EURAMET supplementary comparison of personal dose equivalent at 0.07 mm and 3 mm depth, $H_p(0.07)$ and $H_p(3)$, for beta radiation

EURAMET Project No. 1398

BIPM KCDB: EURAMET.RI(I)-S16

Technical Protocol

R. Behrens, Physikalisch-Technische Bundesanstalt (PTB),
Bundesallee 100, 38116 Braunschweig, Germany

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1. Introduction

In October 1999, national metrology laboratories worldwide signed a Mutual Recognition Arrangement (MRA: 'Arrangement on the mutual recognition of the equivalence of national standards and of calibration certificates issued by national metrology institutes') with the aim of establishing a basis for the mutual recognition of calibrations. In this context, the BIPM has published on its homepage a list of Calibration and Measurement Capabilities (CMC-lists) of the institutes which have signed the MRA. Calibration services can, however, only be included if a quality management system according to ISO standard 17025 has been established. Quality assurance and confidence in the capabilities of other laboratories can only be ensured by the successful participation in a comparison in which the degree of equivalence with other national metrology institutes or calibration laboratories has been determined.

In recent years a great change has taken place in the field of radiation protection dosimetry: the concept and dose limits of radiation protection quantities developed by the ICRP have been adopted by the European Union in Council Directive 2013/59/Euratom. To monitor the dose to local skin, the personal dose equivalent, $H_p(0.07)$, and the directional dose equivalent, $H'(0.07)$, are relevant for individual and area monitoring. To monitor the dose to the lens of the eye, the personal dose equivalent, $H_p(3)$, and the directional dose equivalent, $H'(3)$, are relevant for individual and area monitoring. With the transfer of this directive into the national law of the EU member states, the national standard laboratories must be able to realise and disseminate these units.

For quality assurance of the realization and transfer of the unit of the absorbed dose rate in 0.07 and 3 mm tissue depth for beta radiation, intercomparison measurements among the primary standard facilities are needed. This may be accomplished using transfer ionization chambers.

Up to now, only one comparison for radiation protection qualities using beta radiation has been performed within the scope of EURAMET, namely EUROMET project No. 739 – BIPM KCDB: EUROMET.RI(I)-S2[1]. Sect. I of CCRI decided in its last meeting in January 2016 to support another EURAMET comparison, which is presented here.

A flat ionisation chamber will be used as the transfer instrument. Together with this chamber, a complete electronic measurement system will be circulated. The aim of this comparison is to compare the calibration factors of the transfer instrument obtained by each participant. The circulation of the chamber and of the electronic measurement system will be effected in a star pattern, with both devices being sent back by every five participants to the pilot laboratory for testing.

16 institutes from 16 different countries will calibrate the comparison device according to their quality system in beta reference fields of the radionuclides Pm-147, Kr-85 (and/or Tl-204), Sr-90/Y-90 and Ru-106/Rh-106.

The comparison will be coordinated by the PTB as the pilot laboratory, which will also evaluate the results. The final report or a summary thereof will be submitted to Metrologia for publication. In addition, the results will be sent to BIPM for inclusion in the Key Comparison Data Base (KCDB).

2. Measuring conditions

The object of the comparison is the calibration of an ionisation chamber in terms of the personal dose equivalent, $H_p(0.07)$ and $H_p(3)$. The values for $H_p(0.07)$ and $H_p(3)$ shall be valid for a slab phantom.
The transfer chamber is the flat ionisation chamber 6.3-Beta-FK007-02 with the following parameters:

Outer dimensions:	diameter:	90 mm
	depth:	40 mm
Diameter of the collecting electrode:		40 mm
Depth of the collecting volume:		6.5 mm
Window foil material to measure $H_p(0.07)$:		graphite foil
Tissue equivalent window thickness:		~ 0.07 mm
Additional covering plate to measure $H_p(3)$:		PMMA
Tissue equivalent window and cover thickness:		~ 3 mm
Chamber voltage:		+ 300 V
Reference point (midpoint of the collecting volume):		at 12 mm depth from the surface of the PMMA cover

For $H_p(0.07)$ measurements, the chamber must be operated WITHOUT the PMMA cover.
For $H_p(3)$ measurements, the chamber must be operated WITH the PMMA cover.

For calibration purposes the chamber must be irradiated completely. Therefore, the beam diameter at the measuring point must not be less than 9 cm. The homogeneity of the dose rate across the beam diameter at the measuring distance should be about 5 % or better.

Together with this chamber, a complete electronic measuring device consisting of an electrometer, a high voltage power supply, a temperature, pressure and relative humidity measurement device and, for automatic data registration, and a laptop with PTB-written data acquisition and analysis software, will be circulated. The chamber should be calibrated using this electronic system. One cable for the chamber voltage and one for the chamber signal will be provided, each 10 m in length. The current measured by the chamber at laboratory ambient conditions is corrected by the measurement software to the current at reference conditions (pressure: 101.3 kPa, temperature: 293.15 K, rel. humidity: 65 %) in the collecting volume. As the result of a measurement, the mean current with a standard uncertainty is given by the software. The leakage current is also considered. Detailed technical instructions for handling this system will be enclosed with the electronic device.

3. Measuring programme and quantities to be measured by the participants

Each participant should calibrate the transfer chamber in several beta reference fields of the radionuclides Pm-147, Kr-85 (and/or Tl-204), Sr-90/Y-90 and Ru-106/Rh-106 and for angles of incidence 0°, 45° and/or 60°.
Not all participants have to take part in all these radiation qualities.

The calibration factor N is defined as the quotient of the conventional quantity value of the quantity, $\dot{H}_p(0.07)$ or $\dot{H}_p(3)$, at the air conditions during the calibration measurements and the indicated value, I_c, of the ionisation current at the point of test for the same air conditions. It is expressed for the quantities $H_p(0.07)$ and $H_p(3)$, as

$$N_{Hp(0.07;\alpha)} = \frac{\dot{H}_p(0.07;\alpha)}{I_c} \text{ or}$$

$$N_{Hp(3;\alpha)} = \frac{\dot{H}_p(3;\alpha)}{I_c}$$

where

N	is the calibration factor of the transfer chamber in mSv/(h A)
$\dot{H}_p(0.07;\alpha)$	is the conventional quantity value of the personal dose equivalent rate at a depth of 0.07 mm in tissue for the angle of incidence α measured with an extrapolation chamber (primary standard), valid for a slab phantom
$\dot{H}_p(3;\alpha)$	is the conventional quantity value of the personal dose equivalent rate at a depth of 3 mm in tissue for the angle of incidence α measured with an extrapolation chamber (primary standard), valid for a slab phantom
I_c	is the ionisation current measured in the flat chamber at the positive chamber voltage.

The ISO standards ISO 6980-2 [2] and ISO 6980-3 [3] should be used as a guide for the calculation of the conventional quantity value, $\dot{H}_p(0.07;\alpha)$.
The scientific paper by Behrens and Buchholz [4] should be used as a guide for the calculation of the conventional quantity value, $\dot{H}_p(3;\alpha)$.
The values of the half-lives to be used are those of ISO 6980-2 [2]:

(958.2 ± 8) days for Pm-147
(1381 ± 8) days for Tl-204
(3915 ± 3) days for Kr-85
(10523 ± 35) days for Sr-90/Y-90
(373.6 ± 15) days for Ru-106/Rh-106

The comparison reference values $C_E(N_n)$ will be determined for each quantity and radiation quality as the weighted mean of the calibration factors N_n of the participants. The weighting factor of each calibration factor N_n will be its reciprocal uncertainty $1/u_{Nn}$ (uncertainty using coverage factor $k = 2$, see chapter 4). These reference values $C_E(N_n)$ will be used to determine the degree of equivalence for each participating laboratory.

4. Duties

Duties of the pilot laboratory

- The pilot laboratory must supply the Instructions for Use including detailed information on the electronic measuring device and the transfer chamber. A statement of the uncertainty of the electronic measuring system must be also included.
- The pilot laboratory will participate in the comparison. It will determine its values of the calibration factors at the radiation qualities listed in section 3 in January 2018. The report of these measurements will be sent to the EURAMET TC-IR Chairman at the latest 6 weeks after the end of the measurements.
- The pilot laboratory will evaluate the comparison on the basis of the results and the measurement reports sent by the participants. The pilot laboratory will calculate the comparison reference value for each quantity and radiation quality as a weighted mean value (see section 3).
- The pilot laboratory will prepare a draft of a final report for circulation to all participants for comments and discussion of the results. This, or a revised version, will be the official report of the comparison and will be submitted to the EURAMET TC-IR Chairman and to the CCRI(I). It is anticipated that the official report or a summary thereof will be published in Metrologia in joint authorship and with the consent of each participant. In addition, the results will be sent to BIPM for inclusion in the Key Comparison Data Base (KCDB).

Duties of the laboratories participating

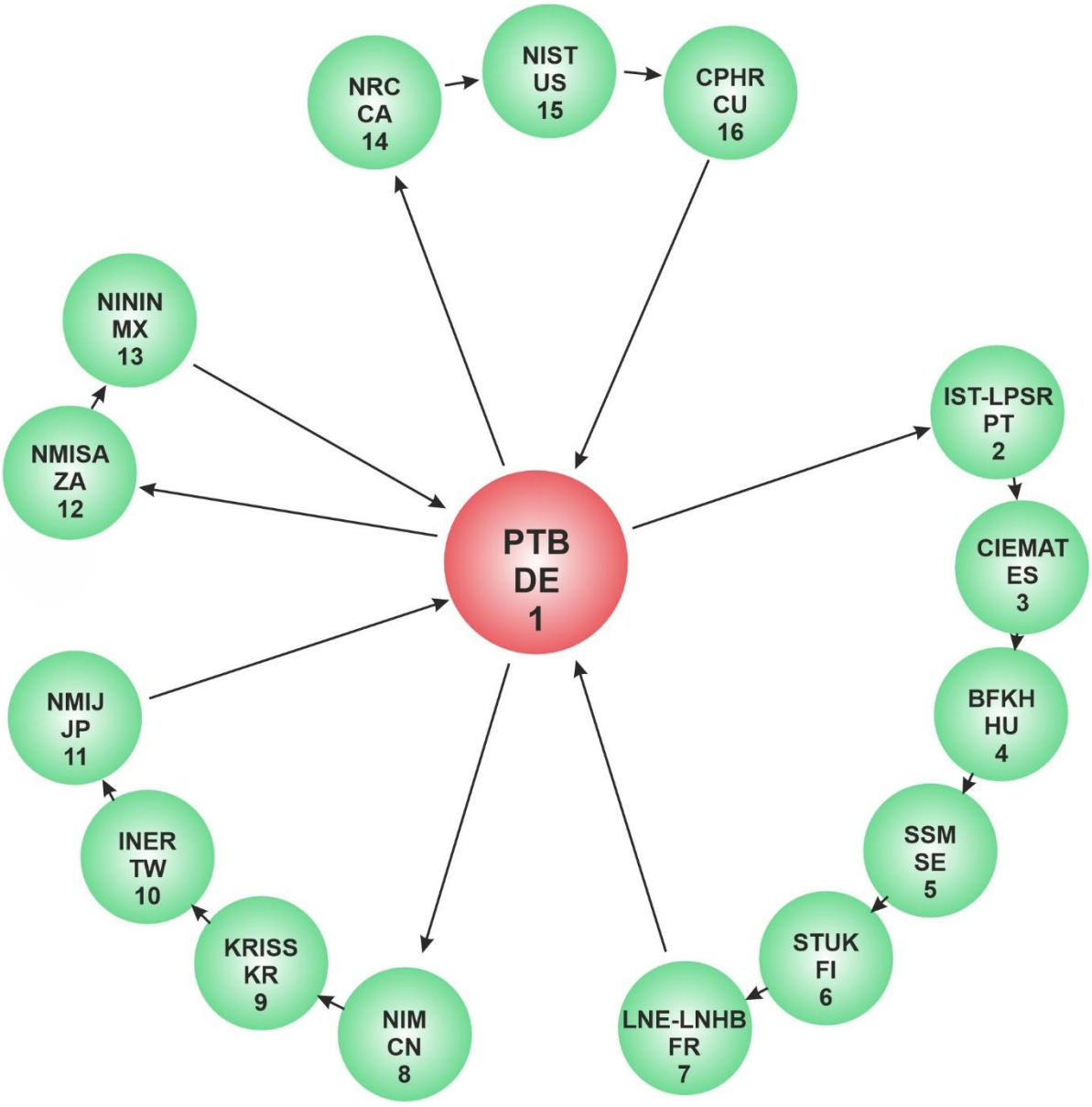
Each participant must send to the pilot laboratory (PTB) a report describing the measurements which have been carried out for the comparison. The report must be signed by the person in the laboratory who has been in charge of the comparison and must comprise the following details:

- Method of the measurement of the conventional quantity value of the personal dose equivalent rate, $\dot{H}_\mathrm{p}(0.07;\alpha)$ and $\dot{H}_\mathrm{p}(3;\alpha)$. Short description of the measuring devices used for the determination including information about the traceability to primary standards and their quality assurance. Information about the beta reference fields and the standard devices which are used.
- Detailed description of the calculation of the conventional quantity value of the personal dose equivalent rate, $\dot{H}_\mathrm{p}(0.07;\alpha)$ and $\dot{H}_\mathrm{p}(3;\alpha)$, including all corrections used. Specification of the uncertainty, the confidence level (recommended: two standard deviations, $k = 2$) and the principal components of the uncertainty.
- Description of the calibration measurements, if possible with pictures of the experimental set-up.
- Determination of the calibration factor for each radiation quality used including a complete uncertainty budget according to GUM [5][6] (recommended coverage factor $k = 2$)
- Within the instructions for use the pilot laboratory will send forms. In these forms the participant will document all parameters and measurement results. The forms should be part of the measurement report.

The measurement report is to be sent to the pilot laboratory at the latest two months after the end of the measurements.

5. Organisation and participants

16 laboratories have registered for the comparison: PTB (DE); IST-LPSR (PT); CIEMAT (ES); BFKH (HU); SSM (SE); STUK (FI); LNE-LNHB (FR); NIM (CN); KRISS (KR); INER (TW); NMIJ (JP); NMISA (ZA); ININ (MX); NRC (CA); NIST (US); CPHR (CU). The contact persons and the addresses of the partners are listed in Appendix A. The circulation of the transfer chamber and of the electronic system will be performed in a star-like pattern. Every five participants the comparison devices (chamber and measuring device) will be sent back to the pilot laboratory for testing (see the Table). Each partner has one month to perform the measurements and to send the system to the next participant / pilot laboratory. This period of time must be observed by each participant in order to avoid an extension of the duration of this comparison. The pilot laboratory has one month for testing of the system and sending it to the next partner. More time is planned for shipment concerned with customs formalities, see table below. The circulation scheme is shown in the following figure.



The following time schedule was agreed upon by the 16 partners. The start of the comparison is January 2018. The prospective end is 2023.

Participant	Calibration measurements at the participant	Repeat measurements at PTB / DE	Transfer to the next participant or return to PTB	Report of the results from the participant
PTB; DE	01/2018		01-02/2018	
IST-LPSR; PT	03/2018		03/2018	05/2018
CIEMAT; ES	04/2018		04/2018	06/2018
BFKH; HU	05/2018		05/2018	07/2018
SSM; SE	06/2018		06/2018	08/2018
STUK; FI	07/2018		07/2018	09/2018
LNE-LNHB; FR	08/2018		08/2018	10/2018
PTB; DE		09/2018	03/2019	
NIM; CN	04/2019		04-05/2019	06/2019
KRISS; KR	06/2019		06-07/2019	08/2019
INER; TW	08/2019		08-09/2019	10/2019
NMIJ; JP	10/2019		11-12/2019	12/2019
PTB; DE		01/2020		
Interruption due to Covid-19 and replacement of laptop				
PTB; DE		02/2020	02-03/2020	
NMISA; ZA	07/2020		07-08/2020	09/2020
ININ; MX	09/2020		09-10/2020	11/2020
Interruption due to Covid-19 and repairment of the electrometer				
PTB; DE		05/2021	07-08/2021	
NRC; CA	12/2021		12/2021-01/2022	02/2022
NIST; US	05/2022		05-06/2022	07/2022
CPHR; CU	08/2022		09/2022-01/2023	10/2022
PTB; DE		02/2023		

Task	Date	Participant
Draft of final report	04/2023	PTB / DE
Comments of all partners	06/2023	All partners
Final report for publication via KCDB and as *Metrologia Technical supplement*	08/2023	PTB / DE

The comparison will extend over a long period of time, in total three years. The pilot laboratory will inform the partners on the progress of the comparison by newsletters sent by e-mail. The list of the partners with their e-mail addresses is given in Appendix A. In addition, the responsible TC Chairman will be informed of the progress by newsletters.

6. Agreement on the presentation of the results

After the end of the comparison, all results delivered by the partners will be made available to each participant.

Each laboratory participating agrees not to reveal any measurement data whatsoever and, in any way, neither by publication (e.g. in the Annual Report of the one's own laboratory or in a paper) nor orally.

The partners agree that after the end of the comparison, any presentation of results is always done in joint authorship.
Because of the long duration of the comparison the first partner will have to wait for the final results for a very long time. To reduce this time and give some initial information, initial results may be presented before the end of the comparison as soon as the reports of the results of the first five partners have been submitted to the pilot laboratory. For every radiation quality, the calibration factors of each partner normalized to the respective mean value will be calculated by the pilot laboratory. A figure including these data in anonymous form may then be sent to the participants and presented at conferences.

7. Transport

Each participant must arrange the transport of the system himself. The cost of dispatch and insurance including customs charges have to be borne by the participant who is sending the system to the next participant / pilot laboratory.
The addresses in Appendix A will be used for the shipment.
Transport container:
The transport container (appr. 121 cm x 83 cm x 81 cm; 110 kg) includes two boxes:

1.) a blue box containing the electronic measuring device:
approximate dimensions: 71 cm x 61 cm x 47 cm

2.) a case containing the transfer ionisation chamber:
approximate dimensions: 50 cm x 39 cm x 20 cm

After the receipt of the measuring system the participant must check the electronic device and the chamber for damage and inform the pilot laboratory immediately about the arrival of the system and its condition.
The transport container should be opened by laboratory staff only.

8. References

[1] R. Behrens et al. *International comparison EUROMET.RI(I)-S2 of extrapolation chamber measurements of the absorbed dose rate in tissue for beta radiation (EUROMET project No 739): Final report.* Metrologia **44** 06003 (2007) doi:10.1088/0026-1394/44/1A/06003

[2] International Organization for Standardization. ISO 6980-2, *Reference beta particle radiation – Part 2: Calibration fundamentals related to basic quantities characterizing the radiation field* (2004)

[3] International Organization for Standardization. ISO 6980-3, *Reference beta particle radiation – Part 3: Calibration of area and personal dosemeters and determination of their response as a function of energy and angle of incidence* (2006)

[4] R. Behrens and G. Buchholz. *Extensions to the Beta Secondary Standard BSS 2.* 2011 JINST **6** P11007 and Erratum (2012 JINST **7** E04001) and Addendum (2012 JINST **7** A05001). A consolidated version is available

[5] European Accreditation, EA. *Evaluation of the Uncertainty of Measurements in Calibration*. Publication EA-4/02 M rev 02 (September 2013)

[6] BIPM, *Evaluation of measurement data –Guide to the Expression of Uncertainty in Measurement*, JCGM 100:2008, GUM 1995 with minor corrections

Appendix A
Addresses of the participants (for shipment of the instruments)

Pilot laboratory

1. GERMANY

Rolf Behrens
Physikalisch-Technische Bundesanstalt (PTB; DE)
Bundesallee 100
38116 Braunschweig
Germany
Phone: +49 531 592 6340
Rolf.Behrens@PTB.de

2. PORTUGAL

João Cardoso
Instituto Tecnológico e Nuclear, Laboratório de Proteção e Segurança Radiológica
Metrology Laboratory of Ionising Radiation Group (IST-LPSR; PT)
Estrada Nacional 10 (km 139,7)
2695-066 Bobadela LRS
Portugal
Phone: +351 21 994 6336
jcardoso@ctn.ist.utl.pt

3. SPAIN

Milagros Pozuelo
Ionising Radiation Metrology Laboratory (CIEMAT; ES)
Avda Complutense 40
28040 Madrid
Spain
Phone: +34 91 346 6283
milagros.pozuelo@ciemat.es

4. HUNGARY

Viktória Finta
Government Office of the Capital City Budapest (BFKH; HU)
Metrological and Technical Supervisory Department; Radiation Physics and Chemistry
Németvölgyi út 37-39.
H-1124 Budapest
Hungary
Phone: +36 1 458-5911
szucs.laszlo@bfkh.gov.hu

5. SWEDEN

Linda Persson
Swedish Radiation Safety Authority (SSM; SE)
Solna strandväg 122
SE-171 54 Solna
Sweden
Phone: + 46 8 799 41 50
linda.persson@ssm.se

6. FINLAND

Jussi Huikari
Radiation and Nuclear Safety Authority (STUK; FI)
Laippatie 4
00880 Helsinki
Finland
Phone: +358 9 7598 8605
jussi.huikari@stuk.fi

7. FRANCE

Claire Lecante
Commissariat à l'énergie atomique / Laboratoire National Henri Becquerel (LNE-LNHB; FR)
DRT/LIST/DM2I/LNHB/Laboratoire de Métrologie de la Dose
Centre de Saclay - bâtiment 534 pièce 95 – Point courrier 104
91191 Gif-sur-Yvette Cedex - France
Phone: +33 1 69 08 37 34
claire.lecante@cea.fr

8. CHINA

Dehong LI
National Institute of Metrology (NIM; CN)
Division of Ionizing Radiation
No.18, Bei San Huan Dong Lu, Chaoyang Dist.
Beijing,100029
P.R. China
Phone: +86 10 6452 5024
lidh@nim.ac.cn

9. REPUBLIC OF KOREA

Chul-Young Yi
Korea Research Institute of Standards and Science (KRISS; KR)
267 Gajeong-Ro Yuseong-Gu
Daejeon 34113
Rep. of Korea
Phone: +82 10 3452 4307
cyyi@kriss.re.kr

10. TAIWAN

Chien-Hau Chu
Institute of Nuclear Energy Research (INER; TW)
1000 Wenhua Rd. Jiaan Village, Longtan District
Taoyuan City 32507
Taiwan (ROC)
Phone: +886 3 4711400
chchu1@iner.gov.tw

11. JAPAN

Masahiro KATO/ Senior Researcher
National Metrology Institute of Japan (NMIJ; JP)
National Institute of Advanced Industrial Science and Technology
Central 2, 1-1-1, Umezono
Tsukuba, Ibaraki 305-8568
Phone: +81 29 861 4273
masahiro-katou@aist.go.jp

12. SOUTH AFRICA

Sibusiso Jozela
National Metrology Institute of South Africa (NMISA; ZA)
CSIR Campus, Building 6, Meiring Naude Road
Brummeria Pretoria 0182
South Africa
Phone: +27 12 841 2097
sjozela@nmisa.org

13. MEXICO
José Trinidad Álvarez Romero
Instituto Nacional de Investigaciones Nucleares (ININ; MX)
Carretera Federal Mexico Toluca S/N.
La Marqueza Ocoyocac. Estado de Méxioc, CP 52750
Mexico
Phone: +52 55 53297255
trinidad.alvarez@inin.gob.mx

14. CANADA
Patrick Saull
National Research Council Canada (NRC; CA)
Ionizing Radiation Standards
1200 Montreal Road, Bldg M-35
Ottawa, ON K1A 0R6
Canada
Phone: +613 993 2715 240
patrick.saull@nrc-cnrc.gc.ca

15. USA
Michael G. Mitch
National Institute of Standards and Technology (NIST; US)
100 Bureau Dr. MS 8460
Gaithersburg, MD 20899-8460
USA
Phone: +1 301 975 5491
michael.mitch@nist.gov

16. CUBA
Gonzalo Walwyn Salas
Centro de Protección e Higiene de las Radiaciones (CPHR; CU)
Dirección: Carretera a la cantera “La Victoria II”, km 2 ½, Guanabacoa
La Habana
Cuba
Phone: +53 7682 9571
gonzalo@cphr.edu.cu