaborating Center for One Health Innovation in Emerging and Endemic Virus Surveillance and Response, reflecting its increasingly integrated role across human, animal, and environmental health systems.

Quality systems and reference laboratory activities will continue to strengthen in parallel. Preparations toward ISO 17025 accreditation remain a central institutional objective and will support internationally recognized standards for laboratory quality, validation, and reference activities. Expansion of laboratory information management systems (LIMS) strengthened documentation and quality assurance processes, and sustained participation in international proficiency testing programs will further improve reliability and operational excellence. The Unit also seeks to broaden its reference laboratory portfolio, including expansion of rabies diagnostics and serology and exploration of future WOAH-linked reference activities where strategically appropriate.

The coming years are therefore expected to be transformative. Building upon 30 years of scientific experience and partnership, the Virology Unit seeks not simply to remain responsive to emerging pathogens, but increasingly to define new approaches for understanding and mitigating infectious disease threats at their source. The long-term vision is a laboratory and research platform that is scientifically rigorous, regionally embedded, globally connected, and capable of translating innovation into measurable public health impact.

3.4.8 Scientific Publications 2025

Note: *The name of authors from the Institut Pasteur du Cambodge are underlined*

1. **Can Wastewater Surveillance Enhance Genomic Tracking of Climate-Driven Pathogens?**
   L.A.E. Van Poelvoorde, E.A. Karlsson, M.D -Rouzeyrol, N. H. C. J. Roosens.
   Microorganisms *2025,* 13*(2), 28th Jan*, 294; https://doi.org/10.3390/microorganisms13020294

2. **Insect-specific Alphamesonivirus-1 (Mesoniviridae) in lymph node and lung tissues from two horses with acute respiratory syndrome**
   Jurisic L, Auerswald H, Marcacci M, et al. ASM Journals. 2025 Jan 24. doi: 10.1128/jvi.02144-24

3. **Viral Kinetics During Acute Chikungunya Virus Infection: Insights Into Potential Role of Monoclonal Antibodies in Viral Clearance and Prophylaxis Using Mathematical Modeling.**
   Ou TP, Sorn S, Nguon K, In S, Ken S, Ly S, Flamand C, Voirin N, Mandron M, Watson H, Duong V.
   J Med Virol. 2025 May;97(5):e70391. doi: 10.1002/jmv.70391.

4. **An African swine fever vaccine-like variant with multiple gene deletions caused reproductive failure in a Vietnamese breeding herd.**
   Nguyen TC, Bui NTT, Nguyen LT, Ngo TNT, Van Nguyen C, Nguyen LM, Nouhin J, Karlsson E, Padungtod P, Pamornchainavakul N, Kesdangsakonwut S, Thanawongnuwech R, Do DT.
   Sci Rep. 2025 Apr 28;15(1):14919. doi: 10.1038/s41598-025-95641-3.

5. **Characterization and evolutionary history of novel SARS-CoV-2-related viruses in bats from Cambodia**
   Ou TP, Guillebaud J, Baidaliuk A, et al. doi: 10.1101/2025.04.15.648942.

6. **Study of coronavirus diversity in wildlife in Northern Cambodia suggests continuous circulation of SARS-CoV-2-related viruses in bats.**
Guillebaud J, Ou TP, Hul V, Hoem T, Meng C, Nuon S, Hoem S, Lim R, Khun L, Furey NM, Cappelle J, Duong V, Chevalier V.
Sci Rep. 2025 Apr 12;15(1):12628. doi: 10.1038/s41598-025-92475-x.

7. **Toward a deeper understanding of dengue: novel method for quantification and isolation of envelope protein epitope-specific antibodies**
Lay S, Bohaud C, Sorn S, Ken S, Rey FA, Ariën KK, Ly S, Duong V, Barba-Spaeth G, Auerswald H, Cantaert T.
mSphere. 2025 Apr 11:e0096124. doi: 10.1128/msphere.00961-24

8. **Zoonotic disease risk at traditional food markets.**
Sparaciari FE, Firth C, Karlsson EA, Horwood PF.
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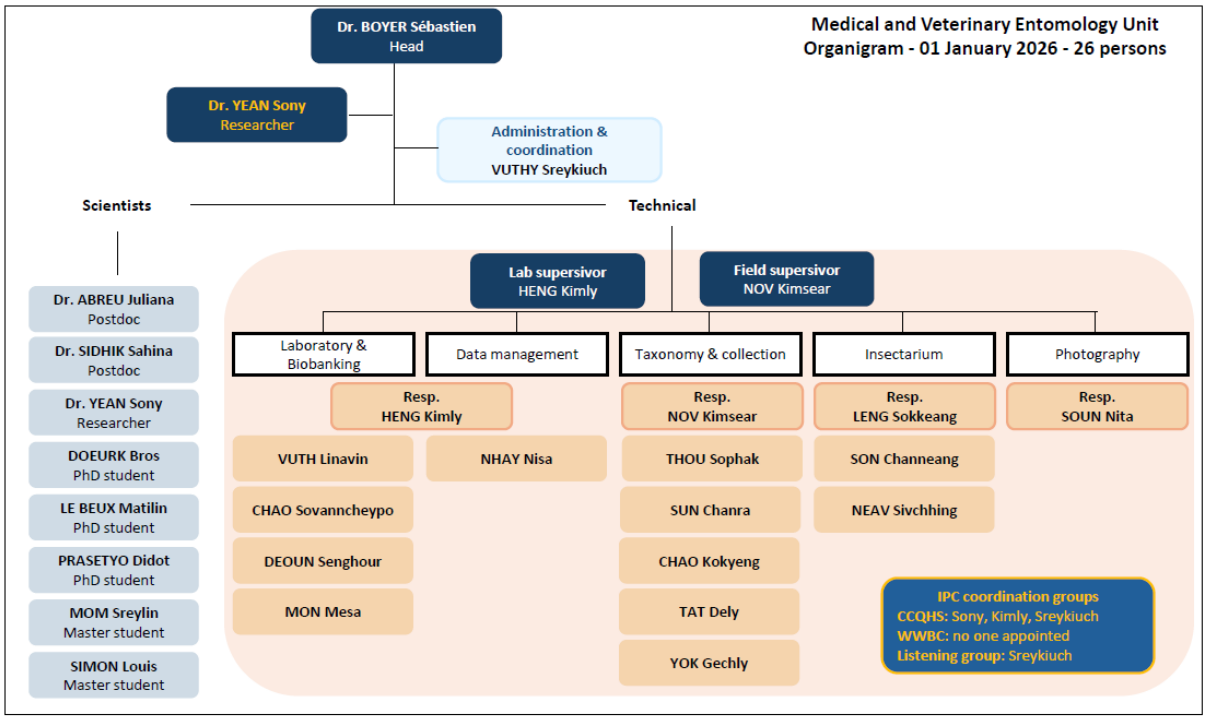
3.5 Medical & Veterinary Entomology Unit

3.5.1 Functional Structure

The Medical and Veterinary Entomology Unit was officially established on October 1, 2018 (reference: N°413/IPC/DIR/2018), coinciding with the recruitment of Dr. Sébastien BOYER by *Institut Pasteur* in Paris for a permanent position. **On January 1st, 2026, the unit's staff comprises 26 members**.



The Unit is structured around integrated field, laboratory, and analytical activities dedicated to the study of arthropod vectors of human and animal diseases. We combine expertise in taxonomy, ecology, vector biology, pathogen surveillance and One Health approaches. Research programs are supported by transversal platforms including field entomology, insectary facilities, MALDI-TOF MS identification, imaging, and molecular diagnostics. The unit operates in close interaction with national authorities and regional partners, ensuring translation of research outputs into public health and veterinary action.

3.5.2 Research Program - Major Achievements in 2025

Overview

In 2025, the Medical and Veterinary Entomology Unit pursued research, surveillance and capacity building focused on arthropod vectors of human and animal diseases, mainly on mosquitoes and ticks. Activities combined field investigations, laboratory-based analyses and regional collaborations within SEA.

Major achievements included the consolidation of large-scale entomological surveillance activities targeting *Aedes*, *Culex* and tick species of medical and veterinary importance. Field missions enabled the collection of extensive mosquito and tick samples from domestic animals, wildlife interfaces and human-modified environments, supporting studies on vector distribution, seasonality, and host associations. Particular attention was given to hard-to-identify species complexes, strengthening taxonomic resolution through the combined use of morphology, molecular tools, and MALDI-TOF mass spectrometry. Finally, two regional workshops on Taxonomy and Surveillance (SEAROADS project) and Entomology-Climate (ECOMORE 3 project) have been organized by our unit respectively

in May and June 2025, regrouping eight different countries (Cambodia, Laos, Thailand, Vietnam, Philippines, Mauritius, Fiji and France).

Human Resources Movement

Departures (2):

- SUN Reaksa, technician entomologist
- LONG Zanory, technician entomologist

Arrivals (14):

- AIZAWA PORTO DE ABREU Juliana, post-doctoral scientist
- SIDHIK Sahina, post-doctoral scientist
- CHAO Kokyoeng, technician entomologist
- NEAV Sivchhing, technician entomologist
- TAT Dely, technician entomologist
- SON Channeang, technician entomologist
- YOK Gechly, technician entomologist
- MON Mesa, technician entomologist
- THOU Sophak, technician entomologist
- CHAO Sovancheypo, technician entomologist
- DEOUN Senghour, technician entomologist
- SUN Chanra, technician entomologist
- SIMON TORRES Louis, Master student
- MOM Sreylin, Master 2 student

Field Missions in 2025

During 2025, the Medical and Veterinary Entomology Unit conducted **38 field missions** in Cambodia (compared to 25 in 2024, 58 in 2023, 39 in 2022 and 35 in 2021), totaling **136 mission days** in the field (compared to 367 in 2024, 539 in 2023, 399 in 2022 and 393 in 2021).

Insects: The art of Detail : A photo exhibition (12 September – 1st November, Institut Français du Cambodge)

After organizing the 1st conference on ticks and tick-borne diseases in Southeast Asia in 2023, the 6th international conference on the tiger mosquito, *Aedes albopictus* in 2024 and publishing a book on "the insects in Cambodia" in three languages (Khmer, English, French) in 2024, we organized a photo exhibition related to the biodiversity and medical entomology. The exhibition "Insects: The Art of Detail" reveals unknown abundant and beautiful biodiversity through a series of photographs.

Trained in groundbreaking photographic techniques developed by French inventor Nathanaël Maury, we capture extremely small subjects in very high resolution. These remarkably sharp images reveal details, essential for identifying species and understanding their interactions with their environment. They also reveal unexpected elements, thus opening new perspectives in entomology—the study of insects.

PhD defense of Ms. YEAN Sony – 21 November 2025

On 21 November 2025, the IPC hosted the PhD defense of Ms. Sony Yean, a founding member of the Medical and Veterinary Entomology Unit. She defended her thesis entitled *"Ticks and Tick-borne Diseases in Cambodia"*, conducted under the Doctoral School "Life Science and Health" of Université Paris-Saclay.

This defense represents a major milestone for national capacity building, as Ms. Yean is the first Cambodian scientist to obtain a PhD in medical and veterinary entomology, directly contributing to the sustainable development of national expertise in vector-borne diseases. Her work reflects three years of intensive research on ticks and tick-borne diseases, combining field investigations, laboratory analyses, and international collaborations. The thesis was supervised by Dr. Boyer and Pr. Malagnac. Ms. Yean acknowledged the support of the Unit and IPC, Cambodian academic institutions, and the Ambassade de France au Cambodge through the BGF scholarship and the FSPI-VECAM project, which provided essential support.

Scientific projects

In 2025, NIH-PICREID project concluded while ANR-BCOMING, FEF-R CISED, FEF-R Photo and ANRS-MIE SEAROADS projects continued. Also, the projects ICEMR Malaria, AFD-AFRICAM, AFD-ECOMORE 3 and WT-RACSMEI began.

List of projects

NIH PICREID Project: Pasteur Institute – Center for Research on Emerging Infectious Diseases (PICREID)

The PICREID project aims to establish a "One Health" approach to enhance the capacity for rapid and effective responses to emerging infectious diseases outbreaks in Southeast Asia. The surveillance enhancement component of the PICREID project is based on RNA virus detection, understanding the transmission of endemic RNA viruses, identifying factors that influence RNA adaptations to new hosts, and studying the adaptive responses of emerging infectious diseases.

The mosquito component seeks to study the dynamics of the main dengue virus vector species in Kampong Thom Province (*Aedes aegypti* and *Aedes albopictus*), describe mosquito behavior, characterize their ecology, and further analyze and model their spatial distribution and the effects of land-use on their dynamics. Another objective is to model dengue risk by correlating the number of dengue vectors with the number of dengue cases in humans. Additionally, the project integrates pathogen discovery with entomological genomic surveillance in collaboration with the Institut Pasteur in Paris. In 2025, six last field missions have been conducted.

Collaborations	Immunology, Epidemiology and Virology Units (IPC), Cambodia; Ministry of Health, Cambodia; Kheobs-ITC, Cambodia; Institut Pasteur, France; IRD (GeoHealth), France.
Funding	NIH-U01AI151758-01:2020-2024

Biodiversity Conservation to Mitigate the Risks of Emerging Infectious Diseases (BCOMING)

The project will analyze how biodiversity impacts the risk of infectious disease emergence and aims to develop tools for biodiversity conservation and restoration strategies to reduce zoonotic risk. Biodiversity loss in hotspots is critical to understanding and preventing future pandemics. The COVID-19 crisis highlighted limitations in implementing 'One Health' approaches, particularly the lack of context-adapted solutions for stakeholders. To address this, BCOMING will build on past international projects to co-develop innovations with stakeholders in biodiversity hotspots, reducing zoonotic risk through conservation and surveillance strategies.

BCOMING will enhance understanding of biodiversity's role in disease emergence and develop participatory tools for context-adapted conservation. Its detection and surveillance strategies aim to prevent epidemics from escalating into pandemics. With a strong multi-actor consortium and

integration into the PREZODE Initiative, the project will scale up innovations and disseminate socio-economic and environmental strategies globally.

In 2025, the Unit carried out four field missions across Cambodia, including two in Stung Treng Province, one in Battambang Province and one in Phnom Penh. Ectoparasites were collected directly from the bats using forceps and preserved in 70% ethanol. To date, more than 4,100 ectoparasite specimens have been collected, including 1,016 bat flies from the family Nycteribiidae (14 species, five genera), 2,680 bat flies from the family Streblidae (nine species, three genera), and 429 specimens from other ectoparasite groups, including the orders Hemiptera, Acari, and Siphonaptera (14 species, 13 genera). In addition, a total of 8,590 sand fly specimens were identified, representing 5 genera and 19 species.

Collaborations	Virology Unit (IPC), Cambodia; Ministry of Environment, Cambodia; Institut Technologique du Cambodge (ITC), Cambodia; Royal University of Phnom Penh, Cambodia; CIRAD (Julien CAPPELLE), France.
Funding	French National Research Agency (ANR- Agence nationale de la recherche) 2023-2026

Comprehensive Integrated Surveillance and Early Detection System for Dengue (FEF-R CISED)

In 2023, Cambodia experienced a major dengue outbreak, highlighting the urgent need to strengthen surveillance and management of vector-borne diseases. The country's environmental conditions favour the proliferation of Aedes mosquitoes, the primary dengue vectors. Existing surveillance systems operated by the National Center for Parasitology, Entomology, and Malaria Control (CNM) and the CDC remain limited, particularly for early outbreak detection. The CISED-Dengue project addresses these gaps by integrating epidemiological, virological, entomological, and environmental data from multiple sources.

Developed in collaboration with IRD, CDC, MoH, CNM and IPC, CISED-Dengue aims to improve real-time understanding of dengue dynamics to support public health responses. The project aligns with the WHO Early Warning, Alert and Response System (EWARS) Framework and promotes inter-institutional data sharing and knowledge exchange.

A digital dashboard with public and professional interfaces will enable real-time analysis and decision-making, while a dedicated platform will facilitate transparent data sharing between key institutions. In parallel, targeted training sessions will strengthen the capacity of health professionals to use integrated data for decision-making. Overall, CISED-Dengue aims to enhance early outbreak detection, support evidence-based interventions, and increase public awareness and engagement in dengue prevention.

Collaborations	Ambassade de France au Cambodge, Cambodia; Centers for Disease Control and Prevention (CDC), Ministry of Health, Cambodia; National Center for Parasitology, Entomology and Malaria Control (CNM), Ministry of Health, Cambodia; Institut de Recherche pour le Développement (IRD), GeoHealth, Cambodia
Funding	FEF-R - Fonds Equipe France Rapide, Paris, France

An Innovative New Tool in Cambodia: Toward a Global Revolution in Imaging for Health Sciences (FEF-R Photo)

The Institut Pasteur du Cambodge (IPC), in collaboration with the Ministry of Environment and other national institutions, is developing innovative tools to raise awareness of biodiversity and its links to health. The Medical and Veterinary Entomology Unit has contributed through mosquito species identification, public outreach, and the production of educational materials in Khmer, French, and English, including an illustrated insect encyclopedia for children. The project is based on a unique high-

resolution photographic technique that reveals previously unseen biological details. This innovation has led to the development of a world-first functional prototype for insect imaging, achieving unprecedented resolution, with promising preliminary tests on human liver cells demonstrating its potential for health sciences.

Project activities include the installation of the imaging system at IPC with stakeholder training, field missions to document biodiversity, and methodological testing across a wide range of organisms. The project has already demonstrated strong public impact through a successful photo exhibition, which attracted wide interest and effectively raised awareness of biodiversity and scientific innovation. The final phase will strengthen communication and outreach to highlight the biodiversity crisis and the potential applications of this technology in research and public health.

Collaborations	Ambassade de France au Cambodge, Cambodia; Institut Français du Cambodge, Cambodia ; Toxo Inc, Vientiane, Laos.
Funding	FEF-R - Fonds Equipe France Rapide, Paris, France

One Health Regional Approach for Integrated and Interconnected Urban Dengue Surveillance Southeast Asia (SEAROADS)

Mosquitoes transmit major infectious diseases, including malaria and arboviruses such as dengue, Zika, and chikungunya. Climate change and urbanization are increasing the risk of mosquito-borne diseases, facilitating their spread beyond tropical regions, as illustrated by recent autochthonous dengue transmission in southern France. In Southeast Asia, long-standing dengue endemicity provides a unique opportunity to understand urban transmission dynamics and develop mitigation strategies relevant to Europe.

This project addresses three challenges: (i) characterizing intra-urban spatial variation in transmission risk, (ii) strengthening entomological surveillance, and (iii) improving surveillance tools at local, national, and regional scales. A multi-scale approach will integrate human mobility, mosquito habitat suitability, and climate data to predict dengue risk. An agent-based model will be developed and calibrated in Bangkok using innovative mosquito indices and mobility data, then extrapolated to other Southeast Asian cities. At national and regional levels, aggregated mobility, epidemiological, and environmental data will support the development of an interoperable Early Warning System. Overall, the project aims to deliver a scalable prediction and surveillance framework enabling rapid public health responses to emerging mosquito-borne diseases.

In 2025, entomological field missions began on 1st July in Phnom Penh, covering 72 sites distributed across four classes within six clusters. In total, 26 field missions were conducted, during which 171,020 mosquito larvae were collected. Although detailed analyses will be performed at a later stage, preliminary observations indicate that *Aedes aegypti* (74%) and *Aedes albopictus* (19%)—the primary dengue vectors—were the most abundant species.

Collaborations	*Ambassade de France au Cambodge*, Cambodia ; Centers for Disease Control and Prevention (CDC), Ministry of Health, Cambodia; IRD (GeohEalth), Cambodia; KHEOBS - ITC, Cambodia; NCLE, MoH, Lao PDR; VCC-SEA, Lao PDR; IRASEC, Thailand; Mahidol University, Thailand; IP HCMC, Vietnam; NIMPE, Vietnam ; Institut Pasteur, France; IDEES (UMR CNRS IDEES), Université de Rouen, France
Funding	*ANRS-MIE*, Paris, France

AFD-AfriCam Preventing Zoonotic Diseases Emergence (PREZODE)

Through the PREZODE Initiative, Cambodia is the only Asian country involved in the AfriCam project, alongside four African countries: Cameroon, Guinea, Madagascar, and Senegal. This project, running from 2022 to 2024, aimed to study how hydrological dynamics, climate, and environmental factors

influence the risk of zoonotic disease emergence across diverse ecosystems. These ecosystems represent key interfaces between humans, animals, and the environment. Another goal of the project was to implement measures that reduce zoonotic risks. This included strengthening existing surveillance systems in coordination with local and national partners. These efforts are expected to pave the way for an integrated One Health surveillance system in the future.

The AfriCam project was divided into three main components. First, it focused on assessing the risks of zoonotic disease emergence. Second, it investigated the environmental and climatic influences on these risks. It established preventive strategies to reduce the likelihood of zoonotic disease emergence. The project aimed to enhance surveillance systems towards a more integrated One Health approach.

In 2025, entomological field missions began in June in Battambang, encompassing three sites with 25 households (75 households in total). Three field missions were conducted, during which 50,000 mosquitoes were collected outdoors using BG traps (targeting anthropophilic vectors) and CDC light traps (targeting zoophilic vectors). *Culex vishnui* group—comprising species of major importance as vectors of Japanese encephalitis—was the most abundant (78.39% of the total mosquitoes collected).

Collaborations	Epidemiology, Virology, LBM units (IPC), Cambodia; Ministry of Health, Cambodia; Agronomes et Vétérinaires sans Frontières (AVSF), Cambodia; International Development Enterprises (IDE), Cambodia; ITC, Cambodia; Wildlife Conservation Society (WCS), Cambodia; Battambang Hospital, Cambodia; IRD, France; CIRAD, France; Institut Pasteur, France.
Funding	Agence Française de Développement (AFD)

International Center of Excellence in Malaria Research (ICEMR)

In Mondulkiri, two villages located just 5 kilometers apart displayed striking differences in malaria transmission. One village reported active malaria cases, while the other, which was once a hotspot, reported none. Both villages are surrounded by forest and separated by a deforested transitional zone. This contrast provided a unique opportunity to study malaria ecology and control strategies. The project analyzed vector populations in these two villages, focusing on species diversity, density, and *Plasmodium* carriage. The proximity of rice fields to one of the villages allowed researchers to explore how forest vectors adapt to agricultural environments, a pattern observed in other regions like Madagascar. These findings were critical in developing malaria elimination strategies, particularly in addressing gaps in vector control and identifying risks for re-emergence in transitional habitats.

The study also examined mosquito biting behaviors to assess human exposure risks and analyzed seasonal patterns of *Plasmodium* prevalence. Researchers identified the ecological and behavioral roles of Anopheles species in malaria transmission. Additionally, the study evaluated the limitations of current vector control tools and investigated the role of rice fields as breeding grounds for mosquitoes. This provided insights into how vectors adapt to changing environments, contributing to malaria risk.

Collaborations	WEHI, Australia (Ivo Mueller); Burnett Institute, Australia (Leanne Robinson); Institut Pasteur, France (Michael White); CNM, Cambodia (Dysoley Lek).
Funding	NIH – ICEMR Asia-Pacific 2017-2029

Welcome Trust- RACSMEI

This project focused on developing a multidisciplinary and cost-effective Precision Public Health framework to address significant knowledge gaps in Cambodia. Cambodia is recognized as a hotspot for zoonotic and vector-borne diseases, including dengue, Japanese encephalitis, avian influenza, and

leptospirosis. Adopting a One Health perspective, the study integrated data from humans, animals, vectors and the environment to assess priority pathogens identified by Cambodian health authorities. A nationwide cross-sectional survey is conducted on 10,000 individuals and their associated ecosystems. Advanced tools such as multiplex serology, metagenomics, and environmental sampling were utilized.

The project aimed to map seroprevalence, understand transmission dynamics, and identify the spatial and behavioral determinants of disease. By linking environmental factors with disease distribution, the project aimed to provide culturally appropriate, targeted intervention strategies. The expected outcomes included generating precise burden estimates for zoonotic and vector-borne diseases, identifying transmission determinants and hotspots, and developing predictive models for pathogen diversity and risk. The project also aimed to propose evidence-based recommendations for intervention strategies.

For vector collection, sentinel BG traps were deployed in selected villages. Traps were placed in ten randomly selected households per village. Mosquitoes collected were identified in the field at the genus level and later confirmed in the laboratory at the species level. This approach generated valuable data on species composition, abundance, distribution, and vector potential, enhancing understanding of vector-borne disease transmission determinants in Cambodia. Field missions will begin in 2026.

Collaborations	Epidemiology and Public Health, Virology and LBM units, IPC, Cambodia; Malaria Consortium, Cambodia; MoH, Cambodia; MaFF, Cambodia; MoE, Cambodia; CIRAD, France.
Funding	Wellcome Trust Discovery Award, AFD-Ecomore: 2024-2030

ECOMORE 3

The entomological work package of the Ecomore 3 project (ECOnomic development, ECOsystem Modifications, and emerging infectious diseases Risk Evaluation) in Cambodia aimed to study vector-borne disease transmission in relation to entomological indices and land use. The goal was to support national health authorities in developing effective vector control strategies. The specific objectives included identifying and characterizing mosquito vector species and analyzing the impact of land use on these species. At the regional level, the project focused on understanding how human activities, land-use changes, and climate change influence the distribution of mosquito vectors across Southeast Asia.

The project aimed to model the transmission dynamics of vector-borne diseases to support the development of a regional health surveillance system. Specific regional objectives included studying the impact of climate and climate change on mosquito species and analyzing how land-use changes affect vector distribution.

The project also sought to standardize mosquito capture methods across the region, improving surveillance and control efforts.

Collaborations	Epidemiology, Virology, LBM units (IPC), IRD, Kheobs-ITC, Cambodge; IPL, Lao PDR; IPHCMC, Vietnam; NIMPE, Vietnam; Research Institute for Tropical Medicine (RITM), Philippines.
Funding	Agence Française pour le Développement AFD)

Taxonomy

Several taxonomy projects continued in 2025, as mainly described in 2024. As a listing the development of the MALDI-TOF MS database for mosquito species is in progress, the barcoding of

mosquito species of Cambodia is still on-going, and the development of the identification key for mosquito and tick species, and for *Streblidae* and *Nycteribiidae* of Cambodia is on progress. You can find details in the annual scientific meeting report of the unit of 2024.

3.5.3 Research Programs - Outlook for 2026

In 2026, the Medical and Veterinary Entomology Unit will pursue and expand several research programs initiated in previous years, while launching new projects aligned with emerging priorities in vector-borne disease surveillance, climate change, and One Health.

Key ongoing and forthcoming programs would focus on integrated surveillance of mosquito- and tick-borne diseases, with particular attention to vector ecology, pathogen circulation, and drivers of emergence linked to environmental and climatic changes. Projects such as SEROTICK and SEADREAMS would continue to structure the unit's activities on tick-borne diseases at national and regional levels, combining field investigations, laboratory diagnostics, and capacity building. In parallel, research on Aedes and Culex mosquitoes would be strengthened, including studies on insecticide resistance, vector competence, and operational implications for vector control.

The unit also anticipates the initiation of new collaborative projects in 2026, notably in climate-driven vector surveillance and early-warning systems, in line with international funding priorities and regional needs. These initiatives aim to integrate entomological data with environmental and climatic indicators to support risk assessment and preparedness.

2026 activities will emphasize regional collaboration, methodological innovation, and translation of research outputs into tools and evidence to support national authorities. Training of students and technical staff will remain embedded within research programs, ensuring sustainability and long-term impact.

SEROTICK proposal to deposit to SEADREAM call

The SEROTICK project aims to establish an integrated One Health surveillance system for tick-borne diseases in Southeast Asia, focusing on Cambodia, Laos, and Thailand. Tick-borne diseases are largely under-recognised in the region despite growing evidence of their circulation in humans and animals. Building preliminary data showing widespread exposure to pathogens such as *Rickettsia*, *Anaplasma*, *Babesia* and *Borrelia*, the project hypothesizes that multiple tick-borne pathogens are silently circulating at significant prevalence.

SEROTICK will implement coordinated surveillance in humans, animals, and vectors using innovative tools including multiplex serology, molecular diagnostics, MALDI-TOF MS, and geospatial modelling. The project combines field studies, laboratory diagnostics, and environmental analyses to identify high-risk areas and transmission drivers linked to land-use and climate change. A strong capacity-building component will train national scientists, laboratory staff, and ministries, including structured PhD programs. By integrating research, surveillance, and policy translation, SEROTICK could generate harmonized regional data, support evidence-based decision-making and strengthen preparedness for emerging tick-borne threats in Southeast Asia.

HORIZON H2025- NAME

This project aims to strengthen regional capacity in Southeast Asia for the surveillance, characterization, and control of ticks and tick-borne diseases of medical and veterinary importance. Building collaborations between IPC, IPL, and MORU in Bangkok, the project will investigate tick

diversity, host associations, and pathogen circulation across different ecological and anthropogenic settings. Field collections will target ticks infesting domestic animals and selected wildlife species.
Tick identification will combine morphological approaches with innovative tools such as MALDI-TOF mass spectrometry and molecular methods. Pathogen screening will focus on major bacterial and viral agents with zoonotic and epidemic potential. The project will generate harmonized regional data, improve diagnostic and surveillance capacities, and contribute to risk assessment of tick-borne diseases. By integrating entomology, ecology, and One Health approaches, this initiative will support preparedness and evidence-based strategies for emerging tick-borne threats in SEA.

IKI-SEA-ALERT

This prospective project would aim to establish a regional consortium in Southeast Asia dedicated to climate-driven vector surveillance and early-warning systems. It would integrate climate, environmental, and entomological data to improve preparedness for vector-borne diseases. Cambodia would contribute through field implementation, vector ecology expertise, and stakeholder engagement.
The initiative would strengthen community-based surveillance and national capacities, producing harmonized protocols, climate-informed risk indicators, and decision-support tools. By linking climate science, entomology, and One Health approaches, the project would enhance early detection of climate-sensitive health risks and support evidence-based responses.

3.5.4 Support to National Authorities

In 2025, the Unit continued to provide scientific and technical support to national authorities in the fields of vector surveillance and control, and risk assessment. Within a One Health framework, we worked in close collaboration with the Ministry of Health (MoH), the Ministry of Agriculture, Forestry and Fisheries (MAFF), the Ministry of Environment (MoE), and the Ministry of Education, Youth and Sport (MoEYS),
Support activities included technical expertise for entomological surveillance programs and contributions to the interpretation of entomological data to inform decision-making. The unit provided guidance on vector identification, insecticide resistance monitoring and ecological interpretation of vector dynamics related to environmental and climatic factors. Notably, the unit contributed to national recommendations issued in February 2025 concerning *Culex quinquefasciatus*.
In parallel, the unit supported several large-scale, ministry-led initiatives. The FEF-R CISED project, initiated in 2024 and led by the CDC–MoH, benefits from the unit's scientific and technical support. The SEAROADS project was co-constructed with the MoH in Cambodia and with the MoH in Laos, Vietnam, and Thailand; representatives from all involved ministries participated in the kick-off meeting to jointly define objectives and methodologies.
The unit is also actively involved in upcoming and ongoing intersectoral projects. The RACSMEI project, led by the Epidemiology Unit, aims to develop national risk maps and involves three departments from three different ministries as direct co-investigators, all engaged since the project's inception. Similarly, the SEROTICK project has been co-constructed over the past two years with MAFF, MoE, and MoH, reflecting a long-term commitment to joint governance and shared ownership. These activities are fully embedded in a One Health approach, integrating human, animal, and environmental health to support evidence-based public health decision-making.

3.5.5 Teaching and Training

Mentorship

Master's Students (2025)

- **Ms. MOM Sreylin** (Master of Science in Biodiversity and Conservation, Royal university of Phnom Penh), January-December 2025. M2 thesis title: Diversity and larval habitat characterization of mosquitoes in Phnom Penh, Cambodia.
- **Ms. VUTH Linavin** (Master of Life Sciences and Health, Université Paris-Saclay, Paris, France), January-June 2025. M2 thesis title: *Seroprevalence of Tick-Borne diseases on cattle serum*.
- **Mr. SIMON-TORES Louis** (Master of Biodiversity, Ecology and Evolution, Paul Sabatier University), September 2025 – August 2026. M2 thesis title: *Bat's ectoparasites of Cambodia* (six months) / *Study of disease vectors along a longitudinal gradient* (six months).
- **Ms. HOEUN Sokeang** (Master2 IDIL-ECO-Epidemiology of Emerging Disease, Université de Montpellier) January-June2025. M2 thesis title: *Habitat Suitability Modeling of domestic mosquitoes (Aedes aegypti / Ae. albopictus / Culex quinquefasciatus) in Cambodia*).

PhD Students

- **Ms. YEAN Sony**, Cambodian national, October 2022-September 2025, Doctoral school SDSV of Paris-Saclay (SDSV = Structure et dynamique des systèmes vivants), France. PhD title: *Tick Species and Tick-Borne Diseases in Cambodia*.
- **Mr. DOEURK Bros**, Cambodian national, October 2023-September 2026, Doctoral school SDSV of Paris-Saclay (SDSV = Structure et dynamique des systèmes vivants), France. PhD title: *Bionomic of dengue vector mosquitoes in Cambodia*.
- **Ms. ROZIER Héloïse**, French national, October 2023-September 2026, Doctoral school MathSTIC Bretagne Océane, Université de Rennes, France. PhD title: *Statistical distribution of mosquitoes in Cambodia*.
- **Mr. LE BEUX Matilin**, French national, October 2024 – September 2027, Doctoral school BIOSPC (Bio Sorbonne Pasris Cité), Paris, France. PhD title: *Machine learning application in Medical Entomology: determining potential biomarkers in mosquito and human for Dengue and Chikungunya viruses*.
- **Mr. PRASETYO Didot**, Indonesian national, October 2024 – September 2027, Doctoral school SFS (Sciences Fondamentales Santé), Université de Reims Champagne-Ardenne (URCA), France. PhD title: *Neglected ectoparasites in Cambodia and impact for Public Health.*

Teaching

Since 2020, Sebastien BOYER has been responsible for the "*Vector Borne Diseases and Vector Transmission*" module within the second year of the International Joint Master's in Infectiology: Biology of Infectious Diseases. The module represents 2.5 ECTS credits and consists of 20 hours of instruction. The module was created in 2020, requiring significant time to prepare and complete. It consists of 8 lectures, each lasting 1.5 hours. Our team also conducts examinations and grading. Especially, in 2025, Unit members were actively involved in teaching with PhD students and post-docs involved in the module.

Training

In 2025, all newly recruited staff members (n = 12) completed the online Aptitude Training Course on Laboratory Security and Good Laboratory Practices, provided by IPC. In addition, a wide range of internal (unit- and IPC-level) and external training activities were provided for the unit members, representing a total of 365 person-days of training.

Intern Unit trainings		
8-10 April 2025	Taxonomy (trainers: Ms. HENG & Mr. PRASETYO)	3 persons
10-22 February 2025	Insectarium (Ms. LENG)	2 persons
10 Feb-10 Mars 2025	Taxonomy: mounting (Mr. PRASETYO)	2 persons
01-31 March	Taxonomy Culicidae (Ms. HENG & Mr. NOV)	4 persons
02 Feb- 02 March 2025	Insectarium (Ms. LENG)	1 person
05-08 May 2025	Taxonomy Phlebotomus (Mr. PRASETYO & Mr. NOV)	1 person
05-06 August 2025	Maldi-TOf MS (Ms. HENG)	2 persons
06 August 2025	Taxonomy: larvae identification (Mr. NOV)	1 person
Intern IPC training		
20 Mars 2025	Quality Health & Safety (Mr. HOKKEAN)	2 persons
19-21 May 2025	Statistics in R (Dr. SOMMEN & Ms. ANTONIOLLI)	3 persons
21 August 2025	Quality Health & Safety (Mr. HOKKEAN)	2 persons
02 & 05 Dec 2025	Python for beginners course (Mr. GONNELLA)	4 persons
20 October 2025	Quality Health & Safety (Mr. HOKKEAN)	2 persons
External trainings		
22-23-April 2025	Unconscious Bias Sexual Harassment Prevention (GADC)	1 person
06-07 February	Masterclass Macro Photography (Mr. MAURY)	2 persons
April-July 2025	Global Public Health Project Management (Univ Washington)	4 persons
17 July 2025	First Aid training (FFS & Pharma Co & Red Cross)	7 persons
08-09 September 2025	Masterclass Macro Photography (Mr. MAURY)	2 persons
June-September 2025	Professional Project management (USA)	1 person
18 September 2025	Sexual Harassment Policy (Shift Balance)	1 person
02 October 2025	Molecular techniques: PCR (Dr. HIDE)	5 persons
24-29 November 2025	Immune response to arbovirus infection from a One Health Perspective (IUIS-Pasteur Network)	1 person
19 December 2025	Molecular techniques: Sequence alignement (Dr. HIDE)	11 persons

3.5.6 Outlook for upcoming 3-5 years

Over the next 3 to 5 years, the Unit aims to consolidate its position as a national and regional reference for the research on arthropod vectors of human and animal diseases within a One Health framework. The unit will continue to integrate field-based research, innovative diagnostic tools, and interdisciplinary approaches to address emerging and re-emerging vector-borne disease threats in Cambodia and SEA.

Within 3 years

Over the next three years, priority will be given to (i) vector surveillance and resistance monitoring, (ii) integrative modelling linking entomology, epidemiology, and environmental data, and (iii) capacity building through PhD training and national partnerships.

At the three-year horizon, priorities will focus on climate- and land-use-driven changes impact on vector distribution. The unit will further develop identification and diagnostic platforms, including MALDI-TOF MS and serological tools, and expand their application at national and regional levels. Research efforts should prioritize insecticide resistance, tick-borne diseases and integrated vector surveillance, while reinforcing links with national authorities and regional networks. Capacity building

will remain central. In addition, vector-based therapeutic target discovery research will identify and characterize vector proteins to support the development of vaccines based on monoclonal antibody.

- Two long-term projects
- Recruitment of 1 post-doctoral researchers (see priority profiles below)
- Consolidation of team members
- Thesis defenses of four PhD students in Medical and Veterinary Entomology
- Development of more mechanistic research (see topics below)
- Anticipation of leadership transitions and succession planning.

Within 5 years

At the five-year horizon, the unit aims to contribute to the development of integrated early-warning and risk assessment systems for vector-borne diseases, combining entomological, environmental and epidemiological data. The unit will strengthen its role in regional consortia and international research initiatives. Long-term objectives include consolidating national human resources within the unit, developing interdisciplinary collaborations and maintaining high scientific output.

- New insectarium and additional space (laboratory and office)
- Future research will depend on the new Head of Unit
- Strengthening the Veterinary and Medical Entomology themes
- Consolidating vector biology research on bat ectoparasites.

Recruitment

- Prioritize filling the identified roles through clear job descriptions and collaborations with universities.
- Needed Profiles: Ecologist, Vector Competence Specialist, Taxonomist, Bioinformatic Specialist, Molecular Scientist, Project Manager, Data Manager, Statistician, Veterinarian.

Research Focus

- Align ongoing and future projects with the thematic listed, ensuring a balance of fieldwork, lab experiments, and computational analysis.
- Priority Scientific Thematic: Pathogen Discovery, Vector Competence, eDNA on Mosquitoes, Insecticide Resistance, Vector Control Innovations, Microbiota Research.

Develop vector control and insecticide resistance research thematics

- Focus on Vector Control and Prevention
    - Target priority vectors, such as those of dengue and Japanese encephalitis virus (JEV), with research and actionable control measures.
    - Investigate and implement alternative control methods (e.g., Wolbachia, microbiota manipulation).
- Develop a Surveillance System
    - Design a robust, tech-enabled system for real-time vector and disease monitoring.
    - Use data from fieldwork and environmental studies to improve prediction and control strategies.
- Alternative Vector Control Strategies
    - Research innovative methods beyond traditional insecticides.

Capacity Building

Methods

- Invest in training in emerging methods (A.I., MinION) and technologies (bioinformatics).
- Molecular Techniques (e.g.MinION multiplex sequencing for high-throughput data).
- Cell Culture (P2-P3) studies with Virology Unit

- AI and Photo-based Identification
- Bioinformatics
- New data management tools

Human resources

We want to develop structured mentorship and coaching programs to support junior staff development and ensure effective succession planning within the unit and promote continuous professional development by encouraging participation in scientific conferences, peer-reviewed publications, and leadership and management training. The unit will invest in people by guiding junior staff, developing their skills, preparing future leaders, and supporting ongoing learning and scientific excellence.

- Organize internal and external training sessions on priority topics (R, GIS, molecular techniques) Increase efforts to attract and retain talent (better salaries, clear career growth opportunities)
- Define clear roles and responsibilities within the unit
- Establish a systematic process for internal knowledge-sharing and meetings.
- Strengthening partnerships with public health professionals (workshops, internships, shared projects).
- Encourage multi-disciplinary skill-building (e.g., combining ecology with molecular biology).

3.5.7 Scientific Publications 2025

Note: *The name of authors from the Institut Pasteur du Cambodge are underlined*

1. **Anopheles Mosquitoes in Mondulkiri Forest, Cambodia: Abundance, Distribution, Seasonal Patterns and Plasmodium prevalence**
   Boyer S, Doeurk B, Rakotonirina A, Chy S, Vong C, Piv EP, Tat B, Ea M, Chhin C, Phen S, Kloeung N, Ke S, Popovici J, Piola P, Witkowski B, Maquart PO, Vantaux A. Malaria Journal. 2025 Jan 10;24(1):6. https://doi.org/10.1186/s12936-024-05166-9

2. **Population structure of the invasive Asian tiger mosquito, Aedes albopictus, in Europe.**
   Corley MK, Cosme L, Armbruster PA, Sharakhova M, Della Torre A, Caputo B, Pichler V, Bega A, Urbanelli S, Martins A, Velo E, Kadriaj P, Eritja R, Beebe N, Chen CH, Crawford JE, Fontaine MC, Boyer S, Gill RJ, Huynh T, Maringer K, Maynard A, Mukherjee S, Munstermann LE, Noble Surendran S, Wahid I, Schaffner F, Bueno Marí R, Michaelakis A, Balatsos G, Akiner M, Puggioli A, Horvath C, Bravo-Barriga D, Rogozi E, Collantes F, Besnard G, Kavran M, Mikov O, Medialdea-Carrera R, Melillo T, Borg ML, Johnson T, Hackett K, Wu T, Pinto J, Valadas V, Caccone A. Ecol Evol. 2025 Mar 7;15(3):e71009. https://doi.org/10.1002/ece3.71009

3. **Current Knowledge of Exposure to Tick-borne Pathogens among Rural Population in Cambodia.**
   Nouhin J, Maquart PO, Khun ML, Sen MS, Heng MK, Ali SM, Leng S, Ken S, Dziedziech A, Heng L, Bigot T, Bonnet S, Dheilly N, Boyer S, Eloit M, Paul R, Duong V, Sakuntabhai A. International Journal of Infectious Diseases 152, 107419 https://doi.org/10.1016/j.ijid.2024.107419

4. **Spatio-temporal distribution and environmental determinants of dengue vectors in Phnom Penh, Cambodia.**
   Herbreteau V, Maquart PO, Hoeun S, Doeurk B, Girond F, Boyer S. PLoS Neglected Tropical Disease. 2025 Oct 29;19(10):e0013667. https://doi.org/10.1371/journal.pntd.0013667

5. **Emerging Approaches to Mosquito Species Identification: An Overview with Emphasis on Nanopore Sequencing Technology.**
   Rakotonirina A, Dusadeepong R, Hide M, Vuth L, Chea R, Heng K, Maquart PO, Vandelannoote K, Boyer S. Journal of Medical Entomology, 2025: tjaf044 https://doi.org/10.1093/jme/tjaf044

6. **News from the forest of Mondulkiri: additions to the mosquito fauna of Cambodia (Diptera:Culicidae).**
   Maquart PO, Suor K, Vantaux A, Doeurk B, Chhoy K, Heng K, Sen S, Chea R, Nov K, Keum T, Leng S, Boyer S. Parasite 2025; 32:75. https://doi.org/10.1051/parasite/2025064

7. **Seasonal dynamic of ticks infesting cattle (Bos indicus) farms in two provinces in Cambodia.**
   Yean S, Prasetyo DB, Ren T, Krib D, Sen S, Chea B, Tum S, Sorn S, Sum S, Boyer S.
   PLoS One. 2025 Apr 16;20(4):e0320879. doi: 10.1371/journal.pone.0320879

8. **Checklist and diversity of tick fauna associated with domestic animals in Cambodia.**
   Yean S, Prasetyo DB, Ren T, Krib D, Sen S, Chea B, Tum S, San S, Sum S, Bonnet S, Boyer S. Tick and tick-borne diseases 2025; 16:102570.

9. **First evidence of human borreliosis local transmission in Cambodia.**
   Yean S, Maquart PO, Delvallez G, Boyer S. Int J Infect Dis. 2026 Feb;163:108208. doi: 10.1016/j.ijid.2025.108208. Epub 2025 Nov 14.

10. **Tick diversity and tick-borne pathogens in livestock and companion animals in Cambodia: A narrative review and new field data (2022– 2023)**
    Yean S, Krib D, Chea R, Sum S, Ren S, San S, Maquart PO, Boyer S. Veterinary Parasitology: Regional Studies and Reports 2025; 101407 https://doi.org/10.1016/j.vprsr.2025.101407

11. **The sixth International Workshop on Aedes albopictus: updating the main challenges against the globally invasive Asian tiger mosquito.**
    Doeurk B, IWAA participants, Prasetyo DB, Fontenille D, Bonizzoni M, Boyer S. Pathogens Global Health https://doi.org/10.1080/20477724.2025.2486012

12. **Impact of temperature on survival, development and longevity of Aedes aegypti and Aedes albopictus (Diptera: Culicidae) in Phnom Penh, Cambodia**
    Doeurk B, Leng S, Long Z, Maquart PO, Boyer S. Parasites & Vectors, 2025, 18(1):362. https://doi.org/10.1186/s13071-025-06892-y

13. **Reevaluating the presence of Rhipicephalus australis in SEA: A Phylogenetic approach.**
    Prasetyo DB, Yean S, Boyer S. Tick and Tick borne diseases 2025; 16:102478. https://doi.org/10.1016/j.ttbdis.2025.102478

14. **Not here yet, but one bite away: Risk for vector-borne zoonotic diseases.**
    Prasetyo DB, Mathieu B, Depaquit J, Boyer S. PLoS NTD 2025; 19(12): e0013802 https://doi.org/10.1371/journal.pntd.0013802

15. **Evaluating experimental design to sample mosquitoes.**
    Rozier H, Gloaguen P, Septier F, Boyer S. Scientific Report 2025; 15:43552 https://doi.org/10.1038/s41598-025-27465-0

16. **Review of the genus Megascolia Betrem, 1928 (Hymenoptera, Scoliidae)**
    Castagnet JB, Cabon F. 2025. Zootaxa, 5700 (1), 1–127. https://doi.org/10.11646/zootaxa.5700.1.1

17. **The genus Microscolia Betrem, 1927 (Hymenoptera, Scoliidae, Scoliini): a new species and remarkable records from Asia.**
    Castagnet JB, Mita T, Keith D, Cabon F. 2025 Zootaxa, 5722 (3), 408–420. https://doi.org/10.11646/zootaxa.5722.3.6

18. **A new melanistic species of Megacampsomeris Betrem, 1928 from the Philippines and taxonomic reassessment of Laevicampsomeris luzonensis (Rohwer, 1921) (Hymenoptera, Scoliidae, Campsomerini).**
    Castagnet JB, Cabon F. Zootaxa. 2025 Oct 7;5701(5):573-585. https://doi.org/10.11646/zootaxa.5701.5.6.

19. **New records of the genus Sericocampsomeris Betrem from Vietnam, with the description of the female of S. vietnamica (Hymenoptera, Scoliidae, Campsomerini).**
Cabon F, Maury N, Castagnet JB. Bulletin de la Société Entomologique de France, 2025, 130 (1), pp.15 - 29. https://doi.org/10.32475/bsef_2352

20. **Comparative morphometric and biosystematic analysis of Kyasanur forest disease vectors (Haemaphysalis Bispinosa and H. turturis) from South India.**
Sidhik S, Esakkiammal B, Balasubramanian R. Sci Rep. 2025 Dec 11;15(1):43624. https://doi.org/10.1038/s41598-025-27392-0

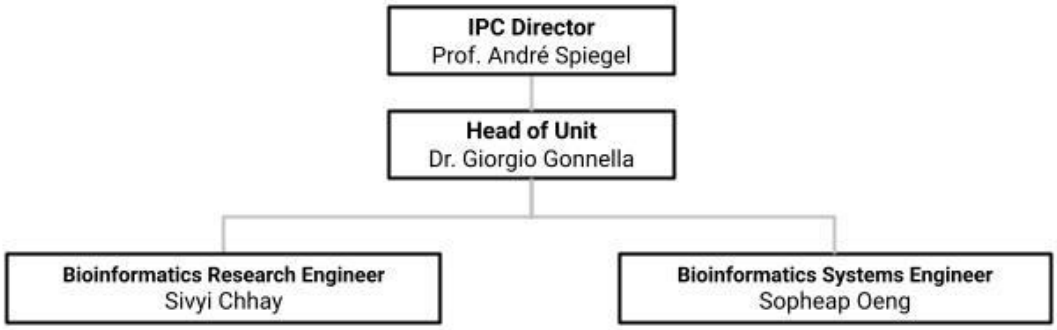
3.6 Bioinformatics and Artificial Intelligence Applications Unit

The Bioinformatics and Artificial Intelligence Applications (BAIA) Unit is a transversal research unit at the Institut Pasteur du Cambodge (IPC), established in late 2024, designed to advance bioinformatics, computational biology and artificial intelligence expertise in IPC, with applications to multiple scientific domains. The unit is lead by Dr. Giorgio GONNELLA, and operated throughout 2025, with a compact structure, composed of two further full-time staff members, a Bioinformatics Research Engineer and a Bioinformatics Systems Engineer (see Figure below), which were internally trained in the first months of the year, and achieved productivty in the following months, assisting in research and capacity building activities.

In 2025, BAIA interacted with several research units at IPC, including Immunology, Virology, Malaria Research, Medical Biology Laboratory, Epidemiology and Public Health. It collaborates with the IT support service on the installation, maintenance and update of bioinformatics tools and databases, and on designing IT institutional policies, in particular those regarding the institute High Perfomance Clustering. BAIA often acts as a interface between the research community and the IT systems administration, e.g. organizing a 3-monthly Working Group for Bioinformatics and AI (WGBAI), encouraging efficient dialog between the parts.

The unit activities include providing bioinformatics expertise through collaborative projects, consultancy and support, as well as conducting own research projects related to the institute core mission. During 2025, international partnerships were established. In the Pasteur Network, BAIA organizes a thematic group in the Asia Pacific region, called PAPIBI (Pasteur Asia-Pacific International Bioinformatics Initiative). BAIA also regularly welcomes intern students from Cambodian and international educational institutions fostering knowledge exchange and capacity building and organizes internal and external Bioinformatics courses.

3.6.1 Functional Structure



3.6.2 Research Programs – Major Achievements in 2025

Axis 1: Single cell RNA-sequencing analysis pipelines, tools and methods

Single cell RNA-seq analysis and methods development is one of the pillars of the BAIA unit since its conception, thanks to the tight collaboration with the Immunology Unit. During the year, we also established own research projects on single cell data visualization and improving deep-learning-based methods for cell type annotation.

Single-cell RNA-sequencing analysis.

During the year, we improved the computational pipeline, based on Cell Ranger, Seurat and Platypus downstream analyses, that we are using for the analysis of single cell sequencing data. We worked further on the analysis of multiple datasets, investigating the immune response to infectious diseases, such as Dengue, Chikungunya and Malaria, in collaboration with the Immunology Unit and the Malaria Research Unit. Introduced improvements included adaptation and better organization of existing helper modules and scripts, and implementation of new analyses, e.g. the analysis of metabolic pathways with ClusterProfiler, which we now use in single-cell and bulk RNA-seq.

Start/End Year	2024-ongoing
Collaborations	Immunology Unit (IPC)
Funding	Institut Pasteur du Cambodge \ Immunology Unit funds and grants

Meta-analysis and interactive visualization of *Plasmodium vivax* scRNA-seq data.

During the year, we implemented an interactive visualization system for exploring, e.g. through 2D and 3D multidimensional reduction embedding plots, the gene expression landscape of *P.vivax* parasites, in all life cycle stages. Besides the tool itself, our project includes a meta-analysis of all currently publicly available *P.vivax* single cell RNA-seq datasets. Our tool includes multiple innovative functions, not present in state-of-the-art visualization tools. We believe that it will represent an essential tool for the Malaria research community.

Start/End Year	2025-2026
Collaborations	Malaria Research Unit (IPC), Anthony Ruberto (Center for Tropical and Emerging Global Diseases; University of Georgia; USA), Thomas Obadia (Institut Pasteur, Paris)
Funding	Institut Pasteur du Cambodge

Axis 2: Genomics and metagenomics analysis pipelines

Our existing collaboration with the Virology Unit continued in year 2025. During this time, we maintained existing pipelines, locally deployed complex bioinformatics software and created new *ad hoc* pipelines

Deployment and development of software and databases for viral pathogen detection and analysis.

The Virology Unit routinely uses pipelines, such as IRMA, Lilo and Artic for the analysis of samples in their monitoring, outbreak response and research programs. The BAIA Unit created wrapper scripts and containers, which ensure continuous availability and reproducibility of the pipelines. We kept those pipelines updated and organized the availability and update of local copies of sequence databases. Additionally, we created new pipelines, for example for the analysis of amplicon data from HPV cohorts, which can be adapted and extended to the analysis of other viral infections.

Start/End Year	2024-ongoing
Collaborations	Virology Unit (IPC)
Funding	Institut Pasteur du Cambodge

Nanopore sequencing data analysis pipelines.

Nanopore sequencing offers significant advantages for pathogen detection and discovery over other sequencing technologies in terms of costs, speed and operability in the field. During 2025, we worked in a consultancy role, with Fiocruz for the preparation of a new Covid analysis pipeline based on Nanopore data, which is currently being finalized. Furthermore, we closely worked with the Virology Unit for creating host detection pipelines, which can be easily deployed in the field.

Start/End Year	2025-2026
Collaborations	Virology Unit; T. de Lima Campos (Fiocruz, Brasil)
Funding	Institut Pasteur du Cambodge

3.6.3 Research Programs – Outlook 2026

Axis 1: Single cell RNA-sequencing analysis pipelines, tools and methods

Single-cell RNA-seq computational analysis

The BAIA Unit aims to provide a reference point for this kind of analysis in the Pasteur Network, open to collaborations with other institutes. Our expertise in this field will be further extended, including the handling of other data modalities and techniques, such as cell hashing multiplexing and CITE-Seq. The analysis pipelines will also cover new aspects of the data analysis, such as pseudotime analysis and cell-to-cell communication analysis.

Start/End Year	2026-ongoing
Collaborations	Immunology Unit (IPC)
Funding	Institut Pasteur du Cambodge / Immunology Unit funds and grants

Improvement of scRNA-seq cell type annotations methods

Current methods for the annotation of cell types in single cell RNA-seq analysis are based on marker genes (which are not always visible in the gene expression profiles), correlations to existing datasets (which are useful but unprecise at single-cell level) and deep learning. The existing deep learning methods mostly only allow rough annotations (e.g. distinguishing T cells from B cells) but lack the detail necessary to understand the immune system interplay of different cell types. We are currently evaluating existing methods, constructing deep learning models on curated data and investigating possible method improvements for fine-grade cell type annotation.

Start/End Year	2025-ongoing
Collaborations	Immunology Unit (IPC)
Funding	Institut Pasteur du Cambodge

Axis 2: Genomics and metagenomics analysis pipelines

Nextstrain protocol for the analysis of avian influenza cases.

To support the Virology Unit in standardizing and automatizing the analysis of avian influenza outbreaks, we will create Standard Operating Procedures for the installation, update and operation of a local instance of Nextstrain, dedicated to it. Scripts will help in the validation of the input and reference data, and precise instructions and documentation will ensure the operability by designated Virology technical staff. The system will subsequently be extendable to other viruses.

Start/End Year	2025-2026
Collaborations	Virology Unit (IPC)
Funding	Grants of the Virology Unit (IPC)

Pipelines for the analysis of antimicrobial resistance data. During 2025, we pioneered the collaboration with the Bacteriology and Antibiotic Resistance (BAAR) Research Group of the Medical

Biology Laboratory Unit. We delivered a preliminary version of a re-usable modern reproducible modular pipeline for the assembly, annotation and phylogenomic analysis of Enterobacteriaceae genomes, including the detection of antimicrobial resistance.

Start/End Year	2025-ongoing
Collaborations	Bacteriology and Antibiotic Resistance Research Group (IPC)
Funding	Institut Pasteur du Cambodge

Axis 3: Applications of large language models to scientific research at IPC

The use of Large Language Models (LLMs) is revolutionizing all aspects of scientific research. The BAIA unit is exploring the range of applications in the fields of research of IPC, including cases where local deployment is a necessity, due to extended data privacy concerns. Besides the projects indicated below, more applications will be explored throughout the year, supported by the planned acquisition of more staff dedicated to AI application research.

Systems for information retrieval in qualitative research.

In collaboration with the Epidemiology and Public Health Unit, BAIA will develop systems for the retrieval of information in large corpora of qualitative research interviews. These systems will be implemented using techniques such as Retrieval Augmented Generation and dedicated databases. In addition, system for semi-automated coding will be developed, which will suggest, employ and allow to interactively improve codebooks and text annotations.

Start/End Year	2025-2027
Collaborations	Epidemiology and Public Health Unit (IPC)
Funding	Institut Pasteur du Cambodge

3.6.4 Teaching and Training

Students

Bachelor Students

- Kao Kimsoun, Cambodia Academy for Digital Transformation (CADT), (2022 – 2026), Internship Year 3: Improving cell type annotations in single cell RNA-seq data

Master Students

- Kahn Furqan, University of Health Sciences / Paris Saclay, (2024 - 2026), Internship M1 (Shared: BAIA / MBL): assembly, annotation, phylogenomic analysis of Enterobacteriaceae

Teaching

- Basics of Linux Command Line (Part 2), January 2025, Internal IPC Course, 3 hours teaching and hands on tutorial
- Metagenomic Sequencing PREPARE-PGI Workshop, May 2025, Duke NUS, about 30 hours teaching and hands on tutorial
- Python for Beginners, December 2025, Internal IPC Course, 6 hours teaching and hands on tutorial

3.6.5 Outlook for upcoming 3 – 5 years

Artificial Intelligence (AI) represents a huge opportunity for LMICs, such as Cambodia, giving access to information, know-how and expertise which previously were not available locally. AI Applications are essential for growing the scientific research capacity and for applications in public health. The BAIA unit aspires to achieve a central role in AI, as underlined by its growing network of local and

international partnerships. During 2025, e.g., we were invited to participate in a Panel Discussion organized by the Konrad-Adenauer Stiftung about the Applications of AI in Public Health, held at CADT. In the upcoming years, we will further expand the focus of the unit to Artificial Intelligence Applications, with new collaborations, funding acquisition efforts and human resources dedicated to this aspect.

Besides AI, the focus of BAIA is Bioinformatics, an indispensable tool in modern scientific research. The BAIA Unit represents a focal point for the growth of the institute capacity in the field, offering to other research units collaborations and capacity building, with the aim in upcoming years of reducing the dependency of IPC from international partners for bioinformatics analyses. Furthermore, we are strengthening our network in the Bioinformatics field, aiming at international research partnerships and training initiatives.

Pasteur Asia-Pacific International Bioinformatics Initiative

During 2025, the Pasteur Asia-Pacific International Bioinformatics Initiative (PAPIBI) took life. The initiative aims at creating a bioinformatics knowledge-sharing network among Pasteur Network institutes in the Asia-Pacific region. These institutes often share common goals, due to geographical proximity and similar epidemiological profiles of their host countries, as well as common challenges, such as limited funding, network infrastructure constraints, and hardware procurement difficulties. Researchers of Pasteur Institutes in Vietnam, Laos, New Caledonia and South Korea took part to the meetings. In total four online meetings were held starting from March 2025. A survey was conducted, which led to a poster presentation at the Pasteur Network Annual Meeting, which was held in October 2025 in Ho Chi Minh City (Vietnam). The Pasteur Network expressed strong interest in the initiative and supports its further development.

3.6.6 Scientific Publications 2025

Note: *The name of authors from the Institut Pasteur du Cambodge are underlined*

1. **Epidemiology and Phylogenomic Characterization of the Clade IIb C.1 Mpox Outbreak in Phnom Penh, Cambodia (2023-2024).**
   Nouhin J, Jansen D, Nay T, Chin S, Dantas PHLF, Pum L, Khun L, Mov C, Pho S, Keo S, Kruy L, Lim R, Chel K, Chea K, Siegers JY, Rath S, Elise Laumen JG, Gonnella G, Chau D, Krang S, Ly S, Vercauteren K, Karlsson EA.
   Emerg Microbes Infect. 2026 Jan 23:2622215. doi: 10.1080/22221751.2026.2622215.

2. **Immune profiling in subclinical secondary dengue-infected cases reveals adaptive immune signatures correlated to protection from severe dengue.**
   Gonnella G, Libri V, Gioacchino E, Mella S, Sann S, Sorn S, Ken S, Seffer V, Ya N, Heng L, Yay C, Sakuntabhai A, Ly S, Dussart P, Duong V, Hasan M, Cantaert T.
   Cell Host Microbe. 2025 Jun 24:S1931-3128(25)00235-5. doi: 10.1016/j.chom.2025.06.006.

4 Health Services Activities

4.1 Medical Biology Laboratory

4.1.1 Functional Structure

The Medical Biology Laboratory (MBL) provides a comprehensive platform for biological analysis, offering more than 170 different tests to public and private hospitals, clinics, non-governmental organizations (NGOs), and individual walk-in patients. The MBL team comprises 47 staff members working across seven sectors: Reception, Sampling, Microbiology, Mycobacteriology, Blood biology, Molecular Biology Platform, and the Bacteriology Research Laboratory.

In 2018, the MBL obtained ISO 15189:2012 accreditation for biochemistry, haematology, and microbiology from the French Committee for Accreditation (COFRAC). In 2024, the MBL successfully transitioned to the ISO 15189:2022 standard, which replaced ISO 15189:2012. The renewal of this accreditation by COFRAC was granted for a period of three years.

Throughout the accreditation cycle, a continuous surveillance program is implemented through regular audits to ensure ongoing compliance with ISO 15189 requirements. The S5 surveillance audit was conducted by COFRAC in December 2025.

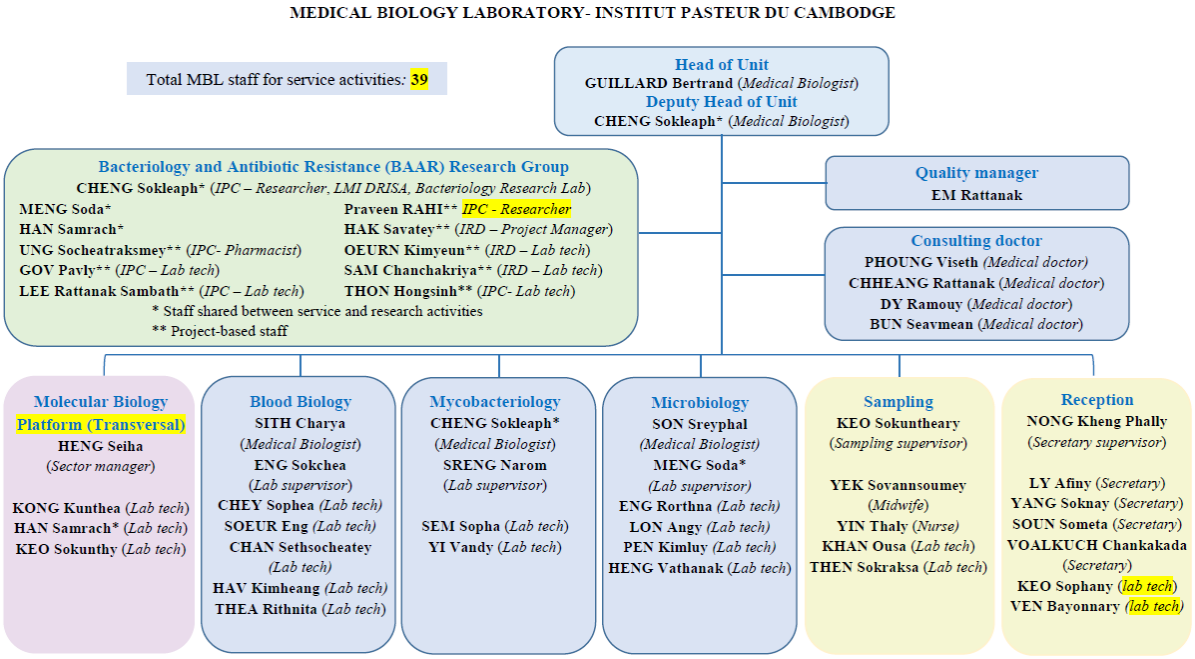


Figure 17: *Organigram- Medical Biology Laboratory (January 2026)*

4.1.2 Service Activities in 2025

To assess the level of activity of the MBL, analyses are expressed in "key-letter B" units, according to the French nomenclature for medical laboratory procedures (*Nomenclature des Actes de Biologie Médicale: NABM*). In 2025, the MBL performed 167 627 analyses (+2.3% compared to 2024), resulting in 5.1 million B (-8.5% compared to 2024). This reduction in activity in B is mainly due to the high level of HIV drug resistance genotyping activity in 2024, conducted in collaboration with the National Centre for HIV/AIDS, Dermatology and STD (NCHADS).

Figure 18 illustrates the evolution of our activities over the last few years.

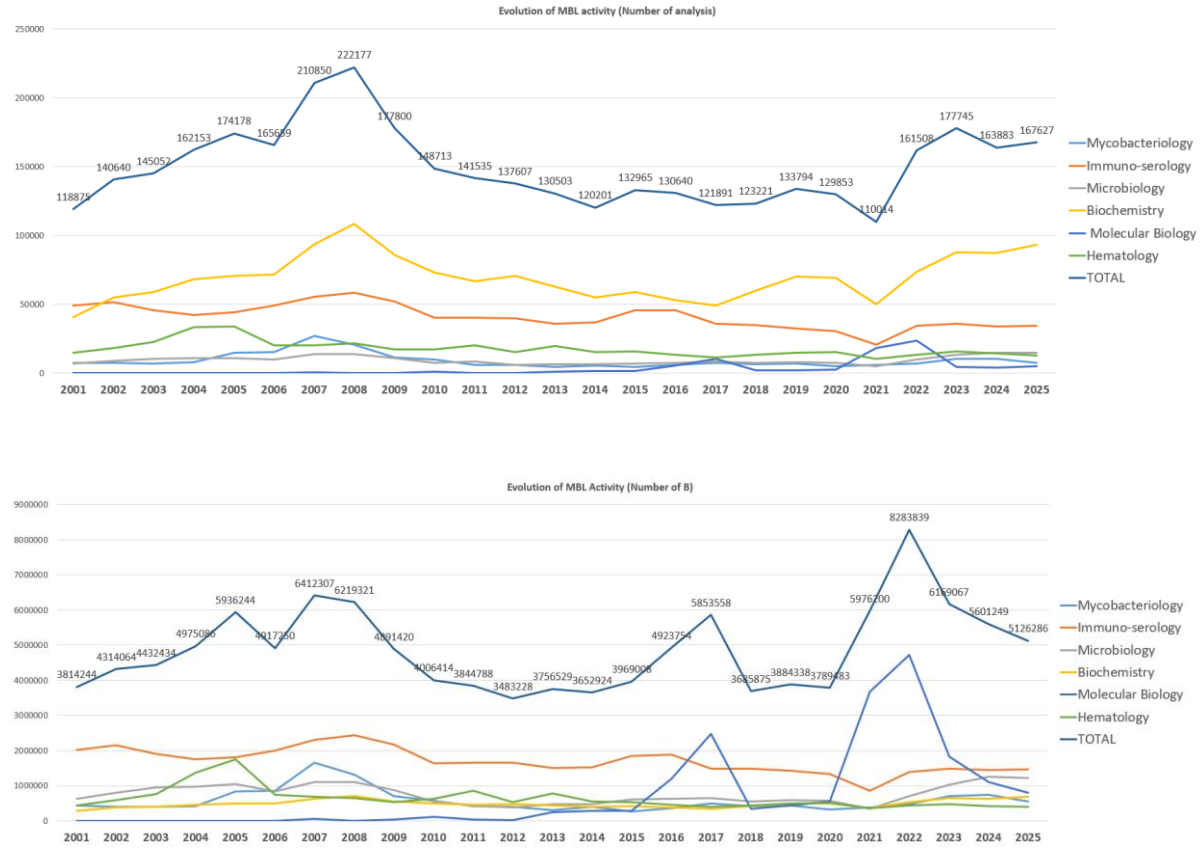


Figure 18: *Trends in MBL activities, values expressed in number of analysis and in key-letter B (adapted for the MBL using the French NABM)*

The MBL remains a reference laboratory in Cambodia, despite an evolving medical biology sector in Cambodia, characterized by the emergence of new private laboratories in Phnom Penh and the establishment of in-house laboratories within private clinics. Nonetheless, MBL is frequently approached for its microbiology and molecular biology services and to verify pathological blood results from other laboratories.

The development of the laboratory information system (LIS, software provider Datamed), implemented two years ago, continues to pose challenges for us, as significant issues that had not been resolved prior to its launch remain unresolved in 2025. Datamed's ability to meet our requirements has always been questioned since the beginning of our collaboration.

In order to improve service delivery and facilitate public access, the MBL has extended its opening hours from Monday to Friday until 6:00 p.m. since 8 September 2025, and added Saturday afternoon until 5:00 p.m. since 10 January 2026.

4.1.2.1 HIV

Voluntary Confidential Counselling and Testing for HIV (VCCT)

In 2025, 236 patients consulted the VCCT and received a free HIV consultation and screening test (see *Figure 19).* Of these consultations, 25.8 % were HIV-positive. This high seropositivity rate can be explained by the fact that most patients were referred by other health centres for free confirmation of a positive rapid HIV antibody test carried out elsewhere. 149 patients (63%) voluntarily came to IPC for a blood test, often to confirm a previous positive test. 87 patients (37%) were referred by national

hospitals (Calmette Hospital, Ang Duong Hospital, Preah Kossamak Hospital, Khmer-Soviet Friendship Hospital, etc.) and private clinics.

In recent years, we have seen a decline in VCCT activities, due to the opening of new HIV testing centres targeting the most at-risk populations. However, the MBL's VCCT activities remain the reference for these centres in order to confirm their results.

HIV Nominative Serology (MBL routine patients)

In 2025, 1958 HIV serological tests have been carried out (the same number as in 2024). The HIV-positive rate among MBL patients is similar to last year's, at 6.8 % (see Figure XX). This prevalence exceeds that of the general population, partly due to samples sent by other laboratories to confirm their positive results.

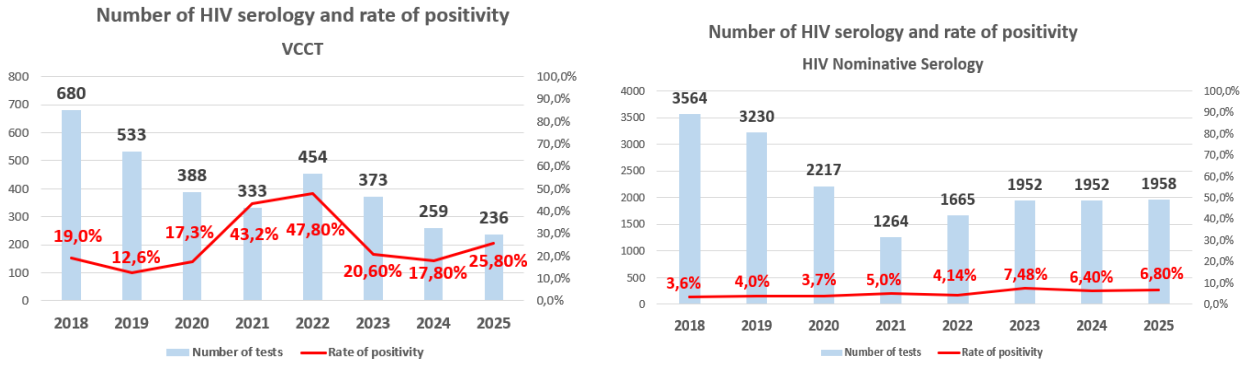


Figure 19: *HIV serology and rate of positivity at VCCT and MBL*

4.1.2.2. Tuberculosis

In 2025, a total of 7,632 analyses were performed for mycobacteriology testing, including smear microscopy, culture, drug susceptibility testing, and molecular assays. This represented a 26% decrease compared to the previous year, likely due to the completion of several ongoing projects. However, GeneXpert rapid testing for TB detection increased by 12%. During 2025, 2,115 Xpert MTB/RIF Ultra tests were conducted for rapid tuberculosis diagnosis, of which 17% were positive for *Mycobacterium tuberculosis* complex, and 0.8% of the positive samples showed resistance to rifampicin. *Figure 20* illustrates the evolution of rifampicin resistance in *M. tuberculosis* over the past five years.

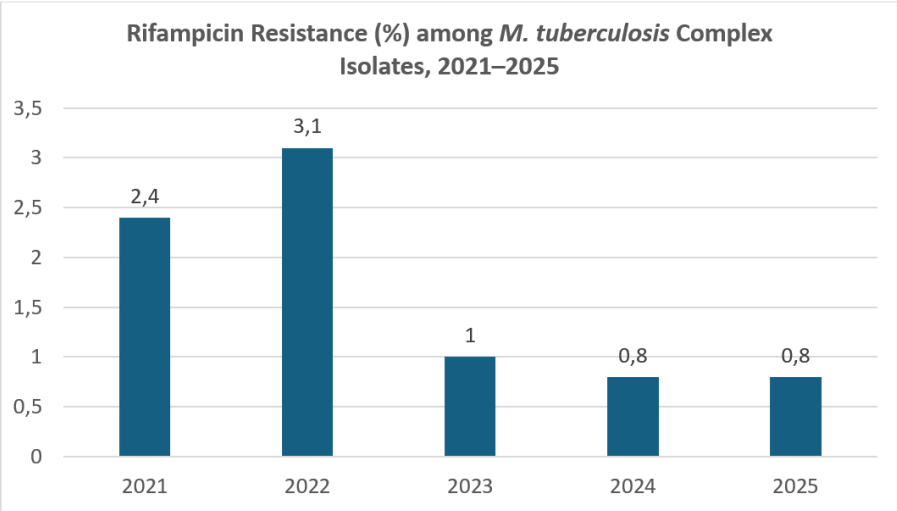


Figure 20: *Evolution of rifampicin resistance in M. tuberculosis complex, 2021-2025 (Xpert MTB/RIF Ultra)*

4.1.2.3. Bacteriology

In 2025, the total number of samples for bacteriological culture decreased by 3.4% but remains high compared to previous years (see Table 8). Compared with 2024, the rate of third-generation cephalosporin-resistant *Enterobacteriaceae* increased by 8% (38.5%), the rate of carbapenem-resistant *Enterobacteriaceae* increased by 1.2% (3.1%) and the rate of methicillin-resistant *Staphylococcus aureus* (MRSA) decreased by 8% (26.5%).

Bacteria of particular public health importance	2021	2022	2023	2024	2025
Samples tor bacteriological culture	2508	5023	7101	9158	**8859**
Positive cultures with antibiogram	967 (38,6%)	1548 (30,8%)	2623 (36,9%)	2994 (32,7%)	**3262(36.82%)**
Third-generation cephalosporin-resistant (3GCRE) (CRE excluded)					
Enterobacteriaceae				536/1769 (30,3%)	**629/1635 (38.47%)**
Escherichia coli	/	/	/	498/1014 (49,1%)	**535/960 (55.73%)**
Klebsiella pneumoniae				34/455 (7,5%)	**67/401 (16.71%)**
Others				4/300 (1,3%)	**27/274 (9.85%)**
Extended spectrum beta-lactamase (ESBL)					
Enterobacteriaceae	143/503 (28,4%)	290/851 (34,1%)	405/1466 (27,6%)	483/1769 (27,3%)	**507/1635 (31.01%)**
Escherichia coli	107/254 (42,1%)	240/487 (49,3%)	347/893 (38,9%)	461/1014 (45,5%)	**443/960 (46.15%)**
Klebsiella pneumoniae	25/127 (19,7%)	34/242 (14%)	43/341 (12,6%)	20/455 (4,4%)	**46/401 (11.47%)**
Others	11/122 (9%)	16/122 (13,1%)	15/232 (6,5%)	2/300 (0,7%)	**18/274 (6.57%)**
Cephalosporinase hyperproduction					
Enterobacteriaceae				53/1769 (3%)	**122/1635 (7.46%)**
Escherichia coli	/	/	/	37/1014 (3,6%)	**92/960 (9.58%)**
Klebsiella pneumoniae				14/455 (3,1%)	**21/401 (5.24%)**
Others				2/300 (0,7%)	**9/274 (3.28%)**
Carbapenem-resistant					
Enterobacteriaceae (CRE)	30/503 (6%)	40/851 (4,7%)	20/1466 (1,4%)	34/1769 (1,9%)	**50/1635 (3.06%)**
Escherichia coli	21/254 (8,3%)	20/487 (4,1%)	17/893 (1,9%)	19/1014 (1,9%)	**36/960 (3.75%)**
Klebsiella pneumoniae	7/127 (5,5%)	17/242 (7%)	2/341 (0,6%)	15/455 (3,3%)	**14/401 (3.49%)**
Others	2/122 (1,6%)	3/122 (2,5%)	1/232 (0,4%)	0	**0/167 (0.00%)**
Carbapenemase types	NDM, OXA-48, KPC	NDM, OXA-48, KPC	NDM, OXA-48	NDM, OXA-48	**/**
***Acinetobacter baumannii* carbapenem-resistant (CRAB)**	9/17 (52,9%)	8/21 (38,1%)	21/78 (26,9%)	41/98 (41,8%)	**24/79(30.38%)**
Salmonella fluoroquinolone-resistant					
Salmonella typhi	/	/	/	1/4 (25%)	**0/5 (0.00%)**
Salmonella non-typhi	/	/	/	2/8 (25%)	**1/13 (7.69%)**
Salmonella paratyphi A	/	/	/	/	**3/8 (37.50%)**
***Enterococcus faecium* vancomycin-resistant**	0/6	0/25	0/15	1/29 (3,4%)	**4/22 (18.18%)**
***Pseudomonas aeruginosa* carbapenem-resistant (CRPA)**	/	/	/	5/163 (3,1%)	**2/125(1.60%)**
Neisseria gonorrhoeae					
third-generation cephalosporin-resistant	3/6 (50%)	1/4 (25%)	1/1 (100%)	1/2 (50%)	**0/4 (0.00%)**
fluoroquinolone-resistant	/	/	/	2/2 (100%)	**3/4 (75.00%)**
***Staphylococcus aureus* methicillin-resistant (MRSA)**	43/139 (30,9%)	71/204 (34,8%)	116/333 (34,8%)	135/391 (34,5%)	**100/377 (26.53%)**

Table 8: *Overview of Bacteriological Data: 2021-2025*

In addition, during our routine activities, four cases of vancomycin-resistant *Enterococcus faecium* (VR*Efm*), an important pathogen in healthcare-associated infections that is causing increasing concern, were identified in 2025, compared to only one in 2024 and none in previous years. This upward trend highlights the importance of continued surveillance of the evolution of resistance patterns. The genome sequencing of these new strains is anticipated to help understand the mechanism of resistance.

In 2025, as an alternative to the classic bacterial culture for the diagnosis of sexually transmitted infections (STIs), the MBL conducted real-time PCR for the detection of DNA from *Chlamydia trachomatis*/*Neisseria gonorrhoeae* on vaginal, urine, urethral, throat, and anal samples. Among 508 samples tested, 7.9 % (n = 40) were positive for *Chlamydia trachomatis*, 3.9 % (n = 20) for *Neisseria gonorrhoeae*, while we identified 11 co-infections (2.2 %).

4.1.2.4. Analysis referred to Laboratoire Cerba

In 2025, MBL referred 531 patient's files to Laboratoire Cerba in France for highly specialized or rarely requested tests, representing a 95% increase from the 272 files in 2024. This increase demonstrates

patients' trust in MBL's commitment to providing comprehensive access to advanced diagnostic services through strong international partnerships with ISO 15189-accredited referral laboratories.

4.1.2.5. Occupational Health & Staff Insurance Testing

In 2025, MBL provided laboratory testing services to the IPC Occupational Health Service for:

- Colorectal cancer screening: 10 staff members;
- Rabies immunity control: samples from 31 staff members sent to Laboratoire Cerba;
- Routine occupational health assessments (pre-employment and periodic medical follow-up): 39 staff members.

In addition, MBL carried out tests related to the IPC personnel insurance on 263 files for 115 individuals (staff members and their families).

4.1.3 Research Programs - Major Achievements in 2025

PREACT AFRICAM Cambodia

Under the PREZODE (Preventing Zoonotic Disease Emergence) initiative, the AfriCam Project was established and funded by the French Development Agency (AFD) to support national strategies and policies aimed at ensuring food security and sustaining community livelihoods in five countries—Cambodia, Cameroon, Guinea, Madagascar, and Senegal—to combat local and international zoonotic diseases. The objective of **AfriCam Cambodia** is to study zoonotic risks associated with hydrological dynamics, and climatic and environmental changes at the human–animal–environment interface. The project implements activities to reduce the emergence of zoonotic risks and to strengthen the surveillance system toward a "One Health" approach. The MBL was primarily involved in Component 1: Risk Assessment, with specific objectives to (i) study the risks of zoonotic disease emergence associated with hydrological, climatic, and environmental changes in diverse ecosystems, and (ii) investigate the circulation of pathogens at the human–animal–environment interface through field sampling, molecular and serological testing, and climatic, environmental, and hydrological analyses. During the first half of 2025, activities focused on developing the study protocol and obtaining ethical clearance, as well as optimizing and implementing laboratory methods. Nine bacteria (*Shigella spp.*, *Salmonella Typhi*, *Salmonella Paratyphi*, *Leptospira interrogans*, *Burkholderia pseudomallei*, *Orientia tsutsugamushi*, *Rickettsia typhi*, *Coxiella burnetii*, and *Borrelia burgdorferi*) and five parasites (*Toxoplasma gondii*, *Entamoeba histolytica*, *Clonorchis sinensis*, *Opisthorchis viverrine*, and *Schistosoma japonicum*) were selected for the study. Molecular detection methods are being used to identify the nine bacterial pathogens in domestic animals (DA), rodents, and environmental samples. The five main pathogens—*Leptospira interrogans*, *Burkholderia pseudomallei*, *Coxiella burnetii*, *Borrelia burgdorferi*, and *Toxoplasma gondii*—are being tested in human samples by serological assays. In the second half of the year, activities focused on organizing field missions for sample collection.

Following the human seroepidemiological survey conducted in June, the first field mission in Battambang Province took place from August to September. Among 391 households, 1,263 individual serum samples were collected, and 90 of the 391 households were selected for DA, rodent, and environmental sampling. A total of 941 samples were collected, comprising soil (269), water (213), rodent (100), and DA (359) samples. Two additional field missions were conducted in Koh Thom District, where 631 samples were collected, including soil (126), water (127), rodent (124), and DA (254) samples. Molecular detection and serological testing are still in progress.

Collaborations	IPC: MBL (B. GUILLARD, S. CHENG, P. GAO, R. S. LEE, H. THON), Virology (V. Hul, J Nouhin), Epidemiology and Public Health (A. Antoniolli, K. Nguon, C Flamand, and S Ly), Medical Entomology Unit (S Boyer) IRD: A-L Banuls, M. Hide, V Herbreteau, S. HAK, and C. SAM, M. LIM Cirad: F Goutard, H. Guis Other Partners: Agronomes et Vétérinaires sans Frontières, International Development Enterprises, ITC, Wildlife Conservation Society, Battambang Hospital.
Funding	French Development Agency (AFD)

ExposUM PEACH: Pathogens Exposure from Aquifers: A Cambodian Health interdisciplinary case study

In Cambodia, the upper Mekong delta is subject to large natural flooding every monsoon season. Climate change, dam building upstream, irrigation and drainage infrastructures modify the flood dynamics, resulting in shorter flooding periods and shallower water levels. These modifications in water conditions have been directly associated with the presence of waterborne pathogens like *Burkholderia pseudomallei* and *Leptospira interrogans*, responsible for melioidosis and leptospirosis, respectively. The PEACH project proposes to characterize the role of groundwater in the environmental exposure to bacteria in the floodplain of the upper delta of the Mekong River. The objective is to gain essential knowledge on the ecology of *L. interrogans* and *B. pseudomallei* and define how shifting hydric conditions influence the origin and timing of the associated water exposome, impacting public health.

In 2024, the MBL focused primarily on study design and field sampling plans. In 2025, MBL continued with study implementation, field sampling, and laboratory analyses. Two of the six planned field missions were conducted jointly with the AfriCam project to collect vertical soil and water samples. Sample collection and laboratory testing are ongoing, with MBL targeting the completion of all six missions by the end of 2026 and the finalization of analyses by mid-2027.

Collaborations	IPC MBL: B. GUILLARD, S. CHENG, RS. LEE, and H. THON IRD: S. MASSUEL, M. HIDE, S. HAK, and C. SAM Other partner: ITC
Funding	Montpellier University

CircUs - Pilot phase in Cambodia

The CircUs pilot study in Cambodia, a multi-country One Health initiative (Burkina Faso, Côte d'Ivoire, Madagascar), investigates the circulation of multidrug-resistant Enterobacteriaceae (MDR-E) across human, animal, food, and environmental compartments through multidisciplinary work packages (WPs).

Hospital-based surveillance (WP1) at Takeo Provincial Referral Hospital (May 2023–September 2024) recruited 64 patients with *Enterobacteriaceae* infections identified in blood, urine, or stool samples, where *E. coli* (75.3%) and *K. pneumoniae* (17.8%) were the predominant species. Household and environmental sampling (WP2) from 36 patients' households collected 406 samples: humans (patients and household members; 23%), domestic animals (16%), environment (30%), and food (22%). A total of 687 MDR-E isolates (*E. coli* 46%, *K. pneumoniae* 35%, *Enterobacter cloacae* complex 17%) were detected. Of 351 bacterial isolates, including *E. coli, K. pneumoniae,* and *Enterobacter cloacae* complex, from patients and households submitted for whole-genome sequencing in 2025, sequencing is complete, with analysis planned for 2026.

Collaborations	IPC MBL-BAAR: S. CHENG, B. GUILLARD, V. HENG, P. GAO IRD: A-L Banuls, S. HAK Takeo Provincial Referral Hospital: S. SEANG General Directorate of Animal Health and Production (GDAPH), MAFF: S. SAN
Funding	AVIESAN AMR-SUD ANR “Antibiorésistance : comprendre, innover, agir (AMR)"

Effectiveness analysis and economic evaluation of a modified program for cervical cancer screening in Cambodia assisted by a cloud-based digital system - Additional testing

Cervical cancer screening is a global and Cambodian public health priority, with emerging methods indicating superiority over existing VIA-based screening. The WHO recommends primary HPV screening as the preferred strategy wherever affordable. Important country-specific implementation issues include the choice of the most effective triage test for HPV-positive women and the most accepted mode of HPV test collection. In 2023, the MBL conducted high-risk HPV (hrHPV) testing using the Cobas 4800® platform (Roche) on a total of 10,046 patient samples to detect HPV16, HPV18, and 12 other pooled hrHPV genotypes. High-risk HPV was identified in 5.1% of samples, of which 31.4% were HPV16/18 and 77.6% corresponded to other hrHPV types. Multiple hrHPV infections were observed in 8.8% of samples. Only 0.6% of samples yielded invalid results. In 2025, HPV genotyping using the SeeGene Allplex™ HPV28 Detection assay was implemented at MBL. A total of 482 samples, comprising 90% hrHPV-positive and 10% hrHPV-negative samples, were selected for genotyping. The observed overall agreement between Cobas and SeeGene assays for any hrHPV detection was 97.5%: 422/433 (97.5%) were true positives on both platforms and 48/49 (98.0%) were true negatives. The observed agreement between Cobas and SeeGene tests for HPV16, HPV18, and other hrHPV genotypes was 98.1%, 99.4%, and 95.6%, respectively. Multiple hrHPV genotypes were detected in 28.8% (122/423) of hrHPV-positive samples. Overall, HPV16 was the most prevalent genotype among all hrHPV types identified. The distribution of HPV genotypes by oncogenic potential showed similar proportions across high-risk (HPV16, 18, 45), medium-risk (HPV31, 33, 35, 52, 58), and low-risk groups (HPV39, 51, 56, 59, 68).

Collaborations	IPC MBL: S. CHENG, S. HENG, B. GUILLARD Heidelberg University: H. BUSSMANN Ministry of Health: Dr S. VONG
Funding	Heidelberg University, Oncgnostics GmbH

Prevalence of invasive fungal infections - Histoplasma capsulatum, Talaromyces marneffei, Cryptococcus spp - in severe immunocompromised HIV-infected patients in Cambodia

Histoplasmosis, talaromycosis, and cryptococcosis are serious invasive fungal infections (IFIs) in patients with advanced HIV disease. Although these infections are common in Southeast Asia, they remain rarely diagnosed in Cambodia, likely due to limited clinical awareness, overlapping symptoms with tuberculosis (TB), and inadequate access to reliable diagnostic tools. In recent years, antigenic and molecular techniques have emerged as promising tools for the rapid diagnosis of IFIs. The objective of the Fungi-Cam project is to assess, using these new methods, the prevalence of these IFIs in Cambodia among patients living with HIV (PLHIV) at an advanced stage who participated in the STATIS study (ANRS_12290), a study on the management of TB associated with HIV. The secondary objective is to raise awareness and train local health workers on these infections and modern diagnostic tools. A four-day Laboratory Training Workshop took place in October 2024 at the MBL, covering both theoretical and practical aspects of diagnosing these IFI. Following the workshop, new antigenic detection methods using LFA and EIA on urine samples and PCR on plasma samples were

implemented at MBL. In 2025, a clinical training workshop was also organized to strengthen clinical awareness and IFI case management for laboratory managers and clinicians involved in TB-HIV care from various national hospitals. The laboratory analysis of 193 patient samples for cryptococcosis (LFA and PCR), histoplasmosis (LFA, EIA and PCR), and talaromycosis (LFA) have been completed. The molecular assays for *Talaromyces marneffei* are scheduled to be performed in February 2026, and the data analysis and results dissemination workshop will be organized in March 2026.

Collaborations	IPC MBL-BAAR : S. Cheng, IPC Epidemiology and Public Health Unit: N. De Rekeneire, B. DIM IPP: A. STURNY LECLERE, F. LANTERNIER University of Health Sciences: E. MOSNIER Cayenne Hospital (French Guiana, France): A. ADENIS, U. FRANCOISE
Funding	Inserm - ANRS MIE Sponsor: IPC

Nontuberculous mycobacterial (NTM) infections associated with climate change and major weather events: enhancing surveillance and mitigation strategies

Nontuberculous mycobacteria (NTM), known to cause chronic infections, are environmental pathogens commonly found in water and soil. The incidence of NTM infections is increasing dramatically in Australia, Japan, the United States, and other global regions. In many Asian countries, however, epidemiological data on NTM are lacking, as public health prioritizes tuberculosis cases. Therefore, this multi-party collaboration will evaluate the epidemiology of NTM infections in Australia, the US, Japan, Thailand, and Cambodia and identify the impact of climate change variables and major weather events on NTM incidence. In 2025, retrospective collection of positive NTM data spanning from January 2010 to December 2025 was initiated, with data extracted from the Laboratory Information System (LIS) of the Mycobacteriology Laboratory, Institut Pasteur du Cambodge (IPC).

In the beginning of 2025, retrospective collection of positive NTM data spanning January 2010 to December 2025 was initiated, with data extracted from the Laboratory Information System (LIS) of the Mycobacteriology Laboratory, Institut Pasteur du Cambodge (IPC). A NTM dataset was built, including demographic, clinical, and bacteriological information. Members of the research team participated in a training workshop on statistical modeling in the epidemiology of NTM and climate data in July 2025 in Brisbane, Australia. In December 2025, the complete climate dataset was obtained from Pelmorex Weather Source. Data integration and statistical analysis will be conducted in the following year to investigate the association between environmental and climate factors and NTM incidence rates. A manuscript describing NTM incidence in the five countries is being developed.

Collaborations	IPC MBL-BAAR: S. Cheng, S. UNG University of Queensland (Australia): R. Thomson National Institutes of Health (USA): D.R. Prevots Research Institute of Tuberculosis, Japan Anti-Tuberculosis Association: K. Morimoto Ministry of Public Health (Thailand): S. Mahasirimongkol
Funding	e-ASIA Joint Research Program (e-ASIA JRP) NIAID funding to support activities in Cambodia

Diagnostics and surveillance of acute meningo-encephalitis among children in Cambodia with a focus on Japanese Encephalitis Virus (DEMELE-JEV project)

Infectious meningitis and encephalitis pose major public health threats in Southeast Asia due to high morbidity, mortality, and epidemic potential. Japanese encephalitis virus (JEV) remains prevalent in Cambodian children despite vaccination since 2015, driven by diagnostic gaps and poor surveillance. Advanced molecular diagnostics offer new opportunities to improve the detection and management

of these disease in resource-limited settings. The objectives of the DEMELE-JEV are to quantify the clinical burden of Japanese Encephalitis (JE) and the asymptomatic circulation of JEV among Cambodian children, to estimate anti-JEV seropositivity rates, to identify the etiologies of febrile neurological syndrome in children, to develop and evaluate new tools for diagnosis. Children will be recruited in Kantha Bopha hospitals in Phnom Penh and Siem Reap. At the beginning of 2025, the study protocol was developed and submitted to Cambodia's National Ethical Committee for Health Research. After ethical approval, a kick-off meeting and training workshop for data collection were organized to officially launch the project in November 2025. Twenty-one CSF samples were received in 2025 for TB testing using GeneXpert and culture. Data collection is ongoing in 2026.

Collaborations	IPC MBL : S. CHENG, B. GUILLARD UHS : Pr SAPHONN Vonthanak Unité des Virus Émergents, Aix-Marseille Université, France: Dr A. DUBOT-PERES
Funding	MEAE / ANRS-MIE (2024-2026)

CAM-ONE AMR - Antibiotic Resistance: One Health for Surveillance and Action in Cambodia

The Cam-One AMR (Cambodia One Health Antibiotic Resistance Surveillance and Action) study, jointly coordinated by the Cambodian CDC and the French National Research Institute for Sustainable Development (IRD), aims to strengthen AMR surveillance in Cambodia through a comprehensive One Health approach.

The initiative seeks to improve the quality, accuracy, and responsiveness of laboratory and diagnostic capacities by standardizing surveillance procedures and developing a centralized AMR digital dashboard for data visualization and analysis. By generating robust data across human, animal, and environmental health sectors, the study aims to support the foundations of a resilient national surveillance system and evidence-based public health decisions driven by resistance patterns within a One Health approach.

The project is structured around three complementary components:

- Component 1, led by the Cambodian CDC, focuses on standardized data collection and the development of the centralized AMR dashboard
- Component 2, coordinated by Institut Pasteur du Cambodge (IPC) and IRD, addresses AMR at the human–animal–environment interface; and ;
- Component 3, led by the French Agricultural Research Centre for International Development (CIRAD), targets improved health practices in both humans and animals.

A Kick-Off Meeting held on December 15, 2025, officially launched the study, presented its objectives and implementation plan, and strengthened coordination among all partners. Following this, detailed discussions with selected sentinel sites are planned to refine operational strategies. The study protocol is being developed for ethical clearance, with field sampling expected to begin in early 2026.

Collaborations	IPC MBL-BAAR: S. CHENG, P. RAHI, S. HAN IRD: A.L. BAÑULS, M. HIDE, S. HAK Communicable Disease Control Department, Ministry of Health: S. KRANG CIRAD: A. Hobeika NAPHRI, GDAPH, MAFF: S. Tum
Funding	MEAE / French Embassy (2025-2027)

Dual resistance to carbapenems and colistin in *Enterobacter*

Enterobacter species are rising as tough nosocomial pathogens, with bacteremia linked to high mortality. Intrinsic AmpC β-lactamase and widespread fluoroquinolone resistance shrink options,

making carbapenems critical. Additionally, the global carbapenem resistance is surging, plus high colistin heteroresistance. Our recent study on the dual resistance to carbapenem and colistin in a substantial proportion of *Enterobacter* isolates at the population level makes this genus an emerging priority for hospital infection control and antimicrobial resistance surveillance.
Further, these findings underscore the urgent need for improved diagnostics, strengthened antimicrobial resistance surveillance, and optimized treatment strategies.

Collaborations	IPC MBL-BAAR: P. RAHI National Health Research Institutes (Taiwan): YC. HUANGA, YR. CHEN, SC. KUO, CT. FANG National Taiwan University (Taiwan): CT. FANG Taipei Medical University (Taiwan): TW. HUANG
Funding	Expertise France

4.1.4 Research Programs - Outlook for 2026

SPARK HAAPI: Haemophilus Africa-Asia-Pacific Initiative

Haemophilus influenzae is a human-restricted bacterium that colonizes the upper respiratory tract and can cause non-invasive or invasive diseases. While vaccination has reduced serotype b cases, infections from other serotypes and non-typeable strains are increasing. Ampicillin is the main treatment, but rising resistance has led the WHO to stress the urgent need for new antibiotics and improved surveillance, especially for vulnerable groups. Historically, β-lactam resistance in *Haemophilus* through ftsI mutations or TEM/ROB β-lactamases was limited to ampicillin and could be managed with third-generation cephalosporins (3GCs). However, new mutations and extended-spectrum β-lactamase production now confer 3GC resistance, and multidrug-resistant strains are increasing worldwide. Genetic plasticity of the genus is a concern, and the lack of genomic datasets from low- middle-income countries, particularly in Africa, Asia-Pacific, means recent evolutionary dynamics remain poorly understood.
In response, the HAAPI is implementing a comprehensive, multi-step strategy to address antibiotic-resistant *Haemophilus* in 3 understudied territories.
This initiative, which involves early-career scientists and aligns with Institut Pasteur strategic priorities, will enable the development of the first joint project among the consortium members.
The scientific objectives are as follows: (i) to employ genomic epidemiology to map strain distribution and place local diversity in a global context, drawing on both newly collected samples and the consortium's historical collections to provide insight into recent biological evolution; and (ii) to combine genomic and in vitro experimental approaches to investigate the emergence and spread of specific resistance within these collections.

Collaborations	IP Partner(s) : Institut Pasteur de Nouvelle-Calédonie (M. POT), Institut Pasteur d'Algérie (S. MAHRANE), Institut Pasteur du Cambodge (S. CHENG)
Funding	Pasteur Network - SPARK 2025 (2026-2027)

RACSMEI: Risk assessment of Community spread of multiple endemic infectious diseases in a one health perspective

From 2025 to 2030, the RACSMEI project aims to enhance Precision Public Health in Cambodia, a highburden country for infectious diseases. By integrating human, animal, and environmental data through a One Health approach, the project will conduct a nationally-representative survey on several priority zoonotic and endemic diseases, covering 10,000 individuals, animals, vectors, and

environmental factors. The research will utilize cutting-edge multiplex serology, environmental sampling, metagenomics and mathematical modeling to understand disease transmission dynamics, focusing on priority pathogens such as dengue, Chikungunya, Zika, Japanese encephalitis, Avian influenza, Nipah virus, Hantavirus, *Leptospira*, *Burkholderia pseudomallei*, arenaviruses, tick-borne encephalitis virus (TBEV), and severe fever with thrombocytopenia syndrome virus (SFTSV) and others. The findings will inform targeted interventions, strengthen surveillance, and contribute to informed public health policies and long-term collaborative research.

The field missions for sample collection were initiated in 2025 by the Epidemiology and Public Health Unit, the Virology Unit, and the Medical and Veterinary Entomology Unit. However, the laboratory activities at the Medical Biology Laboratory (MBL) are scheduled to begin later in 2026.

Collaborations	Team leaders: Epidemiology and Public Health Unit (S. Ly, T. Sieng, C. Flamand), CIRAD (H. Guis), Virology Unit (Erik Karlsson), LBM (S. Cheng, B. Guillard), Medical and Veterinary Entomology Unit (S. Boyer), Malaria Consortium, MoH, MaFF, MoE
Funding	Wellcome TrustDiscovery Award, AFD-Ecomore : 2025-2030

4.1.5 Support to National Authorities

- MBL is member of the Technical Working Group on Antimicrobial Resistance at MoH
- MBL is member of the Multidisciplinary Technical Working Group on AMR
- Voluntary Confidential Counselling and Testing for HIV (VCCT) activities in MBL

4.1.6 Teaching and Training

Continuing Professional Training and Development for MBL Staff in 2025

N°	Training title	Trained by	Staff
1	Biological & Chemical risks	Kaptitude	EM.R, THEA.R, HAV.K, HON.H, LEE.R, GOV.P, BUN.S, VEN. B, THEN.S
2	ISO15189:2022 Awareness	Punyam Academy	EM.R, NONG.K.
3	ISO15189:2022 Awareness	EM Rattanak	BUN.S, THEA.R, HAV.K, HON.H, LEE.R, VEN.B, THEN.S
4	ISO15189:2022 Auditor, ISO/IEC 17025:2017 Awareness, ISO/IEC 17025:2017 Auditor, ISO35001:2019 Awareness, ISO35001:2019 Auditor	Punyam Academy	EM.R
5	Fire Prevention and Fighting	Mr. Sok Vannra	HENG.S, NOP.P
6	Strengthening genomics-informed surveillance, diagnosis, and control of infectious diseases across the Asia-Pacific	CENTRE for PATHOGEN GENOMICS (Australia)	HAN.S
7	Methylation on HPV by Application Specialist of Oncognostics (CE IVD-marked in vitro diagnostic (IVD) test)	Oncgnostics Application	HENG.S, KONG.K, KEO.S, HAN.S
8	Biological and Chemical Spill Kits	LIM Hokkean, EM Rattanak, HENG Seiha	EM.R, HENG.S, KONG.K, KEO.S, HAN.S, SITH.C, ENG.S, CHEY.S, CHAN.S, SRENG.N, SEM.S, SON.S, MENG.S, LON.A, PEN.K, HENG.V
9	Project Management in Global Health Syllabus	University of Washington's	UNG.S
10	Unconscious Bias and Sexual Harassment Prevention	GADC and Shiftbalance team	HENG.S, ENG.S, KEO.S, CHHEANG.R

11	Herpes simplex virus Type I/II, Mycoplasma Geneitalium and ZDC virus by Real time PCR	BioPerfectus	HENG.S, KONG.K, HAN.S, CHENG.S, NOP.P, SITH.C
12	Allplex HPV 28 detection-HPV genotyping by application specialist of Seegen	EASTERM-Vietnam	HENG.S, KONG.K, KEO.S, HAN.S
13	Nonconformity management	EM Rattanak	GUILLARD.B, HENG.S, KONG.K, KEO.S, HAN.S, SITH.C, ENG.S, CHEY.S, SOEUR.E, CHAN.S, HAV.K, CHENG.S, SRENG.N, SEM.S, YI.V, NOP.P, MENG.S, LON.A, PEN.K, HENG.V, ENG.R, KEO.S, YEK.S, YIN.T, TEAV.V, KHAN.O, NONG.K, SOUN.S, KEO.S, CHHEANG.R, DY.R, BUN.S.
14	Infectious substances & Triple packaging	KENG Neavuthea	EM.R, HENG.S
15	Specimen collection, transport & storage	KEO Sokuntheary	YEK.S, KHAN.O, YIN.T, TEAV.V
16	First Aid / Occupational Health and Safety	Cambodia Red Cross & Future Focus Solution	EM.R, DY.R, CHHEANG.R
17	First Aid	Cambodia Red Cross & Future Focus Solution	HENG.S
18	Excellence in customer service	KHENG NONG Phally	LY.A, YANG.S, VOALKUCH.C, KEO.S, SOUN.S
19	Documents and Records Management	EM Rattanak	BUN.S, DY.R, SRENG.N, YI.V, UNG.S, SON.S, NOP.P, LON.A, HENG.V, HENG.S, KONG.K
20	Hemoglobin Electrophoresis Result Interpretation	HOEUB Pengheang- from MediGroup	GUILLARD.B, CHENG.S, PHOUNG.V, CHHEANG.R, DY.R, BUN.S, SITH.C, ENG.S, THEA.R, SOEUR.E, HAV.K, CHAN.S, SON.S, NOP.P.
21	FORMATION INTERFACES AUTOMATES	DGLab	GUILLARD.B, CHENG.S, SITH.C.
22	Blood culture and quality indicators	NOP Puthea	MENG.S, ENG.R, PEN.K, LON.A, HENG.V
23	Hematology (e-HEMATimage)	e-MEDICINimage	SITH.C.
24	Mycology (e-MYCOimage), Parasitology (e-PARASITimage)	e-MEDICINimage	NOP.P.
25	General English Program	ACE	SEM.S, LON.A, HENG.V, KHAN.O
26	CLS: DPD: Recommandations, enjeux et perspectives	Cerba Live Session	HENG.S
27	CLS: Analyse des chromosomes du caryotype standard aux dernieres techniques moleculaires	Cerba Live Session	HENG.S, SITH.C
28	CLS: Les zoonoses, de l'animal a l'Homme: Focus sur Bartonella,Coxiella et Francisella.	Cerba Live Session	CHHEANG.R, PHOUNG.V
29	CLS: Prolactine et Diagnostics: Eviter les faux pas	Cerba Live Session	CHHEANG.R
30	CLS: Alcool et biomarqueurs	Cerba Live Session	CHHEANG.R, BUN.S
31	CLS: CMV et grossesse:	Cerba Live Session	GUILLARD.B, SITH.C
32	CLS: VRS, virus repiratoires et grippe:	Cerba Live Session	CHHEANG.R, BUN.S, SITH.C
33	CLS: Myeloma Multiple	Cerba Live Session	BUN.S, SITH.C

34	Attended workshop- Cambodia: Heart Association (CHA)	CHA	CHHEANG.R
35	ENGLISH- Completed the EF SET Certificate: B1 level	Cert.efset.org/U5Qeui	SON.S
36	Cobas 5800 On-site Basic Training	Roche	HENG.S, KONG.K, KEO.S, HAN.S, SITH.C, SON.S, NOP.P
37	MALDI-TOF based Identification of Microbes	Praveen RAHI	SON.S, NOP.P, MENG.S, HENG.V, ENG.R, PEN.K, LON.A, CHENG.S, SRENG.N, YI.V, SEM.S

Medical Biologist

Ms SON Sreyphal, a Pharmacist at the MBL, defended her master's thesis in medical biology on January 14, 2026, at the University of Health Sciences in Phnom Penh: *"Prevalence of invasive fungal infections in severe immunocompromised HIV-infected patients in Cambodia: a retrospective study"*.

Young talents of MBL

Two MBL laboratory technicians (Mr HAN Samrach and Mr ENG Sokchea) are participating in the IPC's Young Talent's Program. They are enrolled in the bachelor's degree program in medical laboratory technology (2025-2027) at Puthisastra University (Phnom Penh) with their tuition fees covered by IPC. The objective is to enable them to take on greater responsibilities in service and research.

Internships

The MBL plays an important role in training activities. In 2025, MBL welcomed 54 university and high school students who participated in its training programs to enhance their knowledge and practical skills in medical laboratory testing:

- University of Health Science (UHS): 36 pharmacy students and 4 master's students in medical biology
- University of Puthisastra (UP): 6 master's students in medical biology and 5 students in laboratory technology
- Lycée Français René Descartes (LFRD): 2 high school students
- YuKunThor High School: 1 High school student

4.1.7 Outlook for 2026

Quality

The MBL maintains its quality system to guarantee reliable, accurate results and compliance with ISO 15189, while promoting ongoing improvement of its activities. One of the main objectives of MBL for 2026 is to update bacteriology procedures and SOPs with the aim of expanding the scope of accreditation at the next COFRAC audit.

Development plan

The MBL must adapt to changes in the medical biology landscape in Cambodia. In 2026, the MBL's development plan will continue.

This involves collaboration between MBL and the IPC management:

- Revision of test prices in the MBL catalogue
- Introduction of new tests and acquisition of new equipment
- Creation of an off-campus sampling site

- Improving MBL's communication with its customers (patients and healthcare providers): website, satisfaction surveys, contract reviews, use of social media, …

Research activities

- Building Technical Capacity: Priority development includes bacterial genomic sequencing, metagenomics, genomic/data analysis, manuscript drafting, and grant proposal writing to expand BAAR group capabilities.
- Strengthening Research Capacity: Recruitment of one or more local PhD students or post-doctoral research through existing collaborations to strengthen the team research capacity.
- Strategic Research Development: Develop new studies targeting core thematic priorities (Tuberculosis, Priority AMR pathogens through One Health approaches, Wastewater-based surveillance for early detection of antimicrobial resistance and emerging pathogens)
- Boosting Scientific Output: Establish internal manuscript review processes and external professional editing before journal submission.

4.1.8 Scientific Publications 2025

Note: *The name of authors from the Institut Pasteur du Cambodge are underlined*

1. **Hybrid sequencing of chromosome and plasmids from multidrug-resistant Escherichia coli isolated in Cambodia: Are megaplasmids vectors of antibiotic resistance genes?**
   Marcy E, Chiek S, Hidé M, Hak S, Ma C, Lem M, Delvallez G, Bañuls AL, Cheng S, Hayer J.
   Glob Antimicrob Resist. 2025 Dec;45:115–24. doi:10.1016/j.jgar.2025.09.003

2. **Prevalence and characterization of third-generation cephalosporin, carbapenem and colistin-resistant Enterobacterales isolated from clinical samples in Cambodia**
   Delvallez G, Cheng S, Girond F, Krang S, Meng S, Nop P, Heng S, Han S, Keo S, Kong K, Bañuls AL, Hide M.
   New Microbes New Infect. 2025 Dec;68:101649. doi:10.1016/j.nmni.2025.101649

3. **Contribution of maternal gut carriage to neonatal acquisition of extended-spectrum beta-lactamase-producing Enterobacterales in Madagascar and Cambodia**
   Beaumont AL, De Lauzanne A, Criscuolo A, Fabre L, Rabenandrasana MAN, Randriamanga NF, Bernabeu S, Harimanana A, Randremanana RV, Herindrainy P, Collard JM, Pring L, Sreng N, Cheng S, Borand L, Kermorvant-Duchemin E, Crucitti T, Guillemot D, Huynh BT.
   Nat Commun. 2025 Nov 24;16(1):10399. doi:10.1038/s41467-025-65352-4

4. **Seroprevalence of Diphtheria in Antananarivo, Madagascar, and Cambodia.**
   Campana F, Noel G, Rajabizadeh M, Harimanana A, Rafetrarivony L, Delvallez G, Hide M, Meng S, Razafimahatratra SL, Dim B, Ait-Ahmed M, Borand L, Collard JM, Guiso N, Taieb F.
   Open Forum Infect Dis. 2025 Feb 20;12(3):ofaf091. doi: 10.1093/ofid/ofaf091. eCollection 2025 Mar.

5. **Absence of Macrolide-Resistant Mutations in *Bordetella pertussis* in Antananarivo (Madagascar) and Cambodia During the Last Pertussis Cycle Before the COVID-19 Pandemic.**
   Campana F, Rajabizadeh M, Hide M, Delvallez G, Han S, Rafetrarivony L, Dim B, Harimanana A, Noel G, Ait-Ahmed M, Collard JM, Borand L, Guiso N, Taieb F.
   Open Forum Infect Dis. 2025 Sep 29;12(10):ofaf566. doi: 10.1093/ofid/ofaf566. eCollection 2025 Oct.

6. **First evidence of human borreliosis local transmission in Cambodia.**
   Yean S, Maquart PO, Delvallez G, Boyer S.
   Int J Infect Dis. 2025 Nov 14:108208. doi: 10.1016/j.ijid.2025.108208.

7. **Hepatitis B core-related antigen rapid diagnostic test for point-of-care identification of women at high risk of hepatitis B vertical transmission: a multicountry diagnostic accuracy study**
   Jeanne Perpétue Vincent, Olivier Ségéral, Dramane Kania, Laurence Borand, Jean-Pierre Adoukara, Adeline Pivert, Amariane Koné, Abdoul Salam Eric Tiendrebeogo, Haoua Tall, Laura Schaeffer, Muriel Vray, Armel Moumouni Sanou, Richard Njouom, Gavin Cloherty, Naofumi Hashimoto, Tetsuo Miura, Wataru Sugiura, Saren Sovann, Jee-Seon Yang, Gauthier Delvallez, Françoise Lunel-Fabiani, Yasuhito Tanaka, Yusuke Shimakawa; HBcrAg-RDT Study Group. Lancet Gastroenterol Hepatol, 2025 Mar 12:S2468-1253(25)00015-9. doi: 10.1016/S2468-1253(25)00015-9

8. **Tea seedlings growth promotion by widely distributed and stress-tolerant PGPR from the acidic soils of the Kangra valley.**
   Thakur R, Rahi P, Gulati A, Gulati A.
   BMC Microbiol. 2025 Feb 28;25(1):102. doi: 10.1186/s12866-025-03811-0.

9. **Sustainable Tea Cultivation with a Rhizobacterial Consortium: A Microbiome-Driven Alternative to Chemical Fertilizers.**
   Sorongpong S, Debnath S, Rahi P, Bera B, Pandey P.
   Microorganisms. 2025 Jul 22;13(8):1715. doi: 10.3390/microorganisms13081715.

4.2 Laboratory of Environment and Food Safety

The Laboratory of Environment and Food Safety (LEFS) was created in 1995. Its activities mainly involve microbiological and chemical analyses of food and water. In more detail, the LEFS aims to:

- Identify and quantify public health issues related to food and water consumption and caused by the presence of pathogens (*Clostridium perfringens*, Coagulase positive Staphylococci, *Salmonella*…) and parasites;
- Promote hygiene practices in restaurants and food industries (training, consulting, auditing).

The laboratory provides the following analysis services, in compliance with international protocol standards:

- Microbiology of food, water and surface swab samples;
- Physical chemistry assays, quality of water samples;
- Identification of Legionella in tap water, cooling towers, pools and spa water.

4.2.1 Functional Structure

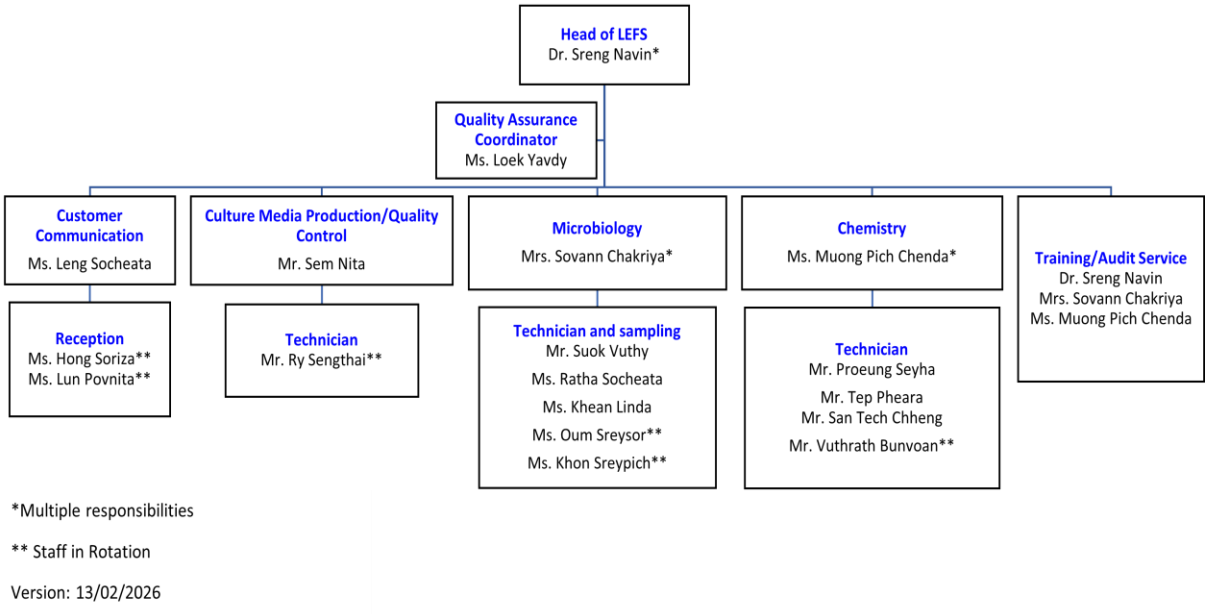


Figure 21: *Laboratory of Environment and Food Safety organogram*

The team's composition changed in 2025 with a resignation of deputy of head. With the financial support from the Cambodia Australia Partnership for Resilient Economic Development (CAPRED) to establish new services for heavy metal testing, as well as pesticide and antibiotic residue testing, in 2025, we could start to sell service for heavy metal testing (Lead, Cadmium, and Nickel) in water and pesticide testing in Rice and Dried pepper and also include them in our scope of accreditation.
The extension service of heavy metal to wastewater and food, and pesticide testing to cashew and other food type is planned for 2026.

4.2.2 Service Activities in 2025

In 2025, our laboratory analysed a total of 8,542 samples, including 1,767 food samples, 3,213 water samples, 1,515 surface and air samples for microbiological testing, and 45 food samples along with 2,002 water samples for chemical testing. Additionally, we successfully conducted 2 training sessions on food safety and 1 training on technical test analysis.
Compared to 2024, the total number of samples tested increased by 0.8%, while the overall number of tests rose by 0.9%.
The analytical activities (sample numbers and test numbers) over the last five years are shown in the figure below:

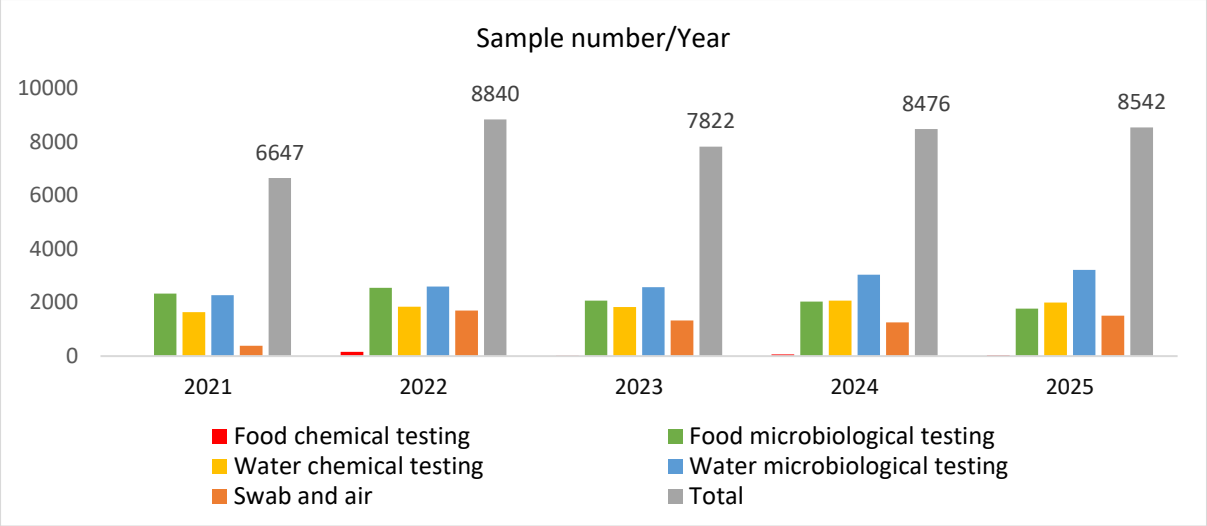


Figure 22: *Evolution of the number of samples by year (2021-2025)*

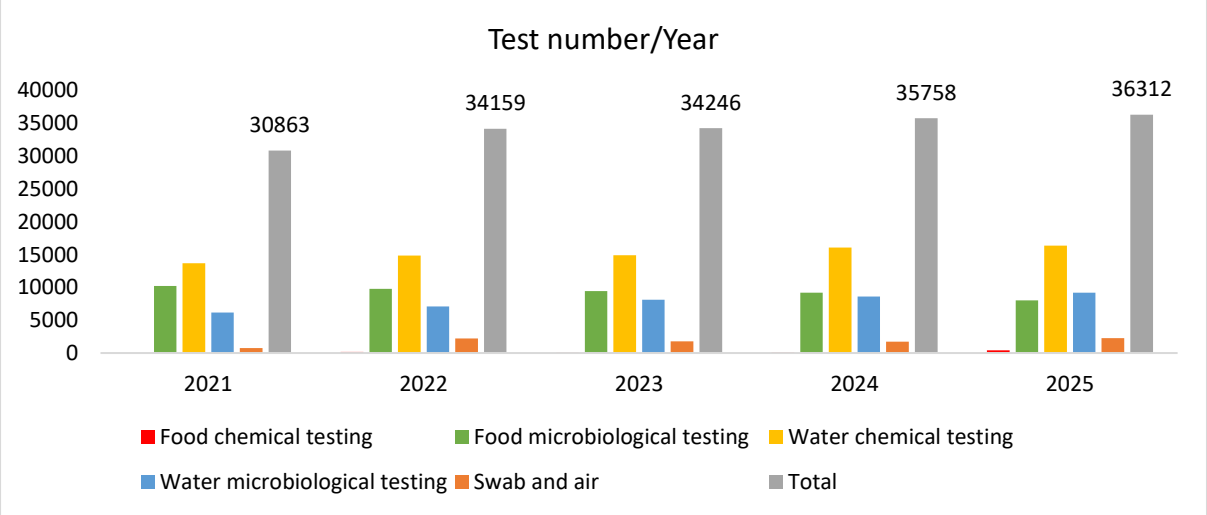


Figure 23: *Evolution of the number of analysis by year (2021-2025)*

If we look more closely at the data collected for each sample category in terms of quality, we note that:

Food sample

- 47% of food microbiology samples (829/1,767) were requested to compare the results with reference standards or customer requirements, and 15% (124/829) were found to be unsatisfactory.
- The unsatisfactory results were due to *Salmonella* contamination (15%), and to high levels of hygiene risk indicators such as Total plate count (42%), *E. coli* (13%), Coagulase positive Staphylococci (10%), Coliforms bacteria (8%), yeast and mould (6%), and *Clostridium perfringens* (3%).
- 79% of Salmonella-positive food samples were raw meat (15/19) followed by salad and raw ready to eat food at 10.5% (2/19), and raw fish at 14.8 % (2/19).

Water

- 39% of water samples sent to microbiology testing (1,242/3,213) were requested to compare the results with reference standards or customer requirements, and 27% (333/1,242) were

unsatisfactory due to the contamination of Coliforms bacteria (73%), *E.coli* (10%), Total plate count (4%), and other bacteria (13%).

- 37 % of ice cube samples (150/406) from restaurants and bars were found to be contaminated by faecal bacteria, such as coliforms and *E. coli*.

Quality Management System

The LEFS was accredited for food microbiology analysis by the International Accreditation Service (IAS) on 6th September 2022, under the accreditation number TL-1056, according to the ISO/IEC 17025:2017 standard.

In 2025, with financial support of CAPRED, LEFS broadened its accreditation scope by adding 2 more parameters of heavy metal on water along with 8 additional parameters of pesticide residue in rice and pepper, as detailed below.

Parameters – Food / Environment	Method	New (Yes/No)
Culturable microorganisms at 30°C	NF EN ISO 4833-1	No
Presumptive *Bacillus cereus* at 30°C	NF EN ISO 7932	No
Coliforms bacteria	NF ISO 4832	No
Enterobacteriaceae	NF EN ISO 21528-2	No
Escherichia coli	NF ISO 16649-2	No
Yeasts and Moulds	NF V 08-059	No
Listeria monocytogenes	NF EN ISO 11290-1	No
Listeria monocytogenes	NF EN ISO 11290-2	No
Salmonella	NF EN ISO 6579-1	No
Coagulase positive Staphylococci	NF EN ISO 6888-1	No
Parameters – Water	Method	
Culturable microorganisms at 22°C	NF EN ISO 6222	No
Culturable microorganisms at 36°C	NF EN ISO 6222	No
Coliforms bacteria	NF EN ISO 9308-1	No
Escherichia coli	NF EN ISO 9308-1	No
Heavy metal – Water	Method	
Lead	NF EN ISO 15586	Yes
Cadmium	NF EN ISO 15586	Yes
Pesticide residues – Rice and dried pepper	Method	
Carbaryl	BS EN 15662	Yes
Chlorpyrifos(ethyl)	BS EN 15662	Yes
Imidacloprid	BS EN 15662	Yes
Oxadixyl	BS EN 15662	Yes
Pirimiphos-ethyl	BS EN 15662	Yes
Thiamethoxam	BS EN 15662	Yes
Tricyclazole	BS EN 15662	Yes
Triticonazole	BS EN 15662	Yes

Table 9: *LEFS scope of accreditation with ISO17025:2017*

4.2.3 Research Programs - Major Achievements in 2025

AMR Working Group - IPC

The Head of LEFS is a member of the AMR Working Group at IPC, which was established in early 2023. In this role, she regularly attend meetings, contribute AMR-related insights, and engage in discussions to explore collaborative opportunities among various IPC units.

AMR Symposium

The Head of LEFS is a member of **RAPID team** and participate regularly the monthly meeting and annual symposium. In 2025, the annual symposium held on 23rd September in Institut Pasteur in Nha Trang, Vietnam.

RAPID (R&D Alliance for Preparedness of Infectious Diseases) is a newly established research and development alliance initiated by scientists in the Pasteur Network Asia Hub. It aims to promote international R&D collaborations in infectious disease research, with a particular emphasis on Antimicrobial Resistance (AMR).

4.2.4 Support to National Authorities

For several years, the LEFS has supported different national authorities in Cambodia, including the Food and Drug Department of the Ministry of Health, and the National Animal Health and Production Research Institute, attached to the Ministry of Agriculture, Forestry and Fisheries.

In 2025, as part of a national monitoring program, the Ministry of Health sent 87 samples to LEFS. These samples were obtained through product hygiene campaigns of industrial foods imported and exported.

Also as part of a national monitoring program, the Ministry of Agriculture, Forestry and Fisheries sent 100 sample to LEFS.

The head of LEFS is a member of the Foodborne Outbreak Response Team (FORT), coordinated by the CDC-MOH in Cambodia. In addition to supporting testing services during outbreaks, we contribute to drafting food safety policies, reviewing standard operating procedures (SOPs), and participating in risk assessment evaluation meetings related to outbreak events.

4.2.5 Teaching and Training

The Laboratory supervised ten trainees from various universities and school in Cambodia for internships. Details are provided below.

University	Number of students	Program Year	Period (Month)	Date
Royal University of Phnom Penh	1	Year 3	1.5	19/05/2025-30/06/2025
	1	Year 3	1	01/07/2025–31/07/2025
	2	Year 3	1	01/08/2025–31/08/2025
International University	1	Year 3	1	01/09/2025–30/09/2025
Institute of Technology of Cambodia	1	Year 4	3	01/10/2025–31/12/2025
University of Puthisastra	1	Master	9	31/03/2025-29/08/2025
Lycee Rene DESCARTES	2	Student	9 days	23/06/2025-02/07/2025
	1	Student	5 days	15/12/2025-19/12/2025

Table 10: *Internship Students at the LEFS in 2025*

4.2.6 Outlook for the Upcoming 3-5 Years

The LEFS's outlook for the upcoming three to five years comprises the following objectives:

- Maintain the lab accreditation status;
- Increase laboratory visibility/recognition with the public;
- Extend heavy metal testing from water matrix to other matrix such as food and soil using GF-AAS and also extend to other metal
- Extend pesticide testing from rice and dried pepper matrix to other food matrix such as cashew, fresh fruit, fresh vegetable…by using LC-MS/MS and GC-MS/MS
- Extend accredited scopes to heavy metal and pesticide residue testing
- Develop increasing cooperation with internal and external partners for research projects.

4.2.7 Scientific Publications 2025

Note: *The name of authors from the Institut Pasteur du Cambodge are underlined*

1. **Contribution of maternal gut carriage to neonatal acquisition of extended-spectrum beta-lactamase-producing Enterobacterales in Madagascar and Cambodia.**
   Beaumont AL, de Lauzanne A, Criscuolo A, Fabre L, Rabenandrasana MAN, Randriamanga NF, Bernabeu S, Harimanana A, Randremanana RV, Herindrainy P, Collard JM, Pring L, Sreng N, Cheng S, Borand L, Kermorvant-Duchemin E, Crucitti T, Guillemot D, Huynh BT.
   Nat Commun. 2025 Nov 24;16(1):10399. doi: 10.1038/s41467-025-65352-4.

4.3 Vaccination Service

The Vaccination Service at the *Institut Pasteur du Cambodge* (IPC) is composed of ***the International Vaccination Center*** (IVC) in Phnom Penh and three ***Rabies Prevention Centers*** (RPCs), in Phnom Penh, Battambang, and Kampong Cham (Rabies PEP & International Vaccination Service).

4.3.1 Functional Structure

The Unit is composed of 31 team members across Phnom Penh and two provincial centers. The team includes 12 Medical Doctors (MDs), 16 Nurses, 1 Administrative Staff, and 2 Hygiene Personnel.

A Deputy Head was recently appointed to support the Unit Head in providing strategic leadership, overseeing day-to-day operations, and ensuring the effective functioning of the four centers within the Vaccination Service.

In response to increasing public demand and the objective of enhancing service quality, the Unit's human resources were significantly reinforced during 2025–2026.

These additions have strengthened operational capacity and contributed to maintaining high standards of service delivery and efficiency across all centers. Additional resources:

- 1 additional MD for the International Vaccination Center (IVC)
- 1 MD and 1 nurse for Phnom Penh Rabies Prevention Center (PP-RPC)
- 1 nurse for Battambang Rabies Prevention Center (BTB-RPC)
- 1 nurse for Kampong Cham Rabies Prevention Center (KCH-RPC).

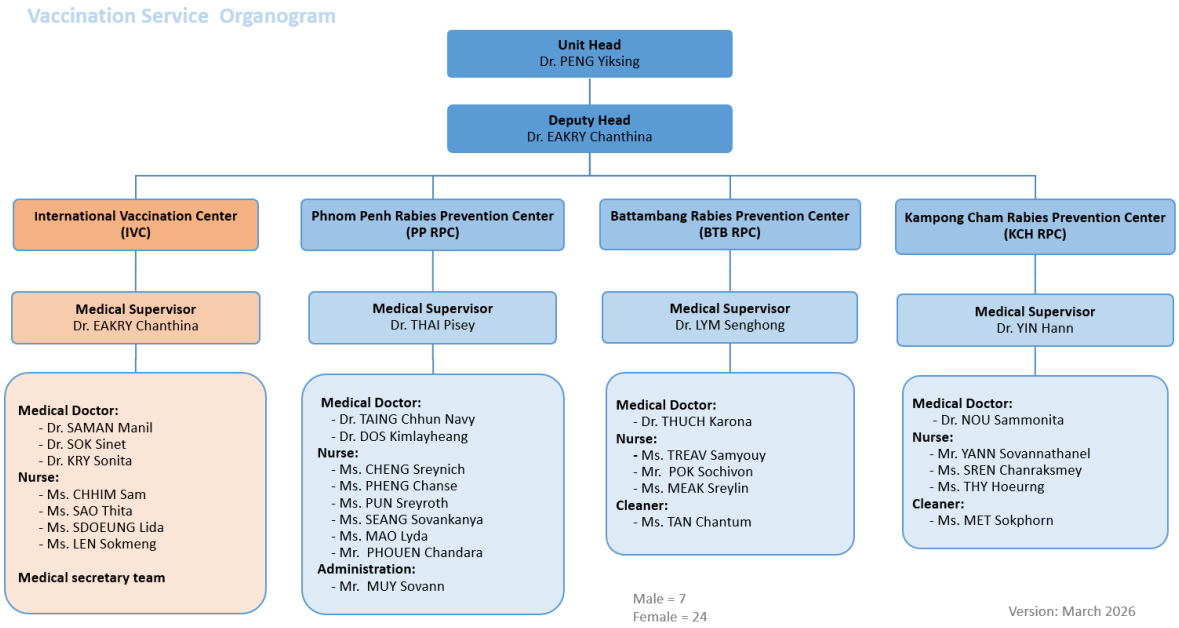


Figure 24: *Vaccination Service Organogram*

4.3.2 Rabies Prevention Centers

The three Rabies Prevention Centers (RPCs) operate under the leadership of the Head of the Vaccination Service and employ 22 full-time staff. These centers provide post-exposure prophylaxis (PEP) against rabies, including the administration of Equine Rabies Immunoglobulins (ERIG) at subsidized rates, ensuring treatment is affordable for the public.

Since July 2018, following the World Health Organization (WHO) 2018 recommendations, IPC has implemented a full rabies PEP intradermal protocol, consisting of three sessions of 2-site intradermal injections using 0.1 mL vaccine per site (IPC protocol).

Starting 1 January 2026, the PEP cost was adjusted to 20 USD per full protocol. This fee adjustment ensures the financial sustainability of the service and allows IPC to improve service quality through strategic human resource recruitment. To the best of our knowledge, this remains the lowest cost for a full PEP course in Cambodia, reflecting IPC's commitment to maintain broad public access to this health service.

The Virology Unit performs diagnostic tests on brain samples from biting animals, providing timely results free of charge, including for samples shipped from the provincial PEP centers.

IPC RPCs play a critical role in supporting the MoH in its mission to eliminate rabies in Cambodia:

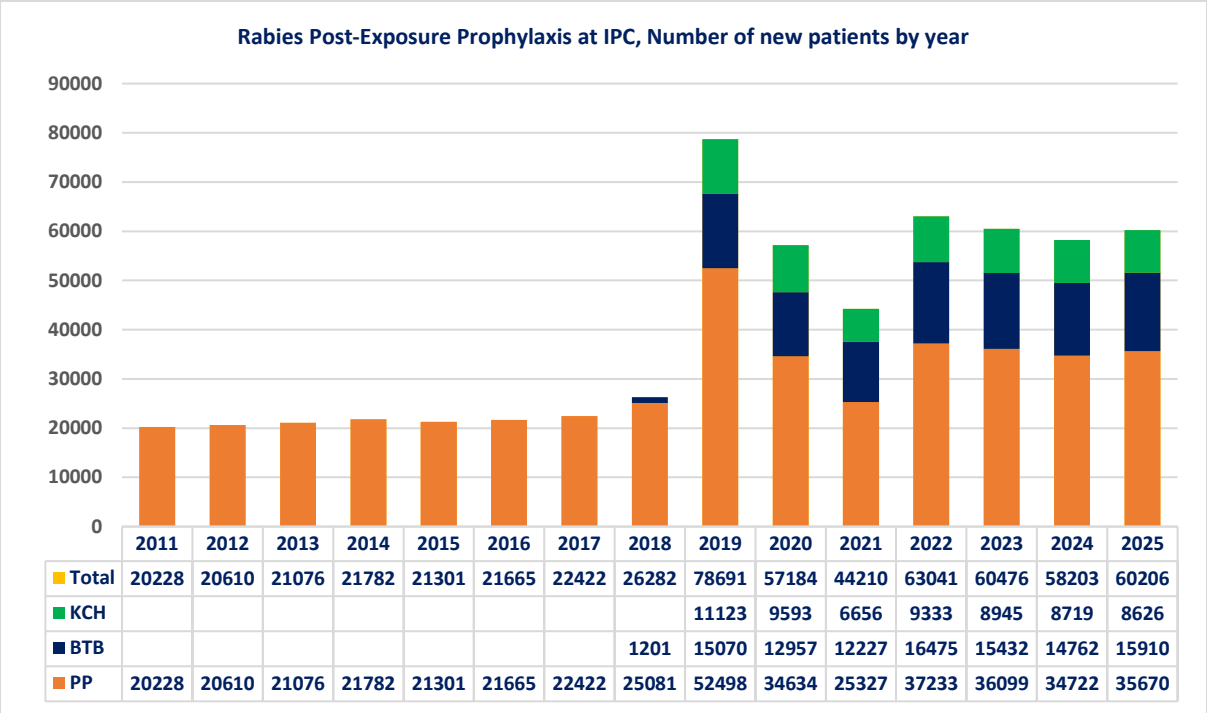
- Largest provider of Rabies PEP in the country, with approximately 60,000 treatments per year;
- Reliable and affordable PEP service, ensuring broad public access;
- Extending PEP services to remote areas, improving geographic coverage;
- Supporting the development of the National Strategic Plan for Rabies Elimination;
- Contributing to the National Rabies Surveillance Guideline, strengthening disease monitoring;
- Providing technical assistance to the MoH for Cambodia's application to Gavi for the Rabies Vaccine Program Support.

Rabies Prevention Centers Activities in 2025

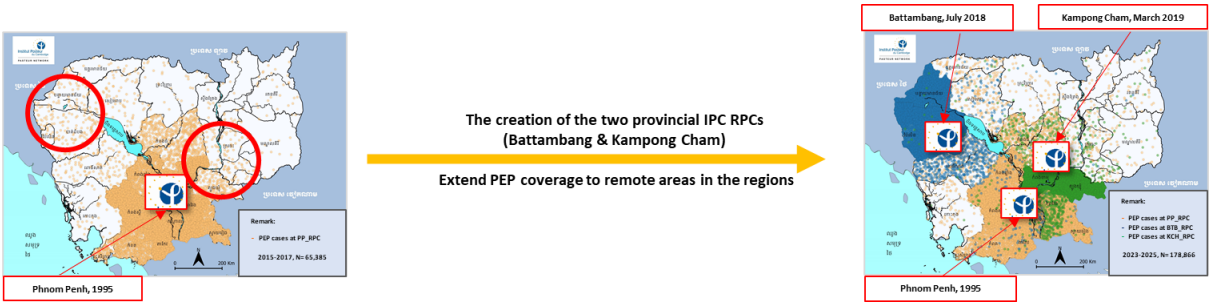
- Provided rabies post-exposure prophylaxis to a total of 60,206 patients, distributed as follows:
    - 35,670 patients received rabies PEP at the Rabies Prevention Center in Phnom Penh;

- 15,910 patients received rabies PEP at the Rabies Prevention Center in Battambang;
- 8,626 patients received rabies PEP at the Rabies Prevention Center in Kampong Cham.

- Despite ongoing efforts by the MoH-CDC Cambodia, and GDAPH to eliminate human rabies through dog mass vaccination campaigns in Phnom Penh, Kandal, and Battambang during 2023 - 2025, the number of patients receiving PEP at IPC remained stable compared to 2024.
- The Virology Unit conducted rabies testing on 226 animal heads, with the following results:
  - 139 samples (61.5%) tested positive for rabies
  - Dogs: 135/197 samples positive (68.5%)
  - Cats: 4/28 samples positive (14.3%).
- The results highlight the ongoing risk of rabies exposure and the critical role of IPC RPCs in providing timely PEP and supporting national rabies surveillance.



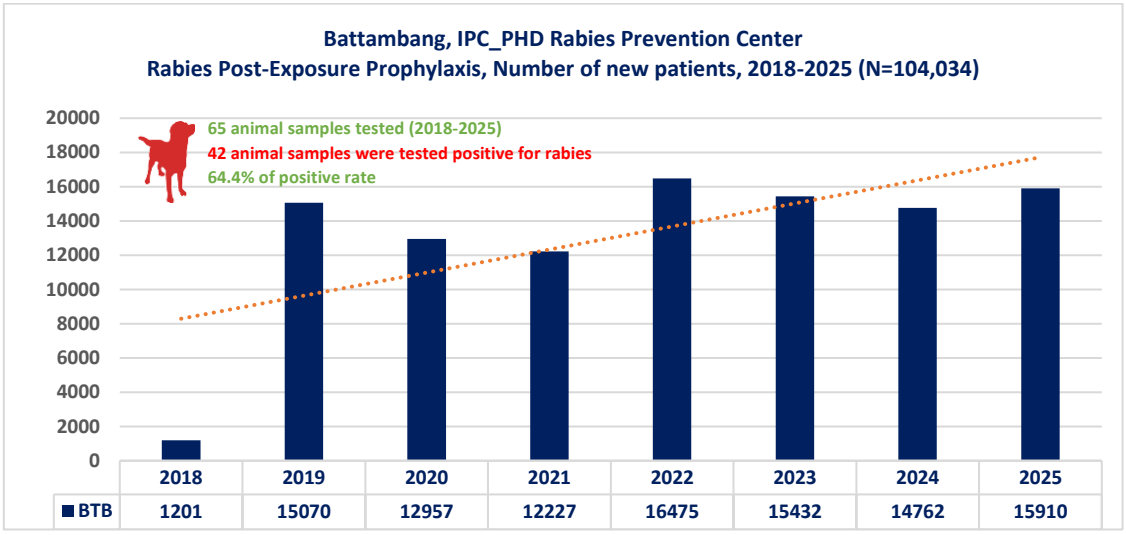
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Total	20228	20610	21076	21782	21301	21665	22422	26282	78691	57184	44210	63041	60476	58203	60206
KCH									11123	9593	6656	9333	8945	8719	8626
BTB								1201	15070	12957	12227	16475	15432	14762	15910
PP	20228	20610	21076	21782	21301	21665	22422	25081	52498	34634	25327	37233	36099	34722	35670



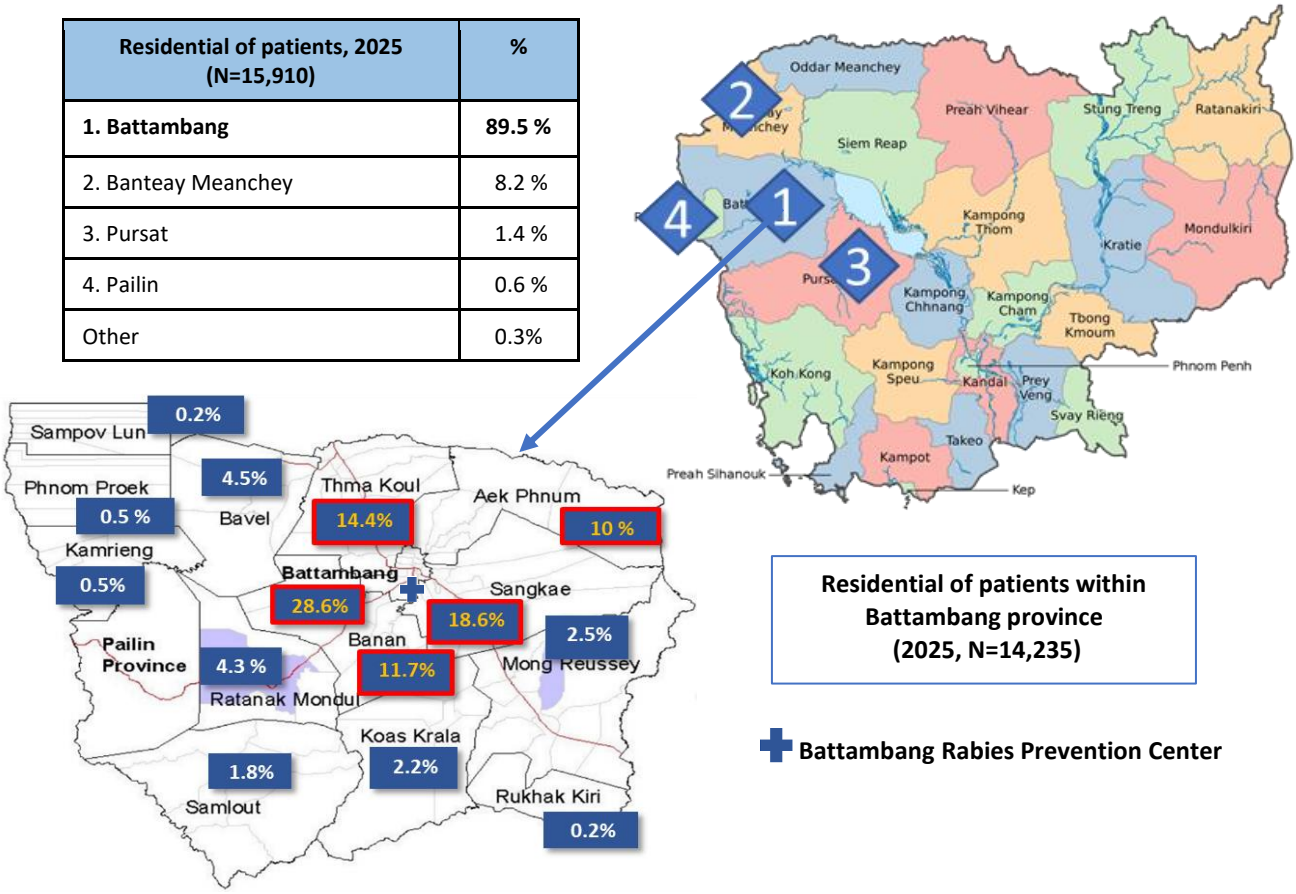
4.3.2.1 Battambang Rabies Prevention Center

The Center is located within the provincial hospital premises. It was officially inaugurated on 28th September 2018, following an MoU signed on 25 December 2017 between the Battambang Provincial Health Department (PHD) and the Director of the Institut Pasteur du Cambodge (IPC). Under this collaboration framework, the PHD provides the building and utility services to support the center's operations. The establishment of this center significantly expanded access to rabies post-

exposure prophylaxis (PEP) services in the northwest region and is expected to extend coverage not only to Battambang Province but also to five neighboring provinces, thereby improving geographical accessibility and reducing the burden on patients requiring urgent rabies treatment.



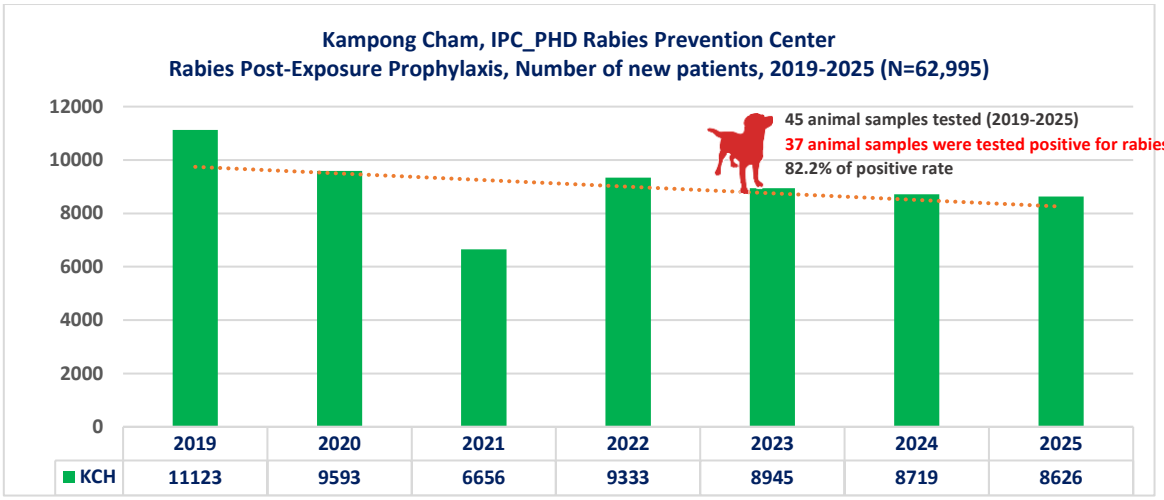
Residential of patients, 2025 (N=15,910)	%
1. Battambang	**89.5 %**
2. Banteay Meanchey	8.2 %
3. Pursat	1.4 %
4. Pailin	0.6 %
Other	0.3%



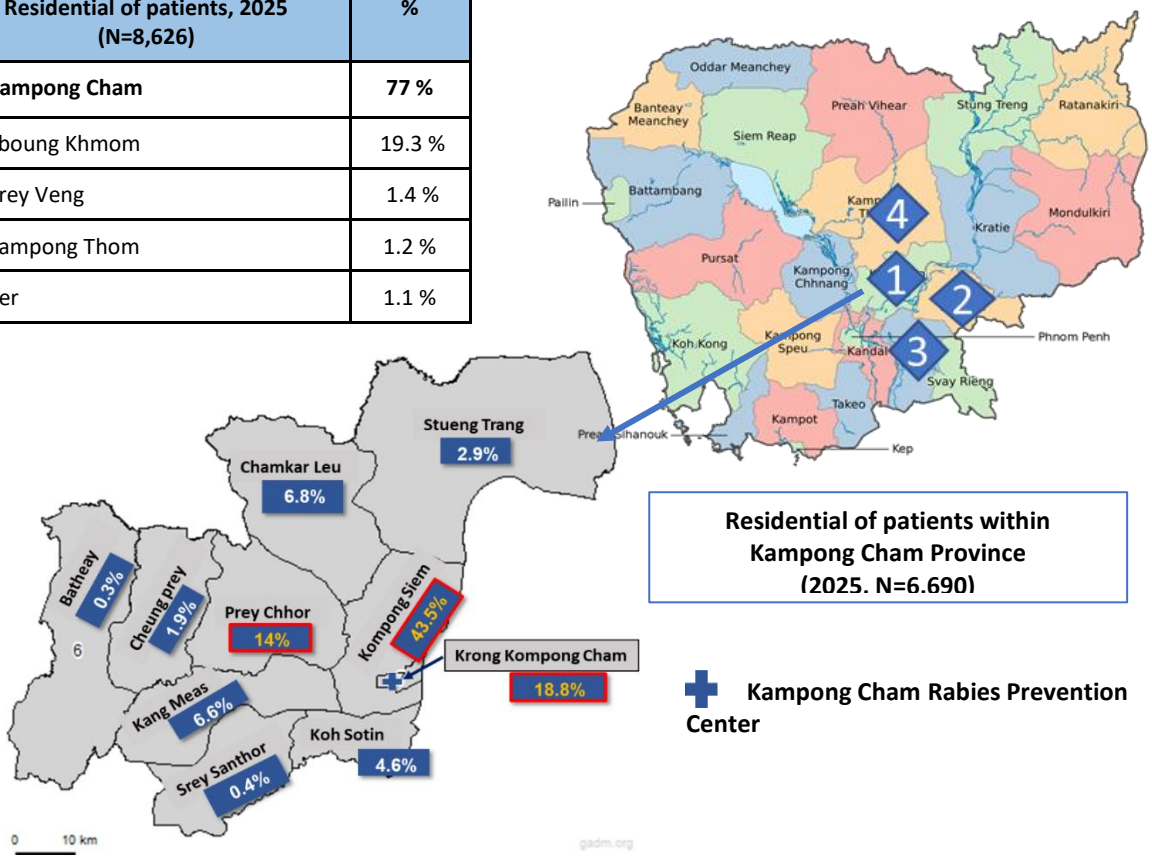
4.3.2.2. Kampong Cham Rabies Prevention Center

The center was opened on 7th March 2019 through a collaboration between the IPC and the Kampong Cham Provincial Health Department. The establishment of the center was part of the emergency response to a sudden surge in patients seeking rabies PEP. Initially, the center operated in a temporary building provided by the provincial hospital.

On 6th May 2024, IPC, in collaboration with the MoH, officially inaugurated a new Rabies Prevention Center in Kampong Cham, replacing the temporary facility. This center offers improved visibility, accessibility, and infrastructure, enabling IPC to deliver PEP and vaccination services under optimal reception and safety conditions. It plays a strategic role in expanding rabies PEP coverage to six provinces in Northeast Cambodia, significantly improving access to life-saving treatment in the region.



Residential of patients, 2025 (N=8,626)	%
1. Kampong Cham	**77 %**
2. Tboung Khmom	19.3 %
3. Prey Veng	1.4 %
4. Kampong Thom	1.2 %
Other	1.1 %

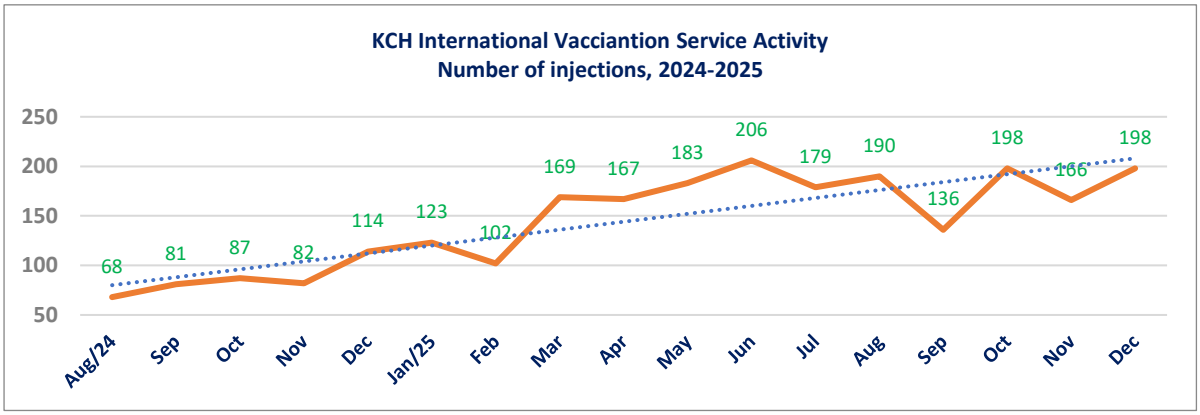


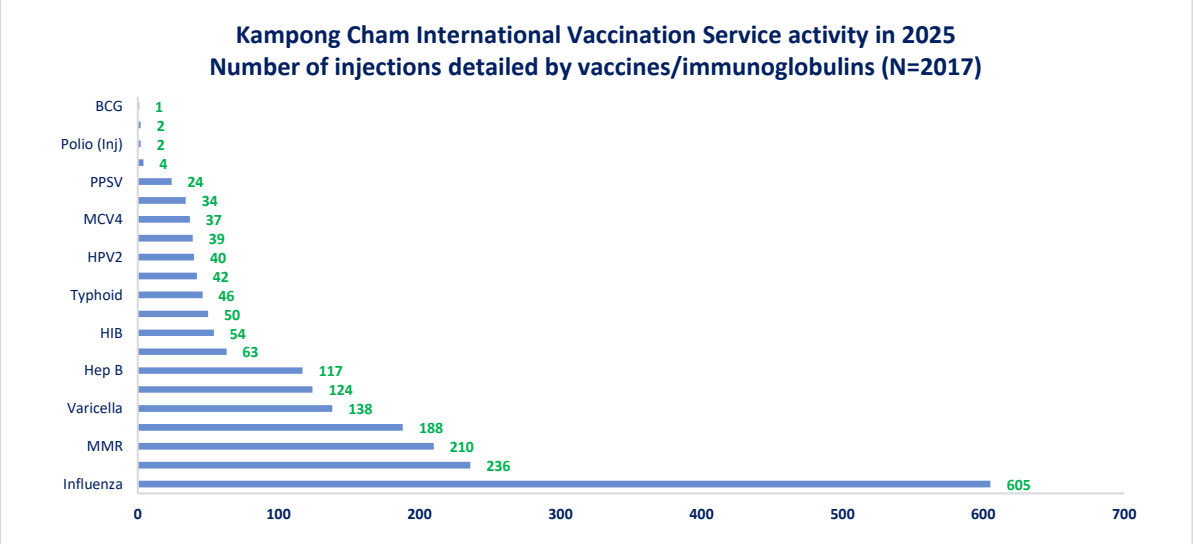
4.3.2.3. Kampong Cham International Vaccination Center

In response to a proposal from the MoH and the Kampong Cham Provincial Health Department, the Institut Pasteur du Cambodge (IPC) assessed the feasibility of establishing an International Vaccination Service in Kampong Cham to enhance public health services for the local population.

On 1st August 2024, the International Vaccination Service was officially integrated into the existing IPC–KC PHD Rabies Prevention Center. The operation of this new service fully complies with the standard operating procedures (SOPs) applied at the International Vaccination Center in Phnom Penh. This ensures consistency in service delivery standards, cold chain management, vaccine quality assurance, and patient care.

The introduction of the International Vaccination Service in Kampong Cham represents a significant step in expanding IPC's high-quality vaccination services beyond rabies prevention. Currently, a wide range of vaccines is available at the Kampong Cham RPC, contributing to strengthened immunization coverage and improved preventive healthcare services in the province.





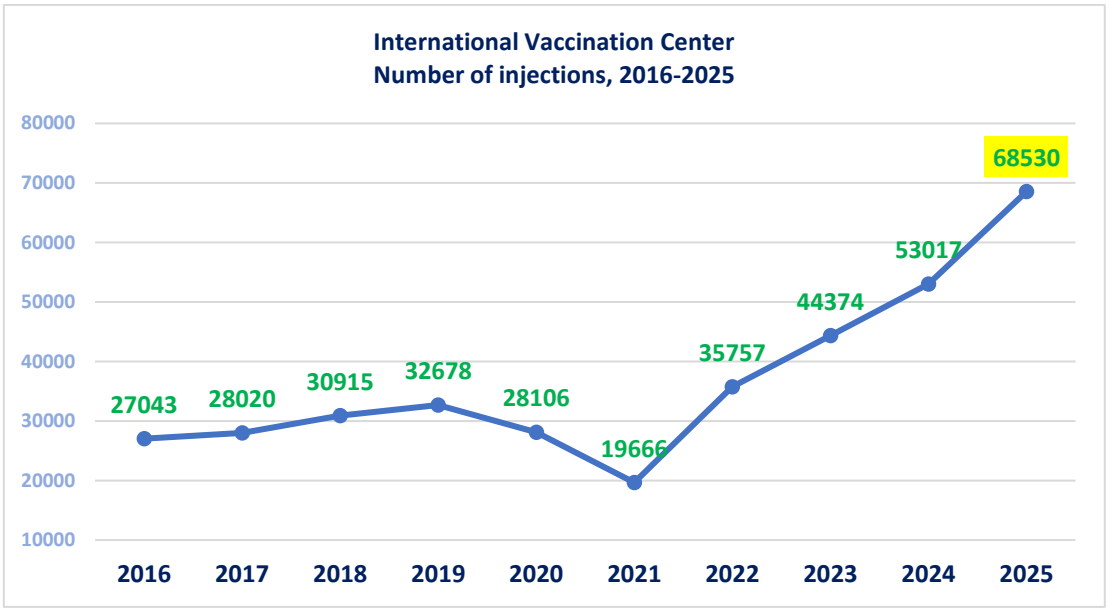
4.3.3 International Vaccination Center

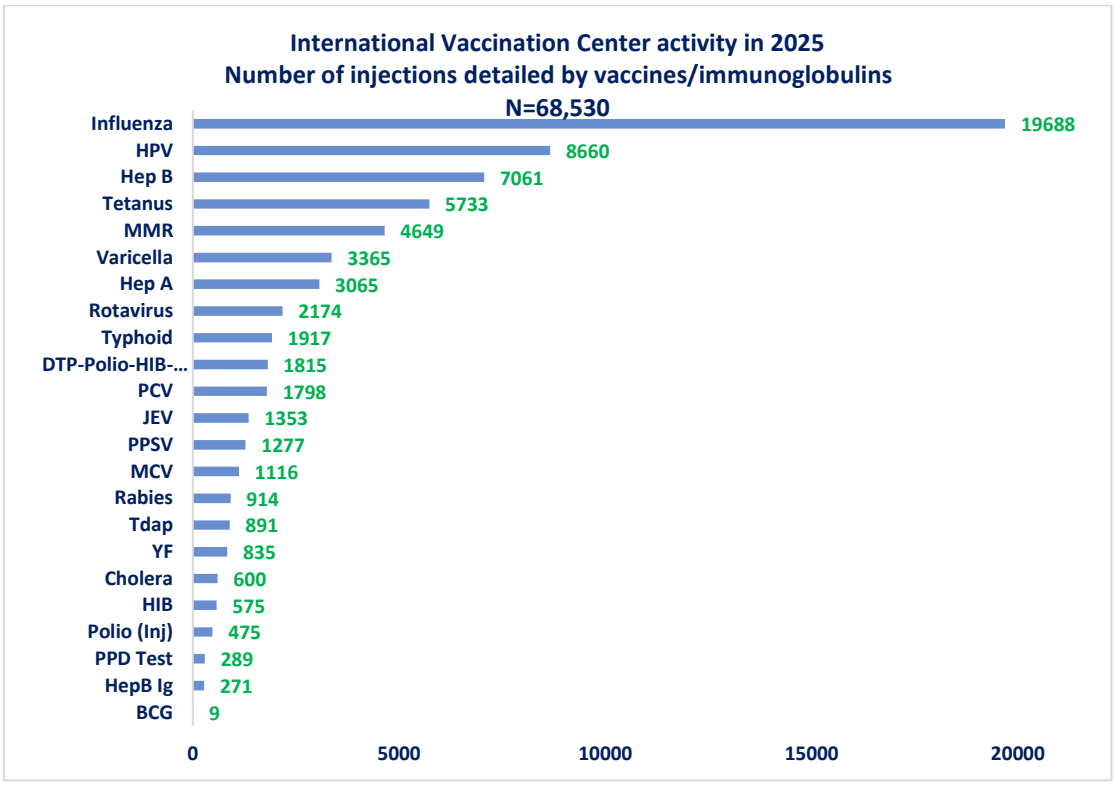
The International Vaccination Center (IVC) at the Institut Pasteur du Cambodge (IPC) operates under the responsibility of the Head of the Vaccination Service and is supported by a dedicated team of eight full-time staff members. In response to a significant increase in client attendance, one additional MD was recruited in 2025, further strengthening the Center's capacity to deliver timely and high-quality services. The IVC offers a comprehensive range of vaccines and immunoglobulins, including vaccines recommended in the National Immunization Program, essential optional vaccines, vaccines for international travelers, and specific vaccines for at-risk groups

The Center maintains international standards in all aspects of service delivery, including the use of certified vaccine products, strict cold chain management, robust quality control systems, and

professional and patient-centered service delivery. The International Vaccination Center achieved record-breaking results in 2025, confirming its role as a key pillar of IPC's public health services. The global activity of the International Vaccination Center increased by 29.2% compared to 2024 (68,530 vs. 53,017 injections) and by 101% compared to the Pre-COVID year 2019. Several factors contributed to these outstanding achievements:

- Strong leadership and strategic management
- Secured vaccine supply
- Responsiveness to evolving public health needs
- Institutional reputation and accreditation
- High quality of service delivery
- Effective communication and public engagement





4.3.4 Support to National Authorities

Contributions to the fight against rabies in Cambodia

The Vaccination Service of the Institut Pasteur du Cambodge (IPC) plays a central role in supporting the Ministry of Health (MoH) in the national effort to eliminate rabies in Cambodia through various key activities including providing rabies PEP to the public at an affordable price, contributes to the development of the National Rabies Elimination Strategy, the development of the National Rabies Surveillance Guideline, technical assistance to prepare Cambodia's application to Gavi for Rabies Vaccine Program Support, participates in EIC (education, information, and communication) activities, and is a national reference training center for rabies PEP. The Vaccination Service also cooperates with several national authorities and international agencies (MoH, US-CDC, *Institut Pasteur* in Paris, WHO, GDAPH, FAO, CIRAD, GIZ, and others) to contribute to rabies elimination programs and research studies, especially on rabies.

National Immunization Policy Support

IPC's International Vaccination Center also plays a crucial role in supporting the Cambodia Ministry of Health with technical advice on immunization practices and applied policy regarding vaccination programs.

4.3.5 The Vaccination Service's Vision for Next 2-5 Years

The Vaccination Service of the Institut Pasteur du Cambodge (IPC) has set strategic objectives for the next 2–5 years to further strengthen its public health impact in Cambodia.

Maintain the quality of our services

IPC aims to maintain the highest standards of vaccination service delivery quality by upholding professional excellence, international best practices, and operational consistency, ensuring continued public trust and satisfaction.

Establishing an external International Vaccination site in PP

In response to a significant increase in public demand on International Vaccination Service, IPC aims to expand its capacity to enhance public health services for the local population.

Contributing to the fight against rabies in Cambodia

As an ASEAN member state, Cambodia has committed to eliminating rabies by 2030. To support this national goal, IPC has developed three key action plans in collaboration with the Ministry of Health:

- Increasing accessibility to rabies PEP by improving the visibility and reach of IPC centers;
- Raising public awareness of rabies through targeted education, information, and communication (EIC) activities;
- Supporting the MoH in rabies elimination efforts by actively contributing to the development and implementation of the National Rabies Elimination Strategy.

Supporting and promoting additional research

- Enhance career development for staff, particularly young Cambodian staff, by providing opportunities to participate in rabies and vaccination-related research studies.
- Continue to promote and expand the Vaccination Service's research activities, in close collaboration with other units of IPC, to generate evidence-based improvements in public health interventions.

These strategic directions reflect IPC's commitment to sustainable, high-quality vaccination services, continued leadership in rabies prevention, and the promotion of scientific research to strengthen Cambodia's public health system.

4.3.6 Scientific Publications 2025

Note: *The name of authors from the Institut Pasteur du Cambodge are underlined*

1. **Analysis of predictors of rabies-positive biting animals in Cambodia using spatio-temporal Bayesian regression modelling.**
   Baron JN, Peng YS, Martínez-López B, Ly S, Dussart P, Chevalier V.
   PLoS Negl Trop Dis. 2025 Sep 5;19(9):e0013478. doi: 10.1371/journal.pntd.0013478.

2. **Drivers of rabies post-exposure prophylaxis noncompletion in Cambodia, 2019 to 2022.**
   Banza Kongolo H, Peng Y, Chan M, Auerswald H, Duong V, Thai P, Thap V, Hann Y, Mohhamad A, Girond F, Ly S, Flamand C, Guis H.
   PLoS Negl Trop Dis. 2025 Dec 18;19(12):e0013813. doi: 10.1371/journal.pntd.0013813.

5 Technical Platforms

5.1 BSL3 Laboratory

2025 at IPC's BSL3 laboratory: advancing biosafety and operational excellence

Following the 2024 installation of the Matachana S1000 steam sterilizer and earlier renovations to the ventilation and cooling systems, the BSL-3 laboratory maintained stable and optimized operational conditions throughout 2025. Preventive maintenance of facilities and critical equipment was conducted in November 2025, ensuring the reliability and integrity of containment systems. Maintenance, calibration, and validation procedures were reviewed and updated to align with ISO 35001:2019 requirements.

In 2025, IPC focused on consolidating routine operations while strengthening staff competencies and emergency preparedness. Comprehensive technical and biosafety training programs were delivered to personnel working across all BSL-3 modules (Mycobacteria, Arboviruses, Zoonoses, and Avian Influenza). Training covered standard operating procedures, biosafety and biosecurity principles, emergency response, and ISO 35001:2019 requirements. Preparedness was reinforced through regular drills addressing spill response, waste management, personal protective equipment uses, fire safety, first aid, and evacuation procedures. Scheduled maintenance of the entire BSL-3 facility was completed in November 2025 and included inspection, calibration, and validation of critical equipment and engineering controls. These activities confirmed the laboratory's operational performance, safety, and compliance with international biorisk management standards.

A structured audit pathway supported the laboratory's certification process. A Stage 1 external audit conducted in April 2025 identified six non-conformities, all of which were addressed through corrective actions. Internal audits in June 2025 identified twelve additional non-conformities, primarily related to climate change considerations, monitoring of risk mitigation plans, document control, and equipment maintenance. All findings were resolved prior to the certification audit. **In December 2025, the IPC BSL-3 laboratory was officially certified to ISO 35001:2019, confirming full compliance with international biosafety, biosecurity, and biorisk management standards.**

Throughout the year, the laboratory maintained a proactive risk management approach. Risks associated with aerosol generation, autoclave malfunction, unauthorized access, PPE non-compliance, power outages, spills, biosecurity breaches, natural hazards, and cyber threats were systematically identified, assessed, and monitored. All risks were classified as low level due to existing control measures, requiring continued monitoring without immediate corrective action.

Compliance with procedures and work instructions was reinforced through training, supervision, and internal monitoring. No complaints were reported during the year, indicating effective operational oversight.In parallel with internal operations, IPC continued to provide technical expertise at the national level. **Support was provided for the construction and operational readiness of the BSL-3 facility at the National Institute of Public Health (NIPH)**, scheduled for inauguration in January 2026. IPC also contributed to the upgrading of laboratory protocols for specialized projects at Calmette Hospital including Cyclotron and Bone Marrow Transplant facilities and to national biorisk initiatives, including inventory and biosecurity management of high-risk pathogens with Ministry of Defense (NACW). As Cambodia's sole Biosafety Level 3 facility, IPC continued to serve as a national and regional reference center for the safe handling and research of high-risk pathogens, including avian influenza viruses, Mycobacterium tuberculosis, SARS-CoV-2, and other emerging zoonotic viruses. The laboratory operates under a clearly defined organizational structure, with the General BSL-3 Manager supported by module supervisors and dedicated teams for waste management, quality assurance, and occupational health, ensuring sustained compliance with ISO 35001:2019 (Figure 25: Organigram of the BSL3 Management).

In 2025, the laboratory also conducted its first full Biorisk Management System (BMS) management review. Biorisk objectives were reviewed quarterly, focusing on biosafety performance, operational sustainability, occupational health and safety, environmental impact reduction, and climate-resilient practices, with progress systematically documented to support continuous improvement.

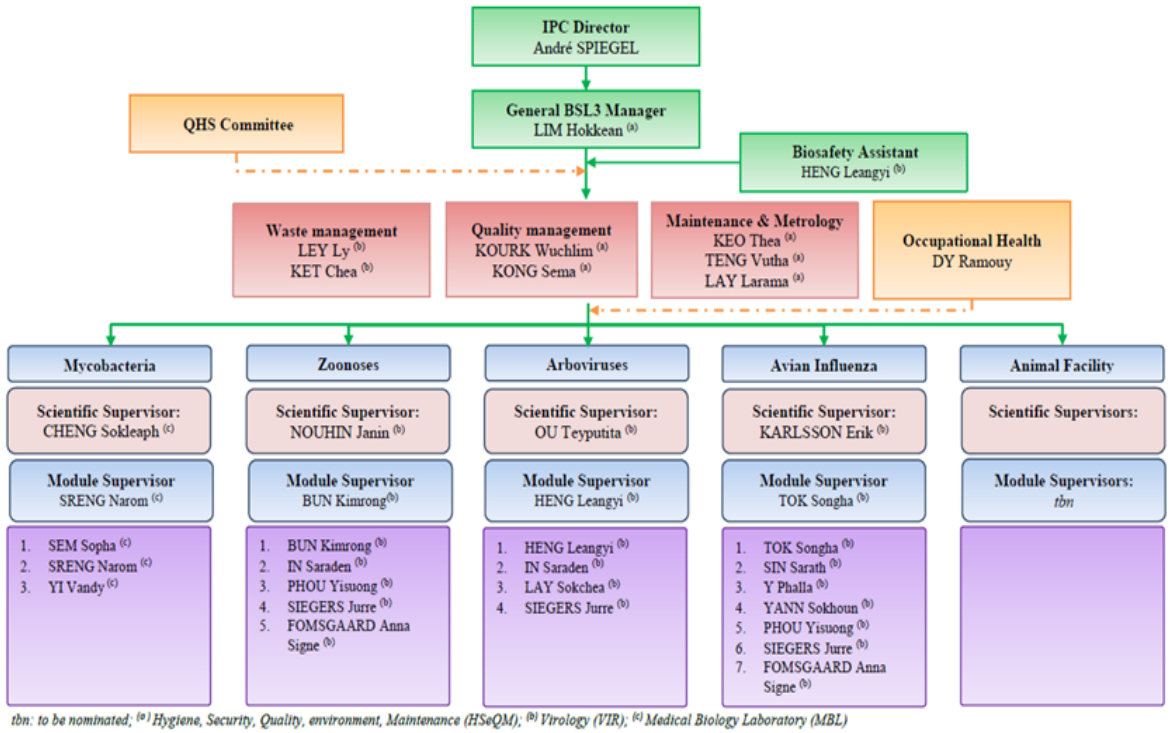


Figure 25: *Organigram of the BSL3 Management*

5.1.1 Teaching, Training and Collaboration

Educational Initiatives and Skill Development at IPC's BSL3

In 2025, the Institut Pasteur du Cambodge (IPC) further expanded its educational and capacity-building initiatives to reinforce national competencies in biosafety and biosecurity.

IPC delivered structured courses on biosafety and biosecurity for Master of Medical Biology, and Master of infectiology students at the University of Health Sciences, integrating theoretical principles with practical considerations relevant to laboratory design, risk assessment, and containment systems. In addition, IPC implemented targeted role-specific training for BSL-3 laboratory personnel and facility maintenance teams, with a focus on safe pathogen handling, equipment operation, preventive maintenance, and emergency preparedness, including incident response and containment failure scenarios. These training activities contribute to institutional sustainability by strengthening technical expertise, promoting a culture of biosafety, and supporting the long-term development of a skilled workforce capable of safely managing high-risk infectious agents within Cambodia's laboratory system. In parallel, the General BSL3 manager is pursuing doctoral training at the School of Public Health, National Institute of Public Health, Cambodia. His PhD research focuses on Enhancing Biosafety Level 3 (BSL-3) Laboratory Practices in Low-Middle Income Countries by Assessing Biosafety Regulations, Standards, Infrastructure and Practices. The study aims to develop a context specific, evidence-based recommendations to strengthen BSL3 implementation and governance in Cambodia and other LMICs.

5.1.2 Outlook for 2026

Building on the achievements of 2025, IPC aims to:

1. Maintain ISO 35001:2019 certification through continuous monitoring, audits, and improvement of the Biorisk Management System.
2. Continue implementing and evaluating corrective actions and performance indicators across all BSL3 modules.
3. Enhance staff competencies through ongoing technical training, emergency drills, and meeting.
4. Support national and regional initiatives in biosafety, biosecurity, and infectious disease management.
5. Develop a biosafety and biosecurity courses inside the BSL3 laboratory for external collaborators.

IPC remains committed to maintaining the highest standards of biosafety, operational excellence, and scientific contribution, reinforcing its role as Cambodia's flagship BSL3 laboratory and regional center of expertise.

5.2 Biobank

5.2.1 Background

The biobank section is under the Hygiene, Security, Environment, Quality and Maintenance (HSeQM) service/Administration unit.

It has a cross-cutting role to support research and testing laboratories at IPC with different materials including documents such as standard operating procedures (SOPs) and software to monitor the samples. Current key responsibilities and functions in biobanking at IPC are as described below.

- Biobank software: managing the biobank software, working with developers, handling complaints from users, and solving problems/errors reported by users relating to the software;
- Sample labelling: printing labels for users (biobank label template + QR code);
- Material transfer agreement (MTA): reviewing MTA and providing reference numbers

The person responsible for Biobanking graduated a Master of Science in Biobanks and Complex Data Management at the Université Côte d'Azur in Nice, France in September 2025.
The knowledge and competencies acquired through this training are being applied at IPC to strengthen biobank governance, data management, and overall quality of biobanking operations.
The current users of the biobank are the Virology Unit and the Epidemiology and Public Health Unit.
All samples are stored in -80°C freezers with a total of 49 units currently in operation. In addition, selected samples are stored in liquid Nitrogen (N_2) from Malaria Unit and Immunology Unit.
IPC operates its own liquid nitrogen generator, producing approximately 100 litters per day, which is sufficient to meet the demand of use for all the laboratories at IPC.
All of the freezers are installed in a purpose-designed room equipped with continuously operating air conditioners.
Access to this room is strictly restricted to authorized personnel. Freezers performance and storage conditions are continuously monitored using automated temperature-monitoring sensors (Oceasoft system), ensuring sample integrity and operational reliability.

5.2.2 Functional Structure

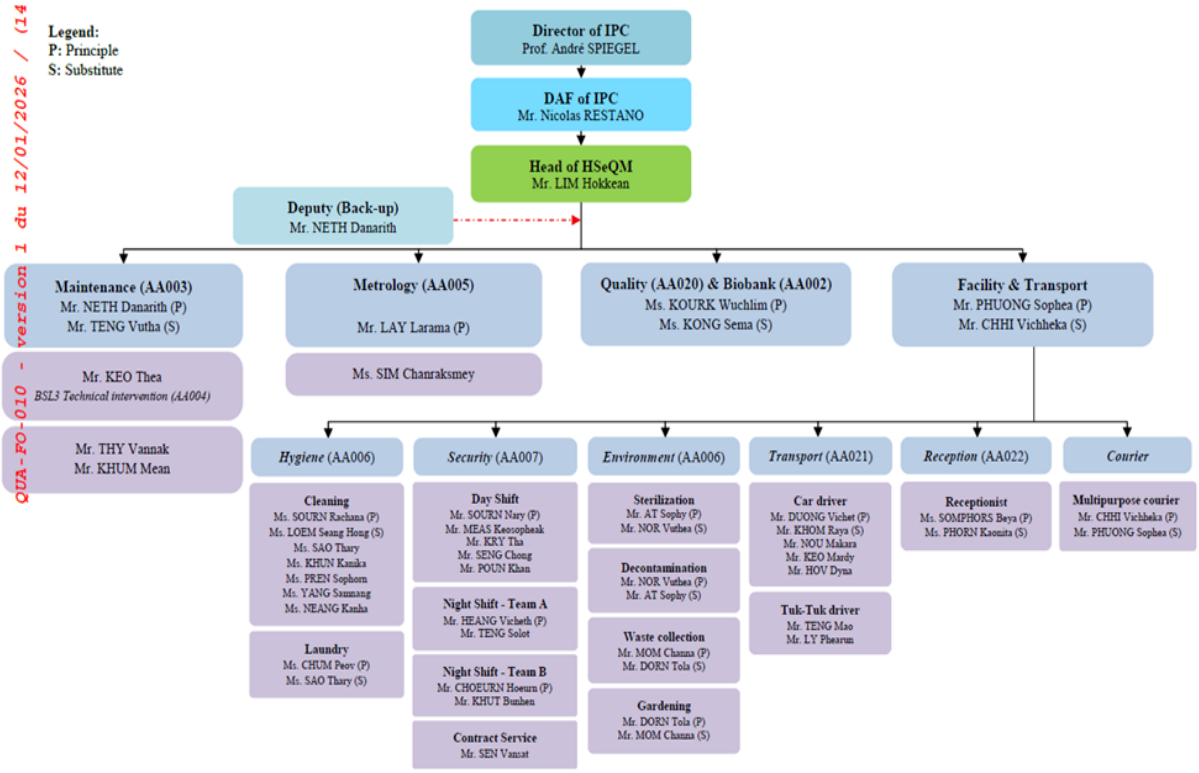


Figure 26: *Organigram of the HSeQM*

5.2.3 Biobank Database

As of 14/01/2026, there are 12 research projects registered in the biobank software with the total number of 56,599 samples as shown in more detail in the Table below.

Collection/Project	No. of samples	Nature of samples	Storage
Laboratory of Environment and Food Safety (LEFS)			
Food Safety Innovation Lab	674	*E. coli* *Salmonella*	-80°C freezer (HSM-04) Freezer code: I/01599
Medical Biology Laboratory (MBL)			
Aspergilloma in Cambodia	3051	Serum Aspergillus	-80°C freezer (PRA-11) Freezer code: PRA Asia R11
Virology (VIR)			
ECOMORE 2	6421	Serum Saliva	-80°C freezer (HSM-04) Freezer code: 00439
Immuno PEP follow up 2019	234	Serum	-80°C freezer (VIR-02) Freezer code: 01324
RAB00056 IM/ID (Sanofi study)	26	Serum	-80°C freezer (VIR-02) Freezer code: 01324
Rabies surveillance	14050	Ammon's horn Spinal bulb	-80°C freezer (HSM-04) & VIR-02 Freezer code: 01475 & 01324
Rodents as Reservoir for Hepatitis E Virus (HEV), Arenavirus and Other Rodent-borne Viruses and risk assessment of infection in human in Cambodia	1938	Kidneys, Swab, Urine, Heart, Lung, Liver, Ectoparasite, Blood clot, blood serum, Pool organ	N/A
Epidemiology and Public Health (EPH)			
HEPEDIAC- Pilot therapeutic study of DAA treatment for children and adolescents with active HCV infection in Cambodia	583	Whole blood and plasma	-80°C freezer (HSM-04) Freezer code: IPC/01609
Lowering Interleukin-1 Receptor Antagonist Concentrations after TB Treatment Onset: A proof of concept study in Cambodia and Ivory	303	Plasma Buffy coat	-80°C freezer (HSM-04) Freezer code: LILAC-TB
TB-Speed Output 2 - Severe pneumonia	1794	Plasma Stool Whole blood	-80°C freezer (HSM-04) Freezer code: 01551
Tenofovir As Prevention Of Hepatitis b Mother-to-child transmission	27509	Plasma Blood Red blood cell Buffy coat	-80°C freezer (HSM-04) Freezer code: 01475
Zika Sentinel Surveillance in prenatal care visit and maternity ward in Calmette Hospital (Phnom Penh, Cambodia)	16	Serum Urine	-80°C freezer (HSM-04) Freezer code: 00439
Total samples	**56,599**		

5.2.4 Action Plan

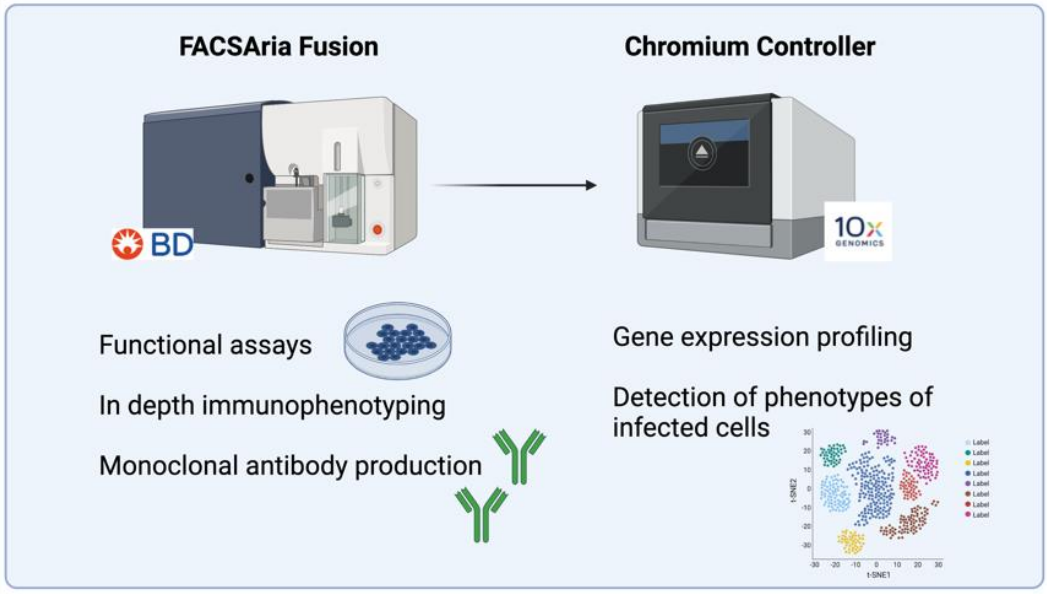
The biobank room is planned to be put under sole control of the Biobank service who is taking care of all inputs and outputs of samples. The SOPs relevant for the management of Biobank are currently being written. Additionally, the Biobank policy will be developed and implemented in 2026.

5.3 Single Cell Analysis

Host-pathogen interactions are complex and biomedical research has evolved to interrogate multiple parameters at the same time using different -omics approaches. Single cell analysis and functional assays on purified cell populations have become established methodologies to study cell and pathogen heterogeneity. This platform allows us to investigate complex pathogen-host interactions to the single cell level directly on site in a low/middle income country. The availability of this equipment and patient cohorts in the same location allows us to advance our basic research on infectious diseases of major importance in Cambodia.

In 2020, we have purchased and implemented a new 4 laser, 18-color single cell sorter (FACSAria Fusion III). Funding was obtained from Wellcome Trust (Multi User Equipment grant, PI: Cantaert Tineke, Co-investigators: Jean Popovici, Benoit Witkowski and Erik Karlsson) and GIZ. Moreover, we purchased and implemented a 10x Genomics Chromium Controller for single cell RNA sequencing, funded by the NIH PI-CREID grant (country PI: Cantaert Tineke). Both pieces of equipment are placed in a BSLII+ biosafety environment.

In terms of functioning, the platform is open to researchers both inside and outside of IPC, research entities and Universities in Cambodia on a collaborative basis. The platform provides expertise in the experimental design and a dedicated research engineer will perform the experiments. No user fees will be charged but the collaborative partners should purchase the reagents and consumables needed for the experiment.



5.3.1 Functional Structure

The platform is integrated within the Immunology Unit.

5.3.2 Research Programs – Major Achievements in 2025

In 2025, the platform was used for the following research projects:

- Characterization of DENV-specific B cells responses folowing dengue virus infection
- Analysis of B cell receptor (BCR) repertoires in the context of dengue virus infection
- Analysis of T cell receptor (TCR) repertoires during acute dengue virus infection
- Characterization of CCHFV-specific B cells responses folowing CCHFV infection
- Generation and characterization of monoclonal antibodies targeting dengue virus and CCHFV

- Understanding of immune responses to chikungunya virus infection leading to chronic symptoms
- Identification of mechanisms leading to clinical protection from Plasmodium vivax infection
- Cellular Indexing of Transcriptomes and Epitopes by Sequencing (CITE seq): integrated analysis of innate immune cell responses and metabolic pathways during acute dengue infection

5.3.3 Research Programs – Outlook for 2026

In 2026, a continuation of the above mentioned research projects is envisioned. In addition, our pipelines for the production of monoclonal antibodies will be extended to other viruses of major concern in South-East Asia, such as SFTSV. The acquisition of the Chromium X platform at the beginning of 2026 will enhance our single-cell multi-omics capabilities, increasing throughput and resolution.

Perspectives

In the upcoming years, we aim to strengthen further the single cell analysis platform, with new projects on antibody discovery for relevant mosquito-borne infections, studying antigen-specific T cells and expanding our experimental pipelines to perform CITE-seq.

The platform can be utilized to study interactions between host and pathogens of major health importance in Cambodia.

The platform can help in the design, planning and execution of the experiments. Bioinformatics analysis are strengthened with the establishment of the BAIA Unit at IPC. Within Cambodia, we aim to setup novel collaborations with universities and other research entities. Indeed, we have an ongoing collaboration with the NIH-funded ICER (International Center for Excellence in Research) which is located at the National Center for Parasitology, Entomology and Malaria Control (CNM), Ministry of Health. Moreover, the platform aims to support research programs in Cambodia and in the region through workshops and training.

5.4 Sequencing Platform

5.4.1 Functional Structure

Established in April 2021, the Sequencing Platform is a technical facility dedicated to strengthening - in transversal within IPC – research activities and public health responses related to genomic sequencing. Equipped with cutting-edge infrastructure, including a high-throughput next generation sequencer (Illumina MiSeq System) and a range of accessory instruments, the platform facilitates in-house advanced sequencing capabilities.

In 2025, the platform operated under the leadership of Dr. Janin Nouhin, who dedicated 30% of his time to platform activities, in addition to his duty as Deputy Head of the Virology Unit. Technical expertise was provided by Mr. Vireak HEANG (Research Engineer) and Mr. Sereyrith Saulim (Laboratory Technician). In line with the strategic perspective of integrating the platform into the Virology Unit, Mr. Saulim was administratively transferred in January 2025, followed by Mr. Heang in June 2025.

Both staff members continued to contribute to the platform activities throughout the year. Our activities encompass nucleic acid library preparation and next generation sequencing (NGS) using Illumina MiSeq System.

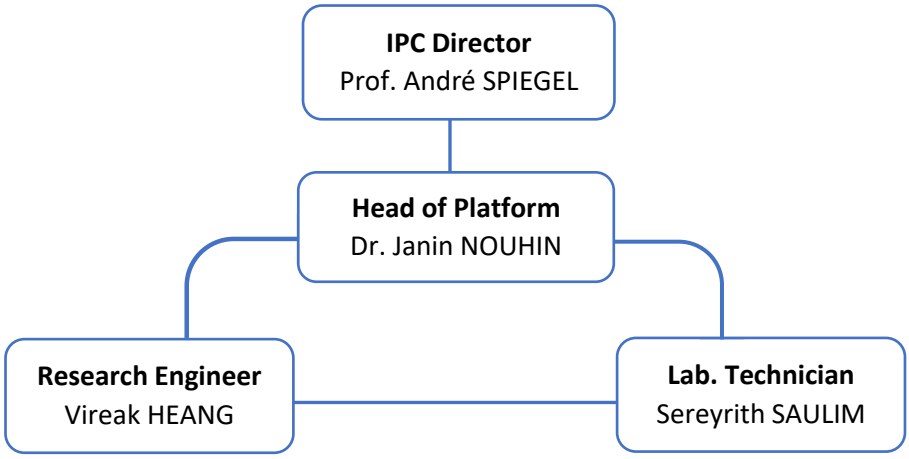


Figure 27: *Sequencing Mini-Platform organogram, 2025*

5.4.2 Research Programs – Major Achievements in 2025

In 2025, the platform team performed 8 runs of NGS service using Illumina Miseq. Seven sequencing runs of 84 samples were conducted in framework of collaborative projects with the Virology Unit and one run of 12 pools of samples was conducted for fee-based user.

Collaborative Projects

Assesment of metagenomics sequencing methods to detect and characterize Sarbecovirus in bat: Becoming Sub-study

The aim of this work is to assess the performance of metagenomics sequencing protocols to detect and characterize Sarbecovirus in bat.

These protocols included Twist CVRP on Illumina MiSeq, SISPA on ONT GridION, and an in-house protocol developed by Dr. Etienne Simon-Lorriere's team on Illumina NextSeq. The assessment was conducted on 12 bat rectal swabs, collected in the framework of Becoming project, tested positive for Sarbecovirus. As a result, the sequencing data obtained with Twist CVRP on Illumina MiSeq System provided a comparable coverage in most Sarbecovirus genome, but lower coverage for S gene.

Research Project Name	Assesment of metagenomics sequencing methods to detect and characterize Sarbecovirus in bat: Becoming Sub-study
Funding	IPC internal budget
Project duration	2025
Collaboration	Institut Pasteur du Cambodge: Virology Unit and Sequencing Platform (L Khun, S. Saulim, P T Ou, V Heang, E Karlsson) Institut Pasteur in Paris (E Simon-Lorriere)

Assessing the impact of a lid on defeathering machines to reduce airborne avian influenza contamination in Cambodian live bird markets

The study was conducted with coordination led by Ms. Frida Esther Sparaciari, PhD student enrolled at James Cook University. The aims of this study are:

- to evaluate the effectiveness of a partial lid on defeathering machines in reducing airborne AIV contamination in Cambodian LBMs;

- to assess changes in environmental AIV contamination in key high-risk areas of the market before and after the intervention;
- to assess worker acceptability and comfort with the lid intervention through structured surveys; and,
- to develop evidence-based recommendations for biosecurity interventions in Cambodian LBMs.

In November 2025, the Sequencing Platform performed six metagenomics sequencing runs of 72 environmental samples including air, water, poultry swabs, and surface swab using Twist Comprehensive Virus Research Panel (CVRP). Data analysis is ongoing.

Research Project Name	Assessing the impact of a lid on defeathering machines to reduce airborne avian influenza contamination in Cambodian live bird markets
Funding	FAO
Project duration	August – December, 2025
Collaboration	Institut Pasteur du Cambodge: Virology Unit and Sequencing Platform (E Karlsson, J Siegers, V S Horm, S Tok, S S, V Heang, L Khun, S Saulim) James Cook University (F E Sparaciari)

User fee services

The Sequencing Mini-Platform provided fee-based user services for IPC and as well as external researchers.

In collaboration with Wildlife Conservation Society (WCS), the Sequencing Platform managed to provide metagenomics sequencing service for one run of rodent samples (n=12 pools) from our archived Lacanet Project using Twist CVRP. This collaborative research activity was conducted in August 2025 under the coordinated by Dr. Xu Cong, a postdoctoral research scientist at University of Calgary and WCS. The aim of the research project is to study the ecological drivers and genomic mechanisms of wildlife viral emergence caused by deforestation in Cambodia using rodent and rodent-borne pathogens as models.

5.4.3 Outlook for 2026

Building on the initiative to optimize resources and strengthen operation efficiency, the formal integration of the Sequencing Platform into the Virology Unit is planned for 2026. The proposal, submitted to IPC top management on April 22, 2025, received positive initial feedback from the Chief Financial Officer, noting its alignment with the broader review of the Virology Unit's structure, human resources, and operation efficiency.

The organizational evolution is expected to consolidate technical expertise, enhance next-generation sequencing capacity within the Virology Unit, and strengthen operation coherence. The Sequencing Platform will continue to operate as a transversal facility, supporting genomic research, surveillance activities, and collaborative project across IPC.

Governance Plan

Following its integration into the Virology Unit, the Sequencing Platform operates under a structured governance framework designed to ensure transparent prioritization, efficient resource allocation, and long-term sustainability, while maintaining its transversal institutional role across IPC.

Strategic oversight

The Sequencing Platform is placed under the authority of the Head of the Virology Unit, who holds responsibility for strategic direction, activity prioritization, and resource allocation. The Platform Lead manages day-to-day technical operations. Governance operates across three complementary levels:

- Strategic level**:** Annual and quarterly planning defines sequencing priorities aligned with IPC research and public health mandates, evaluates collaborations, and anticipates capacity and technology needs.
- Operational level: Routine coordination manages scheduling of sequencing runs, allocation of machine time across projects, and monitoring of turnaround time.
- Emergency response level: During outbreak investigations or urgent national surveillance needs, sequencing activities are automatically reprioritized to support public health response.

Project prioritization and access

Access to sequencing capacity follows a transparent prioritization framework:

- National public health response and outbreak investigation
- Ongoing IPC surveillance programs
- Funded collaborative research projects
- Training and capacity-building activities
- Fee-for-service users

This approach ensures equitable access and protects staff from ad-hoc allocation pressures.

Financial governance

The platform budget is managed within the Virology Unit financial structure to support sustainability and cost recovery. Financial oversight includes annual operating budget planning, per-run cost tracking, internal cost-sharing between projects, and periodic review of external service pricing. The objective is long-term operational continuity rather than profit generation.

Human resource management

Platform personnel are administratively embedded within the Virology Unit while maintaining specialized technical roles. The Unit oversees supervision, workload balancing, competency-based training, and succession planning to ensure continuity of operations independent of individual staff availability.

Data governance and quality assurance

Sequencing activities operate under standardized procedures including validated laboratory protocols, traceability of samples and metadata, centralized data storage and backup, and defined responsibilities for analysis and reporting. These measures ensure reproducibility, accountability, and compliance with national and international data-sharing frameworks.

Institutional role

Despite administrative integration, the Sequencing Platform remains a shared institutional facility providing sequencing support to research programs, surveillance activities, and collaborative projects across IPC and with external partners.

Overall, this governance framework strengthens managerial oversight, clarifies decision-making processes, and supports the sustainable operation of sequencing activities within IPC.

5.4.4 Meeting and Workshop

- Mr. Sereyrith Saulim attended “Antimicrobial Resistance in Bacterial Pathogens, Asia” workshop organized by Welcome Connecting Science and Mahidol University, from February 2–7, 2025, Bangkok, Thailand.
- Mr. Vireak Heang joined the training at the University of Melbourne titled “Strengthening genomics informed surveillance, diagnosis, and control of infectious diseases across the Asia-Pacific” from January 20 – February 21, 2025, Melbourne, Australia.

- Dr. Janin Nouhin and Mr. Vireak Heang participated as trainers in a workshop organized by the Asia Pathogen Genomics Initiative through the Duke-NUS Centre for Outbreak Preparedness: “Metagenomic Sequencing of Respiratory Viruses” from May 15-21, 2025, Singapore.

5.4.5 Outlook for upcoming 3 – 5 years

The integration of the Sequencing Platform into the Virology Unit will strengthen strategic oversight, optimize resource allocation, and enhance scientific and technical synergies.

The Sequencing Platform is expected to significantly expand NGS capacity within the Virology Unit, supporting advanced genomic research, surveillance, and national and regional training initiatives. While embedded within the Unit, the platform will retain its transversal function, continuing to provide critical sequencing support to a broad spectrum of research project across IPC and reinforcing the institution’s role as a regional center of excellence in genomics.

6 Services Support

6.1 Grants Office

6.1.1 Functional Structure

The Grants Office (GO) serves as a central service dedicated to strengthening IPC’s institutional capacity in fundraising and grant management. Reporting directly to the Director of IPC, the GO works in close collaboration with DAF units and support services to streamline procedures and harmonize operational workflows (Figure 28).

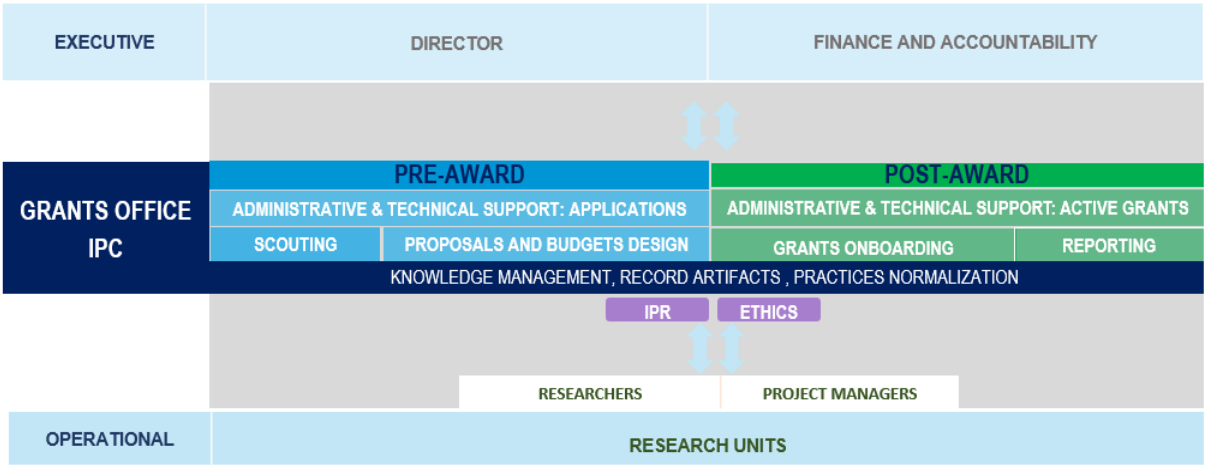


Figure 28: *IPC Grants Office organization*

In 2025, the Grants Office handled more than 78 tasks and requests. Most of the workload remained in post-award tasks (63%), compared with pre-award activities (33%). Less than 4% of GO staff time was allocated to workflow structuring and internal organization of the Grants Office segments.

Pre-award	
Scouting	3
Matchmaking	9
Application	14
Post-Award	
Awarding	15
Renewal and subaward contract	14
Reporting	13
Monitoring	8
Collaborative Agreement	4
Other Contracts	
MoU, DTA	3

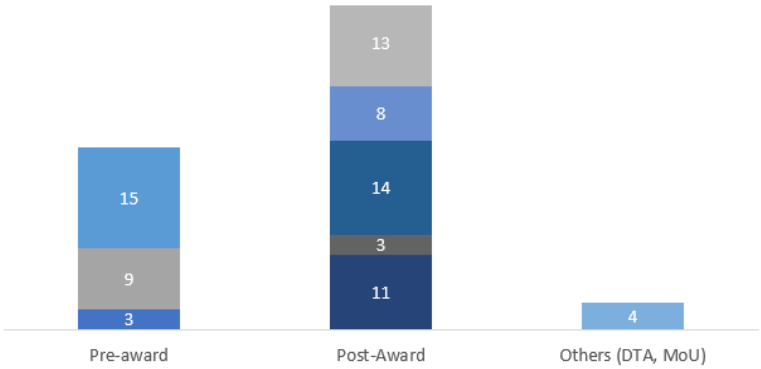


Figure 29: *GO IPC performed tasks in 2025*

6.1.2 Activities

Funding Opportunities and Scouting

Scouting of funding opportunities and matchmaking with IPC's needs and expertise were carried out. Three newsletters featuring 33 funding opportunities were shared, in addition to targeted dissemination to specific teams. At least three applications resulted directly from the advertised opportunities.

The Grants Office also organized an information session on upcoming Horizon Europe calls to draw attention to opportunities in infectious diseases, One Health, pandemic preparedness, and climate-related research, where IPC teams may have a strong position as third-country beneficiary.

Project Applications and Grants Onboarding

In 2025, the Grants Office supported 14 funding applications, including six proposals where IPC had a leading role (Wellcome Trust, EC, ANRS, WHO). Three coordinated initiatives (WT, ANRS, EC) were managed with GO support, in addition to contributions to SPARK and WHO applications. The Grants Office also provided onboarding assistance for 15 newly awarded grants.

Monitoring, Reporting and Related Coordination

The Grants Office contributed to 13 reporting tasks, covering both financial reports and support for technical report preparation (NIH, EC, CRDF, WT). The Grants Office and the Finance Department are strengthening upstream coordination with units to improve grants monitoring and ensure compliant expenditure and appropriate use of resources. Corrective measures and negotiations are carried out with internal and external stakeholders when needed.

The year was also marked by significant NIH policy changes affecting foreign recipient organizations. The Grants Office conducted risk-assessment review to ensure institutional readiness and limit the impact of potential funding disruptions. Compliance adjustments were applied to one project, and two actions were suspended, with no major financial consequences. These changes also affected the planning of new applications, which had to be redirected toward alternative funding opportunities.

Collaboration and Contractual Guidance

Besides managing grant and consortium agreements for new awards, the Grants Office oversees subaward contract management for coordinated grants and follows up on renewal processes for its subawards. The GO also supports the setup of specific terms for collaborative research agreements. Guidance on contractual aspects related to intellectual property and ethical considerations is provided as much as possible.

Tools for Portfolio Management

Digital workspace has been set up as single access point for Grants Office tools and documentation. It offers a user-friendly interface and serves as the core repository for project artefacts and GO activities. It also provides a collaborative space for sharing, preparing proposals and reporting within an institutional framework.

Currently, the workspace is mainly used by the Grants Office team and few collaborators. Over time, it is expected to evolve into a central repository and operational space for all applications and awarded projects.

The project directory created in 2024 has been integrated into IPC's digital environment and is regularly updated. It now serves as a planning tool for monitoring and managing IPC's active projects portfolio.

Figure 30: *GO Digital Workspace*

Training in Project Management for Capacity Building

The Grants Office coordinated the deployment of the Global Health Project Management training as part of its capacity building plan. The objective was to strengthen project management competencies across institutional stakeholders and to enhance shared understanding of key concepts in project and grant management.

A total of 35 staff from different units and profiles were enrolled, and 32 successfully completed the program and obtained certification.

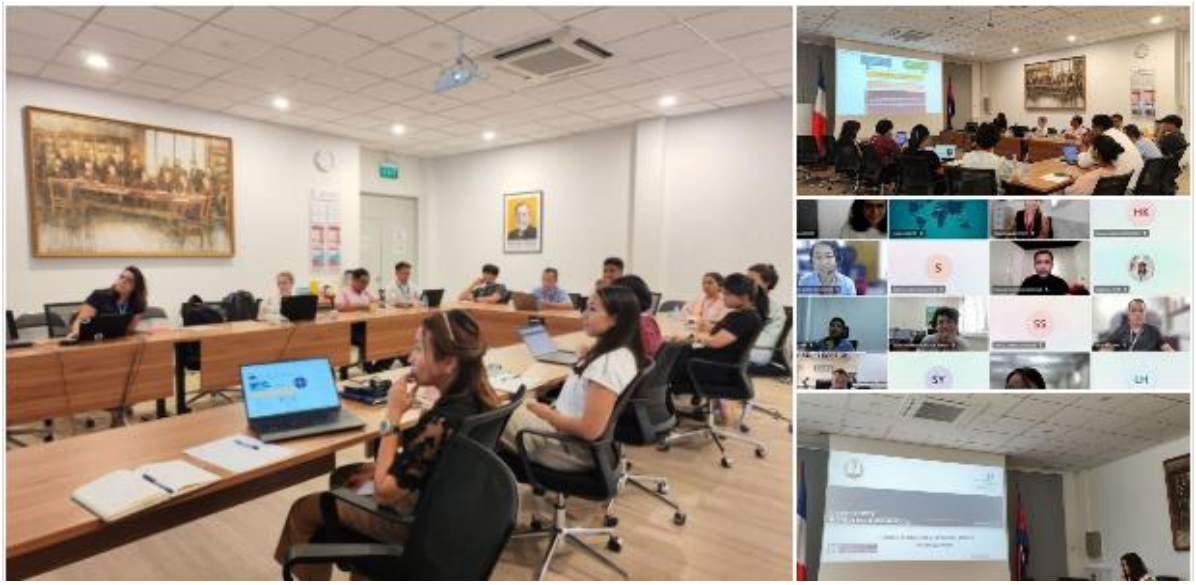


Figure 31: *Training site meeting*

6.1.3 IPC Grants Portfolio Highlights

IPC's grants portfolio comprises 73 active funded lines, including 8 grants starting in 2026. Of these, 56 are project-based grants and 9 are service contracts (Annex. IPC Grant Portfolio 2025–2026).

Active funding in 2025 is distributed across nine scientific and operational clusters (Figure 3. Project Distribution by Research Theme). The largest cluster is Malaria, with 18 active projects. One Health, Zoonoses & Spillover follows with 14 projects, spanning cross-sectoral surveillance and emerging disease risks.

The Arboviruses & Vector-Borne Viral Diseases cluster includes 13 projects, covering dengue, chikungunya and Japanese encephalitis. Influenza & Respiratory Viruses includes 9 projects, covering avian influenza, respiratory pathogens, and viral genomic surveillance.

Other areas include TB, HIV & Fungal Infections (5 projects), Wastewater & Environmental Surveillance (5 projects), Clinical Research (4 projects), Public Health, Epidemiology & Modeling (2 projects), and Food Safety & Environmental Testing (2 projects). Antimicrobial resistance (AMR) is represented by one project.

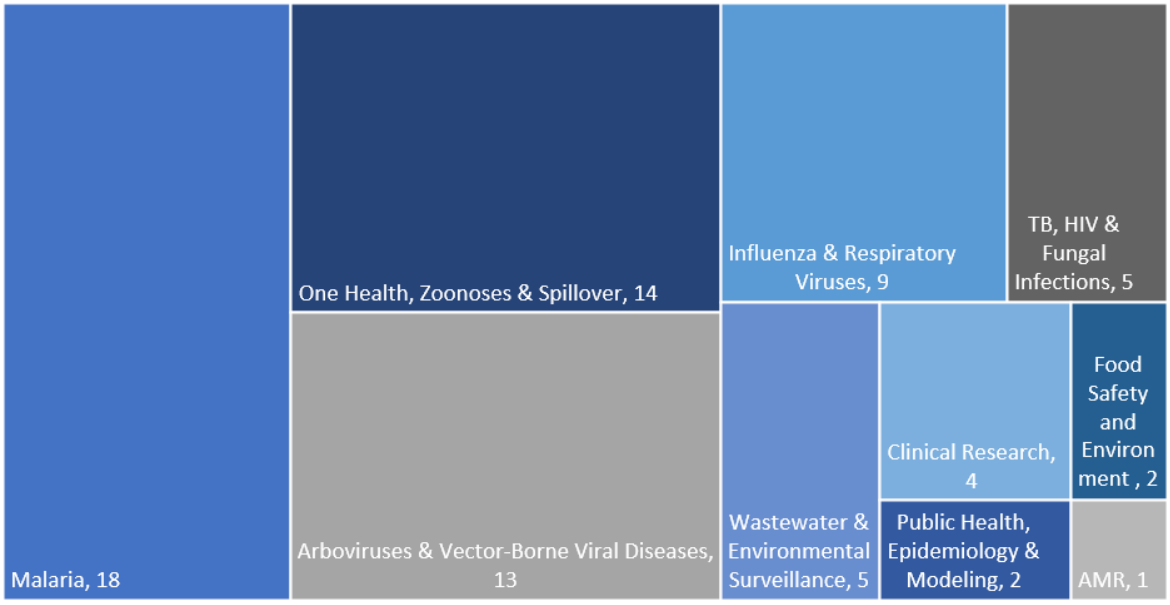


Figure 32: *Project Distribution by Research Theme*

No	Acronym	Title	Fund	Start Date	End Date
1	BioPREVAIL	Develop an on-site closed-loop system to transform non-hazardous plastic waste into lab and field supplies using 3D-printing technology	GHFS	9/30/2025	12/31/2025
2	DEKLIC	Unraveling the human, ecological, and environmental drivers of Plasmodium knowlesi malaria emergence in Cambodia	IRD	8/1/2025	7/31/2028
3	-	Diagnostics and surveillance of acute meningo-encephalitis among children in Cambodia with a focus on Japanese Encephalitis Virus	MEAE-FEF	7/8/2025	7/7/2027
4	-	Coopération sanitaire (résistance aux antibiotiques)	MEAE-FEF	7/5/2025	11/1/2027

5	WASP	Detection of pathogens with pandemic potential in urban wastewater as an early warning of human adaptation and transmission	IPLtd	7/2/2025	6/2/2028
6	OUCRU SPILLOVER	Development and assessment of novel, high-throughput immunological assays to improve surveillance of spillover of viral families of pandemic potential.	UKRI	4/1/2025	3/31/2028
7	CANARIES	Framework for Live Animal Market Investigations and Guidelines Harmonization and Techniques in Africa and Asia	AMS	3/1/2025	1/3/2027
8	VIRAGE	Vigilance Intégrée pour le Renforcement des Actions de Gestion et l'Élimination de la Rage au Cambodge	AFD	3/1/2025	11/3/2026
9	UNITEDENGUE	Estimating the Epidemic Potential, Immune Escape, and Disease Severity of Emerging Mosquito-Borne Virus Lineages in South-East Asia	NAE	1/7/2025	6/30/2028
10	NTM	Nontuberculous mycobacterial (NTM) infections associated with climate change and major weather events: enhancing surveillance and mitigation strategies	CRDF	1/3/2025	2/28/2028
11	PVESMEE	Plasmodium vivax escape strategies to malaria elimination efforts	IP _PIU	1/1/2025	12/31/2030
12	IMPACT	IP network_Training funding_Immune responses to arbovirus infections from a One Health perspective,	PN	1/1/2025	12/3/2025
13	ECOMORE	Economic Development, Ecosystem Modifications, & Emerging Infectious Diseases Risk Evaluation	AFD	1/1/2025	12/31/2028
14	RACSMEI	Risk Assessment of Community Spread of Multiple Endemic Infectious Disease pathogens in a One Health Perspective	WT	1/1/2025	12/31/2030
15	ANRS-2025	Budget annuel du site ANRS du Cambodge 2025	ANRS	1/1/2025	12/31/2025
16	PVCULT	Leveraging access to parasite natural diversity to identify Plasmodium vivax culture-	NIH	12/27/2024	11/30/2027
17	CHIKV	Characterization of the immunological mechanisms that drive chronic chikungunya disease pathogenesis	WT	11/15/2024	11/14/2030
18	RESPIRO	Aetiologic Agents of Community Acquired Pneumonia in South-East Asia	TTSH	10/28/2024	1/27/2026
19	VIDUNAF	Plasmodium vivax Erythrocyte Invasion Mechanisms and Humoral Immune Response in Duffy Negatives Africans	NIH	9/2/2024	1/31/2027
20	CISED DENGUE	Comprehensive Integrated Surveillance and Early Detection System for Dengue	JCU/AFD/CDC	7/29/2024	7/28/2026
21	IMAGERIE	Un nouvel outil innovant au Cambodge: vers une revolution mondiale de l'image en sciences de la sante (Imagerie)	French Embassy	7/18/2024	7/20/2025
22	PEACH	Pathogens Exposure from Aquifers: A Cambodian Health interdisciplinary case study	IRD	6/11/2024	1/12/2026

23	METABODEN IRD	IMPACT OF LIPID METABOLISM ON SEVERE DENGUE: BIOMARKERS AND PATHOGENESIS	ANR/IRD	4/23/2024	5/23/2026
24	CAPRED_CAP24-G027	Support to Institut Pasteur du Cambodge to set up two accredited testing laboratory services: Pesticides and-Antibiotics, and Heavy Metals Testing	DAFT	4/22/2024	12/31/2026
25	FUNGI-CAM	Prevalence of invasive fungal infection – Histoplasma spp., Talaromyces marneffei, Cryptococcus spp. – in severe immunocompromised HIV-infected patients in Cambodia	ANRS	3/1/2024	2/28/2025
26	SROUL	Amélioration des pratiques d'information dans les recherches biomédicales liées aux zoonoses au Cambodge : une approche de co-construction des messages	IP	1/12/2024	11/3/2025
27	FLU-SENT	Influenza A (H5N1) sentinel market study	INRAE	1/11/2024	1/31/2026
28	SEA-ROADS	Approche régionale One Health pour la surveillance intégrée et interconnectée de la dengue urbaine en Asie du Sud-Est	ANRS	1/10/2024	9/30/2027
29	AFRICAM	Preventing Zoonotic Diseases Emergence	AFD/IRD	1/10/2024	6/30/2026
30	DUKE NUS	Asia PGI Accelerating Pathogen Detection through Wastewater Surveillance	GATES	1/6/2024	10/31/2026
31	DEMELE	Diagnostics and surveillance of acute Meningo-encephalitis among children in Cambodia with a focus on Japanese Encephalitis Virus	ANRS	1/5/2024	11/30/2206
32	ALERTA	Assessing local entomological risks to support precision Public Health	IP-Fondation Simone et Cino del Duca	1/5/2024	11/15/2024
33	TRACKFLU	Tracking the spread of avian influenza viruses in live bird market networks	EC	1/5/2024	4/30/2029
34	CCHVACIM	Crimean-Congo Haemorrhagic Fever Vaccine and Immunotherapy (CCHFV2)	EC	1/1/2024	12/31/2027
35	ANRS-SITE	Budget Site Cambodge 2024	ANRS	1/1/2024	3/31/2026
36	CAP COVID GUYANE	Connaissances, attitudes et pratiques associées aux vaccins COVID-19	ARD-GUYANE	1/1/2024	12/31/2024
37	ACIP CLIMPATHIC	Strategy for genomic surveillance of pathogens in wastewater	IP-ACIP	1/1/2024	12/31/2025
38	AVERT-CAM	An Early Warning System for AIV Transmission and Gene Flow in Cambodia" (AVERT-Cam)	IP-ACIP	1/1/2024	12/31/2026
39	PIU-IMMUNO	Décryptage des réponses immunitaires adaptatives au cours des infections dues à des pathogènes émergents à fort potentiel épidémique COVID-19 – DENGUE – DISEASE X	IP_PIU	1/1/2024	12/31/2028
40	PREEMPT	Predicting the emergence and spread of drug resistant malaria parasites	NHMRC	1/1/2024	12/30/2027

41	HEPEDIAC	Etude thérapeutique pilote de traitement par AAD des enfants et adolescents présentant une infection VHC active et nés de mères Co infectées VIH/VHC au Cambodge	ANRS	6/1/2023	5/31/2025
42	IMUVIVAX	Comprehensive characterization of the genetic factors and the host immune response associated to protection from clinical Plasmodium vivax malaria	NIH	3/16/2023	2/29/2028
43	HYPNOMICS	Multi-Omics Characterization of Plasmodium Vivax Hypnozoites	NIH	1/12/2023	11/30/2028
44	DENGUEADE	Mechanisms of antibody-dependent enhancement of dengue disease (DENV)	NIH	1/9/2023	8/31/2028
45	MULTIVAX	Accelerating Discovery of an Efficacious Plasmodium Vivax Multivalent Multi Stage Vaccine	NIH	1/7/2023	11/30/2025
46	PVEVAS	Extent, dynamics and mechanisms of Plasmodium vivax immune evasion caused by PvDBP gene amplification	NIH	1/7/2023	6/30/2028
47	ANRS-SITE	Budget Site Cambodge 2023	ANRS	1/1/2023	3/31/2025
48	INVAVAX	Host and parasite factors influencing P. vivax RBC invasion and asexual development	NIH	8/6/2022	3/31/2029
49	ICEMR-BARMAL	Understanding and Targeting the Barriers to Effective Malaria Control and Elimination in the Asia-Pacific Region	NIH	8/6/2022	3/31/2027
50	BCOMING	Biodiversity Conservation to Mitigate the risks of emerging infectious diseases	EC	8/1/2022	7/31/2026
51	Imager	Defining targets of protective immunity to vivax malaria using human monoclonal antibodies	NIH	1/3/2021	2/28/2025
52	DATURA	Determination of Adequate tuberculosis Regimen in Adults and adolescents hospitalised with HIV-associated severe immune suppression.	ANRS	10/1/2020	9/30/2024
53	PRICURE	Rigorous Assessment of P. vivax Relapses and Primaquine Efficacy for Radical Cure	NIH	7/17/2020	6/30/2025
54	HYPNOLEAD	Lead optimization and target identification of drugs targeting hypnozoites	NIH	7/8/2020	7/31/2025
55	PICREID	Inter-regional study of transmission, adaptation and pathogenesis of viruses with pandemic potential in Southeast Asia and West/Central Africa	NIH	1/6/2020	5/31/2025
56	WT-TBC	Advancing flow cytometry for the on-site study of tropical infectious diseases	WT	1/4/2020	1/4/2025

Table 11: *IPC Grant Portfolio – Active Projects in 2025*

6.1.4 Outlook for the Next 3–5 Years

3-Year Goals:

- Strengthening specialization across pre-award and post-award processes, including enhanced expertise in technology transfer and contractual management for collaborative research.

5-Year Goals:

- Establish IPC Grants Office as a key support service for IPC's strategic research management, driving collaboration and enhancing competitiveness, and expanding funding and networks.

6.2 Communication Service

6.2.1 Functional Structure

In 2025, the Communication Service of the Institut Pasteur du Cambodge continued to strengthen its strategic positioning within the institution. The Service reinforced its role in promoting IPC's scientific excellence, public health missions, and institutional visibility at national, regional, and international levels. Communication operated both as a dissemination mechanism and as a strategic support function, ensuring coherence between research units, services, institutional governance, and external stakeholders. The primary objective remained to enhance IPC's visibility, credibility, transparency, and accessibility through structured, data-driven, and impact-oriented communication.

6.2.2 Activities

Digital Presence & Platform Development

In 2025, IPC significantly expanded and structured its digital ecosystem.

On Facebook, the Institute's main page increased from 38,800 followers to over 43,000 followers, representing a growth of approximately 10.8%. Digital performance indicators showed strong progression, with 123,900 visits recorded, reflecting a 20.2% increase compared to 2024. Content interactions reached 18,700, marking a growth of 47.5%, while link clicks rose to 8,000, corresponding to a significant increase of 602.8 %, with a total of 197 posts published throughout the year. This strong rise in link clicks reflected improved content structuring, clearer calls to action, and increased public interest in IPC's services and scientific outputs. Facebook remained IPC's principal public-facing platform, predominantly reaching Cambodian audiences and supporting the visibility of health services and research activities. In addition to the development of the main Facebook page, three dedicated Unit pages were created in 2025 for the Medical Biology Laboratory, the Epidemiology & Public Health Unit, and the Laboratory of Environment & Food Safety. These pages enabled more targeted communication, improved accessibility for patients and partners, and clearer presentation of unit-specific activities and services. LinkedIn experienced substantial expansion during 2025. The number of followers increased from 1,900 to over 5,000, representing a growth of approximately 163%. This expansion significantly strengthened IPC's professional positioning and international visibility within the Pasteur Network and the broader scientific community.

LinkedIn continued to serve as the primary platform for scientific valorization, institutional announcements, and international engagement, with 178 posts shared over the year.

IPC also continued developing its TikTok presence in 2025 and reached over 1,000 followers. The strategic objective of this platform was to connect with younger generations by explaining IPC's mission in simplified and accessible formats. Content focused on presenting public health professions, research activities, and institutional roles in order to improve scientific literacy and support recruitment of future collaborators and staff. TikTok therefore contributed to enhancing IPC's institutional attractiveness and outreach among younger audiences.

Listening, Surveys & Data-Driven Communication

In 2025, the Communication Service reinforced its role as a data-driven support structure for institutional decision-making. More than 6,000 responses were collected through 36 active survey forms deployed across services and units. Monthly reporting was shared with Heads of Units, and an

annual consolidated analysis was presented to IPC Direction. The collected data supported service optimization, patient experience improvement, and evidence-based management decisions. Communication thereby contributed directly to institutional performance monitoring and quality enhancement processes.

Scientific Publications & Knowledge Valorisation

Scientific publication valorization remained a priority throughout the year. IPC scientists published 62 scientific publications in 2025. The Communication Service highlighted research outputs through 23 dedicated social media posts and relayed approximately half of the year's publications across digital platforms. Scientific outputs were systematically integrated into the monthly internal newsletter, and a structured bibliometric report was produced to provide a consolidated overview of research productivity and impact. These actions strengthened research visibility, institutional credibility, and public access to scientific information.

Events & Institutional Visibility

Service ensured the development of all communication materials and maintained visual coherence and digital coverage. Immuno-Cambodia 2025, organized in Siem Reap, brought together 37 participants from **12 countries** and benefited from dedicated communication support. Communication also accompanied the launch of strategic projects, including VIRAGE and RACSMEI, ensuring consistent institutional branding and visibility across all materials and channels.

Institutional Culture & Internal Communication

Internal communication and institutional culture were further strengthened in 2025. The Service produced 19 institutional posters and formatted six internal procedures to ensure standardized presentation and clarity. The monthly internal newsletter continued to inform staff about institutional developments, while weekly scientific seminar posters supported internal scientific engagement. Opening hours signage was updated, IPC certificates were redesigned to ensure visual consistency, and a newcomer booklet was developed for visitors and new staff to facilitate onboarding and institutional integration. These actions improved internal information circulation and reinforced institutional coherence.

Network Actions & Pasteur Network Engagement

At the regional level, IPC remained actively engaged within the Pasteur Network. The Communication Service continued participating in the Asia-Pacific (APAC) Communication Group and designed and delivered training sessions on artificial intelligence tools, including ChatGPT, as well as Canva design trainings for institutes within the Network. IPC was appointed as a member of the Pasteur Network Working Group on the History of the Pasteur Network. Regular exchanges were maintained with communication officers across institutes in the Asia-Pacific region and beyond, contributing to shared learning and mutual capacity building.

Communication Materials & Visual Production

Throughout 2025, the Communication Service produced various institutional and scientific materials. These included a zoonosis awareness poster and scientific communication visuals supporting projects such as RACSMEI and ECOMORE III. In close collaboration with IPC Direction, **standardized institutional templates** were developed and finalized, including the Code of Conduct, the Gender Equity Plan, and anti-fraud and anti-corruption policies. These materials reinforced IPC's governance transparency and institutional consistency. All communication outputs were developed in compliance with IPC's graphic charter and institutional identity guidelines, ensuring visual coherence and alignment with IPC's values.

6.2.3 Outlook for the Next 3–5 Years

Overall, 2025 was characterized by strong digital growth, structured data collection, increased scientific publication visibility, reinforced institutional culture, and active engagement within the Pasteur Network.

Communication further consolidated its role as a strategic institutional pillar supporting governance, scientific dissemination, and public health visibility.

Looking ahead to 2026, the Communication Service will continue developing youth-oriented communication formats, strengthening video-based scientific dissemination, integrating communication components into research proposals, and enhancing the international visibility of IPC scientific outputs. Continued regional collaboration within the Pasteur Network will remain a priority in order to position IPC as a leading public health communication actor in Cambodia and within the Network.

7 Scientific Publications in 2025

Note: *The name of authors from the Institut Pasteur du Cambodge are underlined*

1. **14 days of high-dose versus low-dose primaquine treatment in patients with Plasmodium vivax infection in Cambodia: a randomised, single-centre, open-label efficacy study.**
   Eng V, Lek D, Sin S, Feufack-Donfack LB, Orban A, Salvador J, Seng D, Heng S, Khim N, Tebben K, Flamand C, Sommen C, van der Pluijm RW, White M, Witkowski B, Serre D, Popovici J.
   Lancet Infect Dis. 2025 Mar 17:S1473-3099(25)00033-7. doi: 10.1016/S1473-3099(25)00033-7.
   IF: 36.4
2. **Absence of Macrolide-Resistant Mutations in *Bordetella pertussis* in Antananarivo (Madagascar) and Cambodia During the Last Pertussis Cycle Before the COVID-19 Pandemic.**
   Campana F, Rajabizadeh M, Hide M, Delvallez G, Han S, Rafetrarivony L, Dim B, Harimanana A, Noel G, Ait-Ahmed M, Collard JM, Borand L, Guiso N, Taieb F.
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   IF: 3.8
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8 Annexes

8.1 List of Acronyms

BSL3	Biosafety Level 3
ISO	International Organization for Standardization
PPE	Personal Protective Equipment
NIPH	National Institute of Public Health
IPC	Institut Pasteur du Cambodge
NACW	National Authority for Chemical Weapons
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
BMS	Biorisk Management System
PhD	Doctor of Philosophy
LMICs	Low- and Middle-Income Countries
HSeQM	Hygiene, Security, Environment, Quality and Maintenance
SOPs	Standard Operating Procedures
QR	Quick Response
MTA	Material Transfer Agreement
N_2	Nitrogen
LEFS	Laboratory of Environment and Food Safety
HSM	Hardware Security Module
MBL	Medical Biology Laboratory
PRA	Plant Risk Assessment
MVE	Medical Veterinary Entomology
IMM	Immunology
VIR	Virology
ECOMORE	Economic Development, Ecosystem Modifications, and Emerging Infectious Diseases Risk Evaluation
PEP	Post-Exposure Prophylaxis
HEV	Hepatitis E Virus
EPH	Epidemiology and Public Health
DAA	Direct Acting Antivirals
HCV	Hepatitis C
TB	Tuberculosis
HEPEDIAC	Etude thérapeutique pilote de traitement par AAD des enfants et adolescents présentant une infection VHC active et nés de mères Co infectées VIH/VHC au Cambodge
DIR	Direction
MALDI-TOF MS	Matrix-Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry
SEA	South East Asia
FSPI-VECAM	Fonds de Solidarité pour les Projets Innovants - Vector-borne Diseases in Cambodia
BGF	Bourses du Gouvernement Français (French Government Scholarship)
SEAROADS	One Health Regional Approach for Integrated and Interconnected Urban Dengue Surveillance Southeast Asia
NIH-PICREID	National Institutes of Health – Pasteur International Center for Research on Emerging Infectious Diseases
ANR	French National Research Agency
BCOMING	Biodiversity Conservation to Mitigate the Risks of Emerging Infectious Diseases
FEF-R	Fond Equipe France Rapide

CISED	Comprehensive Integrated Surveillance and Early Detection System for Dengue
ANRS	Agence Nationale de Recherches sur le Sida et les Hépatites Virales
AVSF	Agronomes et Vétérinaires sans Frontières
ICEMR	International Center of Excellence in Malaria Research
WT-RACSMEI	Wellcome Trust – Risk Assessment of Community Spread of Multiple Endemic Infectious Disease
RNA	Ribonucleic Acid
IRD	Institut de Recherche pour le Développement
COVID-19	Coronavirus disease of 2019
PREZODE	Preventing Zoonotic Diseases Emergence
ITC	Institut Technologique du Cambodge
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
CNM	National Center for Parasitology, Entomology, and Malaria Control
CDC	Centers for Disease Control and Prevention
MOH	Ministry of Health
WHO	World Health Organization
EWARS	Early Warning, Alert and Response System
AVSF	Agronomes et Vétérinaires sans Frontières
IDE	International Development Enterprise
WCS	Wildlife Conservation Society
WEHI	Walter and Eliza Hall Institute of Medical Research
MAFF	Ministry of Agriculture, Forestry, and Fisheries
MOE	Ministry of Environment
IPL	Institut Pasteur du Laos
IPHCMC	Institut Pasteur in Ho Chi Minh
NIMPE	National Institute of Malariology, Parasitory and Entomology
RITM	Research Institute for Tropical Medicine
MOEYS	Ministry of Education, Youth and Sport
MORU	Mahidol Oxford Tropical Medicine Research Unit
SDSV	Structure et dynamique des systèmes vivants
URCA	Université de Reims Champagne-Ardenne
ECTS	European Credit Transfer and Accumulation System
GADC	Gender and Development for Cambodia
USA	United State of America
JEV	Japanese Encephalitis Virus
eDNA	Environmental Deoxyribonucleic Acid
AI	Artificial Intelligence
GIS	Geographic Information System
IVC	International Vaccination Center
RPCs	Rabies Prevention Centers
SWOT	Strength, Weakness, Opportunity, Threat
MDs	Medical Doctors
PP-RPC	Phnom Penh Rabies Prevention Center
BTB-RPC	Battambang Rabies Prevention Center
KCH-RPC	Kampong Cham Rabies Prevention Center
ERIG	Equine Rabies Immunoglobulins
PHD	Provincial Health Department

EIC	Education, Information and Communication
GDAPH	General Directorate of Animal Health and Production
FAO	Food and Agriculture Organization
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
CVRP	Comprehensive Virus Research Panel
NGS	Next Generation Sequencing
SISPA	Sequence-Independent, Single-Primer Applification
BAIA	Bioinformatics and Artificial Intelligence Applications
WGBAI	Working Group for Bioinformatics and AI
PAPIBI	Pasteur Asia-Pacific International Bioinformatics Initiative
P.vivax	Plasmodium Vivax
CITE-Seq	Cellular Indexing of Transcriptomes and Epitopes by Sequencing
BAAR	Bacteriology and Antibiotic Resistance
LLMs	Large Language Models
CADT	Cambodia Academy of Digital Technology
GO	Grants Office
DAF	Director of Administration and Finance
HIV	Human Immunodeficiency Virus
TB	Tuberculosis
AMR	Antimicrobial Resistance
CRDF	Civilian Research and Development Foundation
WT	Wellcome Trust
CAPRED	Cambodia Australia Partnership for Resilient Economic Development
IAS	International Accreditation Service
ISO	International Organization for Standardization
IEC	International Electrotechnical Commission
FORT	Foodborne Outbreak Response Team
GF-AAS	Graphite Furnace Atomic Absorption Spectroscopy
LC-MS/MS	Liquid Chromatography-Tandem Mass Spectrometry
GC-MS/MS	Gas Chromatography-Triple Quadrupole Mass Spectrometry
DENV	Dengue Virus
BCR	B Cell Receptor
TCR	T Cell Receptor
CCHFV	Crimean-Congo Hemorrhagic Fever Virus
CITE seq	Cellular Indexing of Transcriptomes and Epitopes by Sequencing
SFTSV	Severe Fever with Thrombocytopenia Syndrome Virus
ICER	International Center for Excellence in Research
MBL	Medical Biology Laboratory
NGOs	Non-Governmental Organizations
COFRAC	French Committee for Accreditation
NABM	Nomenclature des Actes de Biologie Médicale
NCHADS	National Centre for HIV/AIDS, Dermatology and STD
LIS	Laboratory Information System
VCCT	Voluntary Confidential Counselling and Testing for HIV
MRSA	Methicillin-Resistant Staphylococcus Aureus
3GCRE	Third-Generation Cephalosporin-Resistant Enterobacteriaceae
CRE	Carbapenem-Resistant Enterobacteriaceae
ESBL	Extended Spectrum Beta-Lactamase

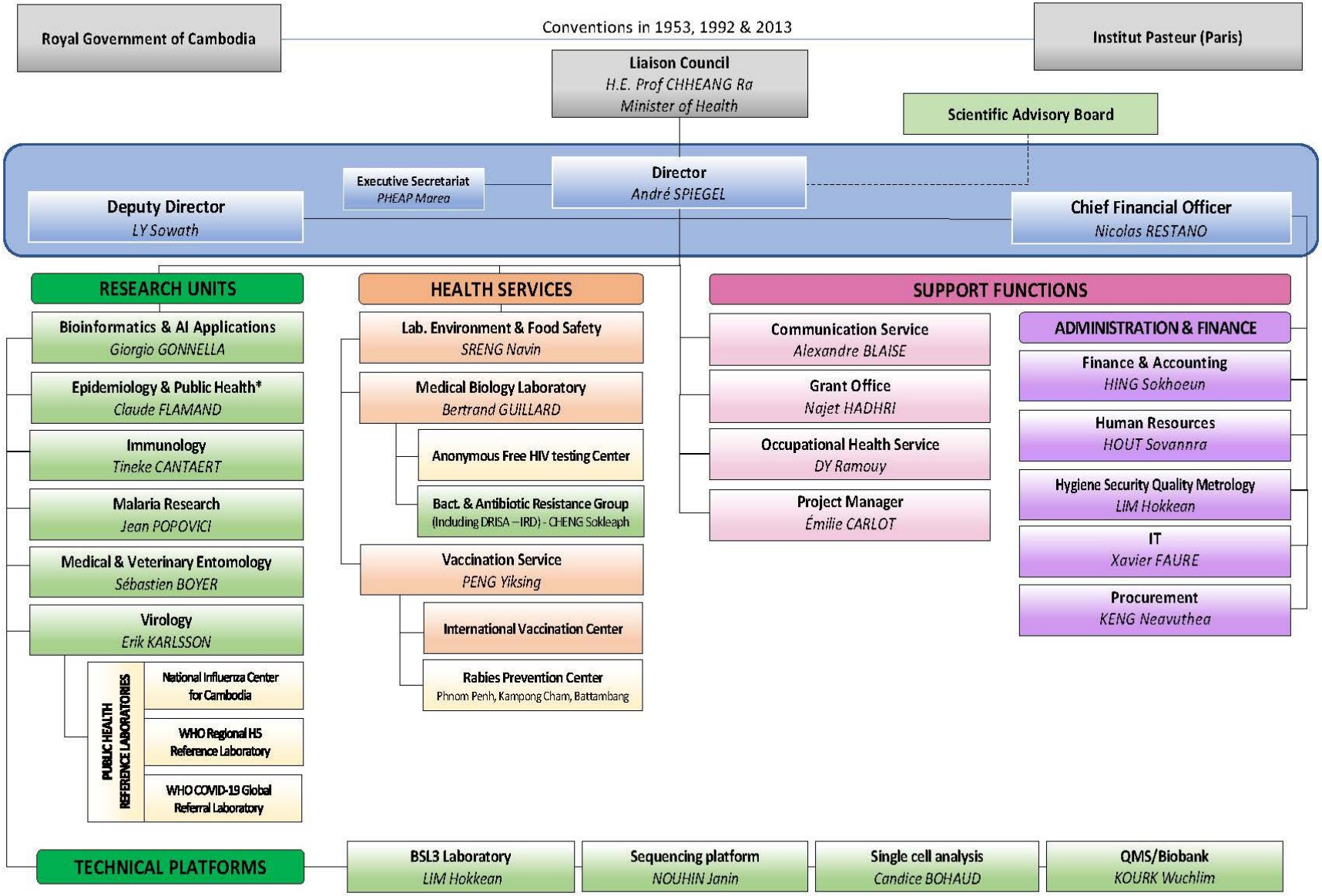
CRAB	Acinetobacter Baumannii Carbapenem-Resistant
CRPA	Pseudomonas Aeruginosa Carbapenem-Resistant
VREfm	Vancomycin-Resistant Enterococcus faecium
STIs	Sexually Transmitted Infections
MTB/RIF	Mycobacterium Tuberculosis / Resistance to Rifampicin
AFD	French Development Agency
DA	Domestic Animals
PEACH	Pathogens Exposure from Aquifers: A Cambodia Health Interdisciplinary
MDR-E	Multidrug-Resistant Enterobacteriaceae
WPs	Work Packages
GDAPH	General Directorate of Animal Health and Production
MAFF	Ministry of Agriculture, Forestry and Fisheries
HPV	Human Papillomavirus
IFIs	Invasive Fungal Infections
PLHIV	patients living with Human Immunodeficiency Virus
NTM	Nontuberculous Mycobacterial
JRP	Joint Research Program
NIAID	National Institute of Allergy and Infectious Diseases
DEMELE-JEV	Diagnostic and Surveillance of Acute Meningo-Encephalitis among Children in Cambodia with a focus on Japanese Encephalitis Virus
CSF	Cerebrospinal Fluid
CAM-ONE AMR	Cambodia One Health Antibiotic Resistance Surveillance and Action
MEAE	Ministère de l'Europe et des Affaires étrangères
HAAPI	Haemophilus Africa-Asia-Pacific Initiative
3GCs	Third-Generation Cephalosporins
RACSMEI	Risk Assessment of Community Spread of Multiple Endemic Infectious Diseases in a One Health Perspective
TBEV	Tick-Borne Encephalitis Virus
SFTSV	Severe Fever with Thrombocytopenia Syndrome Virus
UHS	University of Health Sciences
UP	University of Puthisastra
LFRD	Lycée Français René Descartes
PVESMEE	Plasmodium vivax escape strategies to malaria elimination efforts
DFAT	Department of Foreign Affairs and Trade - Australia
Duca	Fondation Simone et Cino del Duca
EC	European Commission
GATES	Bill & Melinda Gates Foundation
IAEA	International Atomic Energy Agency
INRAE	Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement
INSERM	Institut National de la Santé et de la Recherche Médicale
IP	Institut Pasteur
IP-ACIP	Institut Pasteur - Actions Concertées Inter-Pasteuriennes
IP-PIU	Institut Pasteur – Pasteur International Joint unit
NHMRC	National Health and Medical Research Council
NIID	National Institute of Infectious Diseases
Royal Veterinary	The Royal Veterinary College
TTSH	Tan Tock Seng Hospital

UNIDO	United Nations Industrial Development Organization
DATURA	Determination of Adequate tuberculosis Regimen in Adults and adolescents hospitalized with HIV-associated severe immune suppression
MRU	Malaria Research Unit
PIU	Pasteur International Unit
GMS	Greater Mekong Subregion
TES	Therapeutic Efficacy Studies
iDES	integrated drug efficacy surveillance
NMCPs	National Malaria Control Programs
MMV	Medicine for Malaria Venture
PQ	Primaquine
UMD	University of Maryland
PRICURE	Rigorous Assessment of P. vivax Relapses and Primaquine Efficacy for Radical Cure
PvDBP	Plasmodium vivax Duffy Binding Protein
PvRBP	Plasmodium vivax reticulocyte binding protein
A*STAR	Agency for Science, Technology and Research
CWRU	Case Western Reserve University
NTU	Nanyang Technological University
TBV	Transmission-blocking vaccine development
USF	University of South Florida
LSHTM	London School of Hygiene and Tropical Medicine
RDTs	Rapid diagnostic tests
SPARK	Seeded Partnerships for Advancing Research & Knowledge
PVCULT	Plasmodium vivax culture
VISPA	The Vivax Serology Partnership
UKNEQAS	The United Kingdom National External Quality Assessment Service
OHS	Occupational Health Service
CPR	Cardiopulmonary Resuscitation
LFA	Lateral Flow Assays
EIA	Enzyme Immunoassay
Cam-One AMR	Cambodia One Health Antibiotic Resistance Surveillance and Action
CREID	Centers for Research in Emerging Infectious Diseases
DenThom	Study of dengue-like illnesses in Kampong Thom Province
ELISA	Enzyme-Linked Immunosorbent Assay
IgG	Immunoglobulin G
IgM	Immunoglobulin M
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
KAIST	Korea Advanced Institute of Science and Technology
CISED	Centre for Interdisciplinary Studies in Environment and Development
RT-qPCR	Reverse Transcription Quantitative Polymerase Chain Reaction
LBMs	Live Bird Markets
NAHPRI	National Animal Health and Production Research Institute
AIV	Avian Influenza Virus
WHOCC	WHO Collaborating Centre
PCR	Polymerase Chain Reaction
HPAI	Highly Pathogenic Avian Influenza

KBH	Kantha Bopha Hospital
RSV	Respiratory Syncytial Virus
SARI	Severe Acute Respiratory Illness
USAID	United States Agency for International Development
US-DHHS	United States Department of Health and Human Resource Services
Duke-NUS	Duke National University of Singapore
NAMRU-2	Navel Medical Research Unit No.2
ES	Environmental Sampling
ODK	Open Data Kit
INRAE	National Research Institute for Agriculture, Food and Environment
LPAI	Low Pathogenic Avian Influenza
NPIs	Non-Pharmaceutical Interventions
CENV	Cencurut Virus
KPFA	Khoo Postdoctoral Fellowship Award
CoViNet	Coronavirus Network
H5N1	Hemagglutinin type 5 Neuraminidase type 1
AHRI	Africa Health Research Institute
KWTRP	Kenya Medical Research Institute-Wellcome Trust Research Programme
OUCRU	Oxford University Clinical Research Unit
MLW	Malawi-Liverpool-Wellcome Trust Clinical Research Programme
CAP	Community-acquired pneumonia
RT-PCR	Reverse Transcription Polymerase Chain Reaction
HEPAR	Hepatitis E virus (HEV), Arenavirus and other rodent-borne viruses and Risk Assessment of Infection in Human in Cambodia
CIRAD-ASTRE	Agricultural Research Centre for International Development – AnimalS, health, Territories, Risks, Ecosystems
CERFIG	Center for Research and Training in Infectiology of Guinea
CANARIES	The Consortium of Animal market Networks to Assess Risk of Emerging Infectious diseases through Enhanced Surveillance
MMT	Market Mapping Tool
DTRA–UKGCRF	Defense Threat Reduction Agency - UK Research and Innovation (UKRI) Global Challenges Research Fund
LIMS	Laboratory Information Management System
FAVNT	Fluorescent Antibody Virus Neutralization Test
IZSAM	Istituto Zooprofilattico Sperimentale dell'Abruzzo e del Molise
MPXV	Monkeypox virus
AIMA-CC	AIDS Malignancies in Africa & Asia - Cervical Cancer
CPC	Centre Pasteur du Cameroon
ONT	Oxford Nanopore Technologies
Avia-GIS	Agriculture and Veterinary Information and Analysis
HPgV-2	Human pegivirus 2
EEHV	Elephant Endotheliotropic Herpesvirus
PTWRC	Phnom Tamao Wildlife Rescue Centre
FTD33	Fast Track Diagnostic respiratory pathogens 33 multiplex assay
NIHE	National Institute of Hygiene and Epidemiology
PPR	Preparedness and response
NECHR	National Ethics Committee for Health Research
CHIKV	Chikungunya Virus
ZIKV	Zika Virus

WNV	west Nile Virus
CLIMPATHIC	Strategy for Genomic Surveillance of Pathogens in Wastewater
WaSPP	Detection of pathogens with pandemic potential in urban wastewater as an early warning of human adaptation and transmission
ASFV	African Swine Fever Virus
NCVD	National Center for Veterinary Diagnosis
RAP	Regional Office for Asia and the Pacific
PGI	Pathogen Genomics Initiative
NIC	National Influenza Center
GDAHP	General Directorate of Animal Health and Production
ZODIAC	Zoonotic Disease Integrated Action
ES	Environmental Surveillance
COP	Centre for Outbreak Preparedness
RPA	Recombinase polymerase amplification
LAMP	Loop-mediated isothermal amplification
NDCP	National Dengue Control Program
LBM	Medial Biological Laboratory
ILI	Influenza-like illness
PIV	Parainfluenza virus
GISRS+	Global influenza surveillance and response system
CFR	Case fatality rate
HA	Hemagglutinin
MAFFT	Multiple Alignment using Fast Fourier Transform
BIC	Bayesian Information Criterion
PACAI	Preventing Avian Influenza in the Pacific
PICTs	Pacific Island Countries and Territories
IAC	Institut Agronomique Néo-Calédonien
UKRI	United Kingdom Research and Innovation
WOAH	World Organisation for Animal Health
PSRL	Professional Skills for Research Leaders
SEA-ROADS	One Health Regional Approach for Integrated and Interconnected Urban Dengue Surveillance Southeast Asia
PN	Pasteur Network
CFO	Chief Financial Officer
UNICEF	United Nations International Children's Emergency Fund
HR	Human Resource
SAB	Scientific Advisory Board Meeting
UPS	Université Paris-Saclay
KAP	Knowledge, attitudes and practices
NHQC	National Health Products Quality Control Center
MSF	Médecins Sans Frontières
IPP	Institut Pasteur in Paris
SIDC	Sarawak Infectious Disease Centre
APAC	Asia-Pacific

8.2 Organizational Chart of IPC



*Including **Community Epidemiology Group, Clinical Research Group, Methodological and Statistical Analysis Group***

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