The Ice Memory Programme

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**Information Paper submitted by France and Italy**

*Summary*

The purpose of this paper is to provide a brief update about the Ice Memory Programme and address the different questions raised by Parties during the CEP XXIV.

The first phase of the Programme is currently underway, and involves collecting ice cores from the deep layers of key endangered glaciers along the world before they lose their ability to preserve environmental history in optimal conditions. The second phase of the Programme will develop the long-term storage of these ice cores for future generations of scientists. The purpose of this paper is to provide an update about the Ice Memory Programme within the framework of the Antarctic Treaty Consultative Meeting (ATCM), following its initial presentation during the 42nd ATCM meeting in Prague in 2019 and to address the different questions raised by Parties during the CEP XXIV in Germany.

Collaboration and endorsement by Parties would be beneficial as the goal of the Programme is of global importance to humanity. This means launching a process that complies with the Antarctic Treaty and its Protocol on Environmental Protection (Madrid Protocol), especially Annex I on Environmental Impact Assessment.

*Background and update of the IM Programme*

The Ice Memory (IM) Programme was launched by France and Italy in 2015. The worldwide importance of the Ice Memory (IM) Programme was acknowledged by UNESCO (through the solicitation of its French and Italian National Commissions), calling on its Member States to support the initiative. The IM Programme features international scientific collaboration between national Antarctic programmes. Its international dimension has grown since 2015 following contributions by Russia, Switzerland and Norway. The international scientific community is working to make it an as global an initiative as possible, in the coming years.

The overall goal of the IM Programme is to:

* 1- Collect an ice core archive from the deep layers of key endangered glaciers before they lose their ability to preserve environmental history in optimal conditions;
* 2- Store these ice cores on a long-term basis (possibly hundreds to thousands of years) for future generations of scientists and humanity in general.

At a later stage of the IM Programme, a governance framework will need to be defined with involvement of the ATCM Parties which plan to contribute to the long-term storage of ice cores in Antarctica, particularly to ensure this complies with the Antarctic Treaty and the Madrid Protocol. The IM Programme has recently launched a “Law and Governance” Chair to address this important topic.

CEP Members may want to refer to IP 108 submitted at CEP XXIV for a comprehensive description of the IM Programme.

Since 2022, new drilling operations took place with a view to collect new ice cores from mountain glaciers and achieve the IM Programme’s goals. In June 2022, the southernmost glacier of Europe, Calderone located in the Italian Apennine Mountains, was drilled down to bedrock (25 metres of thickness), giving success to the seventh IM drilling operation. An IM drilling project was expected to take place on Mount Kilimanjaro (Tanzania) in September 2022, but unfortunately it had to be abandoned for administrative reasons. In April 2023, an IM team composed of Italian, Norwegian, US and French scientists drills three ice cores down to bedrock at 74 m of depth on the Holtedahlfonna glacier in north-west Svalbard at 79°N, one of the fastest warming area in the world.

These ice cores are (or will be for Holtedahlfonna) all stored in commercial freezers in France, or in Italy, or in Switzerland, or in Russia (for logistic convenience and depending where is located the Principal Investigator of the corresponding drilling operation), pending the construction of the long-term storage repository in Antarctica.

*Answers to questions raised by CEP members during CEP XXIV*

Link between the IM Programme and legal aspects of the Madrid Protocol and notably the Non-Native Species Manual

The principles of the Protocol on Environmental Protection to the Antarctic Treaty include the protection of Antarctic biodiversity and intrinsic values by preventing the unintended introduction to the Antarctic region of species not native to that region, and the movement of species within Antarctica from one biogeographic zone to another. As stated by the Non-Native Species Manual, measures should be put in place to minimise the risk of impacts from non-native species in the Antarctic, taking all possible steps towards prevention.

Bacteria, pollen and other microorganisms are already naturally present in Antarctica, transported long distances by atmospheric aerosols from places such as South America, or introduced by existing human activities. For instance, the few available estimates concerning pollens indicate values of around 20 to 30 pollen particles per kilogramme of surface snow. Cao et al. (2020) measured the airborne bacterial community diversity and sources along the Antarctic coast and demonstrated that they were largely immigrated to Antarctica through long-range transport and sea-air exchange pathways. Regarding anthropogenic factors and human introduction of microorganisms in Antarctica, as highlighted in the review of Pearce et al. (2009), even materials left in camps erected by early Antarctic expeditions led by Scott and Shackleton still included imported viable microorganisms even after decades in the Antarctic environment.

Italy and France take in deep consideration this issue as ice cores drilled from glaciers outside Antarctica contains microorganisms (bacteria, virus, fungae), as well as pollens and spores – although in very small quantities – that are present in the atmosphere over mountain glaciers in remote regions and then incorporated in the ice, and which could possibly be introduced in the Antarctic environment whenever the ice cores would melt by accident. That is why all the logistic chain will be carefully evaluated and the Non-Native Species Manual, will be followed. The Non-Native Species Manuel provides key guiding principles to minimize the risk of unintentional introduction of non-native species in Antarctica. They concern both prevention and monitoring.

In the case of the IM Programme, the risk of introduction or redistribution of microorganisms being trapped in ice cores clearly concerns two main aspects:

* Partial or total melting of ice core samples, followed by dispersal of the meltwater in the surrounding environment,
* Occurrence of the melting accident during logistic transfer at the Antarctic coast, where endemic animals are located.

The prevention guidelines that will be drafted by France and Italy will express operational recommendations and will imply to handle the risk at its origin. Storage at negative temperature provide the best guarantee to prevent any release of the microbial content of ice cores in the surrounding environment, as microorganisms cannot escape the ice as long as it is frozen. These conditions are naturally met on the East Antarctic plateau (Concordia) where ambient temperature never goes above 0°C, but not on the coast where positive temperature exists. As such, we will especially ensure that the IM ice cores are maintained at temperatures below 0°C during transfer of ice core boxes from the *L’Astrolabe* supply vessel to the logistic traverse, between Dumont d’Urville and Robert Guillard stations on the coast.

In the improbable case where the cold chain would accidentally break down, dispersion in the environment will be avoided by the containment of ice cores in different layers of sealings. Each individual ice core is stored in polyethylene bags hermetically sealed at the time of drilling or during the intermediate storage in commercial freezers. Before transferring the IM ice cores to Antarctica, additional layers of polyethylene insulation will be set inside the ice core boxes, as well as around the boxes themselves, avoiding any meltwater spilling in the surrounding environment in case of accidental melting. If such accident would happen, the resulting melted ice cores will transported back to the Antarctic gateway city, for water evacuation in the local water sewage system.

Once at Concordia station and notably inside the storage cave, the risk of accidental melting of IM ice cores is inexistent due to the permanently negative temperatures on site. Still, as a precautionary measure, bacterial monitoring could be set on site, going beyond the simple survey of temperature inside the IM storage caves.

Monitoring of bacterial content in the atmosphere and in surface snow is already in place at Concordia station through various research projects. It thus provides the reference horizon for existing contamination by microorganism on this site. For instance, Van Houdt et al. (2009) evaluated the environmental airborne bacterial population inside the station for a period of one year. They identified the predominant microflora associated with human activity and environmental species, revealing 346 morphologically different isolates including pathogens, which could be spread in the immediate environment of the station through the ventilation system and opening / closing of access doors. Michaud et al. (2014) investigated the microbial diversity in surface snow surrounding Concordia station, at a clean site located about 2 km from the station. Bacterial densities of 200 to 5000 cells per ml of snow were observed. The bacterial community composition revealed more than 300 phylotypes. They appeared similar to that reported in glaciers, snow, lake ice, sea ice and atmospheric clouds. A strong influence from the marine environment seemed to exist as well. They could not exclude that a minor part of observed microorganisms could come from human activity around the station as well. Lastly, their study did not provide direct evidence for possibly activity of the depicted bacterial community in snow, although it could not be excluded.

Hughes et al. (2003) studied faecal coliform bacteria being airborne transferred around Rothera station in the Antarctic Peninsula. They showed that after surface deposition away from the station, moderate doses of solar UV radiation (~20 W.m-2) were capable of reducing the number of viable bacteria by up to 99.9%, within 1 hour of deposition. Airborne transfer of faecal coliform bacteria around Concordia station is plausible as well. The mean summer UV radiation observed at Concordia station during summer time being 24 ± 15 W.m-2, it thus provides challenging conditions for microorganisms to survive and possibly replicate within the surface snow layers.

In conclusion, as long as the IM ice cores will remain frozen during transportation and in the repository, they will not risk releasing non-native living organisms into the Antarctic environment and they will not increase the existing contamination due to already existing human activities in Antarctica. In addition, specific procedures concerning packaging, transportation and handling will be applied to limit as much as possible the risk of dispersion in the environment in case of sample melting. The cold logistic chain from the coast to Concordia has been successfully tested since the beginning of the European deep drilling operation “European Project for Ice Coring in Antarctica” (EPICA) and is well in place. The experience of the personnel from the French Polar Institute IPEV and the National Italian Antarctic Program PNRA lowers the probability of accidents.

What will be the carbon footprint of the transfer of IM ice cores to repositories in Antarctica?

We calculated the carbon footprint using the scenario of IM ice core transfer from Europe to Concordia station. The following logistical steps need to be taken into account:

* The IM ice cores will be transferred in 20-foot reefers on container ships making the various trips between Le Havre (France), Singapore, Melbourne and Hobart in Tasmania.
* The reefers will then be transhipped to the Hobart docks and loaded aboard the French supply ship *L'Astrolabe* to reach the French Dumont d'Urville Antarctic coastal station.
* The isothermal boxes containing the ice cores will then be taken out of the reefers to be heliported from the ship to the Franco-Italian Robert Guillard coastal station located at Cap Prud'homme, the departure point of the heavy land logistic convoy (called "traverse").
* They will then be loaded into other reefers positioned on sledges pulled by the traverse's Challenger MT65 tractors. These tractors will then travel the 1100 km separating the Robert Guillard station from the Franco-Italian Concordia station, in 11 to 12 days of driving.
* Once arrived at Concordia, the reefers will be emptied from their isothermal boxes, which will be placed on racks installed on sledges, themselves positioned inside the IM storage caves.

We anticipate that each 20-foot reefer will contain about 720 m of IM ice cores. Assuming that the IM Programme will produce 20 heritage ice cores, a total of six 20-foot reefers will be needed.

Using CO2-equivalent metrics for each step of the logistical transfer (details available to Parties at request) and applying them to six 20-foot reefers, we obtain the following footprint:

* Transfer from Europe to Hobart with container ships: 11.2 tons of CO2.
* Transfer from Hobart to Dumont d’Urville with *L’Astrolabe*: 53.6 tons of CO2.
* Transfer from Dumont d’Urville to Robert Guillard: 3.6 tons of CO2.
* Transfer from Robert Guillard to Concordia: 27.6 tons of CO2.
* Construction of the storage cave at Concordia: 4.6 tons of CO2.

Therefore, the carbon footprint of the transfer operation of IM ice cores from Europe to Concordia, including the construction of the storage cave, is ~100 tons of CO2, the most important contributions coming from the transfer between Hobart and Dumont d'Urville with the *L’Astrolabe* vessel as well as the transfer by land with the traverse to Concordia station

For comparison, this represents the average annual carbon footprint of 15 European citizens. ~100 tons of CO2 also correspond to ~1.5 days of emissions from a typical supply vessel supporting logistical operations in Antarctica.

The carbon footprint of the IM Programme logistics in Antarctica would in any case be much lower than the one of a storage solution of the IM ice cores in commercial freezers. A recent study conducted by Cascini et al. (2016) estimates the carbon footprint of a 5 m3 cold room (volume of 1.6 x 1.6 x 2 m) and operating at -25°C, over its entire life cycle and assuming the use of two different refrigerants (R404A and R407F). The energy consumption as well as the CO2 equivalent associated with the leakage of these refrigerants with a very high greenhouse effect potential have been taken into account. Considering a 10-year life span of the installation, the authors conclude that the carbon footprint of such a small cold room is around 9 tons of CO2.equivalent. For all the IM cores, 38 cold rooms with these volume characteristics would be needed. We therefore conclude that over 10 years of storage (life of the installation), the carbon footprint of storage in Europe would be 342 tons of CO2.equivalent, without taking into account the carbon footprint associated with the need to restore the equipment at the end of its expected life time.

The carbon footprint of a transfer from Europe to Antarctica, added to that of the creation of the storage cave at Concordia, would correspond to only ~3 years of CO2 emissions from a commercial walk-in freezer plant at -25°C in Europe. The IM Programme projects itself over a much longer period of time, i.e. decades to centuries. It can therefore be concluded that its carbon footprint based on long-term storage in Antarctica will be a major improvement in terms of carbon footprint compared to a commercial solution on the mainland, in addition to the inherent safety brought by storing the ice in the cold East Antarctic plateau.

What are the impacts of the project on the environment and Antarctic protected assets?

The IM Programme will not conduct any activity in Antarctic Specially Protected Areas.

*What will a permit look like? What conditions are envisaged?*

An Environmental Impact Assessment will be submitted to the French National Competent Authority (TAAF), before the planned start of the IM ice core transfer toward Concordia station. The EIA will be submitted to the French Polar Environment Committee, a scientific committee advising the NCA. It will cover the construction of the storage cave and the IM ice core transfer. The EIA will meet the requirement of Annex I of the Madrid Protocol and will serve as a basis for the grant of the permit.

*How will the IM ice cores be transported to Antarctica from all over the world?*

In the case of transportation from Europe, details of the operations are provided in the answer to the question above about the carbon footprint of the IM Programme.

In other cases where IM ice cores would be temporarily stored outside Europe, three scenarios are envisaged:

* IM partners outside Europe and having a National Antarctic Programme (NAP) could use the NAP logistic support to carry their IM ice cores from their home country to Hobart, where they would be taken in charge by the logistics of IPEV and PNRA toward Concordia station,
* If the NAP envisions to build an additional IM repository at a research station located on the East Antarctic plateau, it could handle the corresponding logistics from the home country to the Antarctic research station,
* If the IM partner outside Europe has no NAP, the French and Italian partners of the IM Programme would organize the IM ice core transfer from the home country to Hobart and then to Concordia station with financial support for transport coming directly from the IM partner and/or the IM Programme.

Regarding possible transportation of IM ice core sub-samples back from the Antarctic repository to a research laboratory at a later stage, NAP leaders who are in charge of the research station where the ice core repository is located, will be responsible for securing it and granting access to future research projects.

Any sub-sampling operation will be decided on/accredited by a suitable international research committee on the model of the current International Partnerships in Ice Core Sciences (IPICS), an international group composed of all ice core scientists from around the world. It would be carried out in accordance with Article VII of the Antarctic Treaty (on informing the ATCM of activities taking place in the Antarctic) and Article 3 of the Madrid Protocol (on conducting activities in Antarctica).

*Can safe storage be guaranteed in the long term? Is it really necessary to realize the project in Antarctica?*

It could appear easier to store the Ice Memory ice cores in cold chambers nearby a research facility of one or several of the ATCM Parties, as this is the case for most of the currently drilled and analysed ice cores in the world. However, experience has shown that accidents unfortunately happen, usually because of a major breakdown of the cooling or energy supply, leading to the loss of extremely precious samples. We know of such accidents that took place in Canada in 2017, leading to the loss of part of the world’s largest collection of ice cores from the Canadian Arctic (The Guardian, 2017). Other commercial freezer failures have been experienced for instance in Russia (at Moscow, loss of precious ice core samples from the Elbrous glacier) or in France (loss of samples for the Vostok ice core), usually due to human error. The IM ice cores are expected to be stored untouched for decades to centuries.

The high altitude of the East Antarctic plateau is the natural place to consider for guaranteeing safe storage on the long term. At Concordia station, the mean annual temperature today is close to -55°C. In winter time, the temperature goes down to -70°C and the coldest temperature recorded so far is -84°C. In summer time, usually the temperature never gets above -20°C. The warmest temperature ever recorded at Concordia station is -14°C. Although it is expected that global warming will also affect the East Antarctic plateau in the coming decades, there is no risk that surface temperature becomes positive even at the scale of the next century. Under a high emission scenario, the climate simulations for the end of the 21st century lead to an average surface temperature increase in Antarctica of 3.6°C (Chown et al., 2022). Moreover, the IM ice cores will be stored at about 10 m of depth below the snow surface. At this depth, the summer “heat” has no impact, due to thermal inertia generated by heat diffusion. The temperature inside the IM repository will be close to the mean annual temperature, i.e. less than -50°C.

Transfer of IM ice cores to Concordia station will rely on a reliable logistical chain already in place and active nearly each Antarctic field season to transfer ice core samples in the opposite way, from Concordia station to Europe. As a reminder, about 40% of the ice cores resulting from EPICA are still stored in a cave at Concordia. Nearly each year, one or two scientists are present at Concordia station to sub-sample the EPICA ice core archive at the request of the EPICA consortium. IPEV / PNRA then ensure the safe cold transfer of the sub-samples back to Europe.

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